Writing Device Drivers

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THE NETWORK IS THE COMPUTER™

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Preface

Writing Device Drivers provides information on developing device drivers for character-oriented devices, block-oriented devices, and small computer system interface (SCSI) target devices. This book discusses the development of a dynamically loadable and unloadable, multithreaded reentrant device driver applicable to all architectures that conform to the Solaris™ 2.x DDI/DKI. A common driver programming approach is taken so that drivers can be written without concern for platform-specific issues such as *endianness* and data ordering.

Who Should Use This Book

The audience for this book is UNIX® programmers familiar with UNIX device drivers. Several overview chapters at the beginning of the book provide background information for the detailed technical chapters that follow, but they are not intended as a general tutorial or text on device drivers.

How This Book Is Organized

This book is organized into the following chapters.

- Chapter 1, "SunOS Kernel and Device Tree," provides an overview of the SunOS™ kernel and the manner in which it represents devices as nodes in a device tree.
- Chapter 2, "Hardware Overview," discusses multiplatform hardware issues related to device drivers.

- Chapter 3, “Overview of SunOS Device Drivers,” gives an outline of the kinds of device drivers and their basic structure. It points out the common data access routines and concludes with an illustrated roadmap of common driver entry points and structures.
- Chapter 4, “Multithreading,” describes the mechanisms of the SunOS multithreaded kernel that are of interest to driver writers.
- Chapter 5, “Autoconfiguration,” details the support a driver must provide for autoconfiguration.
- Chapter 6, “Interrupt Handlers,” describes the interrupt handling mechanisms. These include registering, servicing, and removing interrupts.
- Chapter 7, “DMA,” describes direct memory access (DMA) and the DMA interfaces.
- Chapter 8, “Power Management,” covers the interfaces for Power Management™, a framework designed to regulate and reduce the power consumed by computer systems and devices.
- Chapter 9, “Drivers for Character Devices,” describes the structure and functions of a driver for a character-oriented device.
- Chapter 10, “Drivers for Block Devices,” describes the structure and functions of a driver for a block-oriented device.
- Chapter 11, “Mapping Device or Kernel Memory” describes the set of interfaces that allow device drivers to manage access to memory, control the context of user processes accessing a device, and take advantage of large data transfers using new MMU hardware.
- Chapter 12, “Device Context Management,” describes the set of interfaces that allow device drivers to manage user access to devices.
- Chapter 13, “SCSI Target Drivers,” outlines the Sun Common SCSI Architecture and describes the additional requirements of SCSI target drivers.
- Chapter 14, “SCSI Host Bus Adapter Drivers” explains how to write a SCSI Host Bus Adapter (HBA) driver using the Sun Common SCSI Architecture (SCSA).
- Chapter 15, “Loading and Unloading Drivers,” provides information on compiling and linking a driver, and for installing it in the system.

- Chapter 16, “Debugging,” gives coding suggestions, debugging hints, a simple `adb/kadb` tutorial, and some hints on testing the driver.
- Appendix A, “Converting a SunOS 4.x Device Driver to SunOS 5.6,” gives hints on converting SunOS 4.x drivers to SunOS 5.5.
- Appendix B, “Interface Transition List” presents a list of DDI/DKI data access interface functions that have changed from Solaris 2.4 to Solaris 2.6. It also presents data access functions new to Solaris 2.6.
- Appendix C, “Summary of Solaris 2.6 DDI/DKI Services,” summarizes, by topic, the kernel functions device driver can use.
- Appendix D, “Sample Driver Source Code Listings” displays a list of sample drivers, and the location of the sample code in the DDK.
- Appendix E, “Driver Code Layout Structure” presents header files and an outline of xx.c source code samples for a typical driver.
- Appendix F, “Making a Device Driver 64-Bit Ready,” provides guidelines for updating a device driver to run in a 64-bit environment.
- Appendix G, “Advanced Topics,” presents a collection of optional topics.

Related Books

For detailed reference information about the device driver interfaces, see the man page sections 9, 9E (entry points), 9F (functions), and 9S (structures). For information on hardware issues and other driver-related issues, the following books may be helpful.

- *Writing PCMCIA Device Drivers,* SunSoft, 1997.
- *Application Packaging Guide,* SunSoft, 1996.
- *Streams Programming Guide,* SunSoft, 1996.
- *Multithreading Programming Guide,* SunSoft 1996.
- *SPARC Architecture Manual, Version 9,* Sun Microsystems Computer Company, 1996.
- *80386 Programmer’s Reference Manual*, Intel Corporation, 1986. ISBN 1-55512-022-9.
- *i486 Microprocessor Hardware Reference Manual*, Intel Corporation, 1990. ISBN 1-55512-112-8.

- *Pentium Processor User's Manual - Volume 3: Architecture and Programming Manual*, Intel Corporation, 1993. ISBN 1-55512-195-0.
- *Open Boot PROM Toolkit User's Guide*, Sun Microsystems Computer Company, 1996.

Ordering Sun Documents

The SunDocs^{SM} program provides more than 250 manuals from Sun Microsystems, Inc. If you live in the United States, Canada, Europe, or Japan, you can purchase documentation sets or individual manuals using this program.

For a list of documents and how to order them, see the catalog section of the SunExpress™ Internet site at `http://www.sun.com/sunexpress`.

What Typographic Changes Mean

Table P-1 describes the typographic changes used in this book.

Table P-1 Typographic Conventions

Typeface or Symbol	**Meaning**	**Example**
`AaBbCc123`	The names of commands, files, and directories; on-screen computer output	`di_add_intr()` registers a device interrupt with the system. `add_drv` adds a driver to the system.

`AaBbCc123`	What you type, contrasted with on-screen computer output	`machine_name%` **`su`**
		`Password:`

AaBbCc123	Command-line placeholder: replace with a real name or value	*number* is the number of the interrupt to register.
AaBbCc123	Book titles, new words or terms, or words to be emphasized	Read Chapter 6 in *Writing Device Drivers*. A *mutual exclusion lock* is....

Note – The term “x86” refers to the Intel 8086 family of microprocessor chips, including the Pentium and Pentium Pro processors and compatible microprocessor chips made by AMD and Cyrix. In this document the term “x86” refers to the overall platform architecture, whereas “*Intel Platform Edition*” appears in the product name of x86 products.

SunOS Kernel and Device Tree 1

This chapter provides an overview of the SunOS kernel and the manner in which it represents devices as nodes in a device tree. It covers general kernel structure and function, and the Solaris 2.x Device Driver Interface/Driver Kernel Interface (DDI/DKI). In addition, driver binding to device nodes is discussed in relation to both specific and generic device names.

What Is the Kernel?

The SunOS kernel is a program that manages system resources. It insulates applications from the system hardware and provides them with essential system services such as input/output (I/O) management, virtual memory, and scheduling. The kernel consists of object modules that are dynamically loaded into memory when needed.

The kernel provides a set of interfaces for applications to use called *system calls*. System calls are documented in the *Solaris 2.6 Reference Manual* (see `Intro(2)`). The function of some system calls is to invoke a device driver to perform I/O. Device drivers are loadable modules that insulate the kernel from device hardware and manage data transfers.

The remainder of this book discusses the specifics of device drivers. For details on compiling and installing a device driver, see Chapter 15, “Loading and Unloading Drivers.” The following sections provide additional high-level information on the SunOS kernel.

Multithreading Considerations

In most UNIX systems, the *process* is the unit of execution. In the SunOS 5.x system, a *thread* is the unit of execution. A thread is a sequence of instructions executed within a program. A process consists of one or more threads. There are two types of threads: application threads, which run in user space, and kernel threads, which run in kernel space.

The kernel is multithreaded (MT). Many kernel threads can be running kernel code, and may be doing so concurrently on a multiprocessor (MP) machine. Kernel threads may also be pre-empted by other kernel threads at any time. This is a departure from the traditional UNIX model where only one process can be running kernel code at any one time, and that process is not pre-emptable (though it is interruptible).

The multithreading of the kernel imposes some additional restrictions on the device drivers. For more information on multithreading considerations, see Chapter 4, "Multithreading" and Appendix G, "Advanced Topics."

Virtual Memory

A complete overview of the SunOS virtual memory (VM) system is beyond the scope of this book, but two virtual memory terms of special importance are used when discussing device drivers: virtual address and address space.

- Virtual address – A *virtual address* is an address that is mapped by the memory management unit (MMU) to a physical hardware address. All addresses directly accessible by the driver are kernel virtual addresses; they refer to the *kernel address space*.
- Address space – An *address space* is a set of *virtual address segments*, each of which is a contiguous range of virtual addresses. Each user process has an address space called the *user address space*. The kernel has its own address space called the *kernel address space*.

Special Files

In UNIX, devices are treated as files. They are represented in the file system by *special files*. These files are advertised by the device driver and commonly reside in the `/devices` directory hierarchy.

Special files may be of type *block* or *character*. The type indicates which kind of device driver operates the device.

Associated with each special file is a *device number*. This consists of a *major number* and a *minor number*. The major number identifies the device driver associated with the special file. The minor number is created and used by the device driver to further identify the special file. Usually, the minor number is an encoding that identifies the device the driver should access and the type of access to perform. The minor number, for example, could identify a tape device requiring backup and also specify whether the tape needs to be rewound when the backup operation is complete.

Dynamic Loading of Kernel Modules

Kernel modules are loaded dynamically as references are made to them. For example, when a device special file is opened (see open(2)), the corresponding driver is loaded if it is not already in memory. Device drivers must provide support for dynamic loading. See Chapter 5, “Autoconfiguration,” for more details about the loadable module interface.

Overview of the Solaris 2.x DDI/DKI

In System V Release 4 (SVR4), the interface between device drivers and the rest of the UNIX kernel has been standardized and documented in Section 9 of the of the *Solaris 2.6 Reference Manual*. The reference manual documents driver entry points, driver-callable functions and kernel data structures used by device drivers. These interfaces, known collectively as the Solaris 2.x Device Driver Interface / Driver Kernel Interface (Solaris 2.x DDI / DKI), are divided into the following subdivisions:

- Device Driver Interface / Driver Kernel Interface (DDI / DKI) – Includes architecture-independent interfaces supported on all implementations of System V Release 4 (SVR4).
- Solaris DDI – Includes architecture-independent interfaces specific to Solaris.
- Solaris SPARC DDI – Includes SPARC Instruction Set Architecture (ISA) interfaces specific to Solaris.
- Solaris x86 DDI– Includes x86 Instruction Set Architecture interfaces specific to Solaris.

- Device Kernel Interface (DKI) – Includes DKI-only architecture-independent interfaces specific to SVR4. These interfaces may not be supported in future releases of System V. Only two interfaces belong to this group: `segmap`(9E) and `hat_getkpfnum`(9F).

The Solaris 2.x DDI/DKI, like its SVR4 counterpart, is intended to standardize and document all interfaces between device drivers and the kernel. In addition, the Solaris 2.x DDI/DKI is designed to allow source compatibility for drivers on any SunOS 5.x-based machine, regardless of the processor architecture (such as SPARC or x86). It is also intended to provide binary compatibility for drivers running on any SunOS 5.x-based processor, regardless of the specific platform architecture (sun4c, sun4d, sun4m, sun4u, i86pc). Drivers using only kernel facilities that are part of the Solaris 2.x DDI/DKI are known as *Solaris 2.x DDI/DKI-compliant device drivers*.

The Solaris 2.x DDI/DKI allows platform-independent device drivers to be written for SunOS 5.x-based machines. These *shrink-wrapped* (binary compatible) drivers allow third-party hardware and software to be more easily integrated into SunOS 5.x-based machines. The Solaris 2.x DDI/DKI is designed to be architecture independent and enable the same driver to work across a diverse set of machine architectures.

Platform independence is accomplished in the design of DDI portions of the Solaris 2.x DDI/DKI. The following main areas are addressed:

- Interrupt handling
- Accessing the device space from the kernel or a user process (register mapping and memory mapping)
- Accessing kernel or user process space from the device (DMA services)
- Managing device properties

Device Tree

The kernel uses a tree structure to represent various physical machine configurations. Each node in the tree structure is described by a device-information structure. Standard device drivers and their devices are associated with leaf nodes. These drivers are called *leaf* drivers. Bus drivers are associated with bus nexus nodes and are called *bus nexus* drivers. This manual documents writing leaf drivers and one type of nexus driver, a SCSI host bus adapter (HBA) driver. This manual does not document any other type of bus nexus driver. Figure 1-1 on page 5 illustrates two possible device tree configurations.

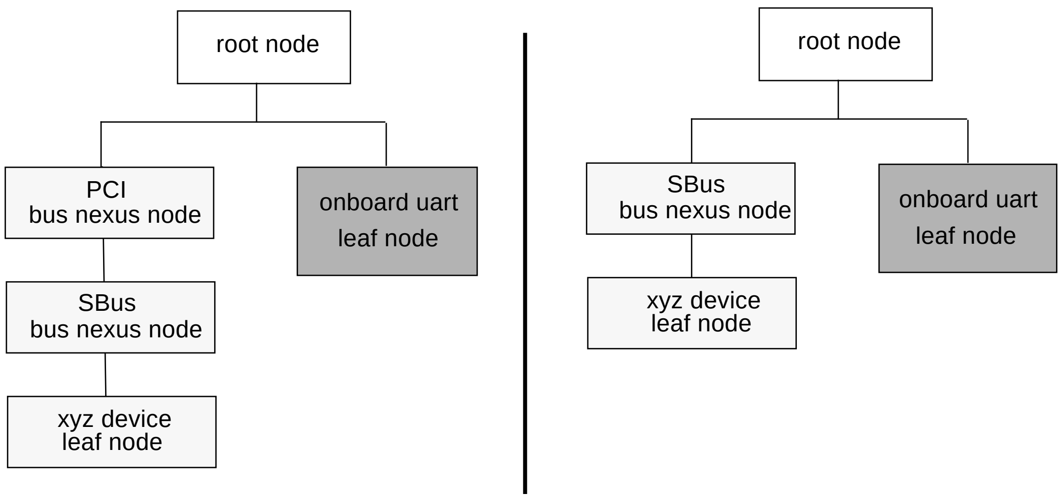


Figure 1-1 Possible Device Tree Configurations

The topmost node in the device tree is called the *root node*. The tree structure creates a parent-child relationship between nodes. This parent-child relationship is the key to architectural independence. When a leaf or bus nexus driver requires a service that is architecturally dependent in nature, it requests its parent to provide the service.

The intermediate nodes in the tree are generally associated with buses, such as the SBus, SCSI, and PCI buses. These nodes are called *bus nexus nodes* and the drivers associated with them are called *bus nexus drivers*. Bus nexus drivers encapsulate the architectural dependencies associated with a particular bus.

This approach enables drivers to function regardless of the architecture of the machine or the processor. The *xyz* driver, for example, is source compatible with the architectural configurations shown in Figure 1-1; it can be binary compatible if the system uses the same instruction set architecture.

Additionally, in Figure 1-1, the bus nexus driver associated with the PCI-to-SBus adapter card handles all of the architectural dependencies of the interface. The *xyz* driver only needs to determine that it is connected to an SBus.

Example Device Tree

In this example, the system builds a tree structure that contains information about the devices connected to the machine at boot time. The system uses this information to create a dependency tree with bus nexus nodes and leaf nodes.

Figure 1-2 illustrates a sample device tree for a frame buffer (`SUNW,ffb`), a pseudo bus nexus node, and several PCI devices associated with a PCI bus nexus node.

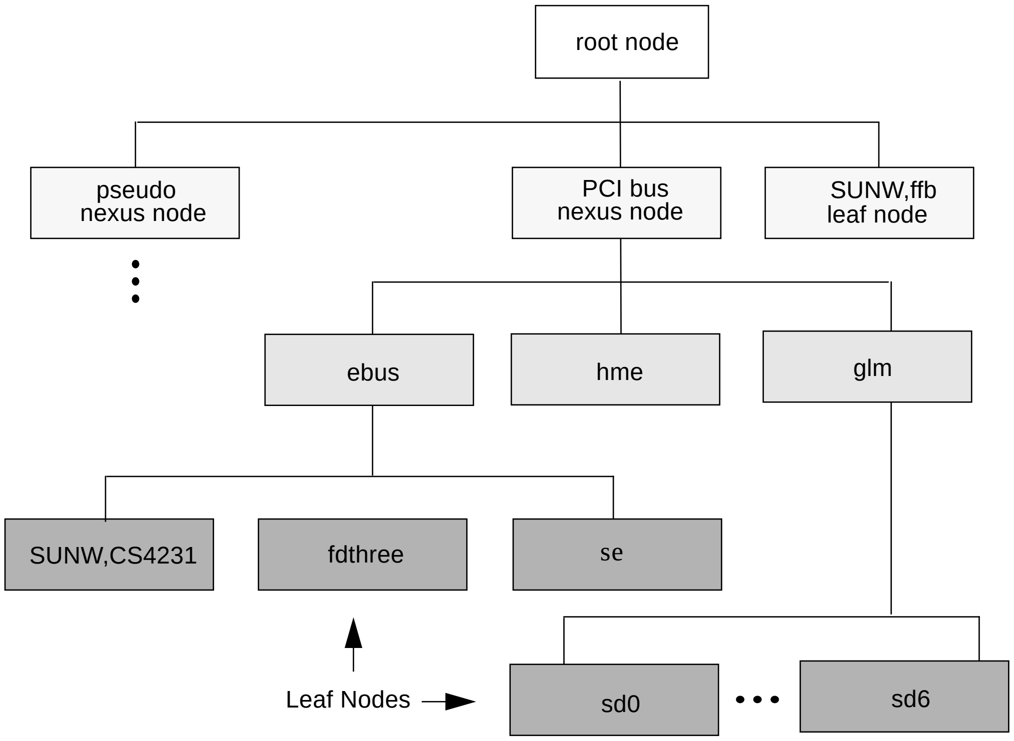


Figure 1-2 Example Device Tree

In Figure 1-2, the `SUNW,ffb` leaf node represents a system frame buffer. The pseudo bus nexus node is the parent node of any pseudo device drivers (drivers without hardware). The PCI bus nexus node is the parent node for the following children:

- `ebus`—the ebus bus nexus node
- `hme`—the Ethernet driver
- `glm`—the SCSI host bus adapter (HBA) nexus node

The `ebus` nexus node is both the child of the PCI bus nexus node and the parent node of the following leaf nodes: `fdthree` (a floppy disk device), `SUNW,CS4231` (an audio device) and `se` (a serial device). The Ethernet driver (`hme`) is a leaf node and therefore has no children. The SCSI HBA node (`glm`) has a number of disk devices as leaf nodes.

Device Drivers

Associated with each leaf or bus nexus node may be a device driver. Each driver has associated with it a device operations structure (see `dev_ops`(9S)) that defines the operations that the device driver can perform. The device operations structure contains function pointers for generic operations such as `getinfo`(9E) and `attach`(9E). It also contains a pointer to operations specific to bus nexus drivers and a pointer to operations specific to leaf drivers.

Displaying the Device Tree

The device tree can be displayed in two ways:

1. The `prtconf`(1M) command displays all of the device nodes in the device tree.

2. The `/devices` hierarchy is a representation of the device tree; use `ls`(1) to view it.

Note – `/devices` displays only devices that have drivers configured into the system. `prtconf`(1M) shows all device nodes regardless of whether a driver for the device exists on the system or not.

`prtconf(1M)`

The `prtconf`(1M) command (excerpted example follows) displays all the devices in the system:

```
SUNW,Ultra-1
...
pci, instance #0
   ebus, instance #0
       auxio (driver not attached)
       power (driver not attached)
       SUNW,pll (driver not attached)
       sc (driver not attached)
       se, instance #0
       su, instance #0
       su, instance #1
       ecpp (driver not attached)
       fdthree (driver not attached)
       eeprom (driver not attached)
       flashprom (driver not attached)
       SUNW,CS4231 (driver not attached)
   network, instance #0
   scsi, instance #0
       disk (driver not attached)
       tape (driver not attached)
       sd, instance #0
       sd, instance #1 (driver not attached)
       sd, instance #2 (driver not attached)
       sd, instance #3 (driver not attached)
       sd, instance #4 (driver not attached)
       sd, instance #5 (driver not attached)
       ....
pci, instance #1
SUNW,UltraSPARC-II (driver not attached)
SUNW,ffb (driver not attached)
pseudo, instance #0
```

/devices

The /devices hierarchy provides a name space that represents the device tree. Following is an abbreviated listing of the /devices name space. The sample output corresponds to the example device tree and prtconf(1M) output shown previously.

```
/devices
/devices/pseudo
/devices/SUNW,ffb@1e,0:ffb0
/devices/pci@1f,4000/ebus@1
/devices/pci@1f,4000/scsi@3
```

```
/devices/pci@1f,4000/scsi@3:devctl
/devices/pci@1f,4000/ebus@1/ecpp@14,3043bc:ecpp0
/devices/pci@1f,4000/ebus@1/se@14,400000:0,hdlc
/devices/pci@1f,4000/ebus@1/se@14,400000:1,hdlc
/devices/pci@1f,4000/ebus@1/se@14,400000:a
/devices/pci@1f,4000/ebus@1/se@14,400000:a,cu
/devices/pci@1f,4000/ebus@1/se@14,400000:b
/devices/pci@1f,4000/ebus@1/se@14,400000:b,cu
/devices/pci@1f,4000/ebus@1/SUNW,CS4231@14,200000:sound,audio
/devices/pci@1f,4000/ebus@1/SUNW,CS4231@14,200000:sound,audioctl
/devices/pci@1f,4000/scsi@3/sd@0,0:a
/devices/pci@1f,4000/scsi@3/sd@0,0:a,raw
```

Binding a Driver to a Device Node

In addition to constructing the device tree, the kernel must also determine the drivers that will be used to manage the devices.

Binding a driver to a device node refers to the process by which the system selects a driver to manage a particular device. The driver binding name is the name that links a driver to a unique device node in the device information tree. For each device in the device tree, the system chooses a driver from a list of drivers.

Each device node has a *name* property associated with it. This property may be derived either from an external agent such as the PROM during system boot or from a `driver.conf` file. In either case, the `name` property represents the node name assigned to a device in the device tree.

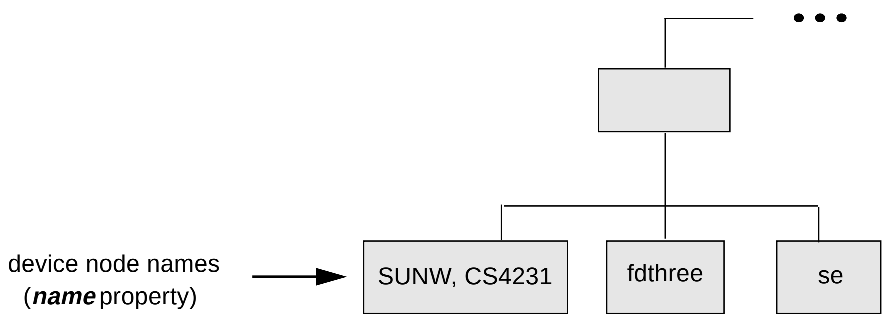


Figure 1-3 Device Node Names

A device node may also have a *compatible* property associated with it. The *compatible* property (if it exists) contains an ordered list of one or more possible driver names for the device.

The system uses both the *name* and the *compatible* properties to select a driver for the device. The system first attempts to match the contents of the device *name* property to a driver on the system. If this fails, the system checks for the existence of a *compatible* property. The *compatible* property is simply a listing of possible driver names from which the system can determine the specific driver binding name for the device.

Beginning with the first driver name on the *compatible* property list, the system attempts to match the driver name to a known driver on the system. It processes each entry on the list until either a match is found or the end of the list is reached.

If the contents of either the *name* property or the *compatible* property match a driver on the system, then that driver is bound to the device node. If no match is found, no driver is bound to the device node.

Generic Device Names

Some devices with a *compatible* property use a generic device name as the value for the *name* property. Generic device names describe the function of a device without actually identifying a specific driver for the device. For example, a SCSI host bus adapter may have a generic device name of `scsi`. An Ethernet device may have a generic device name of `ethernet`.

The *compatible* property allows the system to determine alternate driver names (like `glm` for `scsi` HBA device drivers or `hme` for `ethernet` device drivers) for devices with a generic device name.

Devices with generic device names must supply a *compatible* property.

Note – For a complete description of *generic device names*, see the IEEE 1275 Open Firmware Boot Standard.

Figure 1-4 on page 11 and Figure 1-5 on page 11 show two device nodes: one node uses a specific device name and the other uses a generic device name.

For the device node with a specific device name, the driver binding name `SUNW,ffb` is the same name as the device node name.

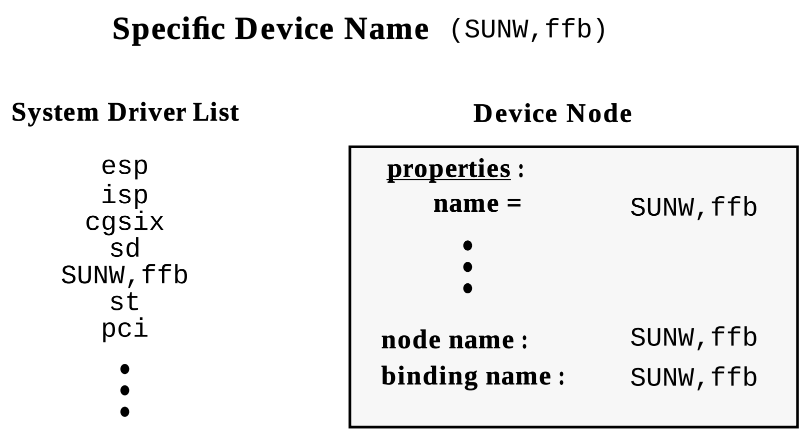


Figure 1-4 Specific Driver Node Binding

For the device node with the generic device name `display`, the driver binding name `SUNW,ffb` is the first name on the *compatible* property driver list that matches a driver on the system driver list. In this case, `display` is a generic device name for frame buffers.

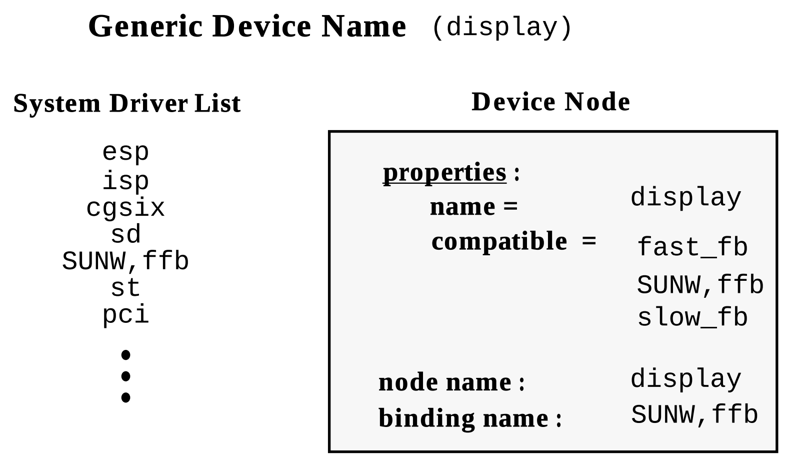


Figure 1-5 Generic Driver Node Binding

Hardware Overview 2

This chapter discusses some general issues about the hardware that the SunOS 5.x operating system runs on. This includes issues related to the processor, bus architectures, and memory models supported by the Solaris 2.x system, various device issues, and the PROM used in Sun platforms.

Note – The information presented here is for informational purposes only and may be of help during driver debugging. However, the Solaris 2.x DDI/DKI hides many of these implementation details from device drivers.

SPARC Processor Issues

This section describes a number of SPARC processor-specific topics including data alignment, byte ordering, register windows, and availability of floating-point instructions. For information on x86 processor-specific topics, see "x86 Processor Issues" on page 15.

SPARC Data Alignment

All quantities must be aligned on their natural boundaries. Using standard C data types:

- `short` integers are aligned on 16-bit boundaries.
- `int` integers are aligned on 32-bit boundaries.

- `long` integers are aligned on either 32-bit boundaries or 64-bit boundaries, depending on whether the data model of the kernel is 64-bit or 32-bit. For information on data models, see Appendix F, "Making a Device Driver 64-Bit Ready".
- `long long` integers are aligned on 64-bit boundaries.

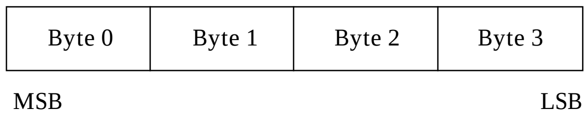
Usually, the compiler handles alignment issues. Driver writers are more likely to be concerned about alignment as they must use the proper data types to access their device. Since device registers are commonly accessed through a pointer reference, drivers must ensure that pointers are properly aligned when accessing the device. See "Data Access Functions" on page 49 for more information about accessing device registers.

SPARC Structure Member Alignment

Because of the data alignment restrictions imposed by the SPARC processor, C structures also have alignment requirements. Structure alignment requirements are imposed by the most strictly-aligned structure component. For example, a structure containing only characters has no alignment restrictions, while a structure containing a `long long` member must be constructed to guarantee that this member falls on a 64-bit boundary. See "Structure Padding" on page 53 for more information on how this restriction relates to device drivers.

SPARC Byte Ordering

The SPARC processor uses *big-endian* byte ordering; in other words, the most significant byte of an integer is stored at the lowest address of the integer.



SPARC Register Windows

SPARC processors use register windows. Each register window is comprised of 8 *in* registers, 8 *local* registers, and 8 *out* registers (which are the *in* registers of the next window). There are also 8 *global* registers. The number of register windows ranges from 2 to 32, depending on the processor implementation.

Because drivers are normally written in C, the compiler usually hides the fact that register windows are used. However, it may be necessary to use them when debugging the driver. See "Debugging Tools" on page 356 for more information on how register windows are used when debugging.

SPARC Floating-Point Operations

Drivers should not perform floating-point operations, as they are not supported in the kernel.

SPARC Multiply and Divide Instructions

The Version 7 SPARC processors do not have multiply or divide instructions. These instructions are emulated in software and should be avoided. Because a driver cannot determine whether it is running on a Version 7, Version 8, or Version 9 processor, intensive integer multiplication and division should be avoided if possible. Instead, use bitwise left and right shifts to multiply and divide by powers of two.

SPARC Architecture Manual

The *SPARC Architecture Manual, Version 9*, contains more specific information on the SPARC CPU.

x86 Processor Issues

This section describes a number of x86 processor-specific topics including data alignment, byte ordering, and floating-point instructions.

x86 Data Alignment

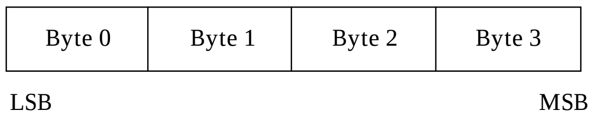
There are no alignment restrictions on data types. However, extra memory cycles may be required for the x86 processor to properly handle misaligned data transfers.

x86 Structure Member Alignment

See “Structure Padding” on page 53 for more information on how this relates to device drivers.

x86 Byte Ordering

The x86 processor uses *little-endian* byte ordering. The least significant byte of an integer is stored at the lowest address of the integer.



x86 Floating-Point Operations

Drivers should not perform floating-point operations, as they are not supported in the kernel.

x86 Architecture Manuals

Intel Corporation publishes a number of books on the x86 family of processors:

- Intel Corporation, *80386 Programmer’s Reference Manual*, 1986. ISBN 1-55512-022-9.
- Intel Corporation, *i486 Microprocessor Hardware Reference Manual*, 1990. ISBN 1-55512-112-8.
- Intel Corporation, *Pentium Processor User’s Manual - Volume 3: Architecture and Programming Manual*, 1993. ISBN 1-55512-195-0.

Store Buffers

To improve performance, the CPU uses internal store buffers to temporarily store data. This may affect the synchronization of device I/O operations. Therefore, the driver needs to take explicit steps to make sure that writes to registers are completed at the proper time.

For example, when access to device space (such as registers or a frame buffer) is synchronized by a lock, the driver needs to check that the store to the device space has actually completed before releasing the lock. Releasing the lock does not guarantee the flushing of I/O buffers.

To give another example, when acknowledging an interrupt, the driver usually sets or clears a bit in a device control register. The driver must ensure that the write to the control register has reached the device before the interrupt handler returns. Similarly, if the device requires a delay (the driver busy-waits) after writing a command to the control register, the driver must ensure that the write has reached the device before delaying.

If the device registers can be read without undesirable side effects, verification of a write can be as simple as reading the register immediately after writing to it. If that particular register cannot be read without undesirable side effects, another device register in the same register set can be used.

System Memory Model

The system memory model defines the semantics of memory operations such as *load* and *store* and specifies how the order in which these operations are issued by a processor is related to the order in which they reach memory. The memory model applies to both uniprocessors and shared-memory multiprocessors. Two memory models are supported: total store ordering (TSO) and partial store ordering (PSO).

Total Store Ordering (TSO)

TSO guarantees that the sequence in which store, FLUSH, and atomic load-store instructions appear in memory for a given processor is identical to the sequence in which they were issued by the processor.

Both x86 and SPARC processors support TSO.

Partial Store Ordering (PSO)

PSO does not guarantee that the sequence in which store, FLUSH, and atomic load-store instructions appear in memory for a given processor is identical to the sequence in which they were issued by the processor. The processor can reorder the stores so that the sequence of stores in memory is not the same as the sequence of stores in the CPU.

SPARC processors support PSO; x86 processors do not.

For SPARC processors, conformance between *issuing* order and *memory* order is provided by the system framework using the STBAR instruction: if two of the above instructions are separated by an STBAR in the issuing order of a processor, or if they reference the same location, the memory order of the two instructions is the same as the issuing order. Note that enforcement of strong data ordering in DDI-compliant drivers is provided by the `ddi_regs_map_setup`(9F) interface. Compliant drivers cannot use the STBAR instruction directly.

See the *SPARC Architecture Manual, Version 9*, for more details on the SPARC memory model.

Bus Architectures

This section describes a number of bus-specific topics including device identification, device addressing, and interrupts.

Device Identification

Device identification is the process of determining which devices are present in the system.

Self-Identifying Devices

Some devices are self-identifying—the device itself provides information to the system so that it can identify the device driver that needs to be used. The device usually provides additional information to the system in the form of name-value (name=value) pairs that can be retrieved using the property interfaces. See “Properties” on page 65 for more information on properties.

SBus and PCI local bus devices are examples of self-identifying devices. On SBus, the information is usually derived from a small Forth program stored in the FCode PROM on the device. PCI devices provide a configuration space containing device configuration information. See `sbus`(4) and `pci`(4) for more information.

Non-Self-Identifying Devices

Devices that do not provide information to the system to identify themselves are called non-self-identifying devices. Drivers for these devices must have a `probe`(9E) routine that determines whether the device is really present. In addition, information about the device must be provided in a hardware configuration file (see `driver.conf`(4)), so that the system can provide `probe`(9E) with the information it needs to contact the device. See `probe`(9E) for more information.

A VMEbus device is an example of a non-self-identifying device. See `vme`(4) for more information.

Interrupts

The SunOS system supports polling interrupts and vectored interrupts.The Solaris 2.x DDI/DKI interrupt model is the same for both. See "Types of Interrupts" on page 115 for more information about interrupt handling.

Bus Specifics

This section covers addressing and device configuration issues specific to the buses that the SunOS system supports.

PCI Local Bus

The PCI local bus is a high-performance bus designed for high-speed data transfer. The PCI bus usually resides on the system board and operates at speeds close to those of the host processor. The PCI bus is normally used as an interconnect mechanism between highly integrated peripheral components, peripheral add-on boards, and processor or memory systems. The processor, main memory, and the PCI bus itself are connected through a PCI host bridge, as shown in Figure 2-1 on page 20.

A tree structure of interconnected I/O buses is supported through a series of PCI bus bridges. Subordinate PCI bus bridges can be extended underneath the PCI host bridge to allow a single bus system to be expanded into a complex system with multiple secondary buses. PCI devices can be connected to one of these secondary buses. In addition, other bus bridges, such as SBus or ISA-bus, can be connected.

Every PCI device has a unique vendor ID and device ID. Multiple devices of the same kind are further identified by their unique device numbers on the bus where they reside.

Typical PCI devices include SCSI adapters, graphics and display adapters, host bus adapters, network controllers, and so on.

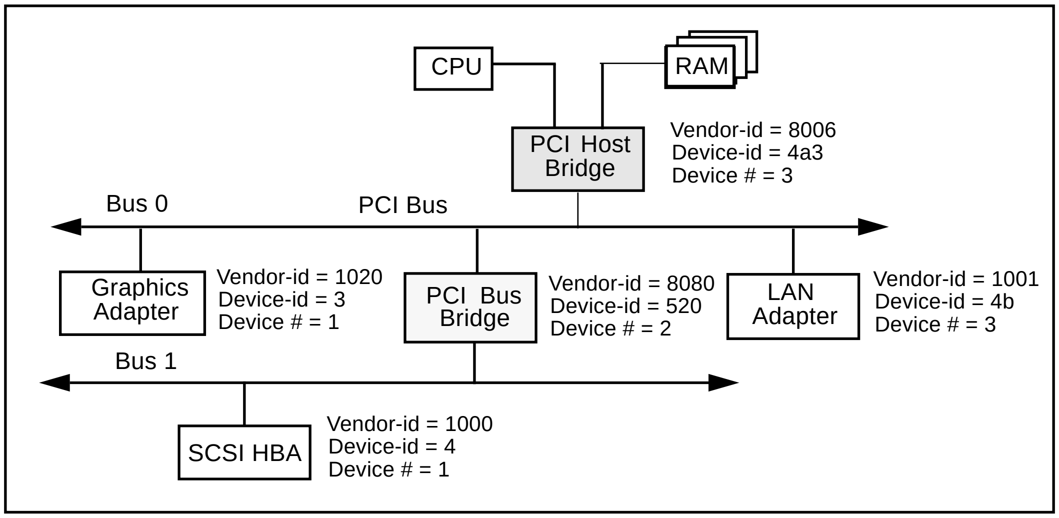


Figure 2-1 Machine Block Diagram

The PCI host bridge provides an interconnect between the processor and peripheral components. Through the PCI host bridge, the processor can directly access main memory independent of other PCI bus masters. For example, while the CPU is fetching data from the cache controller in the host bridge, other PCI devices can also access the system memory through the host bridge. The advantage of this architecture lies in its separation of the I/O bus from the processor's host bus.

The PCI host bridge also provides data access mappings between the CPU and peripheral I/O devices. It maps every peripheral device to the host address domain so that the processor can access the device through *memory mapped* I/O or *special* I/O instructions. On the local bus side, the PCI host bridge maps the system memory to the PCI address domain so that the PCI device can access the host memory as a bus master. Figure 2-2 shows the two address domains.

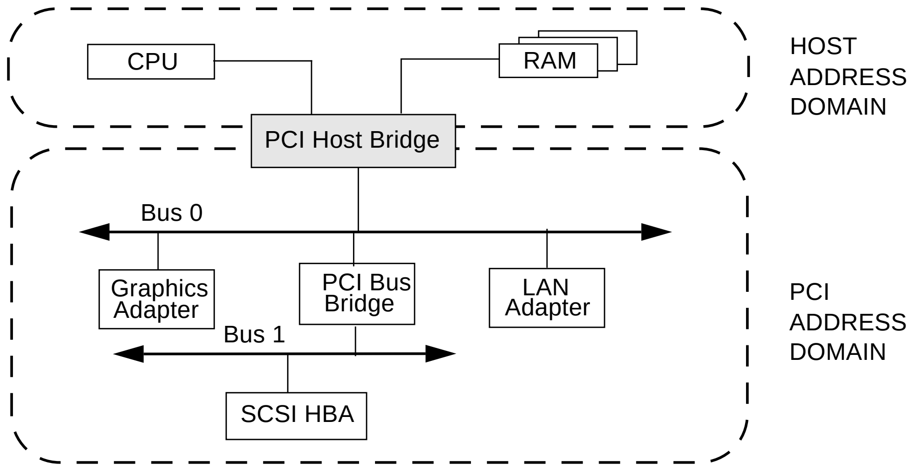


Figure 2-2 Host and Bus Address Domains

PCI Address Domain

The PCI address domain consists of three distinct address spaces: configuration, memory, and I/O space.

PCI Configuration Address Space

Configuration space is defined geographically; in other words, the location of a peripheral device is determined by its physical location within an interconnected tree of PCI bus bridges. A device is usually located by its *bus number* and *device* (*slot*) *number.* Each peripheral device contains a set of well-defined configuration registers in its PCI configuration space. The registers are used not only to identify devices but also to supply device configuration information to the configuration framework. For example, base address registers in the device configuration space must be mapped before a device can respond to data access. Figure 2-3 illustrates the configuration space registers.

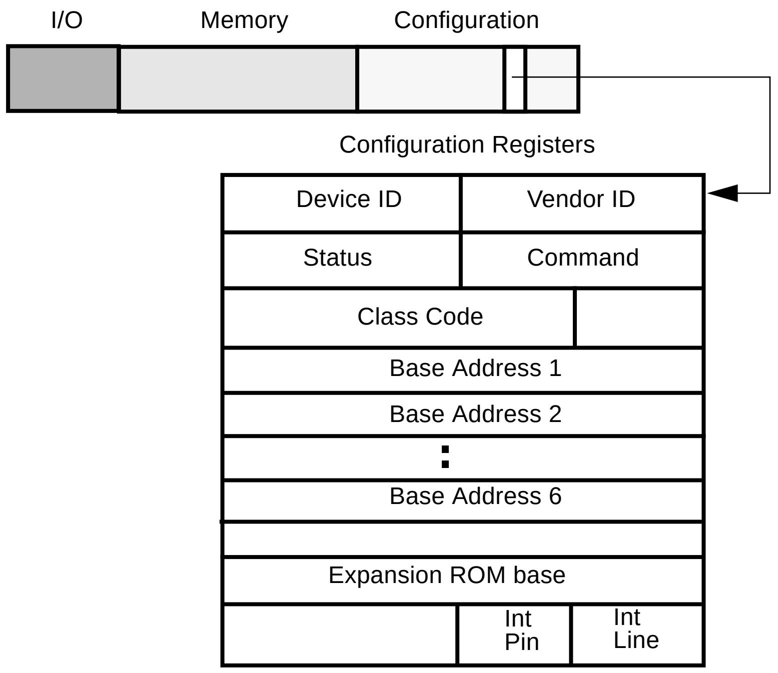


Figure 2-3 PCI Configuration Address Space

The method for generating configuration cycles is host dependent. In x86 machines, special I/O ports are used. On other platforms, the PCI configuration space may be *memory-mapped* to certain address locations corresponding to the PCI host bridge in the host address domain. When a device configuration register is accessed by the processor, the request will be routed to the PCI host bridge. The bridge then translates the access into proper configuration cycles on the bus.

PCI Configuration Base Address Registers

The PCI configuration space consists of up to six 32-bit base address registers for each device. These registers provide both size and data type information. System firmware assigns base addresses in the PCI address domain to these registers.

The firmware identifies the size of each addressable region by writing all 1's to the base address register and then reading back the value. The device will return 0's in all *don't-care* address bits, effectively specifying the size of the address space.

Each addressable region can be either memory or I/O space. The value contained in bit 0 of the base address register identifies the type. A value of 0 in bit 0 indicates a memory space and value of 1 indicates an I/O space. Figure 2-4 shows two base address registers: one for memory; the other for I/O types.

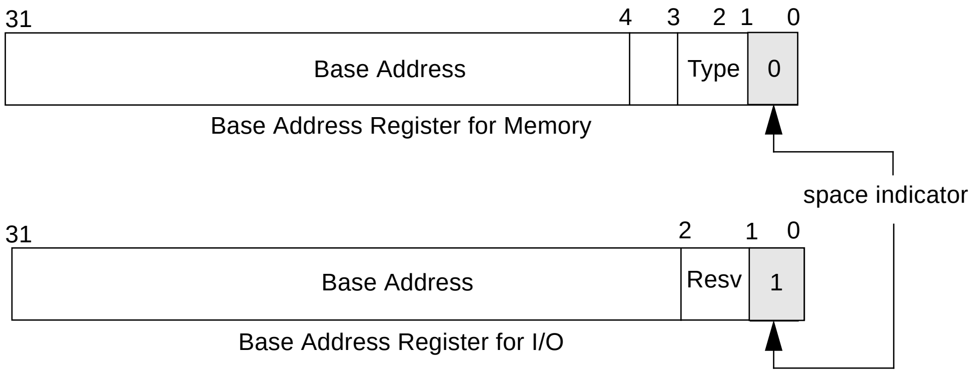

31
4
3
2
1
0
Base Address
Type
0
Base Address Register for Memory
space indicator
31
2
1
0
Base Address
Resv
1
Base Address Register for I/O

Figure 2-4 Base Address Registers for Memory and I/O

PCI Memory Address Space

PCI supports both 32-bit and 64-bit addresses for memory space. System firmware assigns regions of memory space in the PCI address domain to PCI peripherals. The base address of a region is stored in the base address register of the device's PCI configuration space. The size of each region must be a power of two, and the assigned base address must be aligned on a boundary equal to the size of the region. Device addresses in memory space are *memor*y-*mapped* into the host address domain so that data access to any device can be performed by the processor's native load or store instructions.

PCI I/O Address Space

PCI supports 32-bit I/O space. I/O space may be accessed differently on different platforms. Processors with special I/O instructions, like the Intel processor family, access the I/O space with `in` and `out` instructions. Machines with no special I/O instructions are usually *memory-mapped* to the address locations corresponding to the PCI host bridge in the host address domain. When the processor accesses the *memory-mapped* addresses, an I/O request will be sent to the PCI host bridge. It then translates the addresses into I/O cycles and puts them on the PCI bus. *Memory-mappe*d I/O is performed by the native load/store instructions of the processor. For example, reading from or writing to a memory mapped data register can be done by a load or store instruction to that register's I/O address.

PCI Hardware Configuration Files

Hardware configuration files should be unnecessary for PCI local bus devices. However, on some occasions drivers for PCI devices may need to use hardware configuration files to augment the driver private information. See `driver.conf`(4) and `pci`(4) for further details.

SBus

Typical SBus systems consist of a motherboard (containing the CPU and SBus interface logic), a number of SBus devices on the motherboard itself, and a number of SBus expansion slots. An SBus can also be connected to other types of buses through an appropriate bus bridge.

The SBus is geographically addressed; each SBus slot exists at a fixed physical address in the system. An SBus card has a different address depending on which slot it is plugged into. Moving an SBus device to a new slot causes the system to treat it as a new device. See "Persistent Instances" on page 97 for more information.

The SBus uses polling interrupts. When an SBus device interrupts, the system only knows which of several devices might have issued the interrupt. The system interrupt handler must ask the driver for each device whether it is responsible for the interrupt.

SBus Physical Address Space

Table 2-1 shows the physical address space layout of the Sun Ultra™ 2. A physical address on the Ultra 2 consists of 41 bits. The 41-bit physical address space is further broken down into multiple 33-bit address spaces identified by PA(40:33).

Table 2-1 Device Physical Space in the Ultra 2

PA(40:33)	33-bit Space	Usage
0x0	`0x000000000 - 0x07FFFFFFF`	2GB Main memory
0x80 – 0xDF	Reserved on Ultra 2	Reserved on Ultra 2
0xE0	Processor 0	Processor 0
0xE1	Processor 1	Processor 1
0xE2 – 0xFD	Reserved on Ultra 2	Reserved on Ultra 2
0xFE	`0x000000000 - 0x1FFFFFFFF`	UPA Slave (FFB)
0xFF	`0x000000000 - 0x0FFFFFFFF`	System I/O space
	`0x100000000 - 0x10FFFFFFF`	SBus Slot 0
	`0x110000000 - 0x11FFFFFFF`	SBus Slot 1
	`0x120000000 - 0x12FFFFFFF`	SBus Slot 2
	`0x130000000 - 0x13FFFFFFF`	SBus Slot 3
	`0x1D0000000 - 0x1DFFFFFFF`	SBus Slot D
	`0x1E0000000 - 0x1EFFFFFFF`	SBus Slot E
	`0x1F0000000 - 0x1FFFFFFFF`	SBus Slot F

Physical SBus Addresses

The SBus has 32 address bits, as described in the *SBus Specification*. Table 2-2 describes how the Ultra 2 uses the address bits.

Table 2-2 Ultra 2 SBus Address Bits

Bits	**Description**
0 - 27	These bits are the SBus address lines used by an SBus card to address the contents of the card.
28 - 31	Used by the CPU to select one of the SBus slots. These bits generate the SlaveSelect lines.

This addressing scheme yields the Ultra 2 addresses shown in Table 2-1. Other implementations may use a different number of address bits.

The Ultra 2 has seven SBus slots, four of which are physical. Slots 0 through 3 are available for SBus cards. Slots 4-12 are reserved. The slots are used in the following way:

- Slots 0–3 are physical slots that have DMA-master capability.
- Slots D, E, and F are not actual physical slots, but refer to the onboard direct memory access (DMA), SCSI, Ethernet, and audio controllers. For convenience, these are viewed as being plugged into slots D, E, and F.

Note – Some SBus slots are slave-only slots, such as slot 3 on the SPARCstation1. Drivers that require DMA capability should use `ddi_slaveonly`(9F) to determine if their device is in a DMA-capable slot. For an example of this function, see "attach( )" on page 101.

SBus Hardware Configuration Files

Hardware configuration files are normally unnecessary for SBus devices. However, on some occasions drivers for SBus devices may need to use hardware configuration files to augment the information provided by the SBus card. See `driver.conf`(4) and `sbus`(4) for further details.

VMEbus

The VMEbus supports multiple address spaces. Appropriate entries in the `driver.conf`(4) file should be made for the address spaces used by the device For DMA devices, the address space that the board uses for its DMA transfers must be known by the driver (this is usually a 32- or 24-bit space).

A VMEbus card has its own address, possibly configurable by jumpers. A VMEbus card has the same address no matter which slot it is plugged into. Changing the address of a VME card causes the system to treat it as a new device.

The VMEbus uses vectored interrupts. When a VMEbus device interrupts, the system can identify which device is interrupting and call the correct device driver directly.

VMEbus Hardware Configuration Files

Most VME devices require hardware configuration files to inform the system that the device hardware may be present. The configuration file must specify the device addresses on the VMEbus and any interrupt capabilities that the device has.

Configuration files for VMEbus devices should identify the parent bus driver implicitly using the *class* keyword and specifying class “vme.” This removes the dependency on the name of the particular bus driver involved, since the driver may be named differently on different platforms. See `driver.conf`(4) and `vme`(4) for further details.

ISA Bus

ISA Bus Memory and I/O Space

Two address spaces are provided: memory address space and I/O address space. Depending on the device, registers may appear in one or both of these address spaces. Table 2-3 shows the registers for memory and I/O address spaces in the ISA bus.

Table 2-3 ISA Bus Address Space

ISA Space Name	**Address Size**	**Data Transfer Size**	**Physical Address Range**
Main memory	24	16	0x0-0xffffff
I/O	—	8/16	0x0-0xfff

Registers can be mapped in memory address space and used by the driver as normal memory (see "Memory Space Access" on page 50).

Registers in I/O space are accessed through I/O port numbers using separate kernel routines. See "I/O Space Access" on page 51 for more information.

Hardware Configuration Files

Beginning with the Solaris 2.6 system, the use of hardware configuration files to provide arguments to `probe`(9E) on x86 platforms is highly discouraged, since probes can lead to system hangs and resets. Exact device configuration information is maintained by the booting system and is passed to the `probe`(9E) function.

A separate realmode driver may need to be developed for the booting system. See the *Realmode Drivers* white paper in the Driver Development Site at `http://www.sun.com/developers/driver` for information on realmode drivers. Hardware configuration files may be needed on some occasions to augment the information provided by the booting system. See `driver.conf`(4) and `isa`(4) for further details.

EISA Bus

Memory and I/O Space

Two address spaces are provided: memory address space and I/O address space. Depending on the device, registers may appear in one or both of these address spaces. Table 2-4 shows the registers for memory and I/O address spaces in the EISA bus.

Table 2-4 EISA Bus Address Space

EISA Space Name	**Address Size**	**Data Transfer Size**	**Physical Address Range**
Main Memory	32	32	0x0-0xffffffff
I/O	—	8/16/32	0x0-0xffff

Registers can be mapped in memory address space and used by the driver as normal memory (see "Memory Space Access" on page 50).

Registers in I/O space are accessed through I/O port numbers using separate kernel routines. See "I/O Space Access" on page 51 for more information.

Hardware Configuration Files

Beginning with the Solaris 2.6 system, the use of hardware configuration files to provide arguments to `probe`(9E) on x86 platforms is highly discouraged, since probes can lead to system hangs and resets. Exact device configuration information is maintained by the booting system and is passed to the `probe`(9E) function.

A separate realmode driver may need to be developed for the booting system. See the *Realmode Drivers* white paper in the Driver Development Site at `http://www.sun.com/developers/driver` for information on realmode drivers. Hardware configuration files may be needed on some occasions to augment the information provided by the booting system. See `driver.conf`(4) and `eisa`(4) for further details.

MCA Bus

Memory and I/O Space

Two address spaces are provided: memory address space and I/O address space. Depending on the device, registers may appear in one or both of these address spaces.

Table 2-5 MCA Address Space

MCA Space Name	**Address Size**	**Data Transfer Size**	**Physical Address Range**
Main Memory	32	32	0x0-0xffffffff
I/O	—	8/16/32	0x0-0xfff

Registers can be mapped in memory address space and used by the driver as normal memory (see “Device Memory Mapping” on page 45).

Registers in I/O space are accessed through I/O port numbers using separate kernel routines. See “I/O Space Access” on page 51) for more information.

Hardware Configuration Files

Hardware configuration files are normally unnecessary for MCA devices. However, on some occasions drivers for MCA devices may need to use hardware configuration files to augment the information provided by the MCA card. See `driver.conf`(4) and `mca`(4) for further details.

Device Issues

Timing-Critical Sections

While most driver operations can be performed without synchronization and protection mechanisms beyond those provided by the locking primitives described in "Locking Primitives" on page 78, some devices require that a sequence of events happen in order without interruption. In conjunction with the locking primitives, the function `ddi_enter_critical`(9F) asks the system to guarantee, to the best of its ability, that the current thread will neither be pre-empted nor interrupted. This stays in effect until a closing call to `ddi_exit_critical`(9F) is made. See `ddi_enter_critical`(9F) for details.

Delays

Many chips specify that they can be accessed only at specified intervals. For example, the Zilog Z8530 SCC has a "write recovery time" of 1.6 microseconds. This means that a delay must be enforced with `drv_usecwait`(9F) when writing characters with an 8530. In some instances, it is unclear what delays are needed; in such cases, they must be determined empirically.

Internal Sequencing Logic

Devices with internal sequencing logic map multiple internal registers to the same external address. There are various kinds of internal sequencing logic:

- The Intel 8251A and the Signetics 2651 alternate the same external register between *two* internal mode registers. Writing to the first internal register is accomplished by writing to the external register. This write, however, has the side effect of setting up the sequencing logic in the chip so that the next read/write operation refers to the second internal register.
- The NEC PD7201 PCC has multiple internal data registers. To write a byte into a particular register, two steps must be performed. The first step is to write into register zero the number of the register into which the following byte of data will go. The data is then written to the specified data register. The sequencing logic automatically sets up the chip so that the next byte sent will go into data register zero.

- The AMD 9513 timer has a data pointer register that points at the data register into which a data byte will go. When sending a byte to the data register, the pointer is incremented. *The current value of the pointer register cannot be read.*

Interrupt Issues

The following are some common interrupt-related issues:

- A controller interrupt does *not* necessarily indicate that *both* the controller *and* one of its slave devices are ready. For some controllers, an interrupt may indicate that either the controller is ready or one of its devices is ready, but not both.
- Not all devices power up with interrupts disabled and then start interrupting only when told to do so.
- Some devices do not provide a way to determine that the board has generated an interrupt.
- Not all interrupting boards shut off interrupts when told to do so or after a bus reset.

Byte Ordering

To achieve the goal of multiple platform, multiple instruction set architecture portability, host bus dependencies were removed from the drivers. The first dependency issue to be addressed was the endian-ness (or byte ordering) of the processor. For example, the x86 processor family is little endian while the SPARC architecture is big endian.

Bus architectures display the same endian-ness types as processors. The PCI local bus, for example, is little endian, the SBus is big endian, the ISA bus is little endian and so on.

To maintain portability between processors and buses, DDI-compliant drivers must be endian neutral. Although drivers could conceivably manage their endian-ness by runtime checks or by preprocessor directives like `#ifdef _LITTLE_ENDIAN` or `_BIG_ENDIAN` statements in the source code, long-term maintenance would be troublesome. The Solaris 2.6 DDI solution hides the endian-ness issues from the drivers as illustrated in Figure 2-5. In some cases, the DDI framework performs the byte swapping using a software approach. In other cases, where byte swapping can be done by hardware (as in memory management unit (MMU) page-level swapping or by special machine instructions), the DDI framework will take advantage of the hardware features to improve performance.

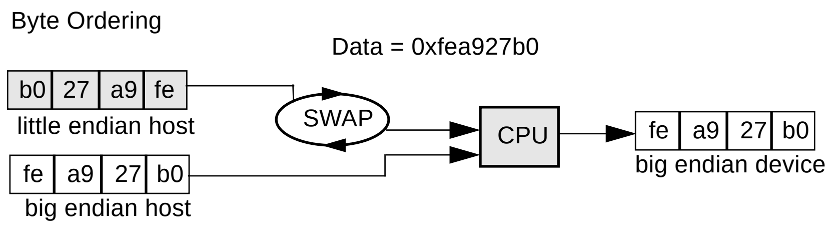


Figure 2-5 Byte Ordering Host Bus Dependency

Along with being endian-neutral, portable drivers must also be independent from data ordering of the processor. Under most circumstances, data must be transferred in the sequence instructed by the driver. However, sometimes data can be merged, batched, or reordered to streamline the data transfer, as illustrated in Figure 2-6. For example, data merging may be applied to accelerate graphics display on frame buffers. Drivers have the option to advise the DDI framework to use other optimal data transfer mechanisms during the transfer.

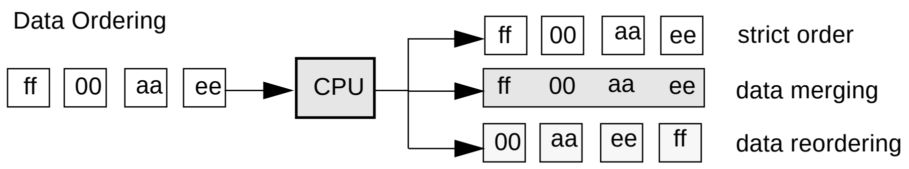


Figure 2-6 Data Ordering Host Bus Dependency

Device Attribute Representations

Device attribute (or device-related) information may be represented with a *name=value* pair notation called a *property.*

For example, a *reg* property is used to represent device registers and onboard memory. The *reg* property is a software abstraction that describes device hardware registers; its value encodes the device register address location and size. Drivers use the reg property to access device registers.

An *interrupt* property is a software abstraction used to represent the device interrupt; its value encodes the device-interrupt pin number.

PROM on SPARC Machines

Some platforms have a PROM monitor that provides support for debugging a device without an operating system. This section describes how to use the PROM on SPARC machines to map device registers so that they can be accessed. Usually, the device can be exercised enough with PROM commands to determine if the device is working correctly.

The PROM has several purposes; it serves to:

- Bring the machine up from power on, or from a hard reset PROM `reset` command.
- Provide an interactive tool for examining and setting memory, device registers, and memory mappings.
- Boot the SunOS system or the kernel debugger `kadb`(1M).

Simply powering up the computer and attempting to use its PROM to examine device registers will likely fail. While the device may be correctly installed, those mappings are SunOS specific and do not become active until SunOS is booted. Upon power up, the PROM maps only essential system devices, such as the keyboard.

Open Boot PROM 3.x

For complete documentation on the Open Boot PROM, see the *Open Boot PROM Toolkit User's Guide* and `monitor`(1M). The examples in this section refer to a Sun-4u architecture; other architectures may require different commands to perform actions.

Note – The Open Boot PROM is currently used on Sun machines with an SBus or UPA / PCI. The Open Boot PROM uses an "`ok`" prompt. On older machines, it may be necessary to type '`n`' to get the "`ok`" prompt.

If the PROM is in *secure mode* (the `security-mode` parameter is not set to *none*) the PROM password may be required (set in the `security-password` parameter).

The `printenv` command displays all parameters and their values.

Help

Help is available with the `help` command.

History

EMACS-style command-line history is available. Use Control-N (next) and Control-P (previous) to traverse the history list.

Forth Commands

The Open Boot PROM uses the Forth programming language. This is a stack-based language; arguments must be pushed on the stack before running the desired command (called a *word*), and the result is left on the stack.

To place a number on the stack, type its value.

```
ok 57
ok 68
```

To add the two top values on the stack, use the + operator.

```
ok +
```

The result remains on the stack. The stack is shown with the .s *word*.

```
ok .s
bf
```

The default base is hexadecimal. The hex and decimal *words* can be used to switch bases.

```
ok decimal
ok .s
191
```

See the *Forth User's Guide* for more information.

Walking the PROMs Device Tree

The SunOS-like commands pwd, cd, and ls walk the PROM device tree to get to the device. The cd command must be used to establish a position in the tree before pwd will work. This example is from an Ultra-1 workstation with a *cgsix* frame buffer on an Sbus.

```
ok cd /
```

To see the devices attached to the current node in the tree, use `ls`.

```
ok ls
f006a064 SUNW,UltraSPARC@0,0
f00598b0 sbus@1f,0
f00592dc counter-timer@1f,3c00
f004eec8 virtual-memory
f004e8e8 memory@0,0
f002ca28 aliases
f002c9b8 options
f002c880 openprom
f002c814 chosen
f002c7a4 packages
```

The full node name can be used:

```
ok cd sbus@1f,0
ok ls
f006a4e4 cgsix@2,0
f0068194 SUNW,bpp@e,c800000
f0065370 ledma@e,8400010
f006120c espdma@e,8400000
f005a448 SUNW,pll@f,1304000
f005a394 sc@f,1300000
f005a24c zs@f,1000000
f005a174 zs@f,1100000
f005a0c0 eeprom@f,1200000
f0059f8c SUNW,fdtwo@f,1400000
f0059ec4 flashprom@f,0
f0059e34 auxio@f,1900000
f0059d28 SUNW,CS4231@d,c000000
```

Rather than using the full node name in the previous example, you could have used an abbreviation. The abbreviated command line entry looks like this:

```
ok cd sbus
```

The name is actually *device@slot,offset* (for SBus devices). The *cgxis* device is in slot 2 and starts at offset 0. If an SBus device is displayed in this tree, the device has been recognized by the PROM.

The.`properties` command displays the PROM properties of a device. These can be examined to determine which properties the device exports (this is useful later to ensure that the driver is looking for the correct hardware properties). These are the same properties that can be retrieved with `ddi_getprop(9F)`. See `sbus(4)` and “Properties” on page 65 for related information.

```
ok cd cgsix
ok .properties
character-set           ISO8859-1
intr                    00000005 00000000
interrupts              00000005
reg                     00000002 00000000 01000000
dblbuf                  00 00 00 00
vmsize                  00 00 00 01
...
```

The *reg* property defines an array of register description structures containing the following fields:

```
    u_int   bustype;           /* cookie for related bus type*/
    u_int   addr;              /* address of reg relative to bus */
    u_int   size;              /* size of this register set */
```

For the *cgsix* example, the address is 0.

Mapping the Device

To test the device, it must be mapped into memory. The PROM can then be used to verify proper operation of the device by using data-transfer commands to transfer bytes, words, and long words. If the device can be operated from the PROM, even in a limited way, the driver should also be able to operate the device.

To set up the device for initial testing, perform the following steps:

1. Determine the SBus slot number the device is in. In this example, the *cgsix* device is located in slot 2.

2. Determine the offset within the physical address space used by the device.

   The offset used is specific to the device. In the *cgsix* example, the video memory happens to start at an offset of 0x800000.

3. Use the select-dev *word* to select the sbus device and the `map-in` *word* to map the device in.

   The select-dev word takes a string of the device path as its argument. The `map-in` *word* takes an *offset*, a *slot number*, and a *size* as arguments to map. Like the offset, the size of the byte transfer is specific to the device. In the *cgsix* example, the size is set to 0x100000 bytes.

In the following code example, the sbus path is displayed as an argument to the `select-dev` word, and the offset, slot number, and size values for the frame buffer are displayed as arguments to the `map-in` word. Notice that there should be a *space* between the opening quote and / in the `select-dev` argument. The virtual address to use remains on top of the stack. The stack is shown using the `.s` word. It can be assigned a name with the `constant` operation.

```
ok " /sbus@1f,0" select-dev
ok 800000 2 100000 map-in
ok .s
ffe98000
ok constant fb
```

Reading and Writing

The PROM provides a variety of 8-bit, 16-bit, and 32-bit operations. In general, a `C` (character) prefix indicates an 8-bit (one byte) operation; a `W` (word) prefix indicates a 16-bit (two byte) operation; and an `L` (longword) prefix indicates a 32-bit (four byte) operation.

A suffix of ! is used to indicate a write operation. The write operation takes the first two items off the stack; the first item is the address, and the second item is the value.

```
ok 55 ffe98000 c!
```

A suffix of @ is used to indicate a read operation. The read operation takes one argument (the address) off the stack.

```
ok ffe98000 c@
ok .s
55
```

A suffix of ? is used to display the value, without affecting the stack.

```
ok ffe98000 c?
55
```

Be careful when trying to query the device. If the mappings are not set up correctly, trying to read or write could cause errors. There are special words provided to handle these cases. `cprobe`, `wprobe`, and `lprobe`, for example, read from the given address but return zero if the location does not respond, or nonzero if it does.

```
ok fffa4000 c@
Data Access Error
ok fffa4000 cprobe
ok .s
0
ok ffe98000 cprobe
ok .s
0 ffffffffffffffff
```

A region of memory can be shown with the `dump` word. This takes an *address* and a *length*, and displays the contents of the memory region in bytes.

In the following example the `fill` word is used to fill video memory with a pattern. `fill` takes the address, the number of bytes to fill, and the byte to use (there is also a `wfill` and an `Lfill` for words and longwords). This causes the *cgsix* to display simple patterns based on the byte passed.

```
ok “ /sbus” select-dev
ok 800000 2 100000 map-in
ok constant fb
ok fb 10000 ff fill
ok fb 20000 0 fill
ok fb 18000 55 fill
ok fb 15000 3 fill
ok fb 10000 5 fill
ok fb 5000 f9 fill
```

Interrupts

Certain machine-specific interrupt levels are ignored when the Open Boot PROM controls the machine.

Overview of SunOS Device Drivers 3

This chapter gives an overview of SunOS device drivers. It discusses what a device driver is and the types of device drivers that Solaris 2.6 supports. It also provides a general discussion of the routines that device drivers must implement and points out compiler-related issues.

What Is a Device Driver?

A *device driver* is a kernel module responsible for managing low-level I/O operations for a particular hardware device. Device drivers can also be software-only, emulating a device that exists only in software, such as a RAM disk or a pseudo-terminal. Such device drivers are called pseudo device drivers and cannot perform functions requiring hardware (such as DMA).

A device driver contains all the device-specific code necessary to communicate with a device and provides a standard I/O interface to the rest of the system. This interface protects the kernel from device specifics just as the system call interface protects application programs from platform specifics. Application programs and the rest of the kernel need little (if any) device-specific code to address the device. In this way, device drivers make the system more portable and easier to maintain.

3

Types of Device Drivers

There are several kinds of device drivers, each handling a different kind of I/O. Block device drivers manage devices with physically addressable storage media, such as disks. All other devices are considered character devices. Two types of character device drivers are standard character device drivers and STREAMS device drivers.

Block Device Drivers

Devices that support a file system are known as *block devices*. Drivers written for these devices are known as block device drivers. Block device drivers take a file system request (in the form of a `buf`(9S) structure) and issue the I/O operations to the disk to transfer the specified block. The main interface to the file system is the `strategy`(9E) routine. See Chapter 10, “Drivers for Block Devices,” for more information.

Block device drivers can also provide a character driver interface that allows utility programs to bypass the file system and access the device directly. This device access is commonly referred to as the *raw* interface to a block device.

Standard Character Device Drivers

Character device drivers normally perform I/O in a byte stream. They can also provide additional interfaces not present in block drivers, such as I/O control (`ioctl`(9E)) commands, memory mapping, and device polling. See Chapter 9, “Drivers for Character Devices,” for more information.

Byte-Stream I/O

The main task of any device driver is to perform I/O, and many character device drivers do what is called *byte-stream* or *character* I/O. The driver transfers data to and from the device without using a specific device address. This is in contrast to block device drivers, where part of the file system request identifies a specific location on the device.

The `read`(9E) and `write`(9E) entry points handle byte-stream I/O for standard character drivers. See “I/O Request Handling” on page 183 for more information.

I/O Control

Many devices have characteristics and behavior that can be configured or tuned. The `ioctl`(2) system call and the `ioctl`(9E) driver entry point provide a mechanism for application programs to change and determine the status of a driver's configurable characteristics. For example, the baud rate of a serial communications port is usually configurable in this way.

The I/O control interface is open ended, enabling device drivers to define special commands for the device. The definition of the commands is entirely determined by the driver and is restricted only by the requirements of the application programs using the device and the device itself.

Certain classes of devices such as frame buffers or disks must support standard sets of I/O control requests. These standard I/O control interfaces are documented in the *Solaris 2.6 Reference Manual*. For example, `fbio`(7I) documents the I/O controls that frame buffers must support, and `dkio`(7I) documents standard disk I/O controls. See "Miscellaneous I/O Control" on page 198 for more information on I/O control.

Note – This manual does not cover I/O control commands.

Device Memory Mapping

For certain devices, such as frame buffers, it is more efficient for application programs to have direct access to device memory. Applications can map device memory into their address spaces using the `mmap`(2) system call. To support memory mapping, device drivers implement `segmap`(9E) and `devmap`(9E) entry points. For information on `devmap`(9E), see Chapter 11, "Mapping Device or Kernel Memory." For information on `segmap`(9E), see Chapter 9, "Drivers for Character Devices".

Drivers that define an `devmap`(9E) entry point usually do not define `read`(9E) and `write`(9E) entry points, as application programs perform I/O directly to the devices after calling `mmap`(2).

Device Polling

The `poll`(2) system call enables application programs to monitor or *poll* a set of file descriptors for certain conditions or *events*. `poll`(2) can be used to find out whether data are available to be read from the file descriptors or whether data may be written to the file descriptors without delay. Drivers referred to by these file descriptors must provide support for the `poll`(2) system call by implementing a `chpoll`(9E) entry point.

Drivers for communication devices such as serial ports should support polling, as they are used by applications that require synchronous notification of changes in read and write status. Many communications devices, however, are better implemented as STREAMS drivers.

STREAMS Drivers

STREAMS is a separate programming model for writing a character driver. Devices that receive data asynchronously (such as terminal and network devices) are suited to a STREAMS implementation. STREAMS device drivers must provide the loading and autoconfiguration support described in Chapter 5, "Autoconfiguration." See the *STREAMS Programming Guide* for additional information on how to write STREAMS drivers.

Bus Address Spaces

Three types of bus address space are memory space, I/O space, and configuration space. The device driver usually accesses memory space through memory mapping and I/O space through I/O ports. The configuration address space is accessed primarily during system initialization.

The preferred method depends on the device; it is generally not software configurable. For example, SBus and VMEbus devices do not provide I/O ports or configuration space, but some PCI devices may provide all three.

The data format of the host may also have different endian characteristics than the data format of the device. If this is the case, data transferred between the host and the device needs to be byte swapped to conform to the data format requirements of the destination location. Other devices may have the same endian characteristics as their host. In this case, no byte swapping is required.

The DDI framework performs any required byte swapping on behalf of the driver. The driver simply needs to specify the endianness of the device to the framework.

Address Mapping Setup

Before a driver can access a device's bus address, the bus address spaces must be set up using `ddi_regs_map_setup`(9F). The driver can then access the device by passing the data access handle returned from `ddi_regs_map_setup`(9F) to one of the `ddi_get8`(9F) or `ddi_put8`(9F) family of routines.

One of the arguments required by `ddi_regs_map_setup`(9F) is a pointer to a device access attributes structure, `ddi_device_acc_attr`(9S). The `ddi_device_acc_attr`(9S) structure describes the data access characteristics and requirements of the device. The `ddi_device_acc_attr`(9S) structure contains the following members:

```
ushort_t   devacc_attr_version;
uchar_t    devacc_attr_endian_flags;
uchar_t    devacc_attr_dataorder;
```

`devacc_attr_version` member identifies the version number of this structure. The current version number is `DDI_DEVICE_ATTR_V0`.

`devacc_attr_endian_flags` member describes the endian characteristics of the device. If `DDI_NEVERSWAP_ACC` is set, data access with no byte swapping is indicated. This flag should be set when no byte swapping is required. For example, if a device does byte-stream I/O, no byte swapping is required. If `DDI_STRUCTURE_BE_ACC` is set, the device data format is big endian. If `DDI_STRUCTURE_LE_ACC` is set, the device data format is little endian.

The framework will do any required byte swapping on behalf of the driver based on the flags indicated in `devacc_attr_endian_flags` and the host's data format endian characteristics.

`devacc_attr_dataorder` describes the order in which the CPU will reference data. Certain hosts may load or store data in certain orders to pipeline performance. The data ordering may be programmed to execute in one of the following ways:

- *Strong data ordering* – If DDI_STRICTORDER_ACC is set, the CPU must issue the references in order, as specified by the programmer. This is the default behavior.
- *Reordering* – If DDI_UNORDERED_OK_ACC is set, the CPU may reorder the data reference. This includes all kinds of reordering (for example, a load followed by a store may be replaced by a store followed by a load).
- *Data merging* – If DDI_MERGING_OK_ACC is set, the CPU may merge individual stores to consecutive locations. For example, the CPU may turn two consecutive byte stores into one halfword store. It may also batch individual loads. For example, the CPU may turn two consecutive byte loads into one halfword load. DDI_MERGING_OK_ACC also implies reordering.
- *Cache loading* – If DDI_LOADCACHING_OK_ACC is set, the CPU may cache the data it fetches and reuse it until another store occurs. The default behavior is to fetch new data on every load. DDI_LOADCACHING_OK_ACC also implies merging and reordering.
- *Cache storing* – If DDI_STORECACHING_OK_ACC is set, the CPU may keep the data in the cache and push it to the device (perhaps with other data) at a later time. The default behavior is to push the data right away. DDI_STORECACHING_OK_ACC also implies load caching, merging, and reordering.

Note – The restriction to the hosts diminishes while moving from strong data ordering to cache storing in terms of data accesses by the driver.

The values assigned to devacc_attr_dataorder are advisory, not mandatory. For example, data can be ordered without being merged or cached, even though a driver requests unordered, merged, and cached together.

A driver for a big-endian device that requires strict data ordering during data accesses would encode the ddi_device_acc_attr structure as follows:

```
static ddi_device_acc_attr_t access_attr = {
    DDI_DEVICE_ATTR_V0,/* version number */
    DDI_STRUCTURE_BE_ACC, /* big endian */
    DDI_STRICTORDER_ACC/* strict ordering */
}
```

The system will use the information stored in the `ddi_device_acc_attr` structure and other system-specific information to encode an opaque data handle as one of the returned parameters from `ddi_map_regs_setup`(9F). The returned data handle is used as a parameter to the data access routines (such as `ddi_put8`(9F) or `ddi_get8`(9F)) during subsequent accesses to the mapped registers. The driver must never attempt to interpret the contents of the data handle.

If successful, `ddi_regs_map_setup`(9F) also returns a kernel virtual address that is mapped to the bus address base. The address base may be used as a base reference address in deriving the effective address of other registers by adding the appropriate offset.

Note – Drivers should not directly dereference the returned address. A driver must access the device through one of the data access functions.

Data Access Functions

Data access functions allow drivers to transfer data to and from devices without directly referencing the hardware registers. As mentioned above, `ddi_regs_map_setup`(9F) creates a bus address space mapping for the device register set. The driver then transfers data to (or receives data from) the device using the desired family of data access routines — such as the `ddi_put8`(9F) or the `ddi_get8`(9F) family of routines — to access the mapped registers.

The `ddi_put8`(9F) family of routines allows a driver to write data to the device in quantities of 8 bits (`ddi_put8`(9F)), 16 bits (`ddi_put16`(9F)), 32 bits (`ddi_put32`(9F)), and 64 bits (`ddi_put64`(9F)). A similar set of functions (the `ddi_get8`(9F) family) exists for reading from a device. Multiple values may be written or read by using the `ddi_rep_put8`(9F) or `ddi_rep_get8`(9F) family of routines respectively. See Appendix C for more information on data access functions.

Note – These routines may be applied to any address base returned from `ddi_regs_map_setup`(9F) regardless of the address space the register resides in (such as memory, I/O, or configuration space).

Code Example 3-1 illustrates the use of `ddi_regs_map_setup`(9F) and `ddi_put8`(9F) to access device registers.

Code Example 3-1 Accessing Device Registers

```
static ddi_device_acc_attr_t access_attr = {
    DDI_DEVICE_ATTR_V0,/* version number */
    DDI_STRUCTURE_BE_ACC, /* big endian */
    DDI_STRICTORDER_ACC/* strict ordering */
};

caddr_t reg_addr;
ddi_acc_handle_t data_access_handle;

ddi_regs_map_setup(..., &reg_addr, ..., &access_attr,
    &data_access_handle);
```

When `ddi_regs_map_setup`(9F) returns, `reg_addr` contains the address base and `data_access_handle` contains the opaque data handle to be used in subsequent data accesses. The driver may now access the mapped registers. The following example writes one byte to the first mapped location.

```
ddi_put8(data_access_handle, (uint8_t *)reg_addr, 0x10);
```

Similarly, `ddi_get8`(9F) could have been used to read data from the device registers.

Memory Space Access

In memory-mapped access, device registers appear in memory address space. The driver must call `ddi_regs_map_setup`(9F) to set up the mapping. The device registers can then be accessed using one of the `ddi_put8`(9F) or `ddi_get8`(9F) family of routines.

Memory space may also be accessed using the `ddi_mem_put8`(9F) and `ddi_mem_get8`(9F) family of routines. These functions may be more efficient on some platforms. Use of these routines, however, may limit the ability of the driver to remain portable across different bus versions of the device.

I/O Space Access

In I/O space access, the device registers appear in I/O space. Each addressable element of the I/O address is called an I/O port. Device registers are accessed through I/O port numbers. These port numbers can refer to 8, 16, or 32-bit registers. The driver must call `ddi_regs_map_setup`(9F) to set up the mapping. The I/O port can then be accessed using one of the `ddi_put8`(9F) or `ddi_get8`(9F) family of routines.

I/O space may also be accessed using the `ddi_io_put8`(9F) and `ddi_io_get8`(9F) family of routines. These functions may be more efficient on some platforms. Use of these routines, however, may limit the ability of the driver to remain portable across different bus versions of the device.

Configuration Space Access

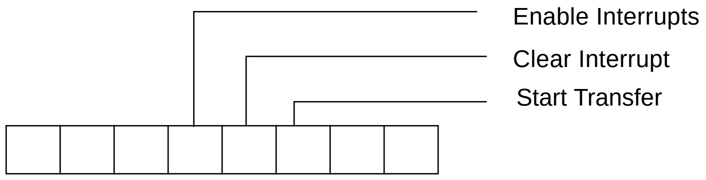
Configuration space is used primarily during device initialization. It determines the location and size of register sets and memory buffers located on the device. The configuration space may be accessed using the `ddi_regs_map_setup`(9F) and `ddi_put`(9F)/`ddi_get`(9F) functions as described previously.

Note – For PCI local bus devices, an alternative set of routines exists. `pci_config_setup`(9F) may be used in place of `ddi_regs_map_setup`(9F) to get access to the configuration address space. The family of routines `pci_config_get8`(9F) and `pci_config_put8`(9F) may be used in place of the generic routines `ddi_get8`(9F) and `ddi_put8`(9F). These functions provide equivalent configuration space access as defined in the PCI bus binding for the IEEE 1275 specifications for FCode drivers. However, use of these routines may limit the ability of the driver to remain portable across different bus versions of the device.

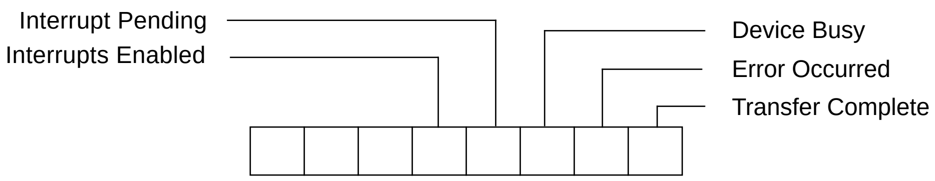
Example Device Registers

Most of the examples in this manual use a fictitious device that has an 8-bit command and status register (csr), followed by an 8-bit data register. The command and status register is so called because writes to it go to an internal command register, and reads from it are directed to an internal status register.

The *command registe*r looks like this:



The *status register* looks like this:



Many drivers provide macros for the various bits in their registers to make the code more readable. The examples in this manual use the following names for the bits in the command register:

```
#define ENABLE_INTERRUPTS        0x10
#define CLEAR_INTERRUPT          0x08
#define START_TRANSFER           0x04
```

For the bits in the status register, the following macros are used:

```
#define INTERRUPTS_ENABLED       0x10
#define INTERRUPTING             0x08
#define DEVICE_BUSY              0x04
#define DEVICE_ERROR             0x02
#define TRANSFER_COMPLETE        0x01
```

Device Register Structure

Using pointer accesses to communicate with the device results in unreadable code. For example, the code that reads the data register when a transfer has been completed might look like this:

```
uint8_t data;
uint8_t status;
/* get status */
status = ddi_get8(data_access_handle, (uint8_t *)reg_addr);
if (status & TRANSFER_COMPLETE) {
        data = ddi_get8(data_access_handle,
            (uint8_t *)reg_addr + 1); /* read data */
    }
```

To make the code more readable, it is common to define a structure that matches the layout of the device registers. In this case, the structure could look like this:

```
    struct device_reg {
        uint8_t csr;
        uint8_t data;
    };
```

The driver then maps the registers into memory and refers to them through a pointer to the structure:

```
    struct device_reg *regp;

    ...
    ddi_regs_map_setup(..., (caddr_t *)&regp, ... ,
        &access_attributes, &data_access_handle);
    ...
```

The code that reads the data register upon a completed transfer now looks like this:

```
    uint8_t data;
    uint8_t status;
    /* get status */
    status = ddi_get8(data_access_handle, &regp->csr);
    if (status & TRANSFER_COMPLETE) {
        /* read data */
        data = ddi_get8(data_access_handle, &regp->data);
    }
```

Structure Padding

A device that has a 1-byte command and status register followed by a 4-byte data register might lead to the following structure layout:

```
    struct device_reg {
        uint8_t    csr;
        uint32_t   data;
    };
```

This structure is *not* correct, because the compiler places *padding* between the two fields. For example, the SPARC processor requires each type to be on its natural boundary, which is 1-byte alignment for the `csr` field, but 4-byte alignment for the `data` field. This results in three unused bytes between the two fields. When the driver accesses a data register, it will be three bytes off. Consequently, this layout should *not* be used.

Finding Padding

The ANSI C `offsetof`(3C) macro may be used in a test program to determine the offset of each element in the structure. Knowing the offset and the size of each element, the location and size of any padding can be determined.

Code Example 3-2 Structure Padding

```
#include <sys/types.h>
#include <stdio.h>
#include <stddef.h>

struct device_reg {
    uint8_t    csr;
    uint32_t   data;
};

int main(void)
{
    printf("The offset of csr is %d, its size is %d.\n",
        offsetof(struct device_reg, csr), sizeof (uint8_t));
    printf("The offset of data is %d, its size is %d.\n",
        offsetof(struct device_reg, data), sizeof (uint32_t));
    return (0);
}
```

Here is a sample compilation with Sun WorkShop™ Compiler C version 4.2 and a subsequent run of the program:

```
test% cc -Xa c.c
test% a.out
The offset of csr is 0, its size is 1.
The offset of data is 4, its size is 4.
```

Driver developers should be aware that padding is dependent not only on the processor but also on the compiler.

Driver Interfaces

The kernel expects device drivers to provide certain routines that must perform certain operations; these routines are called *entry points*. This is similar to the requirement that application programs have a `_start`( ) entry point or that C applications have the more familiar `main`( ) routine.

Entry Points

Each device driver defines a standard set of functions called *entry points*, which are defined in the *Solaris 2.6 Reference Manual*. Drivers for different types of devices have different sets of entry points according to the kinds of operations the devices perform. A driver for a memory-mapped character-oriented device, for example, supports a `devmap`(9E) entry point, while a block driver does not.

Some operations are common to all drivers, such as the functions that are required for module loading (`_init`(9E), `_info`(9E), and `_fini`(9E)), and the required autoconfiguration entry points `attach`(9E) and `getinfo`(9E). Drivers may also support the optional autoconfiguration entry points for `probe`(E) and `detach`(9E). Most drivers have `open`(9E) and `close`(9E) entry points to control access to their devices.

Traditionally, all driver function and variable names have some prefix added to them. Usually, this is the name of the driver, such as *xx*`open`() for the `open`(9E) routine of driver *xx*. In subsequent examples, *xx* is used as the driver prefix.

Note – In the SunOS 5.x system, only the loadable module routines must be visible outside the driver object module. Other routines can have the storage class `static`.

Loadable Module Routines

```
int _init(void);
int _info(struct modinfo *modinfop);
int _fini(void);
```

All drivers must implement the `_init`(9E), `_fini`(9E) and `_info`(9E) entry points to load, unload and report information about the driver module. The driver is single-threaded when the kernel calls `_init`. No other thread will enter a driver routine until `mod_install`(9F) returns success.

Any resources global to the device driver should be allocated in `_init`(9E) before calling `mod_install`(9F) and should be released in `_fini`(9E) after calling `mod_remove`(9F).

Note – Drivers *must* use these names, and they must *not* be declared `static`, unlike the other entry points where the names and storage classes are determined by the driver.

Autoconfiguration Entry Points

```
static int xxprobe(dev_info_t *dip);
static int xxattach(dev_info_t *dip, ddi_attach_cmd_t cmd);
static int xxdetach(dev_info_t *dip, ddi_detach_cmd_t cmd);
static int xxgetinfo(dev_info_t *dip,ddi_info_cmd_t infocmd,
               void *arg, void **result);
```

Any per-device resources should be allocated in `attach`(9E) and released in `detach`(9E). No resources global to the driver should be allocated in `attach`(9E). For information on autoconfiguration entry points, see Chapter 5, “Autoconfiguration”.

Block Driver Entry Points

```
int xxopen(dev_t *devp, int flag, int otyp, cred_t *credp);
int xxclose(dev_t dev, int flag, int otyp, cred_t *credp);
int xxstrategy(struct buf *bp);
int xxprint(dev_t dev, char *str);
int xxdump(dev_t dev, caddr_t addr, daddr_t blkno, int nblk);
int xxprop_op(dev_t dev, dev_info_t *dip, ddi_prop_op_t prop_op,
              int mod_flags, char *name, caddr_t valuep,
              int *length);
```

For information on block driver entry points, see Chapter 10, “Drivers for Block Devices”.

Character Driver Entry Points

```
int xxopen(dev_t *devp, int flag, int otyp, cred_t *credp);
int xxclose(dev_t dev, int flag, int otyp, cred_t *credp);
int xxread(dev_t dev, struct uio *uiop, cred_t *credp);
int xxwrite(dev_t dev, struct uio *uiop, cred_t *credp);
int xxioctl(dev_t dev, int cmd, intptr_t arg, int mode,
           cred_t *credp, int *rvalp);
int xxdevmap(dev_t dev, devmap_cookie_t dhp, offset_t off,
           size_t len, size_t *maplen, uint_t model);
int xxmmap(dev_t dev, off_t off, int prot);
int xxsegmap(dev_t dev, off_t off, struct as *asp,
           caddr_t *addrp, off_t len, unsigned int prot,
           unsigned int maxprot, unsigned int flags,
           cred_t *credp);
int xxchpoll(dev_t dev, short events, int anyyet,
           short *reventsp, struct pollhead **phpp);
int xxprop_op(dev_t dev, dev_info_t *dip,
           ddi_prop_op_t prop_op, int mod_flags,
           char *name, caddr_t valuep, int *length);
int xxaread(dev_t dev, struct aio_req *aio, cred_t *credp);
int xxawrite(dev_t dev, struct aio_req *aio, cred_t *credp);
```

For information on character driver entry points, see Chapter 9, “Drivers for Character Devices”.

Power Management Entry Point

```
int xxpower(dev_info_t *dip, int component, int level);
```

Drivers for hardware devices that provide Power Management functionality may support the optional `power`(9E) entry point. See Chapter 8, “Power Management” for details about this entry point.

Driver Structure Overview

Figure 3-1 on page 58 shows data structures and routines that may define the structure of a character or block device driver. Such drivers typically include a device loadable driver section, device configuration section, and device access section.

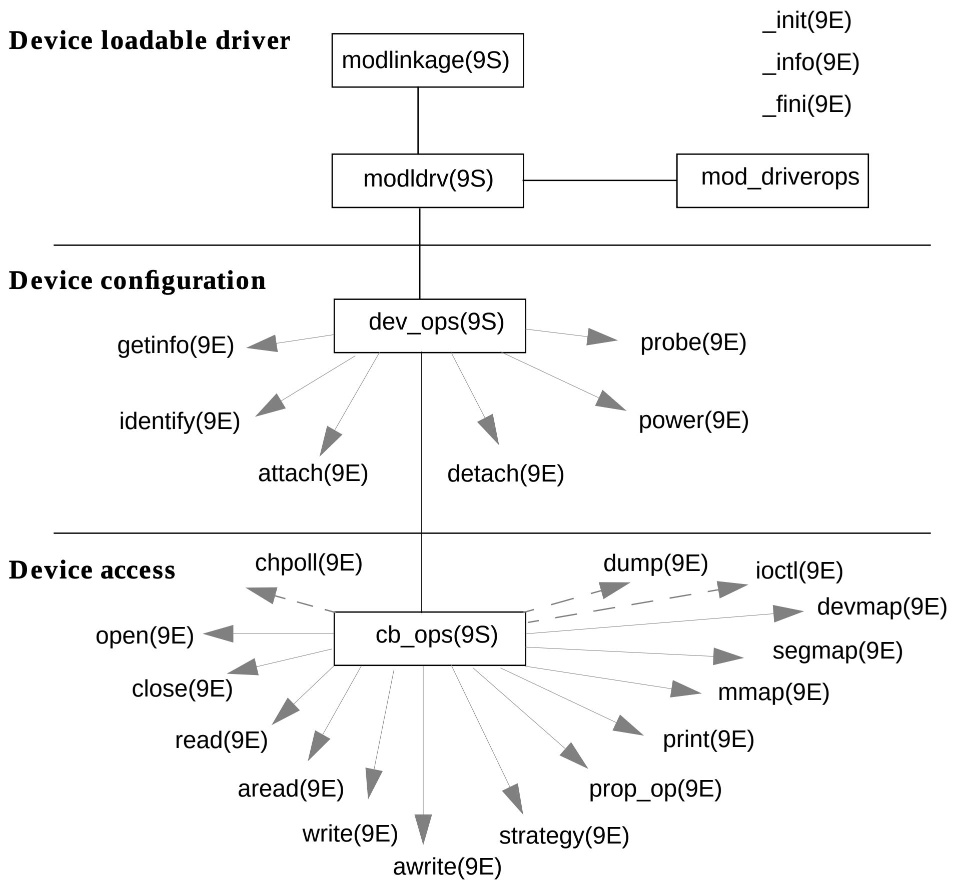


Figure 3-1 Device Driver Roadmap

Note – The first two sections in Figure 3-1 are discussed in Chapter 5, “Autoconfiguration”; the third section is discussed in Chapter 9, “Drivers for Character Devices” and Chapter 10, “Drivers for Block Devices”.

Callback Functions

Some routines provide a *callback* mechanism. This is a way to schedule a function to be called when a condition is met. Typical conditions for which callback functions are set up include:

- When a transfer has completed
- When a resource *might* become available
- When a time-out period has expired

Transfer completion callbacks perform the tasks usually done in an interrupt service routine.

In some sense, callback functions are similar to entry points. The functions that allow callbacks expect the callback function to perform certain tasks. In the case of DMA routines, a callback function must return a value indicating whether the callback function needs to be rescheduled in case of a failure.

Callback functions execute as a separate interrupt thread and must handle all the usual multithreading issues.

Note – All scheduled callback functions must be canceled before a device is detached.

Interrupt Handling

The Solaris 2.x DDI/DKI addresses these aspects of device interrupt handling:

- Registering device interrupts with the system
- Removing device interrupts from the system

Interrupt information is contained in a property called *interrupts* (or *intr* on x86 platforms, see `isa`(4)), which is either provided by the PROM of a self-identifying device, in a hardware configuration file, or by the booting system on the x86 platform. See `sbus`(4), `vme`(4), `pci`(4), `eisa`(4), `isa`(4), `mca`(4), and "Properties" on page 65 for more information.

Because the internal implementation of interrupts is an architectural detail, special *interrupt cookies* are used to enable drivers to perform interrupt-related tasks. The types of cookies for interrupts are:

- Device-interrupt cookies
- Block-interrupt cookies

Device-Interrupt Cookies

Defined as type `ddi_idevice_cookie_t`, this cookie is a data structure containing information used by a driver to program the interrupt-request level (or the equivalent) for a programmable device. See `ddi_add_intr`(9F), `ddi_idevice_cookie`(9S), and "Registering Interrupts" on page 117 for more information.

Block-Interrupt Cookies

Defined as type `ddi_iblock_cookie_t` this cookie is used by a driver to initialize the mutual exclusion locks it uses to protect data. This cookie should not be interpreted by the driver in any way. For more information on `ddi_get_iblock_cookie`(9F), see "Interrupt Block Cookies" on page 114.

Driver Context

There are four contexts in which driver code executes:

- User
- Kernel
- Interrupt
- High-level interrupt

The following sections point out the context in which driver code can execute. The driver context determines which kernel routines the driver is permitted to call. For example, in kernel context the driver must not call `copyin`(9F). The manual pages in section 9F document the allowable contexts for each function.

User Context

A driver entry point has *user context* if it was directly invoked because of a user thread. The `read`(9E) entry point of the driver, invoked by a `read`(2) system call, has user context.

Kernel Context

A driver function has *kernel context* if it was invoked by some other part of the kernel. In a block device driver, the `strategy`(9E) entry point may be called by the pageout daemon to write pages to the device. Because the page daemon has no relation to the current user thread, `strategy`(9E) has kernel context in this case.

Interrupt Context

Interrupt context is a more restrictive form of kernel context. Driver interrupt routines operate in interrupt context and have an interrupt level associated with them. See Chapter 6, “Interrupt Handlers” for more information.

High-level Interrupt Context

High-level interrupt context is a more restricted form of interrupt context. If `ddi_intr_hilevel`(9F) indicates that an interrupt is high level, the driver interrupt handler will run in high-level interrupt context. See “Handling High-Level Interrupts” on page 122 for more information.

Printing Messages

Device drivers do not usually print messages. Instead, the entry points should return error codes so that the application can determine how to handle the error. If the driver really needs to print a message, it can use `cmn_err`(9F) to do so. This is similar to the C function `printf`(3S), but only prints to the console, to the message buffer displayed by `dmesg`(1M), or both.

void cmn_err(int level, char *format, ...);

format is similar to the printf(3S) format string, with the addition of the format %b, which prints bit fields. level indicates which label will be printed, as shown in Table 3-1.

Table 3-1 cmn_err() Messages

Level	Message
CE_NOTE	NOTICE: format\n
CE_WARN	WARNING:format\n
CE_CONT	format
CE_PANIC	panic: format\n

CE_PANIC has the side effect of crashing the system. This level should only be used if the system is in such an unstable state that to continue would cause more problems. It can also be used to get a system core dump when debugging.

The first character of the format string is treated specially. See cmn_err(9F) for more details.

Dynamic Memory Allocation

Device drivers must be prepared to simultaneously handle all attached devices that they claim to drive. There should be no driver limit on the number of devices that the driver handles, and all per-device information must be dynamically allocated.

void *kmem_alloc(size_t size, int flag);

The standard kernel memory allocation routine is kmem_alloc(9F). It is similar to the C library routine malloc(3C), with the addition of the flag argument. The flag argument can be either KM_SLEEP or KM_NOSLEEP, indicating whether the caller is willing to block if the requested size is not available. If KM_NOSLEEP is set, and memory is not available, kmem_alloc(9F) returns NULL.

kmem_zalloc(9F) is similar to kmem_alloc(9F), but also clears the contents of the allocated memory.

Note – Kernel memory is a limited resource, not pageable, and competes with user applications and the rest of the kernel for physical memory. Drivers that allocate a large amount of kernel memory may cause system performance to degrade.

`void kmem_free(void *cp, size_t size);`

Memory allocated by `kmem_alloc`(9F) or by `kmem_zalloc`(9F) is returned to the system with `kmem_free`(9F). This is similar to the C library routine `free`(3C), with the addition of the `size` argument. Drivers *must* keep track of the size of each object they allocate in order to call `kmem_free`(9F) later.

Software State Management

Software State Structure

For each device that the driver handles, the driver must keep some state information. At a minimum, this consists of a pointer to the `dev_info` node for the device (required by `getinfo`(9E)). The driver can define a structure that contains all the information needed about a single device:

```
struct xxstate {
    dev_info_t *dip;
};
```

This structure will grow as the device driver evolves. Additional useful fields might be a pointer to each of the device's mapped registers, or flags such as *busy* or *suspended*. The initial state structure the examples in this book use is given in Code Example 3-3.

Code Example 3-3 Initial State Structure

```
struct xxstate {
    dev_info_t                    *dip;
    struct device_reg             *regp;
    int                           xx_busy;
    struct xx_saved_device_state  device_state;
};
```

Subsequent chapters in this manual may require that new fields be added to the state structure. Each chapter will list any additions.

Software State Management Routines

To assist device driver writers in allocating state structures, the Solaris 2.x DDI/DKI provides a set of memory management routines called the *software state management routines* (also known as the *soft state routines*). These routines dynamically allocate, retrieve, and destroy memory items of a specified size, and hide all the details of list management in a multithreaded kernel. An *item number* is used to identify the desired memory item; this number can be (and usually is) the instance number assigned by the system.

The driver must provide a *state* pointer, which is used by the soft state system to create the list of memory items:

```
static void *statep;
```

Routines are provided to:

- Initialize the provided state pointer – `ddi_soft_state_init`(9F)
- Allocate space for a certain item – `ddi_soft_state_zalloc`(9F)
- Retrieve a pointer to the indicated item – `ddi_get_soft_state`(9F)
- Free the memory item – `ddi_soft_state_free`(9F)
- Finish using the state pointer – `ddi_soft_state_fini`(9F)

When the module is loaded, the driver calls `ddi_soft_state_init`(9F) to initialize the driver state pointer, passing a hint indicating how many items to pre-allocate. If more items are needed, they will be allocated as necessary. The driver must call `ddi_soft_state_fini`(9F) when the driver is unloaded.

To allocate an instance of the soft state structure, the driver calls `ddi_soft_state_zalloc`(9F), then `ddi_get_soft_state`(9F) to retrieve a pointer to the allocated structure. This is usually performed when the device is attached, and the inverse operation, `ddi_soft_state_free`(9F), is performed when the device is detached.

Once the item is allocated, the driver needs only to call `ddi_get_soft_state`(9F) to retrieve the pointer.

See “Loadable Driver Interface” on page 94 for an example use of these routines.

Properties

Properties define arbitrary characteristics of the device or device driver. Properties may be defined by the FCode of a self-identifying device, by a hardware configuration file (see `driver.conf`(4)), or by the driver itself using the `ddi_prop_update`(9F) family of routines.

A property is a name-value pair. The name is a string that identifies the property with an associated value. Examples of properties are the height and width of a frame buffer, the number of blocks in a partition of a block device, or the name of a device. The value of a property may be one of five types:

- A byte array that has an arbitrary length and whose value is a series of bytes
- An integer property whose value is an integer
- An integer array property whose value is an array of integers
- A string property whose value is a NULL-terminated string
- A string array property whose value is a list of NULL-terminated strings

A property that has no value is known as a Boolean property. It is considered to be true if it exists and false if it doesn't.

Note – Strictly speaking, DDI/DKI software property names are not restricted in any way; however, there are certain recommended uses. As defined in IEEE 1275-1994 (the Standard for Boot Firmware), a property "is a human readable text string consisting of one to thirty-one printable characters. Property names *shall* not contain upper case characters or the characters "/", "\", ":", "[", "]" and "@". Property names beginning with the character "+" are reserved for use by future revisions of IEEE 1275-1994." By convention, underscores are not used in property names; use a hyphen (-) instead. Also by convention, property names ending with the question mark character (`auto-boot?`) contain values that are strings, typically true or false.

A driver can request a property from its parent, which in turn might ask its parent. The driver can control whether the request can go higher than its parent.

For example, the “esp” driver maintains an integer property for each target called `target x-sync-speed` where “`x`” is the target number. The `prtconf`(1M) command in its verbose mode displays driver properties. The following example shows a partial listing for the “esp” driver.

```
test% prtconf -v
...
       esp, instance #0
            Driver software properties:
                name <target2-sync-speed> length <4>
                    value <0x00000fa0>.
...
```

Table 3-2 displays several uses of property interfaces.

Table 3-2 Property Interface Uses

Family	**Property Interfaces**	**Description**
`ddi_prop_lookup`		
	`ddi_prop_exists(9F)`	Looks up property and returns success if one exists. Returns failure if one does not exist.
	`ddi_prop_get_int(9F)`	Looks up and returns an integer property.
	`ddi_prop_lookup_int_array(9F)`	Looks up and returns an integer array property.
	`ddi_prop_lookup_string(9F)`	Looks up and returns a string property.
	`ddi_prop_lookup_string_array(9F)`	Looks up and returns a string array property.
	`ddi_prop_lookup_byte_array(9F)`	Looks up and returns a byte array property.
`ddi_prop_update`		
	`ddi_prop_update_int(9F)`	Updates an integer property.
	`ddi_prop_update_int_array(9F)`	Updates an integer array property.
	`ddi_prop_update_string(9F)`	Updates a string property.

Table 3-2 Property Interface Uses *(Continued)*

Family	Property Interfaces	Description
	`ddi_prop_update_string_array(9F)`	Updates an string array property.
	`ddi_prop_update_byte_array(9F)`	Updates a byte array property.
`ddi_prop_remove`		
	`ddi_prop_remove(9F)`	Removes a property.
	`ddi_prop_remove_all(9F)`	Removes all properties associated with a device.

prop_op( )

The `prop_op`(9E) entry point reports the values of device properties to the system. In many cases, the `ddi_prop_op`(9F) routine may be used as the driver's `prop_op(9E)` entry point in the `cb_ops`(9S) structure. `ddi_prop_op`(9F) performs all of the required processing and is sufficient for drivers that do not need to perform any special processing when handling a device property request.

However, there are cases when it is necessary for the driver to provide a `prop_op`(9E) entry point. For example, if a driver maintains a property whose value changes frequently, updating the property with `ddi_prop_update`(9F) each time it changes may not be efficient. Instead, the driver can maintain a local *copy* of the property in a C variable. The driver updates the C variable when the value of the property changes and does not call one of the `ddi_prop_update`(9F) routines. In this case, the `prop_op`(9E) entry point would need to intercept requests for this property and call one of the `ddi_prop_update`(9F) routines to update the value of the property before passing the request to `ddi_prop_op`(9F) to process the property request. See Code Example 3-4 on page 68.

Here is the `prop_op`(9E) prototype:

```
int xxprop_op(dev_t dev, dev_info_t *dip,
    ddi_prop_op_t  prop_op, int flags, char *name,
    caddr_t valuep, int *lengthp);
```

This section describes a simple implementation of the `prop_op`(9E) routine that intercepts property requests then uses the existing software property routines to update property values. For a complete description of all the parameters to `prop_op`(9E), see the manual page.

In Code Example 3-4, the `prop_op`(9E) intercepts requests for the `temperature` property. The driver updates a variable in the state structure whenever the property changes but only updates the property when a request is made. It then uses the system routine `ddi_prop_op`(9F) to process the property request. If the property request is not specific to a device, the driver does not intercept the request. This is indicated when the value of the dev parameter is equal to `DDI_DEV_T_ANY` (the wildcard device number).

State Structure

This section adds the following field to the state structure. See "Software State Structure" on page 63 for more information.

```
    int     temperature; /* current device temperature */
```

Code Example 3-4 `prop_op`(9E) Routine

```
static int
xxprop_op(dev_t dev, dev_info_t *dip, ddi_prop_op_t prop_op,
    int flags, char *name, caddr_t valuep, int *lengthp)
{
    minor_t instance;
    struct xxstate *xsp;

    if (dev != DDI_DEV_T_ANY) {
        return (ddi_prop_op(dev, dip, prop_op, flags, name,
            valuep, lengthp));

    }

    instance = getminor(dev);
    xsp = ddi_get_soft_state(statep, instance);
    if (xsp == NULL)
        return (DDI_PROP_NOTFOUND);

    if (strcmp(name, "temperature") == 0) {
        ddi_prop_update_int(dev, dip, name, temperature);
    }
    other cases
}
```

Driver Layout

Driver code is usually divided into the following files:

- Headers (`.h` files)
- Source files (`.c` files)
- Optional configuration files (`driver.conf` file)

Note – These files represent a typical driver layout. They are not absolutely required for a driver, as only the final object module matters to the system.

Header Files

Header files define data structures specific to the device (such as a structure representing the device registers), data structures defined by the driver for maintaining state information, defined constants (such as those representing the bits of the device registers), and macros (such as those defining the static mapping between the minor device number and the instance number).

Some of this information, such as the state structure, may only be needed by the device driver. This information should go in *private* headers. These header files are included only by the device driver itself.

Any information that an application might require, such as the I/O control commands, should be in *public* header files. These are included by the driver and any applications that need information about the device.

There is no standard for naming private and public files. One possible convention is to name the private header file `xximpl.h` and the public header file `xxio.h`. See Appendix E, "Driver Code Layout Structure," for more information.

Source Files

A `.c` file for a device driver contains the data declarations and the code for the entry points of the driver. It contains the `#include` statements the driver needs, declares `extern` references, declares local data, sets up the `cb_ops` and `dev_ops` structures, declares and initializes the module configuration section, makes any other necessary declarations, and defines the driver entry points. See Appendix E, "Driver Code Layout Structure," for more information.

Configuration Files

See `driver.conf`(4), `sbus`(4), `pci`(4). `isa`(4), and `vme`(4).

64-Bit-Safe Device Drivers

Future versions of the Solaris system will run in 64-bit mode on appropriate hardware and provide a 64-bit kernel with a 64-bit address space for applications. To update a device driver to be 64-bit ready, driver writers will need to understand the 32-bit and 64-bit C data type models, know how to use the system derived types and the fundamental C data types, and understand specific driver issues, such as how to enable a 64-bit driver and a 32-bit application to share data structures.

For details on making a device driver ready for a 64-bit environment, see Appendix F, “Making a Device Driver 64-Bit Ready”.

C Language and Compiler Modes

The Sun WorkShop™ Compiler C version 4.2 provides ANSI C compilers for the Solaris environment. It supports several compilation modes, a number of useful keywords, and function prototypes.

Compiler Modes

Note the following compiler modes.

-Xa (ANSI C Mode)

This mode accepts ANSI C and Sun C compatibility extensions. In case of a conflict between ANSI and Sun C, the compiler issues a warning and uses ANSI C interpretations. This is the default mode.

-Xt (Transition Mode)

This mode accepts ANSI C and Sun C compatibility extensions. In case of a conflict between ANSI and Sun C, a warning is issued and Sun C semantics are used.

Function Prototypes

Function prototypes specify the following information to the compiler:

- The type returned by the function
- The number of the arguments to the function
- The type of each argument

Code Example 3-5 Function Prototypes

```
static int
xxgetinfo(dev_info_t *dip, ddi_info_cmd_t cmd, void *arg,
   void **result)
{
    /* definition */
}
static int
xxopen(dev_t *devp, int flag, int otyp, cred_t *credp)
{
    /* definition */
}
```

This allows the compiler to do more type checking and also to promote the types of the parameters to the type expected by the function. For example, if the compiler knows that a function takes a pointer, casting NULL to that pointer type is no longer necessary. Prototypes are provided for all Solaris 2.x DDI/DKI functions, provided the driver includes the proper header file (documented in the manual page for the function).

Keywords

ANSI C provides the following driver-related keywords.

const

The `const` keyword can be used to define constants instead of using `#define`:

```
    const int  count=5;
```

However, it is most useful when combined with function prototypes. Routines that should not be modifying parameters can define the parameters as constants, and the compiler will then give errors if the parameter is modified.

Because C passes parameters by value, most parameters don't need to be declared as constants. If the parameter is a *pointer*, though, it can be declared to point to a constant object:

```
int strlen(const char *s)
{
    ...
}
```

Any attempt to change the string by `strlen`() is an error, and the compiler will catch the error.

`volatile`

The correct use of `volatile` is necessary to prevent elusive bugs. It instructs the compiler to use exact semantics for the declared objects—in particular, to not optimize away or reorder accesses to the object. There are two instances where device drivers must use the `volatile` qualifier:

1. When data refers to an external hardware device register (memory that has side effects other than just storage). Note, however, that if the DDI data access functions are used to access device registers, it is not necessary to use `volatile`.

2. When data refers to global memory that is accessible by more than one thread, is not protected by locks, and therefore is relying on the sequencing of memory accesses

In general, drivers should not qualify a variable as `volatile` if it is merely accessible by more than one thread and protected from conflicting access by synchronization routines.

The following example uses `volatile`. A busy flag is used to prevent a thread from continuing while the device is busy and the flag is not protected by a lock:

```
while (busy) {
    /* do something else */
 }
```

The testing thread will continue when another thread turns off the `busy` flag:

```
busy = 0;
```

However, since busy is accessed frequently in the testing thread, the compiler may optimize the test by placing the value of busy in a register, then test the contents of the register without reading the value of busy in memory before every test. The testing thread would never see busy change and the other thread would only change the value of busy in memory, resulting in deadlock. Declaring the busy flag as volatile forces its value to be read before each test.

Note – It would probably be preferable to use a condition variable mutex, discussed under "Condition Variables" on page 81 rather than the busy flag in this example.

It is also recommended that the volatile qualifier be used in such a way as to avoid the risk of accidental omission. For example, this code

```
struct device_reg {
    volatile uint8_t csr;
    volatile uint8_t data;
};
struct device_reg *regp;
```

is recommended over:

```
struct device_reg {
    uint8_t csr;
    uint8_t data;
};
volatile struct device_reg *regp;
```

Although the two examples are functionally equivalent, the second one requires the writer to ensure that volatile is used in every declaration of type struct device_reg. The first example results in the data being treated as volatile in all declarations and is therefore preferred. Note as mentioned above, that the use of the DDI data access functions to access device registers makes it unnecessary to qualify variables as volatile.

Multithreading 4

This chapter describes the locking primitives and thread synchronization mechanisms of the SunOS multithreaded kernel.

Threads

A *thread of control*, or *thread,* is a sequence of instructions executed within a program. A thread can share data and code with other threads and can run *concurrently* with other threads. There are two kinds of threads: *user threads* and *kernel threads.* See *Multithreaded Programming Guide* for more information on threads.

User Threads

Each process in the SunOS operating system has an address space that contains one or more *lightweight processes* (LWPs), each of which in turn runs one or more user threads. Figure 4-1 on page 76 shows the relationship between threads, LWPs, and processes. An LWP schedules its user threads and runs one user thread at a time, though multiple LWPs may run concurrently. User threads are handled in user space.

The LWP is the interface between user threads and the kernel. The LWP can be thought of as a virtual CPU that schedules user thread execution. When a user thread issues a system call, the LWP running the thread calls into the kernel and remains bound to the thread at least until the system call is complete.

When an LWP is running in the kernel, executing a system call on behalf of a user thread, it runs one kernel thread. Each LWP is therefore associated with exactly one kernel thread.

Kernel Threads

There are two types of kernel threads: those bound to an LWP and those not associated with an LWP. Threads not associated with LWPs are system threads, such as those created to handle hardware interrupts. For those threads bound to an LWP, there is one and only one kernel thread per LWP. On a multiprocessor system, several kernel threads can run simultaneously. Even on uniprocessors, running kernel threads can be preempted at any time to run other threads. Drivers are mainly concerned with kernel threads as most device driver routines run as kernel threads. Figure 4-1 illustrates the relationship between threads and lightweight processes.

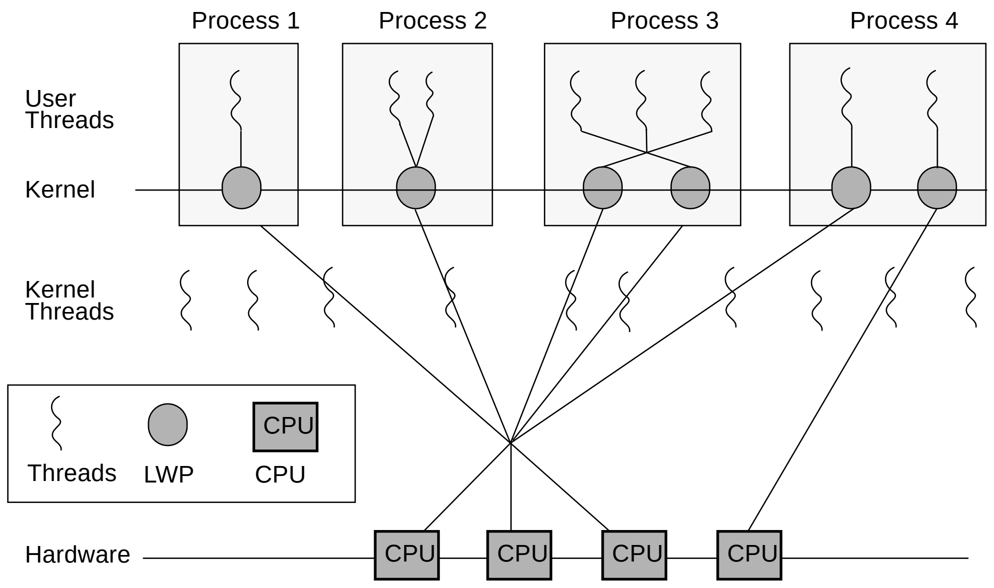
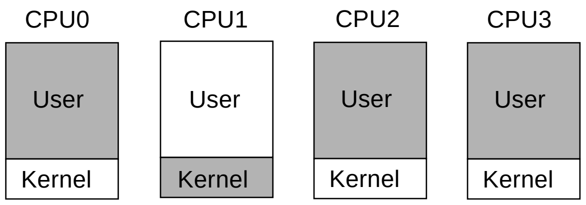


Figure 4-1 Threads and Lightweight Processes

A multithreaded kernel requires consideration of *locking primitives* and *thread synchronization*.

Multiprocessing Changes Since the SunOS 4.x System

Here is a simplified view of how the earlier releases of the SunOS kernel ran on multiprocessors. Only one processor could run kernel code at any one time, and this was enforced by using a *master lock* around the entire kernel. When a processor needed to execute kernel code, it acquired the master lock, blocking other processors from accessing kernel code. It released the lock on exiting the kernel.



CPU 1

```
Acquire master_lock;
Run code;
Release master_lock;
```

Figure 4-2 SunOS 4.x Kernels on a Multiprocessor

In Figure 4-2 CPU1 executes kernel code. All other processors are locked out of the kernel; the other processors could, however, run user code.

In the SunOS 5.x system, instead of one master lock, there are many locks that protect smaller regions of code or data. In the example shown in Figure 4-3 on page 78, there is a kernel lock that controls access to data structure A, and another that controls access to data structure B. Using these locks, only one processor at a time can be executing code dealing with data structure A, but another could be accessing data within structure B. This allows a greater degree of concurrency.

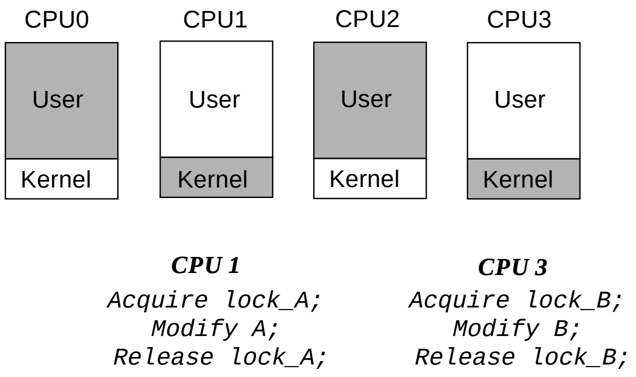


Figure 4-3 SunOS 5.x on a Multiprocessor

In Figure 4-3, CPU1 and CPU3 are executing kernel code simultaneously.

Locking Primitives

In traditional UNIX systems, any section of kernel code runs until it explicitly gives up the processor by calling `sleep()` or is interrupted by hardware. *This is not true in SunOS 5.x!* A kernel thread can be preempted at any time to run another thread. Because all kernel threads share kernel address space, and often need to read and modify the same data, the kernel provides a number of locking primitives to prevent threads from corrupting shared data. These mechanisms include *mutual exclusion locks*, *readers/writer locks*, and *semaphores*.

Storage Classes of Driver Data

The storage class of data is a guide to whether the driver might need to take explicit steps to control access to the data.

Automatic (Stack) Data

Because every thread has a private stack, drivers never need to lock automatic variables.

Global and Static Data

Global and static data can be shared by any number of threads in the driver; the driver might need to lock this type of data at times.

Kernel Heap Data

Any number of threads in the driver might share kernel heap data, such as data allocated by `kmem_alloc`(9F). If this data *is* shared, the driver might need to protect it at times.

State Structure

This section adds the following field to the state structure. See “Software State Structure” on page 63 for more information.

```
int        busy;   /* device busy flag */
kmutex_t   mu;     /* mutex to protect state structure */
kcondvar_t cv;     /* threads wait for access here */
```

Mutual-Exclusion Locks

A *mutual-exclusion lock*, or *mutex*, is usually associated with a set of data and regulates access to that data. Mutexes provide a way to allow only one thread at a time access to that data.

Table 4-1 Mutex Routines

Name	**Description**
`mutex_init(9F)`	Initializes a mutex.
`mutex_destroy(9F)`	Releases any associated storage.
`mutex_enter(9F)`	Acquires a mutex.
`mutex_tryenter(9F)`	Acquires a mutex if available; but does not block.
`mutex_exit(9F)`	Releases a mutex.
`mutex_owned(9F)`	Test sif the mutex is held by the current thread. To be used in ASSERT(9F) only.

Setting Up Mutexes

Device drivers usually allocate a mutex for each driver data structure. The mutex is typically a field in the structure and is of type `kmutex_t`. `mutex_init`(9F) is called to prepare the mutex for use. This is usually done at `attach`(9E) time for per-device mutexes and `_init`(9E) time for global driver mutexes.

For example,

```
    struct xxstate *xsp;
    ...
    mutex_init(&xsp->mu, “xx mutex”, MUTEX_DRIVER, NULL);
    ...
```

For a more complete example of mutex initialization see Chapter 5, “Autoconfiguration.”

The driver must destroy the mutex with `mutex_destroy`(9F) before being unloaded. This is usually done at `detach`(9E) time for per-device mutexes and `_fini`(9E) time for global driver mutexes.

Using Mutexes

Every section of the driver code that needs to read or write the shared data structure must do the following:

- Acquire the mutex.
- Access the data.
- Release the mutex.

For example, to protect access to the *busy* flag in the state structure:

```
    ...
    mutex_enter(&xsp->mu);
    xsp->busy = 0;
    mutex_exit(&xsp->mu);
    ....
```

The scope of a mutex—the data it protects—is entirely up to the programmer. A mutex protects some particular data structure *because the programmer chooses to do so* and uses it accordingly. A mutex protects a data structure only if every code path that accesses the data structure does so while holding the mutex. For additional guidelines on using mutexes see Appendix G, “Advanced Topics.”

Readers/Writer Locks

A *readers/writer lock* regulates access to a set of data. The readers/writer lock is so called because many threads can hold the lock simultaneously for reading, but only one thread can hold it for writing.

Most device drivers do not use readers/writer locks. These locks are slower than mutexes and provide a performance gain only when protecting data that is not frequently written but is commonly read by many concurrent threads. In this case, contention for a mutex could become a bottleneck, so using a readers/writer lock might be more efficient. See `rwlock`(9F) for more information.

Semaphores

Counting semaphores are available as an alternative primitive for managing threads within device drivers. See `semaphore`(9F) for more information.

Thread Synchronization

In addition to protecting shared data, drivers often need to synchronize execution among multiple threads.

Condition Variables

Condition variables are a standard form of thread synchronization. They are designed to be used with mutexes. The associated mutex is used to ensure that a condition can be checked atomically, and that the thread can block on the associated condition variable without missing either a change to the condition or a signal that the condition has changed. Condition variables must be initialized by calling `cv_init`(9F) and must be destroyed by calling `cv_destroy`(9F).

Note – Condition variable routines are approximately equivalent to the routines `sleep()` and `wakeup()` used in SunOS 4.x.

Table 4-2 lists the condvar(9F) interfaces. The four wait routines – cv_wait(9F), cv_timedwait(9F), cv_wait_sig(9F), and cv_timedwait_sig(9F) – take a pointer to a mutex as an argument.

Table 4-2 Condition Variable Routines

Name	Description
cv_init(9F)	Initializes a condition variable.
cv_destroy(9F)	Destroys a condition variable.
cv_wait(9F)	Waits for condition.
cv_timedwait(9F)	Waits for condition or timeout.
cv_wait_sig(9F)	Waits for condition or return zero on receipt of a signal.
cv_timedwait_sig(9F)	Waits for condition or timeout or signal.
cv_signal(9F)	Signals one thread waiting on the condition variable.
cv_broadcast(9F)	Signals all threads waiting on the condition variable.

Initializing Condition Variables

Declare a condition variable (type kcondvar_t) for each condition. Usually, this is done in the driver's soft-state structure. Use cv_init(9F) to initialize each one. Similar to mutexes, condition variables are usually initialized at attach(9E) time. For example:

```
...
cv_init(&xsp->cv, NULL, CV_DRIVER, NULL);
...
```

For a more complete example of condition variable initialization see Chapter 5, "Autoconfiguration."

Using Condition Variables

To use condition variables, follow these steps in the code path waiting for the condition:

1. Acquire the mutex guarding the condition.
2. Test the condition.

3. If the test results do not allow the thread to continue, use `cv_wait`(9F) to block the current thread on the condition. `cv_wait`(9F) releases the mutex before blocking. Upon return from `cv_wait`(9F) (which will reacquire the mutex before returning), repeat the test.

4. Once the test allows the thread to continue, set the condition to its new value. For example, set a device flag to busy.

5. Release the mutex.

Follow these steps in the code path signaling the condition:

1. Acquire the mutex guarding the condition.

2. Set the condition.

3. Signal the blocked thread with `cv_signal`(9F).

4. Release the mutex.

Code Example 4-1 uses a busy flag, and mutex and condition variables to force the `read`(9E) routine to wait until the device is no longer busy before starting a transfer.

Code Example 4-1 Using Mutexes and Condition Variables

```
static int
xxread(dev_t dev, struct uio *uiop, cred_t *credp)
{
    struct xxstate *xsp;
    ...
    mutex_enter(&xsp->mu);
    while (xsp->busy)
        cv_wait(&xsp->cv, &xsp->mu);
    xsp->busy = 1;
    mutex_exit(&xsp->mu);
    perform the data access
}
static u_int
xxintr(caddr_t arg);
{
    struct xxstate *xsp = (struct xxstate *)arg;
    mutex_enter(&xsp->mu);
    xsp->busy = 0;
    cv_broadcast(&xsp->cv);
    mutex_exit(&xsp->mu);
}
```

In Code Example 4-1, `xxintr( )` always calls `cv_broadcast`(9F), even if there are no threads waiting on the condition. This extra call can be avoided by using a *want* flag in the state structure, as shown in Code Example 4-2. Before a thread blocks on the condition variable (such as because the device is busy), it sets the *want* flag, indicating that it wants to be signaled when the condition occurs. When the condition occurs (the device finishes the transfer), the call to `cv_broadcast`(9F) is made only if the *want* flag is set.

Code Example 4-2 Using a *want* Flag

```
static int
xxread(dev_t dev, struct uio *uiop, cred_t *credp)
{
    struct xxstate *xsp;
    ...
    mutex_enter(&xsp->mu);
    while (xsp->busy) {
        xsp->want = 1;
        cv_wait(&xsp->cv, &xsp->mu);
    }
    xsp->busy = 1;
    mutex_exit(&xsp->mu);
    perform error recovery
}
static u_int
xxintr(caddr_t arg);
{
    struct xxstate *xsp = (struct xxstate *)arg;
    mutex_enter(&xsp->mu);
    xsp->busy = 0;
    if (xsp->want) {
        xsp->want = 0;
        cv_broadcast(&xsp->cv);
    }
    mutex_exit(&xsp->mu);
}
```

cv_timedwait( )

If a thread blocks on a condition with `cv_wait`(9F), and that condition does not occur, it may wait forever. One way to prevent this is to establish a callback with `timeout`(9F). This callback sets a flag indicating that the condition did not occur normally, and then unblocks the thread. The notified thread then notices that the condition did not occur and can return an error (such as *device broken*).

A better solution is to use `cv_timedwait`(9F). An absolute wait time is passed to `cv_timedwait`(9F), which returns `-1` if the time is reached and the event has not occurred. It returns nonzero otherwise. This saves a lot of work setting up separate `timeout`(9F) routines and avoids having threads get stuck in the driver.

`cv_timedwait`(9F) requires an absolute wait time expressed in clock ticks since the system was last rebooted. This can be determined by retrieving the current value with `drv_getparm`(9F). The `drv_getparm`(9F) function takes an address to store a value and an indicator of which kernel parameter to retrieve. In this case, LBOLT is used to get the number of clock ticks since the last reboot. The driver, however, usually has a maximum number of seconds or microseconds to wait, so this value is converted to clock ticks with `drv_usectohz`(9F) and added to the value from `drv_getparm`(9F).

Code Example 4-3 shows how to use `cv_timedwait`(9F) to wait up to five seconds to access the device before returning EIO to the caller.

Code Example 4-3 Using `cv_timedwait`(9F)

```
clock_t    cur_ticks, to;

mutex_enter(&xsp->mu);

while (xsp->busy) {

    drv_getparm(LBOLT, &cur_ticks);
    to = cur_ticks + drv_usectohz(5000000); /* 5 seconds from now */
    if (cv_timedwait(&xsp->cv, &xsp->mu, to) == -1) {
        /*
         * The timeout time 'to' was reached without the
         * condition being signalled.
         */

        tidy up and exit
        mutex_exit(&xsp->mu);
        return (EIO);
    }
}
xsp->busy = 1;
mutex_exit(&xsp->mu);
```

cv_wait_sig( )

There is always the possibility that either the driver accidentally waits for a condition that will never occur (as described in “cv_timedwait( )” on page 85) or that the condition will not happen for a long time. In either case, the user may want to abort the thread by sending it a signal. Whether the signal causes the driver to wake up depends upon the driver.

`cv_wait_sig`(9F) allows a signal to unblock the thread. This allows the user to break out of potentially long waits by sending a signal to the thread with `kill`(1) or by typing the interrupt character. `cv_wait_sig`(9F) returns zero if it is returning because of a signal, or nonzero if the condition occurred.

Code Example 4-4 shows how to use `cv_wait_sig`(9F) to allow a signal to unblock the thread.

Code Example 4-4 Using `cv_wait_sig`(9F)

```
mutex_enter(&xsp->mu);
while (xsp->busy) {
    if (cv_wait_sig(&xsp->cv, &xsp->mu) == 0) {
        /* Signalled while waiting for the condition. */
        tidy up and exit
        mutex_exit(&xsp->mu);
        return (EINTR);
    }
}
xsp->busy = 1;
mutex_exit(&xsp->mu);
```

cv_timedwait_sig( )

`cv_timedwait_sig`(9F) is similar to `cv_timedwait`(9F) and `cv_wait_sig`(9F), except that it returns `-1` without the condition being signaled after a timeout has been reached, or `0` if a signal (for example, `kill`(2)) is sent to the thread.

For both `cv_timedwait`(9F) and `cv_timedwait_sig`(9F), time is measured in absolute clock ticks since the last system reboot.

Choosing a Locking Scheme

The locking scheme for most device drivers should be kept straightforward. Using additional locks may allow more concurrency but increase overhead. Using fewer locks is less time consuming but allows less concurrency. Generally, use one mutex per data structure, a condition variable for each event or condition the driver must wait for, and a mutex for each major set of data global to the driver. Avoid holding mutexes for long periods of time.

To look at lock usage, use `lockstat`(1M). `lockstat`(1M) monitors all kernel lock events, gathers frequency and timing data about the events, and displays the data.

For more information on locking schemes, see Appendix G, “Advanced Topics”. Also see the *Multithreaded Programming Guide* for more details on multithreading operations.

Autoconfiguration 5

This chapter describes the support a driver must provide for autoconfiguration.

Autoconfiguration Overview

Autoconfiguration is the process of getting the driver's code and static data loaded into memory and registered with the system. Autoconfiguration also involves configuring (attaching) individual device instances that are controlled by the driver. "Loadable Driver Interface" on page 94 and "Device Configuration" on page 96 discuss these processes in more detail. The autoconfiguration process includes both of these processes and begins when the device is put into use.

Additions to State Structure

This section adds the following fields to the state structure. See "Software State Structure" on page 63 for more information.

```
int                    instance;
ddi_iblock_cookie_t    iblock_cookie;
ddi_idevice_cookie_t   idevice_cookie;
ddi_acc_handle_t       data_access_handle;
```

5

Driver Loading and Configuration

Figure 5-1 illustrates a structural overview of a device driver. The shaded area of this figure shows the autoconfiguration process, which is subdivided into two parts: driver loading (performed by the kernel) and driver configuration.

Note – The third section (device access) is discussed in Chapter 9, “Drivers for Character Devices,” and Chapter 10, “Drivers for Block Devices.”

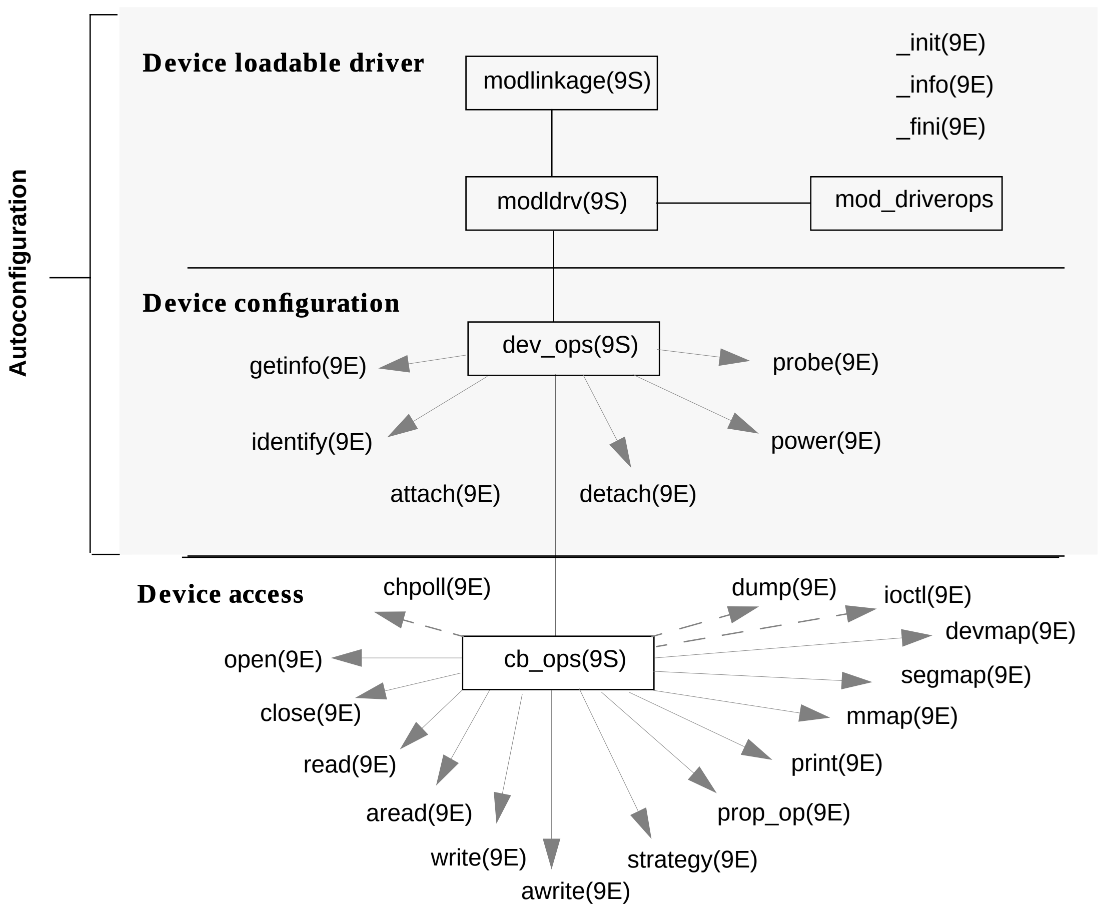


Figure 5-1 Autoconfiguration Roadmap

Data Structures

The data structures illustrated in Figure 5-1 must be provided and initialized correctly for the driver to load and for its routines to be called. If an operation is not supported by the driver, the address of the routine `nodev`(9F) can be used to fill it in. If the driver supports the entry point, but does not need to do anything except return success, the address of the routine `nulldev`(9F) can be used.

Note – These structures should be initialized at compile-time. They should not be accessed or changed by the driver at any other time.

modlinkage()

```
int     ml_rev;
void    *ml_linkage[4];
```

The `modlinkage`(9S) structure is exported to the kernel when the driver is loaded. The `ml_rev` field indicates the revision number of the loadable module system, which should be set to `MODREV_1`. Drivers can only support one module, so only the first element of `ml_linkage` should be set to the address of a `modldrv`(9S) structure. `ml_linkage[1]` should be set to `NULL`.

modldrv()

```
struct mod_ops     *drv_modops;
char               *drv_linkinfo;
struct dev_ops     *drv_dev_ops;
```

This structure describes the module in more detail. The `drv_modops` field points to a structure describing the module operations, which is `&mod_driverops` for a device driver. The `drv_linkinfo` field is displayed by the `modinfo`(1M) command and should be an informative string identifying the device driver. The `drv_dev_ops` field points to the next structure in the chain, the `dev_ops`(9S) structure.

dev_ops()

```
int     devo_rev;
int     devo_refcnt;
int     (*devo_getinfo)(dev_info_t *dip,ddi_info_cmd_t infocmd,
            void *arg, void **result);
int     (*devo_identify)(dev_info_t *dip);
int     (*devo_probe)(dev_info_t *dip);
int     (*devo_attach)(dev_info_t *dip, ddi_attach_cmd_t cmd);
int     (*devo_detach)(dev_info_t *dip, ddi_detach_cmd_t cmd);
int     (*devo_reset)(dev_info_t *dip, ddi_reset_cmd_t cmd);
int     (*devo_power)(dev_info_t *dip, int component,
            int level);
struct cb_ops  *devo_cb_ops;
struct bus_ops *devo_bus_ops;
```

The dev_ops(9S) structure allows the kernel to find the autoconfiguration entry points of the device driver. The devo_rev field identifies the revision number of the structure itself, and must be set to DEVO_REV. The devo_refcnt field must be initialized to zero. The function address fields should be filled in with the address of the appropriate driver entry point. Exceptions are:

- If a probe(9E) routine is not needed, use nulldev(9F).
- identify(9E) is obsolete and no longer required. Set this field to nulldev(9F).
- Use nodev(9F) in devo_detach to prevent the driver from being unloaded.
- Set devo_reset to nodev(9F).
- Drivers for devices that provide Power Management functionality must have a power(9E) entry point. If a power(9E) routine is not needed, set this field to NULL.

The devo_cb_ops member should include the address of the cb_ops(9S) structure. The devo_bus_ops field must be set to NULL.

cb_ops

```
int     (*cb_open)(dev_t *devp, int flag, int otyp,
            cred_t *credp);
int     (*cb_close)(dev_t dev, int flag, int otyp,
            cred_t *credp);
int     (*cb_strategy)(struct buf *bp);
int     (*cb_print)(dev_t dev, char *str);
int     (*cb_dump)(dev_t dev, caddr_t addr, daddr_t blkno,
            int nblk);
int     (*cb_read)(dev_t dev, struct uio *uiop, cred_t *credp);
int     (*cb_write)(dev_t dev, struct uio *uiop, cred_t *credp);
int     (*cb_ioctl)(dev_t dev, int cmd, intptr_t arg, int mode,
            cred_t *credp, int *rvalp);
int     (*cb_devmap)(dev_t dev, devmap_cookie_t dhp,
            offset_t off, size_t len, size_t *maplen,
            uint_t model);
int     (*cb_mmap)(dev_t dev, off_t off, int prot);
int     (*cb_segmap)(dev_t dev, off_t off, struct as *asp,
            addr_t *addrp, off_t len, unsigned int prot,
            unsigned int maxprot, unsigned int flags,
            cred_t *credp);
int     (*cb_chpoll)(dev_t dev, short events, int anyyet,
            short *reventsp, struct pollhead **phpp);
int     (*cb_prop_op)(dev_t dev, dev_info_t *dip,
            ddi_prop_op_t prop_op, int mod_flags,
            char *name, caddr_t valuep, int *length);
struct streamtab   *cb_str;   /* STREAMS information */
int     cb_flag;
int     cb_rev;
int     (*cb_aread)(dev_t dev, struct aio_req *aio,
            cred_t *credp);
int     (*cb_awrite)(dev_t dev, struct aio_req *aio,
            cred_t *credp);
```

The `cb_ops`(9S) structure contains the entry points for the character and block operations of the device driver. Any entry points the driver does not support should be initialized to `nodev`(9F). For example, character device drivers should set all the block-only fields (such as `cb_stategy` to `nodev`(9F)). Note that the `mmap`(9E) entry point is maintained for compatibility with previous releases, and drivers should use the `devmap`(9E) entry point for device memory mapping. If `devmap`(9E) is supported, set `mmap`(9E) to `nodev`(9F).

The `cb_str` field is used to determine if this is a STREAMS-based driver. The device drivers discussed in this book are not STREAMS based. For a non-STREAMS-based driver, `cb_str` *must* be set to `NULL`.

The `cb_flag` member contains the following flags:

- If the driver is safe for multithreading, it should set the `D_MP` flag. If it is a new-style driver, set the(`D_NEW` flag. All drivers are new-style drivers, and should properly handle the multithreaded environment, so `cb_flag` should be set to both (`D_NEW | D_MP`).

- If the driver properly handles 64-bit offsets, it should set the D_64BIT flag in the cb_flag field. This specifies that the driver will use the uio_loffset field of the uio(9S) structure.
- If the driver supports the devmap(9E) entry point, it should set the D_DEVMAP flag.

cb_rev is the cb_ops(9S) structure revision number. This field must be set to CB_REV.

Loadable Driver Interface

Device drivers *must* be dynamically loadable and should be unloadable to help conserve memory resources. Drivers that can be unloaded are also easier to test and debug.

Each device driver has a section of code that defines a loadable interface. This code section defines a static pointer for the soft state routines, the structures described in “Data Structures” on page 91, and the routines involved in loading the module.

Code Example 5-1 Loadable Interface Section

```
static void *statep;            /* for soft state routines */
static struct cb_ops xx_cb_ops;   /* forward reference */
static struct dev_ops xx_ops = {
    DEVO_REV,
    0,
    xxgetinfo,
    nulldev,
    xxprobe,
    xxattach,
    xxdetach,
    xxpower,
    nodev,
    &xx_cb_ops,
    NULL
};
static struct modldrv modldrv = {
    &mod_driverops,
    "xx driver v1.0",
    &xx_ops
};
```

```
static struct modlinkage modlinkage = {
    MODREV_1,
    &modldrv,
    NULL
};
int
_init(void)
{
    int error;
    ddi_soft_state_init(&statep, sizeof (struct xxstate),
        estimated number of instances);
    further per-module initialization if necessary
    error = mod_install(&modlinkage);
    if (error != 0) {
        undo any per-module initialization done earlier
        ddi_soft_state_fini(&statep);
    }
    return (error);
}
int
_fini(void)
{
    int error;
    error = mod_remove(&modlinkage);
    if (error == 0) {
        release per-module resources if any were allocated
        ddi_soft_state_fini(&statep);
    }
    return (error);
}
int
_info(struct modinfo *modinfop)
{
    return (mod_info(&modlinkage, modinfop));
}
```

Any one-time resource allocation or data initialization should be performed during driver loading in `_init`(9E). For example, any mutexes global to the driver should be initialized here. Do not, however, use `_init`(9E) to allocate or initialize anything that has to do with a particular instance of the device. Per-instance initialization must be done in `attach`(9E). For example, if a driver for a printer can drive more than one printer at the same time, allocate resources specific to each printer instance in `attach`(9E).

Similarly, in `_fini`(9E), release only those resources allocated by `_init`(9E).

Note – Once `_init`(9E) has called `mod_install`(9F), the driver should not change any of the data structures hanging off the `modlinkage`(9S) structure, as the system may make copies of them or change them.

Device Configuration

Each driver must provide the following entry points that are used by the kernel for device configuration:

- `probe`(9E)
- `attach`(9E)
- `detach`(9E)
- `getinfo`(9E)

Every device driver must have an `attach`(9E) and `getinfo`(9E) routine. `probe`(9E) is only required for non self-identifying devices. For self-identifying devices an explicit probe routine may be provided or `nulldev`(9F) may be specified in the `dev_ops` structure for the `probe`(9E) entry point.

Note – The `identify`(9E) entry point is obsolete and is no longer required.

The driver is single-threaded on a per-device basis when the kernel calls these entry points for autoconfiguration, with the exception of `getinfo`(9E). The kernel may be in a multithreaded state when calling `getinfo`(9E), which can occur at any time. No calls to `attach`(9E) will occur on the same device concurrently. However, calls to `attach`(9E) on different devices that the driver handles might occur concurrently.

Instance Numbers

The system assigns an instance number to each device. The driver may not reliably predict the value of the instance number assigned to a particular device. The driver should retrieve the particular instance number that has been assigned by calling `ddi_get_instance`(9F), as shown in Code Example 5-4 on page 101.

Instance numbers are derived in an implementation-specific manner from different properties for the different device types. The following properties are used to derive instance numbers:

- The `reg` property is used for SBus, PCI, VMEbus, ISA, EISA, and MCA devices. Non-self-identifying device drivers provide this property in the hardware configuration file. See `sbus`(4), `pci`(4), `isa`(4), and `vme`(4).
- The `target` and `lun` properties are used for SCSI target devices. These are provided in the hardware configuration file. See `scsi`(4).
- The `instance` property is used for pseudo-devices. This is provided in the hardware configuration file. See `pseudo`(4).

Persistent Instances

Once an instance number has been assigned to a particular physical device by the system, it stays the same even across reconfiguration and reboot. Because of this, instance numbers seen by a driver may not appear to be in consecutive order.

identify( )

The `identify`(9E) entry point is obsolete and is no longer required. `identify`(9E) was used to determine whether a driver accessed the device pointed to by `dip`. `identify`(9E) is currently supported only to provide backward compatibility with older drivers and should not be implemented. `nulldev`(9F) should be specified in the `dev_ops`(9S) structure.

probe( )

This entry point is not required for self-identifying devices such as SBus or PCI devices. `nulldev`(9F) may be used instead.

For non-self-identifying devices (see “Device Identification” on page 18) this entry point should determine whether the hardware device is present on the system and return:

`DDI_PROBE_SUCCESS`	if the probe was successful
`DDI_PROBE_FAILURE`	if the probe failed

`DDI_PROBE_DONTCARE`	if the probe was unsuccessful, yet `attach`(9E) should still be called
`DDI_PROBE_PARTIAL`	if the instance is not present now, but may be present in the future

For a given device instance, `attach`(9E) will not be called before `probe`(9E) has succeeded at least once on that device.

It is important that `probe`(9E) free all the resources it allocates, because it may be called multiple times; however, `attach`(9E) will not necessarily be called even if `probe`(9E) succeeds.

For probe to determine whether the instance of the device is present, `probe`(9E) may need to do many of the things also commonly done by `attach`(9E). In particular, it may need to map the device registers.

Probing the device registers is device specific. The driver probably has to perform a series of tests of the hardware to assure that the hardware is really there. The test criteria must be rigorous enough to avoid misidentifying devices. It may, for example, appear that the device is present when in fact it is not, because a different device appears to behave like the expected device.

When the driver's `probe`(9E) routine is called, it does not know whether the device being probed exists on the bus. Therefore, it is possible that the driver may attempt to access device registers for a nonexistent device. A bus fault may be generated on some buses as a result.

Buses such as ISA, EISA, and MCA do not generate bus faults as a result of such accesses. Code Example 5-2 is a sample `probe`(9E) routine for devices on these buses.

Code Example 5-2 `probe`(9E) Routine

```
static int
xxprobe(dev_info_t *dip)
{
    int         instance;
    caddr_t     reg_addr;
    ddi_acc_handle_t data_access_handle;

    /* define device access attributes */
    ddi_device_acc_attr_t access_attr = {
        DDI_DEVICE_ATTR_V0,
        DDI_STRUCTURE_BE_ACC,
            DDI_STRICTORDER_ACC
        };
        if (ddi_dev_is_sid(dip) == DDI_SUCCESS) /* no need to probe */
            return (DDI_PROBE_DONTCARE);

        instance = ddi_get_instance(dip); /* assigned instance */

        if (ddi_intr_hilevel(dip, inumber)) {
            cmn_err(CE_CONT,
                "?xx driver does not support high level interrupts."
                " Probe failed.");
            return (DDI_PROBE_FAILURE);
        }

        /* Map device registers and try to contact device.*/
        if (ddi_regs_map_setup(dip, rnumber, &reg_addr, offset, len,
                &access_attr, &data_access_handle) != DDI_SUCCESS)
            return (DDI_PROBE_FAILURE);

        if (ddi_get8(data_access_handle, (uint8_t *)reg_addr) !=
                some_value)
            goto failed;

        free allocated resources

        ddi_regs_map_free(&data_access_handle);

        if (device is present and ready for attach)
            return (DDI_PROBE_SUCCESS);
        else if (device is present but not ready for attach)
            return (DDI_PROBE_PARTIAL);
        else    /* device is not present */
            return (DDI_PROBE_FAILURE);
    failed:
        free allocated resources
        ddi_regs_map_free(&data_access_handle);

        return (DDI_PROBE_FAILURE);
    }
```

The string printed in the high-level interrupt case begins with a '?' character. This causes the message to be printed only if the kernel was booted with the `verbose (-v)` flag. (See `kernel`(1M)). Otherwise the message only goes into the message log, where it can be seen by running `dmesg`(1M).

`ddi_dev_is_sid`(9F) may be used in a driver's `probe`(9E) routine to determine if the device is self-identifying. This is useful in drivers written for self-identifying and non-self-identifying versions of the same device.

For VME device drivers, a fault may occur as a result of attempting to access device registers for a device that is not present. In this case, the `ddi_peek`(9F) and `ddi_poke`(9F) family of routines must be used to access the device registers. Code Example 5-3 shows a `probe`(9E) routine that uses `ddi_peek`(9F) and `ddi_poke`(9F) to check for the existence of the device.

Code Example 5-3 `probe`(9E) Routine Using `ddi_peek`(9F)

```
static int
xxprobe(dev_info_t *dip)
{
    int         instance;
    caddr_t     reg_addr;

    if (ddi_dev_is_sid(dip) == DDI_SUCCESS) /* no need to probe */
        return (DDI_PROBE_DONTCARE);

    instance = ddi_get_instance(dip); /* assigned instance */

    if (ddi_intr_hilevel(dip, inumber)) {
        cmn_err(CE_CONT,
            "?xx driver does not support high level interrupts."
            " Probe failed.");
        return (DDI_PROBE_FAILURE);
    }

    /*
     * Map device registers and try to contact device.
     */

    if (ddi_regs_map_setup(dip, rnumber, &reg_addr, offset, len,
            &access_attr, &data_access_handle) != DDI_SUCCESS)
        return (DDI_PROBE_FAILURE);

    if (ddi_peek8(dip, reg_addr, NULL) != DDI_SUCCESS)
        goto failed;

    free allocated resources
    ddi_regs_map_free(&data_access_handle);
    if (device is present and ready for attach)
        return (DDI_PROBE_SUCCESS);
    else if (device is present but not ready for attach)
        return (DDI_PROBE_PARTIAL);
    else    /* device is not present */
        return (DDI_PROBE_FAILURE);

    failed:
    free allocated resources
    ddi_regs_map_free(&data_access_handle);
    return (DDI_PROBE_FAILURE);
}
```

In this example, `ddi_regs_map_setup`(9F) is used to map the device registers. `ddi_peek8`(9F) reads a single character from the location `reg_addr`.

attach( )

The system calls `attach`(9E) to *attach* a device instance to the system or to resume operation after power has been suspended. `attach`(9E) should handle the following commands:

- `DDI_ATTACH` – `attach`(9E) is called with `DDI_ATTACH` to initialize the device instance.
- `DDI_PM_RESUME` – `attach`(9E) is called with `DDI_PM_RESUME` to restore the hardware state of a device when the device has been suspended.
- `DDI_RESUME` – `attach`(9E) is called with `DDI_RESUME` to restore the hardware state of a device when the entire system has been suspended.

Only the `DDI_ATTACH` command is discussed in this section. For information on `DDI_PM_RESUME` and `DDI_RESUME`, see Chapter 8, "Power Management."

Note that `attach`(9E) is single-threaded when processing the `DDI_ATTACH` command, but is not single-threaded when processing the `DDI_RESUME` or `DDI_PM_RESUME` commands.

The responsibilities of the `DDI_ATTACH` case of `attach`(9E) include:

- Optionally allocating a soft state structure for the instance
- Registering an interrupt handler
- Mapping device registers
- Initializing per-instance mutexes and condition variables
- Creating minor device nodes for the instance
- Creating power-manageable components

Code Example 5-4 provides an example of an `attach`(9E) routine.

Code Example 5-4 `attach`(9E) Routine

```
static int
xxattach(dev_info_t *dip, ddi_attach_cmd_t cmd)
{
```

```
struct xxstate *xsp;
int instance;

/* define device access attributes */
ddi_device_acc_attr_t access_attr = {
    DDI_DEVICE_ATTR_V0,
    DDI_STRUCTURE_BE_ACC,
    DDI_STRICTORDER_ACC
};
switch (cmd) {
case DDI_ATTACH:

    /* get assigned instance number */
    instance = ddi_get_instance(dip);

    if (ddi_soft_state_zalloc(statep, instance) != 0)
        return (DDI_FAILURE);

    xsp = ddi_get_soft_state(statep, instance);

    /* retrieve interrupt block cookie */
    if (ddi_get_iblock_cookie(dip, inumber,
            &xsp->iblock_cookie) != DDI_SUCCESS) {
        ddi_soft_state_free(statep, instance);
        return (DDI_FAILURE);
    }

    /* initialize locks. Note that mutex_init wants a */
    /* ddi_iblock_cookie, not the _address_ of one, */
    /* as the fourth argument.*/
    mutex_init(&xsp->mu, "xx mutex", MUTEX_DRIVER,
        (void *)xsp->iblock_cookie);
    cv_init(&xsp->cv, "xx cv", CV_DRIVER, NULL);

    /* set up interrupt handler for the device */
    if (ddi_add_intr(dip, inumber, NULL,
        &xsp->idevice_cookie, NULL, intr_handler, intr_handler_arg)
        != DDI_SUCCESS) {
        ddi_soft_state_free(statep, instance);
        return (DDI_FAILURE);
    }

    /* map device registers */
    if (ddi_regs_map_setup(dip, rnumber, &xsp->regp,
        offset, sizeof(struct device_reg), &access_attr,
        &xsp->data_access_handle) != DDI_SUCCESS) {
        ddi_remove_intr(dip, inumber, xsp->iblock_cookie);
        ddi_soft_state_free(statep, instance);
```

```
            return (DDI_FAILURE);
        }
        xsp->dip = dip;
        initialize the rest of the software state structure;
        make device quiescent;                /* device-specific */
        /*
         * for devices with programmable bus interrupt level
         */
        program device interrupt level using  xsp->idevice_cookie;
        if device has power manageable components (see Chapter 8, “Power Management”),
        then include the following statement:
        if (pm_create_components(dip, num_components) != DDI_SUCCESS)
            goto failed;
        if (ddi_create_minor_node(dip, "minor name", S_IFCHR,
            minor_number, node_type, 0) != DDI_SUCCESS)
            goto failed;

        initialize driver data, prepare for  a later open of the device;/*device-specific */
        ddi_report_dev(dip);
        return (DDI_SUCCESS);

    case DDI_PM_RESUME:
        For information, see Chapter 8, “Power Management”
    case DDI_RESUME:
        For information, see Chapter 8, “Power Management”
    default:
        return (DDI_FAILURE);
    }
failed:
    free allocated resources
    ddi_regs_map_free(&xsp->data_access_handle);
    ddi_remove_intr(dip, inumber, xsp->iblock_cookie);
    pm_destroy_components(dip);
    cv_destroy(&xsp->cv);
    mutex_destroy(&xsp->mu);
    ddi_soft_state_free(statep, instance);
    return (DDI_FAILURE);
}
```

During the autoconfiguration process, `attach`(9E) checks for the `DDI_ATTACH` command and then calls `ddi_get_instance`(9F) to get the instance number the system has assigned to the `dev_info` node indicated by `dip`. Since the driver must be able to return a pointer to its `dev_info` node for each instance, `attach`(9E) must save `dip`, usually in a field of a per-instance state structure.

If any of the resource allocation routines fail, the code at the `failed` label should free any resources that had already been allocated before returning `DDI_FAILURE`. This can be done with a series of checks that look like this:

```
if (xsp->regp)
    ddi_regs_map_free(&xsp->data_access_handle);
```

There should be such a check and a deallocation operation for each allocation operation that may have been performed.

Note also that drivers should return `DDI_FAILURE` for all commands they do not recognize.

Registering Interrupts Overview

In the call to `ddi_add_intr`(9F), *inumber* specifies which of several possible interrupt specifications is to be handled by *intr_handler*. For example, if the device interrupts at only one level, pass `0` for `inumber`. The interrupt specifications being referred to by *inumber* are described by the *interrupts* property (see `driver.conf`(4), `isa`(4), `eisa`(4), `mca`(4), `sysbus`(4), `vme`(4), and `sbus`(4)). *intr_handler* is a pointer to a function, in this case `xxintr()`, to be called when the device issues the specified interrupt. *intr_handler_arg* is an argument of type `caddr_t` to be passed to *intr_handler*. *intr_handler_arg* may be a pointer to a data structure representing the device instance that issued the interrupt. `ddi_add_intr`(9F) returns a device cookie in `xsp->idevice_cookie` for use with devices having programmable bus-interrupt levels. The device cookie contains the following fields:

```
u_short    idev_vector;
u_short    idev_priority;
```

The *idev_priority* field of the returned structure contains the bus interrupt priority level, and the *idev_vector* field contains the vector number for vectored bus architectures such as VMEbus.

Note – There is a potential race condition in attach(9E). The interrupt routine is eligible to be called as soon as ddi_add_intr(9F) returns. This may result in the interrupt routine being called before any mutexes have been initialized with the interrupt block cookie. If the interrupt routine acquires the mutex before it has been initialized, undefined behavior may result. See “Registering Interrupts” on page 117 for a solution to this problem.

Mapping Device Registers

In the ddi_regs_map_setup(9F) call, dip is the dev_info pointer passed to attach(9E). *rnumber* specifies which register set to map if there is more than one. For devices with only one register set, pass 0 for *rnumber*. The register specifications referred to by *rnumber* are described by the *reg* property (see driver.conf(4), isa(4), eisa(4), mca(4), sysbus(4), vme(4), sbus(4), and pci(4)). ddi_regs_map_setup(9F) maps a device register set (register specification) and returns a bus address base in xsp->regp. This address is *offset* bytes from the base of the device register set, and the mapping extends sizeof(struct device_reg) bytes beyond that. To map all of a register set, pass zero for *offset* and the length.

Minor Device Nodes

A minor device node contains the information exported by the device that the system uses to create a special file for the device under */devices* in the file system.

In the call to ddi_create_minor_node(9F), the *minor name* is the character string that is the last part of the base name of the special file to be created for this minor device number; for example, "b,raw" in "fd@1,f7200000:b,raw". S_IFCHR means create a character special file. Finally, the node type is one of the following system macros, or any string constant that does not conflict with the values of these macros (see ddi_create_minor_node(9F) for more information).

Table 5-1 Possible Node Types

Constant	Description
`DDI_NT_SERIAL`	Serial port
`DDI_NT_SERIAL_DO`	Dialout ports
`DDI_NT_BLOCK`	Hard disks
`DDI_NT_BLOCK_CHAN`	Hard disks with channel or target numbers
`DDI_NT_CD`	ROM drives (CD-ROM)
`DDI_NT_CD_CHAN`	ROM drives with channel or target numbers
`DDI_NT_FD`	Floppy disks
`DDI_NT_TAPE`	Tape drives
`DDI_NT_NET`	Network devices
`DDI_NT_DISPLAY`	Display devices
`DDI_NT_MOUSE`	Mouse
`DDI_NT_KEYBOARD`	Keyboard
`DDI_PSEUDO`	General pseudo devices

The node types `DDI_NT_BLOCK`, `DDI_NT_BLOCK_CHAN`, `DDI_NT_CD`, and `DDI_NT_CD_CHAN` cause `disks`(1M) to identify the device instance as a disk and to create a symbolic link in the `/dev/dsk` or `/dev/rdsk` directory pointing to the device node in the `/devices` directory tree.

The node type `DDI_NT_TAPE` causes `tapes`(1M) to identify the device instance as a tape and to create a symbolic link from the `/dev/rmt` directory to the device node in the `/devices` directory tree.

The node type `DDI_NT_SERIAL` causes `ports`(1M) to identify the device instance as a serial port and to create symbolic links from the `/dev/term` and `/dev/cua` directories to the device node in the `/devices` directory tree and to add a new entry to `/etc/inittab`.

Vendor-supplied strings should include an identifying value to make them unique, such as their name or stock symbol (if appropriate). The string (along with the other node types not consumed by disks(1M), tapes(1M), or ports(1M)) can be used in conjunction with devlinks(1M) and devlink.tab(4) to create logical names in /dev.

Deferred Attach

open(9E) might be called before attach(9E) has succeeded. open(9E) must then return ENXIO, which will cause the system to attempt to attach the device. If the attach succeeds, the open is retried automatically.

detach( )

detach(9E) handles the following commands:

- DDI_DETACH – detach(9E) is called with DDI_DETACH for each device instance when the system attempts to unload a driver module.
- DDI_PM_SUSPEND – detach(9E) is called with DDI_PM_SUSPEND to suspend activity of a device before power is removed. This command is issued when the device is being suspended.
- DDI_SUSPEND – detach(9E) is called with DDI_SUSPEND to suspend activity of a device before power is removed. This command is issued when the entire system is being suspended.

This section discusses only the DDI_DETACH command. For information on DDI_PM_SUSPEND and DDI_SUSPEND, see Chapter 8, “Power Management.” Note that detach(9E) is single-threaded when processing the DDI_DETACH command, but is not single-threaded when processing the DDI_SUSPEND or DDI_PM_SUSPEND commands.

When processing the DDI_DETACH command, detach(9E) is the inverse operation of attach(9E). The main purpose of the DDI_DETACH case of detach(9E) is to free resources allocated by attach(9E) for the specified device. For example, detach(9E) should unmap any mapped device registers, remove any interrupts registered with the system, and free the soft state structure for this device instance.

The system calls the `DDI_DETACH` case of `detach`(9E) for a device instance only if the device instance is not open. No calls to other driver entry points for that device instance occur during `detach`(9E), although interrupts and time-outs may occur.

If the `detach`(9E) routine entry in the `dev_ops`(9S) structure is initialized to `nodev`, it implies that `detach`(9E) always fails, and the driver will not be unloaded. This is the simplest way to specify that a driver is not unloadable.

Code Example 5-5 `detach`(9E) Routine

```
static int
xxdetach(dev_info_t *dip, ddi_detach_cmd_t cmd)
{
    struct xxstate *xsp;
    int     instance;

    switch (cmd) {
    case DDI_DETACH:
        instance = ddi_get_instance(dip);
        xsp = ddi_get_soft_state(statep, instance);
        make device quiescent;          /* device-specific */
        ddi_remove_minor_node(dip, NULL);
        pm_destroy_components(dip);
        ddi_regs_map_free(&xsp->data_access_handle);
        ddi_remove_intr(dip, inumber, xsp->iblock_cookie);
        mutex_destroy(&xsp->mu);
        cv_destroy(&xsp->cv);
        ddi_soft_state_free(statep, instance);
        return (DDI_SUCCESS);
    case DDI_PM_SUSPEND:
        For information, see Chapter 8, “Power Management”
    case DDI_SUSPEND:
        For information, see Chapter 8, “Power Management”
    default:
        return (DDI_FAILURE);
    }
}
```

In the call to `ddi_regs_map_free`(9F), `xsp->data_access_handle` is the data access handle previously allocated by the call to `ddi_regs_map_setup`(9F) in `attach`(9E). Similarly, in the call to `ddi_remove_intr`(9F), *inumber* is the same value that was passed to `ddi_add_intr`(9F).

Callbacks

The `detach`(9E) routine must not return `DDI_SUCCESS` while it has callback functions pending. This is critical only for callbacks registered for device instances that are not currently open, since the `DDI_DETACH` case is not entered if the device is open.

There are two types of callback routines of interest: callbacks that can be canceled, and callbacks that must run to completion.

Callbacks that can be canceled do not pose a problem; just remember to cancel the callback before `detach`(9E) returns `DDI_SUCCESS`. Each of the callback cancellation routines in Table 5-2 atomically cancels callbacks so that a callback routine does not run while it is being canceled.

Table 5-2 Example of Functions With Cancelable Callbacks

Function	**Canceling Function**
`timeout`(9F)	`untimeout`(9F)
`bufcall`(9F)	`unbufcall`(9F)
`esbbcall`(9F)	`unbufcall`(9F)

Some callbacks cannot be canceled—for these it is necessary to wait until the callback has been called. In some cases, such as `ddi_dma_buf_bind_handle`(9F), the callback must also be prevented from rescheduling itself. See "Canceling DMA Callbacks" on page 145 for an example.

Following is a list of some functions that may establish callbacks that cannot be canceled:

- `esballoc`(9F)
- `ddi_dma_addr_bind_handle`(9F)
- `ddi_dma_buf_bind_handle`(9F)
- `scsi_init_pkt`(9F)

getinfo( )

The system calls getinfo(9E) to obtain configuration information that only the driver knows. The mapping of minor numbers to device instances is entirely under the control of the driver. The system sometimes needs to ask the driver which device a particular dev_t represents.

getinfo(9E) is called during module loading and at other times during the life of the driver. It can take one of two commands as its *infocmd* argument: DDI_INFO_DEVT2INSTANCE, which asks for a device's instance number, and DDI_INFO_DEVT2DEVINFO, which asks for pointer to the device's dev_info structure.

In the DDI_INFO_DEVT2INSTANCE case, *arg* is a dev_t, and getinfo(9E) must translate the minor number to an instance number. In the following example, the minor number *is* the instance number, so it simply passes back the minor number. In this case, the driver must not assume that a state structure is available, since getinfo(9E) may be called before attach(9E). The mapping the driver defines between minor device number and instance number does not necessarily follow the mapping shown in the example. In all cases, however, the mapping must be static.

In the DDI_INFO_DEVT2DEVINFO case, *arg* is again a dev_t, so getinfo(9E) first decodes the instance number for the device. It then passes back the dev_info pointer saved in the driver's soft state structure for the appropriate device. This is shown in Code Example 5-6.

Code Example 5-6 getinfo(9E) Routine

```
static int
xxgetinfo(dev_info_t *dip, ddi_info_cmd_t infocmd, void *arg,
  void **result)
{
    struct xxstate *xsp;
    dev_t   dev;
    int     instance, error;

    switch (infocmd) {
    case DDI_INFO_DEVT2INSTANCE:
        dev = (dev_t)arg;
        *result = (void *)getminor(dev);
        error = DDI_SUCCESS;
        break;
    case DDI_INFO_DEVT2DEVINFO:
        dev = (dev_t)arg;
        instance = getminor(dev);
        xsp = ddi_get_soft_state(statep, instance);
        if (xsp == NULL)
            return (DDI_FAILURE);
        *result = (void *)xsp->dip;
        error = DDI_SUCCESS;
        break;

    default:
        error = DDI_FAILURE;
        break;
    }
    return (error);
}
```

Interrupt Handlers 6

This chapter describes device driver interrupt handlers. It provides information on registering an interrupt handler and discusses the responsibilities of an interrupt handler.

Interrupt Handler Overview

An interrupt is a hardware signal from a device to the CPU. It tells the CPU that the device needs attention and that the CPU should stop performing what it is doing and respond to the device. If the CPU is available (it is not performing a task with higher priority, such as servicing a higher-priority interrupt), it suspends the current thread and eventually invokes the interrupt handler for that device. The job of the interrupt handler is to service the device and stop it from interrupting. Once the handler returns, the CPU resumes what it was doing before the interrupt occurred.

The Solaris 2.x DDI/DKI provides a bus-architecture independent interface for registering and servicing interrupts. Drivers must register their interrupt handlers before they can receive and service interrupts.

Interrupt Specification

The *interrupt specification* is the information the system needs to link the device interrupt source with a specific device interrupt handler. The specification describes the information provided by the hardware to the system when making an interrupt request. Because an interrupt specification is bus specific, the information it contains varies from bus to bus.

Interrupt specifications typically include a *bus-interrupt level*. For *vectored interrupts* the specifications include an *interrupt vector.* On x86 platforms the interrupt specification defines the relative interrupt priority of the device. Because interrupt specifications are bus specific, see `isa`(4), `eisa`(4), `mca`(4), `sbus`(4), `vme`(4), and `pci`(4) for information on interrupt specifications for these buses.

Interrupt Number

When registering interrupts the driver must provide the system with an *interrupt number.* This interrupt number identifies the interrupt specification (with bus-specific interrupt information) for which the driver is registering a handler. Most devices have one interrupt—interrupt number equals zero. However, there are devices that have different interrupts for different events. A communications controller may have one interrupt for *receive ready* and one for *transmit ready.* The device driver normally knows how many interrupts the device has, but if the driver has to support several variations of a controller, it can call `ddi_dev_nintrs`(9F) to find out the number of device interrupts. For a device with *n* interrupts, the interrupt numbers range from 0 to *n*-1.

Interrupt Block Cookies

The *iblock cookie* is an opaque data structure that is returned from either `ddi_get_iblock_cookie`(9F) or `ddi_add_intr`(9F). These interfaces use an interrupt number to return the iblock cookie associated with a specific interrupt source.

The iblock cookie gives the system information on how to block interrupts. It is passed to `mutex_init`(9F) when allocating driver mutexes to be used in the interrupt routine. See `mutex_init`(9F) for more information

Bus Interrupt Levels

Buses prioritize device interrupts at one of several *bus-interrupt levels*. These bus interrupt levels are then mapped to different processor-interrupt levels. For example, SBus devices that interrupt at SBus level 7 interrupt at SPARC level 9 on SPARCstation 2 systems.

High-Level Interrupts

A bus interrupt level that maps to a CPU interrupt priority level above the scheduler priority level is called a *high-level interrupt*. High-level interrupts must be handled without using system services that manipulate threads. In particular, the only kernel routines that high-level interrupt handlers are allowed to call are:

- `mutex_enter`(9F) and `mutex_exit`(9F) on a mutex initialized with an interrupt block cookie associated with the high-level interrupt
- `ddi_trigger_softintr`(9F)

A bus-interrupt level by itself does not determine whether a device interrupts at high level: a given bus-interrupt level may map to a high-level interrupt on one platform, but map to an ordinary interrupt on another platform.

The driver can choose whether to support devices that have high-level interrupts, but it *always* has to check—it *cannot* assume that its interrupts are not high level. The function `ddi_intr_hilevel`(9F), given an interrupt number, returns a value indicating whether the interrupt is high level. For information on checking for high-level interrupts see “Registering Interrupts” on page 117.

Types of Interrupts

There are two common ways in which buses implement interrupts: *vectored* and *polled*. Both methods commonly supply a bus-interrupt priority level. However, vectored devices also supply an interrupt vector; polled devices do not.

Vectored Interrupts

Devices that use vectored interrupts are assigned an *interrupt vector*. This is a number that identifies a particular interrupt handler. This vector may be fixed, configurable (using jumpers or switches), or programmable. In the case of programmable devices, an interrupt device cookie is used to program the device interrupt vector. When the interrupt handler is registered, the kernel saves the vector in a table.

When the device interrupts, the system enters the *interrupt acknowledge cycle*, asking the interrupting device to identify itself. The device responds with its interrupt vector. The kernel then uses this vector to find the responsible interrupt handler.

The VMEbus supports vectored interrupts.

Polled Interrupts

In *polled* (or *autovectored*) devices, the only information the system has about a device interrupt is either the bus interrupt priority level (IPL, on an SBus in a SPARC machine, for example) or the interrupt request number (IRQ on an ISA bus in an x86 machine, for example).

When an interrupt handler is registered, the system adds the handler to a list of potential interrupt handlers for each IPL or IRQ. Once the interrupt occurs, the system must determine which device, of all the devices associated with a given IPL or IRQ, actually interrupted. It does this by calling all the interrupt handlers for the designated IPL or IRQ, until one handler *claims* the interrupt.

The SBus, ISA, EISA, MCA, and PCI buses are capable of supporting polled interrupts.

Software Interrupts

The Solaris 2.x DDI/DKI supports *software interrupts*, also known as *soft interrupts*. Soft interrupts are not initiated by a hardware device; they are initiated by software. Handlers for these interrupts must also be added to and removed from the system. Soft interrupt handlers run in interrupt context and therefore can be used to do many of the tasks that belong to an interrupt handler.

Commonly, hardware interrupt handlers are supposed to perform their tasks quickly, since they may suspend other system activity while running. This is particularly true for high-level interrupt handlers, which operate at priority levels greater than that of the system scheduler. High-level interrupt handlers mask the operations of all lower-priority interrupts—including those of the system clock. Consequently, the interrupt handler must avoid involving itself in an activity (such as acquiring a mutex) that might cause it to sleep.

If the handler sleeps, then the system may hang because the clock is masked and incapable of scheduling the sleeping process. For this reason, high-level interrupt handlers normally perform a minimum amount of work at high-priority levels and delegate remaining tasks to software interrupts, which run below the priority level of the high-level interrupt handler. Because software interrupt handlers run below the priority level of the system scheduler, they can do the work that the high-level interrupt handler was incapable of doing. For more information on high-level interrupts, see "Handling High-Level Interrupts" on page 122.

Note – Drivers have the option of using a high-level mutex to protect shared data between the high-level interrupt handler and the soft interrupt handler. See "High-level Mutexes" on page 122.

Software interrupt handlers must not perform as if they have work to do when they run, since (like hardware interrupt handlers) they can run because some other driver triggered a soft interrupt. For this reason, the driver must indicate to the soft interrupt handler that it should do work before triggering the soft interrupt.

Registering Interrupts

Before a device driver can receive and service interrupts, it must register them with the system by calling `ddi_add_intr`(9F). Registering interrupts provides the system with a way to associate an interrupt handler with an interrupt specification. This interrupt handler is called when the device might have been responsible for the interrupt. It is the handler's responsibility to determine if it should handle the interrupt and, if so, claim it.

To register a driver's interrupt handler, the driver usually performs the following steps in `attach`(9E):

1. Test for high-level interrupts.

   Call `ddi_intr_hilevel`(9F) to find out if the interrupt specification maps to a high-level interrupt. If it does, one possibility is to post a message to that effect and return `DDI_FAILURE`. See Code Example 6-1.

2. Get the iblock cookie by calling `ddi_get_iblock_cookie`(9F).
3. Initialize any associated mutexes with the iblock cookie by calling `mutex_init`(9F).
4. Register the interrupt handler by calling `ddi_add_intr`(9F).

Note – There is a potential race condition between adding the interrupt handler and initializing mutexes. The interrupt routine is eligible to be called as soon as `ddi_add_intr`(9F) returns, as another device might interrupt and cause the handler to be invoked. This may result in the interrupt routine being called before any mutexes have been initialized with the returned interrupt block cookie. If the interrupt routine acquires the mutex before it has been initialized, undefined behavior may result. To ensure that this race condition does not occur, always initialize mutexes and any other data used in the interrupt handler before adding the interrupt.

Code Example 6-1 shows how to install an interrupt handler.

Code Example 6-1 `attach`(9E) Routine Installing an Interrupt Handler

```
static int
xxattach(dev_info_t *dip, ddi_attach_cmd_t cmd)
{
    struct xxstate *xsp;

    switch (cmd) {
    case DDI_ATTACH:
        ...
        if (ddi_intr_hilevel(dip, inumber) != 0){
            cmn_err(CE_CONT,
                "xx: high-level interrupts are not supported\n");
            return (DDI_FAILURE);
        }
        ddi_get_iblock_cookie(dip, inumber, &xsp->iblock_cookie);
        mutex_init(&xsp->mu, "xx mutex", MUTEX_DRIVER,
            (void *)xsp->iblock_cookie);
        cv_init(&xsp->cv, "xx cv", CV_DRIVER, NULL);
        if (ddi_add_intr(dip, inumber, &xsp->iblock_cookie,
            &xsp->idevice_cookie, xxintr,
                    (caddr_t)xsp) != DDI_SUCCESS){
            cmn_err(CE_WARN, "xx: cannot add interrupt handler.");
            goto failed;
        }
        return (DDI_SUCCESS);
    case DDI_PM_RESUME:
        For information, see Chapter 8, "Power Management"
    case DDI_RESUME:
        For information, see Chapter 8, "Power Management"
    default:
        return (DDI_FAILURE);
    }
failed:
    remove interrupt handler if necessary, destroy mutex and condition variable
    return (DDI_FAILURE);
}
```

Responsibilities of an Interrupt Handler

The interrupt handler has a set of responsibilities to perform. Some are required by the framework, and some are required by the device. All interrupt handlers are required to do the following:

1. Determine if the device is interrupting and possibly reject the interrupt.

   The interrupt handler must first examine the device and determine if it has issued the interrupt. If it has not, the handler must return `DDI_INTR_UNCLAIMED`. This step allows the implementation of *device polling*: it tells the system whether this device, among a number of devices at the given interrupt priority level, has issued the interrupt.

2. Inform the device that it is being serviced.

   This is a device-specific operation, but it is required for the majority of devices. For example, SBus devices are required to interrupt until the driver tells them to stop. This guarantees that all SBus devices interrupting at the same priority level will be serviced. Most vectored devices, on the other hand, stop interrupting after the bus interrupt-acknowledge cycle; however, their internal state still indicates that they have interrupted but have not yet been serviced.

3. Perform any I/O request-related processing.

   Devices interrupt for different reasons, such as *transfer done* or *transfer error*. This step may involve using data access functions to read the device's data buffer, examine the device's error register, and set the status field in a data structure accordingly.

   Interrupt dispatching and processing are relatively time consuming. The following points apply to interrupt processing:
   - Do only what absolutely requires interrupt context.
   - Do any additional processing that could save another interrupt, for example, read the next data from the device.

4. Return `DDI_INTR_CLAIMED`.

Code Example 6-2 shows an interrupt routine.

Code Example 6-2 Interrupt Routine

```
static u_int
xxintr(caddr_t arg)
{
    struct xxstate *xsp = (struct xxstate *)arg;
    uint8_t status, temp;

    /*
     * Claim or reject the interrupt.This example assumes
     * that the device's CSR includes this information.
     */
    mutex_enter(&xsp->high_mu);
    /* use data access routines to read status */
    status = ddi_get8(xsp->data_access_handle, &xsp->regp->csr);
    if (!(status & INTERRUPTING)) {
        mutex_exit(&xsp->high_mu);
        return (DDI_INTR_UNCLAIMED); /* dev not interrupting */
    }
    /*
     * Inform the device that it is being serviced, and re-enable
     * interrupts. The example assumes that writing to the
     * CSR accomplishes this. The driver must ensure that this data
     * access operation makes it to the device before the interrupt
     * service routine returns. For example, using the data access
     * functions to read the CSR, if it does not result in unwanted
     * effects, can ensure this.
     */
    ddi_put8(xsp->data_access_handle, &xsp->regp->csr,
           CLEAR_INTERRUPT | ENABLE_INTERRUPTS);
    temp = ddi_get8(xsp->data_access_handle, &xsp->regp->csr);
    perform any I/O related and synchronization processing
    signal waiting threads (biodone(9F) or cv_signal(9F)
    mutex_exit(&xsp->mu);
    return (DDI_INTR_CLAIMED);
}
```

When the system detects an interrupt on a bus architecture that does not support vectored hardware, it calls the driver interrupt handler function for each device that could have issued the interrupt. The interrupt handler must determine whether the device it handles issued an interrupt.

On architectures supporting vectored interrupts, this step is unnecessary, but not harmful, and it enhances portability. The syntax and semantics of the interrupt-handling routine therefore can be the same for both vectored interrupts and polling interrupts.

In the example presented here, the argument passed to *xx*`intr()` is a pointer to the state structure for the device that may have issued the interrupt. This was set up by passing a pointer to the state structure as the *intr_handler_arg* argument to `ddi_add_intr`(9F) in `attach`(9E).

Most of the steps performed by the interrupt routine depend on the specifics of the device itself. Consult the hardware manual for the device to determine the cause of the interrupt, detect error conditions, and access the device data registers.

State Structure

This section adds the following fields to the state structure. See “Software State Structure” on page 63 for more information.

```
    ddi_iblock_cookie_t    high_iblock_cookie;
    ddi_idevice_cookie_t   high_idevice_cookie;
    kmutex_t               high_mu;
    int                    softint_running;
```

```
ddi_iblock_cookie_t    low_iblock_cookie;
kmutex_t               low_mu;
ddi_softintr_t         id;
```

Handling High-Level Interrupts

High-level interrupts are those that interrupt at the level of the scheduler and above. This level does not allow the scheduler to run; therefore, high-level interrupt handlers cannot be preempted by the scheduler, nor can they rely on the scheduler (cannot block)—they can only use mutual exclusion locks for locking.

Because of this, the driver must use `ddi_intr_hilevel`(9F) to determine if it uses high-level interrupts. If `ddi_intr_hilevel`(9F) returns true, the driver can fail to attach, or it can use a two-level scheme to handle interrupts. Properly handling high-level interrupts is the preferred solution.

Note – By writing the driver as if it always uses high-level interrupts, a separate case can be avoided. However, this does result in an extra (software) interrupt for each hardware interrupt.

The suggested method is to add a high-level interrupt handler, which simply triggers a lower-priority software interrupt to handle the device. The driver should allow more concurrency by using a separate mutex for protecting data from the high-level handler.

High-level Mutexes

A mutex initialized with the interrupt block cookie that represents a high-level interrupt is known as a *high-level mutex*. While holding a high-level mutex, the driver is subject to the same restrictions as a high-level interrupt handler. The only routines it can call are:

- `mutex_exit`(9F) to release the high-level mutex
- `ddi_trigger_softintr`(9F) to trigger a soft interrupt

High-Level Interrupt Handling Example

In the example presented Code Example 6-3, the high-level mutex (`xsp->high_mu`) is used only to protect data shared between the high-level interrupt handler and the soft interrupt handler. This includes a queue that the high-level interrupt handler appends data to (and the low-level handler removes data from), and a flag that indicates the low-level handler is running. A separate low-level mutex (`xsp->low_mu`) protects the rest of the driver from the soft interrupt handler.

Code Example 6-3 `attach`(9E) Routine Handling High-Level Interrupts

```
static int
xxattach(dev_info_t *dip, ddi_attach_cmd_t cmd)
{
    struct xxstate *xsp;
    ...
    if (ddi_intr_hilevel(dip, inumber)) {
        ddi_get_iblock_cookie(dip, inumber,
            &xsp->high_iblock_cookie);
        mutex_init(&xsp->high_mu, "xx high mutex", MUTEX_DRIVER,
            (void *)xsp->high_iblock_cookie);
        if (ddi_add_intr(dip, inumber, &xsp->high_iblock_cookie,
            &xsp->high_idevice_cookie, xxhighintr, (caddr_t)xsp)
            != DDI_SUCCESS)
            goto failed;
        ddi_get_soft_iblock_cookie(dip, DDI_SOFTINT_HI,
            &xsp->low_iblock_cookie);
        mutex_init(&xsp->low_mu, "xx low mutex", MUTEX_DRIVER,
            (void *)xsp->low_iblock_cookie);
        if (ddi_add_softintr(dip, DDI_SOFTINT_HI, &xsp->id,
            &xsp->low_iblock_cookie, NULL,
            xxlowintr, (caddr_t)xsp) != DDI_SUCCESS)
            goto failed;
    } else {
        add normal interrupt handler
    }
    cv_init(&xsp->cv, "xx condvar", CV_DRIVER, NULL);
    ...
    return (DDI_SUCCESS);
failed:
    free allocated resources, remove interrupt handlers
    return (DDI_FAILURE);
}
```

The high-level interrupt routine services the device, and enqueues the data. The high-level routine triggers a software interrupt if the low-level routine is not running, as Code Example 6-4 demonstrates.

Code Example 6-4 High-level Interrupt Routine

```
static u_int
xxhighintr(caddr_t arg)
{
    struct xxstate *xsp = (struct xxstate *)arg;
    uint8_t status, temp;
    int     need_softint;

    mutex_enter(&xsp->high_mu);
    /* read status */
    status = ddi_get8(xsp->data_access_handle, &xsp->regp->csr);
    if (!(status & INTERRUPTING)) {
        mutex_exit(&xsp->high_mu);
        return (DDI_INTR_UNCLAIMED); /* dev not interrupting */
    }

    ddi_put8(xsp->data_access_handle,&xsp->regp->csr,
        CLEAR_INTERRUPT | ENABLE_INTERRUPTS);
    temp = ddi_get8(xsp->data_access_handle, &xsp->regp->csr);
    read data from device and queue the data for the low-level interrupt handler;
    if (xsp->softint_running)
        need_softint = 0;
    else
        need_softint = 1;
    mutex_exit(&xsp->high_mutex);
    /* read-only access to xsp->id, no mutex needed */
    if (need_softint)
        ddi_trigger_softintr(xsp->id);
    return (DDI_INTR_CLAIMED);
}
```

The low-level interrupt routine is started by the high-level interrupt routine triggering a software interrupt. Once running, it should continue to do so until there is nothing left to process, as Code Example 6-5 shows.

Code Example 6-5 Low-level Interrupt Routine

```
static u_int
xxlowintr(caddr_t arg)
{
    struct xxstate *xsp = (struct xxstate *)arg;
    ....
    mutex_enter(&xsp->low_mu);
    mutex_enter(&xsp->high_mu);
    if (queue empty || xsp->softint_running) {
        mutex_exit(&xsp->high_mu);
        mutex_exit(&xsp->low_mu);
        return (DDI_INTR_UNCLAIMED);
    }
    xsp->softint_running = 1;
    while (data on queue) {
        ASSERT(mutex_owned(&xsp->high_mu);
        dequeue data from high-level queue;
        mutex_exit(&xsp->high_mu);
        normal interrupt processing
        mutex_enter(&xsp->high_mu);
    }
    xsp->softint_running = 0;
    mutex_exit(&xsp->high_mu);
    mutex_exit(&xsp->low_mu);
    return (DDI_INTR_CLAIMED);
}
```

DMA 7

Many devices can temporarily take control of the bus and perform data transfers to (and from) main memory or other devices. Since the device is doing the work without the help of the CPU, this type of data transfer is known as a *direct memory access* (DMA). DMA transfers can be performed between two devices, between a device and memory, or between memory and memory. This chapter covers transfers between a device and memory only.

DMA Model

The Solaris 2.x device driver interface/driver-kernel interface provides a high-level, architecture-independent model for DMA. This allows the framework (the DMA routines) to hide such architecture-specific details as:

- Setting up DMA mappings
- Building scatter-gather lists
- Ensuring I/O and CPU caches are consistent

There are several abstractions that are used in the DDI/DKI to describe aspects of a DMA transaction. These include:

- *DMA object* – Memory that is the source or destination of a DMA transfer.
- *DMA handle* – An opaque object returned from a successful `ddi_dma_alloc_handle(9F)`call. The DMA handle is used in successive DMA subroutine calls to refer to the DMA object.

- *DMA cookie* – A `ddi_dma_cookie`(9S) structure (`ddi_dma_cookie_t`) describes a contiguous portion of a DMA object that is entirely addressable by the device. It contains DMA addressing information required to program the DMA engine.

Rather than knowing that a platform needs to map an *object* (typically a memory buffer) into a special DMA area of the kernel address space, device drivers instead allocate DMA *resources* for the object. The DMA routines then perform any platform-specific operations needed to set the object up for DMA access. The driver receives a DMA *handle* to identify the DMA resources allocated for the object. This handle is opaque to the device driver; the driver must save the handle and pass it in subsequent calls to DMA routines, but should not interpret it in any way.

Operations are defined on a DMA handle that provide the following services:

- Manipulating DMA resources
- Synchronizing DMA objects
- Retrieving attributes of the allocated resources

Types of Device DMA

Devices may perform one of the following three types of DMA.

Bus-Master DMA

If the device is capable of acting as a true *bus master* (where the DMA engine resides on the device board), the driver should program the device's DMA registers directly. The transfer address and count are obtained from the DMA cookie and given to the device.

Devices on current SPARC platforms use this form of DMA exclusively.

Third-party DMA

Third-party DMA utilizes a system DMA engine resident on the main system board, which has several DMA channels available for use by devices. The device relies on the system's DMA engine to perform the data transfers between the device and memory. The driver uses DMA engine routines (see `ddi_dmae`(9F)) to initialize and program the DMA engine. For each DMA data transfer, the driver programs the DMA engine and then gives the device a command to initiate the transfer in cooperation with that engine.

First-party DMA

Under first-party DMA, the device drives its own DMA bus cycles using a channel from the system's DMA engine. The `ddi_dmae_1stparty`(9F) function is used to configure this channel in a cascade mode so that the DMA engine will not interfere with the transfer.

DMA and DVMA

The platform that the device operates on may provide one of two types of memory access: direct memory access (DMA) or direct virtual memory access (DVMA).

On platforms that support DMA, the system provides the device with a physical address in order to perform transfers. In this case, one logical transfer may actually consist of a number of physically discontiguous transfers. An example of this occurs when an application transfers a buffer that spans several contiguous virtual pages that map to physically discontiguous pages. To deal with the discontiguous memory, devices for these platforms usually have some kind of scatter-gather DMA capability. Typically, x86 systems provide physical addresses for direct memory transfers.

On platforms that support DVMA, the system provides the device with a virtual address to perform transfers. In this case, the underlying platform provides some form of memory management unit (MMU) that translates device accesses to these virtual addresses into the proper physical addresses. The device transfers to and from a contiguous virtual image that may be mapped to discontiguous physical pages. Devices that operate in these platforms don't need scatter-gather DMA capability. Typically, the system that supports SPARC platforms provides virtual addresses for direct memory transfers.

Handles, Windows, and Cookies

A DMA *handle* is an opaque pointer representing an object (usually a memory buffer or address) where a device can perform DMA transfers. Several different calls to DMA routines use the handle to identify the DMA resources allocated for the object.

An object represented by a DMA handle is completely covered by one or more *DMA cookies*. A DMA cookie represents a contiguous piece of memory to or from which the DMA engine can transfer data.The system uses the information in the DMA attribute structure, and the memory location and alignment of the target object, to decide how to divide an object into multiple cookies.

If the object is too big to fit the request within system resource limitations, it has to be broken up into multiple *DMA windows*. Only one window is activated at one time and has resources allocated. The `ddi_dma_getwin`(9F) function is used to position between windows within an object. Each DMA window consists of one or more DMA cookies.

Scatter-Gather

Some DMA engines may be able to accept more than one cookie. Such engines can perform scatter-gather I/O without the help of the system. In this case, it is most efficient if the driver uses `ddi_dma_nextcookie`(9F) to get as many cookies as the DMA engine can handle and program them all into the engine. The device can then be programmed to transfer the total number of bytes covered by all these DMA cookies combined.

DMA Operations

The steps involved in a DMA transfer are similar among the types of DMA.

Bus-Master DMA

In general, the following steps must be performed for bus-master DMA.

1. Describe the DMA attributes. This allows the routines to ensure that the device will be able to access the buffer.
2. Allocate a DMA handle.

3. Lock the DMA object in memory (see `physio`(9F)).

> **Note –** This step is not necessary in block drivers for buffers coming from the file system, as the file system has already locked the data in memory.

4. Allocate DMA resources for the object.
5. Program the DMA engine on the device and start it (this is device specific).

   When the transfer is complete, continue the bus master operation.
6. Perform any required object synchronizations.
7. Release the DMA resources.
8. Free the DMA handle.

First-Party DMA

In general, the following steps must be performed for first-party DMA.

1. Allocate a DMA channel.
2. Configure the channel with `ddi_dmae_1stparty`(9F).
3. Lock the DMA object in memory (see `physio`(9F)).

> **Note –** This step is not necessary in block drivers for buffers coming from the file system, as the file system has already locked the data in memory.

4. Allocate DMA resources for the object.
5. Program the DMA engine on the device and start it (this is device specific).

   When the transfer is complete, continue the bus-master operation.
6. Perform any required object synchronizations.
7. Release the DMA resources.
8. Deallocate the DMA channel.
9. Free the DMA handle.

Third-Party DMA

In general, the following steps must be performed for third-party DMA.

1. Allocate a DMA channel.
2. Retrieve the system's DMA engine attributes with `ddi_dmae_getattr`(9F).
3. Lock the DMA object in memory (see `physio`(9F)).

Note – This step is not necessary in block drivers for buffers coming from the file system, as the file system has already locked the data in memory.

4. Allocate DMA resources for the object.
5. Program the system DMA engine to perform the transfer with `ddi_dmae_prog`(9F).
6. Perform any required object synchronizations.
7. Stop the DMA engine with `ddi_dmae_stop`(9F).
8. Release the DMA resources.
9. Deallocate the DMA channel.
10. Free the DMA handle.

Certain hardware platforms may restrict DMA capabilities in a bus-specific way. Drivers should use `ddi_slaveonly`(9F) to determine if the device is in a slot in which DMA is possible. For an example, see "attach( )" on page 101.

DMA Attributes

DMA attributes describe the built-in attributes and limits of a DMA engine, including:

- Limits on addresses the device can access
- Maximum transfer count
- Address alignment restrictions

To ensure that DMA resources allocated by the system can be accessed by the device's DMA engine, device drivers must inform the system of their DMA engine limitations using a `ddi_dma_attr`(9S) structure. The system may impose additional restrictions on the device attributes, but it never removes any of the driver-supplied restrictions.

ddi_dma_attr(9S)

The DMA attribute structure has the following members:

```
uint_t         dma_attr_version;/*  version number of this structure */
uint64_t       dma_attr_addr_lo;/*  lower bound of bus address range */
uint64_t       dma_attr_addr_hi;/*  inclusive upper bound of range */
uint64_t       dma_attr_count_max;/*  max DMA transfer count - 1  */
uint64_t       dma_attr_align;/*  DMA address aligment */
uint_t         dma_attr_burstsizes;/*  DMA burstsize */
uint32_t       dma_attr_minxfer;/*  minimum DMA transfer size  */
uint64_t       dma_attr_maxxfer;/*  max transfer sizeof a single I/O  */
uint64_t       dma_attr_seg;/*  segment boundary restriction */
int            dma_attr_sgllen;/* length of DMA scatter-gather list *
uint32_t       dma_attr_granular;/*  granularity of transfer count */
uint_t         dma_attr_flags;/*  additional DMA flags */
```

`dma_attr_addr_lo` is the lowest bus address that the DMA engine can access.

`dma_attr_addr_hi` is the highest bus address that the DMA engine can access.

`dma_attr_count_max` specifies the maximum transfer count that the DMA engine can handle in one cookie. The limit is expressed as the maximum count minus one. It is used as a bit mask, so it must also be one less than a power of two.

`dma_attr_align` specifies additional alignment requirements for any allocated DMA resources. This field can be used to force more restrictive alignment than implicitly specified by other DMA attributes such as alignment on a page boundary.

`dam_attr_burstsizes` specifies the *burst sizes* that the device supports. A burst size is the amount of data the device can transfer before relinquishing the bus. This member is a binary encoding of burst sizes, assumed to be powers of two. For example, if the device is capable of doing 1-, 2-, 4-, and 16-byte bursts, this field should be set to 0x17. The system also uses this field to determine alignment restrictions.

`dma_attr_minxfer` is the minimum effective transfer size the device can perform. It also influences alignment and padding restrictions.

`dma_attr_maxxfer` describes the maximum number of bytes that the DMA engine can transmit or receive in one I/O command. This limitation is only significant if it is less than (`dma_attr_count_max + 1`) * `dma_attr_seg`. If the DMA engine has no particular limitation, this field should be set to `0xFFFFFFFF`.

`dma_attr_seg` is the upper bound of the DMA engine's address register. This is often used where the upper 8 bits of an address register are a latch containing a segment number, and the lower 24 bits are used to address a segment. In this case, `dma_attr_seg` would be set to `0xFFFFFF`, and prevents the system from crossing a 24-bit segment boundary when allocating resources for the object.

`dma_attr_sgllen` specifies the maximum number of entries in the scatter-gather list. It is the number of segments or cookies that the DMA engine can consume in one I/O request to the device. If the DMA engine has no scatter-gather list, this field should be set to one.

`dma_attr_granular` field describes the granularity of the device's DMA transfer ability, in units of bytes. This value is used to specify, for example, the sector size of a mass storage device. DMA requests will be broken into multiples of this value. If there is no scatter-gather capability, then the size of each DMA transfer will be a multiple of this value. If there is scatter-gather capability, then a single segment will not be smaller than the minimum transfer value, but may be less than the granularity; however the total transfer length of the scatter-gather list will be a multiple of the granularity value.

`dma_attr_flags` is reserved for future use. It must be set to 0.

SBus—Example One

A DMA engine on an SBus in a SPARC machine has the following attributes:

- It can only access addresses ranging from `0xFF000000` to `0xFFFFFFFF`.
- It has a 32-bit DMA counter register.
- It can handle byte-aligned transfers.

- It supports 1-, 2- and 4-byte burst sizes.
- It has a minimum effective transfer size of 1 byte.
- It has a 32-bit address register.
- It doesn’t have a scatter-gather list.
- The device operates on sectors only (for example a disk).

The resulting attribute structure is:

```
static ddi_dma_attr_t attributes = {
    DMA_ATTR_V0,   /* Version number */
    0xFF000000,    /* low address */
    0xFFFFFFFF,    /* high address */
    0xFFFFFFFF,    /* counter register max */
    1,             /* byte alignment */
    0x7,           /* burst sizes: 0x1 | 0x2 | 0x4 */
    0x1,           /* minimum transfer size */
    0xFFFFFFFF,    /* max xfer size */
    0xFFFFFFFF,    /* address register max */
    1,             /* no scatter-gather */
    512,           /* device operates on sectors */
    0,             /* attr flag: set to 0 */
};
```

VMEbus—Example Two

A DMA engine on a VMEbus in a SPARC machine has the following attributes:

- It can address the full 32-bit range.
- It has a 32-bit DMA counter register.
- It can handle byte-aligned transfers.
- It supports 2- to 256-byte burst sizes, and all powers of 2 in between.
- It has a minimum effective transfer size of 2 bytes.
- It has a 24-bit address register.
- It has a 17-element scatter-gather list.
- The device operates on sectors only.

The resulting attribute structure is:

```
static ddi_dma_attr_t attributes = {
    DMA_ATTR_V0,   /* Version number */
    0x00000000,    /* low address */
    0xFFFFFFFF,    /* high address */
    0xFFFFFFFF,    /* counter register max */
    1,             /* byte alignment */
    0x1FE,         /* burst sizes */
```

```
        0x2,            /* minimum transfer size */
        0xFFFFFFFF,     /* max xfer size */
        0xFFFFFF,       /* address register max */
        17,             /* no scatter-gather */
        512,            /* device operates on sectors */
        0,              /* attr flag: set to 0 */
    };
```

ISAbus—Example Three

A DMA engine on an ISA bus in an x86 machine has the following attributes:

- It accesses only the first 16 megabytes of memory.
- It performs transfers to segments up to 32 Kbytes in size.
- It has a 16-bit counter register.
- It can handle byte-aligned transfers.
- It supports 1-, 2- and 4-byte burst sizes.
- It has a minimum effective transfer size of 1 byte.
- It can hold up to 17 scatter-gather transfers.

The resulting attribute structure is:

```
    static ddi_dma_attr_t attributes = {
        DMA_ATTR_V0,    /* Version number */
        0x00000000,     /* low address */
        0x00FFFFFF,     /* high address */
        0xFFFF,         /* counter register max */
        1,              /* byte alignment */
        0x7,            /* burst sizes */
        0x1,            /* minimum transfer size */
        0xFFFFFFFF,     /* max xfer size */
        0x00007FFF,     /* address register max */
        17,             /* no scatter-gather */
        512,            /* device operates on sectors */
        0,              /* attr flag: set to 0 */
    };
```

Object Locking

Before allocating the DMA resources for a memory object, the object must be prevented from moving. If it is not, the system may remove the object from memory while the device is writing to it, causing the data transfer to fail and possibly corrupting the system. The process of preventing memory objects from moving during a DMA transfer is known as *locking down the object*.

Note – Locking objects in memory is not related to the type of locking used to protect data.

The following object types do not require explicit locking:

- Buffers coming from the file system through `strategy`(9E). These buffers are already locked by the file system.
- Kernel memory allocated within the device driver, such as that allocated by `ddi_dma_mem_alloc`(9F).

For other objects (such as buffers from user space), `physio`(9F) must be used to lock down the objects. This is usually performed in the `read`(9E) or `write`(9E) routines of a character device driver. See "Data Transfer Methods" on page 187 for an example.

Allocating a DMA Handle

A DMA handle is an opaque object that is used as a reference to subsequently allocated DMA resources. It is usually allocated in the driver's attach entry point using `ddi_dma_alloc_handle`(9F). `ddi_dma_alloc_handle`(9F) takes the device information referred to by dip and the device's DMA attributes described by a `ddi_dma_attr`(9S) structure as parameters.

```
int ddi_dma_alloc_handle(dev_info_t *dip, ddi_dma_attr_t *attr,
    int (*callback)(void *), void *arg,
    ddi_dma_handle_t *handlep);
```

`dip` is a pointer to the device's `dev_info` structure.

`attr` is a pointer to a `ddi_dma_attr`(9S) structure as described in "DMA Attributes" on page 132.

`waitfp` is the address of callback function for handling resource allocation failures.

`arg` is the argument to pass to the callback function.

`handlep` is a pointer to DMA handle (to store the returned handle).

Handling Resource Allocation Failures

The resource-allocation routines provide the driver several options when handling allocation failures. The `waitfp` argument indicates whether the allocation routines will block, return immediately, or schedule a callback.

waitfp	**Indicated Action**
`DDI_DMA_DONTWAIT`	Driver does not need to wait for resources to become available.
`DDI_DMA_SLEEP`	Driver is willing to wait indefinitely for resources to become available.
Other values	The address of a function to be called when resources are likely to be available.

Allocating DMA Resources

Two interfaces allocate DMA resources:

- `ddi_dma_buf_bind_handle`(9F) – Used with buffer structures.
- `ddi_dma_addr_bind_handle`(9F) – Used with virtual addresses.

Table 7-1 lists the appropriate DMA resource allocation interfaces for different classes of DMA objects.

Table 7-1 DMA Resource Allocation Interfaces

Type of Object	**Resource Allocation Interface**
Memory allocated within the driver using `ddi_dma_mem_alloc`(9F)	`ddi_dma_addr_bind_handle(9F)`
Requests from the file system through `strategy`(9E)	`ddi_dma_buf_bind_handle(9F)`
Memory in user space that has been locked down using `physio`(9F)	`ddi_dma_buf_bind_handle(9F)`

DMA resources are usually allocated in the driver's `xxstart()` routine, if one exists. See "Asynchronous Data Transfers" on page 220 for discussion of `xxstart()`.

```
int ddi_dma_addr_bind_handle(ddi_dma_handle_t handle,
    struct as *as, caddr_t addr,
    size_t len, uint_t flags, int (*waitfp)(caddr_t),
    caddr_t arg, ddi_dma_cookie_t *cookiep, uint_t *ccountp);
int ddi_dma_buf_bind_handle(ddi_dma_handle_t handle,
    struct buf *bp, uint_t flags,
    int (*waitfp)(caddr_t), caddr_t arg,
    ddi_dma_cookie_t *cookiep, uint_t *ccountp);
```

`ddi_dma_addr_bind_handle`(9F) and `ddi_dma_buf_bind_handle`(9F) take the following arguments:

`handle` is a DMA handle.

The object to allocate resources for.

- For `ddi_dma_addr_bind_handle`(9F), the object is described by an address range, where `as` is a pointer to an address space structure (this must be `NULL`), `addr` is the base kernel address of the object, and `len` is the length of the object in bytes.
- For `ddi_dma_buf_bind_handle`(9F), the object is described by a `buf`(9S) structure pointer to by `bp`.

`flags` is a set of flags indicating the transfer direction and other attributes. `DDI_DMA_READ` indicates a data transfer from device to memory. `DDI_DMA_WRITE` indicates a data transfer from memory to device. See `ddi_dma_addr_bind_handle`(9F) or `ddi_dma_buf_bind_handle`(9F) for a complete discussion of the allowed flags.

`waitfp` is the address of callback function for handling resource allocation failures. See `ddi_dma_alloc_handle`(9F).

`arg` is the argument to pass to the callback function.

`cookiep` is a pointer to the first DMA cookie for this object.

`ccountp` is a pointer to the number of DMA cookies for this object.

State Structure

This section adds the following fields to the state structure. See "Software State Structure" on page 63 for more information.

```
struct buf         *bp;       /* current transfer */
ddi_dma_handle_t   handle;
struct xxiopb      *iopb_array;/* for I/O Parameter Blocks */
ddi_dma_handle_t   iopb_handle;
```

Device Register Structure

Devices that do DMA have more registers than have been used in previous examples. This section adds the following fields to the device register structure to support DMA-capable device examples.

For DMA engines without scatter-gather support:

```
uint32_t       dma_addr;  /* starting address for DMA */
uint32_t       dma_size;  /* amount of data to transfer */
```

For DMA engines with scatter-gather support:

```
struct sglentry {
    uint32_t       dma_addr;
    uint32_t       dma_size;
} sglist[SGLLEN];
caddr_t  iopb_addr;/* When written informs device of the next */
                   /* command's parameter block address. */
                   /* When read after an interrupt,contains */
                   /* the address of the completed command. */
```

DMA Callback Example

In Code Example 7-1 on page 141, `xxstart()` is used as the callback function and the per-device state structure is given as its argument. `xxstart()` attempts to start the command. If the command cannot be started because resources are not available, `xxstart()` is scheduled to be called sometime later, when resources might be available.

Because `xxstart()` is used as a DMA callback, it must follow these rules imposed on DMA callbacks:

- It must not assume that resources are available (it must try to allocate them again).

- It must indicate to the system whether allocation succeed by returning `DDI_DMA_CALLBACK_RUNOUT` if it fails to allocate resources (and needs to be called again later) or `DDI_DMA_CALLBACK_DONE` indicating success (so no further callback is necessary).

Code Example 7-1 Allocating DMA Resources

```
static int
xxstart(caddr_t arg)
{
    struct xxstate *xsp = (struct xxstate *)arg;
    struct device_reg *regp;
    int flags;

    mutex_enter(&xsp->mu);
    if (xsp->busy) {
        /* transfer in progress */
        mutex_exit(&xsp->mu);
        return (0);
    }
    xsp->busy = 1;
    mutex_exit(&xsp->mu);
    regp = xsp->regp;
    if (transfer is a read) {
        flags = DDI_DMA_READ;
    } else {
        flags = DDI_DMA_WRITE;
    }

    if (ddi_dma_buf_bind_handle(xsp->handle,xsp->bp,flags, xxstart,
        (caddr_t)xsp, &cookie, &ccount) != DDI_DMA_MAPPED) {
        /* really should check all return values in a switch */
        return (DDI_DMA_CALLBACK_RUNOUT);
    }
    ...
    program the DMA engine
    ...
    return (DDI_DMA_CALLBACK_DONE);
}
```

Burst Sizes

Drivers specify the DMA burst sizes their device supports in the `dma_attr_burstsizes` field of the `ddi_dma_attr`(9S) structure. This is a bitmap of the supported burst sizes. However, when DMA resources are allocated, the system might impose further restrictions on the burst sizes that may actually be used by the device. The `ddi_dma_burstsizes`(9F) routine can be used to obtain the allowed burst sizes. It returns the appropriate burst size bitmap for the device. When DMA resources are allocated, a driver can ask the system for appropriate burst sizes to use for its DMA engine.

```
#define BEST_BURST_SIZE 0x20 /* 32 bytes */

if (ddi_dma_buf_bind_handle(xsp->handle,xsp->bp,flags, xxstart,
    (caddr_t)xsp, &cookie, &ccount) != DDI_DMA_MAPPED) {
        /* error handling */
        return (0);
}
burst = ddi_dma_burstsizes(xsp->handle);
/* check which bit is set and choose one burstsize to */
/* program the DMA engine */
if (burst & BEST_BURST_SIZE) {
    program DMA engine to use this burst size
} else {
    other cases
}
```

Programming the DMA Engine

When the resources have been successfully allocated, the device must be programmed. Although programming a DMA engine is device specific, all DMA engines require a starting address and a transfer count. Device drivers retrieve these two values from the *DMA cookie* returned by a successful call from `ddi_dma_addr_bind_handle`(9F), `ddi_dma_buf_bind_handle`(9F), or `ddi_dma_getwin`(9F). The latter functions all return the first DMA cookie and a cookie count indicating whether the DMA object consists of more than one cookie. If the cookie count N is greater than 1, `ddi_dma_nextcookie`(9F) has to be called N-1 times to retrieve all the remaining cookies.

A cookie is of type `ddi_dma_cookie`(9S) and has the following fields:

```
uint64_t       dmac_laddress; /* unsigned 64-bit address */
uint32_t       dmac_address;  /* unsigned 32-bit address */
size_t         dmac_size;     /* transfer size */
u_int          dmac_type;     /* bus-specific type bits */
```

The `dmac_laddress` specifies a 64-bit I/O address appropriate for programming the device's DMA engine. If a device has a 64- bit DMA address register a driver should use this field to program the DMA engine. The dmac_laddress field specifies a 32-bit I/O address. It should be used for devices which have a 32-bit DMA address register. dmac_size contains the transfer count. Depending on the bus architecture, the third field in the cookie may be required by the driver. The driver should not perform any manipulations, such as logical or arithmetic, on the cookie.

For example:

```
ddi_dma_cookie_t   cookie;

if (ddi_dma_buf_bind_handle(xsp->handle,xsp->bp,flags, xxstart,
    (caddr_t)xsp, &cookie, &xsp->ccount) != DDI_DMA_MAPPED) {
        /* error handling */
        return (0);
}
sglp = regp->sglist;
for (cnt = 1; cnt <= SGLLEN; cnt++, sglp++) {
    /* store the cookie parms into the S/G list */
    ddi_put32(xsp->access_hdl, &sglp->dma_size,
        (uint32_t)cookie.dmac_size);
    ddi_put32(xsp->access_hdl, &sglp->dma_addr,
        cookie.dmac_address);
    /* Check for end of cookie list */
    if (cnt == xsp->ccount)
        break;
    /* Get next DMA cookie */
    (void) ddi_dma_nextcookie(xsp->handle, &cookie);
}
    /* start DMA transfer */
ddi_put8(xsp->access_hdl, &regp->csr,
    ENABLE_INTERRUPTS | START_TRANSFER);
```

Note – ddi_dma_buf_bind_handle(9F) may return more DMA cookies than fit into the scatter-gather list. In this case, the driver has to continue the transfer in the interrupt routine and reprogram the scatter-gather list with the remaining DMA cookies.

Freeing the DMA Resources

After a DMA transfer is completed (usually in the interrupt routine), the DMA resources may be released by calling ddi_dma_unbind_handle(9F).

As described in “Synchronizing Memory Objects” on page 147, `ddi_dma_unbind_handle`(9F) calls `ddi_dma_sync`(9F), eliminating the need for any explicit synchronization. After calling `ddi_dma_unbind_handle`(9F), the DMA resources become invalid, and further references to them have undefined results. Code Example 7-2 on page 144 shows how to use `ddi_dma_unbind_handle`(9F).

Code Example 7-2 Freeing DMA Resources

```
static u_int
xxintr(caddr_t arg)
{
    struct xxstate *xsp = (struct xxstate *)arg;
    uint8_t status, temp;

    mutex_enter(&xsp->mu);
    /* read status */
    status = ddi_get8(xsp->access_hdl, &xsp->regp->csr);

    if (!(status & INTERRUPTING)) {
        mutex_exit(&xsp->mu);
        return (DDI_INTR_UNCLAIMED);
    }
    ddi_put8(xsp->access_hdl, &xsp->regp->csr, CLEAR_INTERRUPT);

    /* for store buffers */
    temp = ddi_get8(xsp->access_hdl, &xsp->regp->csr);

    ddi_dma_unbind_handle(xsp->handle);
    ...
    check for errors
    ...
    xsp->busy = 0;
    mutex_exit(&xsp->mu);

    if (pending transfers) {
        (void) xxstart((caddr_t)xsp);
    }
    return (DDI_INTR_CLAIMED);
}
```

The DMA resources should be released and reallocated if a different object will be used in the next transfer. However, if the same object is always used, the resources may be allocated once and continually reused as long as there are intervening calls to `ddi_dma_sync`(9F).

Freeing the DMA Handle

When the driver is unloaded, the DMA handle must be freed. `ddi_dma_free_handle`(9F) destroys the DMA handle and any residual resources the system may be caching on the handle. Any further references of the DMA handle will have undefined results. In `ddi_dma_free_handle`(9F), `handlep` is a pointer to the DMA handle.

```
void ddi_dma_free_handle(ddi_dma_handle_t *handlep);
```

Canceling DMA Callbacks

DMA callbacks cannot be cancelled. This requires some additional code in the drivers `detach`(9E) routine, as it must not return `DDI_SUCCESS` if there are any outstanding callbacks. (See Code Example 7-3.) When DMA callbacks occur, the `detach`(9E) routine must wait for the callback to run and must prevent it from rescheduling itself. This can be done using additional fields in the state structure:

```
int        cancel_callbacks;  /* detach(9E) sets this to */
                              /* prevent callbacks from */
                              /* rescheduling themselves */
int        callback_count;    /* number of outstanding
                              /* callbacks */
kmutex_t   callback_mutex;    /* protects callback_count and */
                              /* cancel_callbacks. */
kcondvar_t callback_cv;       /* condition is that
                              /* callback_count is zero*/
                              /* detach(9E) waits on it */
```

Code Example 7-3 Canceling DMA Callbacks

```
static int
xxdetach(dev_info_t *dip, ddi_detach_cmd_t cmd)
{
    ...
    mutex_enter(&xsp->callback_mutex);
    xsp->cancel_callbacks = 1;
    while (xsp->callback_count > 0) {
        cv_wait(&xsp->callback_cv, &xsp->callback_mutex);
    }
    mutex_exit(&xsp->callback_mutex);
    ...
}
```

```
static int
xxstrategy(struct buf *bp)
{
    ...
    mutex_enter(&xsp->callback_mutex);
    xsp->bp = bp;
    error = ddi_dma_buf_bind_handle(xsp->handle, xsp->bp, flags,
                xxdmacallback, (caddr_t)xsp, &cookie, &ccount);
    if (error == DDI_DMA_NORESOURCES)
        xsp->callback_count++;
    mutex_exit(&xsp->callback_mutex);
    ...
}
static int
xxdmacallback(caddr_t callbackarg)
{
    struct xxstate *xsp = (struct xxstate *)callbackarg;
    ...
    mutex_enter(&xsp->callback_mutex);
    if (xsp->cancel_callbacks) {
        /* do not reschedule, in process of detaching */
        xsp->callback_count--;
        if (xsp->callback_count == 0)
            cv_signal(&xsp->callback_cv);
        mutex_exit(&xsp->callback_mutex);
        return (DDI_DMA_CALLBACK_DONE);/* don't reschedule it */
    }
    /*
     * Presumably at this point the device is still active
     * and will not be detached until the DMA has completed.
     * A return of 0 means try again later
     */
    error = ddi_dma_buf_bind_handle(xsp->handle, xsp->bp, flags,
                DDI_DMA_DONTWAIT, NULL, &cookie, &ccount);
    if (error == DDI_DMA_MAPPED) {
        ...
        program the DMA engine
        ...
        xsp->callback_count--;
        mutex_exit(&xsp->callback_mutex);
        return (DDI_DMA_CALLBACK_DONE);
    }
    if (error != DDI_DMA_NORESOURCES) {
        xsp->callback_count--;
```

```
            mutex_exit(&xsp->callback_mutex);
            return (DDI_DMA_CALLBACK_DONE);
        }
        mutex_exit(&xsp->callback_mutex);
        return (DDI_DMA_CALLBACK_RUNOUT);
}
```

Synchronizing Memory Objects

At various points when the memory object is accessed (including the time of removal of the DMA resources), the driver may need to synchronize the memory object with respect to various caches. This section gives guidelines on when and how to synchronize memory objects.

Cache

Cache is a very high-speed memory that sits between the CPU and the system's main memory (CPU cache), or between a device and the system's main memory (I/O cache), as shown in Figure 7-1.

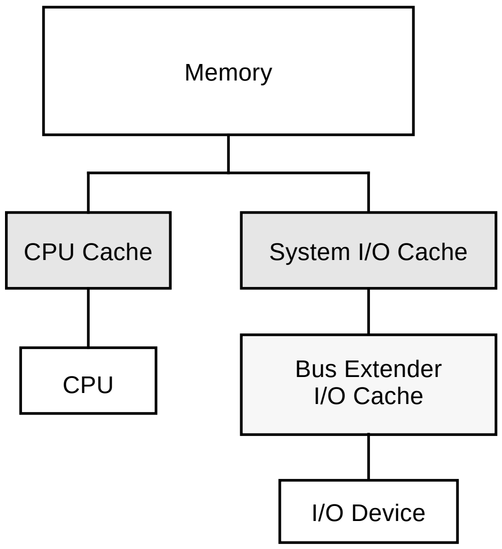


Figure 7-1 CPU and System I/O Caches

When an attempt is made to read data from main memory, the associated cache first determines whether it contains the requested data. If so, it quickly satisfies the request. If the cache does not have the data, it retrieves the data from main memory, passes the data on to the requestor, and saves the data in case that data is requested again.

Similarly, on a write cycle, the data is stored in the cache quickly and the CPU or device is allowed to continue executing (transferring). This takes much less time than it otherwise would if the CPU or device had to wait for the data to be written to memory.

An implication of this model is that after a device transfer has been completed, the data may still be in the I/O cache but not yet in main memory. If the CPU accesses the memory, it may read the wrong data from the CPU cache. To ensure a consistent view of the memory for the CPU, the driver must call a synchronization routine to write the data from the I/O cache to main memory and update the CPU cache with the new data. Similarly, a synchronization step is required if data modified by the CPU is to be accessed by a device.

There may also be additional caches and buffers in between the device and memory, such as caches associated with bus extenders or bridges. `ddi_dma_sync`(9F) is provided to synchronize *all* applicable caches.

ddi_dma_sync( )

If a memory object has multiple mappings—such as for a device (through the DMA handle), and for the CPU—and one mapping is used to modify the memory object, the driver needs to call `ddi_dma_sync`(9F) to ensure that the modification of the memory object is complete before accessing the object through another mapping. `ddi_dma_sync`(9F) may also inform other mappings of the object that any cached references to the object are now stale. Additionally, `ddi_dma_sync`(9F) flushes or invalidates stale cache references as necessary.

Generally, the driver has to call `ddi_dma_sync`(9F) when a DMA transfer completes. The exception to this is that deallocating the DMA resources (`ddi_dma_unbind_handle`(9F)) does an implicit `ddi_dma_sync(9F)` on behalf of the driver.

```
int ddi_dma_sync(ddi_dma_handle_t handle, off_t off,
    size_t length, u_int type);
```

If the object is going to be read by the DMA engine of the device, the device's view of the object must be synchronized by setting *type* to DDI_DMA_SYNC_FORDEV. If the DMA engine of the device has written to the memory object, and the object is going to be read by the CPU, the CPU's view of the object must be synchronized by setting *type* to DDI_DMA_SYNC_FORCPU.

Here is an example of synchronizing a DMA object for the CPU:

```
if (ddi_dma_sync(xsp->handle, 0, length, DDI_DMA_SYNC_FORCPU)
    == DDI_SUCCESS) {
    /* the CPU can now access the transferred data */
    ...
} else {
    error handling
}
```

If the only mapping that concerns the driver is one for the kernel (such as memory allocated by ddi_dma_mem_alloc(9F)), the flag DDI_DMA_SYNC_FORKERNEL can be used. This is a hint to the system that if it can synchronize the kernel's view faster than the CPU's view, it can do so; otherwise, it acts the same as DDI_DMA_SYNC_FORCPU.

DMA Windows

The system might be unable to allocate resources for a large object. If this occurs, the transfer must be broken into a series of smaller transfers. The driver can either do this itself, or it can let the system allocate resources for only part of the object, thereby creating a series of DMA *windows*. Allowing the system to allocate resources is the preferred solution, as the system can manage the resources more effectively than the driver.

A DMA window has attributes *offset* (from the beginning of the object) and *length*. After a partial allocation, only a range of *length* bytes starting at *offset* has resources allocated for it.

A DMA window is requested by specifying the DDI_DMA_PARTIAL flag as a parameter to ddi_dma_buf_bind_handle(9F) or ddi_dma_addr_bind_handle(9F). Both functions return DDI_DMA_PARTIAL_MAP if a window can be established. However, the system might allocate resources for the entire object (less overhead), in which case DDI_DMA_MAPPED is returned. The driver should check the return value (see Code Example 7-4 on page 150) to determine whether DMA windows are in use.

State Structure

This section adds the following fields to the state structure. See “Software State Structure” on page 63 for more information.

```
int partial;       /* DMA object partially mapped, use windows */
int nwin;          /* number of DMA windows for this object */
int windex;        /* index of the current active window */
```

Code Example 7-4 Setting Up DMA Windows

```
static int
xxstart (caddr_t arg)
{
    struct xxstate *xsp = (struct xxstate *)arg;
    struct device_reg *regp = xsp->reg;
    ddi_dma_cookie_t cookie;
    int status;

    mutex_enter(&xsp->mu);
    if (xsp->busy) {
        /* transfer in progress */
        mutex_exit(&xsp->mu);
        return (0);
    }

    xsp->busy = 1;
    mutex_exit(&xsp->mu);

    if (transfer is a read) {
        flags = DDI_DMA_READ;
    } else {
        flags = DDI_DMA_WRITE;
    }
    flags |= DDI_DMA_PARTIAL;

    status = ddi_dma_buf_bind_handle(xsp->handle, xsp->bp,
        flags, xxstart, (caddr_t)xsp, &cookie, &ccount);

    if (status != DDI_DMA_MAPPED &&
        status != DDI_DMA_PARTIAL_MAP)
            return (0);

    if (status == DDI_DMA_PARTIAL_MAP) {
        ddi_dma_numwin(xsp->handle, &xsp->nwin);
        xsp->partial = 1;
        xsp->windex = 0;
        } else {
            xsp->partial = 0;
        }
        ...
        program the DMA engine
        ...
        return (1);
}
```

There are two functions operating with DMA windows. The first, `ddi_dma_numwin`(9F), returns the number of DMA windows for a particular DMA object. The other function, `ddi_dma_getwin`(9F), allows repositioning (reallocation of system resources) within the object. It shifts the current window to a new window within the object. Because `ddi_dma_getwin`(9F) reallocates system resources to the new window, the previous window becomes invalid.

Caution – It is a severe error to call `ddi_dma_getwin`(9F) before transfers into the current window are complete.

`ddi_dma_getwin`(9F) is normally called from an interrupt routine; see Code Example 7-5. The first DMA transfer is initiated as a result of a call to the driver. Subsequent transfers are started from the interrupt routine.

The interrupt routine examines the status of the device to determine if the device completed the transfer successfully. If not, normal error recovery occurs. If the transfer was successful, the routine must determine if the logical transfer is complete (the entire transfer specified by the `buf`(9S) structure) or if this was only one DMA window. If it was only one window, it moves the window with `ddi_dma_getwin`(9F), retrieves a new cookie, and starts another DMA transfer.

If the logical request has been completed, the interrupt routine checks for pending requests and starts a transfer, if necessary. Otherwise, it returns without invoking another DMA transfer. Code Example 7-5 illustrates the usual flow control.

Code Example 7-5 Interrupt Handler Using DMA Windows

```
static u_int
xxintr(caddr_t arg)
{
    struct xxstate *xsp = (struct xxstate *)arg;
    uint8_t status, temp;

    mutex_enter(&xsp->mu);

    /* read status */
    status = ddi_get8(xsp->access_hdl, &xsp->regp->csr);

    if (!(status & INTERRUPTING)) {
        mutex_exit(&xsp->mu);
        return (DDI_INTR_UNCLAIMED);
    }
    ddi_put8(xsp->access_hdl,&xsp->regp->csr, CLEAR_INTERRUPT);

    /* for store buffers */
    temp = ddi_get8(xsp->access_hdl, &xsp->regp->csr);
    if (an error occurred during transfer) {
        bioerror(xsp->bp, EIO);
        xsp->partial = 0;
    } else {
        xsp->bp->b_resid -= amount transferred;
    }


    if (xsp->partial && (++xsp->windex < xsp->nwin)) {
        /* device still marked busy to protect state */
        mutex_exit(&xsp->mu);
        (void) ddi_dma_getwin(xsp->handle, xsp->windex,
                &offset, &len, &cookie, &ccount);

    program the DMA engine with the new cookie(s)
        ...
        return (DDI_INTR_CLAIMED);
    }
    ddi_dma_unbind_handle(xsp->handle);
    biodone(xsp->bp);
    xsp->busy = 0;
    xsp->partial = 0;
    mutex_exit(&xsp->mu);

    if (pending transfers) {
        (void) xxstart((caddr_t)xsp);
    }

    return (DDI_INTR_CLAIMED);
}
```

Allocating Private DMA Buffers

Some device drivers may need to allocate memory for DMA transfers to or from a device, in addition to doing transfers requested by user threads and the kernel. Examples of this are setting up shared memory for communication with the device and allocating intermediate transfer buffers. ddi_dma_mem_alloc(9F) is provided for allocating memory for DMA transfers.

```
int ddi_dma_mem_alloc(ddi_dma_handle_t handle, size_t length,
    ddi_device_acc_attr_t *accattrp, uint_t xfermodes,
    int (*callback)(void *), void *arg, caddr_t *kaddrp,
    size_t *real_length, ddi_acc_handle_t *handlep);
```

handle is a DMA handle.

length is the length in bytes of the desired allocation.

accattrp is a pointer to a device access attribute structure.

xfermodes are data transfer mode flags.

callback is the address of callback function for handling resource allocation failures. See ddi_dma_alloc_handle(9F).

arg is the argument to pass to the callback function.

kaddrp is a pointer (on a successful return) that contains the address of the allocated storage.

real_length is the length in bytes that was allocated.

handlep is a pointer to a data access handle.

xfermodes should be set to DDI_DMA_CONSISTENT if the device accesses in a nonsequential fashion, or if synchronization steps using ddi_dma_sync(9F) should be as lightweight as possible (because of frequent use on small objects). This type of access is commonly known as *consistent* access. I/O parameter blocks that are used for communication between a device and the driver are set up this way.

On x86 systems, DDI_DMA_CONSISTENT can be used to allocate memory that is physically contiguous as well as consistent.

Code Example 7-6 shows how to allocate IOPB memory and the necessary DMA resources to access it. DMA resources must still be allocated, and the `DDI_DMA_CONSISTENT` flag must be passed to the allocation function.

Code Example 7-6 Using `ddi_dma_mem_alloc`(9F)

```
if (ddi_dma_mem_alloc(xsp->iopb_handle, size, &accattr,
    DDI_DMA_CONSISTENT, DDI_DMA_SLEEP, NULL, &xsp->iopb_array,
    &real_length, &xsp->acchandle) != DDI_SUCCESS) {
    error handling
    goto failure;
}
if (ddi_dma_addr_bind_handle(xsp->iopb_handle, NULL,
    xsp->iopb_array, real_length,
    DDI_DMA_READ | DDI_DMA_CONSISTENT, DDI_DMA_SLEEP,
    NULL, &cookie, &count) != DDI_DMA_MAPPED) {
    error handling
    ddi_dma_mem_free(&xsp->acchandle);
    goto failure;
}
```

`xfermodes` should be set to `DDI_DMA_STREAMING` if the device is doing sequential, unidirectional, block-sized and block-aligned transfers to or from memory. This type of access is commonly known as *streaming* access.

For example, if an I/O transfer can be sped up by using an I/O cache, which at a minimum transfers (flushes) one cache line, `ddi_dma_mem_alloc`(9F) will round the size to a multiple of the cache line to avoid data corruption.

`ddi_dma_mem_alloc`(9F) returns the actual size of the allocated memory object. Because of padding and alignment requirements the actual size might be larger than the requested size. `ddi_dma_addr_bind_handle`(9F) requires the actual length.

`ddi_dma_mem_free`(9F) is used to free the memory allocated by `ddi_dma_mem_alloc`(9F).

Note – If the memory is not properly aligned, the transfer will succeed but the system will choose a different (and possibly less efficient) transfer mode that requires fewer restrictions. For this reason, `ddi_dma_mem_alloc`(9F) is preferred over `kmem_alloc`(9F) when allocating memory for the device to access.

Power Management 8

This chapter describes the interfaces for the Power Management framework, which regulates and reduces the power consumed by computer systems and devices.

Power Management Overview

Power management provides the ability to control and manage the electrical power usage of a computer system or device. Power management enables systems to conserve energy by using less power when idle and by shutting down completely when not in use. For example, desktop computer systems can use a significant amount of power, and often (particularly at night) they are left idle. Power management software can detect that the system is not being used and power it or some of its components down. Power management can also be used in battery-powered computers (such as notebook computers) to extend battery life by powering down unused components.

The Solaris Power Management framework depends on device drivers to implement the device-specific power management functionality, such as detection of idleness in the device and changing the power state of the device. In order for a driver to do this, the device must be designed to support multiple power states.

The Solaris Power Management framework is implemented in two ways:

- Device power management – Automatically turns off unused parts of a device so that the system uses less power.

- System power management – Automatically turns off the computer when the entire system is idle. The framework allows devices to reduce their energy consumption after a specified idle time interval.

Device Power Management

To perform effective device power management, system software monitors the different components of the device and determines when they are not in use. Since only device drivers are able to determine when a device is idle, and only device drivers are able to reduce power consumption of a device, the Power Management framework exports interfaces to enable communication between the system software and the device driver.

The Solaris Power Management framework provides the following:

- A device-independent model for power-manageable devices
- System software to implement a power management policy (which is controlled by a user-modifiable configuration file)
- A set of DDI interfaces for the device driver to notify the framework of the parts of a device that can be power managed, and when those parts are idle or busy

System Power Management

System power management consists of turning off the entire computer after saving its state so that it can be returned to the same state immediately when it is turned back on.

To shut down an entire system and later return it to the state it was in prior to the shutdown, it is necessary to stop (and later restart) kernel threads and user processes, notify interested processes that the system has been suspended, and save (and later restore) the hardware state of all devices on the system. System power management is currently implemented only on some SPARC systems supported by the Solaris 2.6 software.

The Solaris System Power Management framework provides the following:

- A platform-independent model of system idleness
- System software to implement a system power management policy (which is controlled by a user-modifiable configuration file).

- A set of interfaces for the device driver to override the method for determining which drivers have hardware state. These interfaces are also used to determine how responsibility for saving the state is assigned.
- A set of interfaces to allow the framework to call into the driver to save and restore the device state, and a mechanism for notifying processes that a suspend or resume operation has occurred.

Power Management Additions to the State Structure

This chapter adds the following fields to the state structure. See “Software State Management” on page 63 for more information.

```
struct xx_saved_device_state  device_state;
int xx_suspended;   /* suspended for system power management */
int xx_pm_suspended;/* suspended for device power management */
int xx_power_level[num_components]; /* component power level */
```

Device Power Management Model

The following sections describe the details of the device power management model. This model includes the following elements:

- Components
- Idleness
- Power levels
- Dependency
- Policy
- Power management interfaces
- Power management entry points

Components

In the power management model, each device is composed of zero or more power-manageable components. If a device has no components, then the device is *not* power manageable.

Components correspond to parts of the device that can be put into a state that requires less power than normal. The definition of which components a device implements depends on the device driver writer, with one exception: component zero must represent all parts of the device that have hardware state that would be lost if power were to be completely removed from the device.

The device driver notifies the system of the device components by calling `pm_create_components`(9F) in its `attach`(9E) entry point as part of driver initialization.

Idleness

Each component of a device may be in one of two states: *busy* or *idle*. The device driver notifies the framework of changes in the device state by calling `pm_busy_component`(9F) and `pm_idle_component`(9F).

Power Levels

The current implementation of the Device Power Management framework only keeps track of two power levels for each device, its *current* power level and its *normal* power level. The normal power level of a component is the power level required for normal operation of the component, and is the power level to which the component is returned by the framework when the device is needed. The device driver informs the framework of the normal power level of the component by calling `pm_set_normal_power`(9F).

The *current* power level of the component is the power level at which the component is currently operating. The device driver should ensure that the component is set to the normal power level at initialization time. The framework assumes that when a device attaches it will be operating at its normal power level until the framework power manages it.

Power-level values that represent *power on* states must be positive integers greater than zero. A value of zero means the device has been set to the lowest operating power available.

Dependency

A device component might depend on one or more other devices. A device component depends on another device if the component can be powered off only when all the components of all the devices it depends on are also powered off. For example, the component of the frame buffer device that represents the monitor depends on the mouse and keyboard devices. The frame buffer monitor component can thus only be powered off when both the mouse and keyboard devices are powered off.

The power.conf(4) file specifies the dependencies among devices.

Policy

The power.conf(4) file lists the devices that may be powered off and specifies dependencies between devices. Associated with each component of a device is a *threshold* of idle time. The threshold for each power-manageable device component is also specified in the power.conf(4) file.

The system checks the state of each device specified in power.conf(4). When a component has been idle for *threshold* seconds and all the dependents of the device are powered off, that component of the device is set to power level zero.

Device Power Management Interfaces

A device driver that supports a device with power-manageable components must notify the system of the existence of these components and their normal power values, and notify the system of the component state transitions from idle to busy and vice versa.

The notification of the existence of the components and their normal power values is typically done in the driver's attach(9E) entry point as part of driver initialization. The following interfaces handle creating and destroying device components and setting and getting the normal power levels of device components.

pm_create_components()

```
int pm_create_components(dev_info_t *dip, int components);
```

pm_create_components(9F) notifies the system that the device indicated by dip has the number of components indicated by components. This function is called in the attach(9E) routine of the device driver.

pm_destroy_components()

```
void pm_destroy_components(dev_info_t *dip);
```

pm_destroy_components(9F) removes all the components associated with the device indicated by dip from the system. This function is called in the detach(9E) routine.

pm_set_normal_power()

```
pm_set_normal_power(dev_info_t *dip, int component, int level);
```

pm_set_normal_power(9F) sets the normal power level for the specified component. Whenever the system turns the component on again, it calls into the driver to set the current power level to normal power level.

pm_get_normal_power()

```
pm_get_normal_power(dev_info_t *dip, int component);
```

pm_get_normal_power(9F) retrieves the current setting of the normal power level for a component.

Busy-Idle State Transitions

The driver must keep the framework informed of device state transitions from idle to busy or busy to idle. Where these transitions happen is entirely device specific. Some components are created and marked busy and never change. Some are created and never marked busy (components created by pm_create_components(9F) are created in an idle state). For example, a frame buffer currently supports two components: component 0 represents the frame buffer electronics and is always busy, and component 1 represents the monitor and is always idle (but dependent on the keyboard and mouse).

Note – Component 0 represents the state of the device that would be lost if power is removed.

Some devices, such as the keyboard and mouse, are never marked busy but have their idle time reset each time a keystroke or mouse event is processed. The transitions from idle to busy and from busy to idle depend on the nature of the device and the abstraction represented by the specific component. For example, SCSI disk target drivers typically export a single component, which represents whether the SCSI target disk drive is spun up or not. It is marked busy whenever there is an outstanding request to the drive and idle when the last queued request finishes.

The following interfaces notify the Power Management framework of busy-idle state transitions.

pm_busy_component()

```
int pm_busy_component(dev_info_t *dip, int component);
```

pm_busy_component(9F) marks the component as busy.

While the component is busy, it will not be powered off. If the component is already powered off, then marking it busy doesn’t change its power level. The driver needs to call ddi_dev_is_needed(9F) for this purpose. Calls to pm_busy_component(9F) are stacked and require a corresponding number of calls to pm_idle_component(9F) to idle the component.

pm_idle_component()

```
int pm_idle_component(dev_info_t *dip, int component);
```

pm_idle_component(9F) marks component as idle. An idle component is subject to being powered off.

pm_idle_component(9F) must be called once for each call to pm_busy_component(9F) in order to idle the component.

Device Power State Transitions

A device driver can call ddi_dev_is_needed(9F) to request that a component be set to a given power level. This is necessary before using a component that has been powered off. For example, a SCSI disk target driver's read(9E) or write(9E) routine might need to spin up the disk if it had been powered off before completing the read or write. ddi_dev_is_needed(9F) notifies the Power Management framework of device state transitions.

ddi_dev_is_needed()

```
int ddi_dev_is_needed(dev_info_t *dip, int component,
                    int level);
```

ddi_dev_is_needed(9F) is called when the driver discovers that a component needed for some operation has been powered off. This interface arranges for the driver to be called to set the current power level of the component to the level specified in the request. All the devices that depend on this component are also brought back to normal power by this call.

When a component has been powered off by pm(7D) and a request or interrupt occurs that requires the component to be powered up, the driver must call ddi_dev_is_needed(9F) so that the framework can restore the component (and all of the devices that depend on it) to normal power.

Entry Points Used by Device Power Management

The Power Management framework uses the following entry points:

- power(9E)
- detach(9E)
- attach(9E)

power()

```
int xxpower(dev_info_t *dip, int component, int level);
```

The system calls the power(9E) entry point (either directly or as a result of a call to ddi_dev_is_needed(9F)) when it determines that a component's current power level needs to be changed. The action taken by this entry point is device driver specific. In the example of the SCSI target disk driver mentioned previously, setting the power level of the component to 0 results in sending a SCSI command to spin down the disk, while setting the power level to the normal power level results in sending a SCSI command to spin up the disk. Code Example 8-1 shows a sample power(9E) routine.

Code Example 8-1 power(9E) Routine

```
int
xxpower(dev_info_t *dip, int component, int level)
{
    struct xxstate *xsp;
    int instance;

    instance = ddi_get_instance(dip);
    xsp = ddi_get_soft_state(statep, instance);

    /*
    * Make sure that the request is valid
    */
    if (xx_valid_power_level(component, level))
        return (DDI_FAILURE);
    mutex_enter(&xsp->mu);
    if (xsp->xx_power_level[component] != level) {
        device- and component-specific setting of power level.
        xsp->xx_power_level[component] = level;
    }
    mutex_exit(&xsp->mu);
    return (DDI_SUCCESS);
}
```

detach()

```
    int detach(dev_info_t *dip, ddi_detach_cmd_t cmd);
```

Before the system sets component 0 (entire device) to power level 0, it calls the driver's `detach`(9E) entry point with a detach command of `DDI_PM_SUSPEND` to allow the driver to save all hardware state to memory.

If the device is busy and has outstanding operations, it should fail the `detach`(9E) call. The framework will try again later after the device has been idle for its threshold time. Otherwise, the driver must arrange to block all subsequent accesses to the hardware until the device has been resumed (which the driver can initiate by calling `ddi_dev_is_needed`(9F)), and save all hardware state to memory.

Code Example 8-2 shows an example of a `detach`(9E) routine with `DDI_PM_SUSPEND` implemented.

Code Example 8-2 `detach`(9E) Routine Showing the Use of `DDI_PM_SUSPEND`

```
int
xxdetach(devinfo_t *dip, ddi_detach_cmd_t cmd)
{
    struct xxstate *xsp;
    int instance;
    instance = ddi_get_instance(dip);
    xsp = ddi_get_soft_state(statep, instance);

    switch (cmd) {
    case DDI_DETACH:
        see chapter 5, Autoconfiguration, for discussion
    case DDI_SUSPEND:
        see Code Example 8-4 for DDI_SUSPEND implementation
    case DDI_PM_SUSPEND:
        /*
         * We won't be called with DDI_PM_SUSPEND when already called
         * with DDI_SUSPEND.
         */
        mutex_enter(&xsp->mu);
        if (xsp->xx_busy) {
            mutex_exit(&xsp->mu);
            return(DDI_FAILURE);
        }

        xsp->xx_pm_suspended = 1;
        Save device register contents into xsp->xx_device_state

        this section is optional, only needed if the driver maintains a running
        timeout (but be sure to drop the  mutex in any case)
        /* cancel timeouts */
        if (xsp->xx_timeout_id) {
            int temp_timeout_id = xsp->xx_timeout_id;

            xsp->xx_timeout_id = 0;
            mutex_exit(&xsp->mu);
            untimeout(temp_timeout_id);
        } else {
            mutex_exit(&xsp->mu);
        }
        return(DDI_SUCCESS);

    default:
        return(DDI_FAILURE);
    }
}
```

attach()

```
int attach(dev_info_t *dip, ddi_attach_cmd_t cmd);
```

When a device that has been suspended is needed again, its `power`(9E) entry point is called to restore the power level of component 0 (entire device) to its normal power. The driver's `attach`(9E) entry point is then called with an attach command value of `DDI_PM_RESUME` to restore the device hardware state saved in the `detach`(9E) routine and unblock any pending operations. Code Example 8-3 shows an `attach`(9E) routine with `DDI_PM_RESUME` implemented.

Code Example 8-3 `attach`(9E) Showing the Use of `DDI_PM_RESUME`

```
int
xxattach(devinfo_t *dip, ddi_attach_cmd_t cmd)
{
    struct xxstate *xsp;
    int instance;

    instance = ddi_get_instance(dip);
    xsp = ddi_get_soft_state(statep, instance);

    switch (cmd) {
    case DDI_ATTACH:
        see chapter 5, Autoconfiguration for discussion

    case DDI_RESUME:
        see Code Example 8-5 for DDI_RESUME implementation

    case DDI_PM_RESUME:
        /*
         * We won't be DDI_PM_RESUMEd while DDI_SUSPENDed
         */
        mutex_enter(&xsp->mu);
        Restore device register contents from xsp->xx_device_state

        this section is optional, only needed if the driver maintains a running timeout
        /* restart timeouts */
        xsp->xx_timeout_id = timeout({...});
```

```
            xsp->xx_pm_suspended = 0;/* allow new operations */
            cv_broadcast(&xsp->cv);
            mutex_exit(&xsp->mu);
            return(DDI_SUCCESS);

        default:
            return(DDI_FAILURE);
        }
}
```

System Power Management Model

This section describes the details of the System Power Management model. The model includes the following components:

- Autoshutdown threshold
- Busy state
- Hardware state
- Policy
- Power management entry points

Autoshutdown Threshold

The system may be shut down (powered off) automatically after a configurable period of idleness. This period is known as the *autoshutdown threshold*. This behavior may be suppressed.

Busy State

There are several ways to measure the busy state of the system. The currently supported built-in metrics are keyboard characters, mouse activity, tty characters, load average, disk reads, and NFS requests. Any one of theses metrics may make the system busy. In addition to the built-in metrics, an interface is defined for running a user-specified process that may indicate that the system is busy.

Hardware State

Devices that export a *reg* property are considered to have hardware state that must be saved prior to shutting down the system. If a device does not have a `reg` property, then it is considered to be stateless. However, this consideration can be overridden by the device driver.

A device that has hardware state but no `reg` property (such as a SCSI target driver, which has hardware at the other end of the SCSI bus), is called to save and restore its state if it exports a *pm-hardware-state* property with the value `needs-suspend-resume`. Otherwise, the lack of a *reg* property is taken to mean that the device has no hardware state. For information on device properties, see "Device Attribute Representations" on page 34.

A device that has a `reg` property but no hardware state may export a *pm-hardware-state* property with the value `no-suspend-resume` to keep the framework from calling into the driver to save and restore that state. For more information on Power Management properties, see the `pm_props`(9E) man page.

Policy

The system will be shut down if the following conditions apply:

- Autoshutdown is enabled in `power.conf`(4).
- The system has been idle for *autoshutdown threshold* minutes.
- All the metrics specified in `power.conf`(4) have been satisfied.

Entry Points Used by System Power Management

System power management passes the command `DDI_SUSPEND` to the `detach`(9E) driver entry point to request the driver to save the device hardware state. It passes the command `DDI_RESUME` to the `attach`(9E) driver entry point to request the driver to restore the device hardware state. If a device has a *reg* property or a *pm-hardware-state* property with a value of `needs-suspend-resume`, then the framework calls into the driver's `detach`(9E) entry point to allow the driver to save the hardware state of the device to memory so that it can be restored after the system power returns.

detach()

```
int detach(dev_info_t *dip, ddi_detach_cmd_t cmd);
```

To process the DDI_SUSPEND command, detach(9E) must do the following:

- Wait until outstanding operations have completed (or abort them if they can be restarted).
- Block further operations from being initiated until the device is resumed (except for dump(9E) requests).
- Cancel pending callouts.
- Save any volatile hardware state to memory. The state includes the contents of device registers, but may also include downloaded firmware.

If, for some reason, the driver is not able to suspend the device and save its state to memory, then it must return DDI_FAILURE, and the framework aborts the system power management operation.

Dump requests must be honored. The framework uses the dump(9E) entry point to write out the state file containing the contents of memory. See dump(9E) for restrictions imposed on the device driver when using this entry point.

Note – The entry point dump(9E) was previously used only for writing kernel crash dumps to disk. It is now also used to write out the state file containing the information necessary to restore the system to its state prior to a system power management suspend.

If the device implements a power-manageable component zero, the device may already have been suspended and powered off using the command DDI_PM_SUSPEND when its detach(9E) entry point is called with the DDI_SUSPEND command. The additional processing necessary in this case is to cancel pending timeouts and suppress the call to ddi_dev_is_needed(9F) until the device is resumed by a call to attach(9E) with a command of DDI_RESUME. The driver must keep sufficient track of its state to be able to deal appropriately with this possibility.

Code Example 8-4 shows an example of a detach(9E) routine with the DDI_SUSPEND command implemented.

Code Example 8-4 `detach`(9E) Routine Showing the Use of `DDI_SUSPEND`

```
int
xxdetach(devinfo_t *dip, ddi_detach_cmd_t cmd)
{
    struct xxstate *xsp;
    int instance;

    instance = ddi_get_instance(dip);
    xsp = ddi_get_soft_state(statep, instance);

    switch (cmd) {
    case DDI_DETACH:
        see chapter 5, Autoconfiguration for discussion

    case DDI_SUSPEND:
        mutex_enter(&xsp->mu);
        xsp->xx_suspended = 1;/* stop new operations */
        if (!xsp->xx_pm_suspended) {
            /*
             * This code assumes that we'll get a cv_broadcast when
             * we're no longer busy
             */
            while(xsp->xx_busy)/* wait for pending ops */
                    cv_wait(&xsp->xx_busy_cv, &xsp->mu);
            Save device register contents into xsp->xx_device_state

            this section is optional, only needed if the driver maintains a running
            timeout (but be sure to drop the  mutex in any case)
            /* cancel timeouts */
            if (xsp->xx_timeout_id) {
                int temp_timeout_id = xsp->xx_timeout_id;

                xsp->xx_timeout_id = 0;
                mutex_exit(&xsp->mu);
                untimeout(temp_timeout_id);
            } else {
                mutex_exit(&xsp->mu);
            }
        } else {
            mutex_exit(&xsp->mu);
        }
        return(DDI_SUCCESS);
    case DDI_PM_SUSPEND:
        see Code Example 8-2 for DDI_PM_SUSPEND case
    default:
        return(DDI_FAILURE);
    }
}
```

attach()

```
    int attach(dev_info_t *dip, ddi_attach_cmd_t cmd);
```

When power is restored to the system, each device with a `reg` property or with a `pm-hardware-state` property of value `needs-suspend-resume` has its `attach`(9E) entry point called with a command value of `DDI_RESUME`. If the system shutdown was aborted for some reason, each driver that was suspended is called to resume, even though the power has not been shut off. Consequently, the resume code in `attach`(9E) must make no assumptions about the state of the hardware; it may or may not have lost power.

The resume code must restore the hardware state from the saved image in memory (possibly including reloading firmware), reregister any necessary timeouts, and unblock any pending requests.

Code Example 8-5 shows an example of an `attach`(9E) routine with the `DDI_RESUME` command.

Code Example 8-5 `attach`(9E) Routine Showing the Use of `DDI_RESUME`

```
int
xxattach(devinfo_t *dip, ddi_attach_cmd_t cmd)
{
    struct xxstate *xsp;
    int instance;

    instance = ddi_get_instance(dip);
    xsp = ddi_get_soft_state(statep, instance);

    switch (cmd) {
    case DDI_ATTACH:
        see chapter 5, Autoconfiguration, for discussion
    case DDI_RESUME:
        mutex_enter(&xsp->mu);
        if (!xsp->xx_pm_suspended) {
            Restore device register contents from xsp->xx_device_state}

            this section is optional, only needed if the driver maintains a running timeout
            /* restart timeouts */
            xsp->xx_timeout_id = timeout({...});
        }
        xsp->xx_suspended = 0;/* allow new operations */
        cv_broadcast(&xsp->cv);
        mutex_exit(&xsp->mu);
        return(DDI_SUCCESS);


    case DDI_PM_RESUME:
        see Code Example 8-3 for DDI_PM_RESUME case


    default:
        return(DDI_FAILURE);
    }
}
```

Note – The `detach`(9E) and `attach`(9E) interfaces may also be used to resume a system that has been quiesced.

Device Access

If power management is supported, and `detach`(9E) and `attach`(9E) have code such as shown in the previous examples, the code fragment in Code Example 8-6 on page 172 can be used where device access is about to be made to the device from user context (for example, in `read`(2), `write`(2), `ioctl`(2)).

In the following example, it is assumed that the operation about to be performed requires a component `component` that is operating at power level `level`.

Code Example 8-6 Device Access

```
/*
 * Because multiple threads may come through this code
 * simultaneously and ddi_dev_is_needed() does not
 * atomically set the power level and trigger the attach
 * call with DDI_PM_RESUME, a lot of checking is done here
 */
mutex_enter(&xsp->mu);
do {
    /*
     * Block commands if/while device suspended via DDI_SUSPEND
     */
    while(xsp->xx_suspended)
        cv_wait(&xsp->cv, &xsp->mu);
    /* system may have been power cycled here */
    if (xsp->xx_power_level[component] < level) {
        /*
         * prevent us from being powered down again immediately
         * due to still being idle
         */
        pm_busy_component(dip, component);
        /*
         * Drop mutex because ddi_dev_is_needed will result in
         * a call back into our power and/or attach routine
         */
        mutex_exit(&xsp->mu);
        ddi_dev_is_needed(dip, component, level);
        mutex_enter(&xsp->mu);
    }
    /*
     * Block commands if device still suspended with
     * DDI_PM_SUSPEND; because we had to drop the mutex to
     * call ddi_dev_is_needed we may be executing in a
     * thread that came in after the power level was raised
     * but before attach was called with DDI_PM_RESUME
     */
    while(xsp->xx_pm_suspended)
        cv_wait(&xsp->cv, &xsp->mu);
    /*
```

```
         * Because we may have dropped the lock in the cv_wait,
         * we could have gotten a DDI_SUSPEND request, or we could
         * have found he power level high enough on the way in
         * but got powered down after we checked it, so we have
         * to check everything over again (except the
         * xx_pm_suspended state that we checked in the last
         * while loop) because any of the things we tested before
         * may have changed when we dropped the mutex
        */

} while(xsp->xx_suspended || xsp->xx_power_level[component]
         < level);
```

check for busy, initiate commands, and so on

when command completes and there are no more commands pending

```
pm_idle_component(dip, component);
....
```

Power Management Flow of Control

The following sections describe the general flow of control for power management states from busy to powered off. The sequence of states differs depending on whether the component is component zero or another component. Figure 8-1 on page 175 illustrates the flow of control in the Power Management framework.

Device Power Management Flow of Control for Component Zero

When a component's activity is complete, a driver can call `pm_idle_component`(9F) to mark the component as idle. When the component has been idle for its threshold time, the framework may power off the component. If the component is component zero, the framework calls the driver's `detach`(9E) entry point with the command `DDI_PM_SUSPEND` to enable the driver to save all hardware state to memory. The framework then calls the `power`(9E) entry point to set the power level of the component to power level zero.

When component zero is needed again, the driver calls `ddi_dev_is_needed`(9F) on the powered off component. The framework then calls `power`(9E) to power up the component and calls `attach`(9E) with the `DDI_PM_RESUME` command to restore the state of the device and unblock any pending operations. At this point, the `ddi_dev_is_needed`(9F) call returns to the device driver. The component is idle but powered on, and the driver can mark it as busy by calling `pm_busy_component`(9F).

Device Power Manangement Flow of Control for Components Other Than Component Zero

As with component zero, the driver uses `pm_idle_component`(9F) to mark components other than zero as idle. The framework may power off an idle component other than component zero by calling the `power`(9E) entry point to set the component to power level zero.

When a driver finds that a needed component is powered off, the driver calls `ddi_dev_is_needed`(9F) on the powered off component. When a driver calls `ddi_dev_is_needed`(9F) for a component other than component 0 that is powered off, the framework calls `power`(9E) to set the new power level before `ddi_dev_is_needed`(9F) returns. `ddi_dev_is_needed`(9F) keeps the framework informed of the state of the device and arranges for devices that this component depends on to be powered up. When `ddi_dev_is_needed`(9F) returns, the component is idle but powered on. The driver can mark it as busy by calling `pm_busy_component`(9F).

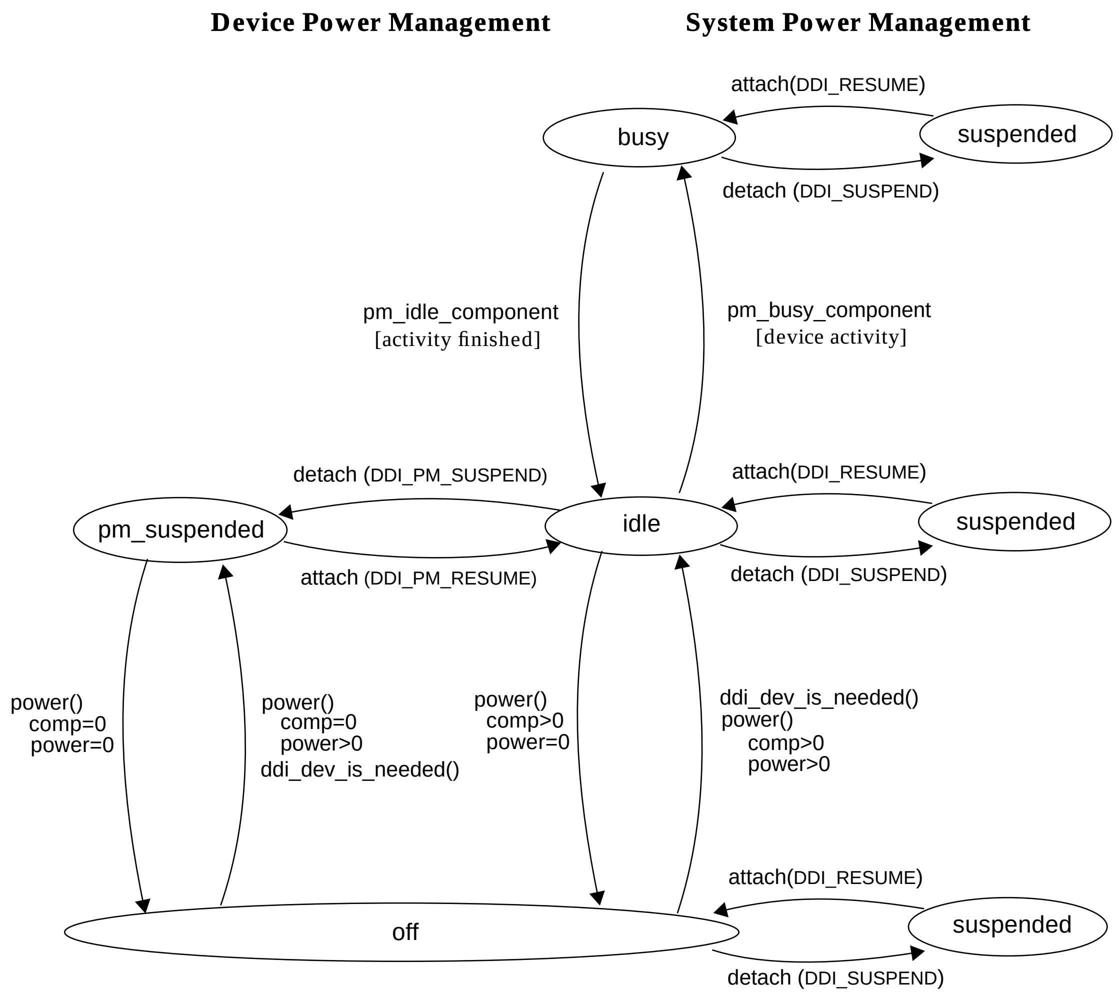


Figure 8-1 Power Management Conceptual State Diagram

Drivers for Character Devices 9

This chapter describes the structure of a character device driver, focusing in particular on the driver entry points. In addition, this chapter covers the use of `physio`(9F) (in `read`(9E) and `write`(9E)) and `aphysio`(9F) (in `aread`(9E) and `awrite`(9E)) in the context of synchronous and asynchronous I/O transfers.

Character Driver Structure Overview

Figure 9-1 shows data structures and routines that define the structure of a character device driver. Device drivers typically include the following:

- Device-loadable driver section
- Device configuration section
- Device access section

Character Driver Device Access

The shaded device access section in Figure 9-1 illustrates character driver entry points.

Note – For a description of block drivers and block driver device access, see Chapter 10, “Drivers for Block Devices.”

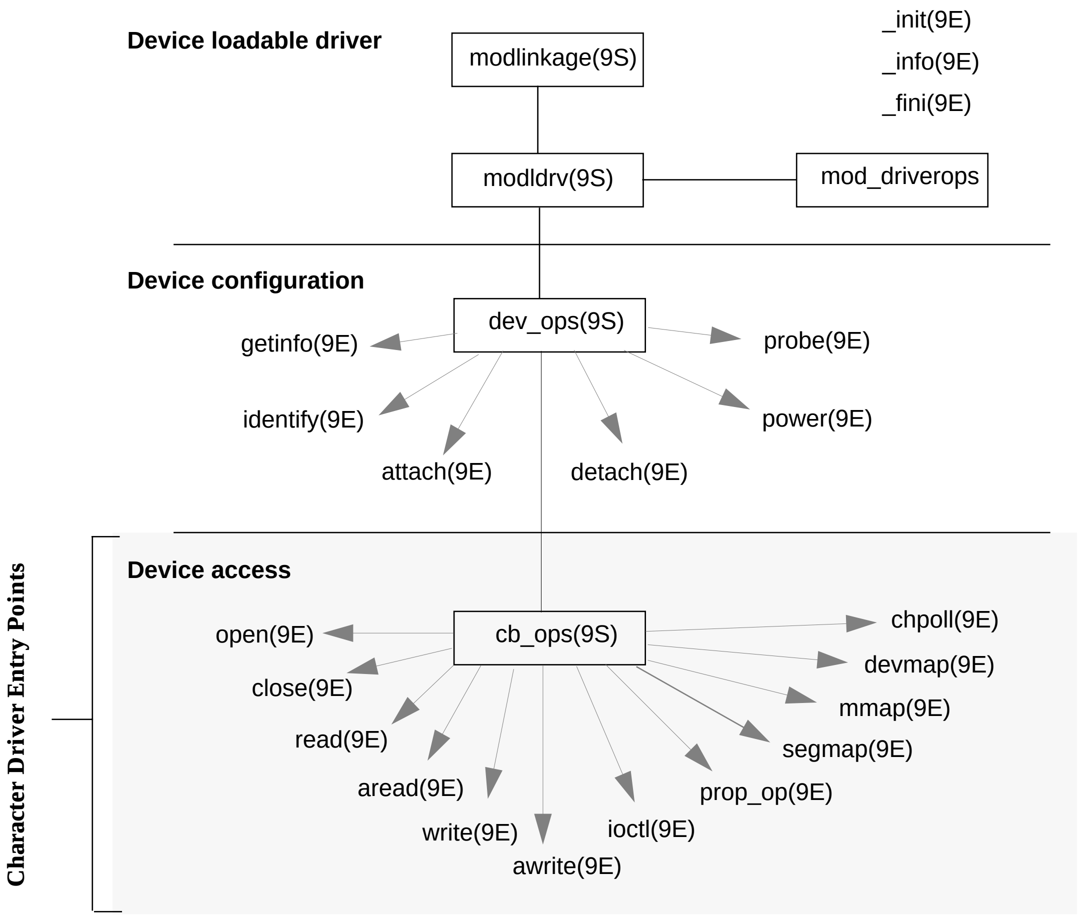


Figure 9-1 Character Driver Roadmap

Entry Points

Associated with each device driver is a `dev_ops`(9S) structure, which in turn refers to a `cb_ops`(9S) structure. These structures contain pointers to the driver entry points. Table 9-1 lists the character device driver autoconfiguration routines and entry points. Note that some of these entry points may be replaced with `nodev`(9F) or `nulldev`(9F) as appropriate.

Table 9-1 Character Driver Autoconfiguration Routines and Entry Points

Entry Point	**Description**
`_init`(9E)	Initializes the loadable-driver module.
`_info`(9E)	Returns the loadable-driver module information.
`_fini`(9E)	Prepares a loadable-driver module for unloading.
`identify`(9E)	Obsolete and no longer required. Set to `nulldev`(9F)
`probe`(9E)	Determines if a device is present.
`attach`(9E)	Performs device-specific initialization and/or power management resume functionality.
`detach`(9E)	Removes device-specific state and/or power management suspend functionality.
`getinfo`(9E)	Gets device driver information.
`power`(9E)	Sets the power level of a device component.
`open`(9E)	Gains access to a device.
`close`(9E)	Relinquishes access to a device.
`read`(9E)	Reads data from device.
`aread`(9E)	Reads data asynchronously from device.
`write`(9E)	Writes data to device.
`awrite`(9E)	Writes data asynchronously to device.
`ioctl`(9E)	Performs arbitrary operations.
`prop_op`(9E)	Manages arbitrary driver properties.
`devmap`(9E)	Validate and translate virtual mapping for a memory mapped device.

Table 9-1 Character Driver Autoconfiguration Routines and Entry Points

Entry Point	**Description**
`mmap`(9E)	Checks virtual mapping for a memory-mapped device. For new drivers, use the `devmap`(9E) entry point.
`segmap`(9E)	Maps device memory into user space.
`chpoll`(9E)	Polls device for events.

Autoconfiguration

The `attach`(9E) routine should perform the common initialization tasks that all devices require. Typically, these tasks include:

- Allocating per-instance state structures
- Registering device interrupts
- Mapping the device's registers
- Initializing mutex and condition variables
- Creating power-manageable components
- Creating minor nodes

See "attach( )" on page 101 for code examples of these tasks.

Character device drivers create minor nodes of type `S_IFCHR`. This causes a character special file representing the node to eventually appear in the `/devices` hierarchy. Code Example 9-1 shows a character driver `attach`(9E) routine.

Code Example 9-1 Character Driver `attach`(9E) Routine

```
static int
xxattach(dev_info_t *dip, ddi_attach_cmd_t cmd)
{
    switch (cmd) {
    case DDI_ATTACH:
        allocate a state structure and initialize it.
        map the device's registers.
        add the device driver's interrupt handler(s).
        initialize any mutexes and condition variables.
        create power manageable components.

        /*
         * Create the device's minor node. Note that the node_type
         * argument is set to DDI_NT_TAPE.
```

```
          */
         if (ddi_create_minor_node(dip, "minor_name", S_IFCHR,
             minor_number, DDI_NT_TAPE, 0) == DDI_FAILURE) {
             free resources allocated so far.
             /* Remove any previously allocated minor nodes */
             ddi_remove_minor_node(dip, NULL);

             return (DDI_FAILURE);
         }
         ...
         return (DDI_SUCCESS);

     case DDI_PM_RESUME:
         For information, see Chapter 8, "Power Management"

     case DDI_RESUME:
         For information, see Chapter 8, "Power Management"

default:
         return (DDI_FAILURE);
     }
}
```

Controlling Device Access

Access to a device by one or more application programs is controlled through the `open`(9E) and `close`(9E) entry points. The `open`(9E) routine of a character driver is always called whenever an `open`(2) system call is issued on a special file representing the device. For a particular minor device, `open`(9E) may be called many times, but the `close`(9E) routine is called only when the final reference to a device is removed. If the device is accessed through file descriptors, this is by a call to `close`(2) or `exit`(2). If the device is accessed through memory mapping, this could also be by a call to `munmap`(2).

open( )

```
int xxopen(dev_t *devp, int flag, int otyp, cred_t *credp);
```

The primary function of `open`(9E) is to verify that the open request is allowed. `devp` is a pointer to a device number. The `open`(9E) routine is passed a pointer so that the driver can change the minor number. This allows drivers to dynamically create minor instances of the device. An example of this might be a pseudo-terminal driver that creates a new pseudo-terminal whenever the driver is opened. A driver that dynamically chooses the minor number, normally creates only one minor device node in attach(9E) with ddi_create_minor_node(9F), then changes the minor number component of *devp using makedevice(9F) and getmajor(9F):

```
    *devp = makedevice(getmajor(*devp), new_minor);
```

The driver must keep track of available minor numbers internally.

otyp indicates how open(9E) was called. The driver must check that the value of otyp is appropriate for the device. For character drivers, otyp should be OTYP_CHR (see the open(9E) manual page).

flag contains bits indicating whether the device is being opened for reading (FREAD), writing (FWRITE), or both. User threads issuing the open(2) system call can also request exclusive access to the device (FEXCL) or specify that the open should not block for any reason (FNDELAY), but it is the driver's responsibility to enforce both cases. A driver for a write-only device such as a printer might consider an open for reading invalid.

credp is a pointer to a credential structure containing information about the caller, such as the user ID and group IDs. Drivers should not examine the structure directly, but should instead use drv_priv(9F) to check for the common case of root privileges. In this example, only *root* is allowed to open the device for writing.

Code Example 9-2 shows a character driver open(9E) routine.

Code Example 9-2 Character Driver open(9E) Routine

```
static int
xxopen(dev_t *devp, int flag, int otyp, cred_t *credp)
{
    minor_t     instance;

    if (getminor(*devp) is invalid)
        return (EINVAL);

    instance = getminor(*devp); /* one-to-one example mapping */

    /* Is the instance attached? */
    if (ddi_get_soft_state(statep, instance) == NULL)
        return (ENXIO);

    /* verify that otyp is appropriate */
    if (otyp != OTYP_CHR)
        return (EINVAL);
    if ((flag & FWRITE) && drv_priv(credp) == EPERM)
        return (EPERM);

    return (0);
}
```

close( )

`int xxclose(dev_t dev, int flag, int otyp, cred_t *credp);`

`close`(9E) should perform any cleanup necessary to finish using the minor device, and prepare the device (and driver) to be opened again. For example, the open routine might have been invoked with the exclusive access (`FEXCL`) flag. A call to `close`(9E) would allow further opens to continue. Other functions that `close`(9E) might perform are:

- Waiting for I/O to drain from output buffers before returning
- Rewinding a tape (tape device)
- Hanging up the phone line (modem device)

I/O Request Handling

This section gives the details of I/O request processing: from the application to the kernel, the driver, the device, the interrupt handler, and back to the user.

User Addresses

When a user thread issues a `write`(2) system call, it passes the address of a buffer in user space:

```
    char buffer[] = “python”;
    count = write(fd, buffer, strlen(buffer) + 1);
```

The system builds a `uio`(9S) structure to describe this transfer by allocating an `iovec`(9S) structure and setting the `iov_base` field to the address passed to `write`(2); in this case, `buffer`. The `uio`(9S) structure is what is passed to the driver `write`(9E) routine (see “Vectored I/O” on page 184” for more information about the `uio`(9S) structure).

The problem is that this address is in user space, not kernel space, and so is not guaranteed to be currently in memory. It is not even guaranteed to be a valid address. In either case, accessing a user address directly from the device driver or from the kernel could crash the system, so device drivers should never access user addresses directly. Instead, they should always use one of the data transfer routines in the Solaris 2.x DDI/DKI that transfer data into or out of the kernel; see "Copying Data" on page 421 and "uio(9S) Handling" on page 473 for a summary of the available routines. These routines are able to handle page faults, either by bringing the proper user page in and continuing the copy transparently, or by returning an error on an invalid access.

Two routines commonly used are `copyout`(9F) to copy data from kernel space to user space and `copyin`(9F) to copy data from user space to kernel space. `ddi_copyout`(9F) and `ddi_copyin`(9F) operate similarly but are to be used in the `ioctl`(9E) routine. `copyin`(9F) and `copyout`(9F) can be used on the buffer described by each `iovec`(9S) structure, or `uiomove`(9F) can perform the entire transfer to or from a contiguous area of driver (or device) memory.

Vectored I/O

In character drivers, transfers are described by a `uio`(9S) structure. The `uio`(9S) structure contains information about the direction and size of the transfer, plus an array of buffers for one end of the transfer (the other end is the device). The following section lists `uio`(9S) structure members that are important to character drivers.

uio( )

The `uio` structure contains the following members:

```
iovec_t    *uio_iov;      /* base address of the iovec */
                          /* buffer description array */
int        uio_iovcnt;    /* the number of iovec structures */
off_t      uio_offset;    /* offset into device where data */
                          /* is transferred from or to */
offset_t   uio_loffset    /* 64-bit offset into file where */
                          /* data is transferred from or to */
int        uio_resid;     /* amount (in bytes) not */
                          /* transferred on completion */
```

A `uio`(9S) structure is passed to the driver `read`(9E) and `write`(9E) entry points. This structure is generalized to support what is called *gather-write* and *scatter-read*. When writing to a device, the data buffers to be written do not have to be contiguous in application memory. Similarly, when reading from a device into memory, the data comes off the device in a contiguous stream but can go into noncontiguous areas of application memory. See readv(2), writev(2), pread(2), and pwrite(2) for more information on scatter-gather I/O.

Each buffer is described by an iovec(9S) structure. This structure contains a pointer to the data area and the number of bytes to be transferred.

```
caddr_t    iov_base;  /* address of buffer */
int        iov_len;   /* amount to transfer */
```

The uio structure contains a pointer to an array of iovec(9S) structures. The base address of this array is held in uio_iov, and the number of elements is stored in uio_iovcnt.

The uio_offset field contains the 32-bit offset into the device at which the application needs to begin the transfer. uio_loffset is used for 64-bit file offsets. If the device does not support the notion of an offset these fields can be safely ignored. The driver should interpret either uio_offset or uio_loffset (but not both). If the driver has set the D_64BIT flag in the cb_ops(9S) structure, it should use uio_loffset.

The uio_resid field starts out as the number of bytes to be transferred (the sum of all the iov_len fields in uio_iov) and *must* be set by the driver to the number of bytes *not* transferred before returning. The read(2) and write(2) system calls use the return value from the read(9E) and write(9E) entry points to determine if the transfer failed (and then return -1). If the return value indicates success, the system calls return the number of bytes requested minus uio_resid. If uio_resid is not changed by the driver, the read(2) and write(2) calls will return 0 (indicating end-of-file), even though all the data was transferred.

The support routines uiomove(9F), physio(9F) and aphysio(9F) update the uio(9S) structure directly, updating the device offset to account for the data transfer. When used with a seekable device, for which the concept of position is relevant, the driver does not need to adjust either the uio_offset or uio_loffset fields. I/O performed to a device in this manner is constrained by the maximum possible value of uio_offset or uio_loffset. An example of such a usage is raw I/O on a disk.

When performing I/O on a device on which the concept of position has no relevance, the driver may save uio_offset or uio_loffset, perform the I/O operation, then restore uio_offset or uio_loffset to the field's initial value. I/O performed to a device in this manner is not constrained by the maximum possible value of `uio_offset` or `uio_loffset`. An example of such a usage is I/O on a serial line.

The following example shows one way to preserve `uio_loffset` in the `read`(9E) function.

```
static int
xxread(dev_t dev, struct uio *uio_p, cred_t *cred_p)
{
    offset_t off;
    ...

    off = uio_p->uio_loffset;  /* save the offset */

    /* do the transfer */

    uio_p->uio_loffset = off;  /* restore it */

}
```

Synchronous Versus Asynchronous I/O

Data transfers can be *synchronous* or *asynchronous* depending on whether the entry point scheduling the transfer returns immediately or waits until the I/O has been completed.

The `read`(9E) and `write`(9E) entry points are synchronous entry points; they must not return until the I/O is complete. Upon return from the routines, the process knows whether the transfer has succeeded.

The `aread`(9E) and `awrite`(9E) entry points are asynchronous entry points. They schedule the I/O and return immediately. Upon return, the process issuing the request knows that the I/O has been scheduled and that the status of the I/O must be determined later. In the meantime, the process may perform other operations.

When an asynchronous I/O request is made to the kernel by a user process, the process is not required to wait while the I/O is in process. A process can perform multiple I/O requests and let the kernel handle the data transfer details. This is useful in applications such as transaction processing where concurrent programming methods may take advantage of asynchronous kernel I/O operations to increase performance or response time. Any performance boost for applications using asynchronous I/O, however, comes at the expense of greater programming complexity.

Data Transfer Methods

Data can be transferred using either programmed I/O or DMA. These data transfer methods may be used by either synchronous or asynchronous entry points, depending on the capabilities of the device.

Programmed I/O Transfers

Programmed I/O devices rely on the CPU to perform the data transfer. Programmed I/O data transfers are identical to other device register read and write operations. Various data access routines are used to read or store values to device memory. See “Data Access Functions” on page 49 for more information.

uiomove( )

uiomove(9F) may be used to transfer data to some programmed I/O devices. uiomove(9F) transfers data between the user space (defined by the uio(9S) structure) and the kernel. uiomove(9F) can handle page faults, so the memory to which data is transferred need not be locked down. It also updates the uio_resid field in the uio(9S) structure. Code Example 9-3 shows one way to write a ramdisk read(9E) routine. It uses synchronous I/O and relies on the presence of the following fields in the ramdisk state structure:

```
    caddr_t     ram;        /* base address of ramdisk */
    int         ramsize;    /* size of the ramdisk */
```

Code Example 9-3 Ramdisk read(9E) Routine Using uiomove(9F)

```
static int
rd_read(dev_t dev, struct uio *uiop, cred_t *credp)
{
    rd_devstate_t *rsp;

    rsp = ddi_get_soft_state(rd_statep, getminor(dev));
    if (rsp == NULL)
        return (ENXIO);
    if (uiop->uio_offset >= rsp->ramsize)
        return (EINVAL);
    /*
     * uiomove takes the offset into the kernel buffer,
     * the data transfer count (minimum of the requested and
     * the remaining data), the UIO_READ flag, and a pointer
     * to the uio structure.
     */
    return (uiomove(rsp->ram + uiop->uio_offset,
        min(uiop->uio_resid, rsp->ramsize - uiop->uio_offset),
        UIO_READ, uiop));
}
```

uwritec( ) *and* ureadc( )

Another example of programmed I/O might be a driver writing data one byte at a time directly to the device's memory. Each byte is retrieved from the uio(9S) structure using uwritec(9F), then sent to the device. read(9E) can use ureadc(9F) to transfer a byte from the device to the area described by the uio(9S) structure.

Code Example 9-4 Programmed I/O write(9E) Routine Using uwritec(9F)

```
static int
xxwrite(dev_t dev, struct uio *uiop, cred_t *credp)
{
    int value;
    struct xxstate *xsp;

    xsp = ddi_get_soft_state(statep, getminor(dev));
    if (xsp == NULL)
        return (ENXIO);
    if the device implements a power manageable component, do this:
    pm_busy_component(xsp->dip, 0);
    if (xsp->pm_suspended)
        ddi_dev_is_needed(xsp->dip, normal power);

    while (uiop->uio_resid > 0) {
        /*
         * do the programmed I/O access
         */
        value = uwritec(uiop);
        if (value == -1)
            return (EFAULT);
        ddi_put8(xsp->data_access_handle, &xsp->regp->data,
            (uint8_t)value);
        ddi_put8(xsp->data_access_handle, &xsp->regp->csr,
            START_TRANSFER);
        /*
         * this device requires a ten microsecond delay
         * between writes
         */
        drv_usecwait(10);
    }
    pm_idle_component(xsp->dip, 0);
    return (0);
}
```

DMA Transfers (Synchronous)

Most character drivers use `physio`(9F) to do most of the setup work for DMA transfers in `read`(9E) and `write`(9E). This is shown in Code Example 9-5.

```
int physio(int (*strat)(struct buf *), struct buf *bp,
    dev_t dev, int rw, void (*mincnt)(struct buf *),
    struct uio *uio);
```

`physio`(9F) requires the driver to provide the address of a `strategy`(9E) routine. `physio`(9F) ensures that memory space is locked down (cannot be paged out) for the duration of the data transfer. This is necessary for DMA transfers because they cannot handle page faults. `physio`(9F) also provides an automated way of breaking a larger transfer into a series of smaller, more manageable ones. See “minphys( )” on page 191 for more information.

Code Example 9-5 `read`(9E) and `write`(9E) Routines Using `physio`(9F)

```
static int
xxread(dev_t dev, struct uio *uiop, cred_t *credp)
{
    struct xxstate *xsp;
    int ret;

    xsp = ddi_get_soft_state(statep, getminor(dev));
    if (xsp == NULL)
        return (ENXIO);
    ret = physio(xxstrategy, NULL, dev, B_READ, xxminphys, uiop);
    pm_idle_component(xsp->dip, 0);
    return (ret);
}

static int
xxwrite(dev_t dev, struct uio *uiop, cred_t *credp)
{
    struct xxstate *xsp;
    int ret;
    xsp = ddi_get_soft_state(statep, getminor(dev));
    if (xsp == NULL)
        return (ENXIO);
    ret = physio(xxstrategy, NULL, dev, B_WRITE, xxminphys, uiop);
    pm_idle_component(xsp->dip, 0);
    return (ret);
}
```

In the call to `physio`(9F), `xxstrategy` is a pointer to the driver strategy routine. Passing `NULL` as the `buf`(9S) structure pointer tells `physio`(9F) to allocate a `buf`(9S) structure. If it is necessary for the driver to provide `physio`(9F) with a `buf`(9S) structure, `getrbuf`(9F) should be used to allocate one. `physio`(9F) returns zero if the transfer completes successfully, or an error number on failure. After calling `strategy`(9E), `physio`(9F) calls `biowait`(9F) to block until the transfer is completed or fails. The return value of `physio`(9E) is determined by the error field in the `buf`(9S) structure set by `bioerror`(9F).

DMA Transfers (Asynchronous)

Character drivers supporting `aread`(9E) and `awrite`(9E) use `aphysio`(9F) instead of `physio`(9F).

```
int aphysio(int (*strat)(struct buf *), int (*cancel)(struct buf *),
    dev_t dev, int rw, void (*mincnt)(struct buf *),
    struct aio_req *aio_reqp);
```

Note – The address of `anocancel`(9F) is the only value that can currently be passed as the second argument to `aphysio`(9F).

`aphysio`(9F) requires the driver to pass the address of a `strategy`(9E) routine. `aphysio`(9F) ensures that memory space is locked down (cannot be paged out) for the duration of the data transfer. This is necessary for DMA transfers because they cannot handle page faults. `aphysio`(9F) also provides an automated way of breaking a larger transfer into a series of smaller, more manageable ones. See “minphys( )” on page 191 for more information. Code examples 8-6 and 8-7 demonstrate that the `aread`(9E) and `awrite`(9E) entry points differ only slightly from the `read`(9E) and `write`(9E) entry points; the difference lies mainly in their use of `aphysio`(9F) instead of `physio`(9F).

Code Example 9-6 aread(9E) and awrite(9E) Routines Using aphysio(9F)

```
static int
xxaread(dev_t dev, struct aio_req *aiop, cred_t *cred_p)
{
    struct xxstate *xsp;

    xsp = ddi_get_soft_state(statep, getminor(dev));
    if (xsp == NULL)
        return (ENXIO);
    return (aphysio(xxstrategy, anocancel, dev, B_READ,
                xxminphys, aiop));
}

static int
xxawrite(dev_t dev, struct aio_req *aiop, cred_t *cred_p)
{
    struct xxstate *xsp;

    xsp = ddi_get_soft_state(statep, getminor(dev));
    if (xsp == NULL)
        return (ENXIO);
    return (aphysio(xxstrategy, anocancel, dev, B_WRITE,
               xxminphys,aiop));
}
```

In the call to aphysio(9F), xxstrategy is a pointer to the driver strategy routine. aiop is a pointer to the aio_req(9S) structure and is also passed to aread(9E) and awrite(9F). aio_req(9S) describes where the data is to be stored in user space. aphysio(9F) returns zero if the I/O request is scheduled successfully or an error number on failure. After calling strategy(9E), aphysio(9F) returns without waiting for the I/O to complete or fail.

minphys( )

xxminphys is a pointer to a function to be called by physio(9F) or aphysio(9F) to ensure that the size of the requested transfer does not exceed a driver-imposed limit. If the user requests a larger transfer, strategy(9E) will be called repeatedly, requesting no more than the imposed limit at a time. This is important because DMA resources are limited. Drivers for slow devices, such as printers, should be careful not to tie up resources for a long time.

Usually, a driver passes the address of the kernel function `minphys`(9F), but the driver can define its own `xxminphys`() routine instead. The job of `xxminphys`() is to keep the `b_bcount` field of the `buf`(9S) structure below a driver limit. There may be additional system limits that the driver should not circumvent, so the driver `xxminphys`() routine should call the system `minphys`(9F) routine after setting the `b_bcount` field and before returning.

Code Example 9-7 `minphys`(9F) Routine

```
#define XXMINVAL (512 << 10)/* 512 KB */

static void
xxminphys(struct buf *bp)
{
    if (bp->b_bcount > XXMINVAL)
        bp->b_bcount = XXMINVAL
    minphys(bp);
}
```

strategy( )

The `strategy`(9E) routine originated in block drivers and is so called because it can implement a strategy for efficient queuing of I/O requests to a block device. A driver for a character-oriented device can also use a `strategy`(9E) routine. In the character I/O model presented here, `strategy`(9E) does not maintain a queue of requests, but rather services one request at a time.

In Code Example 9-8, the `strategy`(9E) routine for a character-oriented DMA device allocates DMA resources for synchronous data transfer and starts the command by programming the device register (see Chapter 7, “DMA,” for a detailed description).

Note – `strategy`(9E) does not receive a device number (`dev_t`) as a parameter; instead, this is retrieved from the `b_edev` field of the `buf`(9S) structure passed to `strategy`(9E).

Code Example 9-8 `strategy`(9E) Routine

```
static int
xxstrategy(struct buf *bp)
{
    minor_t             instance;
    struct xxstate      *xsp;
    ddi_dma_cookie_t    cookie;

    instance = getminor(bp->b_edev);
    xsp = ddi_get_soft_state(statep, instance);
    ...
    if the device has power manageable components (see Chapter 8, “Power Management),
    mark the device busy with pm_busy_components(9F), and then ensure that the device
    is powered up by calling ddi_dev_is_needed(9F).

    set up DMA resources with ddi_dma_alloc_handle(9F) and
    ddi_dma_buf_bind_handle(9F).

    xsp->bp = bp; /* remember bp */

    program DMA engine and start command

    return (0);
}
```

Note – Although `strategy`(9E) is declared to return an `int`, it must always return zero.

On completion of the DMA transfer, the device generates an interrupt, causing the interrupt routine to be called. In Code Example 9-9, `xxintr`() receives a pointer to the state structure for the device that might have generated the interrupt.

Code Example 9-9 Interrupt Routine

```
static u_int
xxintr(caddr_t arg)
{
    struct xxstate *xsp = (struct xxstate *)arg;

    if (device did not interrupt) {
        return (DDI_INTR_UNCLAIMED);
    }

    if (error) {
        error handling
    }

    release any resources used in the transfer, such as DMA resources
    (ddi_dma_unbind_handle(9F) and ddi_dma_free_handle(9F))

    /* notify threads that the transfer is complete */
    biodone(xsp->bp);
    return (DDI_INTR_CLAIMED);
}
```

The driver indicates an error by calling `bioerror`(9F). The driver must call `biodone`(9F) when the transfer is complete or after indicating an error with `bioerror`(9F).

Mapping Device Memory

Some devices, such as frame buffers, have memory that is directly accessible to user threads by way of memory mapping. Drivers for these devices typically do not support the `read`(9E) and `write`(9E) interfaces. Instead, these drivers support memory mapping with the `devmap`(9E) entry point. A typical example is a frame buffer driver that implements the `devmap`(9E) entry point to allow the frame buffer to be mapped in a user thread.

segmap( )

```
int xxsegmap(dev_t dev, off_t off, struct as *asp, caddr_t *addrp,
    off_t len, unsigned int prot, unsigned int maxprot,
    unsigned int flags, cred_t *credp);
```

`segmap`(9E) is the entry point responsible for actually setting up a memory mapping requested by the system on behalf of an `mmap`(2) system call. Drivers for many memory-mapped devices will use `ddi_devmap_segmap`(9F) as the entry point rather than define their own `segmap`(9E) routine.

If a driver wants to check mapping permissions or allocate private mapping resources before setting up the mapping, the driver can provide its own `segmap`(9E) entry point. `segmap`(9E) must call `devmap_setup`(9F) before returning.

In Code Example 9-10, the driver controls a frame buffer that allows `write-only` mappings. The driver returns `EINVAL` if the application tries to gain read access and then calls `devmap_setup`(9F) to set up the user mapping.

Code Example 9-10 `segmap`(9E) Routine

```
static int
xxsegmap(dev_t dev, off_t off, struct as *asp, caddr_t *addrp,
    off_t len, unsigned int prot, unsigned int maxprot,
    unsigned int flags, cred_t *credp)
```

```
{
    if (prot & PROT_READ)
        return (EINVAL);
    return (devmap_setup(dev, (offset_t)off, as, addrp, (size_t)len,
                prot, maxprot, flags, cred));
}
```

devmap( )

```
int xxdevmap(dev_t dev, devmap_cookie_t handle, offset_t off,
    size_t len, size_t *maplen, uint_t model);
```

This entry point is called to export device memory or kernel memory to user applications. `devmap`(9E) is called from `devmap_setup`(9F) inside `segmap`(9E) or on behalf of `ddi_devmap_segmap`(9F). See Chapter 11, “Mapping Device or Kernel Memory” and Chapter 12, “Device Context Management” for details.

Multiplexing I/O on File Descriptors

A thread sometimes needs to handle I/O on more than one file descriptor. One example is an application program that needs to read the temperature from a temperature-sensing device and then report the temperature to an interactive display. If the program makes a read request and there is no data available, it should not block waiting for the temperature before interacting with the user again.

The `poll`(2) system call provides users with a mechanism for multiplexing I/O over a set of file descriptors that reference open files. `poll`(2) identifies those file descriptors on which a program can send or receive data without blocking, or on which certain events have occurred.

To allow a program to poll a character driver, the driver must implement the `chpoll`(9E) entry point.

Adding Polling to the the State Structure

This section adds the following field to the state structure. See “Software State Structure” on page 63 for more information.

```
    struct pollhead pollhead; /* for chpoll(9E)/pollwakeup(9F) */
```

chpoll( )

```
int xxchpoll(dev_t dev, short events, int anyyet, short *reventsp,
    struct pollhead **phpp);
```

The system calls `chpoll`(9E) when a user process issues a `poll`(2) system call on a file descriptor associated with the device. The `chpoll`(9E) entry point routine is used by non-STREAMS character device drivers that need to support polling.

In `chpoll`(9E), the driver must follow these rules:

- Implement the following algorithm when the `chpoll`(9E) entry point is called:

  ```
  if (events are satisfied now) {
      *reventsp = mask of satisfied events;
  } else {
      *reventsp = 0;
      if (!anyyet)
          *phpp = & local pollhead structure;
  }
  return (0);
  ```

  `xxchpoll`( ) should check to see if certain events have occurred; see `chpoll`(9E). It should then return the mask of satisfied events by setting the return events in `*reventsp`.

  If no events have occurred, the return field for the events is cleared. If the `anyyet` field is not set, the driver must return an instance of the `pollhead` structure. It is usually allocated in a state structure and should be treated as opaque by the driver. None of its fields should be referenced.

- Call `pollwakeup`(9F) whenever a device condition of type `events`, listed in Code Example 9-11, occurs. This function should be called only with one event at a time. `pollwakeup`(9F) might be called in the interrupt routine when the condition has occurred.

Code Example 9-11 and Code Example 9-12 show how to implement the polling discipline and how to use `pollwakeup`(9F).

Code Example 9-11 `chpoll`(9E) Routine

```
static int
xxchpoll(dev_t dev, short events, int anyyet,
    short *reventsp, struct pollhead **phpp)
{
    uint8_t status;
    short revent;
    struct xxstate *xsp;

    xsp = ddi_get_soft_state(statep, getminor(dev));
    if (xsp == NULL)
        return (ENXIO);
    revent = 0;
    /*
     * Valid events are:
     * POLLIN | POLLOUT | POLLPRI | POLLHUP | POLLERR
     * This example checks only for POLLIN and POLLERR.
     */
    status = ddi_get8(xsp->data_access_handle, &xsp->regp->csr);
    if ((events & POLLIN) && data available to read) {
        revent |= POLLIN;
    }
    if ((events & POLLERR) && (status & DEVICE_ERROR)) {
        revent |= POLLERR;
    }
    /* if nothing has occurred */
    if (revent == 0) {
        if (!anyyet) {
            *phpp = &xsp->pollhead;
        }
    }
    *reventsp = revent;
    return (0);
}
```

In Code Example 9-12, the driver can handle the `POLLIN` and `POLLERR` events (see `chpoll`(9E) for a detailed discussion of the available events). The driver first reads the status register to determine the current state of the device. The parameter `events` specifies which conditions the driver should check. If the appropriate conditions have occurred, the driver sets that bit in `*reventsp`. If none of the conditions have occurred and `anyyet` is not set, the address of the `pollhead` structure is returned in `*phpp`.

Code Example 9-12 Interrupt Routine Supporting `chpoll`(9E)

```
static u_int
xxintr(caddr_t arg)
{
    struct xxstate *xsp = (struct xxstate *)arg;
    uint8_t status;

    normal interrupt processing
    ...
    status = ddi_get8(xsp->data_access_handle, &xsp->regp->csr);
    if (status & DEVICE_ERROR) {
        pollwakeup(&xsp->pollhead, POLLERR);
    }
    if (just completed a read) {
        pollwakeup(&xsp->pollhead, POLLIN);
    }
    ...
    return (DDI_INTR_CLAIMED);
}
```

`pollwakeup`(9F) is usually called in the interrupt routine when a supported condition has occurred. The interrupt routine reads the status from the status register and checks for the conditions. It then calls `pollwakeup`(9F) for each event to possibly notify polling threads that they should check again. Note that `pollwakeup`(9F) should not be called with any locks held, as it could cause the `chpoll`(9E) routine to be entered, resulting in deadlock if that routine tries to grab the same lock.

Miscellaneous I/O Control

The `ioctl`(9E) routine is called when a user thread issues an `ioctl`(2) system call on a file descriptor associated with the device. The I/O control mechanism is a catchall for getting and setting device-specific parameters. It is frequently used to set a device-specific mode, either by setting internal driver software flags or by writing commands to the device. It can also be used to return information to the user about the current device state. In short, it can do whatever the application and driver need it to do.

ioctl( )

```
int xxioctl(dev_t dev, int cmd, intptr_t arg, int mode,
    cred_t *credp, int *rvalp);
```

The `cmd` parameter indicates which command `ioctl`(9E) should perform. By convention, I/O control commands indicate the driver they belong to in bits 8-15 of the command (usually given by the ASCII code of a character representing the driver), and the driver-specific command in bits 0-7. They are usually created in the following way:

```
#define XXIOC  ('x' << 8) /* 'x' is a character representing */
                          /* device xx */

#define XX_GET_STATUS  (XXIOC | 1) /* get status register */
#define XX_SET_CMD     (XXIOC | 2) /* send command */
```

The interpretation of `arg` depends on the command. I/O control commands should be documented (in the driver documentation, or a manual page) and defined in a public header file, so that applications can determine the names, what they do, and what they accept or return as `arg`. Any data transfer of `arg` (into or out of the driver) must be performed by the driver.

`ioctl`(9E) is usually a switch statement with a case for each supported `ioctl`(9E) request.

Code Example 9-13 `ioctl`(9E) routine

```
static int
xxioctl(dev_t dev, int cmd, intptr_t arg, int mode,
    cred_t *credp, int *rvalp)
{
    uint8_t        csr;
    struct xxstate *xsp;

    xsp = ddi_get_soft_state(statep, getminor(dev));
    if (xsp == NULL) {
        return (ENXIO);
    }
    switch (cmd) {
    case XX_GET_STATUS:
        csr = ddi_get8(xsp->data_access_handle, &xsp->regp->csr);
        if (ddi_copyout(&csr, (void *)arg,
                sizeof (uint8_t), mode) != 0) {
            return (EFAULT);
        }
        break;
    case XX_SET_CMD:
        if (ddi_copyin((void *)arg, &csr,
                sizeof (uint8_t), mode) != 0) {
            return (EFAULT);
        }
        ddi_put8(xsp->data_access_handle, &xsp->regp->csr, csr);
        break;
    default:
        /* generic “ioctl unknown” error */
        return (ENOTTY);
    }
    return (0);
}
```

The `cmd` variable identifies a specific device control operation. If `arg` contains a user virtual address, `ioctl`(9E) must call `ddi_copyin`(9F) or `ddi_copyout`(9F) to transfer data between the data structure in the application program pointed to by `arg` and the driver. In Code Example 9-13, for the case of an `XX_GET_STATUS` request the contents of `xsp->regp->csr` are copied to the address in `arg`. When a request succeeds, `ioctl`(9E) can store in `*rvalp` any integer value to be the return value of the `ioctl`(2) system call that made the request. Negative return values, such as -1, should be avoided, as they usually indicate the system call failed, and many application programs assume that negative values indicate failure.

An application that uses the I/O controls discussed above could look like Code Example 9-14.

Code Example 9-14 Using `ioctl`(2)

```
#include <sys/types.h>
#include “xxio.h”/* contains device’s ioctl cmds and arguments */

int
main(void)
{
    uint8_t status;
    ...

    /*
     * read the device status
     */
    if (ioctl(fd, XX_GET_STATUS, &status) == -1) {
        error handling
    }
    printf("device status %x\n", status);
    exit(0);
}
```

I/O Control Support for 64-Bit Capable Device Drivers

In future releases, the Solaris kernel will be capable of running in 64-bit mode on suitable hardware and will support both 32-bit and 64-bit applications. A 64-bit device driver will be required to support I/O control commands from 32-bit and 64-bit user mode programs. The difference between a 32-bit program and a 64-bit program is its C language type model: a 32-bit program is ILP32 and a 64-bit program is LP64. See Appendix F, “Making a Device Driver 64-Bit Ready,” for information on C data type models.

Any data that flows between programs and the kernel and vice versa (for example using `ddi_copyin`(9F) or `ddi_copyout`(9F)) will either need to be identical in format regardless of the type model of the kernel and application, or the device driver should be able to handle a model mismatch between it and the application and adjust the data format accordingly.

To determine if there is a model mismatch, the `ioctl`(9E) `mode` parameter passes the data model bits to the driver. If `FILP32` is set, data from the application uses the `ILP32` data model. If `FLP64` is set, the data uses the `LP64` data model. As Code Example 9-15 shows, the `mode` parameter is then passed to `ddi_model_convert_from`(9F) to determine if any model conversion is necessary.

In the following example, the driver copies a data structure which contains a user address. Because the data structure changes size from `ILP32` to `LP64`, the 64-bit driver uses a 32-bit version of the structure when communicating with a 32-bit application.

Code Example 9-15 `ioctl`(9E) Routine to Support 32-bit and 64-bit Applications

```
struct args32 {
    uint32_t addr;/* 32-bit address in LP64 */
    int len;
}
```

```
struct args {
    caddr_t addr;/* 64-bit address in LP64 */
    int len;
}


static int
xxioctl(dev_t dev, int cmd, intptr_t arg, int mode,
    cred_t *credp, int *rvalp)
{
    struct xxstate *xsp;
    struct args a;

    xsp = ddi_get_soft_state(statep, getminor(dev));
    if (xsp == NULL) {
        return (ENXIO);
    }
    switch (cmd) {
    case XX_COPYIN_DATA:

        switch(ddi_model_convert_from(mode & FMODELS)) {
        case DDI_MODEL_ILP32:
        {
            struct args32 a32;

            /* copy 32-bit args data shape */
            if (ddi_copyin((void *)arg, &a32,
                sizeof (struct args32), mode) != 0) {
                    return (EFAULT);
            }

            /* convert 32-bit to 64-bit args data shape */
            a.addr = a32.addr;
            a.len = a32.len;
            break;
        }
        case DDI_MODEL_NONE:

            /* application and driver have same data model. */
            if (ddi_copyin((void *)arg, &a, sizeof (struct args),
                mode) != 0) {
                    return (EFAULT);
            }
        }

        /* continue using data shape in native driver data model. */
        break;
    case XX_COPYOUT_DATA:
            /* copyout handling */
            break;
        default:
            /* generic “ioctl unknown” error */
            return (ENOTTY);
        }
        return (0);
    }
```

Drivers for Block Devices 10

This chapter describes the structure of block device drivers. The kernel views a block device as a set of randomly accessible logical blocks. The file system buffers the data blocks between a block device and the user space using a list of `buf`(9S) structures. Only block devices can support a file system. For information on writing disk drivers that support SunOS disk commands (such as `format`(1M)) see Appendix G, "Advanced Topics."

Block Driver Structure Overview

Figure 10-1 on page 206 shows data structures and routines that define the structure of a block device driver. Device drivers typically include the following:

- Device-loadable driver section
- Device configuration section
- Device access section

Block Driver Device Access

The shaded device access section in Figure 10-1 illustrates block driver entry points.

Note – For a description of character drivers and character driver device access, see Chapter 9, "Drivers for Character Devices."

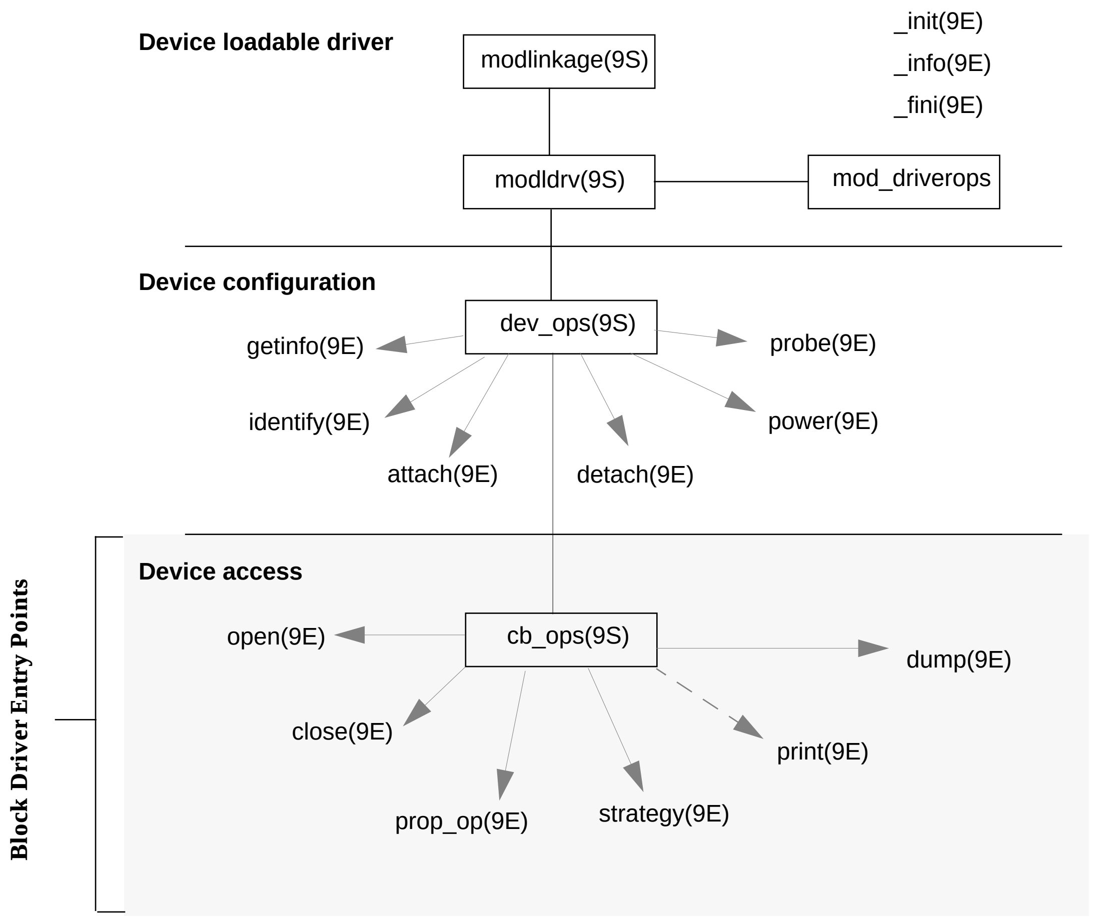


Figure 10-1 Block Driver Roadmap

File I/O

A file system is a tree-structured hierarchy of directories and files. Some file systems, such as the UNIX File System (UFS), reside on block-oriented devices. File systems are created by `mkfs`(1M) and `newfs`(1M).

When an application issues a `read`(2) or `write`(2) system call to an ordinary file on the UFS file system, the file system may call the device driver `strategy`(9E) entry point for the block device on which the file resides. The file system code may call `strategy`(9E) several times for a single `read`(2) or `write`(2) system call.

It is the file system code that determines the logical device address, or *logical block number*, for each block and builds a block I/O request in the form of a `buf`(9S) structure. The driver `strategy`(9E) entry point then interprets the `buf`(9S) structure and completes the request.

State Structure

This chapter adds the following fields to the state structure. See "Software State Structure" on page 63 for more information.

```
int         nblocks;        /* size of device */
int         open;           /* flag indicating device is open */
int         nlayered;       /* count of layered opens */
struct buf *list_head;      /* head of transfer request list */
struct buf *list_tail;      /* tail of transfer request list */
```

Entry Points

Associated with each device driver is a `dev_ops`(9S) structure, which in turn refers to a `cb_ops`(9S) structure. See Chapter 5, "Autoconfiguration," for details regarding driver data structures. Table 10-1 lists the block driver entry points.

Table 10-1 Block Driver Entry Points

Entry Point	Description
`_init`(9E)	Initializes a loadable driver module.
`_info`(9E)	Returns information on a loadable driver module.
`_fini`(9E)	Prepares a loadable driver module for unloading.

Table 10-1 Block Driver Entry Points *(Continued)*

Entry Point	Description
`identify`(9E)	Obsolete and no longer required. Set to `nulldev`(9F).
`probe`(9E)	Determines if a device is present.
`attach`(9E)	Performs device-specific initialization and/or power management resume functionality..
`detach`(9E)	Removes device-specific state and/or power management suspend functionality..
`getinfo`(9E)	Gets device driver information.
`power`(9E)	Sets the power level of a device component.
`dump`(9E)	Dumps memory to the device during system failure.
`open`(9E)	Gains access to a device.
`close`(9E)	Relinquishes access to a device.
`prop_op`(9E)	Manages arbitrary driver properties.
`print`(9E)	Prints error message on driver failure.
`strategy`(9E)	I/O interface for block data.

Note – Some of the entry points listed in Table 10-1 can be replaced by `nodev`(9F) or `nulldev`(9F) as appropriate.

Autoconfiguration

`attach`(9E) should perform the common initialization tasks for each instance of a device. Typically, these tasks include:

- Allocating per-instance state structures
- Mapping the device's registers
- Registering device interrupts
- Initializing mutex and condition variables
- Creating power mangeable components
- Creating minor nodes

Block device drivers create minor nodes of type `S_IFBLK`. This causes a block special file representing the node to eventually appear in the `/devices` hierarchy.

Logical device names for block devices appear in the /dev/dsk directory, and consist of a controller number, bus-address number, disk number, and slice number. These names are created by the disks(1M) program if the node type is set to DDI_NT_BLOCK or DDI_NT_BLOCK_CHAN. DDI_NT_BLOCK_CHAN should be specified if the device communicates on a channel (a bus with an additional level of addressability), such as SCSI disks, and causes a bus-address field (tN) to appear in the logical name. DDI_NT_BLOCK should be used for most other devices.

For each minor device (which corresponds to each partition on the disk), the driver must also create an nblocks property. This is an integer property giving the number of blocks supported by the minor device expressed in units of DEV_BSIZE (512 bytes). The file system uses the nblocks property to determine device limits. See “Properties” on page 65 for details.

Code Example 10-1 shows a typical attach(9E) entry point with emphasis on creating the device’s minor node and the nblocks property.

Code Example 10-1 Block Driver attach(9E) Routine

```
static int
xxattach(dev_info_t *dip, ddi_attach_cmd_t cmd)
{
    switch (cmd) {
    case DDI_ATTACH:
        allocate a state structure and initialize it
        map the devices registers
        add the device driver’s interrupt handler(s)
        initialize any mutexs and condition variables
        read label information if the device is a disk
        create power manageable components

        /*
         * Create the device minor node. Note that the node_type
         * argument is set to DDI_NT_BLOCK.
         */
        if (ddi_create_minor_node(dip, “minor_name”, S_IFBLK,
            minor_number,  DDI_NT_BLOCK, 0) == DDI_FAILURE) {
            free resources allocated so far
            /* Remove any previously allocated minor nodes */
            ddi_remove_minor_node(dip, NULL);
            return (DDI_FAILURE);
        }
        /*
         * Create driver properties like “nblocks”. If the device
         * is a disk, the nblocks property is usually calculated from
         * information in the disk label.
         */
        xsp->nblocks = size of device in 512 byte blocks;
        if (ddi_prop_update_int(makedevice(DDI_MAJOR_T_UNKNOWN,
            instance), dip, “nblocks”, xsp->nblocks)
            != DDI_PROP_SUCCESS) {
            cmn_err(CE_CONT, “%s: cannot create nblocks property\n”,
                ddi_get_name(dip));
            free resources allocated so far
            return (DDI_FAILURE);
        }
        xsp->open = 0;
        xsp->nlayered = 0;
        ...
        return (DDI_SUCCESS);
    case DDI_PM_RESUME:
        For information, see Chapter 8, “Power Management”
    case DDI_RESUME:
        For information, see Chapter 8, “Power Management”
    default:
        return (DDI_FAILURE);
    }
}
```

Properties are associated with device numbers. In Code Example 10-1, `attach`(9E) builds a device number using `makedevice`(9F). At this point, however, only the minor number component of the device number is known, so it must use the special major number `DDI_MAJOR_T_UNKNOWN` to build the device number.

Controlling Device Access

This section describes aspects of the open(9E) and close(9E) entry points that are specific to block device drivers. See Chapter 9, "Drivers for Character Devices," for more information on open(9E) and close(9E).

open( )

```
int xxopen(dev_t *devp, int flag, int otyp, cred_t *credp)
```

The open(9E) entry point is used to gain access to a given device. The open(9E) routine of a block driver is called when a user thread issues an open(2) or mount(2) system call on a block special file associated with the minor device, or when a layered driver calls open(9E). See "File I/O" on page 207 for more information.

The open(9E) entry point should check for the following:

- The device can be opened; for example, it is online and ready.
- The device can be opened as requested; the device supports the operation, and the device's current state does not conflict with the request.
- The caller has permission to open the device.

Code Example 10-2 demonstrates a block driver open(9E) entry point.

Code Example 10-2 Block Driver open(9E) Routine

```
static int
xxopen(dev_t *devp, int flags, int otyp, cred_t *credp)
{
    minor_t instance;
    struct xxstate *xsp;

    instance = getminor(*devp);
    xsp = ddi_get_soft_state(statep, instance);
    if (xsp == NULL)
        return (ENXIO);
    mutex_enter(&xsp->mu);
    /*
     * only honor FEXCL. If a regular open or a layered open
     * is still outstanding on the device, the exclusive open
     * must fail.
     */
    if ((flags & FEXCL) && (xsp->open || xsp->nlayered)) {
        mutex_exit(&xsp->mu);
        return (EAGAIN);
    }
    switch (otyp) {
    case OTYP_LYR:
        xsp->nlayered++;
        break;
    case OTYP_BLK:
        xsp->open = 1;
        break;
    default:
        mutex_exit(&xsp->mu);
        return (EINVAL);
    }
    mutex_exit(&xsp->mu);
    return (0);
}
```

The `otyp` argument is used to specify the type of open on the device. `OTYP_BLK` is the typical open type for a block device. A device may be opened several times with `otyp` set to `OTYP_BLK`, although `close`(9E) will be called only once when the final close of type `OTYP_BLK` has occurred for the device. `otyp` is set to `OTYP_LYR` if the device is being used as a layered device. For every open of type `OTYP_LYR`, the layering driver issues a corresponding close of type `OTYP_LYR`. The example keeps track of each type of open so the driver can determine when the device is not being used in `close`(9E). See the `open`(9E) manual page for more details about the `otyp` argument.

close( )

```
int xxclose(dev_t dev, int flag, int otyp, cred_t *credp)
```

The arguments of the `close`(9E) entry point are identical to arguments of `open`(9E), except that `dev` is the device number, as opposed to a pointer to the device number.

The `close`(9E) routine should verify `otyp` in the same way as was described for the `open`(9E) entry point. In Code Example 10-3, `close`(9E) must determine when the device can really be closed based on the number of block opens and layered opens.

Code Example 10-3 Block Device `close`(9E) Routine

```
static int
xxclose(dev_t dev, int flag, int otyp, cred_t *credp)
{
    minor_t instance;
    struct xxstate *xsp;

    instance = getminor(dev);
    xsp = ddi_get_soft_state(statep, instance);
    if (xsp == NULL)
        return (ENXIO);
    mutex_enter(&xsp->mu);
    switch (otyp) {
    case OTYP_LYR:
        xsp->nlayered--;
        break;
    case OTYP_BLK:
        xsp->open = 0;
        break;
    default:
        mutex_exit(&xsp->mu);
        return (EINVAL);
    }
    if (xsp->open || xsp->nlayered) {
        /* not done yet */
        mutex_exit(&xsp->mu);
        return (0);
    }
    /* cleanup (rewind tape, free memory, etc.) */
    /* wait for I/O to drain */
    mutex_exit(&xsp->mu);

    return (0);
}
```

10

Data Transfers

Most block drivers use the strategy(9F) entry point to transfer data.

strategy( )

```
int xxstrategy(struct buf *bp)
```

The strategy(9E) entry point is used to read and write data buffers to and from a block device. The name *strategy* refers to the fact that this entry point may implement some optimal strategy for ordering requests to the device.

strategy(9E) can be written to process one request at a time (synchronous transfer), or to queue multiple requests to the device (asynchronous transfer). When choosing a method, the abilities and limitations of the device should be taken into account.

The strategy(9E) routine is passed a pointer to a buf(9S) structure. This structure describes the transfer request, and contains status information on return. buf(9S) and strategy(9E) are the focus of block device operations.

buf *Structure*

The following buf structure members are important to block drivers:

```
int             b_flags;    /* Buffer Status */
struct buf      *av_forw;   /* Driver work list link */
struct buf      *av_back;   /* Driver work lists link */
size_t          b_bcount;   /* # of bytes to transfer */
union {
    caddr_t     b_addr;     /* Buffer’s virtual address */
} b_un;
daddr_t         b_blkno;    /* Block number on device */
diskaddr_t      b_lblkno;   /* Expanded block number on device */
size_t          b_resid;    /* # of bytes not transferred */
                            /* after error */
int             b_error;    /* Expanded error field */
void            *b_private;/* “opaque” driver private area */
dev_t           b_edev;     /* expanded dev field */
```

b_flags contains status and transfer attributes of the buf structure. If B_READ is set, the buf structure indicates a transfer from the device to memory, otherwise it indicates a transfer from memory to the device. If the driver encounters an error during data transfer, it should set the B_ERROR field in the b_flags member and provide a more specific error value in b_error. Drivers should use bioerror(9F) rather than setting B_ERROR.

Caution – Drivers should never clear b_flags.

av_forw and av_back are pointers that the driver can use to manage a list of buffers by the driver. See “Asynchronous Data Transfers” on page 220 for a discussion of the av_forw and av_back pointers.

b_bcount specifies the number of bytes to be transferred by the device.

b_un.b_addr is the kernel virtual address of the data buffer.

b_blkno is the starting 32-bit logical block number on the device for the data transfer, expressed in DEV_BSIZE (512 bytes) units. The driver should use either b_blkno or b_lblkno, but not both.

b_lblkno is the starting 64-bit logical block number on the device for the data transfer, expressed in DEV_BSIZE (512 bytes) units. The driver should use either b_blkno or b_lblkno, but not both.

b_resid is set by the driver to indicate the number of bytes that were not transferred because of an error. See Code Example 10-8 for an example of setting b_resid. The b_resid member is overloaded: it is also used by disksort(9F).

b_error is set to an error number by the driver when a transfer error occurs. It is set in conjunction with the b_flags B_ERROR bit. See Intro(9E) for details regarding error values. Drivers should use bioerror(9F) rather than setting b_error directly.

b_private is for exclusive use by the driver to store driver-private data.

b_edev contains the device number of the device involved in the transfer.

bp_mapin( )

When a buf structure pointer is passed into the device driver’s strategy(9E) routine, the data buffer referred to by b_un.b_addr is not necessarily mapped in the kernel’s address space. This means that the driver cannot directly access the data. Most block-oriented devices have DMA capability, and therefore do not need to access the data buffer directly. Instead, they use the DMA mapping routines to allow the device's DMA engine to do the data transfer. For details about using DMA, see Chapter 7, "DMA."

If a driver needs to directly access the data buffer (as opposed to having the device access the data), it must first map the buffer into the kernel's address space using `bp_mapin`(9F). `bp_mapout`(9F) should be used when the driver no longer needs to access the data directly.

Caution – `bp_mapout`(9F) should only be called on buffers which have been allocated and are owned by the device driver. It must not be called on buffers passed to the driver through the `strategy`(9E) entry point (for example a filesystem). Because `bp_mapin`(9F) does not keep a reference count, `bp_mapout`(9F) will remove any kernel mapping that a layer above the device driver might rely on.

Synchronous Data Transfers

This section discusses a simple method for performing synchronous I/O transfers. It assumes that the hardware is a simple disk device that can transfer only one data buffer at a time using DMA, and that the disk can be spun up and spun down by software command**.** The device driver's `strategy`(9E) routine waits for the current request to be completed before accepting a new one. The device interrupts when the transfer is complete or when an error occurs.

1. **Check for invalid `buf`(9S) requests.**

   Check the `buf`(9S) structure passed to `strategy`(9E) for validity. All drivers should check that:

   a. The request begins at a valid block. The driver converts the `b_blkno` field to the correct device offset and then determines if the offset is valid for the device.

   b. The request does not go beyond the last block on the device.

   c. Device-specific requirements are met.

If an error is encountered, the driver should indicate the appropriate error with `bioerror`(9F) and complete the request by calling `biodone`(9F). `biodone`(9F) notifies the caller of `strategy`(9E) that the transfer is complete (in this case, because of an error).

2. **Check if the device is busy.**

   Synchronous data transfers allow single-threaded access to the device. The device driver enforces this by maintaining a busy flag (guarded by a mutex), and by waiting on a condition variable with `cv_wait`(9F) when the device is busy.

   If the device is busy, the thread waits until a `cv_broadcast`(9F) or `cv_signal`(9F) from the interrupt handler indicates that the device is no longer busy. See Chapter 4, “Multithreading,” for details on condition variables.

   When the device is no longer busy, the `strategy`(9E) routine marks it as busy and prepares the buffer and the device for the transfer.

3. **Check if the device is spun up; if it is not, arrange for it to be spun up.**

4. **Set up the buffer for DMA.**

   Prepare the data buffer for a DMA transfer by allocating a DMA handle using `ddi_dma_alloc_handle`(9F) and binding the data buffer to the handle using `ddi_dma_buf_bind_handle`(9F). See Chapter 7, “DMA,” for information on setting up DMA resources and related data structures.

5. **Begin the transfer.**

   At this point, a pointer to the `buf`(9S) structure is saved in the state structure of the device. This is so that the interrupt routine can complete the transfer by calling `biodone`(9F).

   The device driver then accesses device registers to initiate a data transfer. In most cases, the driver should protect the device registers from other threads by using mutexes. In this case, because `strategy`(9E) is single-threaded, guarding the device registers is not necessary. See Chapter 4, “Multithreading,” for details about data locks.

   Once the executing thread has started the device’s DMA engine, the driver can return execution control to the calling routine. (See Code Example 10-4.)

Code Example 10-4 Synchronous Block Driver `strategy`(9E) Routine

```
static int
xxstrategy(struct buf *bp)
{
    struct xxstate *xsp;
    struct device_reg *regp;
    minor_t instance;
    ddi_dma_cookie_t cookie;

    instance = getminor(bp->b_edev);
    xsp = ddi_get_soft_state(statep, instance);
    if (xsp == NULL) {
        bioerror(bp, ENXIO);
        biodone(bp);
        return (0);
    }
    /* validate the transfer request */
    if ((bp->b_blkno >= xsp->nblocks) || (bp->b_blkno < 0)) {
        bioerror(bp, EINVAL);
        biodone(bp);
        return (0);
    }
    /*
     * Hold off all threads until the device is not busy.
     */
    mutex_enter(&xsp->mu);
    while (xsp->busy) {
        cv_wait(&xsp->cv, &xsp->mu);
    }
    xsp->busy = 1;
    mutex_exit(&xsp->mu);
    if the device has power manageable components (see Chapter 8, "Power Management),
    mark the device busy with pm_busy_components(9F), and then ensure that the device
    is powered up by calling ddi_dev_is_needed(9F).

    Set up DMA resources with ddi_dma_alloc_handle(9F)
    and ddi_dma_buf_bind_handle(9F).
    xsp->bp = bp;

    regp = xsp->regp;

    ddi_put32(xsp->data_access_handle, &regp->dma_addr,
            cookie.dmac_address);
    ddi_put32(xsp->data_access_handle, &regp->dma_size,
            (uint32_t)cookie.dmac_size);
    ddi_put8(xsp->data_access_handle, &regp->csr,
            ENABLE_INTERRUPTS | START_TRANSFER);
    return (0);
}
```

6. **Handle the interrupting device.**

   When the device finishes the data transfer it generates an interrupt, which eventually results in the driver's interrupt routine being called. Most drivers specify the state structure of the device as the argument to the interrupt routine when registering interrupts (see `ddi_add_intr`(9F) and "Registering Interrupts" on page 117). The interrupt routine can then access the `buf`(9S) structure being transferred, plus any other information available from the state structure.

   The interrupt handler should check the device's status register to determine if the transfer completed without error. If an error occurred, the handler should indicate the appropriate error with `bioerror`(9F). The handler should also clear the pending interrupt for the device and then complete the transfer by calling `biodone`(9F).

   As the final task, the handler clears the busy flag and calls `cv_signal`(9F) or `cv_broadcast`(9F) on the condition variable, signaling that the device is no longer busy. This allows other threads waiting for the device (in `strategy`(9E)) to proceed with the next data transfer.

Code Example 10-5 Synchronous Block Driver Interrupt Routine

```
static u_int
xxintr(caddr_t arg)
{
    struct xxstate *xsp = (struct xxstate *)arg;
    struct buf *bp;
    uint8_t status;
    mutex_enter(&xsp->mu);
    status = ddi_get8(xsp->data_access_handle, &xsp->regp->csr);
    if (!(status & INTERRUPTING)) {
        mutex_exit(&xsp->mu);
        return (DDI_INTR_UNCLAIMED);
    }
    /* Get the buf responsible for this interrupt */
    bp = xsp->bp;
    xsp->bp = NULL;
    /*
     * This example is for a simple device which either
     * succeeds or fails the data transfer, indicated in the
     * command/status register.
     */
    if (status & DEVICE_ERROR) {
        /* failure */
        bp->b_resid = bp->b_bcount;
        bioerror(bp, EIO);
    } else {
        /* success */
        bp->b_resid = 0;
    }
    ddi_put8(xsp->data_access_handle, &xsp->regp->csr,
        CLEAR_INTERRUPT);
    /* The transfer has finished, successfully or not */
    biodone(bp);
    if the device has power manageable components that were marked busy in
    strategy(9E), mark them idle now with pm_idle_component(9F)

    release any resources used in the transfer, such as DMA resources
    (ddi_dma_unbind_handle(9F) and ddi_dma_free_handle(9F))
    /* Let the next I/O thread have access to the device */
    xsp->busy = 0;
    cv_signal(&xsp->cv);
    mutex_exit(&xsp->mu);
    return (DDI_INTR_CLAIMED);
}
```

Asynchronous Data Transfers

This section discusses a method for performing asynchronous I/O transfers. The driver queues the I/O requests, and then returns control to the caller. Again, the assumption is that the hardware is a simple disk device that allows one transfer at a time. The device interrupts when a data transfer has completed or when an error occurs.

1. **Check for invalid `buf`(9S) requests.**

As in the synchronous case, the device driver should check the `buf`(9S) structure passed to `strategy`(9E) for validity. See “Synchronous Data Transfers” on page 216 for more details.

2. **Enqueue the request.**

   Unlike synchronous data transfers, a driver does not wait for an asynchronous request to complete. Instead, it adds the request to a queue. The head of the queue can be the current transfer, or a separate field in the state structure can be used to hold the active request (as in this example). If the queue was initially empty, then the hardware is not busy, and `strategy`(9E) starts the transfer before returning. Otherwise, whenever a transfer completes and the queue is non-empty, the interrupt routine begins a new transfer. This example actually places the decision of whether to start a new transfer into a separate routine for convenience.

   The `av_forw` and the `av_back` members of the `buf`(9S) structure can be used by the driver to manage a list of transfer requests. A single pointer can be used to manage a singly linked list, or both pointers can be used together to build a doubly-linked list. The driver writer can determine from a hardware specification which type of list management (such as insertion policies) will optimize the performance of the device. The transfer list is a per-device list, so the head and tail of the list are stored in the state structure.

   Code Example 10-6 is designed to allow multiple threads access to the driver shared data, so it is extremely important to identify any such data (such as the transfer list) and protect it with a mutex. See Chapter 4, “Multithreading,” for more details about mutex locks.

Code Example 10-6 Asynchronous Block Driver `strategy`(9E) Routine.

```
static int
xxstrategy(struct buf *bp)
{
    struct xxstate *xsp;
    minor_t instance;

    instance = getminor(bp->b_edev);
    xsp = ddi_get_soft_state(statep, instance);

    ...
    validate transfer request
    ...
```

Add the request to the end of the queue. Depending on the device, a sorting algorithm such as `disksort`*(9F) may be used if it improves the performance of the device.*

```
    mutex_enter(&xsp->mu);
    bp->av_forw = NULL;
    if (xsp->list_head) {
        /* Non-empty transfer list */
        xsp->list_tail->av_forw = bp;
        xsp->list_tail = bp;
    } else {
        /* Empty Transfer list */
        xsp->list_head = bp;
        xsp->list_tail = bp;
    }
    mutex_exit(&xsp->mu);
    /* Start the transfer if possible */
    (void) xxstart((caddr_t)xsp);
    return (0);
}
```

3. Start the first transfer.

Device drivers that implement queuing usually have a `start()` routine. `start()` is so called because it is this routine that dequeues the next request and starts the data transfer to or from the device. In this example, `start()` processes all requests, regardless of the state of the device (busy or free).

Note – `start()` must be written so that it can be called from any context, since it can be called by both the strategy routine (in kernel context) and the interrupt routine (in interrupt context).

`start()` is called by `strategy()` every time it queues a request so that an idle device can be started. If the device is busy, `start()` returns immediately.

`start()` is also called by the interrupt handler before it returns from a claimed interrupt so that a nonempty queue can be serviced. If the queue is empty, `start()` returns immediately.

Since `start()` is a private driver routine, it can take any arguments and return any type. Code Example 10-7 on page 223 is written as if it will also be used as a DMA callback (although that portion is not shown), so it must take a `caddr_t` as an argument and return an `int`. See "Handling Resource Allocation Failures" on page 138 for more information about DMA callback routines.

Code Example 10-7 Block Driver `start()` Routine.

```
static int
xxstart(caddr_t arg)
{
    struct xxstate *xsp = (struct xxstate *)arg;
    struct buf *bp;

    mutex_enter(&xsp->mu);
    /*
     * If there is nothing more to do, or the device is
     * busy, return.
     */
    if (xsp->list_head == NULL || xsp->busy) {
        mutex_exit(&xsp->mu);
        return (0);
    }
    xsp->busy = 1;
    /* Get the first buffer off the transfer list */
    bp = xsp->list_head;
    /* Update the head and tail pointer */
    xsp->list_head = xsp->list_head->av_forw;
    if (xsp->list_head == NULL)
        xsp->list_tail = NULL;
    bp->av_forw = NULL;
    mutex_exit(&xsp->mu);

    if the device has power manageable components (see Chapter 8, "Power Management),
    mark the device busy with pm_busy_components, and then ensure that the device
     is powered up by calling ddi_dev_is_needed.
    Set up DMA resources with ddi_dma_alloc_handle(9F)
    and ddi_dma_buf_bind_handle(9F).
    xsp->bp = bp;
    ddi_put32(xsp->data_access_handle, &xsp->regp->dma_addr,
            cookie.dmac_address);
    ddi_put32(xsp->data_access_handle, &xsp->regp->dma_size,
            (uint32_t)cookie.dmac_size);
    ddi_put8(xsp->data_access_handle, &xsp->regp->csr,
            ENABLE_INTERRUPTS | START_TRANSFER);
    return (0);
}
```

4. **Handle the interrupting device.**

   The interrupt routine is similar to the asynchronous version, with the addition of the call to `start`() and the removal of the call to `cv_signal`(9F).

Code Example 10-8 Asynchronous Block Driver Interrupt Routine

```
static u_int
xxintr(caddr_t arg)
{
    struct xxstate *xsp = (struct xxstate *)arg;
    struct buf *bp;
    uint8_t status;
    mutex_enter(&xsp->mu);
    status = ddi_get8(xsp->data_access_handle, &xsp->regp->csr);
    if (!(status & INTERRUPTING)) {
        mutex_exit(&xsp->mu);
        return (DDI_INTR_UNCLAIMED);
    }
    /* Get the buf responsible for this interrupt */
    bp = xsp->bp;
    xsp->bp = NULL;
    /*
     * This example is for a simple device which either
     * succeeds or fails the data transfer, indicated in the
     * command/status register.
     */
    if (status & DEVICE_ERROR) {
        /* failure */
        bp->b_resid = bp->b_bcount;
        bioerror(bp, EIO);
    } else {
        /* success */
        bp->b_resid = 0;
    }
    ddi_put8(xsp->data_access_handle, &xsp->regp->csr,
        CLEAR_INTERRUPT);
    /* The transfer has finished, successfully or not */
    biodone(bp);
```

if the device has power manageable components that were marked busy in `strategy`*(9E), mark them idle now with* `pm_idle_component`*(9F)*
release any resources used in the transfer, such as DMA resources (`ddi_dma_unbind_handle`*(9F) and* `ddi_dma_free_handle`*(9F))*

```
    /* Let the next I/O thread have access to the device */
    xsp->busy = 0;
    mutex_exit(&xsp->mu);
    (void) xxstart((caddr_t)xsp);
    return (DDI_INTR_CLAIMED);
}
```

Miscellaneous Entry Points

dump( )

The `dump`(9E) entry point is used to copy a portion of virtual address space directly to the specified device in the case of a system failure. It is also used to copy the state of the kernel out to disk during a checkpoint operation (see `cpr`(7), `dump`(9E)). It must be capable of performing this operation without the use of interrupts, since they are disabled during the checkpoint operation.

```
int xxdump(dev_t dev, caddr_t addr, daddr_t blkno, int nblk)
```

`dev` is the device number of the device to dump to, `addr` is the base kernel virtual address at which to start the dump, `blkno` is the first block to dump, and `nblk` is the number of blocks to dump. The dump depends upon the existing driver working properly. It creates a `buf`(9S) request to pass to `strategy`(9E). Code Example 10-9 shows a block driver `dump`(9E) routine.

Code Example 10-9 Block Driver `dump`(9E) Routine

```
static int
xxdump(dev_t dev, caddr_t addr, daddr_t blkno, int nblk)
{
    int error;
    struct buf *bp;
    /* Allocate a buf structure to perform the dump */
    bp = getrbuf(KM_NOSLEEP);
    if (bp == NULL)
        return (EIO);

    /*
     * Set the appropriate fields in the buf structure.
     * This is OK since the driver knows what its strategy
     * routine will examine.
     */
    bp->b_un.b_addr = addr;
    bp->b_edev = dev;
    bp->b_bcount = nblk * DEV_BSIZE;
    bp->b_flags = B_WRITE|B_BUSY;
    bp->b_blkno = blkno;

    (void) xxstrategy(bp);

    /*
     * Wait here until the driver performs a biodone(9F)
     * on the buffer being transferred.
    */
    error = biowait(bp);
    freerbuf(bp);
    return (error);
}
```

print( )

```
int xxprint(dev_t dev, char *str)
```

The print(9E) entry is called by the system to display a message about an exception it has detected. print(9E) should call cmn_err(9F) to post the message to the console on behalf of the system. Here is an example:

```
    static int
    xxprint(dev_t dev, char *str)
    {
        cmn_err(CE_CONT, “xx: %s\n”, str);
        return (0);
    }
```

Mapping Device or Kernel Memory 11

Some device drivers allow applications to access device or kernel memory using `mmap`(2). Examples are a frame buffer driver that allows the frame buffer to be mapped into a user thread or a pseudo driver that communicates with an application using a shared kernel memory pool. This chapter describes how to associate device or kernel memory with user mappings.

Memory Mapping Operations

In general, the steps for exporting device or kernel memory are:

1. Set the `D_DEVMAP` flag in the `cb_flag` flag of the `cb_ops`(9S) structure.
2. Define a `devmap`(9E) driver entry point to export the mapping.
3. To set up user mappings to the device, use `devmap_devmem_setup`(9F). To set up user mappings to kernel memory, use `devmap_umem_setup`(9F).

Exporting the Mapping

The `devmap`(9E) entry point is called as a result of an `mmap`(2) system call. `devmap`(9E) is used to:

- Validate the user mapping to the device or kernel memory.
- Translate the logical offset within the application mapping to the corresponding offset within the device or kernel memory.
- Pass the mapping information to the system for setting up the mapping.

devmap()

```
int xxdevmap(dev_t dev, devmap_cookie_t handle, offset_t off,
    size_t len, size_t *maplen, u_int model);
```

dev is the device whose memory is to be mapped. handle is a device-mapping handle that the system creates and uses to describe a mapping to contiguous device or kernel memory. The system may create multiple mapping handles in one mmap(2) system call (for example, if the mapping contains multiple physically discontiguous memory regions). off is the logical offset within the application mapping which has to be translated by the driver to the corresponding offset within the device or kernel memory. len is the length (in bytes) of the memory being mapped.

Initially devmap(9E) is called with parameters off and len, which were passed by the application to mmap(2). devmap(9E) sets *maplen to the length from off to the end of a contiguous memory region. *maplen must be rounded up to a multiple of a page size. If *maplen is set to less than the original mapping length len, the system will repeatedly call devmap(9E) with a new mapping handle and adjusted off and len parameters until the initial mapping length is satisfied. Setting *maplen to less then len allows the driver to associate different kernel memory regions or multiple physically discontiguous memory regions with one contiguous user application mapping.

model is the data model type of the current thread. If a driver supports multiple application data models, model has to be passed to ddi_model_convert_from(9F) to determine whether there is a data model mismatch between the current thread and the device driver. The device driver might have to adjust the shape of data structures before exporting them to a user thread which supports a different data model. See Appendix F, “Making a Device Driver 64-Bit Ready” for more details.

devmap(9E) must return ENXIO if the logical offset, off, is out of the range of memory exported by the driver.

Associating Device Memory With User Mappings

devmap_devmem_setup(9F) is provided to export device memory to user applications. devmap_devmem_setup(9F) has to be called from the driver’s devmap(9E) entry point:

```
int devmap_devmem_setup(devmap_cookie_t handle,
        dev_info_t *dip,
        struct devmap_callback_ctl *callbackops,
        u_int rnumber, offset_t roff,
        size_t len, u_int maxprot, u_int flags,
        ddi_device_acc_attr_t *accattrp);
```

handle is an opaque structure that the system uses to describe the mapping.

dip is a pointer to the device's dev_info structure.

callbackops is a pointer to a devmap_callback_ctl(9S) structure.

rnumber is the register set number.

roff is the offset into the device memory specified by rnumber.

len is the length in bytes that is exported.

maxprot specifies the maximum protection possible for the exported mapping.

flags must be set to DEVMAP_DEFAULTS.

accattrp is a pointer to a ddi_device_acc_attr(9S) structure.

handle is a device-mapping handle that the system uses to identify the mapping. It is passed in by the devmap(9E) entry point. dip is a pointer to the device's dev_info structure. dip is stored by the driver in its private data structure during attach(9E). callbackops allows the driver to be notified of user events on the mapping. See Chapter 12, "Device Context Management" for a complete description of devmap_callback_ctl(9S).

roff and len describe a range within the device memory specified by the register set rnumber. The register specifications referred to by rnumber are described by the reg property (see driver.conf(4), isa(4), eisa(4), mca(4), sysbus(4), vme(4), sbus(4) and pci(4)). For devices with only one register set, pass zero for rnumber. The range described by roff and len will be made accessible to the user's application mapping at the offset passed in by the devmap(9E) entry point. Usually the driver will pass the devmap(9E) offset directly to devmap_devmem_setup(9F). The return address of mmap(2) will then map to the beginning of the register set.

maxprot allows the driver to specify different protections for different regions within the exported device memory. For example, one region might not allow write access by only setting PROT_READ and PROT_USER.

Code Example 11-1 shows how to export device memory to an application. The driver first determines whether the requested mapping falls within the device memory region. The size of the device memory is determined using ddi_dev_regsize(9F). The length of the mapping is rounded up to a multiple of a page size using ptob(9F) and btopr(9F), and devmap_devmem_setup(9F) is called to export the device memory to the application.

Code Example 11-1 devmap_devmem_setup(9F) Routine

```
static int
xxdevmap(dev_t dev, devmap_cookie_t handle, offset_t off,
    size_t len, size_t *maplen, uint_t model)
{
    struct xxstate *xsp;
    int error, rnumber;
    off_t regsize;

    /* Set up data access attribute structure */
    struct ddi_device_acc_attr xx_acc_attr = {
        DDI_DEVICE_ATTR_V0,
        DDI_NEVERSWAP_ACC,
        DDI_STRICTORDER_ACC
    };
    xsp = ddi_get_soft_state(statep, getminor(dev));
    if (xsp == NULL)
        return (ENXIO);
    /* use register set 0 */
    rnumber = 0;
    /* get size of register set */
    if (ddi_dev_regsize(xsp->dip, rnumber, &regsize) != DDI_SUCCESS)
        return (ENXIO);
    /* round up len to a multiple of a page size */
    len = ptob(btopr(len));
    if (off + len > regsize)
        return (ENXIO);
    /* Set up the device mapping */
    error = devmap_devmem_setup(handle, xsp->dip, NULL, rnumber
               off, len, PROT_ALL, DEVMAP_DEFAULTS, &xx_acc_attr);
    /* acknowledge the entire range */
    *maplen = len;
    return (error);
}
```

Associating Kernel Memory With User Mappings

Some device drivers may need to allocate kernel memory that is made accessible to user programs by using `mmap`(2). Examples of this are setting up shared memory for communication between two applications or between driver and application.

Caution – `MAP_FIXED` must not be set in `mmap`(2) if kernel memory is mapped. Setting `MAP_FIXED` makes the application non-portable.

In general, the steps for exporting kernel memory to user applications are:

1. Allocate kernel memory using `ddi_umem_alloc`(9F).
2. Export the memory using `devmap_umem_setup`(9F).
3. If not needed, free the memory using `ddi_umem_free`(9F).

State Structure

This section adds the following fields to the state structure. See "Software State Structure" on page 63 for more information.

```
void               *umem;     /* exported kernel memory */
ddi_umem_cookie_t  ucookie;   /* kernel memory cookie */
```

Allocating Kernel Memory for User Access

`ddi_umem_alloc`(9F) is provided to allocate kernel memory that is exported to applications:

```
void *ddi_umem_alloc(size_t size, int flag,
        ddi_umem_cookie_t *cookiep);
```

`size` is the number of bytes to allocate.

`flag` is used to determine the sleep conditions and the memory type.

`cookiep` is a pointer to a kernel memory cookie.

ddi_umem_alloc(9F) allocates page-aligned kernel memory and returns a pointer to the allocated memory. The initial contents of the memory is zero-filled. The number of bytes allocated is a multiple of the system page size (roundup of size). The allocated memory can be used in the kernel and can be exported to applications. cookiep is a pointer to the kernel memory cookie that describes the kernel memory being allocated. It is used in devmap_umem_setup(9F) when the driver exports the kernel memory to a user application.

The flag argument indicates whether ddi_umem_alloc(9F) will block or return immediately, and whether the allocated kernel memory is pageable. Table 11-1 lists the values for flag.

Table 11-1 ddi_umem_alloc(9F) flag Values

Values	Indicated Action
DDI_UMEM_NOSLEEP	Driver does not need to wait for memory to become available. Return NULL if memory unavailable.
DDI_UMEM_SLEEP	Driver can wait indefinitely for memory to become available.
DDI_UMEM_PAGEABLE	Driver allows memory to be paged out. If not set, the memory will be locked down.

Code Example 11-2 shows how to allocate kernel memory for application access. The driver exports one page of kernel memory, which is used by multiple applications as a shared memory area. The memory is allocated in segmap(9E) when an application maps the shared page the first time. An additional page is allocated if the driver has to support multiple application data models (for example a 64-bit driver exporting memory to 64-bit and 32-bit applications). 64-bit applications share the first page, and 32-bit applications share the second page.

Code Example 11-2 ddi_umem_alloc(9F) Routine

```
static int
xxsegmap(dev_t dev, off_t off, struct as *asp, caddr_t *addrp,
    off_t len, unsigned int prot, unsigned int maxprot,
    unsigned int flags, cred_t *credp)
{
    int error;
    minor_t instance = getminor(dev);
    struct xxstate *xsp = ddi_get_soft_state(statep, instance);
    mutex_enter(&xsp->mu);
    if (xsp->umem == NULL) {
        size_t mem_size;
#ifdef  _MULTI_DATAMODEL
        /* 64-bit driver supports 64-bit and 32-bit applications */
        mem_size = ptob(2);
#else
        mem_size = ptob(1);
#endif /* _MULTI_DATAMODEL */

        /* allocate the shared area as kernel pageable memory */
        xsp->umem = ddi_umem_alloc(mem_size,
                        DDI_UMEM_SLEEP | DDI_UMEM_PAGEABLE,
                        &xsp->ucookie);
    }
    mutex_exit(&xsp->mu);
    /* Set up the user mapping */
    error = devmap_setup(dev, (offset_t)off, asp, addrp, len,
            prot, maxprot, flags, credp);

    return (error);
}
```

Exporting Kernel Memory to Applications

devmap_umem_setup(9F) is provided to export kernel memory to user applications. devmap_umem_setup(9F) must be called from the driver's devmap(9E) entry point:

```
int devmap_umem_setup(devmap_cookie_t handle, dev_info_t *dip,
        struct devmap_callback_ctl *callbackops,
        ddi_umem_cookie_t cookie, offset_t koff,
        size_t len, u_int maxprot, u_int flags,
        ddi_device_acc_attr_t *accattrp);
```

handle is an opaque structure that the system uses to describe the mapping.

dip is a pointer to the device's dev_info structure.

callbackops is a pointer to a devmap_callback_ctl(9S) structure.

cookie is a kernel memory cookie returned by ddi_umem_alloc(9F).

koff is the offset into the kernel memory specified by cookie.

len is the length in bytes that is exported.

maxprot specifies the maximum protection possible for the exported mapping.

flags must be set to DEVMAP_DEFAULTS.

accattrp is a pointer to a ddi_device_acc_attr(9S) structure.

handle is a device-mapping handle that the system uses to identify the mapping. It is passed in by the devmap(9E) entry point. dip is a pointer to the device's dev_info structure. dip is stored by the driver in its private data structure during attach(9E). callbackops allows the driver to be notified of user events on the mapping. Most drivers will set callbackops to NULL when kernel memory is exported.

koff and len specify a range within the kernel memory allocated by ddi_umem_alloc(9F). This range will be made accessible to the user's application mapping at the offset passed in by the devmap(9E) entry point. Usually the driver will pass the devmap(9E) offset directly to devmap_umem_setup(9F). The return address of mmap(2) will then map to the kernel address returned by ddi_umem_alloc(9F). koff and len must be page aligned.

maxprot enables the driver to specify different protections for different regions within the exported kernel memory. For example, one region might not allow write access by only setting PROT_READ and PROT_USER.

Code Example 11-3 shows how to export kernel memory to an application. The driver first checks if the requested mapping falls within the allocated kernel memory region. If a 64-bit driver receives a mapping request from a 32-bit application, the request is redirected to the second page of the kernel memory area. This ensures that only applications compiled to the same data model will share the same page.

Code Example 11-3 devmap_umem_setup(9F) Routine

```
static int
xxdevmap(dev_t dev, devmap_cookie_t handle, offset_t off,
    size_t len, size_t *maplen, uint_t model)
```

```
{
    struct xxstate *xsp;
    int error;

    /* round up len to a multiple of a page size */
    len = ptob(btopr(len));
    /* check if the requested range is ok */
    if (off + len > ptob(1))
        return (ENXIO);
    xsp = ddi_get_soft_state(statep, getminor(dev));
    if (xsp == NULL)
        return (ENXIO);

#ifdef  _MULTI_DATAMODEL
    if (ddi_model_convert_from(model) == DDI_MODEL_ILP32) {
        /* request from 32-bit application. Skip first page */
        off += ptob(1);
    }
#endif  /* _MULTI_DATAMODEL */
    /* export the memory to the application */
    error = devmap_umem_setup(handle, xsp->dip, NULL, xsp->ucookie,
                off, len, PROT_ALL, DEVMAP_DEFAULTS, NULL);
    *maplen = len;
    return (error);
}
```

Freeing Kernel Memory Exported for User Access

When the driver is unloaded, the memory must be freed. `ddi_umem_free`(9F) frees memory that was allocated by `ddi_umem_alloc`(9F).

```
    void ddi_umem_free(ddi_umem_cookie_t cookie);
```

`cookie` is the kernel memory cookie returned by `ddi_umem_alloc`(9F).

Device Context Management 12

Some device drivers, such as those for graphics hardware, provide user processes with direct access to the device. These devices often require that only one process at a time accesses the device.

This chapter describes the set of interfaces that allow device drivers to manage access to such devices.

What Is a Device Context?

The *context* of a device is the current state of the device hardware. The device driver manages the device context for a process on behalf of the process. The device driver must maintain a separate device context for each process that accesses the device. It is the device driver's responsibility to restore the correct device context when a process accesses the device.

Context Management Model

An accelerated frame buffer is an example of a device that allows user processes (such as graphics applications) to directly manipulate the control registers of the device through memory-mapped access. Because these processes are not using the traditional I/O system calls (`read`(2), `write`(2), and `ioctl`(2)), the device driver is no longer called when a process accesses the device. However, it is important that the device driver be notified when a process is about to access a device so that it can restore the correct device context and provide any needed synchronization.

To resolve this problem, the device context management interfaces enable a device driver to be notified when a user process accesses memory-mapped regions of the device and to control accesses to the device's hardware. Synchronization and management of the various device contexts are responsibilities of the device driver. When a user process accesses a mapping, the device driver must restore the correct device context for that process.

A device driver will be notified whenever one of the following events occurs:

- Access to a mapping by a user process
- Duplication of a mapping by a user process
- Freeing of a mapping by a user process
- Creation of a mapping by a user process

Figure 12-1 shows multiple user processes that have memory mapped a device. The driver has granted process B access to the device, and process B no longer notifies the driver of accesses. However, the driver *is* still notified if either process A or process C accesses the device.

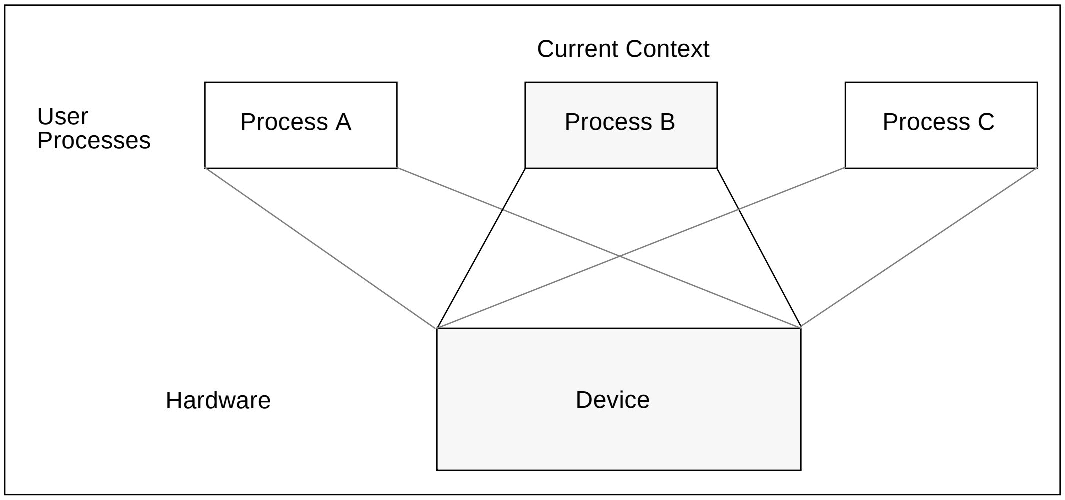


Figure 12-1 Device Context Management

At some point in the future, process A accesses the device. The device driver is notified of this and blocks future access to the device by process B. It then saves the device context for process B, restores the device context of process A, and grants access to process A, as illustrated in Figure 12-2. At this point, the device driver will be notified if either process B or process C accesses the device.

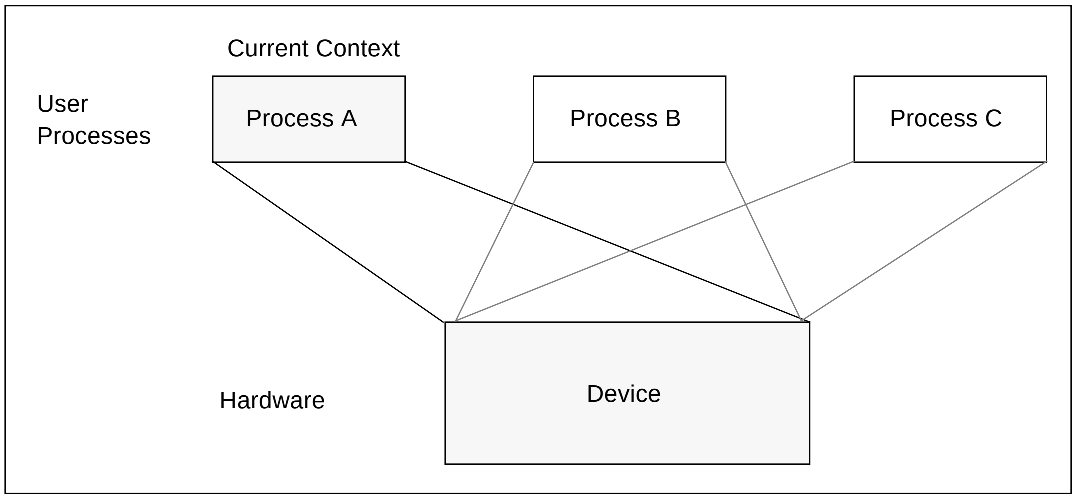


Figure 12-2 Device Context Switched to User Process A

Multiprocessor Considerations

On a multiprocessor machine, multiple processes could be attempting to access the device at the same time. This can cause thrashing. Some devices require a longer time to restore a device context. To prevent more CPU time from being used to restore a device context than to actually use that device context, the minimum time that a process needs to have access to the device can be set using `devmap_set_ctx_timeout`(9F).

The kernel guarantees that once a device driver has granted access to a process, no other process will be allowed to request access to the same device for the time interval specified by `devmap_set_ctx_timeout`(9F).

Context Management Operation

In general, the steps for performing device context management are:

1. Define a `devmap_callback_ctl`(9S) structure.
2. Allocate space to save device context if necessary.
3. Set up user mappings to the device and driver notifications with `devmap_devmem_setup`(9F).
4. Manage user access to the device with `devmap_load`(9F) and `devmap_unload`(9F).
5. Free the device context structure, if needed.

Context Management Additions to the State Structure

This section adds the following fields to the state structure. See "Software State Structure" on page 63 for more information.

```
kmutex_t        ctx_lock;       /* lock for context switching */
void            *ctx_shared;    /* pointer to shared context */
struct xxctx    *current_ctx;   /* current context structure */
```

The structure `xxctx` is the driver private device context structure for the examples used in this section. It looks like this:

```
struct xxctx {
    devmap_cookie_t    handle;
    offset_t           off;
    size_t             len;
    uint_t             flags;
    void               *context;
    struct xxstate     *xsp;
};
#define  XXCTX_SIZE    0x1000  /* size of the context */
```

The `context` field stores the actual device context. In this case, it is simply a pointer to a chunk of memory; in other cases, it may actually be a series of structure fields corresponding to device registers.

Declarations and Data Structures

devmap_callback_ctl

The device driver must allocate and initialize a `devmap_callback_ctl`(9S) structure to inform the system of its device context management entry point routines.

This structure contains the following fields:

```
struct devmap_callback_ctl {
    int devmap_rev;
    int (*devmap_map)(devmap_cookie_t dhp, dev_t dev,
        u_int flags, offset_t off, size_t len, void **pvtp);
    int (*devmap_access)(devmap_cookie_t dhp, void *pvtp,
        offset_t off, size_t len, u_int type, u_int rw);
    int (*devmap_dup)(devmap_cookie_t dhp, void *pvtp,
        devmap_cookie_t new_dhp, void **new_pvtp);
    void (*devmap_unmap)(devmap_cookie_t dhp, void *pvtp,
        offset_t off, size_t len, devmap_cookie_t new_dhp1,
        void **new_pvtp1, devmap_cookie_t new_dhp2,
        void **new_pvtp2);
};
```

`devmap_rev` is the version number of the `devmap_callback_ctl`(9S) structure. It must be set to `DEVMAP_OPS_REV`.

`devmap_map` must be set to the address of the driver's `devmap_map`(9E) entry point.

`devmap_access` must be set to the address of the driver's `devmap_access`(9E) entry point.

`devmap_dup` must be set to the address of the driver's `devmap_dup`(9E) entry point.

`devmap_unmap` must be set to the address of the driver's `devmap_unmap`(9E) entry point.

Associating User Mappings With Driver Notifications

When a user process requests a mapping to a device with `mmap`(2), the driver's `segmap`(9E) entry point is called. The driver must use `ddi_devmap_segmap`(9F) or `devmap_setup`(9F) when setting up the memory mapping if it needs to manage device contexts. Both functions will call the driver's `devmap`(9E) entry point, which uses `devmap_devmem_setup`(9F) to associate the device memory with the user mapping. See Chapter 11, "Mapping Device or Kernel Memory" for details on how to map device memory.

For the driver to get notifications on accesses to the user mapping, it has to inform the system of the `devmap_callback_ctl`(9S) entry points. This is done by providing a pointer to a `devmap_callback_ctl`(9S) structure to `devmap_devmem_setup`(9F). A `devmap_callback_ctl`(9S) structure describes a set of context management entry points that are called by the system to notify a device driver to manage events on the device mappings.

The system associates each mapping with a mapping handle. This handle is passed to each of the context management entry points. The mapping handle can be used to invalidate and validate the mapping translations. If the driver *invalidates* the mapping translations, it will be notified of any future access to the mapping. If the driver *validates* the mapping translations, it will no longer be notified of accesses to the mapping. Mappings are always created with the mapping translations invalidated so that the driver will be notified on first access to the mapping.

Code Example 12-1 shows how to set up a mapping using the device context management interfaces.

Code Example 12-1 `devmap`(9E) Entry Point With Context Management Support

```
static struct devmap_callback_ctl xx_callback_ctl = {
    DEVMAP_OPS_REV,
    xxdevmap_map,
    xxdevmap_access,
    xxdevmap_dup,
    xxdevmap_unmap
};

static int
xxdevmap(dev_t dev, devmap_cookie_t handle, offset_t off,
    size_t len, size_t *maplen, uint_t model)
{
    struct xxstate *xsp;
    u_int rnumber;
    int error;

    /* Setup data access attribute structure */
    struct ddi_device_acc_attr xx_acc_attr = {
        DDI_DEVICE_ATTR_V0,
        DDI_NEVERSWAP_ACC,
        DDI_STRICTORDER_ACC
    };
    xsp = ddi_get_soft_state(statep, getminor(dev));
    if (xsp == NULL)
        return (ENXIO);
    len = ptob(btopr(len));
    rnumber = 0;
    /* Set up the device mapping */
    error = devmap_devmem_setup(handle, xsp->dip, &xx_callback_ctl,
                rnumber, off, len, PROT_ALL, 0, &xx_acc_attr);
    *maplen = len;
    return (error);
}
```

Managing Mapping Accesses

The device driver is notified when a user process accesses an address in the memory-mapped region that does not have valid mapping translations. When the access event occurs, the mapping translations of the process that currently has access to the device must be invalidated. The device context of the process requesting access to the device must be restored, and the translations of the mapping of the process requesting access must be validated.

The functions `devmap_load`(9F) and `devmap_unload`(9F) are used to validate and invalidate mapping translations.

devmap_load()

```
    int devmap_load(devmap_cookie_t handle, offset_t offset,
        size_t len, uint_t type, uint_t rw);
```

`devmap_load`(9F) validates the mapping translations for the pages of the mapping specified by `handle`,`offset`, and `len`. By validating the mapping translations for these pages, the driver is telling the system not to intercept accesses to these pages of the mapping and to allow accesses to proceed without notifying the device driver.

devmap_load(9F) must be called with the offset and the handle of the mapping that generated the access event for the access to complete. If devmap_load(9F) is not called on this handle, the mapping translations will not be validated, and the process will receive a SIGBUS.

devmap_unload()

```
int devmap_unload(devmap_cookie_t handle, offset_t offset,
    size_t len);
```

devmap_unload(9F) invalidates the mapping translations for the pages of the mapping specified by handle, offset, and len. By invalidating the mapping translations for these pages, the device driver is telling the system to intercept accesses to these pages of the mapping and notify the device driver the next time these pages of the mapping are accessed by calling the devmap_access(9E) entry point.

For both functions, requests affect the entire page containing the offset and all pages up to and including the entire page containing the last byte, as indicated by offset + len. The device driver must ensure that for each page of device memory being mapped only one process has valid translations at any one time.

Both functions return zero if they are successful. If, however, there was an error in validating or invalidating the mapping translations, that error is returned to the device driver. It is the device driver's responsibility to return this error to the system.

Device Context Management Entry Points

The following device driver entry points are used to manage device context.

devmap_map()

```
int xxdevmap_map(devmap_cookie_t handle, dev_t dev, u_int flags,
    offset_t offset, size_t len, void **new_devprivate);
```

This entry point is called after the driver returns from its devmap(9E) entry point and the system has established the user mapping to the device memory. The devmap_map(9E) entry point enables a driver to perform additional processing or to allocate mapping specific private data. For example, in order to support context switching, the driver has to allocate a context structure and associate it with the mapping.

The system expects the driver to return a pointer to the allocated private data in `*new_devprivate`. The driver must store `offset` and `len`, which define the range of the mapping, in its private data. Later, when the system calls `devmap_unmap`(9E), the driver will use `offset` and `len` stored in `new_devprivate` to check if the entire mapping, or just a part of it, is being unmapped.

`flags` indicates whether the driver should allocate a private context for the mapping. For example, a driver may allocate a memory region to store the device context if `flags` is set to `MAP_PRIVATE`, or it might return a pointer to a shared region if `MAP_SHARED` is set.

Code Example 12-2 shows an example of a `devmap_map`(9E) entry point. The driver allocates a new context structure and saves relevant parameters passed in by the entry point. Then the mapping is assigned a new context by either allocating a new one or attaching it to an already existing shared context. The minimum time interval that the mapping should have access to the device is set to one millisecond.

Code Example 12-2 `devmap_map`(9E) Routine

```
static int
int xxdevmap_map(devmap_cookie_t handle, dev_t dev, u_int flags,
    offset_t offset, size_t len, void **new_devprivate)
{
    struct xxstate *xsp = ddi_get_soft_state(statep, getminor(dev));
    struct xxctx *newctx;

    /* create a new context structure */
    newctx = kmem_alloc(sizeof (struct xxctx), KM_SLEEP);
    newctx->xsp = xsp;
    newctx->handle = handle;
    newctx->offset = offset;
    newctx->flags = flags;
    newctx->len = len;
    mutex_enter(&xsp->ctx_lock);
    if (flags & MAP_PRIVATE) {
        /* allocate a private context and initialize it */
        newctx->context = kmem_alloc(XXCTX_SIZE, KM_SLEEP);
        xxctxinit(newctx);
    } else {
        /* set a pointer to the shared context */
        newctx->context = xsp->ctx_shared;
    }
    mutex_exit(&xsp->ctx_lock);
    /* give at least 1 ms access before context switching */
    devmap_set_ctx_timeout(handle, drv_usectohz(1000));
    /* return the context strcuture */
    *new_devprivate = newctx;
    return(0);
}
```

devmap_access()

```
int xxdevmap_access(devmap_cookie_t handle, void *devprivate,
    offset_t offset, size_t len, u_int type, u_int rw);
```

This entry point is called when an access is made to a mapping whose translations are invalid. Mapping translations are invalidated when the mapping is created with `devmap_devmem_setup`(9F) in response to `mmap`(2), duplicated by `fork`(2), or explicitly invalidated by a call to `devmap_unload`(9F).

`handle` is the mapping handle of the mapping that was accessed by a user process.

`devprivate` is a pointer to the driver private data associated with the mapping.

`offset` is the offset within the mapping that was accessed.

`len` is the length in bytes of the memory being accessed.

`type` is the type of access operation.

`rw` specifies the direction of access.

The system expects `devmap_access`(9E) to call either `devmap_do_ctxmgt`(9F) or `devmap_default_access`(9F) to load the memory address translations before it returns. For mappings that support context switching, the device driver should call `devmap_do_ctxmgt`(9F). This routine is passed all parameters from `devmap_access`(9E), and in addition a pointer to the driver entry point `devmap_contextmgt`(9E), which handles the context switching. For mappings that do not support context switching, the driver should call `devmap_default_access`(9F), whose only purpose is to call `devmap_load`(9F) to load the user translation.

Code Example 12-3 shows an example of a `devmap_access`(9E) entry point. The mapping is devided into two regions. The region starting at offset `OFF_CTXMG` with a length of `CTXMGT_SIZE` bytes supports context management. The rest of the mapping supports default access.

Code Example 12-3 `devmap_access`(9E) Routine

```
#define OFF_CTXMG      0
#define CTXMGT_SIZE    0x20000

static int
xxdevmap_access(devmap_cookie_t handle, void *devprivate,
    offset_t off, size_t len, u_int type, u_int rw)
{
    offset_t diff;
    int error;

    if ((diff = off - OFF_CTXMG) >= 0 && diff < CTXMGT_SIZE) {
        error = devmap_do_ctxmgt(handle, devprivate, off, len, type,
                    rw, xxdevmap_contextmgt);
    } else {
        error = devmap_default_access(handle, devprivate, off,
                    len, type, rw);
    }
    return (error);
}
```

devmap_contextmgt()

```
int xxdevmap_contextmgt(devmap_cookie_t handle, void *devprivate,
    offset_t offset, size_t len, u_int type, u_int rw);
```

In general, `devmap_contextmgt`(9E) should call `devmap_unload`(9F), with the handle of the mapping that currently has access to the device, to invalidate the translations for that mapping. This ensures that a call to `devmap_access`(9E) occurs for the current mapping the next time it is accessed. To validate the mapping translations for the mapping that caused the access event to occur, the driver must restore the device context for the process requesting access and call `devmap_load`(9F) on the `handle` of the mapping that generated the call to this entry point.

Accesses to portions of mappings that have had their mapping translations validated by a call to devmap_load(9F) do not generate a call to devmap_access(9E). A subsequent call to devmap_unload(9F) invalidates the mapping translations and allows devmap_access(9E) to be called again.

If either devmap_load(9F) or devmap_unload(9F) returns an error, devmap_contextmgt(9E) should immediately return that error. If the device driver encounters a hardware failure while restoring a device context, a -1 should be returned. Otherwise, after successfully handling the access request, devmap_contextmgt(9E) should return zero. A return of other than zero from devmap_contextmgt(9E) will cause a SIGBUS or SIGSEGV to be sent to the process.

Code Example 12-4 shows how to manage a one-page device context.

Note – xxctxsave and xxctxrestore are device-dependent context save and restore functions. xxctxsave reads data from the registers using the Solaris 2.x DDI/DKI data access routines and saves it in the soft state structure. xxctxrestore takes data saved in the soft state structure and writes it to device registers using the Solaris 2.x DDI/DKI data access routines.

Code Example 12-4 devmap_contextmgt(9E) Routine

```
static int
xxdevmap_contextmgt(devmap_cookie_t handle, void *devprivate,
    offset_t off, size_t len, u_int type, u_int rw)
{
    int error;
    struct xxctx *ctxp = devprivate;
    struct xxstate *xsp = ctxp->xsp;

    mutex_enter(&xsp->ctx_lock);
    /* unload mapping for current context */
    if (xsp->current_ctx != NULL) {
        if ((error = devmap_unload(xsp->current_ctx->handle,
            off, len)) != 0) {
                xsp->current_ctx = NULL;
                mutex_exit(&xsp->ctx_lock);
                return (error);
        }
    }
    /* Switch device context - device dependent */
    if (xxctxsave(xsp->current_ctx, off, len) < 0) {
        xsp->current_ctx = NULL;
        mutex_exit(&xsp->ctx_lock);
        return (-1);
    }
    if (xxctxrestore(ctxp, off, len) < 0){
        xsp->current_ctx = NULL;
        mutex_exit(&xsp->ctx_lock);
        return (-1);
    }
    xsp->current_ctx = ctxp;
    /* establish mapping for new context and return */
    error = devmap_load(handle, off, len, type, rw);
    if (error)
        xsp->current_ctx = NULL;
    mutex_exit(&xsp->ctx_lock);
    return (error);
}
```

devmap_dup()

```
int xxdevmap_dup(devmap_cookie_t handle, void *devprivate,
    devmap_cookie_t new_handle, void **new_devprivate);
```

This entry point is called when a device mapping is duplicated, for example, by a user process calling `fork`(2). The driver is expected to generate new driver private data for the new mapping.

`handle` is the mapping handle of the mapping being duplicated.

`new_handle` is the mapping handle of the mapping that was duplicated.

`devprivate` is a pointer to the driver private data associated with the mapping being duplicated.

`*new_devprivate` should be set to point to the new driver private data for the new mapping.

Mappings created with `devmap_dup`(9E) will, by default, have their mapping translations invalidated. This will force a call to the `devmap_access`(9E) entry point the first time the mapping is accessed.

Code Example 12-5 shows a `devmap_dup`(9E) routine.

Code Example 12-5 `devmap_dup`(9E) Routine

```
static int
xxdevmap_dup(devmap_cookie_t handle, void *devprivate,
    devmap_cookie_t new_handle, void **new_devprivate)
{
    struct xxctx *ctxp = devprivate;
    struct xxstate *xsp = ctxp->xsp;
    struct xxctx *newctx;

    /* Create a new context for the duplicated mapping */
    newctx = kmem_alloc(sizeof (struct xxctx), KM_SLEEP);
    newctx->xsp = xsp;
    newctx->handle = new_handle;
    newctx->offset = ctxp->offset;
    newctx->flags = ctxp->flags;
    newctx->len = ctxp->len;
    mutex_enter(&xsp->ctx_lock);
    if (ctxp->flags & MAP_PRIVATE) {
        newctx->context = kmem_alloc(XXCTX_SIZE, KM_SLEEP);
        bcopy(ctxp->context, newctx->context, XXCTX_SIZE);
    } else {
        newctx->context = xsp->ctx_shared;
    }
    mutex_exit(&xsp->ctx_lock);
    *new_devprivate = newctx;
    return(0);
}
```

devmap_unmap()

```
void xxdevmap_unmap(devmap_cookie_t handle, void *devprivate,
    offset_t off, size_t len, devmap_cookie_t new_handle1,
    void **new_devprivate1, devmap_cookie_t new_handle2,
    void **new_devprivate2);
```

This entry point is called when a mapping is unmapped. This can be caused by a user process exiting or calling the `munmap`(2) system call.

`handle` is the mapping handle of the mapping being freed.

`devprivate` is a pointer to the driver private data associated with the mapping.

`off` is the offset within the logical device memory at which the unmapping begins.

len is the length in bytes of the memory being unmapped.

new_handle1 is the handle that the system uses to describe the new region that ends at off - 1. new_handle1 may be NULL.

new_devprivate1 is a pointer to be filled in by the driver with the driver - private mapping data for the new region that ends at off - 1. It is ignored if new_handle1 is NULL.

new_handle2 is the handle that the system uses to describe the new region that begins at off + len. new_handle2 may be NULL.

new_devprivate2 is a pointer to be filled in by the driver with the driver private mapping data for the new region that begins at off + len. It is ignored if new_handle2 is NULL.

The devmap_unmap(9E) routine is expected to free any driver private resources that were allocated when this mapping was created, either by devmap_map(9F) or by devmap_dup(9E). If only a part of the mapping is being unmapped, the driver must allocate a new private data for the remaining mapping before freeing the old private data. There is no need to call devmap_unload(9F) on the handle of the mapping being freed, even if it is the mapping with the valid translations. However, to prevent future problems in devmap_access(9E), the device driver should make sure that its representation of the current mapping is set to “no current mapping”.

Code Example 12-6 shows an example of a devmap_unmap(9E) routine.

Code Example 12-6 devmap_unmap(9E) Routine

```
static void
xxdevmap_unmap(devmap_cookie_t handle, void *devprivate,
    offset_t off, size_t len, devmap_cookie_t new_handle1,
    void **new_devprivate1, devmap_cookie_t new_handle2,
    void **new_devprivate2)
{
    struct xxctx *ctxp = devprivate;
    struct xxstate *xsp = ctxp->xsp;
    mutex_enter(&xsp->ctx_lock);

    /*
     * If new_handle1 is not NULL, we are unmapping
     * at the end of the mapping.
     */
    if (new_handle1 != NULL) {
        /* Create a new context structure for the mapping */
        newctx = kmem_alloc(sizeof (struct xxctx), KM_SLEEP);
        newctx->xsp = xsp;
        if (ctxp->flags & MAP_PRIVATE) {
            /* allocate memory for the private context and copy it */
            newctx->context = kmem_alloc(XXCTX_SIZE, KM_SLEEP);
            bcopy(ctxp->context, newctx->context, XXCTX_SIZE);
        } else {
            /* point to the shared context */
            newctx->context = xsp->ctx_shared;
        }
        newctx->handle = new_handle1;
        newctx->offset = ctxp->offset;
        newctx->flags = ctxp->flags;
        newctx->len = off - ctxp->offset;
        *new_devprivate1 = newctx;
    }
    /*
     * If new_handle2 is not NULL, we are unmapping
     * at the beginning of the mapping.
     */
    if (new_handle2 != NULL) {
        /* Create a new context for the mapping */
        newctx = kmem_alloc(sizeof (struct xxctx), KM_SLEEP);
        newctx->xsp = xsp;
        if (ctxp->flags & MAP_PRIVATE) {
            newctx->context = kmem_alloc(XXCTX_SIZE, KM_SLEEP);
            bcopy(ctxp->context, newctx->context, XXCTX_SIZE);
        } else {
            newctx->context = xsp->ctx_shared;
        }
        newctx->handle = new_handle2;
        newctx->offset = off + len;
        newctx->flags = ctxp->flags;
        newctx->len = ctxp->len - (off + len - ctxp->off);
        *new_devprivate2 = newctx;
    }
    if (xsp->current_ctx == ctxp)
        xsp->current_ctx = NULL;
    mutex_exit(&xsp->ctx_lock);
    if (ctxp->flags & MAP_PRIVATE)
        kmem_free(ctxp->context, XXCTX_SIZE);
    kmem_free(ctxp, sizeof (struct xxctx));
}
```

SCSI Target Drivers 13

This chapter describes how to write a SCSI target driver using the interfaces provided by the Sun Common SCSI Architecture (SCSA). Overviews of SCSI and SCSA are presented, followed by the details of implementing a target driver.

Note – For information on SCSI HBA drivers, see Chapter 14, "SCSI Host Bus Adapter Drivers."

SCSI Target Driver Overview

The Solaris DDI/DKI divides the software interface to SCSI devices into two major parts: *target* drivers and *host bus adapter (HBA)* drivers. *Target* refers to a driver for a device on a SCSI bus, such as a disk or a tape drive. *host bus adapter* refers to the driver for the SCSI controller on the host machine, such as the "esp" driver on a SPARCstation. SCSA defines the interface between these two components. This chapter discusses target drivers only. See Chapter 14, "SCSI Host Bus Adapter Drivers" for information on host bus adapter drivers.

Note – The terms "host bus adapter" or "HBA" used in this manual are equivalent to the phrase "host adapter" defined in SCSI specifications.

Target drivers can be either character or block device drivers, depending on the device. Drivers for tape drives are usually character device drivers, while disks are handled by block device drivers. This chapter describes how to write a SCSI target driver and discusses the additional requirements that SCSA places on block and character drivers for SCSI target devices.

Reference Documents

The following reference documents provide supplemental information needed by the designers of target drivers and host bus adapter drivers.

Small Computer System Interface (SCSI) Standard, ANSI X3.131-1986
American National Standards Institute
Sales Department
1430 Broadway, New York, NY 10018
Phone 212 642-4900

Small Computer System Interface 2 (SCSI-2) Standard, document X3.131-1994
Global Engineering Documents
15 Inverness Way, East Englewood, CO 80112-5704
Phone: 800 854-7179 or 303 792-2181
FAX: 303 792-2192

Basics of SCSI
ANCOT Corporation
Menlo Park, California 94025
Phone 415 322-5322
FAX: 415 322-0455

Also refer to the SCSI command specification for the target device, provided by the hardware vendor.

For a pointer to SCSI driver sample code, see Appendix D, “Sample Driver Source Code Listings.” For information on setting global SCSI options, see Appendix G, “Advanced Topics.”

Sun Common SCSI Architecture Overview

The Sun Common SCSI Architecture (SCSA) is the Solaris 2.x SPARC DDI/DKI programming interface for the transmission of SCSI commands from a target driver to a host bus adapter driver. This interface is independent of the type of host bus adapter hardware, the platform, the processor architecture, and the SCSI command being transported across the interface.

By conforming to the SCSA, the target driver can pass any SCSI command to a target device without knowledge of the hardware implementation of the host bus adapter.

The SCSA conceptually separates building the SCSI command (by the target driver) from transporting the SCSI command and data across the SCSI bus. The architecture defines the software interface between high-level and low-level software components. The higher-level software component consists of one or more SCSI target drivers, which translate I/O requests into SCSI commands appropriate for the peripheral device. Figure 13-1 illustrates the SCSI architecture.

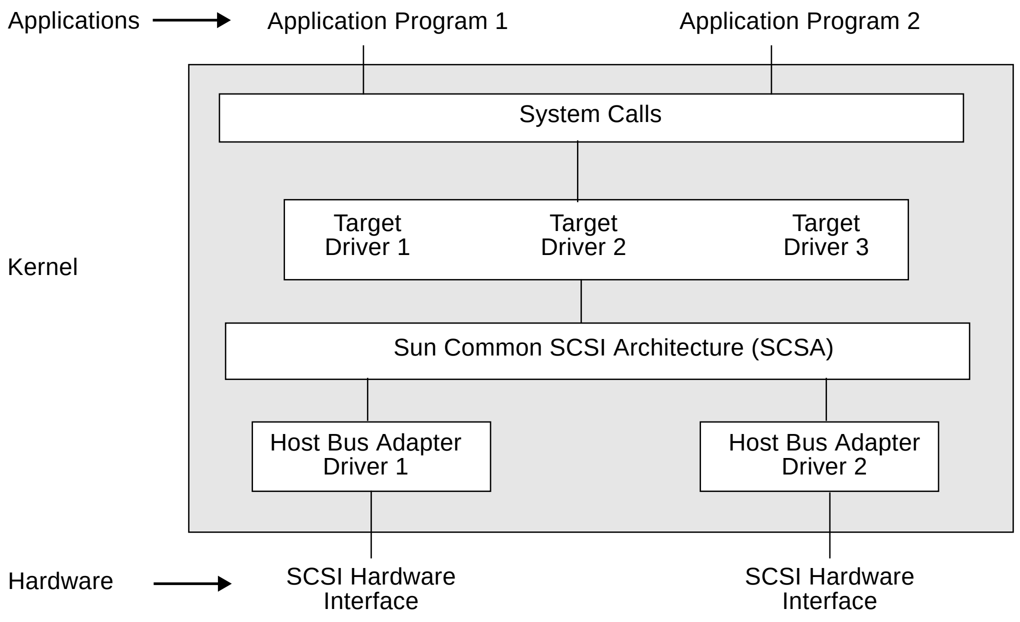


Figure 13-1 SCSA Block Diagram

The lower-level software component consists of a SCSA interface layer and one or more host bus adapter drivers. The host bus adapter driver has several responsibilities. It must:

- Manage host bus adapter hardware.
- Accept SCSI commands from the SCSI target driver.
- Transport the commands to the specified SCSI target device.
- Perform any data transfers that the command requires.
- Collect status.
- Handle auto-request sense (optional).
- Inform the target driver of command completion (or failure).

See Chapter 14, "SCSI Host Bus Adapter Drivers" for more information.

The target driver is completely responsible for the generation of the proper SCSI commands required to execute the desired function.

General Flow of Control

Before transferring data, ensure that the disk is spun up. When transferring data to or from a user address space (using the `read`(9E) or `write`(9E) entry points) SCSI target character device drivers must use `physio`(9F), which locks down memory, prepares a `buf`(9S) structure, and calls the driver's `strategy`(9E) routine.

`physio`(9F) locks down the user buffer into memory before issuing a SCSI command. The file system locks down memory for block device drivers. See Chapter 9, "Drivers for Block Devices", for more information on writing a `strategy`(9E) entry point and Chapter 8, "Drivers for Character Devices", for more information on using `physio`(9F).

Assuming no transport errors occur, the following steps describe the general flow of control for a read or write request, starting from the call to the target driver's strategy routine.

1. The target driver's `strategy`(9E) routine checks the request and allocates a `scsi_pkt`(9S) using `scsi_init_pkt`(9F). The target driver initializes the packet and sets the SCSI command descriptor block (CDB) using the `scsi_setup_cbd`(9F) function. The target driver also specifies a timeout and provides a pointer to a callback function, which is called by the host bus adapter driver on completion of the command. The `buf`(9S) pointer should be saved in the SCSI packet's target-private space.

2. The target driver submits the packet to the host bus adapter driver using `scsi_transport`(9F). The target driver is then free to accept other requests. The target driver should not access the packet while it is in transport. If either the host bus adapter driver or the target support queueing, new requests can be submitted while the packet is in transport.
3. As soon as the SCSI bus is free and the target not busy, the host bus adapter driver selects the target and passes the CDB. The target executes the command and performs the requested data transfers. The target controls the SCSI bus phase transitions. The host bus adapter just responds to these transitions until the command is completed.
4. After the target sends completion status and disconnects, the host bus adapter driver notifies the target driver by calling the completion function that was specified in the SCSI packet. At this time the host bus adapter driver is no longer responsible for the packet, and the target driver has regained ownership of the packet.
5. The SCSI packet's completion routine analyzes the returned information and determines whether the SCSI operation was successful. If a failure has occurred, the target driver may retry the command by calling `scsi_transport`(9F) again. If the host bus adapter driver does not support auto request sense, the target driver must submit a request sense packet to retrieve the sense data in the event of a check condition.
6. If either the command was completed successfully or cannot be retried, the target driver calls `scsi_destroy_pkt`(9F), which synchronizes the data and frees the packet. If the target driver needs to access the data before freeing the packet, it calls `scsi_sync_pkt`(9F).
7. Finally, the target driver notifies the application program that originally requested the read or write that the transaction is complete, either by returning from the `read`(9E) entry point in the driver (for a character device) or indirectly through `biodone`(9F).

The SCSA allows the execution of many of such operations, both overlapped and queued at various points in the process. The model places the management of system resources on the host bus adapter driver. The software interface enables the execution of target driver functions on host bus adapter drivers using SCSI bus adapters of varying degrees of intelligence.

SCSA Functions

SCSA defines a number of functions, listed in Table 13-1, which manage the allocation and freeing of resources, the sensing and setting of control states, and the transport of SCSI commands.

Table 13-1 Standard SCSA Functions

Function Name	**Category**
`scsi_init_pkt`(9F)	Resource management
`scsi_sync_pkt`(9F)	
`scsi_dmafree`(9F)	
`scsi_destroy_pkt`(9F)	
`scsi_alloc_consistent_buf`(9F)	
`scsi_free_consistent_buf`(9F)	
`scsi_transport`(9F)	Command transport
`scsi_ifgetcap`(9F)	Transport information and control
`scsi_ifsetcap`(9F)	
`scsi_abort`(9F)	Error handling
`scsi_reset`(9F)	
`scsi_poll`(9F)	Polled I/O
`scsi_probe`(9F)	Probe functions
`scsi_unprobe`(9F)	
`scsi_setup_cdb`(9F)	CDB initialization function

Note that if a driver needs to work with a SCSI-1 device, it should use the `makecom`(9F) functions listed in Table 13-2.

SCSA Compatibility Functions

The functions listed in Table 13-2 are maintained for both source and binary compatibility with previous releases. However, new drivers should use the new functions listed in Table 13-1.

Table 13-2 SCSA Compatibility Functions

Function Name	Category
`scsi_resalloc`(9F)	Resource management
`scsi_resfree`(9F)	
`scsi_pktalloc`(9F)	
`scsi_pktfree`(9F)	
`scsi_dmaget`(9F)	
`get_pktiopb`(9F)	
`free_pktiopb`(9F)	
`scsi_slave`(9F)	Probe functions
`scsi_unslave`(9F)	
`makecom_g0`(9F)	CDB initialization functions
`makecom_g1`(9F)	
`makecom_g0_s`(9F)	
`makecom_g5`(9F)	

SCSI Target Drivers

Hardware Configuration File

Because SCSI devices are not self-identifying, a hardware configuration file is required for a target driver (see `driver.conf`(4) and `scsi`(4) for details). A typical configuration file looks like this:

```
name="xx" class="scsi" target=2 lun=0;
```

The system reads the file during autoconfiguration and uses the *class* property to identify the driver's possible parent. The system then attempts to attach the driver to any parent driver that is of class *scsi*. All host bus adapter drivers are of this class. Using the *class* property rather than the *parent* property enables the target driver to be attached to any host bus adapter driver that finds the expected device at the specified *target* and *lun* ids. The target driver is responsible for verifying this in its `probe`(9E) routine.

Declarations and Data Structures

Target drivers must include the header file `<sys/scsi/scsi.h>`.

SCSI target drivers must also include this declaration:

```
char _depends_on[] = ″misc/scsi″;
```

`scsi_device` *Structure*

The host bus adapter driver allocates and initializes a `scsi_device`(9S) structure for the target driver before either the `probe`(9E) or `attach`(9E) routine is called. This structure stores information about each SCSI logical unit, including pointers to information areas that contain both generic and device-specific information. There is one `scsi_device`(9S) structure for each logical unit attached to the system. The target driver can retrieve a pointer to this structure by calling `ddi_get_driver_private`(9F).

Caution – Because the host bus adapter driver uses the private field in the target device's `dev_info` structure, target drivers should not use `ddi_set_driver_private`(9F).

The `scsi_device`(9S) structure contains the following fields:

```
struct scsi_address           sd_address;
dev_info_t                    *sd_dev;
kmutex_t                      sd_mutex;
struct scsi_inquiry           *sd_inq;
struct scsi_extended_sense    *sd_sense;
caddr_t                       sd_private;
```

`sd_address` is a data structure that is passed to the SCSI resource allocation routines.

`sd_dev` is a pointer to the target's `dev_info` structure.

sd_mutex is a mutex for use by the target driver. This is initialized by the host bus adapter driver and can be used by the target driver as a per-device mutex. Do not hold this mutex across a call to scsi_transport(9F) or scsi_poll(9F). See Chapter 4, “Multithreading,” for more information on mutexes.

sd_inq is a pointer for the target device’s SCSI inquiry data. The scsi_probe(9F) routine allocates a buffer, fills it in, and attaches it to this field.

sd_sense is a pointer to a buffer to contain SCSI request sense data from the device. The target driver must allocate and manage this buffer itself; see “attach( )” on page 266.

sd_private is a pointer field for use by the target driver. It is commonly used to store a pointer to a private target driver state structure.

scsi_pkt *Structure*

This structure contains the following fields:

```
    struct scsi_address   pkt_address;
    opaque_t   pkt_private;
    void       (*pkt_comp)(struct scsi_pkt *pkt);
    u_int      pkt_flags;
    int        pkt_time;
    u_char     *pkt_scbp;
    u_char     *pkt_cdbp;
    ssize_t    pkt_resid;
    u_int      pkt_state;
    u_int      pkt_statistics;
    u_char     pkt_reason;
```

pkt_address is the target device’s address set by scsi_init_pkt(9F)

pkt_private is a place to store private data for the target driver. It is commonly used to save the buf(9S) pointer for the command.

pkt_comp is the address of the completion routine. The host bus adapter driver calls this routine when it has transported the command. This does not mean that the command succeeded; the target might have been busy or might not have responded before the time-out time elapsed (see the description for pkt_time field). The target driver must supply a valid value in this field, though it can be NULL if the driver does not want to be notified.

Note – There are two different SCSI callback routines. The `pkt_comp` field identifies a *completion callback* routine, which is called when the host bus adapter completes its processing. There is also a *resource callback* routine, called when currently unavailable resources are likely to be available (as in `scsi_init_pkt`(9F)).

`pkt_flags` provides additional control information, for example, to transport the command without disconnect privileges (`FLAG_NODISCON`) or to disable callbacks (`FLAG_NOINTR`). See `scsi_pkt`(9S) for details.

`pkt_time` is a time-out value (in seconds). If the command is not completed within this time, the host bus adapter calls the completion routine with `pkt_reason` set to `CMD_TIMEOUT`. The target driver should set this field to longer than the maximum time the command might take. If the timeout is zero, no timeout is requested. Timeout starts when the command is transmitted on the SCSI bus.

`pkt_scbp` is a pointer to the SCSI status completion block; this is filled in by the host bus adapter driver.

`pkt_cdbp` is a pointer to the SCSI command descriptor block, the actual command to be sent to the target device. The host bus adapter driver does not interpret this field. The target driver must fill it in with a command that the target device can process.

`pkt_resid` is the residual of the operation. When allocating DMA resources for a command `scsi_init_pkt`(9F), `pkt_resid` indicates the number of bytes for which DMA resources could *not* be allocated because of DMA hardware scatter-gather or other device limitations. After command transport, `pkt_resid` indicates the number of data bytes *not* transferred; this is filled in by the host bus adapter driver before the completion routine is called.

`pkt_state` indicates the state of the command. The host bus adapter driver fills in this field as the command progresses. One bit is set in this field for each of the five following command states:

- `STATE_GOT_BUS` – Acquired the bus
- `STATE_GOT_TARGET` – Selected the target
- `STATE_SENT_CMD` – Sent the command
- `STATE_XFERRED_DATA` – Transferred data (if appropriate)
- `STATE_GOT_STATUS` – Received status from the device

pkt_statistics contains transport-related statistics set by the host bus adapter driver.

pkt_reason gives the reason the completion routine was called. The main function of the completion routine is to decode this field and take the appropriate action. If the command completed—in other words, if there were no transport errors—this field is set to CMD_CMPLT; other values in this field indicate an error. After a command is completed, the target driver should examine the pkt_scbp field for a check condition status. See scsi_pkt(9S) for more information.

SCSI Additions to the State Structure

This section adds the following fields to the state structure. See “Software State Structure” on page 63 for more information.

```
struct scsi_pkt    *rqs;      /* Request Sense packet */
struct buf         *rqsbuf;   /* buf for Request Sense */
struct scsi_pkt    *pkt;      /* packet for current command */
struct scsi_device *sdp;      /* pointer to device’s */
                              /* scsi_device(9S) structure. */
```

rqs is a pointer to a SCSI request sense command scsi_pkt(9S) structure, allocated in the attach(9E) routine. This packet is preallocated because the request sense command is small and may be used in time-critical areas of the driver (such as when handling errors).

Autoconfiguration

SCSI target drivers must implement the standard autoconfiguration routines _init(9E), _fini(9E), and _info(9E). See Chapter 5, “Autoconfiguration,” for more information.

probe(9E), attach(9E), and getinfo(9E) are also required, but they must perform SCSI (and SCSA) specific processing.

probe( )

SCSI target devices are not self-identifying, so target drivers must have a probe(9E) routine. This routine must determine whether the expected type of device is present and responding.

The general structure and return codes of the probe(9E) routine are the same as those of other device drivers. See probe() on page 87 for more information. SCSI target drivers must use the scsi_probe(9F) routine in their probe(9E) entry point. scsi_probe(9F) sends a SCSI inquiry command to the device and returns a code indicating the result. If the SCSI inquiry command is successful, scsi_probe(9F) allocates a scsi_inquiry(9S) structure and fills it in with the device's inquiry data. Upon return from scsi_probe(9F), the sd_inq field of the scsi_device(9S) structure points to this scsi_inquiry(9S) structure.

Because probe(9E) must be stateless, the target driver must call scsi_unprobe(9F) before probe(9E) returns, even if scsi_probe(9F) fails.

Code Example 13-1 shows a typical probe(9E) routine. It retrieves its scsi_device(9S) structure from the private field of its dev_info structure. It also retrieves the device's SCSI target and logical unit numbers so that it can print them in messages. The probe(9E) routine then calls scsi_probe(9F) to verify that the expected device (a printer in this case) is present.

If scsi_probe(9F) succeeds, it has attached the device's SCSI inquiry data in a scsi_inquiry(9S) structure to the sd_inq field of the scsi_device(9S) structure. The driver can then determine if the device type is a printer (reported in the inq_dtype field). If it is, the type is reported with scsi_log(9F), using scsi_dname(9F) to convert the device type into a string.

Code Example 13-1 SCSI Target Driver probe(9E) Routine

```
static int
xxprobe(dev_info_t *dip)
{
    struct scsi_device *sdp;
    int rval, target, lun;
    /*
     * Get a pointer to the scsi_device(9S) structure
     */
    sdp = (struct scsi_device *)ddi_get_driver_private(dip);

    target = sdp->sd_address.a_target;
    lun = sdp->sd_address.a_lun;
    /*
     * Call scsi_probe(9F) to send the Inquiry command. It will
     * fill in the sd_inq field of the scsi_device structure.
     */
    switch (scsi_probe(sdp, NULL_FUNC)) {
```

```
    case SCSIPROBE_FAILURE:
    case SCSIPROBE_NORESP:
    case SCSIPROBE_NOMEM:
        /*
         * In these cases, device may be powered off,
         * in which case we may be able to successfully
         * probe it at some future time - referred to
         * as ‘deferred attach’.
         */
        rval = DDI_PROBE_PARTIAL;
        break;
    case SCSIPROBE_NONCCS:
    default:
        /*
         * Device isn’t of the type we can deal with,
         * and/or it will never be usable.
         */
        rval = DDI_PROBE_FAILURE;
        break;
    case SCSIPROBE_EXISTS:
        /*
         * There is a device at the target/lun address. Check
         * inq_dtype to make sure that it is the right device
         * type. See scsi_inquiry(9S)for possible device types.
         */
        switch (sdp->sd_inq->inq_dtype) {
        case DTYPE_PRINTER:
            scsi_log(sdp, “xx”, SCSI_DEBUG,
                “found %s device at target%d, lun%d\n”,
                scsi_dname((int)sdp->sd_inq->inq_dtype),
                target, lun);
            rval = DDI_PROBE_SUCCESS;
            break;
        case DTYPE_NOTPRESENT:
        default:
            rval = DDI_PROBE_FAILURE;
            break;
        }
    }

    scsi_unprobe(sdp);
    return (rval);
}
```

A more thorough probe(9E) routine could also check other fields of the scsi_inquiry(9S) structure as necessary to make sure that the device is of the type expected by a particular driver.

attach( )

After the probe(9E) routine has verified that the expected device is present, attach(9E) is called. This routine allocates and initializes any per-instance data, creates minor device node information, and restores the hardware state of a device when the device or the system has been suspended. See “attach( )” on page 101 for details of this. In addition to these steps, a SCSI target driver again calls scsi_probe(9F) to retrieve the device’s inquiry data and also creates a SCSI request sense packet. If the attach is successful, the attach function should not call scsi_unprobe.

Three routines are used to create the request sense packet: scsi_alloc_consistent_buf(9F), scsi_init_pkt(9F), and scsi_setup_cdb(9F). scsi_alloc_consistent_buf(9F) allocates a buffer suitable for consistent DMA and returns a pointer to a buf(9S) structure. The advantage of a consistent buffer is that no explicit synchronization of the data is required. In other words, the target driver can access the data after the callback. The sd_sense element of the device’s scsi_device(9S) structure must be initialized with the address of the sense buffer. scsi_init_pkt(9F) creates and partially initializes a scsi_pkt(9S) structure. scsi_setup_cdb(9F) creates a SCSI command descriptor block, in this case creating a SCSI request sense command.

Note that since a SCSI device is not self-identifying and does not have a *reg* property, the driver must set the *pm-hardware-state* property to inform the framework that this device needs to be suspended and resumed.

Code Example 13-2 shows the SCSI target driver’s attach(9E) routine.

Code Example 13-2 SCSI Target Driver attach(9E) Routine

```
static int
xxattach(dev_info_t *dip, ddi_attach_cmd_t cmd)
{
    struct xxstate     *xsp;
    struct scsi_pkt    *rqpkt = NULL;
struct scsi_device *sdp;
struct buf         *bp = NULL;
int    instance;

instance = ddi_get_instance(dip);

switch (cmd) {

    case DDI_ATTACH:
        break;

    case DDI_PM_RESUME:
```
For information, see Chapter 8, "Power Management"
```
    case DDI_RESUME:
```
For information, see Chapter 8, "Power Management"
```
    default:

        return (DDI_FAILURE);

}
```
allocate a state structure and initialize it

```
...
xsp = ddi_get_soft_state(statep, instance);
sdp = (struct scsi_device *)ddi_get_driver_private(dip);

/*
 * Cross-link the state and scsi_device(9S) structures.
 */
sdp->sd_private = (caddr_t)xsp;
xsp->sdp = sdp;
```
call `scsi_probe`*(9F) again to get and validate inquiry data*

```
/*
 * Allocate a request sense buffer. The buf(9S) structure
 * is set to NULL to tell the routine to allocate a new
 * one. The callback function is set to NULL_FUNC to tell
 * the routine to return failure immediately if no
 * resources are available.
 */
bp = scsi_alloc_consistent_buf(&sdp->sd_address, NULL,
    SENSE_LENGTH, B_READ, NULL_FUNC, NULL);
if (bp == NULL)
    goto failed;

/*
 * Create a Request Sense scsi_pkt(9S) structure.
 */
rqpkt = scsi_init_pkt(&sdp->sd_address, NULL, bp,
            CDB_GROUP0, 1, 0, PKT_CONSISTENT, NULL_FUNC, NULL);
        if (rqpkt == NULL)
            goto failed;
        /*
         * scsi_alloc_consistent_buf(9F) returned a buf(9S) structure.
         * The actual buffer address is in b_un.b_addr.
         */
        sdp->sd_sense = (struct scsi_extended_sense *)bp->b_un.b_addr;
        /*
         * Create a Group0 CDB for the Request Sense command
         */
        if (scsi_setup_cdb((union scsi_cdb *)rqpkt->pkt_cdbp,
            SCMD_REQUEST_SENSE, 0, SENSE__LENGTH, 0) == 0)
            goto failed;;
        /*
         * Fill in the rest of the scsi_pkt structure.
         * xxcallback() is the private command completion routine.
         */
        rqpkt->pkt_comp = xxcallback;
        rqpkt->pkt_time = 30; /* 30 second command timeout */
        rqpkt->pkt_flags |= FLAG_SENSING;
        xsp->rqs = rqpkt;
        xsp->rqsbuf = bp;
        create minor nodes, report device, and do any other initialization
        /*
         * Since the device does not have the 'reg' property,
         * cpr will not call its DDI_SUSPEND/DDI_RESUME entries.
         * The following code is to tell cpr that this device
         * needs to be suspended and resumed.
         */
        (void) ddi_prop_create(device, dip, DDI_PROP_CANSLEEP,
            "pm-hardware-state", (caddr_t)"needs-suspend-resume",
            strlen("needs-suspend-resume") + 1);
        xsp->open = 0;
        return (DDI_SUCCESS);
    failed:
        if (bp)
            scsi_free_consistent_buf(bp);
        if (rqpkt)
            scsi_destroy_pkt(rqpkt);
    sdp->sd_private = (caddr_t)NULL;
    sdp->sd_sense = NULL;
    scsi_unprobe(sdp);
    free any other resources, such as the state structure
    return (DDI_FAILURE);
}
```

detach( )

The `detach`(9E) entry point is the inverse of `attach`(9E); it must free all resources that were allocated in `attach`(9E). If successful, the detach should call `scsi_unprobe`(9F). Code Example 13-3 shows a target driver `detach`(9E) routine.

Code Example 13-3 SCSI Target Driver `detach`(9E) Routine

```
static int
xxdetach(dev_info_t *dip, ddi_detach_cmd_t cmd)
{
    struct xxstate *xsp;
    switch (cmd) {
    case DDI_DETACH:
        normal detach(9E) operations, such as getting a pointer to the state structure
        ...
        scsi_free_consistent_buf(xsp->rqsbuf);
        scsi_destroy_pkt(xsp->rqs);
        xsp->sdp->sd_private = (caddr_t)NULL;
        xsp->sdp->sd_sense = NULL;
        scsi_unprobe(xsp->sdp);
        remove minor nodes
        free resources, such as the state structure and properties
        remove power managed components
        return (DDI_SUCCESS);
    case DDI_SUSPEND:
        For information, see Chapter 8, “Power Management”
    case DDI_PM_SUSPEND:
        For information, see Chapter 8, “Power Management”
    default:
        return (DDI_FAILURE);
    }
}
```

getinfo( )

The `getinfo`(9E) routine for SCSI target drivers is much the same as for other drivers; see “getinfo( )” on page 110 for more information on `DDI_INFO_DEVT2INSTANCE` case. However, in the `DDI_INFO_DEVT2DEVINFO` case of the `getinfo`(9E) routine, the target driver must return a pointer to its `dev_info` node. This pointer can be saved in the driver state structure or can be retrieved from the `sd_dev` field of the `scsi_device`(9S) structure. Code Example 13-4 shows an alternative SCSI target driver `getinfo`(9E) code fragment.

Code Example 13-4 Alternative SCSI Target Driver `getinfo`(9E) Code Fragment

```
    ...
    case DDI_INFO_DEVT2DEVINFO:
        dev = (dev_t)arg;
        instance = getminor(dev);
        xsp = ddi_get_soft_state(statep, instance);
        if (xsp == NULL)
            return (DDI_FAILURE);
        *result = (void *)xsp->sdp->sd_dev;
        return (DDI_SUCCESS);
    ...
```

Resource Allocation

To send a SCSI command to the device, the target driver must create and initialize a `scsi_pkt`(9S) structure and pass it to the host bus adapter driver.

scsi_init_pkt( )

The `scsi_init_pkt`(9F) routine allocates and zeros a `scsi_pkt`(9S) structure; it also sets pointers to `pkt_private`, `*pkt_scbp`, and `*pkt_cdbp`. Additionally, it provides a callback mechanism to handle the case where resources are not available. This structure contains the following fields:

```
struct scsi_pkt *scsi_init_pkt(struct scsi_address *ap,
    struct scsi_pkt *pktp, struct buf *bp, int cmdlen,
    int statuslen, int privatelen, int flags,
    int (*callback)(caddr_t), caddr_t arg)
```

`ap` is a pointer to a `scsi_address` structure. This is the `sd_address` field of the device's `scsi_device`(9S) structure.

`pktp` is a pointer to the `scsi_pkt`(9S) structure to be initialized. If this is set to `NULL`, a new packet is allocated.

`bp` is a pointer to a `buf`(9S) structure. If this is non-NULL and contains a valid byte count, DMA resources are allocated.

`cmdlen` is the length of the SCSI command descriptor block in bytes.

`statuslen` is the required length of the SCSI status completion block in bytes.

`privatelen` is the number of bytes to allocate for the `pkt_private` field. To store a pointer, specify the size of the pointer here (such as `sizeof(struct xxstate *)` when storing a pointer to the state structure).

`flags` is a set of flags. Possible bits include:

- `PKT_CONSISTENT` – This bit must be set if the DMA buffer was allocated using `scsi_alloc_consistent_buf`(9F). In this case, the host bus adapter driver guarantees that the data transfer is properly synchronized before performing the target driver's command completion callback.

- `PKT_DMA_PARTIAL` – This bit may be set if the driver can accept a partial DMA mapping. If set, `scsi_init_pkt`(9F) allocates DMA resources with the `DDI_DMA_PARTIAL` flag set. The `pkt_resid` field of the `scsi_pkt`(9S) structure may be returned with a nonzero residual, indicating the number of bytes for which `scsi_init_pkt`(9F) was unable to allocate DMA resources.

`callback` specifies the action to take if resources are not available. If set to `NULL_FUNC`, `scsi_init_pkt`(9F) returns immediately (returning `NULL`). If set to `SLEEP_FUNC`, it does not return until resources are available. Any other valid kernel address is interpreted as the address of a function to be called when resources are likely to be available.

`arg` is the parameter to pass to the callback function.

The scsi_init_pkt(9F) routine synchronizes the data prior to transport. If the driver needs to access the data after transport, the scsi_sync_pkt(9F) routine can be used to synchronize any cached data.

The scsi_destroy_pkt(9F) routine synchronizes any remaining cached data associated with the packet, if necessary, and then frees the packet and associated command, status, and target driver-private data areas. This routine should be called in the command completion routine (see scsi_pkt structure on page 193).

If the target driver needs to resubmit the packet after changing the data, scsi_sync_pkt(9F) must be called before calling scsi_transport(9F). However, if the target driver does not need to access the data, there is no need to call scsi_sync_pkt(9F) after the transport.

scsi_alloc_consistent_buf( )

For most I/O requests, the data buffer passed to the driver entry points is not accessed directly by the driver, it is just passed on to scsi_init_pkt(9F). If a driver sends SCSI commands that operate on buffers the driver examines itself (such as the SCSI request sense command), the buffers should be DMA consistent. The scsi_alloc_consistent_buf(9F) routine allocates a buf(9S) structure and a data buffer suitable for DMA-consistent operations. The HBA will perform any necessary synchronization of the buffer before performing the command completion callback.

Caution – scsi_alloc_consistent_buf(9F) uses scarce system resources; it should be used sparingly.

scsi_free_consistent_buf(9F) releases a buf(9S) structure and the associated data buffer allocated with scsi_alloc_consistent_buf(9F). See “attach( )” on page 266 and “detach( )” on page 269 for examples.

Building and Transporting a Command

The host bus adapter driver is responsible for transmitting the command to the device and handling the low-level SCSI protocol. The scsi_transport(9F) routine hands a packet to the host bus adapter driver for transmission. It is the target driver’s responsibility to create a valid scsi_pkt(9S) structure.

Building a Command

The routine `scsi_init_pkt`(9F) allocates space for a SCSI CDB, allocates DMA resources if necessary, and sets the `pkt_flags` field:

```
pkt = scsi_init_pkt(&sdp->sd_address, NULL, bp,
    CDB_GROUP0, 1, 0, 0, SLEEP_FUNC, NULL);
```

This example creates a new packet and allocates DMA resources as specified in the passed `buf`(9S) structure pointer. A SCSI CDB is allocated for a Group 0 (6-byte) command, the `pkt_flags` field is set to zero, but no space is allocated for the `pkt_private` field. This call to `scsi_init_pkt`(9F), because of the `SLEEP_FUNC` parameter, waits indefinitely for resources if none are currently available.

The next step is to initialize the SCSI CDB, using the `scsi_setup_cdb`(9F) function:

```
if (scsi_setup_cdb((union scsi_cdb *)pkt->pkt_cdbp,
    SCMD_READ, bp->b_blkno, bp->b_bcount >> DEV_BSHIFT, 0) == 0)
    goto failed;
```

This example builds a Group 0 command descriptor block and fills in the `pkt_cdbp` field as follows:

- The command itself (byte 0) is set from the parameter (`SCMD_READ`).
- The address field (bits 0-4 of byte 1 and bytes 2 and 3) is set from `bp->b_blkno`.
- The count field (byte 4) is set from the last parameter. In this case it is set to `bp->b_bcount >> DEV_BSHIFT`, where `DEV_BSHIFT` is the byte count of the transfer converted to the number of blocks.

Note – `scsi_setup_cdb`(9F) does not support setting a target device's logical unit number (LUN) in bits 5-7 of byte 1 of the SCSI command block, as defined by SCSI-1. For SCSI-1 devices requiring the LUN bits set in the command block, use `makecom_g0`(9F) (or equivalent) rather than `scsi_setup_cdb`(9F).

After initializing the SCSI CDB, initialize three other fields in the packet and store as a pointer to the packet in the state structure.

```
pkt->pkt_private = (opaque_t)bp;
pkt->pkt_comp = xxcallback;
pkt->pkt_time = 30;
xsp->pkt = pkt;
```

The buf(9S) pointer is saved in the pkt_private field for later use in the completion routine.

Setting Target Capabilities

The target drivers use scsi_ifsetcap(9F) to set the capabilities of the host adapter driver. A *cap* is a name-value pair whose name is a null terminated character string and whose value is an integer. The current value of a capability can be retrieved using scsi_ifgetcap(9F). scsi_ifsetcap(9F) allows capabilities to be set for all targets on the bus.

In general, however, setting capabilities of targets that are not owned by the target driver is not recommended and is not universally supported by HBA drivers. Some capabilities (such as disconnect and synchronous) may be set by default by the HBA driver but others may need to be explicitly set by the target driver (wide-xfer or tagged-queing, for example).

Transporting a Command

After creating and filling in the scsi_pkt(9S) structure, the final step is to hand it to the host bus adapter driver:

```
if (scsi_transport(pkt) != TRAN_ACCEPT) {
    bp->b_resid = bp->b_bcount;
    bioerror(bp, EIO);
    biodone(bp);
}
```

The other return values from scsi_transport(9F) are:

- TRAN_BUSY – There is already a command in progress for the specified target.
- TRAN_BADPKT – The DMA count in the packet was too large, or the host adapter driver rejected this packet for other reasons.
- TRAN_FATAL_ERROR – The host adapter driver is unable to accept this packet.

Warning – The mutex sd_mutex in the scsi_device(9S) structure must not be held across a call to scsi_transport(9F).

If `scsi_transport`(9F) returns `TRAN_ACCEPT`, the packet is the responsibility of the host bus adapter driver and should not be accessed by the target driver until the command completion routine is called.

Synchronous `scsi_transport(9F)`

If `FLAG_NOINTR` is set in the packet, then `scsi_transport`(9F) will not return until the command is complete, and no callback will be performed.

Note – `FLAG_NOINTR` should never be used in interrupt context.

Command Completion

Once the host bus adapter driver has done all it can with the command, it invokes the packet's completion callback routine, passing a pointer to the `scsi_pkt`(9S) structure as a parameter. The completion routine decodes the packet and takes the appropriate action.

Code Example 13-5 presents a very simple completion callback routine. This code checks for transport failures and gives up rather than retry the command. If the target is busy, extra code is required to resubmit the command at a later time.

If the command results in a check condition, the target driver needs to send a request sense command, unless auto request sense has not been enabled.

Note – Normally, the target driver's callback function is called in interrupt context. Consequently, the callback function should never sleep.

Code Example 13-5 SCSI Driver Completion Routine

```
static void
xxcallback(struct scsi_pkt *pkt)
{
    struct buf     *bp;
    struct xxstate *xsp;
    minor_t        instance;
    struct scsi_status *ssp;
    /*
     * Get a pointer to the buf(9S) structure for the command
     * and to the per-instance data structure.
     */
    bp = (struct buf *)pkt->pkt_private;
    instance = getminor(bp->b_edev);
    xsp = ddi_get_soft_state(statep, instance);

    /*
     * Figure out why this callback routine was called
     */
    if (pkt->pkt_reason != CMP_CMPLT) {
        bp->b_resid = bp->b_bcount;
        bioerror(bp, EIO);
        scsi_destroy_pkt(pkt);/* release resources */
        biodone(bp);          /* notify waiting threads */ ;
    } else {
        /*
         * Command completed, check status.
         * See scsi_status(9S)
         */
        ssp = (struct scsi_status *)pkt->pkt_scbp;
        if (ssp->sts_busy) {
            error, target busy or reserved
        } else if (ssp->sts_chk) {
            send a request sense command
        } else {
            bp->b_resid = pkt->pkt_resid; /*packet completed OK */
            scsi_destroy_pkt(pkt);
            biodone(bp);
        }
    }
}
```

Otherwise, the command succeeded. If this is the end of processing for the command, it destroys the packet and calls `biodone`(9F).

In the event of a transport error (such as a bus reset or parity problem), the target driver may resubmit the packet using `scsi_transport`(9E). There is no need to change any values in the packet prior to resubmitting.

This example does not attempt to retry incomplete commands. See Appendix D, “Sample Driver Source Code Listings” for information about sample SCSI drivers. Also see Appendix G, “Advanced Topics,” for further information.

Reuse of Packets

A target driver may reuse packets in the following ways:

- Resubmit the packet unchanged
- Use `scsi_sync_pkt`(9F) to synchronize the data, then process the data in the driver and resubmit.
- Free DMA resources, using `scsi_dma_free`(9F), and pass the `pkt` pointer to `scsi_init_pkt`(9F) for binding to a new `bp`. The target driver is responsible for reinitializing the packet. The CDB has to have the same length as the previous CDB.
- If partial DMA was allocated during the first call to `scsi_init_pkt`(9F), subsequent calls to `scsi_init_pkt`(9F) may be made for the same packet and `bp` to adjust the DMA resources to the next portion of the transfer.

Auto-Request Sense Mode

Auto-request sense mode is most desirable if tagged or untagged queueing is used. A contingent allegiance condition is cleared by any subsequent command and, consequently, the sense data is lost. Most HBA drivers will start the next command before performing the target driver callback. Other HBA drivers may use a separate and lower-priority thread to perform the callbacks, which may increase the time it takes to notify the target driver that the packet completed with a check condition. In this case, the target driver may not be able to submit a request sense command in time to retrieve the sense data.

To avoid this loss of sense data, the HBA driver, or controller, should issue a request sense command as soon as a check condition has been detected; this mode is known as auto-request sense mode. Note that not all HBA drivers are capable of auto-request sense mode, and some can only operate with auto-request-sense mode enabled.

A target driver enables auto-request-sense mode by using `scsi_ifsetcap`(9F). Code Example 13-6 shows enabling auto request sense.

Code Example 13-6 Enabling Auto Request Sense

```
static int
xxattach(dev_info_t *dip, ddi_attach_cmd_t cmd)
{
    struct xxstate *xsp;
    struct scsi_device *sdp = (struct scsi_device *)
        ddi_get_driver_private(dip);
    ...
    /*
     * enable auto-request-sense; an auto-request-sense cmd may fail
     * due to a BUSY condition or transport error. Therefore, it is
     * recommended to allocate a separate request sense packet as
     * well.
     * Note that scsi_ifsetcap(9F) may return -1, 0, or 1
     */
    xsp->sdp_arq_enabled =
       ((scsi_ifsetcap(ROUTE, “auto-rqsense”, 1, 1) == 1) ? 1 : 0);
    /*
     * if the HBA driver supports auto request sense then the
     * status blocks should be sizeof (struct scsi_arq_status); else
     * one byte is sufficient
     */
    xsp->sdp_cmd_stat_size =  (xsp->sdp_arq_enabled ?
        sizeof (struct scsi_arq_status) : 1);
    ...
}
```

When a packet is allocated using `scsi_init_pkt`(9F) and auto request sense is desired on this packet then the target driver must request additional space for the status block to hold the auto request sense structure (as Code Example 13-7 illustrates). The sense length used in the request sense command is `sizeof` (`struct scsi_extended_sense`).

The `scsi_arq_status` structure contains the following members:

```
    struct scsi_status sts_status;
    struct scsi_status sts_rqpkt_status;
    u_char             sts_rqpkt_reason;/* reason completion */
    u_char             sts_rqpkt_resid;/* residue */
    u_int              sts_rqpkt_state;/* state of command */
    u_int              sts_rqpkt_statistics;/* statistics */
    struct scsi_extended_sense sts_sensedata;
```

Auto request sense can be disabled per individual packet by just allocating `sizeof` (`struct scsi_status`) for the status block.

Code Example 13-7 Allocating a Packet With Auto Request Sense

```
    pkt = scsi_init_pkt(ROUTE, NULL, bp, CDB_GROUP1,
        xsp->sdp_cmd_stat_size, PP_LEN, 0, func, (caddr_t) xsp);
```

The packet is submitted using `scsi_transport`(9F) as usual. When a check condition occurs on this packet, the host adapter driver:

- Issues a request sense command if the controller doesn't have auto-request-sense capability.
- Obtains the sense data.
- Fills in the `scsi_arq_status` information in the packet's status block.
- Sets `STATE_ARQ_DONE` in the packet's `pkt_state` field.
- Calls the packet's callback handler (`pkt_comp`)

The target driver's callback routine should verify that sense data is available by checking the `STATE_ARQ_DONE` bit in `pkt_state`, which implies that a check condition has occurred and a request sense has been performed. If auto-request-sense has been temporarily disabled in a packet, there is no guarantee that the sense data can be retrieved at a later time.

The target driver should then verify whether the auto request sense command completed successfully and decode the sense data.

Code Example 13-8 Checking for Auto Request Sense

```
static void
xxcallback(struct scsi_pkt *pkt)
{
    ...
    if (pkt->pkt_state & STATE_ARQ_DONE) {
        /*
         * The transport layer successfully completed an
         * auto-request-sense.
         * Decode the auto request sense data here
         */
        ....
    }
    ...
}
```

See Appendix D, "Sample Driver Source Code Listings," for more information about SCSI drivers.

SCSI Host Bus Adapter Drivers 14

This chapter contains information on creating SCSI host bus adapter (HBA) drivers and provides sample code illustrating the use of the HBA driver interfaces provided by the Sun Common SCSI Architecture (SCSA).

Note – Understanding SCSI target drivers is an essential prerequisite to writing effective SCSI HBA drivers. For information on SCSI target drivers, see Chapter 13, “SCSI Target Drivers.” Target driver developers can also benefit from reading this chapter.

SCSI HBA Driver Overview

As described in Chapter 13, “SCSI Target Drivers,” the Solaris 2.x DDI/DKI divides the software interface to SCSI devices into two major parts:

- Target devices and drivers
- Host bus adapter devices and drivers

Target device refers to a device on a SCSI bus, such as a disk or a tape drive. *Target driver* refers to a software component installed as a device driver. Each target device on a SCSI bus is controlled by one instance of the target driver.

Host bus adapter device refers to HBA hardware, such as an SBus or ISA SCSI adapter card. *Host bus adapter driver* refers to a software component installed as a device driver, such as the `esp` driver on a SPARCstation or the `aha` driver on an x86 machine. An instance of the HBA driver controls each of its host bus adapter devices configured in the system.

Note – The terms “host bus adapter” or “HBA” used in this manual are equivalent to the phrase “host adapter” as defined in the SCSI standards.

The Sun Common SCSI Architecture (SCSA) defines the interface between these target and HBA components.

SCSA Interface

SCSA is the Solaris 2.x DDI/DKI programming interface for the transmission of SCSI commands from a target driver to a host adapter driver. By conforming to the SCSA, the target driver can pass any combination of SCSI commands and sequences to a target device without knowledge of the hardware implementation of the host adapter. SCSA conceptually separates the building of a SCSI command (by the target driver) from the transporting of the command to and data to and from the SCSI bus (by the HBA driver) for the appropriate target device. SCSA manages the connections between the target and HBA drivers through an HBA *transport* layer, as shown in Figure 14-1.

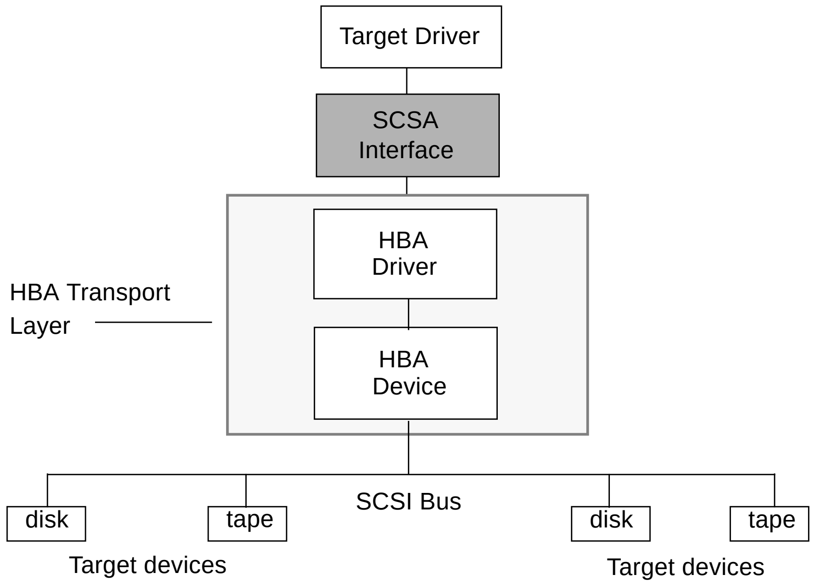


Figure 14-1 SCSA Interface

HBA Transport Layer

The *HBA transport laye*r is a software and hardware layer responsible for transporting a SCSI command to a SCSI target device. The HBA driver provides resource allocation, DMA management, and transport services in response to requests made by SCSI target drivers through SCSA. The host adapter driver also manages the host adapter hardware and the SCSI protocols necessary to perform the commands. When a command has been completed, the HBA driver calls the target driver's SCSI `pkt` command completion routine.

Figure 14-2 illustrates this flow, with emphasis placed on the transfer of information from target drivers to SCSA to HBA drivers. Typical transport entry points and function calls are included.

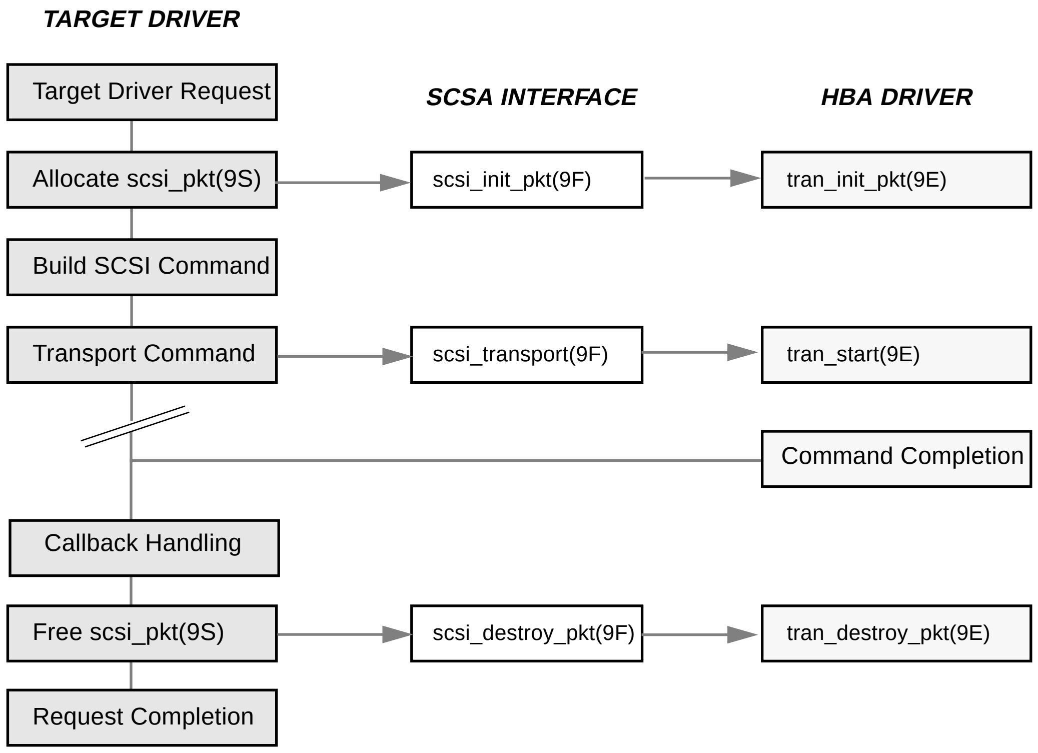


Figure 14-2 Transport Layer Flow

14

SCSA HBA Interfaces

SCSA HBA interfaces include HBA entry points, HBA data structures, and an HBA framework.

SCSA HBA Entry Point Summary

SCSA defines a number of HBA driver entry points, listed in Table 14-1. These entry points are called by the system when configuring a target driver instance connected to the HBA driver, or when the target driver makes a SCSA request. See "SCSA HBA Entry Points" on page 305 for more information.

Table 14-1 SCSA HBA Entry Point Summary

Function Name	**Called as a Result of**
`tran_tgt_init(9E)`	System attaching target device instance
`tran_tgt_probe(9E)`	Target driver calling `scsi_probe`(9F)
`tran_tgt_free(9E)`	System detaching target device instance
`tran_start(9E)`	Target driver calling `scsi_transport`(9F)
`tran_reset(9E)`	Target driver calling `scsi_reset`(9F)
`tran_abort(9E)`	Target driver calling `scsi_abort`(9F)
`tran_getcap(9E)`	Target driver calling `scsi_ifgetcap`(9F)
`tran_setcap(9E)`	Target driver calling `scsi_ifsetcap`(9F)
`tran_init_pkt(9E)`	Target driver calling `scsi_init_pkt`(9F)
`tran_destroy_pkt(9E)`	Target driver calling `scsi_destroy_pkt`(9F)
`tran_dmafree(9E)`	Target driver calling `scsi_dmafree`(9F)
`tran_sync_pkt(9E)`	Target driver calling `scsi_sync_pkt`(9F)
`tran_reset_notify(9E)`	Target driver calling `scsi_reset_notify`(9F)

SCSA HBA Data Structures

SCSA defines data structures to enable the exchange of information between the target and HBA drivers. These data structures include:

- `scsi_hba_tran`(9S)
- `scsi_address`(9S)

- scsi_device(9S)
- scsi_pkt(9S)

scsi_hba_tran

Each instance of an HBA driver must allocate a scsi_hba_tran(9S) structure using scsi_hba_tran_alloc(9F) in the attach(9E) entry point. scsi_hba_tran_alloc(9S) zeroes the scsi_hba_tran(9S) structure before it returns. The HBA driver must initialize specific vectors in the transport structure to point to entry points within the HBA driver. Once initialized, the HBA driver exports the transport structure to SCSA by calling scsi_hba_attach_setup(9F).

Caution – Because SCSA keeps a pointer to the transport structure in the driver-private field on the dev_info(9S) structure, HBA drivers must not use ddi_set_driver_private(9F). They may, however, use ddi_get_driver_private(9F) to retrieve the pointer to the transport structure.

The scsi_hba_tran(9S) structure contains the following fields:

```
dev_info_t *tran_hba_dip;        /* HBA dev_info_t ptr */
void    *tran_hba_private;       /* HBA softstate */
void    *tran_tgt_private;       /* target-specific info */
struct  scsi_device*tran_sd;     /* scsi_device, if clone */
int     (*tran_tgt_init)();      /* target initialization */
int     (*tran_tgt_probe)();     /* target probing */
void    (*tran_tgt_free)();      /* target free */
int     (*tran_start)();;        /* command transport */
int     (*tran_reset)();         /* target/bus reset */
int     (*tran_abort)();         /* command abort */
int     (*tran_getcap)();        /* get capability */
int     (*tran_setcap)();        /* set capability */
struct  scsi_pkt*(*tran_init_pkt)();/* allocate scsi pkt */
void    (*tran_destroy_pkt)();   /* free scsi pkt */
void    (*tran_dmafree)();       /* free dma resources */
void    (*tran_sync_pkt)();      /* sync data after dma */
void    (*tran_reset_notify)();  /* bus reset notification */
```

Note – Code fragments presented subsequently in this chapter use these fields to describe practical HBA driver operations. See “SCSA HBA Entry Points” on page 305 for more information.

`tran_hba_dip` is a pointer to the HBA device instance `dev_info` structure. The function `scsi_hba_attach_setup`(9F) sets this field.

`tran_hba_private` is a pointer to private data maintained by the HBA driver. Usually, `tran_hba_private` contains a pointer to the state structure of the HBA driver.

`tran_tgt_private` is a pointer to private data maintained by the HBA driver when using cloning. By specifying `SCSI_HBA_TRAN_CLONE` when calling `scsi_hba_attach_setup`(9F), the `scsi_hba_tran`(9S) structure is cloned once per target, permitting the HBA to initialize this field to point to a per-target instance data structure in the `tran_tgt_init`(9E) entry point. If `SCSI_HBA_TRAN_CLONE` is not specified, `tran_tgt_private` is NULL and must not be referenced. See “Transport Structure Cloning (optional)” on page 292 for more information.

`tran_sd` is a pointer to a per-target instance `scsi_device`(9S) structure used when cloning. If `SCSI_HBA_TRAN_CLONE` is passed to `scsi_hba_attach_setup`(9F), `tran_sd` is initialized to point to the per-target `scsi_device` structure before any HBA functions are called on behalf of that target. If `SCSI_HBA_TRAN_CLONE` is not specified, `tran_sd` is NULL and must not be referenced. See “Transport Structure Cloning (optional)” on page 292 for more information.

`tran_tgt_init` is a pointer to the HBA driver entry point called when initializing a target device instance. If no per-target initialization is required, the HBA may leave `tran_tgt_init` set to NULL.

`tran_tgt_probe` is a pointer to the HBA driver entry point called when a target driver instance calls `scsi_probe`(9F) to probe for the existence of a target device. If no target probing customization is required for this HBA, the HBA should set `tran_tgt_probe` to `scsi_hba_probe`(9F).

`tran_tgt_free` is a pointer to the HBA driver entry point called when a target device instance is destroyed. If no per-target deallocation is necessary, the HBA may leave `tran_tgt_free` set to NULL.

tran_start is a pointer to the HBA driver entry point called when a target driver calls scsi_transport(9F).

tran_reset is a pointer to the HBA driver entry point called when a target driver calls scsi_reset(9F).

tran_abort is a pointer to the HBA driver entry point called when a target driver calls scsi_abort(9F).

tran_getcap is a pointer to the HBA driver entry point called when a target driver calls scsi_getcap(9F).

tran_setcap is a pointer to the HBA driver entry point called when a target driver calls scsi_setcap(9F).

tran_init_pkt is a pointer to the HBA driver entry point called when a target driver calls scsi_init_pkt(9F).

tran_destroy_pkt is a pointer to the HBA driver entry point called when a target driver calls scsi_destroy_pkt(9F).

tran_dmafree is a pointer to the HBA driver entry point called when a target driver calls scsi_dmafree(9F).

tran_sync_pkt is a pointer to the HBA driver entry point called when a target driver calls scsi_sync_pkt(9F).

tran_reset_notify is a pointer to the HBA driver entry point called when a target driver calls tran_reset_notify(9F).

scsi_address

The scsi_address(9S) structure provides transport and addressing information for each SCSI command allocated and transported by a target driver instance.

The scsi_address(9S) structure contains the following fields:

```
scsi_hba_tran_t *a_hba_tran;  /* HBA transport vectors */
u_short         a_target;     /* Target on SCSI bus */
u_char          a_lun;        /* Lun on that Target */
```

a_hba_tran is a pointer to the scsi_hba_tran(9S) structure, as allocated and initialized by the HBA driver. If SCSI_HBA_TRAN_CLONE was specified as the flag to scsi_hba_attach_setup(9F), a_hba_tran points to a copy of that structure.

a_target identifies the SCSI target on the SCSI bus.

a_lun identifies the SCSI logical unit on the SCSI target.

scsi_device

The HBA framework allocates and initializes a scsi_device(9S) structure for each instance of a target device before calling an HBA driver's tran_tgt_init(9E) entry point. This structure stores information about each SCSI logical unit, including pointers to information areas that contain both generic and device-specific information. There is one scsi_device(9S) structure for each target device instance attached to the system.

If the per-target initialization is successful (in other words, if either tran_tgt_init(9E) returns success or the vector is NULL), the HBA framework will set the target driver's per-instance private data to point to the scsi_device(9S) structure, using ddi_set_driver_private(9F).

The scsi_device(9S) structure contains the following fields:

```
struct scsi_address       sd_address;/* routing information */
dev_info_t                *sd_dev;   /* device dev_info node */
kmutex_t                  sd_mutex;  /* mutex used by device */
struct scsi_inquiry       *sd_inq;
struct scsi_extended_sense*sd_sense;
caddr_t                   sd_private;/* for driver's use */
```

sd_address is a data structure that is passed to the SCSI resource allocation routines.

sd_dev is a pointer to the target's dev_info structure.

sd_mutex is a mutex for use by the target driver. This is initialized by the HBA framework and can be used by the target driver as a per-device mutex. This mutex should not be held across a call to scsi_transport(9F) or scsi_poll(9F). See Chapter 4, “Multithreading,” for more information on mutexes.

sd_inq is a pointer for the target device's SCSI inquiry data. The scsi_probe(9F) routine allocates a buffer, fills it in, and attaches it to this field.

sd_sense is a pointer to a buffer to contain Request Sense data from the device. The target driver must allocate and manage this buffer itself; see the target driver's attach(9E) routine in "attach( )" on page 101 for more information.

sd_private is a pointer field for use by the target driver. It is commonly used to store a pointer to a private target driver state structure.

scsi_pkt

To execute SCSI commands, a target driver must first allocate a scsi_pkt(9S) structure for the command, specifying its own private data area length, the command status, and the command length. The HBA driver is responsible for implementing the packet allocation in the tran_init_pkt(9E) entry point. The HBA driver is also responsible for freeing the packet in its tran_destroy_pkt(9E) entry point. See scsi_pkt(9S) in Chapter 13, "SCSI Target Drivers," for more information.

The scsi_pkt(9S) structure contains these fields:

```
opaque_t            pkt_ha_private;/* HBA private data */
struct  scsi_address*pkt_address;  /* destination address */
opaque_t            pkt_private;   /* target driver private */
void                (*pkt_comp)(); /* pkt completion routine */
u_int               pkt_flags;     /* flags */
int                 pkt_time;      /* completion timeout */
u_char              *pkt_scbp;     /* ptr to status block */
u_char              *pkt_cdbp;     /* ptr to command block */
ssize_t             pkt_resid;     /* bytes not transferred*/
u_int               pkt_state;     /* state of command */
u_int               pkt_statistics;/* statistics */
u_char              pkt_reason;    /* pkt completion reason */
```

The HBA driver must modify the following fields during transport.

- pkt_resid
- pkt_state;
- pkt_statistics
- pkt_reason

`pkt_ha_private` is a pointer to per-command HBA-driver private data.

`pkt_address` is a pointer to the `scsi_address`(9S) structure providing address information for this command.

`pkt_private` is a pointer to per-packet target-driver private data.

`pkt_comp` is a pointer to the target driver completion routine called by the HBA driver when the transport layer has completed this command.

`pkt_flags` are the flags for the command.

`pkt_time` specifies the completion timeout in seconds for the command.

`pkt_scbp` is a pointer to the status completion block for the command.

`pkt_cdbp` is a pointer to the command descriptor block (CDB) for the command.

`pkt_resid` is a count of the data bytes *not* transferred when the command has been completed or the amount of data for which resources have not been allocated.

`pkt_state` is the state of the command.

`pkt_statistics` provides a history of the events the command experienced while in the transport layer.

`pkt_reason` is the reason for command completion.

Per-Target Instance Data

An HBA driver must allocate a `scsi_hba_tran`(9S) structure during `attach`(9E) and initialize the vectors in this transport structure to point to the required HBA driver entry points. This `scsi_hba_tran`(9S) structure is then passed into `scsi_hba_attach_setup`(9F).

The `scsi_hba_tran`(9S) structure contains a `tran_hba_private` field, which may be used to refer to the HBA driver's per-instance state.

Each `scsi_address`(9S) structure contains a pointer to the `scsi_hba_tran`(9S) structure and also provides the target (`a_target`) and logical unit (`a_lun`) addresses for the particular target device. Because every HBA driver entry point is passed a pointer to the `scsi_address`(9S) structure, either directly or indirectly through the `scsi_device`(9S) structure, the HBA driver can reference its own state and can identify the target device being addressed.

Figure 14-3 illustrates the HBA data structures for transport operations.

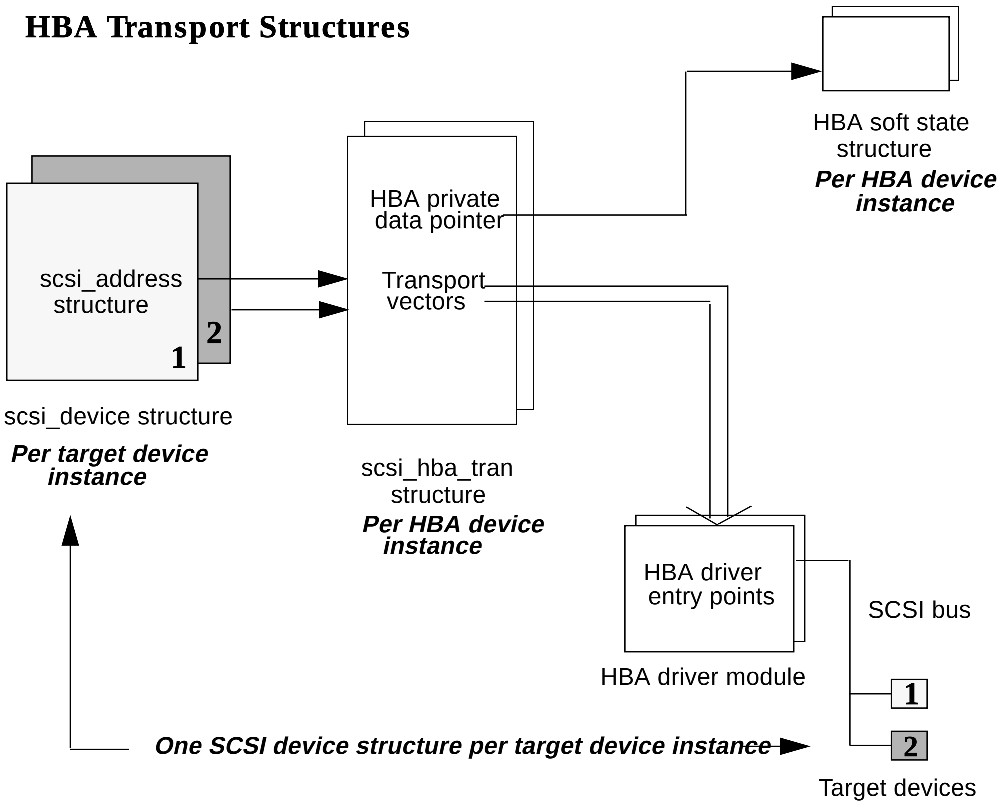


Figure 14-3 HBA Transport Sructures

Transport Structure Cloning (optional)

Cloning may be useful if an HBA driver needs to maintain per-target private data in the `scsi_hba_tran`(9S) structure, or if it needs to maintain a more complex address than is provided in the `scsi_address`(9S) structure.

When cloning, the HBA driver must still allocate a `scsi_hba_tran`(9S) structure at `attach`(9E) time and initialize the `tran_hba_private` soft state pointer and HBA entry point vectors as before. The difference occurs when the framework begins to connect an instance of a target driver to the HBA driver. Before calling the HBA driver's `tran_tgt_init`(9E) entry point, the framework duplicates (clones) the `scsi_hba_tran`(9S) structure associated with that instance of the HBA. This means that each `scsi_address`(9S) structure, allocated and initialized for a particular target device instance, points to a per-target instance *copy* of the `scsi_hba_tran`(9S) structure, not to the `scsi_hba_tran`(9S) structure allocated by the HBA driver at `attach`(9E) time.

Two important pointers that an HBA driver can use when it has specified cloning are contained in the `scsi_hba_tran`(9S) structure.The first pointer is the `tran_tgt_private` field, which the driver can use to point to per-target HBA private data. This is useful, for example, if an HBA driver needs to maintain a more complex address than the `a_target` and `a_lun` fields in the `scsi_address`(9S) structure allow. The second pointer is the `tran_sd` field, which is a pointer to the `scsi_device`(9S) structure referring to the particular target device.

When specifying cloning, the HBA driver must allocate and initialize the per-target data and initialize the `tran_tgt_private` field to point to this data during its `tran_tgt_init`(9E) entry point. The HBA driver must free this per-target data during its `tran_tgt_free`(9E) entry point.

When cloning, the framework initializes the `tran_sd` field to point to the `scsi_device`(9S) structure before the HBA driver `tran_tgt_init`(9E) entry point is called.

The driver requests cloning by passing the `SCSI_HBA_TRAN_CLONE` flag to `scsi_hba_attach_setup`(9F).

Figure 14-4 illustrates the HBA data structures for cloning transport operations.

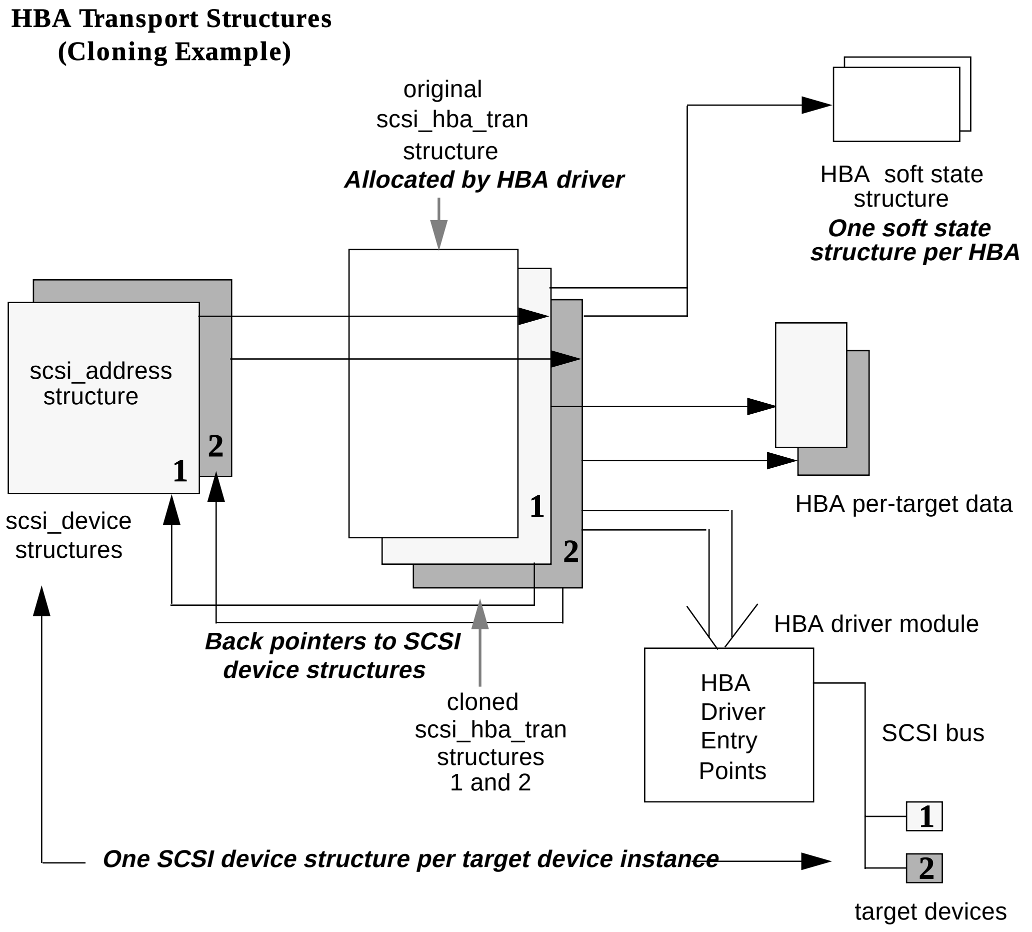


Figure 14-4 Cloning Transport Operation

SCSA HBA Functions

SCSA also provides a number of functions, listed in Table 14-2, intended for use by HBA drivers.

Table 14-2 SCSA HBA Functions

Function Name	Called by Driver Entry Point
`scsi_hba_init(9F)`	`_init(9E)`
`scsi_hba_fini(9F)`	`_fini(9E)`
`scsi_hba_attach_setup(9F)`	`attach(9E)`
`scsi_hba_detach(9F)`	`detach(9E)`
`scsi_hba_tran_alloc(9F)`	`attach(9E)`
`scsi_hba_tran_free(9F)`	`detach(9E)`
`scsi_hba_probe(9F)`	`tran_tgt_probe(9E)`
`scsi_hba_pkt_alloc(9F)`	`tran_init_pkt(9E)`
`scsi_hba_pkt_free(9F)`	`tran_destroy_pkt(9E)`
`scsi_hba_lookup_capstr(9F)`	`tran_getcap(9E)` and `tran_setcap(9E)`

HBA Driver Dependency and Configuration Issues

In addition to incorporating SCSA HBA entry points, structures and functions into a driver, HBA driver developers must also concern themselves with issues surrounding driver dependency and configuration. These issues are summarized in the following list:

- Configuration properties
- Dependency declarations
- State structure and per-command structure
- Module initialization entry points
- Autoconfiguration entry points

HBA Configuration Properties

When attaching an instance of an HBA device, `scsi_hba_attach_setup`(9F) creates a number of SCSI configuration parameter properties for that HBA instance. A particular property is created only if there is no existing property of the same name already attached to the HBA instance, permitting a default property value to be overridden in an HBA configuration file.

An HBA driver must use `ddi_prop_get_int`(9F) to retrieve each property. The HBA driver then modifies (or accepts the default value of) the properties to configure its specific operation.

scsi-reset-delay

The `scsi-reset-delay` property is an integer specifying the SCSI bus or device reset delay recovery time in milliseconds.

scsi-options

The `scsi-options` property is an integer specifying a number of options through individually defined bits. The bits in `scsi_options` are:

- `SCSI_OPTIONS_DR (0x008)` – If not set, the HBA should not grant disconnect privileges to a target device.
- `SCSI_OPTIONS_LINK (0x010)` – If not set, the HBA should not enable linked commands.
- `SCSI_OPTIONS_SYNC (0x020)` – If not set, the HBA should not negotiate synchronous data transfer, and should reject any attempt to negotiate synchronous data transfer initiated by a target.
- `SCSI_OPTIONS_PARITY (0x040)` – If not set, the HBA should run the SCSI bus without parity.
- `SCSI_OPTIONS_TAG (0x080)` – If not set, the HBA should not operate in Command Tagged Queuing mode.
- `SCSI_OPTIONS_FAST (0x100)` – If not set, the HBA should not operate the bus in FAST SCSI mode.
- `SCSI_OPTIONS_WIDE (0x200)` – If not set, the HBA should not operate the bus in WIDE SCSI mode.

Per-target `scsi-options`

An HBA driver may support a per-target `scsi-options` feature in the following format:

```
target<n>-scsi-options=<hex value>
```

In this example, < *n*> is the target ID. If the per-target `scsi-options` property is defined for a particular target, the HBA driver uses the value of the per-target `scsi-options` property for that target rather than the per-HBA driver instance `scsi-options` property. This can provide more precise control if, for example, synchronous data transfer needs to be disabled for just one particular target device. The per-target `scsi-options` property may be defined in the `driver.conf`(4) file.

Here is an example of a per-target scsi-options property definition to disable synchronous data transfer for target device 3:

```
target3-scsi-options=0x2d8
```

Declarations and Structures

HBA drivers must include the following header files, along with a declaration of dependency upon the *scsi* module:

```
#include <sys/scsi/scsi.h>
#include <sys/ddi.h>
#include <sys/sunddi.h>

char _depends_on[] = "misc/scsi";
```

This declaration informs the system that the module depends on SCSA routines (see “SCSA HBA Interfaces” on page 284 for more information). This construct is used only for SCSI drivers and should not be used elsewhere.

Code fragments are presented in this chapter that illustrate the structure of a typical HBA driver. The code samples are derived from a simplified `isp` driver for the QLogic Intelligent SCSI Peripheral device. The complete `isp` source code is available as a sample driver on the DDK.

The `isp` driver supports WIDE SCSI, with up to 15 target devices and 8 logical units (LUNs) per target.

HBA Additions to the State Structure

This chapter adds the following fields to the state structure. See “Software State Structure” on page 63 for more information.

```
    scsi_hba_tran_t    *isp_tran;
    dev_info_t         *isp_dip;
    ddi_iblock_cookie_t  isp_iblock;
    int                isp_target_scsi_options[N_ISP_TARGETS_WIDE];
    int                isp_scsi_tag_age_limit;
    u_int              isp_scsi_reset_delay;
    u_short            isp_cap[N_ISP_TARGETS_WIDE];
    u_short            isp_synch[N_ISP_TARGETS_WIDE];

    struct ispregs     *isp_reg;
    ddi_acc_handle_t   isp_acc_handle;
```

Per-Command Structure

An HBA driver will usually need to define a structure to maintain state for each command submitted by a target driver. The layout of this per-command structure is entirely up to the device driver writer and needs to reflect the capabilities and features of the hardware and the software algorithms used in the driver.

The following structure is an example of a per-command structure. The remaining code fragments of this chapter use this structure to illustrate the HBA interfaces.

```
struct isp_cmd {
    struct isp_request     cmd_isp_request;
    struct isp_response    cmd_isp_response;
    struct scsi_pkt        *cmd_pkt;
    struct isp_cmd         *cmd_forw;
    uint32_t               cmd_dmacount;
    ddi_dma_handle_t       cmd_dmahandle;
    uint_t                 cmd_cookie;
    uint_t                 cmd_ncookies;
    uint_t                 cmd_cookiecnt;
    uint_t                 cmd_nwin;
    uint_t                 cmd_curwin;
    off_t                  cmd_dma_offset;
    uint_t                 cmd_dma_len;
    ddi_dma_cookie_t       cmd_dmacookies[ISP_NDATASEGS];
    u_int                  cmd_flags;
    u_short              cmd_slot;
    u_int                cmd_cdblen;
    u_int                cmd_scblen;
};
```

Module Initialization Entry Points

Drivers for different types of devices have different sets of entry points, depending on the operations they perform. Some operations, however, are common to all drivers, such as the as `_init`(9E), `_info`(9E) and `_fini`(9E) entry points for module initialization. Chapter 3, "Overview of SunOS Device Drivers," gives a omplete description of these loadable module routines. This section describes only those entry points associated with operations performed by SCSI HBA drivers.

The following code for a SCSI HBA driver illustrates a representative `dev_ops`(9S) structure. The driver must initialize the `devo_bus_ops` field in this structure to NULL. A SCSI HBA driver may provide leaf driver interfaces for special purposes, in which case the `devo_cb_ops` field may point to a `cb_ops`(9S) structure. In this example, no leaf driver interfaces are exported, so the `devo_cb_ops` field is initialized to NULL.

```
static struct dev_ops isp_dev_ops = {
    DEVO_REV,               /* devo_rev */
    0,                      /* refcnt  */
    isp_getinfo,            /* getinfo */
    nulldev,                /* probe */
    isp_attach,             /* attach */
    isp_detach,             /* detach */
    nodev,                  /* reset */
    NULL,                   /* driver operations */
    NULL,                   /* bus operations */
    isp_power,              /* power management */
};
```

_init()

The `_init`(9E) function initializes a loadable module and is called before any other routine in the loadable module.

In a SCSI HBA, the _init(9E) function must call scsi_hba_init(9F) to inform the framework of the existence of the HBA driver before calling mod_install(9F). If scsi_hba_init(9F) returns a nonzero value, _init(9E) should return this value. Otherwise, _init(9E) must return the value returned by mod_install(9F).

The driver should initialize any required global state before calling mod_install(9F).

If mod_install(9F) fails, the _init(9E) function must free any global resources allocated and must call scsi_hba_fini(9F) before returning.

The following code sample uses a global mutex to show how to allocate data that is global to all instances of a driver. The code declares global mutex and soft-state structure information. The global mutex and soft state are initialized during _init(9E).

```
/*
 * Local static data
 */
static kmutex_t    isp_global_mutex;
static void        *isp_state;
```

The _init(9E) function in Code Example 14-1 shows how a SCSI HBA driver initializes a global mutex.

Code Example 14-1 SCSI HBA _init(9E) Function

```
int
_init(void)
{
        int     err;

        if ((err = ddi_soft_state_init(&isp_state,
                      sizeof (struct isp), 0)) != 0) {
              return (err);
        }
        if ((err = scsi_hba_init(&modlinkage)) == 0) {
           mutex_init(&isp_global_mutex, "isp global mutex",
               MUTEX_DRIVER, NULL);
           if ((err = mod_install(&modlinkage)) != 0) {
                mutex_destroy(&isp_global_mutex);
                scsi_hba_fini(&modlinkage);
                ddi_soft_state_fini(&isp_state);
```

```
            }
        }
        return (err);
}
```

_fini()

The _fini(9E) function is called when the system is about to try to unload the SCSI HBA driver. The _fini(9E) function must call mod_remove(9F) to determine if the driver can be unloaded. If mod_remove(9F) returns 0, the module can be unloaded, and the HBA driver must deallocate any global resources allocated in _init(9E) and must call scsi_hba_fini(9F).

_fini(9E) must return the value returned by mod_remove(9F).

Note – The HBA driver must not free any resources or call scsi_hba_fini(9F) unless mod_remove(9F) returns 0.

The _fini(9E) function in Code Example 14-2 shows how a SCSI HBA driver deallocates a global mutex initialized in _init(9E).

Code Example 14-2 SCSI HBA _fini(9E) Function

```
int
_fini(void)
{
    int     err;

    if ((err = mod_remove(&modlinkage)) == 0) {
        mutex_destroy(&isp_global_mutex);
        scsi_hba_fini(&modlinkage);
        ddi_soft_state_fini(&isp_state);
    }
    return (err);
}
```

Autoconfiguration Entry Points

Associated with each device driver is a dev_ops(9S) structure, which allows the kernel to locate the autoconfiguration entry points of the driver. A complete description of these autoconfiguration routines is given in Chapter 5, “Autoconfiguration”. This section describes only those entry points associated with operations performed by SCSI HBA drivers. These include attach(9E) and detach(9E).

attach()

The attach(9E) entry point for a SCSI HBA driver must perform a number of tasks to configure and attach an instance of the driver for the device. For a typical driver of real devices, the following operating system and hardware concerns must be addressed:

- Soft-state structure
- DMA
- Transport structure
- Attaching an HBA driver
- Register mapping
- Interrupt specification
- Interrupt handling
- Create power manageable components
- Report attachment status

Soft State Structure

The driver should allocate the per-device-instance soft state structure, being careful to clean up properly if an error occurs.

```
instance = ddi_get_instance(dip);
if (ddi_soft_state_zalloc(isp_state,
        instance) != DDI_SUCCESS) {
    return (DDI_FAILURE);
}
isp = ddi_get_soft_state(isp_state, instance);
```

DMA

If the driver provides DMA, for example, it must specify DMA attributes describing the capabilities and limitations of its DMA engine.

Note – In the Solaris 2.6 system, the HBA driver *must* provide DMA.

```
static ddi_dma_attr_t isp_dma_attr = {
    DMA_ATTR_V0,        /* ddi_dma_attr version */
    0,                  /* low address */
    0xffffffff,         /* high address */
    0x00ffffff,         /* counter upper bound */
    1,                  /* alignment requirements */
    0x3f,               /* burst sizes */
    1,                  /* minimum DMA access */
    0xffffffff,         /* maximum DMA access */
    (1<<24)-1,          /* segment boundary restrictions */
    1,                  /* scatter/gather list length */
    512,                /* device granularity */
    0                   /* DMA flags */
};
```

The driver, if providing DMA, should also check that its hardware is installed in a DMA-capable slot:

```
        if (ddi_slaveonly(dip) == DDI_SUCCESS) {
            return (DDI_FAILURE);
        }
```

Transport Structure

The driver should further allocate and initialize a transport structure for this instance. The `tran_hba_private` field is set to point to this instance's soft-state structure. `tran_tgt_probe` may be set to NULL to achieve the default behavior, if no special probe customization is needed.

```
    tran = scsi_hba_tran_alloc(dip, SCSI_HBA_CANSLEEP);

    isp->isp_tran              = tran;
    isp->isp_dip               = dip;

    tran->tran_hba_private     = isp;
    tran->tran_tgt_private     = NULL;
    tran->tran_tgt_init        = isp_tran_tgt_init;
    tran->tran_tgt_probe       = scsi_hba_probe;
    tran->tran_tgt_free        = (void (*)())NULL;

    tran->tran_start           = isp_scsi_start;
    tran->tran_abort           = isp_scsi_abort;
    tran->tran_reset           = isp_scsi_reset;
```

```
tran->tran_getcap         = isp_scsi_getcap;
tran->tran_setcap         = isp_scsi_setcap;
tran->tran_init_pkt       = isp_scsi_init_pkt;
tran->tran_destroy_pkt    = isp_scsi_destroy_pkt;
tran->tran_dmafree        = isp_scsi_dmafree;
tran->tran_sync_pkt       = isp_scsi_sync_pkt;
tran->tran_reset_notify   = isp_scsi_reset_notify;
```

Attaching an HBA Driver

The driver should attach this instance of the device and perform error cleanup if necessary.

```
i = scsi_hba_attach_setup(dip, &isp_dma_attr, tran, 0);
if (i != DDI_SUCCESS) {
    do error recovery
    return (DDI_FAILURE);
}
```

Register Mapping

The driver should map in its device's registers, specifying the index of the register set, the data access characteristics of the device and the size of the register set to be mapped.

```
ddi_device_acc_attr_t  dev_attributes;

dev_attributes.devacc_attr_version = DDI_DEVICE_ATTR_V0;
dev_attributes.devacc_attr_dataorder = DDI_STRICTORDER_ACC;
dev_attributes.devacc_attr_endian_flags = DDI_STRUCTURE_LE_ACC;

if (ddi_regs_map_setup(dip, 0, (caddr_t *)&isp->isp_reg,
    0, sizeof (struct ispregs), &dev_attributes,
    &isp->isp_acc_handle) != DDI_SUCCESS) {
    do error recovery
    return (DDI_FAILURE);
}
```

Adding an Interrupt Handler

The driver should determine if a high-level interrupt handler is required. If a high-level handler is required and the driver is not coded to provide one, the driver must be rewritten to either include a high-level interrupt or fail the attach.

In the following example, a high-level interrupt is required but not provided by the driver. Consequently, the driver fails the attach.

```
if (ddi_intr_hilevel(dip, 0) != 0) {
    return (DDI_FAILURE);
}
```

The driver must first obtain the *iblock cookie* to initialize mutexes used in the driver handler. Only after those mutexes have been initialized can the interrupt handler be added.

```
i = ddi_get_iblock_cookie(dip, 0, &isp->iblock_cookie};
if (i != DDI_SUCCESS) {
    do error recovery
    return (DDI_FAILURE);
}

mutex_init(&isp->mutex, "isp_mutex", MUTEX_DRIVER,
    (void *)isp->iblock_cookie);
i = ddi_add_intr(dip, 0, &isp->iblock_cookie,
    0, isp_intr, (caddr_t)isp);
if (i != DDI_SUCCESS) {
    do error recovery
    return (DDI_FAILURE);
}
```

Report Attachment Status

Finally, the driver should report that this instance of the device is attached and return success.

```
ddi_report_dev(dip);
return (DDI_SUCCESS);
```

detach()

The Solaris 2.6 DDI/DKI does not support detaching an HBA driver, although target driver children of an HBA can detach. For best results, the HBA driver should fail a detach request. It’s better to fail the detach than to include code that cannot be tested.

Code Example 14-3 provides an example of the `xx_detach`(9E) function.

Code Example 14-3 `isp_detach`(9E)

```
static int
isp_detach(dev_info_t *dip, ddi_detach_cmd_t cmd)
{
    switch (cmd) {
    case DDI_DETACH:
        /*
         * At present, detaching HBA drivers is not supported
         */
        return (DDI_FAILURE);

    case DDI_PM_RESUME:
        For information, see Chapter 8, “Power Management”

    case DDI_RESUME:
        For information, see Chapter 8, “Power Management”

    default:
        return (DDI_FAILURE);
    }
}
```

SCSA HBA Entry Points

For an HBA driver to work with target drivers using the SCSA interface, each HBA driver must supply a number of entry points, callable through the `scsi_hba_tran(9S)`structure.These entry points fall into five functional groups:

- Target driver instance initialization
- Resource allocation
- Command transport
- Capability management
- Abort and reset

Table 14-3 lists the SCSA HBA entry points arranged by function groups.

Table 14-3 SCSA Entry Points

Function Groups	Entry Points Within Group	Description
Target Driver Instance Initialization	`tran_tgt_init(9E)`	Performs per-target initialization (optional)
	`tran_tgt_probe(9E)`	Probes SCSI bus for existence of a target (optional)
	`tran_tgt_free(9E)`	Performs per-target deallocation (optional)
Resource Allocation	`tran_init_pkt(9E)`	Allocates SCSI packet and DMA resources
	`tran_destroy_pkt(9E)`	Frees SCSI packet and DMA resources
	`tran_sync_pkt(9E)`	Synchronizes memory before and after DMA
	`tran_dmafree(9E)`	Frees DMA resources
Command Transport	`tran_start(9E)`	Transports a SCSI command
Capability Management	`tran_getcap(9E)`	Inquires about a capability's value
	`tran_setcap(9E)`	Sets a capability's value
Abort and Reset	`tran_abort(9E)`	Aborts one or all outstanding SCSI commands
	`tran_reset(9E)`	Resets a target device or the SCSI bus
	`tran_reset_notify(9E)`	Request to notify target of bus reset (optional)

Target Driver Instance Initialization

tran_tgt_init()

The tran_tgt_init(9E) entry point allows the HBA to allocate and/or initialize any per-target resources. It also allows the HBA to qualify the device's address as valid and supportable for that particular HBA. By returning DDI_FAILURE, the instance of the target driver for that device will not be probed or attached.

This entry point is not required, and if none is supplied, the framework will attempt to probe and attach all possible instances of the appropriate target drivers.

```
static int
isp_tran_tgt_init(
    dev_info_t          *hba_dip,
    dev_info_t          *tgt_dip,
    scsi_hba_tran_t     *tran,
    struct scsi_device *sd)
{
    return ((sd->sd_address.a_target < N_ISP_TARGETS_WIDE &&
            sd->sd_address.a_lun < 8) ? DDI_SUCCESS : DDI_FAILURE);
}
```

tran_tgt_probe()

The tran_tgt_probe(9E) entry point enables the HBA to customize the operation of scsi_probe(9F), if necessary. This entry point is called only when the target driver calls scsi_probe(9F).

The HBA driver can retain the normal operation of scsi_probe(9F) by calling scsi_hba_probe(9F) and returning its return value.

This entry point is not required, and if not needed, the HBA driver should set the tran_tgt_probe vector in the scsi_hba_tran(9S) structure to point to scsi_hba_probe(9F).

scsi_probe(9F) allocates a scsi_inquiry(9S) structure and sets the sd_inq field of the scsi_device(9S) structure to point to the data in scsi_inquiry(9S). scsi_hba_probe(9F) handles this automatically. scsi_unprobe(9F) then frees the scsi_inquiry(9S) data.

Other than during the allocation of `scsi_inquiry`(9S) data, normally handled by `scsi_hba_probe`(9F), `tran_tgt_probe`(9E) must be stateless, as the same SCSI device might call it multiple times.

Note – The allocation of the `scsi_inquiry`(9S) structure is handled automatically by `scsi_hba_probe`(9F). This is only of concern if custom `scsi_probe`(9F) handling is desired.

```
static int
isp_tran_tgt_probe(
    struct scsi_device*sd,
    int        (*callback)())
{
    Perform any special probe customization needed.
    /*
     * Normal probe handling
     */
    return (scsi_hba_probe(sd, callback));
}
```

tran_tgt_free()

The `tran_tgt_free`(9E) entry point enables the HBA to perform any deallocation or clean-up procedures for an instance of a target. This entry point is optional.

```
static void
isp_tran_tgt_free(
    dev_info_t             *hba_dip,
    dev_info_t             *tgt_dip,
    scsi_hba_tran_t        *hba_tran,
    struct scsi_device     *sd)
{
    Undo any special per-target initialization done earlier in tran_tgt_init(9F) and
     tran_tgt_probe(9F).
}
```

Resource Allocation

tran_init_pkt()

The tran_init_pkt(9E) entry point is the HBA driver function that allocates and initializes, on behalf of the target driver, a scsi_pkt(9S) structure and DMA resources for a target driver request.

The tran_init_pkt(9E) entry point is called when the target driver calls the SCSA function scsi_init_pkt(9F).

Each call of the tran_init_pkt(9E) entry point is a request to perform one or more of three possible services:

- Allocation and initialization of a scsi_pkt(9S) structure
- Allocation of DMA resources for data transfer
- Reallocation of DMA resources for the next portion of the data transfer

Allocation and Initialization of a scsi_pkt*(9S) Structure*

The tran_init_pkt(9E) entry point must allocate a scsi_pkt(9S) structure if pkt is NULL through scsi_hba_pkt_alloc(9F).

scsi_hba_pkt_alloc(9F) allocates the following:

- scsi_pkt(9S)
- SCSI CDB of length cmdlen
- SCSI status completion area of length statuslen
- Per-packet target driver private data area of length tgtlen
- Per-packet HBA driver private data area of length hbalen

The scsi_pkt(9S) structure members, as well as pkt itself, must be initialized to zero except for the following members: pkt_scbp (status completion), pkt_cdbp (CDB), pkt_ha_private (HBA driver private data), pkt_private (target driver private data). These members are pointers to memory space where the values of the fields are stored, as illustrated in Figure 14-5. For more information, refer to “scsi_pkt” on page 289.

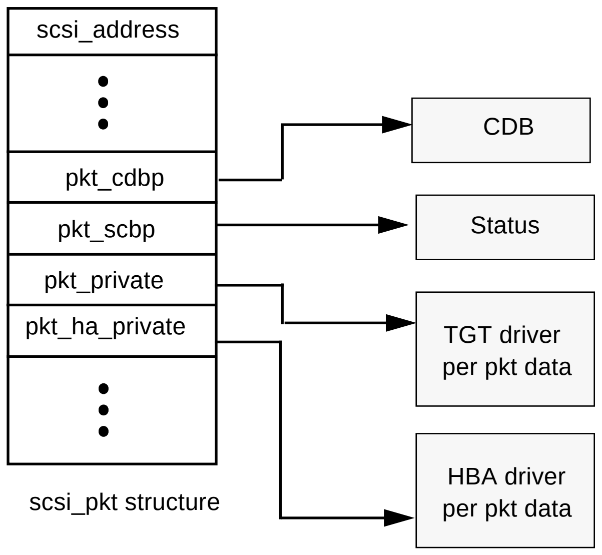


Figure 14-5 `scsi_pkt`(9S) Structure Pointers

Code Example 14-4 provides an example of allocation and initialization of a `scsi_pkt`(9S) structure.

Code Example 14-4 HBA Driver Initialization of a SCSI Packet Structure

```
static struct scsi_pkt     *
isp_scsi_init_pkt(
    struct scsi_address    *ap,
    struct scsi_pkt        *pkt,
    struct buf             *bp,
    int                    cmdlen,
    int                    statuslen,
    int                    tgtlen,
    int                    flags,
    int                    (*callback)(),
    caddr_t                arg)
{
    struct isp_cmd         *sp;
    struct isp             *isp;
    struct scsi_pkt        *new_pkt;

    ASSERT(callback == NULL_FUNC || callback == SLEEP_FUNC);
```

```
isp = (struct isp *)ap->a_hba_tran->tran_hba_private;

/*
 * First step of isp_scsi_init_pkt:  pkt allocation
 */
if (pkt == NULL) {
    pkt = scsi_hba_pkt_alloc(isp->isp_dip, ap, cmdlen,
            statuslen, tgtlen, sizeof (struct isp_cmd),
            callback, arg);
    if (pkt == NULL) {
        return (NULL);
    }

    sp = (struct isp_cmd *)pkt->pkt_ha_private;

    /*
     * Initialize the new pkt
     */
    sp->cmd_pkt        = pkt;
    sp->cmd_flags      = 0;
    sp->cmd_scblen     = statuslen;
    sp->cmd_cdblen     = cmdlen;
    sp->cmd_dmahandle  = NULL;
    sp->cmd_ncookies   = 0;
    sp->cmd_cookie     = 0;
    sp->cmd_cookiecnt  = 0;
    sp->cmd_nwin       = 0;
    pkt->pkt_address   = *ap;
    pkt->pkt_comp      = (void (*)())NULL;
    pkt->pkt_flags     = 0;
    pkt->pkt_time      = 0;
    pkt->pkt_resid     = 0;
    pkt->pkt_statistics= 0;
    pkt->pkt_reason    = 0;

    new_pkt = pkt;
} else {
    sp = (struct isp_cmd *)pkt->pkt_ha_private;
    new_pkt = NULL;
}

/*
 * Second step of isp_scsi_init_pkt:  dma allocation/move
 */
if (bp && bp->b_bcount != 0) {
        if (sp->cmd_dmahandle == NULL) {
            if (isp_i_dma_alloc(isp, pkt, bp,
                flags, callback) == 0) {
                if (new_pkt) {
                    scsi_hba_pkt_free(ap, new_pkt);
                }
                return ((struct scsi_pkt *)NULL);
            }
        } else {
            ASSERT(new_pkt == NULL);
            if (isp_i_dma_move(isp, pkt, bp) == 0) {
                return ((struct scsi_pkt *)NULL);
            }
        }
    }

    return (pkt);
}
```

Allocation of DMA Resources

If bp is not NULL and bp->b_bcount is not zero and DMA resources have not yet been allocated for this scsi_pkt(9S), the tran_init_pkt(9E) entry point must allocate DMA resources for a data transfer. The HBA driver needs to keep track of whether DMA resources have been allocated for a particular command with a flag bit or a DMA handle in the per-packet HBA driver private data.

By setting the PKT_DMA_PARTIAL flag in the pkt, the target driver indicates it can accept breaking up the data transfer into multiple SCSI commands to accommodate the complete request. This may be necessary if the HBA hardware scatter-gather capabilities or system DMA resources are insufficient to accommodate the complete request in a single SCSI command.

If the PKT_DMA_PARTIAL flag is set, the HBA driver may set the DDI_DMA_PARTIAL flag when allocating DMA resources (using, for example, ddi_dma_buf_bind_handle(9F)) for this SCSI command. The DMA attributes used when allocating the DMA resources should accurately describe any constraints placed on the ability of the HBA hardware to perform DMA. If the system can only allocate DMA resources for part of the request, ddi_dma_buf_bind_handle(9F) will return DDI_DMA_PARTIAL_MAP.

The tran_init_pkt(9E) entry point must return the amount of DMA resources not allocated for this transfer in the field pkt_resid.

A target driver may make one request to `tran_init_pkt`(9E) to simultaneously allocate both a `scsi_pkt`(9S) structure and DMA resources for that `pkt`. In this case, if the HBA driver is unable to allocate DMA resources, it must free the allocated `scsi_pkt`(9S) before returning. The `scsi_pkt`(9S) must be freed by calling `scsi_hba_pkt_free`(9F).

The target driver may first allocate the `scsi_pkt`(9S) and allocate DMA resources for this `pkt` at a later time. In this case, if the HBA driver is unable to allocate DMA resources, it must *not* free `pkt`. The target driver in this case is responsible for freeing the `pkt`.

Code Example 14-5 HBA Driver Allocation of DMA Resources

```
static int
isp_i_dma_alloc(
    struct isp     *isp,
    struct scsi_pkt*pkt,
    struct buf     *bp,
    int            flags,
    int            (*callback)())
{
    struct isp_cmd*sp  = (struct isp_cmd *)pkt->pkt_ha_private;
    int            dma_flags;
    ddi_dma_attr_t tmp_dma_attr;
    int            (*cb)(caddr_t);
    int            i;

    ASSERT(callback == NULL_FUNC || callback == SLEEP_FUNC);

    if (bp->b_flags & B_READ) {
        sp->cmd_flags &= ~CFLAG_DMASEND;
        dma_flags = DDI_DMA_READ;
    } else {
        sp->cmd_flags |= CFLAG_DMASEND;
        dma_flags = DDI_DMA_WRITE;
    }
    if (flags & PKT_CONSISTENT) {
        sp->cmd_flags |= CFLAG_CMDIOPB;
        dma_flags |= DDI_DMA_CONSISTENT;
    }
    if (flags & PKT_DMA_PARTIAL) {
        dma_flags |= DDI_DMA_PARTIAL;
    }

    tmp_dma_attr = isp_dma_attr;
    tmp_dma_attr.dma_attr_burstsizes = isp->isp_burst_size;

    cb = (callback == NULL_FUNC) ? DDI_DMA_DONTWAIT : DDI_DMA_SLEEP;

    if ((i = ddi_dma_alloc_handle(isp->isp_dip, &tmp_dma_attr,
        cb, 0, &sp->cmd_dmahandle)) != DDI_SUCCESS) {

        switch (i) {
        case DDI_DMA_BADATTR:
            bioerror(bp, EFAULT);
            return (0);

        case DDI_DMA_NORESOURCES:
            bioerror(bp, 0);
            return (0);
        }
    }

    i = ddi_dma_buf_bind_handle(sp->cmd_dmahandle, bp, dma_flags,
        cb, 0, &sp->cmd_dmacookies[0], &sp->cmd_ncookies);

    switch (i) {
    case DDI_DMA_PARTIAL_MAP:
        if (ddi_dma_numwin(sp->cmd_dmahandle, &sp->cmd_nwin) ==
                DDI_FAILURE) {
            cmn_err(CE_PANIC, "ddi_dma_numwin() failed\n");
        }

        if (ddi_dma_getwin(sp->cmd_dmahandle, sp->cmd_curwin,
            &sp->cmd_dma_offset, &sp->cmd_dma_len,
            &sp->cmd_dmacookies[0], &sp->cmd_ncookies) ==
                DDI_FAILURE) {
            cmn_err(CE_PANIC, "ddi_dma_getwin() failed\n");
        }
        goto get_dma_cookies;

    case DDI_DMA_MAPPED:
        sp->cmd_nwin = 1;
        sp->cmd_dma_len = 0;
        sp->cmd_dma_offset = 0;

get_dma_cookies:
        i = 0;
        sp->cmd_dmacount = 0;
        for (;;) {
            sp->cmd_dmacount += sp->cmd_dmacookies[i++].dmac_size;
```

```
                if (i == ISP_NDATASEGS || i == sp->cmd_ncookies)
                    break;
                ddi_dma_nextcookie(sp->cmd_dmahandle,
                    &sp->cmd_dmacookies[i]);
            }
            sp->cmd_cookie = i;
            sp->cmd_cookiecnt = i;

            sp->cmd_flags |= CFLAG_DMAVALID;
            pkt->pkt_resid = bp->b_bcount - sp->cmd_dmacount;
            return (1);

        case DDI_DMA_NORESOURCES:
            bioerror(bp, 0);
            break;

        case DDI_DMA_NOMAPPING:
            bioerror(bp, EFAULT);
            break;

        case DDI_DMA_TOOBIG:
            bioerror(bp, EINVAL);
            break;

        case DDI_DMA_INUSE:
            cmn_err(CE_PANIC, "ddi_dma_buf_bind_handle:"
                " DDI_DMA_INUSE impossible\n");

        default:
            cmn_err(CE_PANIC, "ddi_dma_buf_bind_handle:"
                " 0x%x impossible\n", i);
        }

        ddi_dma_free_handle(&sp->cmd_dmahandle);
        sp->cmd_dmahandle = NULL;
        sp->cmd_flags &= ~CFLAG_DMAVALID;
        return (0);
    }
```

Reallocation of DMA Resources for Next Portion of Data Transfer

For a previously allocated packet with data remaining to be transferred, the `tran_init_pkt`(9E) entry point must reallocate DMA resources when the following conditions apply:

- Partial DMA resources have already been allocated.
- A non-zero `pkt_resid` was returned in the previous call to `tran_init_pkt`(9E).
- `bp` is not `NULL.`
- `bp->b_bcount` is not zero.

When reallocating DMA resources to the next portion of the transfer, `tran_init_pkt`(9E) must return the amount of DMA resources not allocated for this transfer in the field `pkt_resid`.

If an error occurs while attempting to move DMA resources, `tran_init_pkt`(9E) must not free the `scsi_pkt`(9S). The target driver in this case is responsible for freeing the pkt.

If the callback parameter is `NULL_FUNC`, the `tran_init_pkt`(9E) entry point must not sleep or call any function which may sleep. If the callback parameter is `SLEEP_FUNC` and resources are not immediately available, the `tran_init_pkt`(9E) entry point should sleep until resources are available, unless the request is impossible to satisfy.

Code Example 14-6 HBA Driver DMA Resource Reallocation

```
static int
isp_i_dma_move(
    struct isp            *isp,
    struct scsi_pkt       *pkt,
    struct buf            *bp)
{
    struct isp_cmd *sp = (struct isp_cmd *)pkt->pkt_ha_private;
    int    i;

    ASSERT(sp->cmd_flags & CFLAG_COMPLETED);
    sp->cmd_flags &= ~CFLAG_COMPLETED;

    /*
     * If there are no more cookies remaining in this window,
     * must move to the next window first.
     */
    if (sp->cmd_cookie == sp->cmd_ncookies) {
        /*
         * For small pkts, leave things where they are
         */
        if (sp->cmd_curwin == sp->cmd_nwin && sp->cmd_nwin == 1)
            return (1);

        /*
         * At last window, cannot move
         */
        if (++sp->cmd_curwin >= sp->cmd_nwin)
            return (0);

        if (ddi_dma_getwin(sp->cmd_dmahandle, sp->cmd_curwin,
            &sp->cmd_dma_offset, &sp->cmd_dma_len,
            &sp->cmd_dmacookies[0], &sp->cmd_ncookies) ==
                DDI_FAILURE)
            return (0);

        sp->cmd_cookie = 0;
    } else {
        /*
         * Still more cookies in this window - get the next one
         */
        ddi_dma_nextcookie(sp->cmd_dmahandle,
            &sp->cmd_dmacookies[0]);
    }

    /*
     * Get remaining cookies in this window, up to our maximum
     */
    i = 0;
    for (;;) {
        sp->cmd_dmacount += sp->cmd_dmacookies[i++].dmac_size;
        sp->cmd_cookie++;
        if (i == ISP_NDATASEGS ||
            sp->cmd_cookie == sp->cmd_ncookies)
            break;
        ddi_dma_nextcookie(sp->cmd_dmahandle,
            &sp->cmd_dmacookies[i]);
    }
    sp->cmd_cookiecnt = i;

    pkt->pkt_resid = bp->b_bcount - sp->cmd_dmacount;
    return (1);
}
```

tran_destroy_pkt()

The tran_destroy_pkt(9E) entry point is the HBA driver function that deallocates scsi_pkt(9S) structures. The tran_destroy_pkt(9E) entry point is called when the target driver calls scsi_destroy_pkt(9F).

The tran_destroy_pkt(9E) entry point must free any DMA resources allocated for the packet. Freeing the DMA resources causes an implicit DMA synchronization if any cached data remained after the completion of the transfer. The tran_destroy_pkt(9E) entry point frees the SCSI packet itself by calling scsi_hba_pkt_free(9F).

Code Example 14-7 HBA Driver tran_destroy_pkt(9E) Entry Point

```
static void
isp_scsi_destroy_pkt(
    struct scsi_address*ap,
    struct scsi_pkt*pkt)
{
    struct isp_cmd *sp = (struct isp_cmd *)pkt->pkt_ha_private;

    /*
     * Free the DMA, if any
     */
    if (sp->cmd_flags & CFLAG_DMAVALID) {
        sp->cmd_flags &= ~CFLAG_DMAVALID;
        (void) ddi_dma_unbind_handle(sp->cmd_dmahandle);
        ddi_dma_free_handle(&sp->cmd_dmahandle);
        sp->cmd_dmahandle = NULL;
    }
    /*
     * Free the pkt
     */
    scsi_hba_pkt_free(ap, pkt);
}
```

tran_sync_pkt()

The tran_sync_pkt(9E) entry point is the HBA driver function that synchronizes the DMA object allocated for the scsi_pkt(9S) structure before or after a DMA transfer. The tran_sync_pkt(9E) entry point is called when the target driver calls scsi_sync_pkt(9F).

If the data transfer direction is a DMA read from device to memory, tran_sync_pkt(9E) must synchronize the CPU's view of the data. If the data transfer direction is a DMA write from memory to device, tran_sync_pkt(9E) must synchronize the device's view of the data.

Code Example 14-8 HBA Driver tran_sync_pkt(9E) Entry Point

```
static void
isp_scsi_sync_pkt(
    struct scsi_address*ap,
    struct scsi_pkt*pkt)
{
    struct isp_cmd *sp = (struct isp_cmd *)pkt->pkt_ha_private;

    if (sp->cmd_flags & CFLAG_DMAVALID) {
        (void)ddi_dma_sync(sp->cmd_dmahandle, sp->cmd_dma_offset,
            sp->cmd_dma_len,
            (sp->cmd_flags & CFLAG_DMASEND) ?
            DDI_DMA_SYNC_FORDEV : DDI_DMA_SYNC_FORCPU);
        }
    }
}
```

tran_dmafree()

The tran_dmafree(9E) entry point is the HBA driver function that deallocates DMA resources allocated for a scsi_pkt(9S) structure. The tran_dmafree(9E) entry point is called when the target driver calls scsi_dmafree(9F).

tran_dmafree(9E) must free only DMA resources allocated for a scsi_pkt(9S) structure, not the scsi_pkt(9S) itself. Freeing the DMA resources implicitly performs a DMA synchronization.

Note – The scsi_pkt(9S) will be freed in a separate request to tran_destroy_pkt(9E). Because tran_destroy_pkt(9E) must also free DMA resources, it is important that the HBA driver keep accurate note of whether scsi_pkt(9S) structures have DMA resources allocated.

Code Example 14-9 HBA Driver `tran_dmafree`(9E) Entry Point

```
static void
isp_scsi_dmafree(
    struct scsi_address*ap,
    struct scsi_pkt*pkt)
{
    struct isp_cmd *sp = (struct isp_cmd *)pkt->pkt_ha_private;

    if (sp->cmd_flags & CFLAG_DMAVALID) {
        sp->cmd_flags &= ~CFLAG_DMAVALID;
        (void)ddi_dma_unbind_handle(sp->cmd_dmahandle);
        ddi_dma_free_handle(&sp->cmd_dmahandle);
        sp->cmd_dmahandle = NULL;
    }
}
```

Command Transport

As part of command transport, the HBA driver accepts a command from the target driver, issues the command to the device hardware, services any interrupts that occur, and manages timeouts.

`tran_start()`

The `tran_start`(9E) entry point for a SCSI HBA driver is called to transport a SCSI command to the addressed target. The SCSI command is described entirely within the `scsi_pkt`(9S) structure, which the target driver allocated through the HBA driver's `tran_init_pkt`(9E) entry point. If the command involves a data transfer, DMA resources must also have been allocated for the `scsi_pkt`(9S) structure.

The `tran_start`(9E) entry point is called when a target driver calls `scsi_transport`(9F).

`tran_start`(9E) should perform basic error checking along with whatever initialization the command requires, queue the command for execution on the HBA hardware, and return without blocking. If the hardware is idle, the command may be started immediately.

For commands with the FLAG_NOINTR bit set in the pkt_flags field of the scsi_packet(9S) structure, tran_start(9E) should not return until the command has been completed, and the HBA driver should not call the *pkt* completion routine.

Code Example 14-10 demonstrates how to handle the tran_start(9E) entry point. The ISP hardware provides a queue per-target device. For devices that can manage only one active outstanding command, the driver itself is typically required to manage a per-target queue and starts up a new command upon completion of the current command in a round-robin fashion.

Code Example 14-10 HBA Driver tran_start(9E) Entry Point

```
static int
isp_scsi_start(
    struct scsi_address    *ap,
    struct scsi_pkt        *pkt)
{
    struct isp_cmd         *sp;
    struct isp             *isp;
    struct isp_request     *req;
    u_long                 cur_lbolt;
    int                    xfercount;
    int                    rval= TRAN_ACCEPT;
    int                    i;

    sp = (struct isp_cmd *)pkt->pkt_ha_private;
    isp = (struct isp *)ap->a_hba_tran->tran_hba_private;

    sp->cmd_flags = (sp->cmd_flags & ~CFLAG_TRANFLAG) |
                        CFLAG_IN_TRANSPORT;
    pkt->pkt_reason = CMD_CMPLT;

    /*
     * set up request in cmd_isp_request area so it is ready to
     * go once we have the request mutex
     */
    req = &sp->cmd_isp_request;

    req->req_header.cq_entry_type = CQ_TYPE_REQUEST;
    req->req_header.cq_entry_count = 1;
    req->req_header.cq_flags= 0;
    req->req_header.cq_seqno = 0;
    req->req_reserved = 0;
    req->req_token = (opaque_t)sp;
```

```
req->req_target = TGT(sp);
req->req_lun_trn = LUN(sp);
req->req_time = pkt->pkt_time;
ISP_SET_PKT_FLAGS(pkt->pkt_flags, req->req_flags);

/*
 * Set up dma transfers data segments.
 */
if (sp->cmd_flags & CFLAG_DMAVALID) {

    if (sp->cmd_flags & CFLAG_CMDIOPB) {
        (void) ddi_dma_sync(sp->cmd_dmahandle,
            sp->cmd_dma_offset, sp->cmd_dma_len,
            DDI_DMA_SYNC_FORDEV);
    }

    ASSERT(sp->cmd_cookiecnt > 0 &&
        sp->cmd_cookiecnt <= ISP_NDATASEGS);

    xfercount = 0;
    req->req_seg_count = sp->cmd_cookiecnt;
    for (i = 0; i < sp->cmd_cookiecnt; i++) {
        req->req_dataseg[i].d_count =
            sp->cmd_dmacookies[i].dmac_size;
        req->req_dataseg[i].d_base =
            sp->cmd_dmacookies[i].dmac_address;
        xfercount +=
            sp->cmd_dmacookies[i].dmac_size;
    }

    for (; i < ISP_NDATASEGS; i++) {
        req->req_dataseg[i].d_count = 0;
        req->req_dataseg[i].d_base = 0;
    }

    pkt->pkt_resid = xfercount;

    if (sp->cmd_flags & CFLAG_DMASEND) {
        req->req_flags |= ISP_REQ_FLAG_DATA_WRITE;
    } else {
        req->req_flags |= ISP_REQ_FLAG_DATA_READ;
    }
} else {
    req->req_seg_count = 0;
    req->req_dataseg[0].d_count = 0;
}
```

```
    /*
     * Set up cdb in the request
     */
    req->req_cdblen = sp->cmd_cdblen;
    bcopy((caddr_t)pkt->pkt_cdbp, (caddr_t)req->req_cdb,
        sp->cmd_cdblen);

    /*
     * Start the cmd.  If NO_INTR, must poll for cmd completion.
     */
    if ((pkt->pkt_flags & FLAG_NOINTR) == 0) {
        mutex_enter(ISP_REQ_MUTEX(isp));
        rval = isp_i_start_cmd(isp, sp);
        mutex_exit(ISP_REQ_MUTEX(isp));
    } else {
        rval = isp_i_polled_cmd_start(isp, sp);
    }

    return (rval);
}
```

Interrupt Handler and Command Completion

The interrupt handler must check the status of the device to be sure the device is generating the interrupt in question. It must also check for any errors that may have occurred and service any interrupts generated by the device.

If data was transferred, the hardware should be checked to determine how much data was actually transferred, and the `pkt_resid` field in the `scsi_pkt`(9S) structure should be set to the residual of the transfer.

For commands marked with the `PKT_CONSISTENT` flag when DMA resources were allocated through `tran_init_pkt`(9E), the HBA driver must ensure that the data transfer for the command is correctly synchronized before the target driver's command completion callback is performed.

Once a command has completed, there are two requirements:

- Start a new command (if one is queued up) on the hardware as quickly as possible.
- Call the command completion callback as set up in the `scsi_pkt`(9S) structure by the target driver to notify the target driver that the command is now complete.

It is important to start a new command on the hardware, if possible, before calling the PKT_COMP command completion callback. The command completion handling may take considerable time, as the target driver will typically call functions such as biodone(9F) and possibly scsi_transport(9F) to begin a new command.

The interrupt handler must return DDI_INTR_CLAIMED if this interrupt is claimed by this driver; otherwise, the handler returns DDI_INTR_UNCLAIMED.

Code Example 14-11 shows an interrupt handler for the SCSI HBA isp driver. The caddr_t argument is the parameter set up when the interrupt handler was added in attach(9E) and is typically a pointer to the state structure allocated per instance.

Code Example 14-11 HBA Driver Interrupt Handler

```
static u_int
isp_intr(caddr_t arg)
{
    struct isp_cmd         *sp;
    struct isp_cmd         *head, *tail;
    u_short                response_in;
    struct isp_response    *resp;
    struct isp             *isp = (struct isp *)arg;
    struct isp_slot        *isp_slot;
    int                    n;

    if (ISP_INT_PENDING(isp) == 0) {
        return (DDI_INTR_UNCLAIMED);
    }

    do {
again:
        /*
         * head list collects completed packets for callback later
         */
        head = tail = NULL;

        /*
         * Assume no mailbox events (e.g. mailbox cmds, asynch
         * events, and isp dma errors) as common case.
         */
        if (ISP_CHECK_SEMAPHORE_LOCK(isp) == 0) {
            mutex_enter(ISP_RESP_MUTEX(isp));
        /*
         * Loop through completion response queue and post
         * completed pkts.  Check response queue again
         * afterwards in case there are more
         */
        isp->isp_response_in =
            response_in = ISP_GET_RESPONSE_IN(isp);

        /*
         * Calculate the number of requests in the queue
         */
        n = response_in - isp->isp_response_out;
        if (n < 0) {
            n = ISP_MAX_REQUESTS -
                isp->isp_response_out + response_in;
        }

        while (n-- > 0) {
            ISP_GET_NEXT_RESPONSE_OUT(isp, resp);
            sp = (struct isp_cmd *)resp->resp_token;

            /*
             * copy over response packet in sp
             */
            isp_i_get_response(isp, resp, sp);
            }

            if (head) {
                tail->cmd_forw = sp;
                tail = sp;
                tail->cmd_forw = NULL;
            } else {
                tail = head = sp;
                sp->cmd_forw = NULL;
            }
        }

        ISP_SET_RESPONSE_OUT(isp);
        ISP_CLEAR_RISC_INT(isp);
        mutex_exit(ISP_RESP_MUTEX(isp));

        if (head) {
            isp_i_call_pkt_comp(isp, head);
        }
    } else {
        if (isp_i_handle_mbox_cmd(isp) != ISP_AEN_SUCCESS) {
                return (DDI_INTR_CLAIMED);
            }
            /*
             * if there was a reset then check the response
             * queue again
             */
            goto again;
        }

    } while (ISP_INT_PENDING(isp));

    return (DDI_INTR_CLAIMED);
}

static void
isp_i_call_pkt_comp(
    struct isp          *isp,
    struct isp_cmd      *head)
{
    struct isp          *isp;
    struct isp_cmd      *sp;
    struct scsi_pkt     *pkt;
    struct isp_response*resp;
    u_char              status;

    while (head) {
        sp = head;
        pkt = sp->cmd_pkt;
        head = sp->cmd_forw;

        ASSERT(sp->cmd_flags & CFLAG_FINISHED);

        resp = &sp->cmd_isp_response;

        pkt->pkt_scbp[0] = (u_char)resp->resp_scb;
        pkt->pkt_state = ISP_GET_PKT_STATE(resp->resp_state);
        pkt->pkt_statistics = (u_long)
            ISP_GET_PKT_STATS(resp->resp_status_flags);
        pkt->pkt_resid = (long)resp->resp_resid;

        /*
         * if data was xferred and this is a consistent pkt,
         * we need to do a dma sync
         */
        if ((sp->cmd_flags & CFLAG_CMDIOPB) &&
            (pkt->pkt_state & STATE_XFERRED_DATA)) {
                (void) ddi_dma_sync(sp->cmd_dmahandle,
                    sp->cmd_dma_offset, sp->cmd_dma_len,
                    DDI_DMA_SYNC_FORCPU);
            }

            sp->cmd_flags = (sp->cmd_flags & ~CFLAG_IN_TRANSPORT) |
                    CFLAG_COMPLETED;

            /*
             * Call packet completion routine if FLAG_NOINTR is not set.
             */
            if (((pkt->pkt_flags & FLAG_NOINTR) == 0) &&
                pkt->pkt_comp) {
                (*pkt->pkt_comp)(pkt);
            }
        }
}
```

Timeout Handler

The HBA driver should be prepared to time out the command if it is not complete within a specified time unless a zero timeout was specified in the `scsi_pkt`(9S) structure.

When a command times out, the HBA driver should mark the `scsi_pkt(9S)` with `pkt_reason` set to `CMD_TIMEOUT` and `pkt_statistics` OR'd with `STAT_TIMEOUT`. The HBA driver should also attempt to recover the target and/or bus and, if this recovery can be performed successfully, mark the `scsi_pkt`(9S) with `pkt_statistics` OR'd with either `STAT_BUS_RESET` or `STAT_DEV_RESET`.

Once the command has timed out and the target and bus recovery attempt has completed, the HBA driver should call the command completion callback.

Note – If recovery was unsuccessful or not attempted, the target driver may attempt to recover from the timeout by calling `scsi_reset`(9F).

The ISP hardware manages command timeout directly and returns timed-out commands with the necessary status, so the `isp` sample driver timeout handler checks active commands for timeout state only once every 60 seconds.

The isp sample driver uses the timeout(9F) facility to arrange for the kernel to call the timeout handler every 60 seconds. The caddr_t argument is the parameter set up when the timeout is initialized at attach(9E) time. In this case, the caddr_t argument is a pointer to the state structure allocated per driver instance.

If the driver discovers timed-out commands that have not been returned as timed-out by the ISP hardware, the hardware is not functioning correctly and needs to be reset.

Capability Management

tran_getcap()

The tran_getcap(9E) entry point for a SCSI HBA driver is called when a target driver calls scsi_ifgetcap(9F) to determine the current value of one of a set of SCSA-defined capabilities.

The target driver may request the current setting of the capability for a particular target by setting the whom parameter to nonzero. A whom value of 0 means the request is for the current setting of the capability for the SCSI bus or for adapter hardware in general.

tran_getcap(9E) should return -1 for undefined capabilities or the current value of the requested capability.

The HBA driver may use the function scsi_hba_lookup_capstr(9F) to compare the capability string against the canonical set of defined capabilities.

Code Example 14-12 HBA Driver tran_getcap(9E) Entry Point

```
static int
isp_scsi_setcap(
    struct scsi_address*ap,
    char               *cap,
    int                whom)
{
    struct isp         *isp;
    int                rval = 0;
    u_char             tgt = ap->a_target;

    /*
```

```
 * We don't allow getting capabilities for other targets
 */
if (cap == NULL || whom  == 0){
    return (-1);
}

isp = (struct isp *)ap->a_hba_tran->tran_hba_private;

ISP_MUTEX_ENTER(isp);

switch (scsi_hba_lookup_capstr(cap)) {

case SCSI_CAP_DMA_MAX:
    rval = 1 << 24; /* Limit to 16MB max transfer */
    break;
case SCSI_CAP_MSG_OUT:
    rval = 1;
    break;
case SCSI_CAP_DISCONNECT:
    if ((isp->isp_target_scsi_options[tgt] &
        SCSI_OPTIONS_DR) == 0) {
        break;
    } else if (
        (isp->isp_cap[tgt] & ISP_CAP_DISCONNECT) == 0) {
        break;
    }
    rval = 1;
    break;
case SCSI_CAP_SYNCHRONOUS:
    if ((isp->isp_target_scsi_options[tgt] &
        SCSI_OPTIONS_SYNC) == 0) {
        break;
    } else if (
        (isp->isp_cap[tgt] & ISP_CAP_SYNC) == 0) {
        break;
    }
    rval = 1;
    break;
case SCSI_CAP_WIDE_XFER:
    if ((isp->isp_target_scsi_options[tgt] &
        SCSI_OPTIONS_WIDE) == 0) {
        break;
    } else if (
        (isp->isp_cap[tgt] & ISP_CAP_WIDE) == 0) {
        break;
    }
```

```
        rval = 1;
        break;
    case SCSI_CAP_TAGGED_QING:
        if ((isp->isp_target_scsi_options[tgt] &
            SCSI_OPTIONS_DR) == 0 ||
            (isp->isp_target_scsi_options[tgt] &
            SCSI_OPTIONS_TAG) == 0) {
            break;
        } else if (
            (isp->isp_cap[tgt] & ISP_CAP_TAG) == 0) {
            break;
        }
        rval = 1;
        break;
    case SCSI_CAP_UNTAGGED_QING:
        rval = 1;
        break;
    case SCSI_CAP_PARITY:
        if (isp->isp_target_scsi_options[tgt] &
            SCSI_OPTIONS_PARITY) {
            rval = 1;
        }
        break;
    case SCSI_CAP_INITIATOR_ID:
        rval = isp->isp_initiator_id;
        break;
    case SCSI_CAP_ARQ:
        if (isp->isp_cap[tgt] & ISP_CAP_AUTOSENSE) {
            rval = 1;
        }
        break;
    case SCSI_CAP_LINKED_CMDS:
        break;
    case SCSI_CAP_RESET_NOTIFICATION:
        rval = 1;
        break;
    case SCSI_CAP_GEOMETRY:
        rval = (64 << 16) | 32;
        break;

    default:
        rval = -1;
        break;
    }

    ISP_MUTEX_EXIT(isp);
    return (rval);
}
```

tran_setcap()

The `tran_setcap`(9E) entry point for a SCSI HBA driver is called when a target driver calls `scsi_ifsetcap`(9F) to change the current one of a set of SCSA-defined capabilities.

The target driver may request that the new value be set for a particular target by setting the `whom` parameter to nonzero. A `whom` value of `0` means the request is to set the new value for the SCSI bus or for adapter hardware in general.

`tran_setcap`(9E) should return `-1` for undefined capabilities, `0` if the HBA driver cannot set the capability to the requested value, or `1` if the HBA driver is able to set the capability to the requested value.

The HBA driver may use the function `scsi_hba_lookup_capstr`(9F) to compare the capability string against the canonical set of defined capabilities.

Code Example 14-13 HBA Driver `tran_setcap`(9E) Entry Point

```
static int
isp_scsi_setcap(
    struct scsi_address*ap,
    char                *cap,
    int                 value,
    int                 whom)
{
    struct isp          *isp;
    int                 rval = 0;
    u_char              tgt = ap->a_target;
    int                 update_isp = 0;

    /*
     * We don't allow setting capabilities for other targets
     */
    if (cap == NULL || whom == 0) {
        return (-1);
    }

    isp = (struct isp *)ap->a_hba_tran->tran_hba_private;
```

```
ISP_MUTEX_ENTER(isp);

switch (scsi_hba_lookup_capstr(cap)) {

case SCSI_CAP_DMA_MAX:
case SCSI_CAP_MSG_OUT:
case SCSI_CAP_PARITY:
case SCSI_CAP_UNTAGGED_QING:
case SCSI_CAP_LINKED_CMDS:
case SCSI_CAP_RESET_NOTIFICATION:
    /*
     * None of these are settable via
     * the capability interface.
     */
    break;
case SCSI_CAP_DISCONNECT:
    if ((isp->isp_target_scsi_options[tgt] &
        SCSI_OPTIONS_DR) == 0) {
        break;
    } else {
        if (value) {
            isp->isp_cap[tgt] |= ISP_CAP_DISCONNECT;
        } else {
            isp->isp_cap[tgt] &= ~ISP_CAP_DISCONNECT;
        }
    }
    rval = 1;
    break;
case SCSI_CAP_SYNCHRONOUS:
    if ((isp->isp_target_scsi_options[tgt] &
        SCSI_OPTIONS_SYNC) == 0) {
        break;
    } else {
        if (value) {
            isp->isp_cap[tgt] |= ISP_CAP_SYNC;
        } else {
            isp->isp_cap[tgt] &= ~ISP_CAP_SYNC;
        }
    }
    rval = 1;
    break;
case SCSI_CAP_TAGGED_QING:
    if ((isp->isp_target_scsi_options[tgt] &
        SCSI_OPTIONS_DR) == 0 ||
         (isp->isp_target_scsi_options[tgt] &
                SCSI_OPTIONS_TAG) == 0) {
                break;
            } else {
                if (value) {
                    isp->isp_cap[tgt] |= ISP_CAP_TAG;
                } else {
                    isp->isp_cap[tgt] &= ~ISP_CAP_TAG;
                }
            }
            rval = 1;
            break;
        case SCSI_CAP_WIDE_XFER:
            if ((isp->isp_target_scsi_options[tgt] &
                SCSI_OPTIONS_WIDE) == 0) {
                break;
            } else {
                if (value) {
                    isp->isp_cap[tgt] |= ISP_CAP_WIDE;
                } else {
                    isp->isp_cap[tgt] &= ~ISP_CAP_WIDE;
                }
            }
            rval = 1;
            break;
        case SCSI_CAP_INITIATOR_ID:
            if (value < N_ISP_TARGETS_WIDE) {
                struct isp_mbox_cmd mbox_cmd;

                isp->isp_initiator_id = (u_short) value;

                /*
                 * set Initiator SCSI ID
                 */
                isp_i_mbox_cmd_init(isp, &mbox_cmd, 2, 2,
                    ISP_MBOX_CMD_SET_SCSI_ID,
                    isp->isp_initiator_id,
                    0, 0, 0, 0);
                if (isp_i_mbox_cmd_start(isp, &mbox_cmd) == 0) {
                    rval = 1;
                }
            }
            break;
        case SCSI_CAP_ARQ:
            if (value) {
                isp->isp_cap[tgt] |= ISP_CAP_AUTOSENSE;
            } else {
                isp->isp_cap[tgt] &= ~ISP_CAP_AUTOSENSE;
            }
            rval = 1;
            break;

        default:
            rval = -1;
            break;
        }
        ISP_MUTEX_EXIT(isp);

        return (rval);
    }
```

Abort and Reset Management

`tran_abort()`

The `tran_abort`(9E) entry point for a SCSI HBA driver is called to abort one or all the commands currently in transport for a particular target. This entry point is called when a target driver calls `scsi_abort`(9E).

The `tran_abort`(9E) entry point should attempt to abort the command denoted by the *pkt* parameter. If the *pkt* parameter is NULL, `tran_abort`(9E) should attempt to abort all outstanding commands in the transport layer for the particular target or logical unit.

Each command successfully aborted must be marked with `pkt_reason` `CMD_ABORTED` and `pkt_statistics` OR'd with `STAT_ABORTED`.

`tran_reset()`

The `tran_reset`(9E) entry point for a SCSI HBA driver is called to reset either the SCSI bus or a particular SCSI target device. This entry point is called when a target driver calls `scsi_reset`(9F).

The `tran_reset`(9E) entry point must reset the SCSI bus if level is `RESET_ALL`. If level is `RESET_TARGET`, just the particular target or logical unit must be reset.

Active commands affected by the reset must be marked with pkt_reason CMD_RESET, and with pkt_statistics OR'd with either STAT_BUS_RESET or STAT_DEV_RESET, depending on the type of reset.

Commands in the transport layer, but not yet active on the target, must be marked with pkt_reason CMD_RESET, and with pkt_statistics OR'd with either STAT_ABORTED.

tran_reset_notify()

The tran_reset_notify(9E) entry point for a SCSI HBA driver is called to request that the HBA driver notify the target driver via callback when a SCSI bus reset occurs.

Code Example 14-14 HBA Driver tran_reset_notify(9E) Entry Point

```
isp_scsi_reset_notify(
    struct scsi_address           *ap,
    int                           flag,
    void                          (*callback)(caddr_t),
    caddr_t                       arg)
{
    struct isp                    *isp;
    struct isp_reset_notify_entry *p, *beforep;
    int                           rval = DDI_FAILURE;

    isp = (struct isp *)ap->a_hba_tran->tran_hba_private;

    mutex_enter(ISP_REQ_MUTEX(isp));

    /*
     * Try to find an existing entry for this target
     */
    p = isp->isp_reset_notify_listf;
    beforep = NULL;

    while (p) {
        if (p->ap == ap)
            break;
        beforep = p;
        p = p->next;
    }

    if ((flag & SCSI_RESET_CANCEL) && (p != NULL)) {
        if (beforep == NULL) {
            isp->isp_reset_notify_listf = p->next;
        } else {
            beforep->next = p->next;
        }
        kmem_free((caddr_t)p, sizeof (struct
                    isp_reset_notify_entry));
        rval = DDI_SUCCESS;

    } else if ((flag & SCSI_RESET_NOTIFY) && (p == NULL)) {
        p = kmem_zalloc(sizeof (struct isp_reset_notify_entry),
                KM_SLEEP);
        p->ap = ap;
        p->callback = callback;
        p->arg = arg;
        p->next = isp->isp_reset_notify_listf;
        isp->isp_reset_notify_listf = p;
        rval = DDI_SUCCESS;
    }

    mutex_exit(ISP_REQ_MUTEX(isp));

    return (rval);
}
```

Driver Installation

Hardware Configuration File

SCSI HBA drivers have configuration requirements similar to those for standard device drivers. See Chapter 2, “Hardware Overview,” for more information.

Installing the Driver

Before an HBA driver can be used, it must first be properly installed on the system. The `add_drv`(1M) utility must be used to correctly install the HBA driver.

For example, to install the `isp` sample driver, first copy the driver to the `/kernel/drv` directory:

```
$ su
Password:
# cp isp /kernel/drv
# cp isp.conf /kernel/drv
```

Next, run add_drv(1M) to install the driver. For SCSI HBA drivers, specify class as scsi to permit SCSI target drivers to use the HBA driver to communicate with a target device.

```
# add_drv -m" * 0666 root root" -i'"pci1077,1020"' -c scsi isp
```

Once the HBA driver is installed, a reconfiguration boot is necessary in order to create and attach driver instances for target devices attached on the SCSI bus controlled by the HBA device.

See “Installing and Removing Drivers” on page 341 for more information on driver installation.

x86 Target Driver Configuration Properties

Some SunSoft x86 SCSI target drivers (such as the *cmdk* disk target driver) use the following configuration properties:

- disk
- queue
- flow_control

When using the *cmdk* sample driver to write an HBA driver for an x86 platform, one or more of these properties (as appropriate to the HBA driver and hardware) may need to be defined in the driver.conf(4) file.

Note – These property definitions should appear only in an HBA driver’s driver.conf(4) file. The HBA driver itself should not inspect or attempt to interpret these properties in any way. These properties are advisory only and serve as an adjunct to the *cmdk* driver. They should not be relied upon in any way. The property definitions may or may not be used in future releases.

The disk property may be used to define the type of disk supported by *cmdk*. For a SCSI HBA, the only possible value for the disk property is:

- disk=”scdk” – Disk type is a SCSI disk.

The `queue` property defines how the disk driver sorts the queue of incoming requests during `strategy`(9E). There are two possible values:

- `queue=”qsort”` – One-way elevator queueing model, provided by `disksort`(9F).
- `queue=”qfifo”` – FIFO (first in, first out) queuing model

The `flow_control` property defines how commands are transported to the HBA driver. There are three possible values:

- `flow_control=”dsngl”` – Single command per HBA driver
- `flow_control=”dmult”` – Multiple commands per HBA driver—when the HBA queue is full, the driver returns `TRAN_BUSY.`
- `flow_control=”duplx”` – The HBA can support separate read and write queues, with multiple commands per queue. FIFO ordering is used for the write queue; the queueing model used for the read queue is described by the *queue* property. When an HBA queue is full, the driver returns `TRAN_BUSY`.

Here is an example of a `driver.conf`(4) file for use with an x86 HBA PCI device designed for use with the *cmdk* sample driver:

```
#
# config file for ISP 1020 SCSI HBA driver
#
        flow_control="dsngl" queue="qsort" disk="scdk"
       scsi-initiator-id=7;
```

Loading and Unloading Drivers 15

This chapter describes the procedure for installing a device driver in the system, and for dynamically loading and unloading a device driver during testing and development.

Preparing for Installation

Before the driver is actually installed, all necessary files must be prepared. The driver's module name must either match the name of the device nodes, or the system must be informed that this driver should manage other names. The driver must then be properly compiled, and a configuration file must be created if necessary.

Module Naming

The system maintains a one-to-one association between the name of the driver module and the name of the `dev_info` node. For example, a `dev_info` node for a device named *wombat* is handled by a driver module called ***`wombat`*** in a subdirectory called `drv` (resulting in `drv/wombat`) found in the module path.

If the driver should manage `dev_info` nodes with different names, the `add_drv`(1M) utility can create aliases. The `-i` flag specifies the names of other `dev_info` nodes that the driver handles.

Compiling and Linking the Driver

Compile each driver source file and link the resulting object files into a driver module. For a driver called *xx* that has two C-language source files the following commands are appropriate:

```
test% cc -D_KERNEL -c xx1.c
test% cc -D_KERNEL -c xx2.c
test% ld -r -o xx xx1.o xx2.o
```

The `_KERNEL` symbol must be defined while compiling kernel (driver) code. No other symbols (such as `sun4c` or `sun4m`) should be defined, aside from driver private symbols. `DEBUG` may also be defined to enable any calls to `ASSERT`(9F). There is also no need to use the `-I` flag for the standard headers.

Once the driver is stable, optimization flags can be used. For the Sun WorkShop Compiler C, the normal `-O` flag, or its equivalent `-xO2`, may be used. Note that `-xO2` is the highest level of optimization device drivers should use (see `cc(1)`).

Note – Running `ld -r` is necessary even if there is only one object module.

Writing a Hardware Configuration File

If the device is non-self-identifying, the kernel requires a hardware configuration file for it. If the driver is called *xx*, the hardware configuration file for it should be called *xx*`.conf`. See `driver.conf`(4), `pseudo`(4), `sbus`(4), `scsi`(4), and `vme`(4) for more information on hardware configuration files. On the Intel platform, device information is now supplied by the booting system. Hardware configuration files should no longer be needed to provide `probe`(9E) arguments, even for non-self-identifying devices.

Arbitrary properties can be defined in hardware configuration files by adding entries of the form *property*=*value*, where *property* is the property name, and *value* is its initial value. This allows devices to be configured by changing the property values.

Installing and Removing Drivers

Before a driver can be used, the system must be informed that it exists. The `add_drv`(1M) utility *must* be used to correctly install the device driver. Once the driver is installed, it can be loaded and unloaded from memory without using `add_drv`(1M) again.

Copying the Driver to a Module Directory

Device drivers reside in different directories depending on the platform they run on and whether they are needed at boot time. Platform-dependent device drivers reside in the following locations:

- `/platform/‘uname -i‘/kernel/drv` – Contains drivers that run only on a specific platform, such as the Ultra™ 2
- `/platform/‘uname -m‘/kernel/drv` – Contains drivers that run on a family of platforms, such as Ultra 1 and Ultra 2 platforms. This directory may not be present on all platforms.

Platform-independent drivers reside in either of these directories:

- `/usr/kernel/drv` – Contains drivers not required for system booting
- `/kernel/drv` – Contains drivers required for booting

To install a driver, the driver and its configuration file must be copied to a `drv` directory in the module path. For example, to copy a driver to `/usr/kernel/drv`, type:

```
$ su
# cp xx /usr/kernel/drv
# cp xx.conf /usr/kernel/drv
```

Optionally Editing `/etc/devlink.tab`

If the driver creates minor nodes that do not represent disks, tapes, or ports (terminal devices), `/etc/devlink.tab` can be modified to cause `devlinks`(1M) to create logical device names in `/dev`. See `devlink.tab`(4) for a description of the syntax of this file.

Alternatively, logical names can be created by a program run at driver installation time.

Running `add_drv` *(1M)*

Run `add_drv`(1M) to install the driver in the system. If the driver installs successfully, `add_drv`(1M) will run `disks`(1M), `tapes`(1M), `ports`(1M), and `devlinks`(1M) to create the logical names in `/dev`.

```
# add_drv xx
```

This is a simple case in which the device identifies itself as *xx* and the device special files will have default ownership and permissions (`0600 root sys`). `add_drv`(1M) also allows additional names for the device (aliases) to be specified. See `add_drv`(1M) to determine how to add aliases and set file permissions explicitly.

Note – `add_drv`(1M) should not be run when installing a STREAMS module. See the *STREAMS Programming Guide* for details.

Removing the Driver

To remove a driver from the system, use `rem_drv`(1M), then delete the driver module and configuration file from the module path. The driver cannot be used again until it is reinstalled with `add_drv`(1M).

Loading Drivers

Opening a special file associated with the device driver causes the driver to be loaded. `modload`(1M) can also be used to load the driver into memory, but it does not call any routines in the module. Opening the device is the preferred method.

Getting the Driver Module's ID

Individual drivers can be unloaded by *module id*. To determine the module ID assigned to a driver, use `modinfo`(1M). Find the driver's name in the output. The first column of that entry is the driver's module ID.

```
# modinfo
Id  Loadaddr   Size   Info   Rev    Module Name
...
124 ff211000   1df4   101    1      xx (xx driver v1.0)
```

The number in the `Info` field is the major number chosen for the driver.

Unloading Drivers

Normally, the system automatically unloads device drivers when they are no longer in use. During development, it may be necessary to use `modunload`(1M) to unload the driver before installing a new version. In order for `modunload`(1M) to be successful, the device driver must not be active; there must be no outstanding references to the device, such as through `open`(2) or `mmap`(2).

Use `modunload`(1M) to unload a driver from the system:

```
# modunload -i module_id
```

In addition to being inactive, the driver must have working `detach`(9E) and `_fini`(9E) routines for `modunload`(1M) to succeed.

To unload all currently unloadable modules, specify module ID zero:

```
# modunload -i 0
```

Debugging 16

This chapter describes how to debug a device driver. This includes how to set up a `tip`(1) connection to the test machine, how to prepare for a crash, and how to use debugging tools to test and code device drivers.

Machine Configuration

Setting Up a `tip`(1) Connection

A serial connection can be made between a test system (the machine executing the code to be debugged) and a host system using `tip`(1). This connection enables a window on the host system, called a *tip window*, to be used as the console of the test machine. See `tip`(1) for additional information.

Note – A second machine is *not* required to debug a Solaris 2.x device driver. It is only required for the use of `tip`(1).

Using a tip window confers the following advantages:

- Interactions with the test system or kadb can be monitored. For example, the window can keep a log of the session for use if the driver crashes the test system.
- The test machine can be accessed remotely by logging into a host machine (often called a *tip host*) and using `tip`(1) to connect to the test machine.

Setting Up the Host System

To set up the host system do the following:

1. **Connect the host system to the test machine using serial port A on both machines. This connection must be made with a *null modem* cable.**

2. **On the host system, make an entry in `/etc/remote` for the connection if it is not already there (see `remote(4)`).**
   The terminal entry must match the serial port being used. The Solaris 2.x system comes with the correct entry for serial port B, but a terminal entry must be added for serial port A:

```
debug:\
    :dv=/dev/term/a:br#9600:el=^C^S^Q^U^D:ie=%$:oe=^D:
```

Note – The baud rate must be set to 9600.

---

3. **In a shell window on the host, run `tip`(1) and specify the name of the entry:**

```
test% tip debug
connected
```

   The shell window is now a *tip window* connected to the console of the test machine.

Caution – Do not use L1-A (for SPARC machines) or Control-ALT-D (for x86 machines) on the host machine to send a break to stop the test machine. This action actually stops the host machine. To send a break to the test machine, type **~#** in the tip window. Commands such as this are recognized only if they are the first characters on a line, so press the Return key or Control-U first if there is no effect.

Setting Up the Test System for SPARC Platforms

A quick way to set up the test machine is to unplug the keyboard before turning the machine on. The machine then automatically uses serial port A as the console.

Another way to set up the test machine is to use boot PROM commands to make serial port A the console. On the test machine, at the boot PROM `ok` prompt, direct console I/O to the serial line. To make the test machine always come up with serial port A as the console, set the environment variables *input-device* and *output-device*.

```
ok setenv input-device ttya
ok setenv output-device ttya
```

The `eeprom` command can also be used to make serial port A the console. As root user, execute the following commands to make the *input-device* and *output-device* parameters point to serial port A.

```
eeprom input-device=ttya
eeprom output-device=ttya
```

Executing the `eeprom` commands causes the console to switch to serial port A during reboot.

Setting Up the Test System for x86 Platforms

On x86 platforms, use the `eeprom` command to make serial port A the console. The procedure for this is the same as for SPARC platform and is discussed above. Executing the `eeprom` commands causes the console to switch to serial port A (COM1) during reboot.

Note – Unlike SPARC machines, where the *tip* connection maintains console control throughout the boot process, x86 machines don’t transfer console control to the *tip* connection until an early stage in the boot process.

Preparing for Disasters

It is possible for a driver to render the system incapable of booting. To avoid system reinstallation in this event, some advance work must be done.

Critical System Files

A number of driver-related system files are difficult, if not impossible, to reconstruct. Files such as `/etc/name_to_major`,`/etc/driver_aliases`, `/etc/driver_classes`, and `/etc/minor_perm` can be corrupted if the driver crashes the system during installation (see `add_drv`(1M)).

To be safe, once the test machine is in the proper configuration, make a backup copy of the root file system. If you plan on modifying the `/etc/system` file, make a backup copy of the file before modifying it.

Booting an Alternate Kernel

A kernel other than `/platform/‘uname -i‘/kernel/unix` can be booted by specifying it as the boot file. In fact, backup copies of all the system drivers in `/platform/*` can be made and used if the original drivers fail (this is probably more useful if more than one driver is being debugged). For example:

```
# cp -r /platform/sun4c/kernel /platform/sun4c/kernel.orig
```

To boot the original system, boot `kernel.orig/unix`.

Note – During testing, the new driver should be placed in `/platform/sun4c/kernel` (and *not* in `/kernel` or `/usr/kernel`) so that, the driver is not loaded if the system is booted out of `kernel.orig`. Alternatively, the module path can be changed by booting with the `ask` (`-a`) option.

```
ok boot kernel.orig/unix
...
Rebooting with command: kernel.orig/unix
Boot device: /sbus/esp@0,800000/sd@1,0   File and args:kernel.orig/unix
SunOS Release 5.6 Version Generic [UNIX(R) System V Release 4.0]
Copyright (c) 1983-1997, Sun Microsystems, Inc.
...
```

For more complete control, boot with the ask (`-a`) option; this allows alternate boot parameters to be specified (such as `/dev/null` or `/etc/system.orig` if that is the saved *original* system file that was copied earlier).

```
ok boot -a
...
Rebooting with command: disk1 -a
Boot device: /sbus/esp@0,800000/sd@1,0   File and args: -a
Enter filename [/kernel/unix]: kernel.orig/unix
Enter default directory for modules
[/platform/SUNW,Sun_4_75/kernel.orig /kernel /usr/kernel]:<CR>
SunOS Release 5.6 Version Generic [UNIX(R) System V Release 4.0]
Copyright (c) 1983-1997, Sun Microsystems, Inc.
Name of system file [etc/system]: etc/system.orig
root filesystem type [ufs]: <CR>
Enter physical name of root device
[/sbus@1,f8000000/esp@0,800000/sd@1,0:a]: <CR>
```

Booting Off the Network or CD-ROM

If the system is attached to a network, the test machine can be added as a client of a server. If a problem occurs, the system can be booted off the network. The local disks can then be mounted and fixed. Alternatively, the system can be booted directly from the Solaris 2.x CD-ROM.

Re-creating `/devices` and `/dev`

If the `/devices` or `/dev` directories are damaged—most likely to occur if the driver crashes during `attach`(9E))—they may be recreated by booting the system and running `fsck`(1M) to repair the damaged root file system. The root file system can then be mounted and /devices re-created by running drvconfig(1M) and specifying the /devices directory on the mounted disk. The /dev directory can be repaired by running devlinks(1M), disks(1M), tapes(1M), and ports(1M) on the dev directory of the mounted disk.

On SPARC, for example, if the damaged disk is /dev/dsk/c0t3d0s0, and an alternate boot disk is /dev/dsk/c0t1d0s0, do the following:

```
ok boot disk1
...
Rebooting with command: disk1
Boot device: /sbus/esp@0,800000/sd@1,0   File and args:
SunOS Release 5.6 Version Generic [UNIX(R) System V Release 4.0]
Copyright (c) 1983-1997, Sun Microsystems, Inc.
...
# fsck /dev/dsk/c0t3d0s0
** /dev/dsk/c0t3d0s0
** Last Mounted on /
** Phase 1 - Check Blocks and Sizes
** Phase 2 - Check Pathnames
** Phase 3 - Check Connectivity
** Phase 4 - Check Reference Counts
** Phase 5 - Check Cyl groups
1478 files, 9922 used, 29261 free(141 frags, 3640 blocks, 0.4% fragmentation)
# mount /dev/dsk/c0t3d0s0 /mnt
# drvconfig -r /mnt/devices
# devlinks -r /mnt
# disks -r /mnt
# tapes -r /mnt
# ports -r /mnt
```

Caution – Fixing /devices and /dev may allow the system to boot, but other parts of the system may still be corrupted. This may only be a temporary fix to allow saving information (such as system core dumps) before reinstalling the system.

Booting Off a Backup Root Partition

One way to recover from disaster is to have another bootable root file system. Use `format`(1M) to make a partition the exact size of the original, then use `dd`(1M) to copy it. After making a copy, run `fsck`(1M) on the new file system to ensure its integrity.

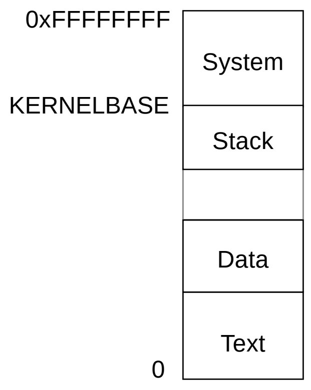
Later, if the system cannot boot from the original root partition, boot the backup partition and use `dd`(1M) to copy the backup partition onto the original one. If the system will not boot but the root file system is undamaged (just the boot block or boot program was destroyed), boot off the backup partition with the ask (`-a`) option, then specify the original file system as the root file system.

Coding Hints

During development, debugging the driver should be a constant consideration. Because the driver is operating much closer to the hardware, and without the protection of the operating system, debugging kernel code is more difficult than debugging user-level code. For example, a stray pointer access can crash the entire system. This section provides some information that may be used to make the driver easier to debug.

Process Layout for Sun4m, Sun4c, Sun4d, and x86 Platforms

On the Sun4m, Sun4c, Sun4d, and x86 platforms, a Solaris 2.x process looks like this:



On these platforms, the kernel and user programs share the same context. The system portion of a process's virtual address space occupies the high end of memory, and the user portion occupies the lower end of memory.

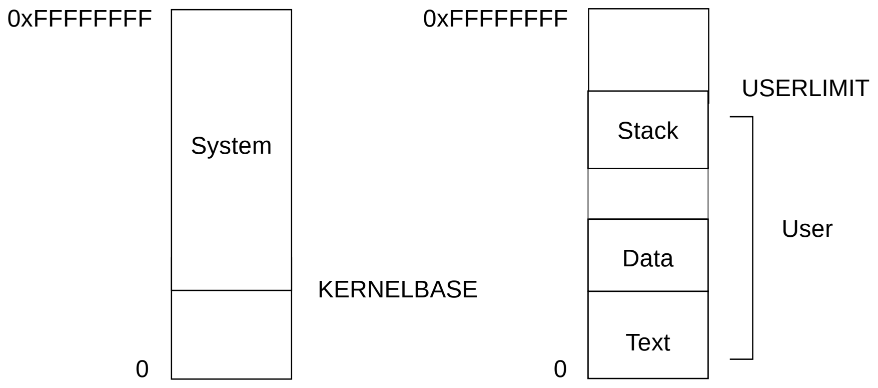
The Solaris 2.x system defines a `KERNELBASE` for each platform. `KERNELBASE` can be used when debugging drivers to determine the address space. Addresses below `KERNELBASE` probably refer to user addresses, while addresses above refer to kernel addresses. Table 16-1 lists the values of `KERNELBASE` for each of these platforms.

Table 16-1 KERNELBASE Values

Platform	**Value**
Sun4c	`0xF0000000`
Sun4m	`0xF0000000`
Sun4d	`0xE0000000`
x86	`0xE0000000`

Process Layout for Sun4u Platforms

On Sun4u platforms, there are separate kernel and user contexts. The process layout looks like this:



On this platform, `KERNELBASE` is set to `0x10000000`. `USERLIMIT` defines the upper limit of the user context; it is set to `0xF0000000`. Addresses below `KERNELBASE` probably refer to user addresses, while addresses above `USERLIMIT` probably refer to kernel addresses.

System Support

The system provides a number of routines that can aid in debugging; these are documented in Section 9 of the *Solaris 2.6 Reference Manual*.

cmn_err()

cmn_err(9F) is used to print messages to the console from within the device driver. cmn_err(9F) provides additional format characters (such as %b) to print device register bits. See cmn_err(9F) and "Printing Messages" on page 61 for more information.

Note – Though printf() and uprintf() currently exist, they should not be used if the driver is to be Solaris DDI-compliant.

ASSERT( )

```
void ASSERT(int expression)
```

ASSERT(9F) can be used to assure that a condition is true at some point in the program. It is a macro whose use varies depending upon whether the compilation symbol DEBUG is defined. If DEBUG is not defined, the macro expands to nothing and the expression is not evaluated. If DEBUG is defined, the expression is evaluated and, if the value is zero, a message is printed to the system console and the system panics.

For example, if a driver pointer should be non-NULL and is not, the following assertion could be used to check the code:

```
    ASSERT(ptr != NULL);
```

If the driver is compiled with DEBUG defined and the assertion fails, a message is printed to the console and the system panics:

```
panic: assertion failed: ptr != NULL, file: driver.c, line: 56
```

Note – Because ASSERT(9F) uses DEBUG, it is suggested that any conditional debugging code also be based on DEBUG, rather than on a driver symbol (such as MYDEBUG). Otherwise, for ASSERT(9F) to function properly, DEBUG must be defined whenever MYDEBUG is defined.

Assertions are an extremely valuable form of active documentation.

mutex_owned( )

```
int mutex_owned(kmutex_t *mp);
```

A significant portion of driver development involves properly handling multiple threads. Comments should always be used when a mutex is acquired; they are even more useful when an apparently necessary mutex is *not* acquired. To determine if a mutex is held by a thread, use mutex_owned(9F) within ASSERT(9F):

```
void helper(void)
{
    /* this routine should always be called with the mutex held */
    ASSERT(mutex_owned(&xsp->mu));
    ...
}
```

Future releases of the Solaris operating system may only support the use of mutex_owned(9F) within ASSERT(9F) by not defining mutex_owned(9F) unless the preprocessor symbol DEBUG is defined.

Conditional Compilation and Variables

Debugging code can be placed in a driver by conditionally compiling code based on a preprocessor symbol such as DEBUG or by using a global variable. Conditional compilation has the advantage that unnecessary code can be removed in the production driver. Using a variable allows the amount of debugging output to be chosen at runtime. This can be accomplished by setting a debugging level at runtime with an I/O control or through a debugger. Commonly, these two methods are combined.

The following example relies on the compiler to remove unreachable code (the code following the always-false test of zero), and also provides a local variable that can be set in `/etc/system` or patched by a debugger.

```
#ifdef DEBUG
comments on values of xxdebug and what they do
static int xxdebug;
#define dcmn_err if (xxdebug) cmn_err
#else
#define dcmn_err if (0) cmn_err
#endif
...
    dcmn_err(CE_NOTE, “Error!\n”);
```

This method handles the fact that `cmn_err`(9F) has a variable number of arguments. Another method relies on the macro having one argument, a parenthesized argument list for `cmn_err`(9F), which the macro removes. It also removes the reliance on the optimizer by expanding the macro to nothing if `DEBUG` is not defined.

```
#ifdef DEBUG
comments on values of xxdebug and what they do
static int xxdebug;
#define dcmn_err(X) if (xxdebug) cmn_err X
#else
#define dcmn_err(X) /* nothing */
#endif
    ...
/* Note:double parentheses are required when using dcmn_err. */
    dcmn_err((CE_NOTE, “Error!”));
```

This can be extended in many ways, such as by having different messages from `cmn_err`(9F) depending on the value of `xxdebug`, but be careful not to obscure the code with too much debugging information.

Another common scheme is to write an `xxlog()` function, which uses `vsprintf`(9F) or `vcmn_err`(9F) to handle variable argument lists.

`volatile` *and* `_depends_on`

`volatile` is a keyword that must be used when declaring any variable that will reference a device register. If this is not done, the optimizer might optimize important accesses away. This is important; neglecting to use `volatile` can result in bugs that are difficult to track down. See “volatile” on page 72 for more information.

Note – `_depends_on` must *not* be declared a static variable; if it is, the compiler might optimize it out of the device driver code.

Debugging Tools

This section describes some programs and files that can be used to debug the driver at runtime.

`/etc/system`

The `/etc/system` file is read once while the kernel is booting. It is used to set various kernel options. After modifying this file, the system must be rebooted for the changes to take effect. If a change in the file causes the system not to work, boot with the `ask (-a)` option and specify `/dev/null` as the system file.

Add the following set commands to the `/etc/system` file:

- To set module variables, the module name must also be specified:

  ```
  set module_name:variable=value
  ```

- To set the variable `xxdebug` in the driver *`xx`*, use the following `set` command:

  ```
  set xx:xxdebug=1
  ```

- To set a kernel integer variable, omit the module name. Other assignments are also supported, such as bitwise OR’ing a value into an existing value:

  ```
  set moddebug | 0x80000000
  ```

See `system`(4) for more information.

Note – Most kernel variables are not guaranteed to be present in subsequent releases.

moddebug

moddebug is a kernel variable that controls the module loading process. The possible values are:

0x80000000	Prints messages to the console when loading or unloading modules.
0x40000000	Gives more detailed error messages.
0x20000000	Prints more detail when loading or unloading (such as including the address and size).
0x00001000	No autounloading drivers: the system will not attempt to unload the device driver when the system resources become low.
0x00000080	No autounloading streams: the system will not attempt to unload the streams module when the system resources become low.
0x00000010	No autounloading of drivers of any type. Module loading is disabled.
0x00000004	Not acceptable to page out symbol table. Prevents kernel from (possibly) paging out the driver's symbol table. kadb requires access to the symbol table to operate properly.
0x00000001	If running with kadb, moddebug causes a breakpoint to be executed and a return to kadb immediately before each module's _init() routine is called. Also generates additional debug messages when the module's _info and _fini routines are executed.

`modload` *and* `modunload`

Because the kernel automatically loads needed modules, and unloads unused ones, these two commands are now obsolete. However, they can be used for debugging.

`modload`(1M) can be used to force a module into memory. The kernel might subsequently unload it, but `modload`(1M) may be used to ensure that the driver has no unresolved references when loaded.

`modunload`(1M) can be used to unload a module, given a module ID (which can be determined with `modinfo`(1M)). Unloading a module does not necessarily remove it from memory. To unload all unloadable modules and forcibly remove them from memory (so that they will be reloaded from the actual object file), use module ID zero:

```
# modunload -i 0
```

Note – A future release might not include `modload`(1M) and `modunload`(1M).

Saving System Core Dumps

When the system panics, it writes the memory image to the dump device (generally the swap device). This is a system core dump, similar to core dumps generated by applications.

There must be enough space in the swap area to contain the core dump. To be safe, the primary swap area should be at least the size of main memory.

`savecore`(1M) is used to copy the system‘s core image to a file. Normally, the system does not examine the swap area for core dumps when it boots. This capability must be enabled in `/etc/init.d/sysetup`.

Change the lines that read:

```
##
## Default is to not do a savecore
##
#if [ ! -d /var/crash/`uname -n` ]
#then mkdir -m 0700 -p /var/crash/`uname -n`
#fi
#              echo ‘checking for crash dump...\c ‘
#savecore /var/crash/`uname -n`
#              echo ‘’
```

To:

```
##
## Default is to not do a savecore
##
if [ ! -d /var/crash/`uname -n` ]
then mkdir -m 0700 -p /var/crash/`uname -n`
fi
                echo ‘checking for crash dump...\c ‘
savecore /var/crash/`uname -n`
                echo ‘’
```

Note – It is not necessary to use `/var/crash` if sufficient disk space is *not* available. In this case, choose a directory where disk space is at least as large as physical memory.

When `savecore`(1M) runs, it makes a copy of the kernel that was running (called `unix.n`) and dumps a core file (called `vmcore.n`) in the specified directory, normally `/var/crash/`*machine_name*. There must be enough space in `/var/crash` to contain the core dump or it will be truncated. Because the file contains holes, it will appear larger than actual size; avoid copying it. `adb`(1) can then be used on the core dump and the saved kernel.

Note – savecore(1M) can be prevented from filling the file system if there is a file called minfree in the directory in which the dump will be saved. This file contains a number of kilobytes to remain free after savecore(1M) has run. However, if not enough space is available, the core file is not saved.

---

adb *and* kadb

adb(1) can be used to debug applications or the kernel, though it cannot debug the kernel interactively (such as by setting breakpoints). To interactively debug the kernel, use kadb(1M). Both adb(1) and kadb(1M) share a common command set.

Starting adb

The command for starting adb(1) to debug a kernel core dump is:

```
% adb -k /var/crash/‘hostname‘/unix.n /var/crash/‘hostname‘/vmcore.n
```

Note – For best results, use adb on the same architecture (such as Sun4m) that generated the core image.

To start adb on a live system, type (as root):

```
# adb -k /dev/ksyms /dev/mem
```

/dev/ksyms is a special driver that provides an image of the kernel’s symbol table to adb(1).

When adb(1) responds with physmem xxx, it is ready for a command.

Note – If the -p option of adb is used, an input prompt is displayed.

Starting kadb

The system must be booted under kadb(1M) before kadb(1M) can be used.

```
ok boot kadb
...
Boot device: /sbus/esp@0,800000/sd@3,0   File and args: kadb
kadb: kernel/unix
Size: 191220+114284+12268 Bytes
/platform/SUNW,Sun_4_75/kernel/unix loaded - 0x70000 bytes used
SunOS Release 5.6 Version Generic [UNIX(R) System V Release 4.0]
Copyright (c) 1983-1997, Sun Microsystems, Inc.
...
```

By default, kadb(1M) boots (and debugs) kernel/unix. It can be passed a file name as an argument to boot a different kernel, or -d can be passed to have kadb(1M) prompt for the kernel name. The -d flag also causes kadb(1M) to provide a prompt after it has loaded the kernel, so breakpoints can be set.

```
ok boot kadb -d
...
Boot device: /sbus/esp@0,800000/sd@3,0   File and args: kadb -d
kadb: kernel/unix
kadb: kernel/unix
Size: 191220+114284+12268 Bytes
/platform/SUNW,Sun_4_75/kernel/unix loaded - 0x70000 bytes used
kadb[0]:
```

Note – Modules are dynamically loaded. Consequently, driver symbols are not generally available until the driver is loaded. To set breakpoints in modules that have not been loaded, use deferred breakpoints. For information on deferred breakpoints, see page 367.

At this point you can set breakpoints or continue with the :c command.

kadb(1M) passes any kernel flags to the booted kernel. For example, the flags -r, -s, and -a can be passed to kernel/unix with the command:

boot kadb -ras.

Once the system is booted, sending a break passes control to `kadb`(1M). A break is generated with L1+A (on the console of SPARC machines) , or by Crtl+Alt+D (on the console of x86 machines) or ~# (if the console is connected through a *tip* window).

```
...
The system is ready.

test console login: ~stopped at 0xfbd01028: ta  0x7d
kadb[0]:
```

The number in brackets is the CPU that `kadb`(1M) is currently executing on; the remaining CPUs are halted. The CPU number is zero on a uniprocessor.

Warning – Before rebooting or turning off the power, always halt the system cleanly (with `init 0` or `shutdown`). Buffers may not be flushed otherwise. If the shutdown must occur from the boot PROM prompt, make sure to flush buffers with `sync`.

To return control to the operating system, use `:c`.

```
kadb[0]: :c

test console login:
```

Exiting

To exit either `adb`(1M) or `kadb`(1M), use `$q`.

```
kadb[0]: $q
Type ‘go’ to resume
ok
```

On SPARC machines, `kadb`(1M) can be resumed by typing `go` at the `ok` prompt. On x86 machines, `kadb`(1M) cannot be resumed.

Warning – No other commands can be performed from the PROM if the system is to be resumed. PROM commands other than `go` may change system state that the Solaris 2.x system depends upon.

Staying at the `kadb`(1M) prompt for too long may cause the system to lose track of the time of day, and cause network connections to time out.

Commands

The general form of an `adb`(1M)/`kadb`(1M) command is:

```
[ address ] [ ,count ] command [;]
```

If *address* is omitted, the current location is used (‘.’ could also be used to represent the current location). The address can be a kernel symbol. If *count* is omitted, it defaults to 1.

Commands to `adb` consist of a *verb* followed by a *modifier* or list of modifiers. Verbs can be:

`?`	Prints locations starting at *address* in the executable.
`/`	Prints locations starting at *address* in the core file.
`=`	Prints the value of *address* itself.
`>`	Assigns a value to a variable or register.
`<`	Reads a value from a variable or register.
RETURN	Repeats the previous command with a count of 1. Increments ‘.’ (the current location).

With `?`, `/`, and `=`, output format specifiers can be used. Lowercase letters normally print 2 bytes, uppercase letters print 4 bytes:

`o, O`	2-, 4-byte octal
`d,D`	2-, 4-byte decimal
`x,X`	2-, 4-byte hexadecimal
`u,U`	2-, 4-byte unsigned decimal
`f,F`	4-, 8-byte floating point

`c`	Prints the addressed character.
`C`	Prints the addressed character using ^ escape notation.
`s`	Prints the addressed string.
`S`	Prints the addressed string using ^ escape notation.
`i`	Prints as machine instructions (disassemble).
`a`	Prints the value of '.' in symbolic form.
`w,W`	2-, 4-byte write

Note – Understand exactly what sizes the objects are, and what effects changing them might have, before making any changes.

For example, to set a bit in the `moddebug` variable when debugging the driver, first examine the value of `moddebug`, then set it to the desired bit.

```
kadb[0]: moddebug/X
moddebug:
moddebug:       1000
kadb[0]: moddebug/W 0x80001000
moddebug:       0x1000 = 0x80001000
```

Routines can be disassembled with the '`i`' command. This is useful when tracing crashes, since the only information may be the program counter at the time of the crash. For example, to print the first four instructions of the `kmem_alloc` function:

```
kadb[0]: kmem_alloc,4?i
kmem_alloc:
kmem_alloc: save    %sp, -0x60, %sp
sub     %i0, 0x1, %l6
sra     %l6, 0x3, %i5
tst     %i5
```

To show the addresses also, specify symbolic notation with the ‘a’ command.

```
kadb[0]: kmem_alloc,4?ai
kmem_alloc:
kmem_alloc:     save    %sp, -0x60, %sp
kmem_alloc+4:   sub     %i0, 0x1, %l6
kmem_alloc+8:   sra     %l6, 0x3, %i5
kmem_alloc+0xc: tst     %i5
```

Register Identifiers

Machine or `kadb`(1M) internal registers are identified with the ‘<‘ command, followed by the register of interest. On SPARC machines, the following register names are recognized:

`.`	*dot*, the current location
`i0-7`	Input registers to current function
`o0-7`	Output registers for current function
`l0-7`	Local registers
`g0-7`	Global registers
`psr`	Processor Status Register
`tbr`	Trap Base Register
`wim`	Window Invalid Mask

For more information on how these registers are normally used, see the *System V Application Binary Interface, SPARC Processor Supplement*.

On x86 machines, the following register names are recognized:

`ebp`	Stack frame base register
`esp`	Stack pointer
`kesp`	Kernel stack pointer
`cs`	Code segment

`ds`	Data segment
`ss`	Stack segment
`eip`	Program pointer or instruction pointer
`efl`	Status flags register

Note – The remaining examples in this chapter are for use on SPARC machines only. For specific register information relating to x86 machines, see the *System V Application Binary Interface, x86 Processor Supplement*.

The following command displays the PSR as a 4-byte hexadecimal value:

```
kadb[0]: <psr=X
                400cc3
```

Display and Control Commands

The following commands display and control the status of `adb`(1)/`kadb`(1M):

`$b`	Display all breakpoints
`$c`	Display stack trace
`$d`	Change default radix to value of dot
`$q`	Quit
`$r`	Display registers
`$M`	Display built-in macros

'`$c`' is useful with crash dumps: it shows the call trace and arguments at the time of the crash. It is also useful in `kadb`(1M) when a breakpoint is reached, but is usually not useful if `kadb`(1M) is entered at a random time. The number of arguments to print can be passed following the '`$c`' ('`$c 2`' for two arguments).

Breakpoints

In kadb(1M), breakpoints can be set that will automatically drop back into kadb when reached. The standard form of a breakpoint command is:

```
[module_name#] addr [, count]:b [command]
```

addr is the address at which the program will be stopped and the debugger will receive control, count is the number of times that the breakpoint address occurs before stopping, and command is almost any adb(1) command.

The optional module_name specifies deferred breakpoints that are set when the module is loaded. module_name identifies a particular module that contains addr. If the module has been loaded, kadb will try to set a regular breakpoint; if the module is not loaded, kadb will set a deferred breakpoint. When the module is loaded, kadb will try to resolve the location of the breakpoint and convert the breakpoint to a regular breakpoint.

Other breakpoint commands are:

`:c`	Continue execution
`:d`	Delete breakpoint
`:s`	Single step
`:e`	Single step, but step over function calls
`:u`	Stop after return to caller of current function
`:z`	Delete all breakpoints

The following example sets a breakpoint in scsi_transport(9F), a commonly used routine. Upon reaching the breakpoint, '$c' is used to get a stack trace. The top of stack is the first function printed. Note that kadb(1M) does not know how many arguments were passed to the function; it always prints six.

```
kadb[0]: scsi_transport:b
kadb[0]: :c

 test console login: root
  Password:
  breakpoint at:
  scsi_transport: save    %sp, -0x60, %sp
  kadb[0]: $c
  scsi_transport(0xf5ad0d78,0x0,0x5,0xf5ad0e1c,0xf5ad0ec8,0x0)
  sdstrategy(0xf5d4b8a8,0xf5ad0e1c,0x0,0x2c1d0,0xf5ad0d78,0x0) + 3c0
  bdev_strategy(0xf5d4b8a8,0xf5cd3dcc,0x8,0x40,0xf0319e60,0x1000) + d0
  ufs_getpage_miss(0x0,0xf6133840,0x0,0x0,0xfbecb8e8,0x1) + 23c
  ufs_getpage(0x0,0x1000,0x0,0x0,0x0,0x1) + 640
  segmap_fault(0xf5b34000,0xf5d76f98,0x0,0x1000,0x0,0x1) + 120
  segmap_getmapflt(0xf0ba4000,0xf0ba4000,0x10000,0x0,0x6c267,0x0) + 4b0
  rdip(0xf61337b8,0x0,0xf6133840,0xf5a74938,0x0,0xf5cda000) + 328
  ufs_read(0xf61338a4,0xfbecbaf0,0x0,0xf5a74938,0xf5ca7e80,0xf61337b8) + 118
  read(0x4) + 274
  syscall_trap(?) + 18c
  Syssize(0x4) + d3c0
  Syssize(0x26ad4,0x27400,0x0,0xef66855c,0xef661f58,0x11e78) + d2bc
  Syssize(0x27b88,0x27400,0xeffffe74,0x26968,0x27f94,0x27a84) + bc28

  kadb[0]: :s
  stopped at:
  scsi_transport+4:               mov     %i0, %i1
  kadb[0]: $b
  breakpoints
  count   bkpt            type      len   command
  1       scsi_transport  :b instr  4
  kadb[0]: scsi_transport:d
  kadb[0]: :c
```

Conditional Breakpoints

This is the general syntax of conditional breakpoints:

```
address,count:b command
```

In this example, `address` is the address at which to set the breakpoint. `count` is the number of times the breakpoint should be ignored (note that 0 means break only when the command returns zero). `command` is the `adb`(1) command to execute.

Breakpoints can also be set to occur only if a certain condition is met. By providing a command, the breakpoint will be taken only if the count is reached or the command returns zero. For example, a breakpoint that occurs only on certain I/O controls could be set in the driver's `ioctl`(9E) routine. Here is an example of breaking only in the `sdioctl`() routine if the `DKIOGVTOC` (get volume table of contents) I/O control occurs.

```
kadb[0]: sdioctl+4,0:b <i1-0x40B
kadb[0]: $b
breakpoints
count   bkpt       command
0       sdioctl+4  <i1-0x40B
kadb[0]: :c
```

Adding four to `sdioctl` skips to the second instruction in the routine, bypassing the `save` instruction that establishes the stack. The '`<i1`' refers to the first input register, which is the second parameter to the routine (the `cmd` argument of `ioctl`(9E)). The count of zero is impossible to reach, so it stops only when the command returns zero, which is when '`i1 - 0x40B`' is true. This means `i1` contains `0x40B` (the value of the `ioctl` command, determined by examining the `ioctl` definition).

To force the breakpoint to be reached, the prtvtoc(1M) command is used. It is known to issue this I/O control:

```
# prtvtoc /dev/rdsk/c0t3d0s0
breakpoint      sdioctl+4:      st      %i5, [%fp + 0x58]
breakpoint sdioctl+4: mov %i0, %o0
kadb[0]: $c
sdioctl(0x800018,0x40b,0xeffffc04,0x5,0xff34dc68,0xf03f0c00) + 4
ioctl(0xf03f0c90,0xf03f0c00,0x3,0x18,0xff445f5c,0xff7a09e0) + 270
syscall_ap(0x3) + 6c
syscall_trap(?) + 150
Syssize(0x3) + 20458
Syssize(0x3,0x22f70,0xeffffc04,0x1,0x4,0xefffff6c) + fc14
Syssize(0xefffff6c,0xffffffff,0x1,0x1,0x3,0x22f70) + f5b4
Syssize(0x2,0xeffffec4,0xeffffed0,0x22c00,0x0,0x1) + ebe4
```

kadb(1M) cannot always determine where the bottom of the stack is. In the previous example, the call to Syssize is not part of the stack.

Macros

adb(1) and kadb(1M) support macros. adb(1) macros are in /usr/lib/adb and /usr/platform/‘uname -i‘/lib/adb, while kadb(1M) macros are builtin and can be displayed with $M. Most of the existing macros are for private kernel structures. New macros for adb can be created with adbgen(1M).

Macros are used in the form:

```
[ address ] $<macroname
```

threadlist is a useful macro that displays the stacks of all the threads in the system. Because this macro does not take an address and can generate excessive output, be ready to use Control-S and Control-Q to start or stop if necessary—this is another good reason to use a tip window. Control-C can be used to abort the listing.

```
kadb[0]: $<threadlist

                ============== thread_id        f0244020
p0:
p0:             process args=   sched
t0:
t0:             lwp             proc            wchan
                f02a3e78        f02a8078        0
t0+0x34:        sp              pc
                f0243af0        sched+0x4e0
?(?) + 0
main(0x0,0xf02b7e20,0xf02a800c,0x0,0x6e,0x0)
afsrbuf(?) + 1b8
exitto(0xf0040000,0xf02a0f58,0x3c,0xf02d3c40,0xfbd7d668,0x0)

                ============== thread_id        fbe01ea0
p0:
p0:             process args=   sched
0xfbe01ea0:     lwp             proc            wchan
                0               f02a8078        0
0xfbe01ed4:     sp              pc
                fbe1fe68        debug_enter+0xb0
?(?) + 0
abort_sequence_enter(0x0,0x740000,0xc4,0x0,0x0,0x40000e7)
zsa_xsint(0xf5dd9000,0x80,0xf5dd906c,0x44,0xff0113,0x0) + 244
zs_high_intr(0xf5dd9000) + 204
_level1(0x0) + 13bc
idle(0xf02a0fac,0x0,0xf02a8078,0xf02a8078,0xf004684c,0x4400ae1) + 50

                ============== thread_id        fbe22ea0
p0:
p0:             process args=   sched
0xfbe22ea0:     lwp             proc            wchan
                0               f02a8078        f5caf024
0xfbe22ed4:     sp              pc
                fbe22d80        cv_wait+0x64
?(?) + 0
cv_wait(0xf5caf024,0xf5caf010,0xffdf1175,0x6ea7e,0xf5caf030,0x40000000)
callout_thread(0xf5caf010,0xf5caf024,0xf02a8078,0xf02a8078,0x1000,0x4400ae5)+38
...
```

Another useful macro is thread. Given a thread ID, this macro prints the corresponding thread structure. This can be used to look at a certain thread found with the threadlist macro, to look at the owner of a mutex, or to look at the current thread.

```
kadb[0]: <g7$<thread
0xfbe01ea0:
0xfbe01ea0:     link            stk             startpc         bound
                0               fbe01e40        f0076d40        f02a0fac
0xfbe01eb0:     affcnt          bind_cpu        flag            procflag
                1               -1              8               0
0xfbe01eb8:     schedflag       preempt         preempt_lk      state
                3               1               0               4
0xfbe01ec0:     pri             epri            pc              sp
                -1              0               f005bdf8        fbe1fe68
0xfbe01ecc:     wchan0          wchan           sobj_ops        cid
                0               0               0               0
0xfbe01edc:     clfuncs         cldata          ctx             lofault
                f02aeed8        0               0               0
0xfbe01eec:     onfault         nofault         swap            lock
                0               0               fbe01000        ff
0xfbe01efa:     delay_cv        cpu             intr            did
                0               f02a0fac        0               1
0xfbe01f08:     tnf_tpdp        tid             alarmid
                f5a75c80        0               0               realitimer
0xfbe01f14:     interval.sec    interval.usec   value.sec       value.usec
                0               0               0               0
0xfbe01f24:     itimerid        sigqueue        sig
                0               0               0               0
0xfbe01f34:     hold                            forw            back
                0               0               0               0
0xfbe01f44:     lwp             procp           next            prev
                0               f02a8078        fbe04ea0        f0244020
0xfbe01f58:     trace           why     what    dslot           pollstate
                0               0       0       0               0
0xfbe01f68:     cred            lbolt           sysnum          pctcpu
                0               0               0               0
0xfbe01f88:     lockp           oldspl          pre_sys         disp_queue
                f02a1014        e0              0               f02a0ff0
 ...
```

Note – No type information is kept in the kernel, so using a macro on an inappropriate object results in garbage output.

Macros do not necessarily output all the fields of the structures, nor is the output necessarily in the order given in the structure definition. Occasionally, memory may need to be dumped for certain structures and then matched with the structure definition in the kernel header files.

Warning – Drivers should never reference header files and structures *not* listed in Section 9S of the *Solaris 2.6 Reference Manual*. However, examining non-DDI-compliant structures (such as `thread` structures) can be useful in debugging drivers.

Example: `adb` *on a Core Dump*

During the development of the example ramdisk driver, the system crashes with a data fault when running `mkfs`(1M).

```
test# mkfs -F ufs -o nsect=8,ntrack=8,free=5 /devices/pseudo/ramdisk:0,raw 1024
BAD TRAP
mkfs: Data fault
kernel read fault at addr=0x4, pme=0x0
Sync Error Reg 80<INVALID>
pid=280, pc=0xff2f88b0, sp=0xf01fe750, psr=0xc0, context=2
g1-g7: ffffff98, 8000000, ffffff80, 0, f01fe9d8, 1, ff1d4900
Begin traceback... sp = f01fe750
Called from f0098050,fp=f01fe7b8,args=1180000 f01fe878 ff1ed280 ff1ed280 2 ff2f8884
Called from f0097d94,fp=f01fe818,args=ff24fd40 f01fe878 f01fe918 0 0 ff2c9504
Called from f0024e8c,fp=f01fe8b0,args=f01fee90 f01fe918 2 f01fe8a4 f01fee90 3241c
Called from f0005a28,fp=f01fe930,args=f00c1c54 f01fe98c 1 f00b9d58 0 3
Called from 15c9c,fp=effffca0,args=5 3241c 200 0 0 7fe00
End traceback...
panic: Data fault
```

`savecore`(1M) was not enabled. After enabling it (see “Saving System Core Dumps” on page 358), the system is rebooted. The crash is then re-created by running `mkfs`(1M) again. When the system comes up, it saves the kernel and the core file, which can then be examined with `adb`(1):

```
# cd /var/crash/test
# ls
bounds    unix.0    vmcore.0
# adb -k unix.0 vmcore.0
physmem 1ece
```

The first step is to examine the stack to determine where the system was when it crashed:

```
$c
complete_panic(0x0,0x1,0xf00b6c00,0x7d0,0xf00b6c00,0xe3) + 114
do_panic(0xf00be7ac,0xf0269750,0x4,0xb,0xb,0xf00b6c00) + 1c
die(0x9,0xf0269704,0x4,0x80,0x1,0xf00be7ac) + 5c
trap(0x9,0xf0269704,0x4,0x80,0x1,0xf02699d8) + 6b4
```

This stack trace is not helpful initially, as the ramdisk routines are not on the stack trace. However, there *is* a useful bit of information: the call to `trap()`. The first argument to `trap()` is the trap type. The second argument to `trap`() is a pointer to a `regs` structure containing the state of the registers at the time of the trap. See *The SPARC Architecture Manual, Version 9* for more information.

```
0xf0269704$<regs
0xf0269704: psr    pc         npc
            c0     ff2dd8b0   ff2dd8b4
0xf0269710: y          g1         g2         g3
            e0000000   ffffff98   8000000    ffffff80
0xf0269720: g4         g5         g6         g7
            0          f02699d8   1          ff22c800
0xf0269730: o0         o1         o2         o3
            f02697a0   ff080000   19000      ef709000
0xf0269740: o4         o5         o6         o7
            8000       0          f0269750   7fffffff
```

Note that the program counter (`pc`) in the previous example was `ff2dd8b0` when the trap occurred. The next step is to determine which routine it is in.

```
ff2dd8b0/i
rd_write+0x2c: ld [%o2 + 0x4], %o3
```

The pc corresponds to rd_write(), which is a routine in the ramdisk driver. The bug is in the ramdisk write routine, and occurs during an load (ld) instruction. This load instruction is dereferencing the value of o2+4, so the next step is to determine the value of o2.

Note – Using the $r command to examine the registers is inappropriate because the registers have been reused in the trap routine. Instead, examine the value of o2 from the regs structure.

o2 has the value 19000 in the regs structure. Valid kernel addresses are constrained to be above KERNELBASE by the ABI, so this is probably a user address. The ramdisk does not deal with user addresses; consequently, the ramdisk write routine should not dereference an address below KERNELBASE.

To match the assembly language with the C code, the routine is disassembled up to the problem instruction. Each instruction is 4 bytes in size, so 2c/4 or 0xb additional instructions should be displayed:

```
rd_write,c/i
rd_write:
rd_write:  sethi   %hi(0xfffffc00), %g1
           add     %g1, 0x398, %g1 ! ffffff98
           save    %sp, %g1, %sp
           st      %i0, [%fp + 0x44]
           st      %i1, [%fp + 0x48]
           st      %i2, [%fp + 0x4c]
           ld      [%fp + 0x44], %o0
           call    getminor
           nop
           st      %o0, [%fp - 0x4]
           ld      [%fp - 0x8], %o2
           ld      [%o2 + 0x4], %o3
```

The crash occurs a few instructions after a call to getminor(9F). If the ramdisk.c file is examined, the following lines stand out in rd_write:

```
int instance = getminor(dev);
rd_devstate_t *rsp;

if (uiop->uio_offset >= rsp->ramsize)
    return (EINVAL);
```

Notice that *rsp* is never initialized. This is the problem. It is fixed by including the correct call to `ddi_get_soft_state`(9F) (as the ramdisk driver uses the soft state routines to do state management):

```
int instance = getminor(dev);
rd_devstate_t *rsp = ddi_get_soft_state(rd_state, instance);
if (uiop->uio_offset >= rsp->ramsize)
    return (EINVAL);
```

Note – Many data fault panics are the result of bad pointer references.

Example: `kadb` *on a Deadlocked Thread*

The next problem is that the system does not panic, but the `mkfs`(1M) command hangs and cannot be aborted. Though a core dump can be forced—by sending a break and then using `sync` from the OBP or using ‘`g 0`’ from SunMon—in this case `kadb`(1M) will be used. After logging in remotely and using `ps` (which indicated that only the `mkfs`(1M) process was hung, not the entire system) the system is shut down and booted using `kadb`(1M).

```
ok boot kadb -d
Boot device: /sbus/esp@0,800000/sd@3,0   File and args: kadb -d
kadb:kernel/unix
Size: 673348+182896+46008 bytes
/platform/SUNW,Sun_4_75/kernel/unix ...
kadb[0]::c
SunOS Release 5.6 Version Generic [UNIX(R) System V Release 4.0]
Copyright (c) 1983-1997, Sun Microsystems, Inc.
...
```

After the rest of the kernel has loaded, `moddebug` is patched to see if loading is the problem. Because it got as far as `rd_write`() before, loading is probably not the problem, but it will be checked anyway.

```
# ~stopped at 0xfbd01028: ta 0x7d
kadb[0]: moddebug/X
moddebug:
moddebug: 0
kadb[0]: moddebug/W 0x80000000
moddebug: 0x0 = 0x80000000
kadb[0]: :c
```

modload(1M) is used to load the driver, to separate module loading from the real access:

```
# modload /home/driver/drv/ramdisk
```

It loads without errors, so loading is not the problem. The condition is recreated with mkfs(1M).

```
# mkfs -F ufs -o nsect=8,ntrack=8,free=5 /devices/pseudo/ramdisk@0:c,raw 1024
ramdisk0: misusing 524288 bytes of memory
```

mkfs(1M) hangs. At this point, kadb(1M) is entered and the stack examined:

```
~stopped        at      Syslimit+0x1028:                ta      0x7d
kadb[0]: $c
Syslimit() + 1028
debug_enter(0x0,0x740000,0xc4,0x0,0x0,0x40000e7) + c0
zsa_xsint(0xf5dd9000,0x80,0xf5dd906c,0x44,0xff0113,0x0) + 244
zs_high_intr(0xf5dd9000) + 204
_level1(0x1) + 13bc
idle(0xf02a0fac,0x0,0xf02a8078,0xf02a8078,0xf004684c,0x4400ae1) + 50
```

In the previous example, the presence of idle on the current thread stack indicates that this thread is not the cause of the deadlock. To determine the deadlocked thread, the entire thread list is checked:

```
kadb[0]: $<threadlist

                ============== thread_id        f0244020
p0:
p0:             process args=   sched
t0:
t0:             lwp             proc            wchan
                f02a3e78        f02a8078        0
t0+0x34:        sp              pc
                f0243af0        sched+0x4e0
?(?) + 0
main(0x0,0xf02b7e20,0xf02a800c,0x0,0x6e,0x0)
afsrbuf(?) + 1b8
exitto(0xf0040000,0xf02a0f58,0x3c,0xf02d3c40,0xfbd7d668,0x0)

                ============== thread_id        fbe01ea0
p0:
p0:             process args=   sched
0xfbe01ea0:     lwp             proc            wchan
                0               f02a8078        0
0xfbe01ed4:     sp              pc
                fbe1fe68        debug_enter+0xb0
?(?) + 0
abort_sequence_enter(0x0,0x740000,0xc4,0x0,0x0,0x40000e7)
zsa_xsint(0xf5dd9000,0x80,0xf5dd906c,0x44,0xff0113,0x0) + 244
zs_high_intr(0xf5dd9000) + 204
_level1(0xf02d40ec) + 13bc
idle(0xf02a0fac,0x0,0xf02a8078,0xf02a8078,0xf004684c,0x4400ae1) + 50

...
                ============== thread_id        f6350a80
0xf6285518:     process args=   mkfs -o nsect=8,ntrack=8,free=5 /devices/pseudo/
                ramdisk@0:c,raw 1024
0xf6350a80:     lwp             proc            wchan
                f634baa0        f6285518        f5ef6fd0
0xf6350ab4:     sp              pc
                fbedc9e0        biowait+0xe4
?(?) + 0
biowait(0xf5ef6f68,0xf5ef6f68,0xf604ee00,0xf591b56c,0xf6306430,0xf591b550)
physio(0xf5ef6f68,0xf02d596c,0x200,0x100,0xf591b550,0xfbedcb50) + 364
write(0x200) + 250
```

Of all the threads, only one has a stack trace that references the ramdisk driver. It happens to be the last one. It seems that the process running `mkfs`(1M) is blocked in `biowait`(9F). After a call to `physio`(9F), `biowait`(9F) takes a `buf`(9S) structure as a parameter. The next step is to examine the `buf`(9S) structure:

```
kadb[0]:  f5ef6f68$<buf
0xf5ef6f68:     flags
                4129
0xf5ef6f6c:    forw           back           av_forw        av_back
                0               0               0               0
0xf5ef6f80:     bcount          bufsize         error           edev
               512            0              0              1180000
0xf5ef6f84:     addr            blkno           resid           proc
               f5f66250       3ff            0              f6285518
0xf5ef6fac:     iodone          vp              pages
                0               0               0
```

The `resid` field is 0, which indicates that the transfer is complete. `physio`(9F) is still blocked, however. The reference for `physio`(9F) in the *Solaris 2.6 Reference Manual AnswerBook* points out that `biodone(9F)` should be called to unblock `biowait`(9F). This is the problem;
`rd_strategy`( ) did not call `biodone`(9F). Adding a call to `biodone`(9F) before returning fixes this problem.

Testing

Once a device driver is functional, it should be thoroughly tested before it is distributed. In addition to the testing done to traditional UNIX device drivers, Solaris 2.x drivers require testing of Solaris 2.x features, such as dynamic loading and unloading of drivers and multithreading.

Configuration Testing

A driver’s ability to handle multiple configurations is as important part of the test process. Once the driver is working on a simple, or default, configuration, additional configurations should be tested. Depending upon the device, this may be accomplished by changing jumpers or DIP switches. If the number of possible configurations is small, all of them should be tried. If the number is large, various classes of possible configurations should be defined, and a sampling of configurations from each class should be tested. The designation of such classes depends on how the different configuration parameters might interact, which in turn depends on the device and on how the driver was written.

For each configuration, the basic functions must be tested, which include loading, opening, reading, writing, closing, and unloading the driver. Any function that depends upon the configuration deserves special attention. For example, changing the base memory address of device registers is not likely to affect the behavior of most driver functions; if the driver works well with one address, it is likely to work as well with a different address, provided the configuration code enables it to work at all. On the other hand, a special I/O control call might have different effects depending upon the particular device configuration.

Loading the driver with varying configurations assures that the `probe`(9E) and `attach`(9E) entry points can find the device at different addresses. For basic functional testing, using regular UNIX commands such as `cat`(1) or `dd`(1M) is usually sufficient for character devices. Mounting or booting may be required for block devices.

Functionality Testing

After a driver has been completely tested for configuration, all of its functionality should be thoroughly tested. This requires exercising the operation of all the driver's entry points. In addition to the basic functional tests done in configuration testing, full functionality testing requires testing the rest of the entry points and functions to obtain confidence that the driver can correctly perform all its functions.

Many drivers will require custom applications to test functionality, but basic drivers for devices such as disks, tapes, or asynchronous boards can be tested using standard system utilities. All entry points should be tested in this process, including `devmap`(9E), `poll`(9E) and `ioctl`(9E), if applicable. The `ioctl`(9E) tests might be quite different for each driver, and for nonstandard devices a custom testing application will be required.

Error Handling

A driver may perform correctly in an ideal environment, but fail to handle cases where a device encounters an error or an application specifies erroneous operations or sends bad data to the driver. Therefore, an important part of driver testing is the testing of its error handling.

All of a driver's possible error conditions should be exercised, including error conditions for actual hardware malfunctions. Some hardware error conditions might be difficult to induce, but an effort should be made to cause them or to simulate them if possible. It should always be assumed that all of these conditions will be encountered in the field. Cables should be removed or loosened, boards should be removed, and erroneous user application code should be written to test those error paths.

Stress, Performance, and Interoperability Testing

To help ensure that the driver performs well, it should be subjected to vigorous stress testing. Running single threads through a driver will not test any of the locking logic and might not test condition variable waits. Device operations should be performed by multiple processes at once to cause several threads to execute the same code simultaneously. The way to do this depends upon the driver; some drivers will require special testing applications, but starting several UNIX commands in the background will be suitable for others. It depends upon where the particular driver uses locks and condition variables. Testing a driver on a multiprocessor machine is more likely to expose problems than testing on a single-processor machine.

Interoperability between drivers must also be tested, particularly because different devices can share interrupt levels. If possible, configure another device at the same interrupt level as the one being tested. Then stress-test the driver to determine if it correctly claims its own interrupts and otherwise operates according to expectations. Stress tests should be run on both devices at once. Even if the devices do not share an interrupt level, this test can still be valuable; for example, if serial communication devices start to experience errors while a network driver is being tested, this could indicate that the network driver is causing the rest of the system to encounter interrupt latency problems.

Driver performance under these stress tests should be measured using UNIX performance-measuring tools. This can be as simple as using the `time`(1) command along with commands used for stress tests.

DDI/DKI Compliance Testing

To assure compatibility with later releases and reliable support for the current release, every driver should be Solaris 2.6 DDI/DKI compliant. One way to determine if the driver is compliant is by inspection. The driver can be visually inspected to ensure that only kernel routines and data structures specified in Sections 9F and 9S of the *Solaris 2.6 Reference Manual* are used.

The Solaris 2.6 Driver Developer Kit (DDK) includes a DDI compliance tool (DDICT) that checks device driver C source code for non-DDI/DKI compliance and issues either error or warning messages when it finds non-compliant code. For best results, all drivers should be written to pass DDICT.

Installation and Packaging Testing

Drivers are delivered to customers in *packages*. A package can be added and removed from the system using a standard mechanism (see the *Application Packaging Guide)*.

Test that the driver has been correctly packaged to ensure that the end user will be able to add it to and remove it from a system. In testing, the package should be installed and removed from every type of media on which it will be released and on several system configurations. Packages must not make unwarranted assumptions about the directory environment of the target system. Certain valid assumptions, however, may be made about where standard kernel files are kept. It is a good idea to test adding and removing of packages on newly-installed machines that have not been modified for a development environment. It is a common packaging error for a package to use a tool or file that exists only in a development environment, or only on the driver writer's own development system. For example, no tools from Source Compatibility package, SUNWscpu, should be used in driver installation programs.

The driver installation must be tested on a minimal Solaris system without any of the optional packages installed.

Testing Specific Types of Drivers

Because each type of device is different, it is difficult to describe how to test them all specifically. This section provides some information about how to test certain types of standard devices.

Tape Drivers

Tape drivers should be tested by performing several archive and restore operations. The `cpio`(1) and `tar`(1) commands may be used for this purpose. The `dd`(1M) command can be used to write an entire disk partition to tape, which can then be read back and written to another partition of the same size, and the two copies compared. The `mt`(1) command will exercise most of the I/O controls that are specific to tape drivers (see `mtio`(7I)); all the options should be attempted. The error handling of tape drivers can be tested by attempting various operations with the tape removed, attempting writes with the write protect on, and removing power during operations. Tape drivers typically implement exclusive-access `open`(9E) calls, which should be tested by having a second process try to open the device while a first process already has it open.

Disk Drivers

Disk drivers should be tested in both the raw and block device modes. For block device tests, a new file system should be created on the device and mounted. Multiple file operations can be performed on the device at this time.

Note – The file system uses a page cache, so reading the same file over and over again will not really exercise the driver. The page cache can be forced to retrieve data from the device by memory-mapping the file (with `mmap`(2)), and using `msync`(2) to invalidate the in-memory copies.

Another (unmounted) partition of the same size can be copied to the raw device and then commands such as `fsck`(1M) can be used to verify the correctness of the copy. The new partition can also be mounted and compared to the old one on a file-by-file basis.

Asynchronous Communication Drivers

Asynchronous drivers can be tested at the basic level by setting up a `login` line to the serial ports. A good start is if a user can log in on this line. To sufficiently test an asynchronous driver, however, all the I/O control functions must be tested, and many interrupts at high speed must occur. A test involving a loopback serial cable and high data transfer rates will help determine the reliability of the driver. Running `uucp`(1C) over the line also provides some exercise; however, since `uucp`(1C) performs its own error handling, it is important to verify that the driver is not reporting excessive numbers of errors to the `uucp`(1C) process.

These types of devices are usually STREAMS based.

Network Drivers

Network drivers may be tested using standard network utilities. `ftp`(1) and `rcp`(1) are useful because the files can be compared on each end of the network. The driver should be tested under heavy network loading, so that various commands can be run by multiple processes. Heavy network loading means:

- Traffic to the test machine is heavy.
- Traffic among all machines on the network is heavy.

Network cables should be unplugged while the tests are executing to ensure that the driver recovers gracefully from the resulting error conditions. Another important test is for the driver to receive multiple packets in rapid succession (*back-to-back* packets). In this case, a relatively fast host on a lightly loaded network should send multiple packets in quick succession to the test machine. It should be verified that the receiving driver does not drop the second and subsequent packets.

These types of devices are usually STREAMS based.

Converting a SunOS 4.x Device Driver to SunOS 5.6

A

This chapter is a guide to the differences between SunOS 4.x and SunOS 5.x device drivers. It can be used by developers to update relatively simple drivers intended to operate on the same platform under the SunOS 5.6 system that they operated on under the SunOS 4.x system.

Drivers that need to operate on multiple platforms, or drivers that need to take advantage of features such as multithreading must be rethought and rewritten along the guidelines specified in this manual.

Before Starting the Conversion

Before starting to convert a driver to the SunOS 5.6 system, take the preliminary steps listed below.

Review Existing Functionality

Make sure that the driver's current functionality is well understood: the way it manages the hardware, and the interfaces it provides to applications (`ioctl`(2) states the device is put in for example). Maintain this functionality in the new driver.

Read the Manual

This chapter is not a substitute for the rest of this book. Make sure that you have access to the SunOS 5.6 reference manuals.

ANSI C Compliance

The unbundled Sun C compiler is now ANSI C compliant. Most ANSI C changes are beyond the scope of this book. A number of ANSI C books are available in local bookstores; in particular, the following books are good references:

- Kernighan and Ritchie, *The C Language*, 2nd Ed., Prentice-Hall, 1988.
- Harbison and Steele, *C: A Reference Manual*, 2nd Ed., Prentice-Hall, 1987.

Development Environment

DDI/DKI

The device driver interface/driver-kernel interface (DDI/DKI) is a new name for the routines formerly called "kernel support routines" in the SunOS 4.x *Writing Device Drivers* manual, and for the "well-known" entry points in the SunOS 4.x `cdevsw` and `bdevsw` structures. The intent is to specify a set of interfaces for drivers that provide a binary and source code interface. If a driver uses only kernel routines and structures described in Section 9 of the *Solaris 2.6 Reference Manual*, it is called Solaris 2.6 DDI/DKI-compliant. A Solaris 2.6 DDI/DKI-compliant driver is likely to be binary compatible across Sun Solaris platforms with the same processor, and binary compatible with future releases of Solaris on platforms the driver works on.

Avoid Using Non-DDI/DKI Interfaces

Many architecture-specific features have been hidden from driver writers behind DDI/DKI interfaces. Specific examples are elements of the `dev_info` structure, `user` structure, `proc` structure, and page tables. If the driver has been using unadvertised interfaces, it must be changed to use DDI/DKI interfaces that provide the required functionality. If the driver continues to use unadvertised interfaces, it loses all the source and binary compatibility features of the DDI/DKI. For example, previous releases had an undocumented routine called `as_fault()` that could be used to lock down user pages in memory. This routine still exists, but is not part of the DDI/DKI, so it should not be used. The only documented way to lock down user memory is to use `physio`(9F).

Do not use any undocumented fields of structures. Documented fields are in Section 9S of the *Solaris 2.6 Reference Manua*l. Do not use fields, structures, variables, or macros just because they are in a header file.

Dynamically allocate structures whenever possible. If `buf`(9S) structure is needed`,` do not declare one. Instead, declare a pointer to one, and call `getrbuf`(9F) to allocate it.

Note – Even using `kmem_alloc(sizeof(struct buf))` is not allowed, because the size of a `buf`(9S) structure might change in future releases.

UNIX System V Release 4

The SunOS 5.x system is the Sun version of AT&T's System V Release 4 (SVR4). The system administration model is different from those in previous SunOS releases, which were more like 4.3 BSD. Differences important to device driver writers are:

- Halting and booting the machine (see the *Solaris 1.x to 2.x Transition Guide*).
- Kernel configuration (see Chapter 5, "Autoconfiguration").
- Software packaging (see the *Application Packaging Developer's Guide*).

For general SVR4 system administration information, see the *Solaris 1.x to 2.x Transition Guide*.

Development Tools

The only compiler that should be used to compile SunOS 5.x device drivers is the unbundled Sun C compiler, Sun WorkShop Compiler C 4.2. See Chapter 15, "Loading and Unloading Drivers" for information on how to compile and load a driver. Note that the compiler's `bin` directory (possibly `/opt/SUNWspro/bin`) and the supporting tools directory (`/usr/ccs/bin`) should be prepended to the `PATH`. When compiling a driver, use the `-Xt` and `-D_KERNEL` options.

When building a loadable driver module from the object modules, use `ld`(1) with the `-r` flag.

Debugging Tools

adb(1), kadb(1M), and crash(1M) are essentially the same as they were in the SunOS 4.x system, though there are new macros. To debug a live kernel, use /dev/ksyms (see ksyms(7)) instead of the kernel name (which used to be /vmunix):

```
# adb -k /dev/ksyms /dev/mem
```

See “Debugging Tools” on page 356 for more information.

ANSI C Features

The unbundled Sun C compiler is now ANSI C compliant. Two important ANSI C features device driver writers should use are the volatile keyword and function prototyping.

volatile

volatile is an ANSI C keyword that is used to prevent the optimizer from removing what it thinks are unnecessary accesses to objects. As an example, if the device has a control register that requires two consecutive writes to get it to take action, the optimizer could decide that the first write is unnecessary since the value is unused if there is no intervening read access.

If a device driver does *not* use the DDI data access functions to access device registers, device registers should be declared volatile. However, if the DDI data access functions are used to access device registers, it is not necessary to use volatile.

Note – It is not an error to declare a variable volatile unnecessarily, but it might impact performance.

Function Prototypes

ANSI C provides function prototypes. This allows the compiler to check the type and number of arguments to functions, and avoids default argument promotions. To prototype functions, declare the type and name of each function in the function definition. Then provide a prototype declaration (including at least the types) before the function is called.

Prototypes are provided for most DDI/DKI functions, so many potentially fatal errors are now caught at compile time.

Header Files

For Solaris 2.x DDI/DKI compliance, drivers are allowed to include only the kernel header files listed in the synopsis sections of Section 9 of the *Solaris 2.6 Reference Manual*. All allowed kernel header files are now located in the `/usr/include/sys` directory.

New header files all drivers must include are `<sys/ddi.h>` and `<sys/sunddi.h>`. These two headers *must* appear last in the list of kernel header include files.

Summary of Changes

Autoconfiguration Changes

Starting with the SunOS 4.1.2 system, the framework initialized all the drivers in the system before starting `init`(8). The advent of loadable module technology enabled some device drivers to be added and removed manually at later times in the life of the system.

The SunOS 5.x system extends this idea to make every driver loadable, and to allow the system to automatically configure itself continually in response to the needs of applications. This, plus the unification of the “mb” style and Open Boot style autoconfiguration, has meant some significant changes to the `probe`(9E) and `attach`(9E) routines, and has added `detach`(9E).

Because all device drivers are loadable, the kernel no longer needs to be recompiled and relinked to add a driver. The `config`(8) program has been replaced by Open Boot PROM information and supplemented by information in hardware configuration files (see `driver.conf`(4)).

Changes to Routines

- The `xxinit( )` routine for loadable modules in the SunOS 4.x system has been split into three routines. The `VDLOAD` case has become `_init`(9E), the `VDUNLOAD` case has become `_fini`(9E), and the `VDSTAT` case has become `_info`(9E).
- The SunOS 5.x `probe`(9E) routine is not the same as `probe`(9E) in the SunOS 4.x system. It is called before `attach`(9E), and may be called any number of times, so it must be stateless. If it allocates resources before it probes the device, it must deallocate them before returning (regardless of success or failure). `attach`(9E) will not be called unless `probe`(9E) succeeds.
- `attach`(9E) is called to allocate any resources the driver needs to operate the device. The system now assigns the *instance number* (previously known as the *unit number*) to the device.

The reason the rules are so stringent is that the implementation will change. If driver routines follow these rules, they will not be affected by changes to the implementation. If, however, they assume that the autoconfiguration routines are called only in a certain order (first `probe`(9E), then `attach`(9E), for example), these drivers will break in some future release.

Instance Numbers

In the SunOS 4.x system, drivers counted the number of devices that they found, and assigned a unit number to each (in the range 0 to the number of units found less one). Now, these unit numbers are called instance numbers, and the system assigns the numbers to devices.

Instances can be thought of as a shorthand name for a particular instance of a device (`foo0` could name instance 0 of device `foo`). The system assigns and retrieves the instance numbers, even after any number of reboots. This is because at `open`(2) time all the system has is a `dev_t`. To determine which device is needed (as it may need to be attached), the system needs to get the instance number (which the driver retrieves from the minor number).

The mapping between instance numbers and minor numbers (see `getinfo`(9E)) should be static. The driver should not require any state information to do the translation, since that information might not be available (the device might not be attached).

Changes to `/devices`

All devices in the system are represented by a data structure in the kernel called the device tree. The `/devices` hierarchy is a representation of this tree in the file system.

In the SunOS 4.x system,the administrator created special device files using `mknod` (or an installation script running `mknod`). Now, device drivers notify the kernel of entries by calling `ddi_create_minor_node`(9F) once they have determined a particular device exists. `drvconfig`(1M) actually maintains the file system nodes. This results in names that completely identify the device.

Changes to`/dev`

In the SunOS 4.x system, device special files were located (by convention) in `/dev`. Now that the `/devices` directory is used for special files, `/dev` is used for logical device names. Usually, these are symbolic links to the real names in `/devices`.

Logical names can be used for backward compatibility with SunOS 4.x applications, a short name for the real `/devices` name, or a way to identify a device without having to know where it is in the `/devices` tree. For example,`/dev/fb` could refer to a `cgsix`, `cgthree`, or `bwtwo` framebuffer, but the application does not need to know this.

See `disks`(1M), `tapes`(1M), `ports`(1M), `devlinks`(1M), and `/etc/devlink.tab` for system-supported ways of creating these links. See also Chapter 5, “Autoconfiguration,” for more information.

Multithreading Changes

The SunOS 5.x system supports multiple *threads* in the kernel, and multiple CPUs. A thread is a sequence of instructions being executed by a program. In the SunOS 5.x system, there are application threads, and there are kernel threads. Kernel threads are used to execute kernel code, and are the threads of concern to the driver writer.

Interrupts are also handled as threads. Because of this, there is less of a distinction between the tophalf and bottomhalf of a driver than there was in the SunOS 4.x system. All driver code is executed by a thread, which may be running in parallel with threads in other (or the same) part of a driver. The distinction now is whether these threads have user context.

See Chapter 4, “Multithreading,” for more information.

Locking Changes

Starting with the SunOS 4.1.2 system, only one processor can be in the kernel at any one time. This is accomplished by using a *master lock* around the entire kernel. When a processor needs to execute kernel code, it needs to acquire the lock (this excludes other processors from running the code protected by the lock) and then release the lock when it is through. Because of this master lock, drivers written for uniprocessor systems did not change for multiprocessor systems. Two processors could not execute driver code at the same time.

In the SunOS 5.x system, instead of one master lock, there are many smaller locks that protect smaller regions of code. For example, there may be a kernel lock that protects access to a particular vnode, and one that protects an inode. Only one processor can be running code dealing with that vnode at a time, but another could be accessing an inode. This allows a greater degree of concurrency.

However, because the kernel is multithreaded, it is possible that two (or more) threads are in driver code at the same time.

1. One thread could be in an entry point, and another in the interrupt routine. The driver had to handle this in the SunOS 4.x system, but with the restriction that the interrupt routine blocked the user context routine while it ran.

2. Two threads could be in a routine at the same time. This could not happen in the SunOS 4.x system.

Both of these cases are similar to situations present in the SunOS 4.x system, but now these threads could run at the *same time* on *different CPUs*. The driver must be prepared to handle these types of occurrences.

Mutual Exclusion Locks

In the SunOS 4.x system, a driver had to be careful when accessing data shared between the tophalf and the interrupt routine. Because the interrupt could occur asynchronously, the interrupt routine could corrupt data or simply hang. To prevent this, portions of the top half of the driver would raise, using the various `spl` routines, the interrupt priority level of the CPU to block the interrupt from being handled:

```
s = splr(pritospl(6));
/* access shared data */
(void)splx(s);
```

In the SunOS 5.x system, this no longer works. Changing the interrupt priority level of one CPU does not necessarily prevent another CPU from handling the interrupt. Also, two top-half routines may be running simultaneously with the interrupt running on a third CPU.

To solve this problem, the SunOS 5.x system provides:

1. A uniform module of execution—even interrupts run as threads. This blurs the distinction between the tophalf and the bottomhalf, as effectively every routine is a bottomhalf routine.

2. A number of locking mechanisms–a common mechanism is to use mutual exclusion locks (mutexes):

```
mutex_enter(&mu);
/* access shared data */
mutex_exit(&mu);
```

A subtle difference from the SunOS 4.x system is that, because everything is run by kernel threads, the interrupt routine needs to explicitly acquire and release the mutex. In the SunOS 4.x system, this was implicit since the interrupt handler automatically ran at an elevated priority.

See “Locking Primitives” on page 78 for more information on locking.

Condition Variables

In the SunOS 4.x system, when the driver needed the current process to wait for something (such as a data transfer to complete), it called `sleep( )`, specifying a channel and a dispatch priority. The interrupt routine then called `wakeup( )` on that channel to notify all processes waiting on that channel that something happened. Because the interrupt could occur at any time, the interrupt priority was usually raised to ensure that the wakeup could not occur until the process was asleep.

Code Example 16-1 SunOS 4.x Synchronization Method

```
int     busy; /* global device busy flag */
int xxread(dev, uio)
dev_t   dev;
struct uio *uio;
{
    int     s;

    s = splr(pritospl(6));
    while (busy)
        sleep(&busy, PRIBIO + 1);
    busy = 1;
    (void)splx(s);
    /* do the read */
}
int xxintr()
{
    busy = 0;
    wakeup(&busy);
}
```

The SunOS 5.x system provides similar functionality with condition variables. Threads are blocked on condition variables until they are notified that the condition has occurred. The driver must acquire a mutex that protects the condition variable before blocking the thread. The mutex is then released before the thread is blocked (similar to blocking/unblocking interrupts in the SunOS 4.x system)

Code Example 16-2 Synchronization in SunOS 5.x Similar to SunOS 4.x

```
int         busy;       /* global device busy flag */
kmutex_t    busy_mu;    /* mutex protecting busy flag */
kcondvar_t  busy_cv;    /* condition variable for busy flag */
```

```
static int
xxread(dev_t dev, struct uio *uiop, cred_t *credp)
{
    mutex_enter(&busy_mu);
    while (busy)
        cv_wait(&busy_cv, &busy_mu);
    busy = 1;
    mutex_exit(&busy_mu);
    /* do the read */
}
static u_int
xxintr(caddr_t arg)
{
    mutex_enter(&busy_mu);
    busy = 0;
    cv_broadcast(&busy_cv);
    mutex_exit(&busy_mu);
}
```

Like `wakeup`(), `cv_broadcast`(9F) unblocks all threads waiting on the condition variable. To wake up one thread, use `cv_signal`(9F) (there was no documented equivalent for `cv_signal`(9F) in the SunOS 4.x system).

Note – There is no equivalent to the dispatch priority passed to `sleep`( ).

Though the `sleep()` and `wakeup()` calls exist, do not use them, since the result would be an MT-unsafe driver.

See "Thread Synchronization" on page 81 for more information.

Catching Signals

The driver *could* accidentally wait for an event that will never occur, or the event might not happen for a long time. In either case, the user might want to abort the process by sending it a signal (or typing a character that causes a signal to be sent to the process). Whether the signal causes the driver to wake up depends upon the driver.

In the SunOS 4.x system, whether the `sleep`() was signal-interruptible depended upon the dispatch priority passed to `sleep`(). If the priority was greater than `PZERO`, the driver was signal-interruptible, otherwise the driver would not be awakened by a signal. Normally, a signal interrupt caused sleep( ) to return to the user, without notifying the driver that the signal had occurred. Drivers that needed to release resources before returning to the user passed the PCATCH flag to sleep( ), then looked at the return value of sleep() to determine why they awoke:

```
while (busy) {
    if (sleep(&busy, PCATCH | (PRIBIO + 1))) {
        /* awakened because of a signal */
        /* free resources */
        return (EINTR);
    }
}
```

In the SunOS 5.x system, the driver can use cv_wait_sig(9F) to wait on the condition variable, but be signal interruptible. Note that cv_wait_sig(9F) returns zero to indicate the return was due to a signal, but sleep( ) in the SunOS 4.x system returned a nonzero value:

```
while (busy) {
    if (cv_wait_sig(&busy_cv, &busy_mu) == 0) {
        /* returned because of signal */
        /* free resources */
        return (EINTR);
    }
}
```

cv_timedwait( )

Another solution drivers used to avoid blocking on events that would not occur was to set a timeout before the call to sleep. This timeout would occur far enough in the future that the event should have happened, and if it did run, it would awaken the blocked process. The driver would then see if the timeout function had run, and return some sort of error.

This can still be done in the SunOS 5.x system, but the same thing may be accomplished with cv_timedwait(9F). An absolute time to wait is passed to cv_timedwait(9F), which will return zero if the time is reached and the event has not occurred. See Code Example 4-3 on page 85 for an example usage of cv_timedwait(9F). Also see "cv_wait_sig( )" on page 86 for information on cv_timedwait_sig(9F).

Other Locks

Semaphores and readers/writers locks are also available. See `semaphore`(9F) and `rwlock`(9F).

Lock Granularity

Generally, start with one lock, and add more depending upon the abilities of the device. See “Choosing a Locking Scheme” on page 87 and Appendix G, “Advanced Topics,” for more information.

Interrupt Changes

In the SunOS 4.x system, two distinct methods were used for handling interrupts.

- Polled, or autovectored, interrupts were handled by calling the `xxpoll( )` routine of the device driver. This routine was responsible for checking all drivers’ active units.
- Vectored interrupt handlers were called directly in response to a particular hardware interrupt on the basis of the interrupt vector number assigned to the device.

In the SunOS 5.x system, the interrupt handler model has been unified. The device driver registers an interrupt handler for each device instance, and the system either polls all the handlers for the currently active interrupt level, or calls that handler directly (if it is vectored). The driver no longer needs to care which type of interrupt mechanism is in use (in the handler).

`ddi_add_intr`(9F) is used to register a handler with the system. A driver-defined argument of type `caddr_t` to pass to the interrupt handler. The address of the state structure is a good choice. The handler can then cast the `caddr_t` to whatever was passed. See “Registering Interrupts” on page 117 and “Responsibilities of an Interrupt Handler” on page 119 for more information.

DMA Changes

In the SunOS 4.x system, to do a DMA transfer the driver mapped a buffer into the DMA space, retrieved the DMA address and programed the device, did the transfer, and freed the mapping. This was accomplished in this sequence:

1. `mb_mapalloc`( ) – Map buffer into DMA space
2. `MBI_ADDR`( ) – Retrieve address from returned cookie
3. Program the device and start the DMA
4. `mb_mapfree`( ) – Free mapping when DMA is complete

The first three usually occurred in a `start`( ) routine, and the last in the interrupt routine.

The SunOS 5.x DMA model is similar, but it has been extended. The goal of the new DMA model is to abstract the platform-dependent details of DMA away from the driver. A sliding DMA window has been added for drivers that need to do DMA to large objects, and the DMA routines can be informed of device limitations (such as 24-bit addressing).

The sequence for DMA is as follows: The driver allocates a DMA handle using `ddi_dma_alloc_handle`(9F). The DMA handle can be reused for subsequent DMA transfers. Then the driver commits DMA resources using either `ddi_dma_buf_bind_handle`(9F) or `ddi_dma_addr_bind_handle`(9F), retrieves the DMA address from the DMA cookie to do the DMA, and frees the mapping with `ddi_dma_unbind_handle`(9F). The new sequence is something like this:

1. `ddi_dma_alloc_handle`(9F) – Allocate a DMA handle
2. `ddi_dma_buf_bind_handle`(9F) – Allocate DMA resources and retrieve address from the returned cookie
3. Program the device and start the DMA
4. Perform the transfer.

Note – If the transfer involves several windows, you can call `ddi_dma_getwin`(9F) to move to subsequent windows.

---

5. `ddi_dma_unbind_handle`(9F) – Free mapping when DMA is complete

6. ddi_dma_free_handle(9F) – Free DMA handle when no longer needed

Additional routines have been added to synchronize any underlying caches and buffers, and handle IOPB memory. See Chapter 7, "DMA," for details.

In addition, in the SunOS 4.x system, the driver had to inform the system that it might do DMA, either through the mb_driver structure or with a call to adddma( ). This was needed because the kernel might need to block interrupts to prevent DMA, but needed to know the highest interrupt level to block. Because the new implementation uses mutexes, this is no longer needed.

Conversion Notes

identify()

identify(9E) is obsolete and no longer required. identify(9E) was used to determine whether a driver drove the device pointed to by dip. identify(9E) is currently supported only to provide backward compatibility with older drivers and should not be implemented. Set this entry point to nulldev(9F).

Note – The framework now handles unit counting. To get the unit number in any routine, call ddi_get_instance(9F). *Do not count units anywhere.*

probe()

SunOS 4.x system:

```
int xxprobe(reg, unit)
caddr_t reg;
int     unit;
```

SunOS 5.x system:

```
int xxprobe(dev_info_t *dip)
```

probe(9E) is still expected to determine if a device exists, but now the routine might be called any number of times, so it must be *stateless* (free anything it allocates).

attach()

SunOS 4.x system: VMEbus   SBus

```
int xxattach(md)              int xxattach(devinfo)
struct mb_device *md;         struct dev_info *devinfo;
```

SunOS 5.x system

```
int xxattach(dev_info_t *dip, ddi_attach_cmd_t cmd)
```

Drivers are not allowed to count instances anywhere. Use `ddi_get_instance`(9F) to get the assigned instance number.

`new_kmem_alloc`( ) and `new_kmem_zalloc`( ) have become `kmem_alloc`(9F) and `kmem_zalloc`(9F). In SunOS 4.x sleep flags were `KMEM_SLEEP` and `KMEM_NOSLEEP`; now they are `KM_SLEEP` and `KM_NOSLEEP`. Consider using `KM_SLEEP` only on small requests, as larger requests could deadlock the driver if there is not (or there will not be) enough memory. Instead, use `KM_NOSLEEP`, possibly shrink the request, and try again.

Any required memory should be dynamically allocated, as the driver should handle all occurrences of its device rather than a fixed number of them (if possible). Instead of statically allocating an array of controller state structures, each should now be allocated dynamically.

Remember to call `ddi_create_minor_node`(9F) for each minor device name that should be visible to applications.

The module loading process turns the information in any `driver.conf`(4) file into properties. Information that used to pass in the `config` file (such as *flags*) should now be passed as properties.

getinfo()

SunOS 5.x system:

```
int xxgetinfo(dev_info_t *dip, ddi_info_cmd_t cmd,
    void *arg, void **resultp)
```

Make sure that the minor number to instance number and the reverse translation is static, since `getinfo`(9E) may be called when the device is not attached. For example:

```
#define XXINST(dev) (getminor(dev) >> 3)
```

This is a required entry point; it cannot be replaced with nulldev(9F) or nodev(9F).

open()

SunOS 4.x system:

```
int xxopen(dev, flag)
dev_t   dev;
int     flag;
```

SunOS 5.x system:

```
int xxopen(dev_t *devp, int flag, int otyp, cred_t *credp)
```

The first argument to open(9E) is a *pointer* to a dev_t. The rest of the cb_ops(9S) routines receive a dev_t.

Verify that the open type is one that the driver actually supports. This is normally OTYP_CHR for character devices, or OTYP_BLK for block devices. This prevents the driver from allowing future open types that it does not support.

If the driver used to check for root privileges using suser(), it should now use driv_priv(9F) instead on the passed credential pointer.

psize()

This entry point does not exist. Instead, block devices should support the *nblocks* property. This property may be created in attach(9E) if its value will not change. A prop_op(9E) entry point may be required if the value cannot be determined at attach time (such as if the device supports removable media). See “Properties” on page 65 for more information.

read() *and* write()

SunOS 4.x system:

```
int xxread(dev, uio)
int xxwrite(dev, uio)
dev_t   dev;
struct uio *uio;
```

SunOS 5.x system:

```
int xxread(dev_t dev, uio_t *uiop, cred_t *credp);
int xxwrite(dev_t dev, uio_t *uiop, cred_t *credp);
```

`physio`(9F) should no longer be called with the address of a statically allocated `buf`(9S) structure. Instead, pass a `NULL` pointer as the second argument, which causes `physio`(9F) to allocate a `buf` structure. The address of the allocated `buf` structure should always be saved in `strategy`(9E), as it is needed to call `biodone`(9F). An alternative is to use `getrbuf`(9F) to allocate the `buf`(9S) structure, and `freerbuf`(9F) to free it.

ioctl()

SunOS 4.x system:

```
int xxioctl(dev, cmd, data, flag)
dev_t   dev;
int     cmd, flag;
caddr_t data;
```

SunOS 5.x system:

```
int xxioctl(dev_t dev, int cmd, intptr_t arg, int mode,
    cred_t *credp, int *rvalp);
```

In the SunOS 4.x system, `ioctl`() command arguments were defined as follows:

```
#define XXIOCTL1  _IOR(m, 1, u_int)
```

The `_IOR`( ), `_IOW`( ), and `_IOWR`( ) macros were used to encode the direction and size of the data transfer. The kernel would then automatically copy the data into or out of the kernel. *This is no longer the case*. To do a data transfer, the driver is now required to use `ddi_copyin`(9F) and `ddi_copyout`(9F) explicitly. Do not dereference `arg` directly.

In addition, use the new method of a left-shifted letter OR'ed with number:

```
#define XXIOC     ('x'<<8)
#define XXIOCTL1  (XXIOC | 1)
```

The credential pointer can be used to check credentials on the call (with `drv_priv`(9F)), and the return value pointer can be used to return a value that has meaning (as opposed to the old method of always getting zero back for success). This number should be positive to avoid confusion with applications that check for `ioctl`(2) returning a negative value for failure.

strategy()

SunOS 4.x system:

```
int xxstrategy(buf)
struct buf *bp;
```

SunOS 5.x system;

```
int xxstrategy(struct buf *bp);
```

Retrieving the minor number from the `b_dev` field of the buf(9S) structure no longer works (or will work occasionally, and fail in new and notable ways at other times). Use the `b_edev` field instead.

If the driver allocated buffers uncached, it should now use `ddi_dma_sync`(9F) whenever consistent view of the buffer is required.

mmap()

SunOS 4.x system:

```
int xxmmap(dev, off, prot)
dev_t   dev;
off_t   off;
int     prot;
```

SunOS 5.x system:

```
int xxdevmap(dev_t dev, devmap_cookie_t handle, offset_t off,
size_t len, size_t *maplen, u_int model);
```

In Solaris 2.6 and subsequent releases, the recommended way for applications to map kernel or device memory is with the `devmap`(9E) interface. For information on `devmap`(9E), see Chapter 11, “Mapping Device or Kernel Memory”.

If the driver checked for root privileges using `suser`(), it should now use `drv_priv`(9F). Because there is no credential pointer passed to `devmap`(9E), the driver must use `ddi_get_cred`(9F) to retrieve the credential pointer.

chpoll()

`chpoll`(9E) is similar in operation to `select`( ), but there are more conditions that can be examined. See “Multiplexing I/O on File Descriptors” on page 195 for details.

SunOS 4.1.x to SunOS 5.6 Differences

Table A-1 compares device driver routines on the SunOS 4.1.x system versus the SunOS 5.6 system. It is not a table of equivalences. That is, simply changing from the function in column one to the function (or group of functions) in column two is not always sufficient. If the 4.1.x driver used a function in column one, read about the function in column two before changing any code.

Table A-1 SunOS 4.1.x and SunOS 5.6 Kernel Support Routines

SunOS 4.1.x	SunOS 5.6	Description
`ASSERT()`	`ASSERT()`	Expression verification
`CDELAY()`	-	Conditional busy-wait
`DELAY()`	`drv_usecwait()`	Busy-wait for specified interval
`OTHERQ()`	`OTHERQ()`	Gets pointer to queue's partner queue
`RD()`	`RD()`	Gets pointer to the read queue
`WR()`	`WR()`	Gets pointer to the write queue
`add_intr()`	`ddi_add_intr()`	Adds an interrupt handler
`adjmsg()`	`adjmsg()`	Trims bytes from a message
`allocb()`	`allocb()`	Allocates a message block
`backq()`	`backq()`	Gets pointer to queue behind the current queue
`bcmp()`	`bcmp()`	Compares two byte arrays
`bcopy()`	`bcopy()`	Copies data between address locations in kernel
`biodone()` `iodone()`	`biodone()`	Indicates I/O is complete
`biowait()` `iowait()`	`biowait()`	Wait sfor I/O to complete
`bp_mapin()`	`bp_mapin()`	Allocates virtual address space
`bp_mapout()`	`bp_mapout()`	Deallocates virtual address space
`brelse()`	-	Returns buffer to the free list
`btodb()`	-	Converts bytes to disk sectors

Table A-1 SunOS 4.1.x and SunOS 5.6 Kernel Support Routines *(Continued)*

SunOS 4.1.x	SunOS 5.6	Description
`btop()`	`btop()` `ddi_btop()`	Converts size in bytes to size in pages (round down)
`btopr()`	`btopr()` `ddi_btopr()`	Converts size in bytes to size in pages (round up)
`bufcall()`	`bufcall()`	Calls a function when a buffer becomes available
`bzero()`	`bzero()`	Zeros out memory
`canput()`	`canput()`	Tests for room in a message queue
`clrbuf()`	`clrbuf()`	Erases the contents of a buffer
`copyb()`	`copyb()`	Copies a message block
`copyin()`	`ddi_copyin()`	Copies data from a user program to a driver buffer
`copymsg()`	`copymsg()`	Copies a message
`copyout()`	`ddi_copyout()`	Copies data from a driver to a user program
`datamsg()`	`datamsg()`	Tests whether a message is a data message
`delay()`	`delay()`	Delays execution for a specified number of clock ticks
`disksort()`	`disksort()`	Single direction elevator seek-sort for buffers
`dupb()`	`dupb()`	Duplicates a message block descriptor
`dupmsg()`	`dupmsg()`	Duplicates a message
`enableok()`	`enableok()`	Reschedules a queue for service
`esballoc()`	`esballoc()`	Allocates a message block using caller-supplied buffer
`esbbcall()`	`esbbcall()`	Call sfunction when buffer is available
`ffs()`	`ddi_ffs()`	Finds first bit set in a long integer
`fls()`	`ddi_fls()`	Finds last bit set in a long integer

Table A-1 SunOS 4.1.x and SunOS 5.6 Kernel Support Routines *(Continued)*

SunOS 4.1.x	SunOS 5.6	Description
`flushq()`	`flushq()`	Removes messages from a queue
`free_pktiopb()`	`scsi_free_consistent_buf()`	Frees a SCSI packet in the `iopb` map
`freeb()`	`freeb()`	Frees a message block
`freemsg()`	`freemsg()`	Frees all message blocks in a message
`get_pktiopb()`	`scsi_alloc_consistent_buf()`	Allocates a SCSI packet in the `iopb` map
`geterror()`	`geterror()`	Gets buffer's error number
`getlongprop()`	`ddi_getlongprop()`	Gets arbitrary size property information
`getprop()`	`ddi_getprop()`	Gets boolean and integer property information
`getproplen()`	`ddi_getproplen()`	Gets property information length
`getq()`	`getq()`	Gets the next message from a queue
`gsignal()`	-	Sends signal to process group
`hat_getpkfnum()`	`hat_getkpfnum()`	Gets page frame number for kernel address
`index()`	`strchr()`	Returns pointer to first occurrence of character in string
`insq()`	`insq()`	Inserts a message into a queue
`kmem_alloc()`	`kmem_alloc()`	Allocates space from kernel free memory
`kmem_free()`	`kmem_free()`	Frees previously allocated kernel memory
`kmem_zalloc()`	`kmem_zalloc()`	Allocates and clears space from kernel free memory
`linkb()`	`linkb()`	Concatenates two message blocks
`log()`	`strlog()`	Logs kernel errors
`machineid()`	-	Gets host ID from EPROM
`major()`	`getmajor()`	Gets major device number

Table A-1 SunOS 4.1.x and SunOS 5.6 Kernel Support Routines *(Continued)*

SunOS 4.1.x	SunOS 5.6	Description
makecom_g0()	makecom_g0()	Makes packet for SCSI group 0 commands
makecom_g0_s()	makecom_g0_s()	Makes packet for SCSI group 0 sequential commands
makecom_g1()	makecom_g1()	Makes packet for SCSI group 1 commands
makecom_g5()	makecom_g5()	Makes packet for SCSI group 5 commands

mapin()
map_regs()
	ddi_regs_map_setup()	Maps physical-to-virtual space

mapout()
unmap_regs()
	ddi_regs_map_free()	Removes physical-to-virtual mappings

max()	max()	Returns the larger of two integers
mb_mapalloc()	ddi_dma_buf_bind_handle()	Sets up system DMA resources and retrieves DMA address
mb_mapfree()	ddi_dma_unbind_handle()	Releases system DMA resources
mballoc()	-	Allocates a main bus buffer
mbrelse()	-	Frees main bus resources
mbsetup()	-	Sets up use of main bus resources
min()	min()	Returns the lesser of two integers
minor()	getminor()	Gets minor device number
minphys()	minphys()	Limits transfer request size to system maximum
mp_nbmapalloc()	ddi_dma_addr_bind_handle()	Sets up system DMA resources and retrieves DMA address
MBI_ADDR()	-	Retrieves DMA address
msgdsize()	msgdsize()	Returns the number of bytes in a message
nodev()	nodev()	Error function returning ENXIO
noenable()	noenable()	Prevents a queue from being scheduled

Table A-1 SunOS 4.1.x and SunOS 5.6 Kernel Support Routines *(Continued)*

SunOS 4.1.x	SunOS 5.6	Description
nulldev()	nulldev()	Function returning zero
ovbcopy()	-	Copies overlapping byte memory regions
panic()	cmn_err()	Reboots at fatal error
peek()	ddi_peek16()	Reads a 16-bit value from a location
peekc()	ddi_peek8()	Reads a 8-bit value from a location
peekl()	ddi_peek32()	Reads a 32-bit value from a location
physio()	physio()	Limits transfer request size
pkt_transport()	scsi_transport()	Request by a SCSI target driver to start a command
poke()	ddi_poke16()	Writes a 16-bit value to a location
pokec()	ddi_poke8()	Writes a 8-bit value to a location
pokel()	ddi_poke32()	Writes a 32-bit value to a location
printf()	cmn_err()	Displays an error message or panics the system
pritospl()	-	Converts priority level
psignal()	-	Sends a signal to a process

ptob()	ptob()
	ddi_ptob()
		Converts size in pages to size in bytes

pullupmsg()	pullupmsg()	Concatenates bytes in a message
put()	put()	Calls a STREAMS put procedure
putbq()	putbq()	Places a message at the head of a queue
putctl()	putctl()	Sends a control message to a queue
putctl1()	putctl1()	Sends a control message with one-byte parameter to a queue
putnext()	putnext()	Sends a message to the next queue
putq()	putq()	Puts a message on a queue
qenable()	qenable()	Enables a queue

Table A-1 SunOS 4.1.x and SunOS 5.6 Kernel Support Routines *(Continued)*

SunOS 4.1.x	SunOS 5.6	Description
`qreply()`	`qreply()`	Sends a message on a stream in the reverse direction
`qsize()`	`qsize()`	Finds the number of messages on a queue
`remintr()`	`ddi_remove_intr()`	Removes an interrupt handler
`report_dev()`	`ddi_report_dev()`	Announces a device

`rmalloc()`	`rmallocmap()`
	`rmalloc()`
		Allocates resource map
		allocates space from a resource map

`rmalloc(iopbmap)`	`ddi_dma_mem_alloc()`	Allocates consistent memory

`rmfree()`	`rmfreemap()`
	`rmfree()`
		Frees resource map
		frees space back into a resource map

`rmfree(iopbmap)`	`ddi_dma_mem_free()`	Free consistent memory
`rmvb()`	`rmvb()`	Removes a message block from a message
`rmvq()`	`rmvq()`	Removes a message from a queue
`scsi_abort()`	`scsi_abort()`	Aborts a SCSI command
`scsi_dmafree()`	`scsi_dmafree()`	Frees DMA resources for SCSI command
`scsi_dmaget()`	`scsi_init_pkt()`	Allocates DMA resources for SCSI command
`scsi_ifgetcap()`	`scsi_ifgetcap()`	Gets SCSI transport capability
`scsi_ifsetcap()`	`scsi_ifsetcap()`	Sets SCSI transport capability
`scsi_pktalloc()`	`scsi_init_pkt()`	Allocates packet resources for SCSI command
`scsi_pktfree()`	`scsi_destroy_pkt()`	Frees packet resources for SCSI command
`scsi_poll()`	`scsi_poll()`	Runs a polled SCSI command
`scsi_resalloc()`	`scsi_init_pkt()`	Prepares a complete SCSI packet
`scsi_reset()`	`scsi_reset()`	Resets a SCSI bus or target
`scsi_resfree()`	`scsi_destroy_pkt()`	Frees an allocated SCSI packet

Table A-1 SunOS 4.1.x and SunOS 5.6 Kernel Support Routines *(Continued)*

SunOS 4.1.x	**SunOS 5.6**	**Description**
`scsi_slave()`	`scsi_probe()`	Probes for a SCSI target
`selwakeup()`	`pollwakeup()`	Informs a process that an event has occurred
`slaveslot()`	`ddi_slaveonly()`	Tells if device is installed in a slave-only slot
`sleep()`	`cv_wait()`	Supends calling thread and exit mutex atomically
`spl`*`n`*`()`	`mutex_enter()`	Sets CPU priority level
`splr()` `splx()`	`mutex_exit()`	Resets priority level
`splstr()`	-	Sets processor level for STREAMS
`strcmp()`	`strcmp()`	Compares two null-terminated strings
`strcpy()`	`strcmp()`	Copies a string from one location to another
`suser()`	`drv_priv()`	Verifies superuser
`swab()`	`swab()`	Swaps bytes in 16-bit halfwords
`testb()`	`testb()`	Checks for an available buffer
`timeout()`	`timeout()`	Executes a function after a specified length of time
`uiomove()`	`uiomove()`	Copies kernel data using `uio`(9S) structure
`unbufcall()`	`unbufcall()`	Cancels an outstanding `bufcall` request
`unlinkb()`	`unlinkb()`	Removes a message block from the head of a message
`untimeout()`	`untimeout()`	Cancels previous timeout function call
`uprintf()`	`cmn_err()`	Kernel print to controlling terminal
`ureadc()`	`ureadc()`	Adds character to a `uio` structure

Table A-1 SunOS 4.1.x and SunOS 5.6 Kernel Support Routines *(Continued)*

SunOS 4.1.x	SunOS 5.6	Description
`useracc()`	`useracc()`	Verifies whether user has access to memory
`usleep()`	`drv_usecwait`	Busy-waits for specified interval
`uwritec()`	`uwritec()`	Removes a character from a `uio` structure
`wakeup()`	`cv_broadcast()`	Signals condition and wakes all blocked threads

Interface Transition List B

This appendix presents a list of DDI/DKI data access interface functions that have changed from Solaris 2.5 to Solaris 2.6. The Solaris 2.5 interfaces are maintained for binary and source compatibility. The appendix also presents data access functions new to the Solaris 2.6 system. The functions are grouped as follows:

Data Access Methods

- Device access functions
- Common device access functions

Device Memory Mapping

- Default context management
- Custom context management

B

Data Access Methods

Device Access Functions

Table B-1 Transition List for Device Access Functions

Solaris 2.5 Interface	Solaris 2.6 Interface
pci_config_getb(9F)	pci_config_get8(9F)
pci_config_getw(9F)	pci_config_get16(9F)
pci_config_getl(9F)	pci_config_get32(9F)
pci_config_getll(9F)	pci_config_get64(9F)
pci_config_putb(9F)	pci_config_put8(9F)
pci_config_putw(9F)	pci_config_put16(9F)
pci_config_putl(9F)	pci_config_put32(9F)
pci_config_putll(9F)	pci_config_put64(9F)
ddi_io_getb(9F)	ddi_io_get8(9F)
ddi_io_getw(9F)	ddi_io_get16(9F)
ddi_io_getl(9F)	ddi_io_get32(9F)
ddi_io_putb(9F)	ddi_io_put8(9F)
ddi_io_putw(9F)	ddi_io_put16(9F)
ddi_io_putl(9F)	ddi_io_put32(9F)
ddi_io_rep_getb(9F)	ddi_io_rep_get8(9F)
ddi_io_rep_getw(9F)	ddi_io_rep_get16(9F)
ddi_io_rep_getl(9F)	ddi_io_rep_get32(9F)
ddi_io_rep_putb(9F)	ddi_io_rep_put8(9F)
ddi_io_rep_putw(9F)	ddi_io_rep_put16(9F)
ddi_io_rep_putl(9F)	ddi_io_rep_put32(9F)
ddi_mem_getb(9F)	ddi_mem_get8(9F)

Table B-1 Transition List for Device Access Functions *(Continued)*

Solaris 2.5 Interface	Solaris 2.6 Interface
ddi_mem_getw(9F)	ddi_mem_get16(9F)
ddi_mem_getl(9F)	ddi_mem_get32(9F)
ddi_mem_getll(9F)	ddi_mem_get64(9F)
ddi_mem_putb(9F)	ddi_mem_put8(9F)
ddi_mem_putw(9F)	ddi_mem_put16(9F)
ddi_mem_putl(9F)	ddi_mem_put32(9F)
ddi_mem_putll(9F)	ddi_mem_put64(9F)
ddi_mem_rep_getb(9F)	ddi_mem_rep_get8(9F)
ddi_mem_rep_getw(9F)	ddi_mem_rep_get16(9F)
ddi_mem_rep_getl(9F)	ddi_mem_rep_get32(9F)
ddi_mem_rep_getll(9F)	ddi_mem_rep_get64(9F)
ddi_mem_rep_putb(9F)	ddi_mem_rep_put8(9F)
ddi_mem_rep_putw(9F)	ddi_mem_rep_put16(9F)
ddi_mem_rep_putl(9F)	ddi_mem_rep_put32(9F)
ddi_mem_rep_putll(9F)	ddi_mem_rep_put64(9F)

Common Device Access Functions

Table B-2 Transition List for Common Device Access Functions

Solaris 2.5 Interface	Solaris 2.6 Interface
ddi_getb(9F)	ddi_get8(9F)
ddi_getw(9F)	ddi_get16(9F)
ddi_getl(9F)	ddi_get32(9F)
ddi_getll(9F)	ddi_get64(9F)
ddi_putb(9F)	ddi_put8(9F)
ddi_putw(9F)	ddi_put16(9F)
ddi_putl(9F)	ddi_put32(9F)
ddi_putll(9F)	ddi_put64(9F)

Table B-2 Transition List for Common Device Access Functions *(Continued)*

Solaris 2.5 Interface	**Solaris 2.6 Interface**
`ddi_rep_getb(9F)`	`ddi_rep_get8(9F)`
`ddi_rep_getw(9F)`	`ddi_rep_get16(9F)`
`ddi_rep_getl(9F)`	`ddi_rep_get32(9F)`
`ddi_rep_getll(9F)`	`ddi_rep_get64(9F)`
`ddi_rep_putb(9F)`	`ddi_rep_put8(9F)`
`ddi_rep_putw(9F)`	`ddi_rep_put16(9F)`
`ddi_rep_putl(9F)`	`ddi_rep_put32(9F)`
`ddi_rep_putll(9F)`	`ddi_rep_put64(9F)`

Device Memory Mapping

Device Context Management

Default Context Management

Table B-3 Transition List for Default Context Management

Solaris 2.5 Interface	**Solaris 2.6 Interface**
`ddi_segmap(9F)`	`ddi_devmap_segmap(9F)`

Custom Context Management

Table B-4 Transition List for Custom Context Management

Solaris 2.5 Interface	**Solaris 2.6 Interface**
`ddi_mapdev(9F)`	`devmap_devmem_setup(9F)`
	`devmap_do_ctxmgt(9F)`

Summary of Solaris 2.6 DDI/DKI Services *C*

This chapter discusses the interfaces provided by the Solaris 2.6 DDI / DKI. After each category of interfaces is introduced, each function in that category is listed with a brief description. These descriptions should not be considered complete or definitive, nor do they provide a thorough guide to usage. The descriptions are intended to describe what the functions do in general terms, and what the arguments and return values mean. See the manual pages for more detailed information. The categories are:

This appendix does not discuss STREAMS interfaces; to learn more about network drivers, see the *Streams Programming Guide*.

`buf`*(9S) Handling*

These interfaces manipulate the `buf`(9S) data structure. It is used to encode block I/O transfer requests, but some character drivers also use `buf`(9S) to encode character I/O requests with `physio`(9F). Drivers that use `buf`(9S) as their primary means of encoding I/O requests have to implement a `strategy`(9E) routine. For more information, see Chapter 9, “Drivers for Character Devices,” and Chapter 10, “Drivers for Block Devices”.

`void biodone(struct buf *bp);`

`biodone`(9F) marks the I/O described by the `buf`(9S) structure pointed to by `bp` as complete by setting the `B_DONE` flag in `bp->b_flags`. `biodone`(9F) then notifies any threads waiting in `biowait`(9F) for this buffer. Call `biodone`(9F) on `bp` when the I/O request it encodes is finished.

`void bioerror(struct buf *bp, int error);`

`bioerror`(9F) marks the error bits in the I/O described by the `buf`(9S) structure pointed to by `bp` with `error`.

`void bioreset(struct buf *bp);`

Use `bioreset`(9F) reset the `buf`(9S) structure pointed to by `bp`, allowing a device driver to reuse privately allocated buffers. `bioreset`(9F) resets the buffer header to its initially allocated state.

`int biowait(struct buf *bp);`

`biowait`(9F) suspends the calling thread until the I/O request described by `bp` is completed. A call to `biodone`(9F) unblocks the waiting thread. Usually, if a driver does synchronous I/O, it calls `biowait`(9F) in its `strategy`(9E) routine, and calls `biodone`(9F) in its interrupt handler when the request is complete.

`biowait`(9F) is usually not called by the driver; instead it is called by `physio`(9F), or by the file system after calling `strategy`(9F). The driver is responsible for calling `biodone`(9F) when the I/O request is completed.

`void bp_mapin(struct buf *bp);`

`bp_mapin`(9F) maps the data buffer associated with the `buf`(9S) structure pointed to by `bp` into the kernel virtual address space so that the driver can access it. Programmed I/O device drivers often use `bp_mapin`(9F) because they have to transfer data explicitly between the `buf`(9S) structure’s buffer and a device buffer. See “bp_mapin( )” on page 215 for more information.

`void bp_mapout(struct buf *bp);`

`bp_mapout`(9F) unmaps the data buffer associated with the `buf`(9S) structure pointed to by `bp`. The buffer must have been mapped previously by `bp_mapin`(9F). `bp_mapout`(9F) can only be called from user or kernel context.

`void clrbuf(struct buf *bp);`

`clrbuf`(9F) zeroes `bp->b_bcount` bytes starting at `bp->b_un.b_addr`.

void disksort(struct diskhd *dp, struct buf *bp);

disksort(9F) implements a queueing strategy for block I/O requests to block-oriented devices. dp is a pointer to a diskhd structure that represents the head of the request queue for the disk. disksort(9F) sorts bp into this queue in ascending order of cylinder number. The cylinder number is stored in the b_resid field of the buf(9S) structure. This strategy minimizes seek time for some disks.

void freerbuf(struct buf *bp);

freerbuf(9F) frees the buf(9S) structure pointed to by bp. The structure must have been allocated previously by getrbuf(9F).

int geterror(struct buf *bp);

geterror(9F) returns the error code stored in bp if the B_ERROR flag is set in bp->b_flags. It returns zero if no error occurred.

struct buf *getrbuf(int sleepflag);

getrbuf(9F) allocates a buf(9S) structure and returns a pointer to it. sleepflag should be either KM_SLEEP or KM_NOSLEEP, depending on whether getrbuf(9F) should wait for a buf(9S) structure to become available if one cannot be allocated immediately.

int physio(int (*strat)(struct buf *), struct buf *bp, dev_t dev, int rw, void (*mincnt)(struct buf *), struct uio *uio);

physio(9F) translates a read or write I/O request encoded in a uio(9S) structure into a buf(9S) I/O request. strat is a pointer to a strategy(9E) routine that physio(9F) calls to handle the I/O request. If bp is NULL, physio(9F) allocates a private buf(9S) structure.

Before calling strategy(9E), physio(9F) locks down the memory referred to by the buf(9S) structure (initialized from the uio(9S) structure). For this reason, many drivers that do DMA *must* use physio(9F), as it is the only way to lock down memory.

In most block device drivers, read(9E) and write(9E) handle raw I/O requests, and consist of little more than a call to physio(9F).

void minphys(struct buf *bp);

minphys(9F) can be passed as the mincnt argument to physio(9F). This causes physio(9F) to make I/O requests to the strategy routine that are no larger than the system default maximum data transfer size. If the original uio(9S) I/O request is to transfer a greater amount of data than minphys(9F) allows, physio(9F) calls strategy(9E) repeatedly.

Copying Data

These interfaces are data copying utilities, used both for copying data within the kernel, and for copying data between the kernel and an application.

void bcopy(const void *from, void *to, size_t bcount);

bcopy(9F) copies count bytes from the location pointed to by from to the location pointed to by to.

int copyin(const void *userbuf, void *driverbuf, size_t cn);

copyin(9F) copies data from an application's virtual address space to the kernel virtual address space, where the driver can address the data. The driver developer must ensure that adequate space is allocated for driverbuf.

int copyout(const void *driverbuf, void *userbuf, size_t cn);

copyout(9F) copies data from the kernel virtual address space to an application program's virtual address space.

`int ddi_copyin(const void *buf, void *driverbuf,`
`size_t cn, int flags);`

This routine is designed for use in driver `ioctl`(9E) routines. It copies data from a source address to a driver buffer. The driver developer must ensure that adequate space is allocated for the destination address.

The `flags` argument is used to determine the address space information about `buf`. If the `FKIOCTL` flag is set, it indicates that `buf` is a kernel address, and `ddi_copyin`(9F) behaves like `bcopy`(9F). Otherwise, `buf` is interpreted as a user buffer address, and `ddi_copyin`(9F) behaves like `copyin`(9F).

The value of the `flags` argument to `ddi_copyin`(9F) should be passed directly from the `mode` argument of `ioctl`(9E) untranslated.

`int ddi_copyout(const void *driverbuf, void *buf,`
`size_t cn, int flags);`

This routine is designed for use in driver `ioctl`(9E) routines for drivers that support layered I/O controls. `ddi_copyout`(9F) copies data from a driver buffer to a destination address, `buf`.

The `flags` argument is used to determine the address space information about `buf`. If the `FKIOCTL` flag is set, it indicates that `buf` is a kernel address, and `ddi_copyout`(9F) behaves like `bcopy`(9F). Otherwise, `buf` is interpreted as a user buffer address, and `ddi_copyin`(9F) behaves like `copyout`(9F).

The value of the `flags` argument to `ddi_copyout`(9F) should be passed directly from the `mode` argument of `ioctl`(9E) untranslated.

Device Access

These interfaces verify the credentials of application threads making system calls into drivers. They are sometimes used in the `open`(9E) entry point to restrict access to a device, though this is usually achieved with the permissions on the special files in the file system.

int drv_priv(cred_t *credp);

drv_priv(9F) returns zero if the credential structure pointed to by credp is that of a privileged thread. It returns EPERM otherwise. Use drv_priv(9F) only in place of calls to the obsolete suser() function and when making explicit checks of a calling thread's UID.

Device Configuration

These interfaces are used in setting up a driver and preparing it for use. Some of these routines handle the dynamic loading of device driver modules into the kernel, and some manage the minor device nodes in /devices that are the interface to a device for application programs. All of these routines are called in the driver's _init(9E), _fini(9E), _info(9E), attach(9E), detach(9E), and probe(9E) entry points.

int ddi_create_minor_node(dev_info_t *dip, char *name, int spec_type, int minor_num, char *node_type, int is_clone);

ddi_create_minor_node(9F) advertises a minor device node, which will eventually appear in the /devices directory and refer to the device specified by dip.

void ddi_remove_minor_node(dev_info_t *dip, char *name);

ddi_remove_minor_node(9F) removes the minor device node name for the device dip from the system. name is assumed to have been created by ddi_create_minor_node(9F). If name is NULL, all minor node information is removed.

int mod_install(struct modlinkage *modlinkage);

mod_install(9F) links the calling driver module into the system and prepares the driver to be used. modlinkage is a pointer to the modlinkage structure defined in the driver. mod_install(9F) must be called from the _init(9E) entry point.

int mod_remove(struct modlinkage *modlinkage);

mod_remove(9F) unlinks the calling driver module from the system. modlinkage is a pointer to the modlinkage structure defined in the driver. mod_remove(9F) must be called from the _fini(9E) entry point.

int mod_info(struct modlinkage *modlinkage, struct modinfo *modinfop);

mod_info(9F) reports the status of a dynamically loadable driver module. It must be called from the _info(9E) entry point.

Device Information

These interfaces provide information to the driver about a device, such as whether the device is self-identifying, what instance number the system has assigned to a device instance, the name of the dev_info node for the device, and the dev_info node of the device's parent.

int ddi_dev_is_sid(dev_info_t *dip);

ddi_dev_is_sid(9F) returns DDI_SUCCESS if the device identified by dip is self-identifying (see "Device Identification" on page 18). Otherwise, it returns DDI_FAILURE.

int ddi_get_instance(dev_info_t *dip);

ddi_get_instance(9F) returns the instance number assigned by the system for the device instance specified by dip.

char *ddi_get_name(dev_info_t *dip);

ddi_get_name(9F) returns a pointer to a character string that is the name of the dev_info tree node specified by dip.

dev_info_t *ddi_get_parent(dev_info_t *dip);

ddi_get_parent(9F) returns the dev_info_t pointer for the parent dev_info node of the passed node, identified by dip.

int ddi_slaveonly(dev_info_t *dip);

`ddi_slaveonly`(9F) returns `DDI_SUCCESS` if the device indicated by dip is installed in a slave-access only bus slot. It returns `DDI_FAILURE` otherwise.

DMA Handling

These interfaces allocate, synchronize and release DMA resources for devices capable of directly accessing system memory.

DMA resources are identified by a DMA handle. A DMA handle is created obeying the DMA attributes structure. It allows any constraints that the device's DMA controller may impose on DMA transfers to be specified, such as a limited transfer size and DMA address range.

A family of DMA setup functions are provided that make it easier to allocate DMA resources for use with kernel virtual addresses (`ddi_dma_addr_bind_handle`(9F)), and `buf`(9S) structures (`ddi_dma_buf_bind_handle`(9F)). The setup functions pass back a pointer to a DMA cookie, which countains I/O address and size information.

The DMA setup functions also provide a callback mechanism where a function can be specified to be called later if the requested mapping can't be set up immediately.

The DMA window functions allow resources to be allocated for a large object. The resources can be moved from one part of the object to another by moving the DMA window.

The DMA engine functions allow drivers to manipulate the system DMA engine, if there is one. These are currently used on x86 systems.

int ddi_dma_burstsizes(ddi_dma_handle_t handle);

`ddi_dma_burstsizes`(9F) returns an integer that encodes the allowed burst sizes for the DMA resources specified by `handle`. Allowed power of two burst sizes are bit-encoded in the return value. For a mapping that allows only 2-byte bursts, for example, the return value would be `0x2`. For a mapping that allows 1-, 2-, 4-, and 8-byte bursts, the return value would be `0xf`.

int ddi_dma_devalign(ddi_dma_handle_t handle, u_int *alignment, u_int *minxfr);

ddi_dma_devalign(9F) passes back, in the location pointed to by alignment, the required alignment for the beginning of a DMA transfer using the resources identified by handle. The alignment will be a power of two. ddi_dma_devalign(9F) also passes back in the location pointed to by minxfr the minimum number of bytes of the mapping that will be read or written in a single transfer.

int ddi_dma_sync(ddi_dma_handle_t handle, off_t off, size_t len, u_int type);

ddi_dma_sync(9F) ensures that any CPU and the device see the same data starting at off bytes into the DMA resources identified by handle and continuing for len bytes. type should be:

- DDI_DMA_SYNC_FORDEV to make sure the device sees any changes made by a CPU.
- DDI_DMA_SYNC_FORCPU to make sure all CPUs see any changes made by the device.
- DDI_DMA_SYNC_FORKERNEL, similar to DDI_DMA_SYNC_FORCPU, except that only the kernel view of the object is synchronized.

int ddi_dmae_alloc(dev_info_t *dip, int chnl, int (*dmae_waitfp)(), caddr_t arg);

ddi_dmae_alloc(9F) allocates a DMA channel from the system DMA engine. It must be called prior to any operation on a channel.

int ddi_dmae_release(dev_info_t *dip, int chnl);

ddi_dmae_release(9F) releases a previously allocated DMA channel.

`int ddi_dmae_prog(dev_info_t *dip, struct ddi_dmae_req *dmaereqp, ddi_dma_cookie_t *cookiep, int chnl);`

The `ddi_dmae_prog`(9F) function programs the DMA channel for an operation. This function allows access to various capabilities of the DMA engine hardware. It disables the channel prior to setup, and enables the channel before returning.

The DMA address and count are specified by passing `ddi_dmae_prog`(9F) a cookie obtained from `ddi_dma_buf_bind_handle`(9F). Other DMA engine parameters are specified by the DMA engine request structure passed in through `dmaereqp`. The fields of that structure are documented in `ddi_dmae_req`(9S).

`int ddi_dmae_disable(dev_info_t *dip, int chnl);`

The `ddi_dmae_disable`(9F) function disables the DMA channel so that it no longer responds to a device's DMA service requests.

`int ddi_dmae_enable(dev_info_t *dip, int chnl);`

The `ddi_dmae_enable`(9F) function enables the DMA channel for operation. This may be used to re-enable the channel after a call to `ddi_dmae_disable`(9F). The channel is automatically enabled after successful programming by `ddi_dmae_prog`(9F).

`int ddi_dmae_stop(dev_info_t *dip, int chnl);`

The `ddi_dmae_stop`(9F) function disables the channel and terminates any active operation.

`int ddi_dmae_getcnt(dev_info_t *dip, int chnl, int *countp);`

The `ddi_dmae_getcnt`(9F) function examines the count register of the DMA channel and sets (*`countp`) to the number of bytes remaining to be transferred. The channel is assumed to be stopped.

int ddi_dmae_1stparty(dev_info_t *dip, int chnl);

The ddi_dmae_1stparty(9F) function is used, by device drivers using first-party DMA, to configure a channel in the system's DMA engine to operate in a "slave" mode.

int ddi_dmae_getattr(dev_info_t *dip, ddi_dma_attr_t *attrp);

The ddi_dmae_getattr(9F) function fills in the DMA attribute structure, pointed to by attrp, with the DMA attributes of the system DMA engine. This attribute structure must be passed to ddi_dma_alloc_handle(9F). If the device has any particular restrictions on transfer size or granularity (for example, a disk sector size), the driver should further restrict the values in the structure members before passing them to ddi_dma_alloc_handle(9F). The driver must not relax any of the restrictions embodied in the structure after it is filled in by ddi_dmae_getattr(9F).

int ddi_iomin(dev_info_t *dip, int initial, int streaming);

ddi_iomin(9F) returns an integer that encodes the required alignment and the minimum number of bytes that must be read or written by the DMA controller of the device identified by dip. ddi_iomin(9F) is like ddi_dma_devalign(9F), but the memory object is assumed to be primary memory, and the alignment is assumed to be equal to the minimum possible transfer.

int ddi_dma_alloc_handle(dev_info_t *dip, ddi_dma_attr_t *attr, int (*callback)(caddr_t), caddr_t arg, ddi_dma_handle_t *handlep);

ddi_dma_alloc_handle(9F) allocates a new DMA handle. A DMA handle is an opaque object used as a reference to subsequently allocated DMA resources. ddi_dma_alloc_handle(9F) accepts as parameters the device information referred to by dip and the device's DMA attributes described by a ddi_dma_attr(9S) structure. A successful call to ddi_dma_alloc_handle(9F) fills in the value pointed to by handlep. A DMA handle must only be used by the device for which it was allocated and is valid only for one I/O transaction at a time.

If callback is set to DDI_DMA_DONTWAIT, then the caller does not care if the allocation fails, and can handle an allocation failure appropriately. If callback is set to DDI_DMA_SLEEP, then the caller needs to have the allocation routines wait for resources to become available. If any other value is set, and a DMA resource allocation fails, this value is assumed to be a function to call at a later time when resources may become available. When the specified function is called, it is passed arg as an argument. The specified callback function must return either DDI_DMA_CALLBACK_RUNOUT or DDI_DMA_CALLBACK_DONE.

DDI_DMA_CALLBACK_RUNOUT indicates that the callback routine attempted to allocate DMA resources but failed to do so, in which case the callback function is put back on a list to be called again later. DDI_DMA_CALLBACK_DONE indicates either success at allocating DMA resources or the driver no longer available.

int ddi_dma_mem_alloc(ddi_dma_handle_t handle, size_t length, ddi_device_acc_attr_t *accattrp, uint_t flags, int (*waitfp)(caddr_t), caddr_t arg, caddr_t *kaddrp, size_t *real_length, ddi_acc_handle_t *handlep);

ddi_dma_mem_alloc(9F) allocates memory for DMA transfers to or from a device. The allocation will conform to the alignment, padding constraints, and device granularity as specified by the DMA attributes (see ddi_dma_attr(9S)) passed to ddi_dma_alloc_handle(9F) and the more restrictive attributes imposed by the system.

void ddi_dma_mem_free(ddi_acc_handle_t *handlep);

ddi_dma_mem_free(9F) deallocates the memory acquired by ddi_dma_mem_alloc(9F). In addition, it destroys the data access handle handlep associated with the memory.

void ddi_dma_free_handle(ddi_dma_handle_t *handle);

ddi_dma_free_handle(9F) destroys the DMA handle pointed to by the handle. Any further references to the DMA handle will have undefined results. Note that ddi_dma_unbind_handle(9F) must be called prior to ddi_dma_free_handle(9F) to free any resources the system may be caching on the handle.

```
int ddi_dma_addr_bind_handle(ddi_dma_handle_t handle,
     struct as *as, caddr_t addr, size_t len,
     uint_t flags, int (*callback)(caddr_t),
     caddr_t arg, ddi_dma_cookie_t *cookiep,
     uint_t *ccountp);
```

`ddi_dma_addr_bind_handle`(9F) allocates DMA resources for a memory object so that a device can perform DMA to or from the object. DMA resources are allocated with respect to the device's DMA attributes as expressed by `ddi_dma_attr`(9S) (see `ddi_dma_alloc_handle`(9F)).

`ddi_dma_addr_bind_handle`(9F) fills in the first DMA cookie pointed to by `cookiep` with the appropriate address, length, and bus type. `*ccountp` is set to the number of DMA cookies representing this DMA object. Subsequent DMA cookies must be retrieved by calling `ddi_dma_nextcookie`(9F) `*countp - 1` times.

When a DMA transfer completes, the driver should free up system DMA resources by calling `ddi_dma_unbind_handle`(9F).

```
int ddi_dma_set_sbus64(ddi_dma_handle_t handle,
     uint_t burstsizes);
```

`ddi_dma_set_sbus64`(9F) informs the system that the device needs to perform 64-bit data transfers on the SBus. The driver must first allocate a DMA handle using `ddi_dma_alloc_handle`(9F) with a `ddi_dma_attr`(9S) structure describing the DMA attributes for a 32-bit transfer mode.

```
int ddi_dma_buf_bind_handle(ddi_dma_handle_t handle,
     struct buf *bp, uint_t flags,
     int (*callback)(caddr_t),caddr_t arg,
     ddi_dma_cookie_t *cookiep, uint_t *ccountp);
```

`ddi_dma_buf_bind_handle`(9F) allocates DMA resources for a system buffer such that a device can perform DMA to or from the buffer. DMA resources are allocated with respect to the device's DMA attributes as expressed by `ddi_dma_attr`(9S) (see `ddi_dma_alloc_handle`(9F)).

int ddi_dma_unbind_handle(ddi_dma_handle_t handle);

ddi_dma_unbind_handle(9F) frees all DMA resources associated with an existing DMA handle. When a DMA transfer is completed, the driver should call ddi_dma_unbind_handle(9F) to free system DMA resources established by a call to ddi_dma_buf_bind_handle(9F) or ddi_dma_addr_bind_handle(9F).

ddi_dma_unbind_handle(9F) does an implicit ddi_dma_sync(9F), making further synchronization steps unnecessary.

int ddi_dma_numwin(ddi_dma_handle_t handle, uint_t *nwinp);

ddi_dma_numwin(9F) returns the number of DMA windows for a DMA object if partial resource allocation was permitted.

int ddi_dma_getwin(ddi_dma_handle_t handle, uint_t win, off_t *offp, size_t *lenp, ddi_dma_cookie_t *cookiep, uint_t *ccountp);

ddi_dma_getwin(9F) activates a new DMA window. If a DMA resource allocation request returns DDI_DMA_PARTIAL_MAP, indicating that resources for less than the entire object were allocated, the current DMA window can be changed by a call to ddi_dma_getwin(9F).

void ddi_dma_nextcookie(ddi_dma_handle_t handle, ddi_dma_cookie_t *cookiep);

ddi_dma_nextcookie(9F) retrieves subsequent DMA cookies for a DMA object. ddi_dma_nextcookie(9F) fills in the ddi_dma_cookie(9S) structure pointed to by cookiep. The ddi_dma_cookie(9S) structure must be allocated prior to calling ddi_dma_nextcookie(9F).

Flow of Control

These interfaces influence the flow of program control in a driver. These are mostly callback mechanisms, functions that schedule another function to run at a later time. Many drivers schedule a function to run intermittently to check on the status of the device, and possibly issue an error message if a strange condition is detected.

Note – The `detach`(9E) entry point must ensure that no callback functions are pending in the driver before returning successfully. See Chapter 5, “Autoconfiguration.”

`int timeout(void (*ftn)(caddr_t), caddr_t arg, clock_t ticks);`

`timeout`(9F) schedules the function pointed to by `ftn` to be run after `ticks` clock ticks have elapsed. `arg` is passed to the function when it is run. `timeout`(9F) returns a “timeout ID” that can be used to cancel the timeout later.

`int untimeout(int id);`

`untimeout`(9F) cancels the timeout indicated by the timeout ID `id`. If the number of clock ticks originally specified to `timeout`(9F) have not elapsed, the callback function will not be called.

Interrupt Handling

These interfaces manage device interrupts and software interrupts. The basic model is to register with the system an interrupt-handling function to be called when a device interrupts or a software interrupt is triggered.

```
int ddi_add_intr(dev_info_t *dip, u_int inumber,
     ddi_iblock_cookie_t *iblock_cookiep,
     ddi_idevice_cookie_t *idevice_cookiep,
     u_int (*int_handler)(caddr_t),
     caddr_t int_handler_arg);
```

`ddi_add_intr`(9F) tells the system to call the function pointed to by `int_handler` when the device specified by `dip` issues the interrupt identified by `inumber`. `ddi_add_intr`(9F) passes back an interrupt block cookie in the location pointed to by `iblock_cookiep`, and an interrupt device cookie in the location pointed to by `idevice_cookiep`. The interrupt block cookie is used to initialize mutual exclusion locks (mutexes) and other synchronization variables. The device interrupt cookie is used to program the level at which the device interrupts, for those devices that support such programming.

```
void ddi_remove_intr(dev_info_t *dip, u_int inumber,
     ddi_iblock_cookie_t iblock_cookie);
```

`ddi_remove_intr`(9F) tells the system to stop calling the interrupt handler registered for the interrupt `inumber` on the device identified by `dip`. `iblock_cookie` is the interrupt block cookie that was returned by `ddi_add_intr`(9F) when the interrupt handler was set up. Device interrupts must be disabled before calling `ddi_remove_intr`(9F), and always call `ddi_remove_intr`(9F) in the `detach`(9E) entry point before returning successfully (if any interrupts handlers were added).

```
int ddi_add_softintr(dev_info_t *dip, int preference,
     ddi_softintr_t *idp, ddi_iblock_cookie_t *ibcp,
     ddi_idevice_cookie_t *idcp,
     u_int (*int_handler)(caddr_t),
     caddr_t int_handler_arg);
```

`ddi_add_softintr`(9F) tells the system to call the function pointed to by `int_handler` when a certain software interrupt is triggered. `ddi_add_softintr`(9F) returns a software interrupt ID in the location pointed to by `idp`. This ID is later used by `ddi_trigger_softintr`(9F) to trigger the software interrupt.

void ddi_trigger_softintr(ddi_softintr_t id);

ddi_trigger_softintr(9F) triggers the software interrupt identified by id. The interrupt handling function that was set up for this software interrupt by ddi_add_softintr(9F) is then called.

void ddi_remove_softintr(ddi_softintr_t id);

ddi_remove_softintr(9F) tells the system to stop calling the software-interrupt handler for the software interrupt identified by id. If the driver has soft interrupts registered, it must call ddi_remove_softintr(9F) in the detach(9E) entry point before returning successfully.

int ddi_dev_nintrs(dev_info_t *dip, int *result);

ddi_dev_nintr(9F) passes back in the location pointed to by result the number of different interrupt specifications that the device indicated by dip can generate. This is useful when dealing with a device that can interrupt at more than one level.

int ddi_intr_hilevel(dev_info_t *dip, u_int inumber);

ddi_intr_hilevel(9F) returns nonzero if the system considers the interrupt specified by inumber on the device identified by dip to be high level. Otherwise, it returns zero.

Kernel Statistics

These interfaces enable device drivers to store statistics about the device in the kernel for later retrieval by applications.

```
kstat_t *kstat_create(char *module, int instance,
     char *name, char *class, uchar_t type,
     ulong_t ndata, uchar_t ks_flag);
```

kstat_create(9F) allocates and performs necessary system initialization of a kstat(9S) structure. After a successful call to kstat_create(9F), the driver must perform any necessary initialization of the data structure and then use kstat_install(9F) to make the kstat(9S) structure accessible to user applications.

void kstat_delete(kstat_t *ksp);

kstat_delete(9F) removes the kstat(9S) structure pointed to by ksp from the kernel statistics data and frees associated system resources.

void kstat_install(kstat_t *ksp);

kstat_install(9F) enables the kstat(9S) structure pointed to by ksp to be accessible by the user land applications.

void kstat_named_init(kstat_named_t *knp, char *name, uchar_t data_type);

kstat_named_init(9F) associates the name pointed to by name and the type specified in data_type with the kstat_named(9S) structure pointed to by knp.

void kstat_waitq_enter(kstat_io_t *kiop);

kstat_waitq_enter(9F) is used to update the kernel_io(9S) structure pointed to by kiop, indicating that a request has arrived but has not yet been processed.

void kstat_waitq_exit(kstat_io_t *kiop);

kstat_waitq_exit(9F) is used to update the kernel_io(9S) structure pointed to by kiop, indicating that the request is about to be serviced.

void kstat_runq_enter(kstat_io_t *kiop);

kstat_runq_enter(9F) is used to update the kernel_io(9S) structure pointed to by kiop,indicating that the request is in the process of being serviced. kstat_runq_enter(9F) is generally invoked after a call to kstat_waitq_exit(9F).

void kstat_runq_exit(kstat_io_t *kiop);

kstat_runq_exit(9F) is used to update the kernel_io(9S) structure pointed to by kiop, indicating that the request is serviced.

void kstat_waitq_to_runq(kstat_io_t *kiop);

kstat_waitq_to_runq(9F) is used to update the kernel_io(9S) structure pointed to by kiop,indicating that the request is transitioning from one state to the next. kstat_waitq_to_runq(9F) is used when a driver would normally call kstat_waitq_exit(9F) followed immediately by kstat_runq_enter(9F).

void kstat_runq_to_waitq(kstat_io_t *kiop);

kstat_runq_to_waitq(9F) is used to update the kernel_io(9S) structure pointed to by kiop indicating that the request is transitioning from one state to the next. kstat_runq_to_waitq(9F) is used when a driver would normally call kstat_runq_exit(9F) followed immediately by a call to kstat_waitq_enter(9F).

Memory Allocation

These interfaces dynamically allocate memory for the driver to use.

void *kmem_alloc(size_t size, int flag);

kmem_alloc(9F) allocates a block of kernel virtual memory of length *size* and returns a pointer to it. If flag is KM_SLEEP, kmem_alloc(9F) may block, waiting for memory to become available. If flag is KM_NOSLEEP, kmem_alloc(9F) returns NULL if the request cannot be satisfied immediately.

void kmem_free(void *cp, size_t size);

kmem_free(9F) releases a block of memory of length size, starting at address addr, that was previously allocated by kmem_alloc(9F). size must be the original amount allocated.

void *kmem_zalloc(size_t size, int flags);

kmem_zalloc(9F) calls kmem_alloc(9F) to allocate a block of memory of length size, and calls bzero(9F) on the block to zero its contents before returning its address.

These interfaces allocate / free memory that can be exported to applications using `devmap_umem_setup`(9E).

`void *ddi_umem_alloc(size_t size, int flag, ddi_umem_cookie_t *cookiep);`

`ddi_umem_alloc`(9F) allocates a block of kernel virtual memory of length *size* and returns a pointer to it. The memory can be used inside the kernel and it can be exported to user applications using `devmap_umem_setup`(9E). If flag is `DDI_UMEM_SLEEP`, `ddi_umem_alloc`(9F) may block, waiting for memory to become available. If flag is `DDI_UMEM_NOSLEEP`, `ddi_umem_alloc`(9F) returns `NULL` if the request cannot be satisfied immediately. If the `DDI_UMEM_PAGEABLE` flag is set, the memory can be paged out.

`void ddi_umem_free(ddi_umem_cookie_t cookie);`

`ddi_umem_free`(9F) releases a block of memory that was previously allocated by `ddi_umem_alloc`(9F).

Mermory Space Access

`uint8_t ddi_mem_get8(ddi_acc_handle_t handle, uint8_t *dev_addr);`

`uint16_t ddi_mem_get16(ddi_acc_handle_t handle, uint16_t *dev_addr);`

`uint32_t ddi_mem_get32(ddi_acc_handle_t handle, uint32_t *dev_addr);`

`uint64_t ddi_mem_get64(ddi_acc_handle_t handle, uint64_t *dev_addr);`

These routines generate a read of various sizes from memory space or allocated DMA memory. The `ddi_mem_get8`(9F), `ddi_mem_get16`(9F), `ddi_mem_get32`(9F), and `ddi_mem_get64`(9F) functions read 8 bits, 16 bits, 32 bits, and 64 bits of data respectively from the device address, `dev_addr,` in memory space.

Each individual datum is automatically translated to maintain a consistent view between the host and the device, based on the encoded information in the data access handle. The translation may involve byte-swapping if the host and the device have incompatible endian characteristics.

```
void ddi_mem_put8(ddi_acc_handle_t handle,
     uint8_t *dev_addr, uint8_t value);
void ddi_mem_put16(ddi_acc_handle_t handle,
     uint16_t *dev_addr, uint16_t value)
void ddi_mem_put32(ddi_acc_handle_t handle,
     uint32_t *dev_addr, uint32_t value);
void ddi_mem_put64(ddi_acc_handle_t handle,
     uint64_t *dev_addr, uint64_t value);
```

These routines generate a write of various sizes to memory space or allocated DMA memory. The `ddi_mem_put8`(9F), `ddi_mem_put16`(9F), `ddi_mem_put32`(9F), and `ddi_mem_put64`(9F) functions write 8 bits, 16 bits, 32 bits, and 64 bits of data respectively to the device address, `dev_addr`, in memory space.

Each individual datum is automatically translated to maintain a consistent view between the host and the device, based on the encoded information in the data access handle. The translation may involve byte-swapping if the host and the device have incompatible endian characteristics.

```
void ddi_mem_rep_get8(ddi_acc_handle_t handle,
     uint8_t *host_addr, uint8_t *dev_addr,
     size_t repcount, uint_t flags);
```

```
void ddi_mem_rep_get16(ddi_acc_handle_t handle,
     uint16_t *host_addr, uint16_t *dev_addr,
     size_t repcount, uint_t flags);
```

```
void ddi_mem_rep_get32(ddi_acc_handle_t handle,
     uint32_t *host_addr, uint32_t *dev_addr,
     size_t repcount, uint_t flags);
```

```
void ddi_mem_rep_get64(ddi_acc_handle_t handle,
     uint64_t *host_addr, uint64_t *dev_addr,
     size_t repcount, uint_t flags);
```

These routines generate multiple reads from memory space or allocated DMA memory. repcount data is copied from the device address, `dev_addr`, in memory space to the host address, `host_addr`. For each input datum, the `ddi_mem_rep_get8`(9F), `ddi_mem_rep_get16`(9F), `ddi_mem_rep_get32`(9F), and `ddi_mem_rep_get64`(9F) functions read 8 bits, 16 bits, 32 bits, and 64 bits of data respectively from the device address, `dev_addr`. `dev_addr` and `host_addr` must be aligned to the datum boundary described by the function.

Each individual datum is automatically translated to maintain a consistent view between the host and the device, based on the encoded information in the data access handle. The translation may involve byte-swapping if the host and the device have incompatible endian characteristics.

```
void ddi_mem_rep_put8(ddi_acc_handle_t handle,
     uint8_t *host_addr, uint8_t *dev_addr,
     size_t repcount, uint_t flags);
```

```
void ddi_mem_rep_put16(ddi_acc_handle_t handle,
     uint16_t *host_addr, uint16_t *dev_addr,
     size_t repcount, uint_t flags);
```

```
void ddi_mem_rep_put32(ddi_acc_handle_t handle,
     uint32_t *host_addr, uint32_t *dev_addr,
     size_t repcount, uint_t flags);
```

```
void ddi_mem_rep_put64(ddi_acc_handle_t handle,
     uint64_t *host_addr, uint64_t *dev_addr,
     size_t repcount, uint_t flags);
```

These routines generate multiple writes to memory space or allocated DMA memory. `repcount` data is copied from the host address, `host_addr`, to the device address, `dev_addr`, in memory space. For each input datum, the `ddi_mem_rep_put8`(9F), `ddi_mem_rep_put16`(9F), `ddi_mem_rep_put32`(9F), and `ddi_mem_rep_put64`(9F) functions write 8 bits, 16 bits, 32 bits, and 64 bits of data respectively to the device address. `dev_addr` and `host_addr` must be aligned to the datum boundary described by the function.

Each individual datum is automatically translated to maintain a consistent view between the host and the device, based on the encoded information in the data access handle. The translation may involve byte-swapping if the host and the device have incompatible endian characteristics.

Common Device Access Functions

```
uint8_t ddi_get8(ddi_acc_handle_t handle,
     uint8_t *dev_addr);
```

```
uint16_t ddi_get16(ddi_acc_handle_t handle,
     uint16_t *dev_addr);
```

```
uint32_t ddi_get32(ddi_acc_handle_t handle,
     uint32_t *dev_addr);
```

```
uint64_t ddi_get64(ddi_acc_handle_t handle,
     uint64_t *dev_addr);
```

ddi_get8(9F), ddi_get16(9F), ddi_get32(9F), and ddi_get64(9F) read data from the mapped memory address, device register, or allocated DMA memory address.

The ddi_get8(9F), ddi_get16(9F), ddi_get32(9F), and ddi_get64(9F) functions read 8 bits, 16 bits, 32 bits, and 64 bits of data respectively from the device address, dev_addr.

Each individual datum is automatically translated to maintain a consistent view between the host and the device, based on the encoded information in the data access handle. The translation may involve byte-swapping if the host and the device have incompatible endian characteristics.

```
void ddi_put8(ddi_acc_handle_t handle,
     uint8_t *dev_addr, uint8_t value);
```

```
void ddi_put16(ddi_acc_handle_t handle,
     uint16_t *dev_addr, uint16_t value);
```

```
void ddi_put32(ddi_acc_handle_t handle,
     uint32_t *dev_addr, uint32_t value);
```

```
void ddi_put64(ddi_acc_handle_t handle,
     uint64_t *dev_addr, uint64_t value);
```

These routines generate a write of various sizes to the mapped memory or device register. The ddi_put8(9F), ddi_put16(9F), ddi_put32(9F), and ddi_put64(9F) functions write 8 bits, 16 bits, 32 bits, and 64 bits of data respectively to the device address, dev_addr.

Each individual datum is automatically translated to maintain a consistent view between the host and the device, based on the encoded information in the data access handle. The translation may involve byte-swapping if the host and the device have incompatible endian characteristics.

```
void ddi_rep_get8(ddi_acc_handle_t handle,
     uint8_t *host_addr, uint8_t *dev_addr,
     size_t repcount, uint_t flags);
void ddi_rep_get16(ddi_acc_handle_t handle,
     uint16_t *host_addr, uint16_t *dev_addr,
     size_t repcount, uint_t flags);
void ddi_rep_get32(ddi_acc_handle_t handle,
     uint32_t *host_addr, uint32_t *dev_addr,
     size_t repcount, uint_t flags);
void ddi_rep_get64(ddi_acc_handle_t handle,
     uint64_t *host_addr, uint64_t *dev_addr,
     size_t repcount, uint_t flags);
```

These routines generate multiple reads from the mapped memory or device register. repcount data is copied from the device address, dev_addr, to the host address, `host_addr`. For each input datum, the `ddi_rep_get8`(9F), `ddi_rep_get16`(9F), `ddi_rep_get32`(9F), and `ddi_rep_get64`(9F) functions read 8 bits, 16 bits, 32 bits, and 64 bits of data respectively from the device address, `dev_addr`. `dev_addr` and `host_addr` must be aligned to the datum boundary described by the function.

Each individual datum is automatically translated to maintain a consistent view between the host and the device, based on the encoded information in the data access handle. The translation may involve byte-swapping if the host and the device have incompatible endian characteristics.

```
void ddi_rep_put8(ddi_acc_handle_t handle,
     uint8_t *host_addr, uint8_t *dev_addr,
     size_t repcount, uint_t flags);
```

```
void ddi_rep_put16(ddi_acc_handle_t handle,
     uint16_t *host_addr, uint16_t *dev_addr,
     size_t repcount, uint_t flags);
```

```
void ddi_rep_put32(ddi_acc_handle_t handle,
     uint32_t *host_addr, uint32_t *dev_addr,
     size_t repcount, uint_t flags);
```

```
void ddi_rep_put64(ddi_acc_handle_t handle,
     uint64_t *host_addr, uint64_t *dev_addr,
     size_t repcount, uint_t flags);
```

These routines generate multiple writes to the mapped memory or device register. repcount data is copied from the host address, `host_addr`, to the device address, `dev_addr`. For each input datum, the `ddi_rep_put8`(9F), `ddi_rep_put16`(9F), `ddi_rep_put32`(9F), and `ddi_rep_put64`(9F) functions write 8 bits, 16 bits, 32 bits, and 64 bits of data respectively to the device address, `dev_addr`. `dev_addr` and `host_addr` must be aligned to the datum boundary described by the function.

Each individual datum is automatically translated to maintain a consistent view between the host and the device, based on the encoded information in the data access handle. The translation may involve byte-swapping if the host and the device have incompatible endian characteristics.

```
int ddi_device_copy(ddi_acc_handle_t src_handle,
     caddr_t src_addr, ssize_t src_advcnt,
     ddi_acc_handle_t dest_handle,
     caddr_t dest_addr, ssize_t dest_advcnt,
     size_t bytecount, uint_t dev_datasz);
```

The attributes encoded in the access handles, `src_handle` and `dest_handle`, govern how data is actually copied from the source to the destination. Only matching data sizes between the source and destination are supported.

Data will automatically be translated to maintain a consistent view between the source and the destination. The translation may involve byte-swapping if the source and the destination devices have incompatible endian characteristics.

void ddi_device_zero(ddi_acc_handle_t handle, caddr_t dev_addr, size_t bytecount, ssize_t dev_advcnt, uint_t dev_datasz);

ddi_device_zero(9F) function fills the given bytecount with the number of bytes of zeroes to the device register or memory.

The dev_advcnt argument determines the value of the device address, dev_addr, on each access. A value of 0 will use the same device address, dev_addr, on every access. A positive value increments the device address in the next access, while a negative value decrements the address. The device address is incremented or decremented in dev_datasz units.

Polling

These interfaces support the poll(2) system call, which provides a mechanism for application programs to "poll" character-oriented devices, inquiring about their readiness to perform certain I/O operations. See the poll(2) manual page for details.

int nochpoll(dev_t dev, short events, int anyyet, short *reventsp, struct pollhead **pollhdrp);

Use nochpoll(9F) as the chpoll entry in the cb_ops(9S) structure if the driver does not support polling.

void pollwakeup(struct pollhead *php, short event);

If the driver does implement a chpoll(9E) entry point to support polling, it should call pollwakeup(9F) whenever the event occurs.

Power Management

These interfaces support power management functionality.

int ddi_dev_is_needed(dev_info_t *dip, int component, int level);

ddi_dev_is_needed(9F) informs the system that a device component is needed at the specified power level. It sets the component to the required level and sets all of the devices on which it depends (see pm(7D)) to their normal power levels. If component 0 of the device is at power level 0, the ddi_dev_is_needed(9F) call will result in component 0 being returned to normal power and the device being resumed via attach(9E) before ddi_dev_is_needed(9F) returns.

int pm_create_components(dev_info_t *dip, int components);

pm_create_components(9F) creates power manageable components for a device. This function is called from the driver's attach(9F) entry point if a device has power manageable components.

void pm_destroy_components(dev_info_t *dip,);

pm_destroy_components(9F) removes power manageable components for a device. This function is called from the driver's detach(9F) entry point.

int pm_get_normal_power(dev_info_t *dip, int component);

pm_get_normal_power(9F) returns the normal power level of a device component.

void pm_set_normal_power(dev_info_t *dip, int component, int level);

pm_set_normal_power(9F) sets a device component to the specified power level.

int pm_busy_component(dev_info_t *dip, int component);

`pm_busy_component`(9F) sets a device component to busy. When a device component is busy, it will not be power-managed by the system.

int pm_idle_component(dev_info_t *dip, int component);

`pm_idle_component`(9F) sets a device component to idle. A device component that is idle is available to be power-managed by the system.

Printing System Messages

These interfaces are functions that display messages on the system console.

void cmn_err(int level, char *format, ...);

`cmn_err`(9F) is the mechanism for printing messages on the system console. `level` may be one of `CE_NOTE`, `CE_WARN`, `CE_CONT`, or `CE_PANIC`. `CE_NOTE` indicates a purely informational message. `CE_WARN` indicates a warning to the user. `CE_CONT` continues a previous message. And `CE_PANIC` issues a fatal error and crashes the system.

Note – Use `CE_PANIC` only for unrecoverable system errors.

Whenever possible, `CE_CONT` should be used to print system messages. Note that `CE_PANIC`, `CE_NOTE`, and `CE_WARN` cause `cmn_err`(9F) to always append a new line to the message.

void ddi_report_dev(dev_info_t *dip);

`ddi_report_dev`(9F) possibly prints a message announcing the presence of a device on the system. Call this function before returning from a successful `attach`(9E).

char *sprintf(char *buf, const char *fmt, ...);

`sprintf`(9F) is just like the C library's `sprintf`(3). Use it to format a message and place it in `buf`.

`void vcmn_err(int level, char *format, va_list ap);`

`vcmn_err`(9F) is a version of `cmn_err`(9F) that uses `varargs` (see the `stdarg`(5) manual page).

`char *vsprintf(char *buf, const char *fmt, va_list ap);`

`vsprintf`(9F) is a version of `sprintf`(9F) that uses `varargs` (see the `stdarg`(5) manual page).

Process Signaling

These interfaces allow a device driver to send signals to a process in a multithread-safe manner.

`void *proc_ref(void);`

`proc_ref`(9F) retrieves an unambiguous reference to the process of the current thread for signaling purposes.

`int proc_signal(void *pref, int sig);`

`proc_signal`(9F) sends the signal indicated in `sig` to the process defined by `pref` that has been referenced by `proc_ref`(9F).

`void proc_unref(void *pref);`

`proc_unref`(9F) unreferences the process defined by `pref`.

Properties

Properties are name-value pairs defined by the PROM or the kernel at boot time, by hardware configuration files, or by calls to `ddi_prop_create`(9F). These interfaces handle creating, modifying, retrieving, and reporting properties.

```
int ddi_prop_create(dev_t dev, dev_info_t *dip,
     int flags, char *name, caddr_t valuep,
     int length);
```

ddi_prop_create(9F) creates a property of the name pointed to by name and the value pointed to by valuep.

```
int ddi_prop_modify(dev_t dev, dev_info_t *dip,
     int flags, char *name, caddr_t valuep,
     int length);
```

ddi_prop_modify(9F) changes the value of the property identified by name to the value pointed to by valuep.

```
int ddi_prop_update_int_array(dev_t dev,
     dev_info_t *dip, char *name, int *data,
     u_int nelements);
```

```
int ddi_prop_update_int(dev_t dev, dev_info_t *dip,
     char *name, int data);
```

```
int ddi_prop_update_string_array(dev_t dev,
     dev_info_t *dip, char *name, char **data,
     u_int nelements);
```

```
int ddi_prop_update_string(dev_t dev, dev_info_t *dip,
     char *name, char *data);
```

```
int ddi_prop_update_byte_array(dev_t dev,
     dev_info_t *dip, char *name, u_char *data,
     u_int nelements);
```

The property update routines search for and, if found, modify the value of a given property. Properties are searched for based on the dip, name, dev, and the type of the data (integer, string, or byte). The driver software properties list is searched. If the property is found, it is updated with the supplied value. If the property is not found on this list, a new property is created with the value supplied.

For example, if a driver attempts to update the *foo* property, a property named *foo* is searched for on the driver's software property list. If *foo* is found, the value is updated. If *foo* is not found, a new property named *foo* is created on the driver's software property list with the supplied value, even if a *foo* property exists on another property list (such as a PROM property list).

For the routines `ddi_prop_update_int_array`(9F), `ddi_prop_update_string_array`(9F), `ddi_prop_update_string`(9F), and `ddi_prop_update_byte_array`(9F), `data` is a pointer which points to memory containing the value of the property. In each case `data` points to a different type of property value.

int ddi_prop_remove(dev_t dev, dev_info_t *dip, char *name);

`ddi_prop_remove`(9F) frees the resources associated with the property identified by `name`.

void ddi_prop_remove_all(dev_info_t *dip);

`ddi_prop_remove_all`(9F) frees the resources associated with all properties belonging to `dip`. `ddi_prop_remove_all`(9F) should be called in the `detach`(9E) entry point if the driver defines properties.

int ddi_prop_undefine(dev_t dev, dev_info_t *dip, int flags, char *name);

`ddi_prop_undefine`(9F) marks the value of the property identified by `name` as temporarily undefined. The property continues to exist, however, and may be redefined later using `ddi_prop_modify`(9F).

int ddi_prop_op(dev_t dev, dev_info_t *dip, ddi_prop_op_t prop_op, int flags, char *name, caddr_t valuep, int *lengthp);

`ddi_prop_op`(9F) is the generic interface for retrieving properties. `ddi_prop_op`(9F) should be used as the `prop_op`(9E) entry in the `cb_ops`(9S) structure if the driver does not have a `prop_op`(9E) routine. See "Properties" on page 65 for more information.

int ddi_getprop(dev_t dev, dev_info_t *dip, int flags, char *name, int defvalue);

`ddi_getprop`(9F) is a wrapper around `ddi_prop_op`(9F). It can be used to retrieve Boolean and integer-sized properties.

int ddi_prop_exists(dev_t match_dev, dev_info_t *dip, u_int flags, char *name);

`ddi_prop_exists`(9F) checks for the existence of a property regardless of the property value data type.

int ddi_prop_get_int(dev_t match_dev, dev_info_t *dip, u_int flags, char *name, int defvalue);

`ddi_prop_get_int`(9F) searches for an integer property and, if found, returns the value of the property.

int ddi_getlongprop(dev_t dev, dev_info_t *dip, int flags, char *name, caddr_t valuep, int *lengthp);

`ddi_getlongprop`(9F) is a wrapper around `ddi_prop_op`(9F). It is used to retrieve properties having values of arbitrary length. The value returned is stored in a buffer allocated by `kmem_alloc`(9F), which the driver must free with `kmem_free`(9F) when the value is no longer needed.

int ddi_getlongprop_buf(dev_t dev, dev_info_t *dip, int flags, char *name, caddr_t valuep, int *lengthp);

`ddi_getlongprop_buf`(9F) is a wrapper around `ddi_prop_op`(9F). It is used retrieve a property having a value of arbitrary length and to copy that value into a buffer supplied by the driver. `valuep` must point to this buffer.

```
int ddi_prop_lookup_int_array(dev_t match_dev,
     dev_info_t *dip,u_int flags, char *name,
     int **datap, u_int *nelementsp);
```

```
int ddi_prop_lookup_string_array(dev_t match_dev,
     dev_info_t *dip, u_int flags, char *name,
     char **datap, u_int *nelementsp);
```

```
int ddi_prop_lookup_string(dev_t match_dev,
     dev_info_t *dip, u_int flags, char *name,
     char **datap);
```

```
int ddi_prop_lookup_byte_array(dev_t match_dev,
     dev_info_t *dip,u_int flags, char *name,
     u_char **datap, u_int *nelementsp);
```

```
void ddi_prop_free(void *data);
```

The property lookup routines search for and, if bound, returns the value of a given property. Properties are searched for based on the `dip`, `name`, `match_dev`, and the type of the data (integer, string, or byte). The property search order is as follows:

1. Search software properties created by the driver.
2. Search the software properties created by the system (or nexus nodes in the device info tree).
3. Search the driver global properties list.
4. If `DDI_PROP_NOTPROM` is not set, search the PROM properties (if they exist).
5. If `DDI_PROP_DONTPASS` is not set, pass this request to the parent device information node.
6. Return `DDI_PROP_NOT_FOUND`.

```
int ddi_getproplen(dev_t dev, dev_info_t *dip,
     int flags, char *name, int *lengthp);
```

`ddi_getproplen`(9F) is a wrapper around `ddi_prop_op`(9F) that passes back in the location pointed to by `lengthp` the length of the property identified by `name`.

C

Register and Memory Mapping

These interfaces support the mapping of device memory and device registers into kernel memory so that a device driver can address them.

```
int ddi_devmap_segmap(dev_t dev, off_t offset,
        struct as *as, caddr_t *addrp, off_t len,
        u_int prot, u_int maxprot, u_int flags,
        cred_t *credp);
```

ddi_devmap_segmap(9F) supports the mmap(2) system call, which allows application programs to map device or kernel memory into their address spaces. ddi_devmap_segmap(9F) should be used as the segmap(9E) entry in the cb_ops(9S) structure.

```
int devmap_devmem_setup(devmap_cookie_t handle,
        dev_info_t *dip,
        struct devmap_callback_ctl *callbackops,
        u_int rnumber, offset_t roff, size_t len,
        u_int maxprot, u_int flags,
        ddi_device_acc_attr_t *accattrp);
```

devmap_devmem_setup(9F) sets up user mappings to device space. It is called from the devmap(9E) entry point to export a range of a register set specified by rnumber, roff and len.

```
int devmap_umem_setup(devmap_cookie_t handle,
        dev_info_t *dip,
        struct devmap_callback_ctl *callbackops,
        ddi_umem_cookie_t cookie, offset_t koff,
        size_t len, u_int maxprot, u_int flags,
        ddi_device_acc_attr_t *accattrp);
```

devmap_umem_setup(9F) sets up user mappings to kernel memory. It is called from the devmap(9E) entry point to export a range of kernel memory specified by cookie, koff and len.

```
int devmap_load(devmap_cookie_t handle,
      offset_t offset, size_t len, uint_t type,
      uint_t rw);
```

```
int devmap_unload(devmap_cookie_t handle
      offset_t offset, size_t len);
```

devmap_load(9F) and devmap_unload(9F) control whether user accesses to the device mappings created by devmap_devmem_setup(9F) or devmap_umem_setup(9F) in the specified range will generate an access event notification to the device driver.

devmap_unload(9F) tells the system to intercept mapping accesses and invalidates the mapping translations. devmap_load(9F) prevents the system from intercepting mapping accesses and validates the mapping translations.

```
int ddi_dev_nregs(dev_info_t *dip, int *resultp);
```

ddi_dev_nregs(9F) passes back in the location pointed to by resultp the number of register specifications a device has.

```
int ddi_dev_regsize(dev_info_t *dip, u_int rnumber,
      off_t *resultp);
```

ddi_dev_regsize(9F) passes back in the location pointed to by resultp the size of the register set identified by rnumber on the device identified by dip.

```
int ddi_regs_map_setup(dev_info_t *dip, uint_t
      rnumber, caddr_t *addrp, offset_t offset,
      offset_t len, ddi_device_acc_attr_t *accattrp,
      ddi_acc_handle_t *handlep);
```

ddi_regs_map_setup(9F) maps in the register set given by rnumber. The register number determines which register set is mapped if more than one exists.

```
void ddi_regs_map_free(ddi_acc_handle_t *handle);
```

ddi_regs_map_setup(9F) frees the mapping represented by the data access handle. This function is provided for drivers preparing to detach themselves from the system, allowing them to release allocated system resources represented in the handle.

```
int pci_config_setup(dev_info_t *dip,
     ddi_acc_handle_t *handle);
void pci_config_teardown(ddi_acc_handle_t *handle);
```

pci_config_setup(9F) sets up the necessary resources for enabling subsequent data accesses to the PCI local bus configuration space. pci_config_teardown(9F) reclaims and removes those resources represented by the data access handle returned from pci_config_setup(9F).

Device Context Management

The following functions are used to manage device context:

```
int devmap_do_ctxmgt(devmap_cookie_t cookie,
     void *pvtp, offset_t off, size_t len,
     u_int type, u_int rw,
     int (*devmap_contextmgt)(devmap_cookie_t,
     void *, offset_t, size_t, u_int, u_int));
```

Device drivers call devmap_do_ctxmgt(9F) in the devmap_access(9E) entry point to perform device context switching on a mapping. devmap_do_ctxmgt(9F) passes a pointer to a driver supplied callback function, devmap_contextmgt(9E), to the system that will perform the actual device context switching.

```
int devmap_default_access(devmap_cookie_t cookie,
     void *pvtp, offset_t off, size_t len, u_int type,
     u_int rw);
```

devmap_default_access(9F) is a function providing the semantics of devmap_access(9E). The driver calls devmap_default_access(9F) to handle the mappings that do not support context switching. The driver should call devmap_do_ctxmgt(9F) for the mappings that support context management.

PCI Configuration

```
uint8_t pci_config_get8(ddi_acc_handle_t handle,
     off_t offset);
```

```
uint16_t pci_config_get16(ddi_acc_handle_t handle,
     off_t offset);
```

```
uint32_t pci_config_get32(ddi_acc_handle_t handle,
     off_t offset);
```

```
uint64_t pci_config_get64(ddi_acc_handle_t handle,
     off_t offset);
```

```
void pci_config_put8(ddi_acc_handle_t handle,
     off_t offset, uint8_t value);
```

```
void pci_config_put16(ddi_acc_handle_t handle,
     off_t offset, uint16_t value);
```

```
void pci_config_put32(ddi_acc_handle_t handle,
     off_t offset, uint32_t value);
```

```
void pci_config_put64(ddi_acc_handle_t handle,
     off_t offset, uint64_t value);
```

These routines read or write a single datum of various sizes from or to the PCI local bus configuration space. The pci_config_get8(9F), pci_config_get16(9F), pci_config_get32(9F), and pci_config_get64(9F) functions read 8 bits, 16 bits, 32 bits, and 64 bits of data respectively. The pci_config_put8(9F), pci_config_put16(9F), pci_config_put32(9F), and pci_config_put64(9F) functions write 8 bits, 16 bits, 32 bits, and 64 bits of data respectively. The offset argument must be a multiple of the datum size.

Because the PCI local bus configuration space is represented in little-endian data format, these functions translate the data from or to native host format to or from little-endian format.

pci_config_setup(9F) must be called before invoking these functions.

I/O Port Access

These interfaces support the accessing of device registers from the device driver.

```
uint8_t ddi_io_get8(ddi_acc_handle_t handle,
     int dev_port);
```

```
uint16_t ddi_io_get16(ddi_acc_handle_t handle,
     int dev_port);
```

```
uint32_t ddi_io_get32(ddi_acc_handle_t handle,
     int dev_port);
```

These routines generate a read of various sizes from the device port, developer, in I/O space. The ddi_io_get8(9F), ddi_io_get16(9F), and ddi_io_get32(9F) functions read 8 bits, 16 bits, and 32 bits of data respectively from the device port, dev_port.

Each individual datum is automatically translated to maintain a consistent view between the host and the device, based on the encoded information in the data access handle.

The translation may involve byte-swapping if the host and the device have incompatible endian characteristics.

```
void ddi_io_rep_get8(ddi_acc_handle_t handle,
     uint8_t *host_addr, int dev_port,
     size_t repcount);
```

```
void ddi_io_rep_get16(ddi_acc_handle_t handle,
     uint16_t *host_addr, int dev_port,
     size_t repcount);
```

```
void ddi_io_rep_get32(ddi_acc_handle_t handle,
     uint32_t *host_addr, int dev_port,
     size_t repcount);
```

These routines generate multiple reads from the device port, `dev_port`, in I/O space, `repcount` data is copied from the device port, `dev_port`, to the host address, `host_addr`. For each input datum, the `ddi_io_rep_get8`(9F), `ddi_io_rep_get16`(9F), and `ddi_io_rep_get32`(9F) functions read 8 bits, 16 bits, and 32 bits of data, respectively, from the device port. `host_addr` must be aligned to the datum boundary described by the function.

Each individual datum is automatically translated to maintain a consistent view between the host and the device, based on the encoded information in the data access handle. The translation may involve byte-swapping if the host and the device have incompatible endian characteristics.

```
void ddi_io_put8(ddi_acc_handle_t handle,
     int dev_port, uint8_t value);
```

```
void ddi_io_put16(ddi_acc_handle_t handle,
     int dev_port, uint16_t value);
```

```
void ddi_io_put32(ddi_acc_handle_t handle,
     int dev_port, uint32_t value);
```

These routines generate a write of various sizes to the device port, dev_port, in I/O space. The `ddi_io_put8`(9F), `ddi_io_put16`(9F), and `ddi_io_put32`(9F) functions write 8 bits, 16 bits, and 32 bits of data, respectively, to the device port, `dev_port`.

Each individual datum is automatically translated to maintain a consistent view between the host and the device, based on the encoded information in the data access handle. The translation may involve byte-swapping if the host and the device have incompatible endian characteristics.

void ddi_io_rep_put8(ddi_acc_handle_t handle,
uint8_t *host_addr, int dev_port,
size_t repcount);

void ddi_io_rep_put16(ddi_acc_handle_t handle,
uint16_t *host_addr, int dev_port,
size_t repcount);

void ddi_io_rep_put32(ddi_acc_handle_t handle,
uint32_t *host_addr, int dev_port,
size_t repcount);

These routines generate multiple writes to the device port, `dev_port`, in I/O space. `repcount` data is copied from the host address, `host_addr`, to the device port, `dev_port`. For each input datum, the `ddi_io_rep_put8`(9F), `ddi_io_rep_put16`(9F), and `ddi_io_rep_put32`(9F) functions write 8 bits, 16 bits, and 32 bits of data, respectively, to the device port. `host_addr` must be aligned to the datum boundary described by the function.

Each individual datum is automatically translated to maintain a consistent view between the host and the device, based on the encoded information in the data access handle. The translation may involve byte-swapping if the host and the device have incompatible endian characteristics.

SCSI and SCSA

These interfaces are part of the Sun Common SCSI Interface, routines that support the writing of “target drivers” to drive SCSI devices. Most of these routines handle allocating SCSI command “packets,” formulating SCSI commands within those packets, and “transporting” the packets to the host adapter driver for execution. See Chapter 13, “SCSI Target Drivers.”

void makecom_g0(struct scsi_pkt *pkt,
struct scsi_device *devp, int flag,
int cmd, int addr, int cnt);

`makecom_g0`(9F) formulates a group 0 SCSI command for the target device denoted by `devp` in the `scsi_pkt`(9S) structure pointed to by `pkt`. The target must be a nonsequential access device. Use `makecom_g0_s`(9F) to formulate group 0 commands for sequential access devices.

```
void makecom_g0_s(struct scsi_pkt *pkt,
     struct scsi_device *devp, int flag, int cmd,
     int cnt, int fixbit);
```

makecom_g0_s(9F) formulates a group 0 SCSI command for the sequential access target device denoted by devp in the scsi_pkt(9S) structure pointed to by pkt. Use makecom_g0(9F) to formulate group 0 commands for nonsequential access devices.

```
void makecom_g1(struct scsi_pkt *pkt,
     struct scsi_device *devp, int flag, int cmd,
     int addr, int cnt);
```

makecom_g1(9F) formulates a group 1 SCSI command for the target device denoted by devp in the scsi_pkt(9S) structure pointed to by pkt.

```
void makecom_g5(struct scsi_pkt *pkt,
     struct scsi_device *devp, int flag, int cmd,
     int addr, int cnt);
```

makecom_g5(9F) formulates a group 5 SCSI command for the target device denoted by devp in the scsi_pkt(9S) structure pointed to by pkt.

```
int scsi_abort(struct scsi_address *ap,
     struct scsi_pkt *pkt);
```

scsi_abort(9F) cancels the command encoded in the scsi_pkt(9S) structure pointed to by pkt at the SCSI address denoted by ap. To indicate the current target, pass in ap the sd_address field of the scsi_device(9S) structure for the target. To abort the current command, pass NULL for pkt.

```
struct buf *scsi_alloc_consistent_buf(
     struct scsi_address *ap, struct buf *bp,
     size_t datalen, u_int bflags,
     int (*callback)(caddr_t), caddr_t arg);
```

scsi_alloc_consistent_buf(9F) allocates a buffer header and the associated data buffer for DMA transfer. This buffer is allocated from the IOPB space, which is considered consistent memory. If bp is NULL, a new buffer header is allocated using getrbuf(9F). If datalen is nonzero, a new buffer will be allocated using ddi_dma_mem_alloc(9F).

If callback is not NULL_FUNC and the requested DMA resources are not immediately available, the function pointed to by callback will be called when resources may have become available. callback can call scsi_alloc_consistent_buf(9F) again. If callback is SLEEP_FUNC, scsi_alloc_consistent_buf(9F) might block, waiting for resources.

```
char *scsi_cname(u_char cmd, char **cmdvec);
```

scsi_cname(9F) searches for the command code *cmd* in the command vector cmdvec, and returns the command name. Each string in cmdvec starts with a one-character command code, followed by the name of the command. To use scsi_cname(9F), the driver must define a command vector that contains strings of this kind for all the SCSI commands it supports.

```
struct scsi_pkt *scsi_dmaget(struct scsi_pkt *pkt,
     opaque_t dmatoken, int (*callback)(void));
```

scsi_dmaget(9F) allocates resources for an existing scsi_pkt(9S) structure pointed to by pkt. Pass in dmatoken a pointer to the buf(9S) structure that encodes original I/O request.

If callback is not NULL_FUNC and the requested DMA resources are not immediately available, the function pointed to by callback will be called when resources may have become available. callback can call scsi_dmaget(9F) again. If callback is SLEEP_FUNC, scsi_dmaget(9F) might block, waiting for resources.

char *scsi_dname(int dtype);

scsi_dname(9F) decodes the device type code dtype found in the INQUIRY data and returns a character string denoting this device type.

void scsi_free_consistent_buf(struct buf *bp);

scsi_free_consistent_buf(9F) frees a buffer header and consistent data buffer that was previously allocated using scsi_alloc_consistent_buf(9F).

int scsi_hba_attach_setup(dev_info_t *dip, ddi_dma_attr_t *hba_dma_attr, scsi_hba_tran_t *hba_tran, int hba_flags);

scsi_hba_attach_setup(9F) registers the DMA attributes hba_dma_attr and the transport vectors hba_tran of each instance of the HBA device defined by dip. The HBA driver can pass different DMA attributes, and transport vectors for each instance of the device, as necessary, to support any constraints imposed by the HBA itself.

scsi_hba_attach_setup(9F) use the dev_bus_ops field in the dev_ops(9S) structure. The HBA driver should initialize this field to NULL before calling scsi_hba_attach_setup(9F).

int scsi_hba_detach(dev_info_t *dip);

scsi_hba_detach() removes the reference to the DMA attributes structure and the transport vector for the given instance of an HBA driver.

int scsi_ifgetcap(struct scsi_address *ap, char *cap, int whom);

scsi_ifgetcap(9F) returns the current value of the host adapter capability denoted by cap for the host adapter servicing the target at the SCSI address pointed to by ap. See the manual page for a list of supported capabilities. whom indicates whether the capability applies only to the target at the specified SCSI address, or to all targets serviced by the host adapter.

`int scsi_ifsetcap(struct scsi_address *ap, char *cap, int value, int whom);`

```
int scsi_ifsetcap(struct scsi_address *ap,
     char *cap, int value, int whom);
```

`scsi_ifsetcap`(9F) sets the current value of the host adapter capability denoted by `cap`, for the host adapter servicing the target at the SCSI address pointed to by `ap`, to `value`. See the manual page for a list of supported capabilities. `whom` indicates whether the capability applies only to the target at the specified SCSI address, or to all targets serviced by the host adapter.

```
struct scsi_pkt *scsi_init_pkt(
     struct scsi_address *ap, struct scsi_pkt *pktp,
     struct buf *bp, int cmdlen, int statuslen,
     int privatelen, int flags,
     int (*callback)(caddr_t), caddr_t arg);
```

`scsi_init_pkt`(9F) requests the transport layer to allocate a command packet for commands and, possibly, data transfers. If `pktp` is `NULL`, a new `scsi_pkt`(9S) is allocated. If `bp` is non-`NULL` and contains a valid byte count, the `buf`(9S) structure is set up for DMA transfer. If `bp` was allocated by `scsi_alloc_consistent_buf`(9F), the `PKT_CONSISTENT` flag must be set. If `privatelen` is set, additional space is allocated for the `pkt_private` area of the `scsi_pkt`(9S) structure; otherwise, `pkt_private` is a pointer that is typically used to store the `bp` during execution of the command. The `flags` are set in the command portion of the `scsi_pkt`(9S) structure.

If `callback` is not `NULL_FUNC` and the requested DMA resources are not immediately available, the function pointed to by `callback` will be called when resources may have become available. `callback` can call `scsi_init_pkt`(9F) again. If `callback` is `SLEEP_FUNC`, `scsi_init_pkt`(9F) might block, waiting for resources.

```
char *scsi_mname(u_char msg);
```

`scsi_mname`(9F) decodes the SCSI message code `msg` and returns the corresponding message string.

int scsi_poll(struct scsi_pkt *pkt);

scsi_poll(9F) transports the command packet pointed to by pkt to the host adapter driver for execution and waits for it to complete before it returns. Use scsi_poll(9F) sparingly and only for commands that must execute synchronously.

int scsi_probe(struct scsi_device *devp, int (*callback)(void *));

scsi_probe(9F) determines whether a target or lun is present and sets up the scsi_device(9S) structure with inquiry data. scsi_probe(9F) uses the SCSI INQUIRY command to test if the device exists. It may retry the INQUIRY command as appropriate. If scsi_probe(9F) is successful, it will fill in the scsi_inquiry(9S) structure pointed to by the sd_inq member of the scsi_device(9S) structure, and return SCSI_PROBE_EXISTS.

If callback is not NULL_FUNC and necessary resources are not immediately available, the function pointed to by callback will be called when resources may have become available. If callback is SLEEP_FUNC, scsi_probe(9F) might block, waiting for resources.

int scsi_reset(struct scsi_address *ap, int level);

scsi_reset(9F) requests the host adapter driver to reset the target at the SCSI address pointed to by ap if level is RESET_TARGET. If level is RESET_ALL, the entire SCSI bus is reset.

char *scsi_rname(u_char reason);

scsi_rname(9F) decodes the packet completion reason code reason, and returns the corresponding reason string.

char *scsi_sname(u_char sense_key);

scsi_sname(9F) decodes the SCSI sense key sense_key, and returns the corresponding sense key string.

int scsi_transport(struct scsi_pkt *pkt);

scsi_transport(9F) requests the host adapter driver to schedule the command packet pointed to by pkt for execution. Use scsi_transport(9F) to issue most SCSI commands. scsi_poll(9F) may be used to issue synchronous commands.

void scsi_unprobe(struct scsi_device *devp);

scsi_unprobe(9F) is used to free any resources that were allocated on the driver's behalf during scsi_probe(9F).

Soft State Management

These interfaces comprise the soft-state structure allocator, a facility that simplifies the management of state structures for driver instances. For best results, use these routines to keep track of per-instance data.

int ddi_soft_state_init(void **state_p, size_t size, size_t n_items);

ddi_soft_state_init(9F) sets up the soft-state allocator to keep track of soft-state structures for all device instances. state_p points a pointer to an opaque object that keeps track of the soft-state structures.

void ddi_soft_state_fini(void **state_p);

ddi_soft_state_fini(9F) is the inverse operation to ddi_soft_state_init(9F). state_p points a pointer to an opaque object that keeps track of the soft-state structures.

int ddi_soft_state_zalloc(void *state, int item);

ddi_soft_state_zalloc(9F) allocates and zeroes a new instance of a soft-state structure. statep points to an opaque object that keeps track of the soft-state structures.

void *ddi_get_soft_state(void *state, int item);

`ddi_get_soft_state`(9F) returns a pointer to the soft-state structure for the device instance `item`. `statep` points to an opaque object that keeps track of the soft-state structures.

void ddi_soft_state_free(void *state, int item);

`ddi_soft_state_free`(9F) releases the resources associated with the soft-state structure for `item`. `statep` points to an opaque object that keeps track of the soft-state structures.

String Manipulation

These interfaces are generic string manipulation utilities similar to, and in most cases identical to the routines of the same names defined in the standard C library used by application programmers.

int stoi(char **str);

`stoi`(9F) converts the ASCII decimal numeric string pointed to by `*str` to an integer and returns the integer. `*str` is updated to point to the last character examined.

void numtos(unsigned long num, char *s);

`numtos`(9F) converts the integer `num` to an ASCII decimal string and copies the string to the location pointed to by `s`. The driver must provide the storage for the string `s` and ensure that it can contain the result.

char *strchr(const char *str, int chr);

`strchr`(9F) returns a pointer to the first occurrence of the character `chr` in the string pointed to by `str`, or `NULL`, if `chr` is not found in the string.

int strcmp(const char *s1, const char *s2);

`strcmp`(9F) compares two null-terminated character strings. It returns zero if they are identical; otherwise, it returns a nonzero value.

int strncmp(const char *s1, const char *s2, size_t n);

`strncmp`(9F) compares the first `n` characters of the two strings. It returns zero if these characters are identical; otherwise, it returns a nonzero value.

char *strcpy(char *dst, const char *srs);

`strcpy`(9F) copies the character string pointed to by `srs` to the location pointed to by `dst`. The driver must provide storage for the string `dst` and ensure that it is long enough.

char *strncpy(char *dst, const char *srs, size_t n);

`strncpy`(9F) copies `n` characters from the string pointed to by `srs` to the string pointed to by `dst`. The driver must provide storage for the string `dst` and ensure that it is long enough.

size_t strlen(const char *sp);

`strlen`(9F) returns the length of the character string pointed to by `sp`, not including the null-termination character.

System Information

These interfaces return current information about the system, such as the root node of the system `dev_info` tree, and the values of certain system-wide parameters.

dev_info_t *ddi_root_node(void);

`ddi_root_node`(9F) returns a pointer to the root node of the system `dev_info` tree. Device drivers rarely use this.

int drv_getparm(unsigned int parm, void *valuep);

`drv_getparm`(9F) retrieves the value of the system parameter `parm` and returns that value in the location pointed to by `valuep`. See the manual page for a list of possible parameters.

Thread Synchronization

These interfaces enable a device to exploit multiple CPUs on multiprocessor machines. They prevent the corruption of data by simultaneous access by more than one thread. The mechanisms for thread synchronization are mutual exclusion locks (mutexes), condition variables, readers / writer locks, and semaphores.

void cv_init(kcondvar_t *cvp, char *name, kcv_type_t type, void *arg);

`cv_init`(9F) prepares the condition variable pointed to by *cvp* for use. `CV_DRIVER` should be specified for `type`.

void cv_destroy(kcondvar_t *cvp);

`cv_destroy`(9F) releases the resources associated with the condition variable pointed to by `cvp`.

void cv_wait(kcondvar_t *cvp, kmutex_t *mp);

`cv_wait`(9F) must be called while holding the mutex pointed to by `mp`. `cv_wait`(9F) releases the mutex and blocks until a call is made to `cv_signal`(9F) or `cv_broadcast`(9F) for the condition variable pointed to by *cvp*. `cv_wait`(9F) then reacquires the mutex and returns.

Use `cv_wait`(9F) to block on a condition that may take a while to change.

void cv_signal(kcondvar_t *cvp);

`cv_signal`(9F) unblocks one `cv_wait`(9F) call that is blocked on the condition variable pointed to by `cvp`. Call `cv_signal`(9F) when the condition that `cv_wait`(9F) is waiting for becomes true. To unblock all threads blocked on this condition variable, use `cv_broadcast`(9F).

void cv_broadcast(kcondvar_t *cvp);

`cv_broadcast`(9F) unblocks all threads that are blocked on the condition variable pointed to by `cvp`. To unblock only one thread, use `cv_signal`(9F).

int cv_wait_sig(kcondvar_t *cvp, kmutex_t *mp);

cv_wait_sig(9F) is like cv_wait(9F), but if the calling thread receives a signal while cv_wait_sig(9F) is blocked, cv_wait_sig(9F) immediately reacquires the mutex and returns zero.

int cv_timedwait(kcondvar_t *cvp, kmutex_t *mp, clock_t timeout);

cv_timedwait(9F) is like cv_wait(9F), but it returns -1 at time *timeout* if the condition has not occurred. timeout is given as a number of clock ticks since the last reboot. drv_usectohz(9F) converts microseconds, a platform-independent time, to clock ticks.

int cv_timedwait_sig(kcondvar_t *cvp, kmutex_t *mp, clock_t timeout);

cv_timedwait_sig(9F) is like cv_timedwait(9F) and cv_wait_sig(9F), except that it returns -1 at time *timeout* if the condition has not occurred. If the calling thread receives a signal while cv_timedwait_sig(9F) is blocked, cv_timedwait_sig(9F) immediately returns zero. In all cases, cv_timedwait_sig(9F) reacquires the mutex before returning.

void mutex_init(kmutex_t *mp, char *name, kmutex_type_t type, void *arg);

mutex_init(9F) prepares the mutual exclusion lock pointed to by mp for use. MUTEX_DRIVER should be specified for type, and pass an interrupt block cookie of type ddi_iblock_cookie_t for arg. The interrupt block cookie is returned by ddi_get_iblock_cookie(9F).

void mutex_enter(kmutex_t *mp);

mutex_enter(9F) acquires the mutual exclusion lock pointed to by mp. If another thread holds the mutex, mutex_enter(9F) will either block or spin, waiting for the mutex to become available.

Mutexes are not reentrant; if a thread calls mutex_enter(9F) on a mutex it already holds, the system will panic.

mp is assumed to protect a certain set of data, often a single data structure, and all driver threads accessing those data must first acquire the mutex by calling mutex_enter(9F). This is accomplished by mutual agreement and consistency among all driver code paths that access the data in question; mutex_enter(9F) in no way prevents other threads from accessing the data. It is only when all driver code paths agree to acquire the mutex before accessing the data that the data are safe.

void mutex_exit(kmutex_t *mp);

mutex_exit(9F) releases the mutual exclusion lock pointed to by mp.

void mutex_destroy(kmutex_t *mp);

mutex_destroy(9F) releases the resources associated with the mutual exclusion lock pointed to by mp.

int mutex_owned(kmutex_t *mp);

mutex_owned(9F) returns nonzero if the mutual exclusion lock pointed to by mp is currently held; otherwise, it returns zero. Use mutex_owned(9F) *only* in an expression used in ASSERT(9F).

int mutex_tryenter(kmutex_t *mp);

mutex_tryenter(9F) is similar to mutex_enter(9F), but it does not block waiting for the mutex to become available. If the mutex is held by another thread, mutex_tryenter(9F) returns zero. Otherwise, mutex_tryenter(9F) acquires the mutex and returns nonzero.

void rw_destroy(krwlock_t *rwlp);

rw_destroy(9F) releases the resources associated with the readers or writer lock pointed to by rwlp.

`void rw_downgrade(krwlock_t *rwlp);`

If the calling thread holds the lock pointed to by `rwlp` for writing, `rw_downgrade`(9F) releases the lock for writing, but retains the lock for reading. This allows other readers to acquire the lock unless a thread is waiting to acquire the lock for writing.

`void rw_enter(krwlock_t *rwlp, krw_t enter_type);`

If `enter_type` is `RW_READER`, `rw_enter`(9F) acquires the lock pointed to by `rwlp` for reading if no thread currently holds the lock for writing, and if no thread is waiting to acquire the lock for writing. Otherwise, `rw_enter`(9F) blocks.

If `enter_type` is `RW_WRITER`, `rw_enter`(9F) acquires the lock for writing if no thread holds the lock for reading or writing, and if no other thread is waiting to acquire the lock for writing. Otherwise, `rw_enter`(9F) blocks.

`void rw_exit(krwlock_t *rwlp);`

`rw_exit`(9F) releases the lock pointed to by `rwlp`.

`void rw_init(krwlock_t *rwlp, char *name, krw_type_t type, void *arg);`

`rw_init`(9F) prepares the readers or writer lock pointed to by `rwlp` for use. `RW_DRIVER` should be passed for `type`.

`int rw_read_locked(krwlock_t *rwlp);`

The lock pointed to by `rwlp` must be held during a call to `rw_read_locked`(9F). If the calling thread holds the lock for reading, `rw_read_locked`(9F) returns a nonzero value. If the calling thread holds the lock for writing, `rw_read_locked`(9F) returns zero.

`int rw_tryenter(krwlock_t *rwlp, krw_t enter_type);`

`rw_tryenter`(9F) attempts to enter the lock, like `rw_enter`(9F), but never blocks. It returns a nonzero value if the lock was successfully entered, and zero otherwise.

int rw_tryupgrade(krwlock_t *rwlp);

If the calling thread holds the lock pointed to by `rwlp` for reading, `rw_tryupgrade`(9F) acquires the lock for writing if no other threads hold the lock, and no thread is waiting to acquire the lock for writing. If `rw_tryupgrade`(9F) cannot acquire the lock for writing, it returns zero.

void sema_init(ksema_t *sp, u_int val, char *name, ksema_type_t type, void *arg);

`sema_init`(9F) prepares the semaphore pointed to by `sp` for use. `SEMA_DRIVER` should be passed for `type`. `count` is the initial count for the semaphore, which usually should be `1` or `0`. In almost all cases, drivers should pass 1 for `count`.

void sema_destroy(ksema_t *sp);

`sema_destroy`(9F) releases the resources associated with the semaphore pointed to by `sp`.

void sema_p(ksema_t *sp);

`sema_p`(9F) acquires the semaphore pointed to by `sp` by decrementing the counter if its value is greater than zero. If the semaphore counter is zero, `sema_p`(9F) blocks, waiting to acquire the semaphore.

int sema_p_sig(ksema_t *sp);

`sema_p_sig`(9F) is like `sema_p`(9F), except that if the calling thread has a signal pending, and the semaphore counter is zero, `sema_p_sig`(9F) returns zero without blocking.

void sema_v(ksema_t *sp);

`sema_v`(9F) releases the semaphore pointed to by `sp` by incrementing its counter.

`int sema_tryp(ksema_t *sp);`

`sema_tryp`(9F) is similar to `sema_p`(9F), but if the semaphore counter is zero, `sema_tryp`(9F) immediately returns zero.

Timing

These are delay and time value conversion routines.

`void delay(clock_t ticks);`

`delay`(9F) blocks the calling thread for at least `ticks` clock ticks (using `timeout`(9F)).

`void drv_usecwait(clock_t microsecs);`

`drv_usecwait`(9F) busy-waits for `microsecs` microseconds.

`clock_t drv_hztousec(clock_t hertz);`

`drv_hztousec`(9F) converts `hertz` clock ticks to microseconds, and returns the number of microseconds.

`clock_t drv_usectohz(clock_t microsecs);`

`drv_usectohz`(9F) converts `microsecs` microseconds to clock ticks, and returns the number of clock ticks.

uio*(9S) Handling*

These interfaces all handle moving data using the uio(9S) data structure.

int uiomove(caddr_t address, size_t nbytes,
enum uio_rw rwflag, struct uio *uio_p);

uiomove(9F) copies data between the address and the uio(9S) structure pointed to by uio_p. If rwflag is UIO_READ, data are transferred from address to a data buffer associated with the uio(9S) structure. If rwflag is UIO_WRITE, data are transferred from a data buffer associated with the uio(9S) structure to address.

int ureadc(int c, uio_t *uio_p);

ureadc(9F) appends the character c to a data buffer associated with the uio(9S) structure pointed to by uio_p.

int uwritec(uio_t *uio_p);

uwritec(9F) removes a character from a data buffer associated with the uio(9S) structure pointed to by uio_p, and returns the character.

Utility Functions

These interfaces are miscellaneous utilities that the driver may use.

void ASSERT(EX);

The ASSERT(9F) macro does nothing if EX evaluates to nonzero. If EX evaluates to zero, ASSERT(9F) panics the system. ASSERT(9F) is useful in debugging a driver, since it can be used to stop the system when an unexpected situation is encountered, such as an erroneously NULL pointer.

ASSERT(9F) exhibits this behavior only when the DEBUG preprocessor symbol is defined.

```
int bcmp(const void *s1, const void *s2, size_t len);
```

`bcmp`(9F) compares `len` bytes of the byte arrays starting at `s1` and `s2`. If these bytes are identical, `bcmp`(9F) returns zero. Otherwise, `bcmp`(9F) returns a nonzero value.

```
unsigned long btop(unsigned long numbytes);
```

`btop`(9F) converts a size `n` expressed in bytes to a size expressed in terms of the main system MMU page size, rounded down to the nearest page.

```
unsigned long btopr(unsigned long numbytes);
```

`btopr`(9F) converts a size `n` expressed in bytes to a size expressed in terms of the main system MMU page size, rounded up to the nearest page.

```
void bzero(void *addr, size_t bytes);
```

`bzero`(9F) zeroes `bytes` starting at `addr`.

```
unsigned long ddi_btop(dev_info_t *dip,
     unsigned long bytes);
```

`ddi_btop`(9F) converts a size expressed in bytes to a size expressed in terms of the parent bus nexus page size, rounded down to the nearest page.

```
unsigned long ddi_btopr(dev_info_t *dip,
     unsigned long bytes);
```

`ddi_btopr`(9F) converts a size expressed in bytes to a size expressed in terms of the parent bus nexus page size, rounded up to the nearest page.

```
unsigned long ddi_ptob(dev_info_t *dip,
     unsigned long pages);
```

`ddi_ptob`(9F) converts a size expressed in terms of the parent bus nexus page size to a size expressed in bytes.

`int ddi_ffs(long mask);`

`ddi_ffs`(9F) returns the number of the first (least-significant) bit set in `mask`.

`int ddi_fls(long mask);`

`ddi_fls`(9F) returns the number of the last (most-significant) bit set in `mask`.

`caddr_t ddi_get_driver_private(dev_info_t *dip);`

`ddi_get_driver_private`(9F) returns a pointer to the data stored in the driver-private area of the `dev_info` node identified by `dip`.

`void ddi_set_driver_private(dev_info_t *dip, caddr_t data);`

```
void ddi_set_driver_private(dev_info_t *dip,
     caddr_t data);
```

`ddi_set_driver_private`(9F) sets the driver-private data of the `dev_info` node identified by `dip` to the value `data`.

```
int ddi_peek8(dev_info_t *dip, int8_t *addr,
     int8_t *valuep);
```

`ddi_peek8`(9F) reads 8-bit from the address `addr` to the location pointed to by `valuep`.

```
int ddi_peek16(dev_info_t *dip, int16_t *addr,
     int16_t *valuep);
```

`ddi_peek16`(9F) reads 16-bit from the address `addr` to the location pointed to by `valuep`.

```
int ddi_peek32(dev_info_t *dip, int32_t *addr,
     int32_t *valuep);
```

`ddi_peek32`(9F) reads 32-bit from the address `addr` to the location pointed to by `valuep`.

int ddi_peek64(dev_info_t *dip, int64_t *addr,
int64_t *valuep);

ddi_peek64(9F) reads 64-bit from the address addr to the location pointed to by valuep.

int ddi_poke8(dev_info_t *dip, int8_t *addr,
int8_t value);

ddi_poke8(9F) writes the data in value to the address addr.

int ddi_poke16(dev_info_t *dip, int16_t *addr,
int16_t value);

ddi_poke16(9F) writes the data in value to the address addr.

int ddi_poke32(dev_info_t *dip, int32_t *addr,
int32_t value);

ddi_poke32(9F) writes the data in value to the address addr.

int ddi_poke64(dev_info_t *dip, int64_t *addr,
int64_t value);

ddi_poke64(9F) writes the data in value to the address addr.

major_t getmajor(dev_t dev);

getmajor(9F) decodes the major device number from dev and returns it.

minor_t getminor(dev_t dev);

getminor(9F) decodes the minor device number from dev and returns it.

dev_t makedevice(major_t majnum, minor_t minnum);

makedevice(9F) constructs and returns a device number of type dev_t from the major device number majnum and the minor device number minnum.

`int max(int int1, int int2);`

`max`(9F) returns the larger of the integers `int1` and `int2`.

`int min(int int1, int int2);`

`min`(9F) returns the lesser of the integers `int1` and `int2`.

`int nodev();`

`nodev`(9F) returns an error. Use `nodev`(9F) as the entry in the `cb_ops`(9S) structure for any entry point for which the driver must always fail.

`int nulldev();`

`nulldev`(9F) always returns zero, a return which for many entry points implies success. See the manual pages in Section 9 of the *Solaris 2.6 Reference Manual* to learn about entry point return semantics.

`unsigned long ptob(unsigned long numpages);`

`ptob`(9F) converts a size expressed in terms of the main system memory management unit (MMU) page size to a size expressed in bytes.

Sample Driver Source Code Listings D

This chapter lists all the sample driver source code available with the DDK. Sample driver names and driver descriptions are provided.

Table D-1 Sample Driver Source Code Listings

Subdirectory	Driver Description
`sst`	Simple SCSI target driver
`bst`	Block SCSI target driver
`cgsix`	Graphics device driver
`psli`	Data link provider interface (DLPI) network driver template
`pio`	Programmed I/O template driver
`dma`	DMA driver template
`ramdisk`	Simple RAM disk pseudo-device driver
`ae`	PCI DLPI network device – AMD PCnet
`p9000`	PCI frame buffer – Diamond Viper/Weitek P9000
`pvip`	PCI frame buffer – Diamond Viper/Weitek P9000
`pcepp`	PC Card parallel port driver
`pcsram`	PC Card simple memory driver
`tblt`	STREAMS input device
`isp`	SBus and PCI SCSI HBA driver QLogics isp 1000/1020

Driver Code Layout Structure E

This appendix presents the code layout structure of a typical driver. Sample structures and prototypes are displayed for a common device driver.

The code for a device driver is usually divided into the following files:

- Header files (`.h` files)
- Source files (`.c` files)
- Optional configuration file (`driver.conf` file)

Header Files

Header files define data structures specific to the device (such as a structure representing the device registers), data structures defined by the driver for maintaining state information, defined constants (such as those representing the bits of the device registers), and macros (such as those defining the static mapping between the minor device number and the instance number).

Some of this information, such as the state structure, may only be needed by the device driver. This information should go in *private* header files that are only included by the device driver itself.

Any information that an application might require, such as the I/O control commands, should be in *public* header files. These are included by the driver and any applications that need information about the device.

There is no standard for naming private and public files. One possible convention is to name the private header file `xximpl.h` and the public header file `xxio.h`. Code Example E-1 and Code Example E-2 show the layout of these headers.

Code Example E-1 `xximpl.h` Header File

```
/* xximpl.h */
struct device_reg {
     /* fields */
};
/* #define bits of the device registers...*/
struct xxstate {
    /* fields */
};
/* related #define statements */
```

Code Example E-2 `xxio.h` Header File

```
/* xxio.h */
struct xxioctlreq {
    /* fields */
};
/* etc. */
#define XXIOC  (‘b’ << 8)
#define XXIOCTL_1 (XXIOC | 1)        /* description */
#define XXIOCTL_2 (XXIOC | 2)        /* description */
```

xx.c Files

A `.c` file for a device driver contains the data declarations and the code for the entry points of the driver. It contains the `#include` statements the driver needs, declares `extern` references, declares local data, sets up the `cb_ops` and `dev_ops` structures, declares and initializes the module configuration section, makes any other necessary declarations, and defines the driver entry points. The following sections describe these driver components. Code Example E-3 shows the layout of an *xx*`.c` file.

Code Example E-3 *xx*`.c` File

```
/* xx.c */

#include "xximpl.h"
#include "xxio.h"
#include <sys/ddi.h>      /* must include these two files */
#include <sys/sunddi.h>   /* and they must be the last system */
                          /* includes */

/* forward declaration of entry points */

/* static declarations of cb_ops entry point functions...*/

static struct cb_ops xx_cb_ops = {
    /* set cb_ops fields */
};

/* static declarations of dev_ops entry point functions */
static struct dev_ops xx_ops = {
    /* set dev_ops fields*/
};

/* declare and initialize the module configuration section */
static struct modldrv modldrv = {
    /* set modldrv fields */
};

static struct modlinkage modlinkage = {
    /* set modlinkage fields */
};

int
_init(void)
{
    /* definition */
}

int
_info(struct modinfo *modinfop)
{
    /* definition */
}

int
_fini(void)
{
    /* definition */
}
```

```
static int
xxprobe(dev_info_t *dip)
{
    /* definition */
}
static int
xxattach(dev_info_t *dip, ddi_attach_cmd_t cmd)
{
    /* definition */
}
static int
xxdetach(dev_info_t *dip, ddi_detach_cmd_t cmd)
{
    /* definition */
}
static int
xxgetinfo(dev_info_t *dip, ddi_info_cmd_t cmd, void *arg,
   void **result)
{
    /* definition */
}
static int
xxopen(dev_t *devp, int flag, int otyp, cred_t *credp)
{
    /* definition */
}
static int
xxclose(dev_t dev, int flag, int otyp, cred_t *credp)
{
    /* definition */
}
static int
xxstrategy(struct buf *bp)
{
    /* definition */
}

/* for character-oriented devices */
static int
xxread(dev_t dev, struct uio *uiop, cred_t *credp)
{
    /* definition */
}
```

```
/* for asynchronous I/O */
static int
xxaread(dev_t dev, struct aio_req *aiop, cred_t *cred_p)
{
    /* definition */
}
static int
xxwrite(dev_t dev, struct uio *uiop, cred_t *credp)
{
    /* definition */
}

/* for asynchronous I/O */
static int
xxawrite(dev_t dev, struct aio_req *aiop, cred_t *cred_p)
{
    /* definition */
}
static int
xxioctl(dev_t dev, int cmd, intptr_t arg, int mode, cred_t *credp,
    int *rvalp)
{
    /* definition */
}

/* for memory-mapped character-oriented devices */
static int
xxdevmap(dev_t dev, devmap_cookie_t dhp, offset_t off, size_t len,
size_t *maplen, uint_t model)
{
    /* definition */
}

/* for support of the poll(2) system call */
static int
xxchpoll(dev_t dev, short events, int anyyet, short *reventsp,
    struct pollhead **phpp)
{
    /* definition */
}
```

```
/* for drivers needing a xxprop_op routine */
static int
xxprop_op(dev_t dev, dev_info_t *dip, ddi_prop_op_t prop_op,
    int mod_flags, char *name, caddr_t valuep, int *lengthp)
{
    /* definition */
}
```

driver .conf Files

See `driver.conf`(4), `sbus`(4), `pci`(4). `isa`(4), `eisa`(4), and `vme`(4) for more information.

Making a Device Driver 64-Bit Ready F

In future releases, the Solaris kernel will be capable of running in 64-bit mode on suitable hardware and will support both 32-bit and 64-bit applications. This chapter is a guide to updating a device driver to run in a 64-bit environment.

The information in this chapter is being provided in advance of the 64-bit Solaris operating system so that driver writers will have sufficient time to develop 64-bit capable drivers before actually running the 64-bit kernel. For Solaris 2.6, the Solaris operating system is 32 bits only.

When the 64-bit operating system becomes available, applications that need 64-bit capabilities may need to be updated to run on 64-bit Solaris. Device drivers will require at least minimal conversion to run in the 64-bit kernel. For those applications that continue to use 32-bit Solaris on 64-bit hardware, 32-bit device drivers will continue to work without recompilation. The information in this chapter will enable drivers to be written to use common code for the 32-bit and 64-bit environments.

How 64-Bit Drivers Differ From 32-Bit Drivers

Before starting to convert a device driver for the 64-bit environment, it is useful to understand how the 32-bit environment differs from the 64-bit environment. In particular, it is important to become familiar with the C language data type models ILP32 and LP64, and to be aware of driver-specific issues.

F

C Language Data Type Models: LP64 and ILP32

The current 32-bit Solaris C language data model, called ILP32, defines `int`, `long`, and pointers as 32 bits, `short` as 16 bits, and `char` as 8 bits. The C data type model chosen for the 64-bit operating system is LP64. This data model defines `long` and pointers as 64 bits, `int` as 32 bits, `short` as 16 bits, and `char` as 8 bits.

In LP64, only longs and pointers change size; the other C data types stay the same size as in the ILP32 model. Table F-1 lists the standard C data types and their corresponding sizes in bits for ILP32 and LP64.

Table F-1 C Data Type Sizes

C Type	**ILP32**	**LP64**
`char`	8	8
`short`	16	16
`int`	32	32
`long`	**32**	**64**
`long long`	64	64
`pointer`	**32**	**64**

In addition to the data model changes, some system-derived types, such as `size_t`, have been expanded to be 64-bit quantities when compiled in the 64-bit environment.

Potential Problems to Avoid

To run in a 64-bit environment, drivers may need to be converted to use the LP64 data model. There are several potential problem areas caused by the change in size of `long` and pointers:

1. Source code that assumes that `int`, `long`, and pointer types are the same size will be incorrect for 64-bit Solaris.
2. Type casts may need updating, since the underlying data types may have changed.

3. Data structures containing `long` types and pointers will need to be checked for different offset values than expected. This is caused by alignment differences that occur when `long` and pointer fields grow to 64 bits.

Overview of Driver-Specific Issues

In addition to general code cleanup to support the data model changes for LP64, driver writers have several driver-specific issues to consider:

- In the 64-bit environment, new common access functions that use fixed-width data types have been provided so that drivers can clearly specify the size of the data they are requesting. Drivers that use the old common access routines (for example, `ddi_getw()`) will need to be changed.
- A driver may need to be updated to support data sharing between 64-bit drivers and 32-bit applications. The `ioctl`(9E), `devmap`(9E), and `mmap`(9E) entry points must be written so that the driver can determine whether the data model of the application is the same as that of the kernel. If the data models differ, data structures may need to be adjusted. This usually means converting a 64-bit a driver structure to fit in a 32-bit application structure.

General Conversion Steps

The sections below provide information on converting drivers to run in a 64-bit environment. Driver writers may need to do one or more of the following:

- Convert driver code to be LP64 clean
- Update driver data structures to preserve 32-bit data in register layouts
- Check use of derived types that change size in ILP32 and LP64
- Change DDI common access functions to use the new fixed-width versions
- Modify the driver entry points that handle data sharing

Convert Driver Code to Be 64-Bit Clean

As a first step in converting a device driver to run in a 64-bit kernel, make the driver 64-bit clean by converting to the LP64 data model. For example, make sure that the driver’s use of `long` variables remains consistent between data models.

To enable source code to be both 32-bit and 64-bit safe, the Solaris 2.6 system provides new fixed-width integer types, derived types, constants, and macros in the files `<sys/types.h>` and `<sys/inttypes.h>`. The fixed-width types include both signed and unsigned integer types such as `int8_t`, `uint8_t`, `uint32_t`, `uint64_t`, as well as constants that specify their limits.

Note the following when converting to LP64:

1. System-derived types, such as `size_t`, should be used for type declarations whenever possible.

   Using derived types will help make driver code 32-bit and 64-bit safe, since the derived types themselves must be safe for both IPL32 and LP64 data models. In addition, it is a good idea to use system-derived types for definitions to allow for future change.

2. Fixed-width types, such as `uint32_t`, should be used where appropriate to clearly specify type declarations.

   Fixed-width integer types are useful for representing explicit sizes of binary data structures or hardware registers, while fundamental C language data types, such as `int`, can still be used for loop counters or file descriptors. In particular, make sure that use of variables of type `long` remains accurate. As a `long` is 64 bits in LP64, change variables that represent 32-bit data and that are currently defined as `long` to fixed-width 32-bit types, such as `uint32_t`.

3. The new derived types `uintptr_t` or `intptr_t` should be used as the integral type for pointers.

   Pointers are 64 bits in size in the Solaris 64-bit environment. Although pointers could be recast to `long`, the new derived system types should be used instead, particularly when pointers are used to do address arithmetic or alignment. In addition, check for code that assumes that `int` and pointer variables are the same size, and use `uintptr_t` instead of `int` for variables that are cast to pointers. For example, change:

   ```
   char *p;
   p = (char *)((int)p & PAGEOFFSET);
   ```

   to:

   ```
   p = (char *)((uintptr_t)p & PAGEOFFSET);
   ```

The new fixed width data types in `<sys/inttypes.h>` are included in `<sys/ddi.h>`.

Useful Tools to Check Data Model Conversion

Running driver code through the Sun WorkShop Compiler C 4.2 `lint` utility can help find problems with data models. This version of `lint` provides warnings about potential 64-bit problems. It prints the line number of the problem code and a warning message describing the problem, indicates whether a pointer was involved, and provides information about the size of the data types.

To use `lint` to check for data model conversion problems, use the `-errchk=longptr64` option.

Update Data Structures to Preserve 32-Bit Data in Register Layouts

In the 64-bit data model, data structures that use `long` to define the type of arguments might be incorrect if the argument needs to define a 32-bit quantity. For example, some drivers currently use `long` to define 32-bit fields in a hardware register layout. To make a driver 64-bit safe, update data structures where necessary to use `int32_t` or `uint32_t` instead of `long` for 32-bit data. This preserves the binary layout of 32-bit data structures.

For example, change:

```
struct reg {
    ulong_t    addr;
    uint_t     count;
}
```

to:

```
struct reg {
    uint32_t   addr;
    uint32_t   count;
}
```

Check Use of Derived Types That Change Size Between 32-Bit and 64-Bit Environments

Some system-derived types, such as `size_t`, represent 32-bit quantities in a 32-bit system but represent 64-bit quantities in a 64-bit system. Drivers that use these derived types must pay attention to their use, particularly if they are assigning these values to variables of another derived type, such as a fixed-width type. Examples of derived types that change size are:

- `size_t`
- `intptr_t`
- `daddr_t`

Change Common Access Functions to Fixed-Width Versions

Previously, DDI common access functions specified the size of data in terms of bytes, words, and so on. For example, `ddi_getl`(9F) was used to access 32-bit quantities. This function will not work to access a 32-bit quantity in the 64-bit environment because `long` is now a 64-bit quantity.

In Solaris 2.6, new common access functions that use fixed-width types have been added. These functions have been named to reflect the actual data size. For example, in a 64-bit environment, a driver must use `ddi_get32`(9F) to access 32-bit data rather than `ddi_getl`(9F).

```
uint32_t ddi_get32(ddi_acc_handle_t hdl, uint32_t *dev_addr);
```

To make a device driver 64-bit safe, replace all Common Access functions with the new fixed-width versions.

Table F-2 on page 493 shows a subset of the new common access functions. For a complete list of the new functions, see Appendix B, “Interface Transition List”. For a brief description of the new interfaces, see Appendix C, “Summary of Solaris 2.6 DDI/DKI Services”.

Table F-2 Common Access Functions

Solaris 2.5 Version	Solaris 2.6 Version
`ddi_getb`(9F)	`ddi_get8`(9F)
`ddi_getw`(9F)	`ddi_get16`(9F)
`ddi_getl`(9F)	`ddi_get32`(9F)
`ddi_getll`(9F)	`ddi_get64`(9F)
`ddi_putb`(9F)	`ddi_put8`(9F)
`ddi_putw`(9F)	`ddi_put16`(9F)
`ddi_putl`(9F)	`ddi_put32`(9F)
`ddi_putll`(9F)	`ddi_put64`(9F)

Modify Routines That Handle Data Sharing

If a device driver shares data structures with an application using `ioctl`(9E), `devmap`(9E), or `mmap`(9E), and the driver is recompiled for a 64-bit kernel but the application that uses the interface is a 32-bit program, the binary layout of data structures will be incompatible if they contain long types or pointers.

If a data structure is defined in terms of type `long`, but there is no actual need for 64-bit data items, the data structure should be changed to use fundamental types that remain 32 bits in LP64 (`int` and `unsigned int`) or the new fixed-width 32-bit types in `<sys/inttypes.h>`. In the remaining cases, where the data structures contain pointers or structure fields that need to be `long` (32-bits in an ILP32 kernel and 64-bits in an LP64 kernel), the driver needs to be aware of the different structure shapes for ILP32 and LP64 and determine whether there is a model mismatch between the application and the kernel.

To handle potential data model differences, the `ioctl`(9E), `devmap`(9E) and `mmap`(9E) driver entry points, which are passed arguments from user applications, need to be written to determine whether the argument came from an application using the same data type model as the kernel. The new DDI function `ddi_model_convert_from`(9F) enables drivers to determine this.

ddi_model_convert_from(9F)

This function takes the data type model of the user application as an argument and returns the following values:

- DDI_MODEL_ILP32 – Convert from ILP32 application
- DDI_MODEL_NONE – No conversion needed

DDI_MODEL_NONE is returned if no data conversion is necessary. This is the case when application and driver have the same data model (both are ILP32 or LP64). DDI_MODEL_ILP32 is returned if the driver is compiled to the LP64 data model and is communicating with a 32-bit application. Typically, the code that returns the application data model is conditionally compiled depending on the _MULTI_DATAMODEL macro. This macro is defined by the system when the driver supports multiple data models.

If the driver supports multiple data models, it will switch on the return value of ddi_model_convert_from(9F). The DDI_MODEL_ILP32 case should define a 32-bit version of the structure being passed in. Use ddi_copyin(9F) to copy the structure from user space to the 32-bit version of the structure, and then assign each field in the 32-bit structure to the 64-bit version. Otherwise, the code should be unchanged.

The sections that follow show code examples of the use of ddi_model_convert_from(9F).

ioctl*(9E)*

In a 32-bit system, the ioctl(9E) entry point takes an int as the argument to pass a 32-bit value or user address to the device driver. In a 64-bit system, this argument must handle 64-bit values and addresses. Therefore, the ioctl(9E) function prototype has changed from:

```
int (*cb_ioctl)(dev_t dev, int cmd, int arg, int mode,
                        cred_t *credp, int *rvalp);
```

to:

```
int (*cb_ioctl)(dev_t dev, int cmd, intptr_t arg, int mode,
                        cred_t *credp, int *rvalp);
```

Note that intptr_t arg remains 32-bits when compiled in the ILP32 kernel.

To determine whether there is a model mismatch between the application and the driver, the driver uses the FMODELS mask to determine the model type from the ioctl(9E) mode argument. The following values are passed in mode to identify the application data model:

- FLP64 – Application uses the LP64 data model
- FILP32 – Application uses the ILP32 data model

The driver passes the data model type to ddi_model_convert_from(9F), which determines if adjustments are needed to the application data structures.

Code Example F-1 demonstrates the use of the _MULTI_DATAMODEL macro and the ddi_model_convert_from(9F) function.

Code Example F-1 ioctl(9E)

```
struct passargs {
    int     len;
    caddr_t addr
} pa;

xxioctl(dev_t dev, int cmd, intptr_t arg, int mode, cred_t *credp,
            int *rvalp)
{
    ...
#ifdef _MULTI_DATAMODEL
    switch (ddi_model_convert_from(mode & FMODELS)) {
    case DDI_MODEL_ILP32:
    {
        struct passargs32 {
            int         len;
            uint32_t    *addr;
        } pa32;

        (void) ddi_copyin((void *)arg, &pa32,
                    sizeof (struct passargs32), mode);
        pa.len = pa32.len;
        pa.addr = pa32.address;
        break;
    }
    case DDI_MODEL_NONE:
        (void) ddi_copyin((void *)arg, &pa,
                    sizeof (struct passargs), mode);
            break;
        }
#else /* ! _MULTI_DATAMODEL */
    (void) ddi_copyin((void *)arg, &pa,
                sizeof (struct passargs), mode);
#endif /* ! _MULTI_DATAMODEL */
    do_ioctl(&pa);
    ...
}
```

devmap*(9E)*

To enable a 64-bit driver and a 32-bit application to share memory, the binary layout generated by the 64-bit driver must be the same as consumed by the 32-bit application.

To determine whether there is a model mismatch, `devmap`(9E) uses the `model` parameter to pass the data model type expected by the application. `model` is set to one of the following:

- `DDI_MODEL_ILP32` – Application uses the ILP32 data model
- `DDI_MODEL_LP64` – Application uses the LP64 data model

Code Example F-2 shows the `devmap`(9E) `model` parameter being passed to the `ddi_model_convert_from`(9F) function.

Code Example F-2 `devmap`(9E)

```
struct data {
    int         len;
    caddr_t     addr;
};

xxdevmap(dev_t dev, devmap_cookie_t dhp, offset_t offset,
            size_t len, size_t *maplen, uint_t model);
{
    struct data dtc;  /* local copy for clash resolution */
    struct data *dp = (struct data *)shared_area;

#ifdef _MULTI_DATAMODEL
```

```
    switch (ddi_model_convert_from(model)) {
    case DDI_MODEL_ILP32:
    {
        struct data32 {
            int         len;
            uint32_t    *addr;
        } *da32p;

        da32p = (struct data32 *)shared_area;
        dp = &dtc;
        dp->len = da32p->len;
        dp->address = da32p->address;
        break;
    }
    case DDI_MODEL_NONE:
        break;
    }
#endif  /* _MULTI_DATAMODEL */
    /* continues along using dp */
    ...
}
```

mmap*(9E)*

Because mmap(9E) does not have a parameter that can be used to pass data model information, the driver's mmap(9E) entry point should be written to use the new DDI function ddi_mmap_get_model(9F). This function returns one of the following values to indicate the application's data type model:

- DDI_MODEL_ILP32 – Application expects the ILP32 data model
- DDI_MODEL_ILP64 – Application expects the LP64 data model
- DDI_FAILURE – Function was not called from mmap(9E)

As with ioctl(9E) and devmap(9E), the model bits can be passed to ddi_model_convert_from(9F) to determine whether data conversion is necessary.

Code Example F-3 shows the use of ddi_mmap_get_model(9F).

Code Example F-3 `mmap`(9E)

```
struct data {
    int         len;
    caddr_t     addr
};

xxmmap(dev_t dev, off_t off, int prot)
{
    struct data dtc;  /* local copy for clash resolution */
    struct data *dp = (struct data *)shared_area;

#ifdef _MULTI_DATAMODEL
    switch (ddi_model_convert_from(ddi_mmap_get_model())) {
    case DDI_MODEL_ILP32:
    {
        struct data32 {
            int         len;
            uint32_t    *addr
        } *da32p;

        da32p = (struct data32 *)shared_area;
        dp = &dtc;
        dp->len = da32p->len;
        dp->address = da32p->address;
        break;
    }
    case DDI_MODEL_NONE:
        break;
    }

#endif  /* _MULTI_DATAMODEL */
    /* continues along using dp */
    ...
}
```

Advanced Topics G

This appendix contains a collection of topics. Not all drivers need to be concerned with the issues addressed.

Multithreading

This section supplements the guidelines presented in Chapter 4, “Multithreading,” for writing an *MT-safe driver*, a driver that safely supports multiple threads.

Lock Granularity

Here are some issues to consider when deciding on how many locks to use in a driver:

- The driver should allow as many threads as possible into the driver: this leads to *fine-grained* locking.
- However, it should not spend too much time executing the locking primitives: this approach leads to *coarse-grained* locking.
- Moreover, the code should be simple and maintainable.
- Avoid lock contention for shared data.
- Write re-entrant code wherever possible. This makes it possible for many threads to execute without grabbing *any* locks.
- Use locks to protect the *data* and not the code path.

- Keep in mind the level of concurrency provided by the device; if the controller can only handle one request at a time, there is no point in spending excessive time making the driver handle multiple threads.

A little thought in reorganizing the ordering and types of locks around such data can lead to considerable savings.

Avoiding Unnecessary Locks

To avoid unnecessary locks, note the following:

- Use the MT semantics of the entry points to your advantage.
  If an element of a device's state structure is read-mostly—for example, initialized in `attach( )`, and destroyed in `detach( )`, but only read in other entry points—there is no need to acquire a mutex to read that element of the structure. This might seem obvious, but indiscriminately adding calls to `mutex_enter`(9F) and `mutex_exit`(9F) around every access to such a variable can lead to unnecessary locking overhead.

- Make all entry points re-entrant and reduce the amount of shared data by changing static variables to automatic, or by adding them to your state structure.

Note – Kernel-thread stacks are small (currently 8 Kbytes), so do not allocate large automatic variables, and avoid deep recursion.

Locking Order

When acquiring multiple mutexes, be sure to acquire them in the same order on each code path. For example, mutexes A and B are used to protect two resources in the following ways:

```
Code Path 1         Code Path 2
mutex_enter(&A);    mutex_enter(&B);
    ...                 ...
mutex_enter(&B);    mutex_enter(&A);
    ...                 ...
mutex_exit(&B);     mutex_exit(&A);
    ...                 ...
mutex_exit(&A);     mutex_exit(&B);
```

If thread 1 is executing code path one, and thread two is executing code path 2, the following could occur:

1. Thread one acquires mutex A.
2. Thread two acquires mutex B.
3. Thread one needs mutex B, so it blocks holding mutex A.
4. Thread two needs mutex A, so it blocks holding mutex B.

These threads are now deadlocked. This is hard to track, particularly since the code paths are rarely so straightforward. Also, it doesn't always happen, as it depends on the relative timing of threads 1 and 2.

Scope of a Lock

Experience has shown that it is easier to deal with locks that are either held throughout the execution of a routine, or locks that are both acquired and released in one routine. Avoid nesting like this:

```
static void
xxfoo(...)
{
    mutex_enter(&softc->lock);
    ...
    xxbar();
}
static void
xxbar(...)
{
    ...
    mutex_exit(&softc->lock);
}
```

This example works, but will almost certainly lead to maintenance problems.

If contention is likely in a particular code path, try to hold locks for a short time. In particular, arrange to drop locks before calling kernel routines that might block. For example:

```
    mutex_enter(&softc->lock);
    ...
    softc->foo = bar;
```

```
            softc->thingp = kmem_alloc(sizeof(thing_t), KM_SLEEP);
            ...
            mutex_exit(&softc->lock);
```

This is better coded as:

```
            thingp = kmem_alloc(sizeof(thing_t), KM_SLEEP);
            mutex_enter(&softc->lock);
            ...
            softc->foo = bar;
            softc->thingp = thingp;
            ...
            mutex_exit(&softc->lock);
```

Potential Panics

Here is a set of mutex-related panics:

`panic: recursive mutex_enter. mutex %x caller %x`

Mutexes are not re-entrant by the same thread. If you already own the mutex, you cannot own it again. Doing this leads to this panic.

`panic: mutex_adaptive_exit: mutex not held by thread`

Releasing a mutex that the current thread does not hold causes this panic.

`panic: lock_set: lock held and only one CPU`

This panic only occurs on a uniprocessor, and says that a spin mutex is held and it would spin forever, because there is no other CPU to release it. This could happen because the driver forgot to release the mutex on one code path, or blocked while holding it.

A common cause of this panic is that the device's interrupt is high-level (see `ddi_intr_hilevel`(9F) and `Intro`(9F)), and is calling a routine that blocks the interrupt handler while holding a spin mutex. This is obvious if the driver explicitly calls `cv_wait`(9F), but might not be so if it's blocking while grabbing an adaptive mutex with `mutex_enter`(9F).

Note – In principle, this is only a problem for drivers that operate above lock level.

Sun Disk Device Drivers

Sun disk devices represent an important class of block device drivers. A Sun disk device is one that is supported by disk utility commands such as `format`(1M) and `newfs`(1M).

Disk I/O Controls

Sun disk drivers need to support a minimum set of I/O controls specific to Sun disk drivers. These I/O controls are specified in the `dkio`(7) manual page. Disk I/O controls transfer disk information to or from the device driver. In the case where data is copied out of the driver to the user, `ddi_copyout`(9F) should be used to copy the information into the user's address space. When data is copied to the disk from the user, the `ddi_copyin`(9F) should be used to copy data into the kernels address space. Table G-1 lists the mandatory Sun disk I/O controls.

Table G-1 Mandatory Sun Disk I/O Controls

I/O Control	Description
DKIOCINFO	Returns information describing the disk controller.
DKIOCGAPART	Returns a disk's partition map.
DKIOCSAPART	Sets a disk's partition map.
DKIOCGGEOM	Returns a disk's geometry.
DKIOCSGEOM	Sets a disk's geometry.
DKIOCGVTOC	Returns a disk's Volume Table of Contents.
DKIOCSVTOC	Sets a disk's Volume Table of Contents.

Sun disks may also support a number of optional ioctls listed in the `hdio`(7) manual page. Table G-2 lists optional Sun disk ioctls:

Table G-2 Optional Sun Disk Ioctls

I/O Control	Description
HDKIOCGTYPE	Returns the disk's type.
HDKIOCSTYPE	Sets the disk's type.

Table G-2 Optional Sun Disk Ioctls *(Continued)*

I/O Control	**Description**
HDKIOCGBAD	Returns the bad sector map of the device.
HDKIOCSBAD	Sets the bad sector map for the device.
HDKIOCGDIAG	Returns the diagnostic information regarding the most recent command.

Disk Performance

The Solaris 2.x DDI/DKI provides facilities to optimize I/O transfers for improved file system performance. It supports a mechanism to manage the list of I/O requests so as to optimize disk access for a file system. See "Asynchronous Data Transfers" on page 220 for a description of enqueuing an I/O request.

The diskhd structure is used to manage a linked list of I/O requests.

```
struct diskhd {
   long                 b_flags;   /* not used, needed for */
                                   /* consistency          */
   struct buf *b_forw,  *b_back;   /* queue of unit queues */
   struct buf *av_forw, *av_back;  /* queue of bufs for this unit */
   long                 b_bcount;  /* active flag */
};
```

The diskhd data structure has two buf pointers that the driver can manipulate. The av_forw pointer points to the first active I/O request. The second pointer, av_back, points to the last active request on the list.

A pointer to this structure is passed as an argument to disksort(9F), along with a pointer to the current buf structure being processed. The disksort(9F) routine is used to sort the buf requests in a fashion that optimizes disk seek and then inserts the buf pointer into the diskhd list. The disksort program uses the value that is in b_resid of the buf structure as a sort key. The driver is responsible for setting this value. Most Sun disk drivers use the cylinder group as the sort key. This tends to optimize the file system read-ahead accesses.

Once data has been added to the diskhd list, the device needs to transfer the data. If the device is not busy processing a request, the xxstart( ) routine pulls the first buf structure off the diskhd list and starts a transfer.

If the device is busy, the driver should return from the `xxstrategy`( ) entry point. Once the hardware is done with the data transfer, it generates an interrupt. The driver's interrupt routine is then called to service the device. After servicing the interrupt, the driver can then call the `start`( ) routine to process the next `buf` structure in the `diskhd` list.

SCSA

Global Data Definitions

The following is information for debugging, useful when a driver experiences bus-wide problems. One global data variable has been defined for the SCSA implementation: *scsi_options*. This variable is a SCSA configuration longword used for debug and control. The defined bits in the *scsi_options* longword can be found in the file `<sys/scsi/conf/autoconf.h>`. Table G-3 shows their meanings when set.

Table G-3 SCSA Options

Option	Description
SCSI_OPTIONS_DR	Enables global disconnect/reconnect.
SCSI_OPTIONS_SYNC	Enables global synchronous transfer capability.
SCSI_OPTIONS_PARITY	Enables global parity support.
SCSI_OPTIONS_TAG	Enables global tagged queuing support.
SCSI_OPTIONS_FAST	Enables global FAST SCSI support: 10MB/sec transfers, as opposed to 5 MB/sec.
SCSI_OPTIONS_WIDE	Enables global WIDE SCSI.

Note – The setting of *scsi_options* affects *all* host adapter and target drivers present on the system (as opposed to `scsi_ifsetcap`(9F)). Refer to `scsi_hba_attach`(9F) in the *Solaris 2.6 Reference Manual* for information on controlling these options for a particular host adapter.

The default setting for *scsi_options* has these values set:

- `SCSI_OPTIONS_DR`

- SCSI_OPTIONS_SYNC
- SCSI_OPTIONS_PARITY
- SCSI_OPTIONS_TAG
- SCSI_OPTIONS_FAST
- SCSI_OPTIONS_WIDE

Tagged Queueing

For a definition of tagged queuing refer to the SCSI-2 specification. To support tagged queuing, first check the *scsi_options* flag `SCSI_OPTIONS_TAG` to see if tagged queuing is enabled globally. Next, check to see if the target is a SCSI-2 device and whether it has tagged queuing enabled. If this is all true, attempt to enable tagged queuing by using `scsi_ifsetcap`(9F). Code Example G-1 shows an example of supporting tagged queuing.

Code Example G-1 Supporting SCSI Tagged Queuing

```
#define ROUTE &sdp->sd_address
    ...
    /*
     * If SCSI-2 tagged queueing is supported by the disk drive and
     * by the host adapter then we will enable it.
     */
    xsp->tagflags = 0;
    if ((scsi_options & SCSI_OPTIONS_TAG) &&
        (devp->sd_inq->inq_rdf == RDF_SCSI2) &&
        (devp->sd_inq->inq_cmdque)) {
        if (scsi_ifsetcap(ROUTE, “tagged-qing”, 1, 1) == 1) {
            xsp->tagflags = FLAG_STAG;
            xsp->throttle = 256;
        } else if (scsi_ifgetcap(ROUTE, “untagged-qing”, 0) == 1) {
            xsp->dp->options |= XX_QUEUEING;
            xsp->throttle = 3;
        } else {
            xsp->dp->options &= ~XX_QUEUEING;
            xsp->throttle = 1;
        }
    }
```

Untagged Queueing

If tagged queueing fails, you can attempt to set untagged queuing. In this mode, you submit as many commands as you think necessary or optimal to the host adapter driver. Then, the host adapter queues the commands to the target one at a time (as opposed to tagged queueing, where the host adapter submits as many commands as it can until the target indicates that the queue is full).

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