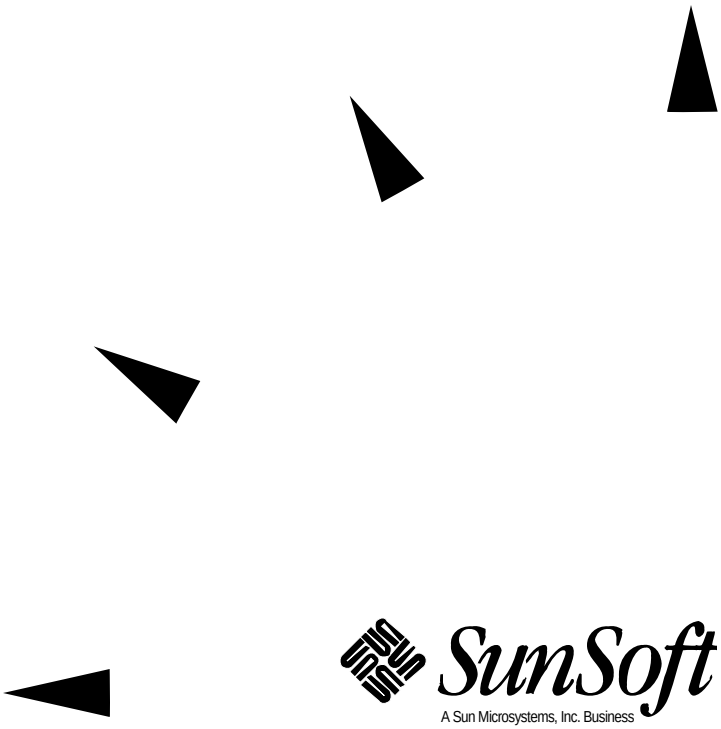
Writing Device Drivers



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Preface

Writing Device Drivers describes how to develop device drivers for character-oriented devices, block-oriented devices, and Small Computer System Interface (SCSI) target devices.

Who Should Read 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 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.

Chapter Overview

- Chapter 1, “Overview of the SunOS Kernel,” provides general background information about the SunOS kernel and the interfaces provided for device drivers.
- Chapter 2, “Hardware Overview,” discusses 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.
- Chapter 4, “Multithreading,” describes the mechanisms of the SunOS multithreaded kernel that are of interest to driver writers.
- Chapter 5, “Autoconfiguration,” describes 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, “Drivers for Character Devices,” describes the structure and functions of a driver for a character-oriented device.
- Chapter 9, “Drivers for Block Devices,” describes the structure and functions of a driver for a block-oriented device.
- Chapter 10, “SCSI Target Drivers,” outlines the Sun Common SCSI Architecture and describes the additional requirements of SCSI target drivers.
- Chapter 11, “Device Context Management” describes the set of interfaces that allow device drivers to manage the context of user processes accessing a device.
- Chapter 12, “Loading and Unloading Drivers,” shows the steps for compiling and linking a driver, and for installing it in the system.
- Chapter 13, “Debugging,” gives coding suggestions, debugging hints, a simple `adb/kadb` tutorial, and some hints on testing the driver.
- Appendix A, “Converting a Device Driver to SunOS 5.4,” gives hints on converting SunOS 4.x drivers to SunOS 5.x.
- Appendix B, “Advanced Topics,” presents a collection of optional topics.
- Appendix C, “Summary of Solaris 2.4 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.

Related Books

For information about writing STREAMS device drivers and modules, see the *STREAMS Programmer's Guide*. For more detailed reference information about the device driver interfaces, see sections 9, 9E (entry points), 9F (functions), and 9S (structures) of the *Solaris 2.4 Reference Manual AnswerBook*.

Typographic Conventions

The following table describes the meanings of the typefaces used in this book:

Typographic Conventions

Typeface	**Meaning**	**Example**
constant width	C language symbol or UNIX command	`ddi_add_intr()` registers a device interrupt with the system. `add_drv` adds a driver to the system.
italic	Placeholder for a value that the driver must supply	*inumber* is the number of the interrupt to register.
italic	Book title, a new word or term, or an emphasized word	See chapter 9 of the *STREAMS Programmer's Guide*. A *mutual exclusion lock* is... Any device interrupts *must* be registered with the system.

Overview of the SunOS Kernel 1

This chapter provides an overview of the SunOS kernel. It covers concepts of particular importance to device driver writers, including general kernel structure and function, kernel and user threads, relevant aspects of the virtual memory (VM) system, and the Solaris 2.x DDI/DKI.

What is the Kernel?

The SunOS kernel is a program that manages system resources. It insulates applications from the 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 main part of the kernel is contained in the file `/kernel/unix`.

The kernel provides a set of interfaces for applications to use called *system calls*. System calls are documented in the *Solaris 2.4 Reference Manual AnswerBook* (see `Intro`(2)). The function of some system calls is to invoke a device driver to perform I/O.

Device drivers are kernel modules, which normally reside in the hierarchy `/kernel` or `/usr/kernel`. See Chapter 12, “Loading and Unloading Drivers,” for the details of compiling and installing device drivers.

1

Multithreading

In most UNIX systems, the *process* is the unit of execution. In SunOS 5.x, 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 preempted 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 preemptable (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 B, “Advanced Topics.”

Virtual Memory

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

Virtual Addresses

A *virtual address* is an address that is mapped by the memory management unit (MMU) to a physical hardware address. All addresses accessed directly by the driver are kernel virtual addresses; they refer to the *kernel address space.*

Address Spaces

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 maintained by the `drvconfig`(1M) program. Special files 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 completes.

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 2.4 Reference Manual AnswerBook*. 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 (ISA) 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 (sun4, sun4c, sun4d, sun4e, Sun4m, 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 allow 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

Architectural independence is achieved in the Solaris 2.x DDI/DKI through a layered approach implemented as a tree structure. 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 book documents writing leaf drivers only. Figure 1-1 illustrates possible device tree configurations.

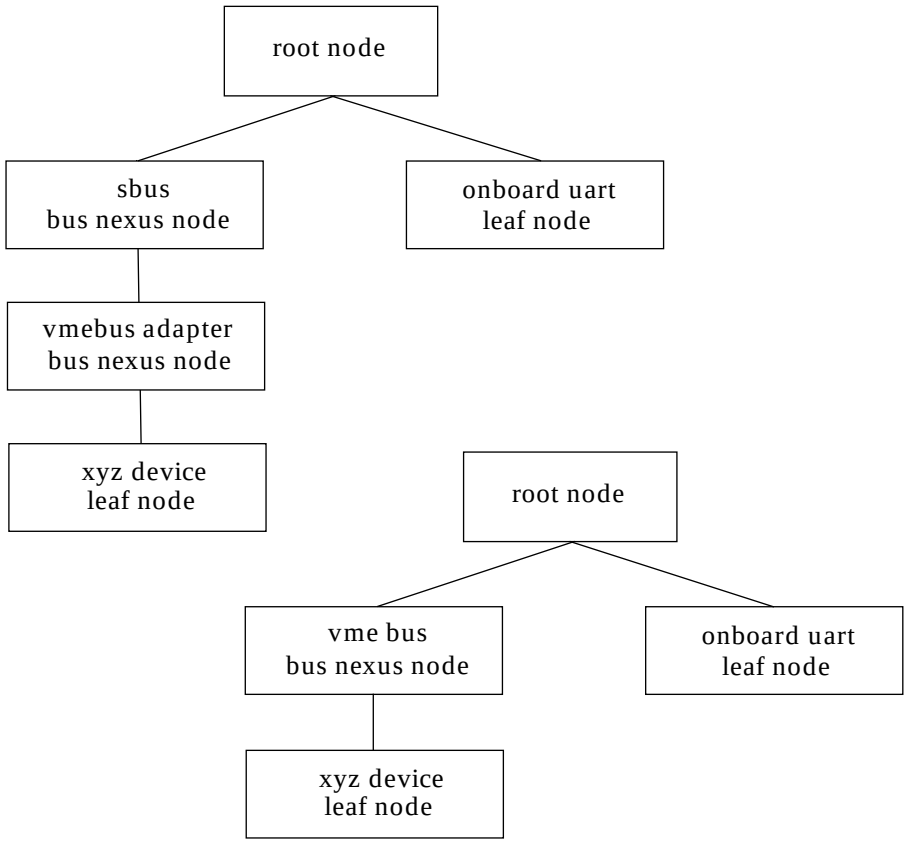


Figure 1-1 Possible device tree configurations

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 EISA busses. 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 manual does not document writing bus nexus drivers.

This approach allows drivers to function regardless of the architecture of the machine or the processor. In all of the architectural configurations in Figure 1-1, the *xyz* driver can be source compatible and 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 SBus-to-VMEbus adapter card handles all of the architectural dependencies of the interface. The *xyz* driver only needs to know that it is connected to a VMEbus.

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 build a node for each device and to create a dependency tree.

Figure 1-2 illustrates two device trees that might be created for particular SPARCstation and x86 machines.

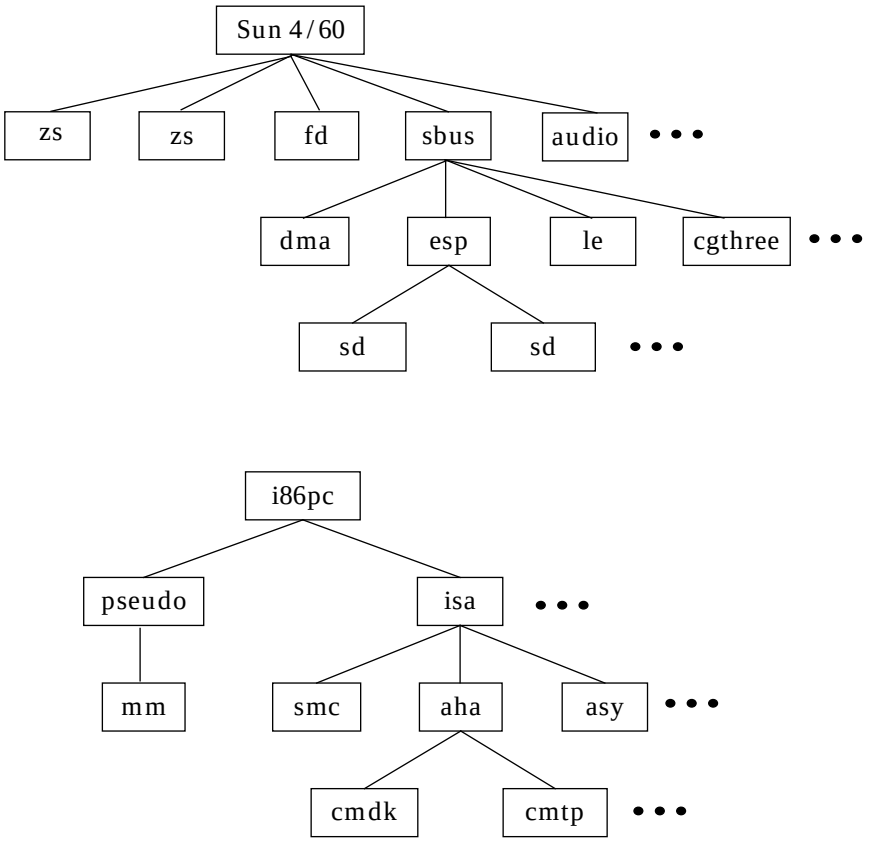


Figure 1-2 Example device trees

Each node is given a name by the kernel internally, which is not necessarily the same name that applications use.

Associated with each leaf or bus nexus node may be a driver. Each device 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 `identify`(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.

The SPARCstation in Figure 1-2 has several on-board devices and a number of SBus devices. On-board, it has some serial chips (zs), a floppy drive (fd) and an audio device. These on-board devices are children of the root node. On the SBus, it has a frame buffer (cgthree), an ethernet interface (le) and a SCSI host adapter (esp). These devices are represented as children of the SBus node. Finally, there are two disk devices (sd) connected to the SCSI host adapter, and these are represented as leaf nodes on the SCSI host adapter.

The x86 device tree has an ISA bus, which has a network device (smc), an asynchronous communication device (asy) and a SCSI host adapter (aha). As in the SPARCstation example, these devices are represented as children of their physical parent, which in this case is the ISA bus node. The SCSI host adapter also has two children, a disk (cmdk) and a tape (cmtp).

The x86 device tree also shows the pseudo bus nexus node. This node is the parent of all pseudo device drivers (drivers without hardware).

The `prtconf`(1M) and `sysdef`(1M) commands display the internal device tree. The `/devices` hierarchy is the external representation of the device tree; `ls`(1) can be used to view it.

Hardware Overview 2

This chapter discusses some general issues about the hardware that SunOS 5.x runs on. This includes issues related to the processor, bus architectures, and memory models supported by Solaris 2.x, 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.

Data Alignment

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

- `short` integers are aligned on 16-bit boundaries.
- `long` integers are aligned on 32-bit boundaries.
- `long long` integers are aligned on 64-bit boundaries.

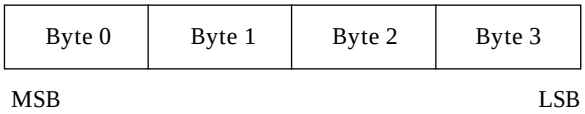
Usually, alignment issues are handled by the compiler. Driver writers are more likely to be concerned about alignment as they must use the proper data types to access their device. Since device registers are commonly accessed through a pointer reference, drivers must ensure that pointers are properly aligned when accessing the device. See “Device Issues” on page 44 for more information about accessing device registers.

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 47 for more information on how this relates to device drivers.

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.



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 fact that register windows are used is usually hidden by the compiler. However, it may be necessary to use them when debugging the driver. See “Debugging Tools” on page 243 for more information on how register windows are used when debugging. Also see the *SPARC Assembly Language Reference Manual* for more information.

Floating Point Operations

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

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. Since a driver cannot tell whether it is running on a Version 7 or Version 8 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 8, 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.

Data Alignment

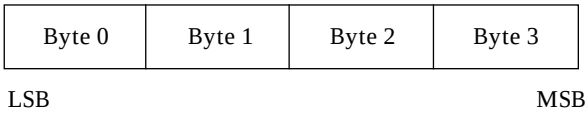
There are no alignment restrictions on data types. However, extra memory cycles may be required for the x86 processor to properly handle misaligned data transfers.

Structure Member Alignment

See “Structure Padding” on page 47 for more information on how this relates to device drivers.

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.



Floating Point Operations

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

x86 Architecture Manuals

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

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.

System Memory Model

This section describes memory model implications for device drivers.

Store Buffers

To improve performance, the system hardware may buffer data written to device memory. This may affect the synchronization of device I/O operations. Writes to device registers may pass through several system I/O buffers before reaching the registers. The driver needs to take explicit steps to make sure that writes to registers complete at the proper time.

For 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 (see `ddi_map_regs`(9F)).

If no device register in the set can be read without undesirable side effects, one of the `ddi_poke`(9F) routines may be used, as a last resort, to write to the registers. When these routines return, they guarantee that the write has reached the device.

Note – Future hardware platform implementations may not permit the `ddi_poke`(9F) routines to guarantee that a write has reached a device. Drivers should avoid the use of `ddi_poke`(9F) for this purpose whenever possible.

SPARC Memory Model

The SPARC 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 by the SPARC processor: Total Store Ordering (TSO) and Partial Store Ordering (PSO). All SPARC processors must support TSO.

TSO guarantees that the store, FLUSH, and atomic load-store instructions of all processors appear to be executed by memory serially in a single order called the memory order. Furthermore, the sequence of store, FLUSH, and atomic load-store instructions in the memory order for a given processor is identical to the sequence in which they were issued by the processor.

Like the TSO memory model, PSO guarantees that the store, FLUSH, and atomic load-store instructions of all processors appear to be executed by memory serially in a single order called the memory order. However, the memory order of store, FLUSH, and atomic load-store instructions for a given processor is, in general, *not* the same as the order in which the instructions were issued by that processor. Conformance between *issuing* order and *memory* order is provided by 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, then the memory order of the two instructions is the same as the issuing order.

See Chapter 6, Appendix J, and Appendix K of *The SPARC Architecture Manual, Version 8* 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 pairs that can be retrieved using the property interfaces. See “Properties” on page 57 for more information on properties.

SBus devices are examples of self-identifying devices. The information is usually derived from a small FORTH program stored in the FCode PROM on the device. See `sbus`(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 which determines whether the device is really there. 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( )” on page 93 for more information.

VMEbus, ISA, EISA, and MicroChannel devices are examples of non-self-identifying devices. SCSI target devices and pseudo devices are also non-self-identifying devices. See `vme`(4), `isa(4)`, `scsi`(4), and `pseudo`(4) for more information.

Device Addressing

Device addressing is different on the buses that SunOS currently supports.

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 93 for more information.

On other buses, such as the VMEbus, each 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.

Interrupts

SunOS supports polling interrupts and vectored interrupts.

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.

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.

The Solaris 2.x DDI/DKI interrupt model is the same for both types of devices. See Chapter 6, “Interrupt Handlers,” for more information about interrupt handling.

Bus Specifics

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

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.

Following is a discussion of how the SBus is implemented in the SPARCstation™ 1 and SPARCstation™ 1+.

Physical Address Space

The physical address space layout of the SPARCstation 1 and SPARCstation 1+ is shown in Table 2-1.

Table 2-1 Physical space in the SPARCstation 1 and SPARCstation 1+

Space	Range	Usage
Main Memory	0x00000000 - 0xEFFFFFFF	Main Memory
I/O Devices	0xF0000000 - 0xF7FFFFF	Sun I/O Devices
	0xF8000000 - 0xF9FFFFF	SBus Slot 0
	0xFA000000 - 0XFBFFFFFF	SBus Slot 1
	0xFC000000 - 0xFDFFFFFF	SBus Slot 2
	0xFE000000 - 0xFFFFFFFF	SBus Slot 3

Physical SBus Addresses

The address bus of the SPARC CPU has 32 bits. The SBus has 28 address bits, as described in the *SBus Specification*.

In the SPARCstation 1, the address bits are used as described in Table 2-2:

Table 2-2 SPARCstation 1 SBus address bits

Bits	Description
0 - 24	These bits are the SBus address lines used by a SBus card to address the contents of the card.
25 - 26	Used by the CPU to select one of the SBus slots. These bits generate the SlaveSelect lines.
27	Used by the CPU to distinguish between SBus devices and devices resident on the CPU board. A one (1) indicates an SBus device, and a zero (0) indicates an on-board device.
28 - 31	Not used. For compatibility with Sun-4 architecture conventions, these bits are assumed to be all ones.

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

SBus Slots

SBus systems have several SBus slots. The number of slots is system-specific.

The SPARCstation 1 has four SBus slots, numbered 0 through 3. Slot 0 is reserved; slots 1, 2 and 3 are available for SBus cards. The slots are used in the following way:

- Slot 0 is not a physical slot, but refers to the on-board DMA, SCSI, and Ethernet controllers. For convenience, these are viewed as being plugged into Slot 0.
- Slots 1 and 2 are physical slots that have DMA-master capability.
- Slot 3 is a slave-only physical slot that does not support boards that operate as DMA masters.

On other systems, for example the SPARCstation 10, slot 15 (slot 0xf) is the on-board slot, and slots 0-3 are available for SBus cards. Slots 4-14 are reserved.

Because some SBus systems (such as the SPARCstation 1) may not allow some slots to perform DMA, drivers that require DMA capability should use `ddi_slaveonly`(9F) to determine if their device is in a DMA-capable slot. For an example use of this function, see “attach( )” on page 95.

Hardware Configuration Files

Hardware configuration files should be 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. An appropriate entry in the `driver.conf`(4) file should be made for the address space used by the device (generally, this is not under control of the driver). 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).

Address Spaces

Sun-4 architecture machines that use a VMEbus are all based on the full 32-bit VMEbus. Table 2-3 contains a listing of the VMEbus address types supported by the generic VMEbus.

Table 2-3 Generic VMEbus (full set)

VMEbus Space Name	Address Size	Data Transfer Size	Physical Address Range
vme32d16	32 bits	16 bits	`0x0 – 0xFFFFFFFF`
vme24d16	24 bits	16 bits	`0x0 – 0xFFFFFF`
vme16d16	16 bits	16 bits	`0x0 – 0xFFFF`

Table 2-3 Generic VMEbus (full set)

VMEbus Space Name	Address Size	Data Transfer Size	Physical Address Range
vme32d32	32 bits	32 bits	0x0 – 0xFFFFFFFF
vme24d32	24 bits	32 bits	0x0 – 0xFFFFFF
vme16d32	16 bits	32 bits	0x0 – 0xFFFF

Not all of these address spaces are commonly used; nevertheless, they are all supported on Sun-4 architecture systems. Table 2-4 indicates their sizes and physical address mappings.

Table 2-4 Page table types for the Sun-4

Type	Address Space Name	Address Range
0	On-board Memory	0x0 – 0xFFFFFFFF
1	On-board I/O	0x0 – 0xFFFFFF
2	vme32d16	0x0 – 0xFEFFFFFF
3	vme32d32	0x0 – 0xFEFFFFFF
2	vme24d16—Stolen from top 16M of vme32d16	0x0 - 0xFEFFFF
2	vme16d16—Stolen from top 64K of vme24d16	0x0 - 0xFFFF
3	vme24d32—Stolen from top 16M of vme32d32	0x0 - 0xFEFFFF
3	vme16d32—Stolen from top 64K of vme24d32	0x0 - 0xFFFF

The type is a field in the page table entry used by the Sun4 MMU to implement the virtual memory subsystem. It indicates the type of memory referenced:

- Type 0 - main memory
- Type 1 - on-board I/O
- Type 2 - VMEbus memory, 16 bit data
- Type 3 - VMEbus memory, 32 bit data

Other Sun machines, such as the SPARCServer 600 series, have a different format for page table entries.

When a smaller VME space overlays a larger VME space, it steals memory from the larger space and is considered by the MMU to be part of the larger address space. There is no way to physically access VMEbus addresses above `0xFF000000` in 32-bit VMEbus space, or above `0x00FF0000` in 24-bit VMEbus space.

Figure 2-1 illustrates the overlaying of VMEbus address apaces.

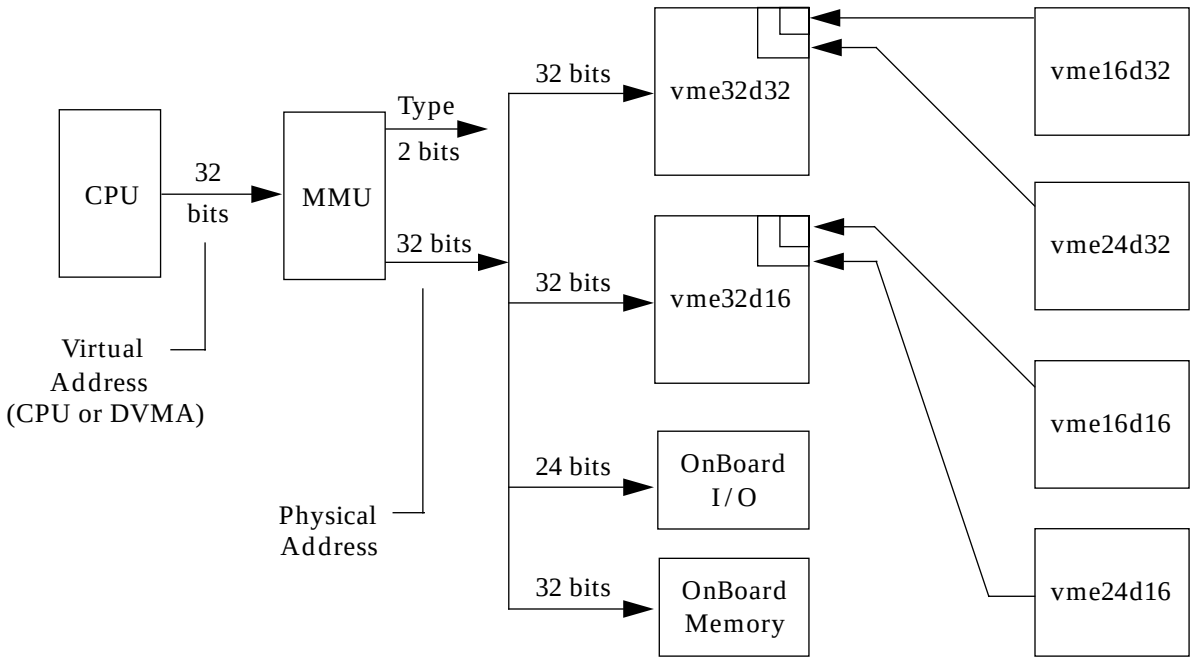


Figure 2-1 Sun-4 architecture VMEbus address spaces

Caution – There are restrictions on device addressing. The lower ranges of the 32-bit and 24-bit VME space are reserved for DMA. For example, on the Sun-4 architecture, devices must not be present in the low megabyte of VME address

space or the system will not boot. In addition, there may be devices on the bus with addresses that conflict. These can be determined by examining the hardware configuration files.

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* key word 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.

x86 Buses

Currently, there are three buses supported on the x86 platform:

- ISA - Industry Standard Architecture
- EISA - Extended Industry Standard Architecture
- MCA - MicroChannel Architecture

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 2-5 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-mapped Access” on page 44).

Registers in I/O space are accessed through I/O port numbers using separate kernel routines. See “I/O Port Access” on page 45 for more information.

Hardware Configuration Files

ISA bus devices require hardware configuration files to inform the system that the hardware may be present. The configuration file must specify any device I/O port addresses, any interrupt capabilities that the device may have, and any memory-mapped addresses it may occupy.

Configuration files for these devices should normally identify the parent bus driver as “isa”. However, since the EISA bus is a super set of the ISA bus, all ISA devices can also be configured to run in the EISA bus slot. In this case, instead of implicitly specifying a particular parent in the configuration file, driver writers can use the *class* key word and specify the class as “sysbus.” This removes the dependency on the name of a particular bus driver. 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 2-6 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-mapped Access” on page 44).

Registers in I/O space are accessed through I/O port numbers using separate kernel routines. See “I/O Port Access” on page 45) for more information.

Hardware Configuration Files

EISA bus devices require hardware configuration files to inform the system that the hardware may be present. The configuration file must specify any device I/O port addresses, any interrupt capabilities that the device may have, and any memory-mapped addresses it may occupy.

Configuration files for these devices should normally identify the parent bus driver as “`eisa`”. See `driver.conf`(4) and `eisa`(4) for further details.

2

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 2-7 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 “Memory-mapped Access” on page 44).

Registers in I/O space are accessed through I/O port numbers using separate kernel routines. See “I/O Port Access” on page 45) for more information.

Hardware Configuration Files

MCA bus devices require hardware configuration files to inform the system that the hardware may be present. The configuration file must specify any device I/O port addresses, any interrupt capabilities that the device may have, and any memory-mapped addresses it may occupy.

Configuration files for these devices should normally identify the parent bus driver as “`mca`”. 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 74, 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 preempted 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

Peripheral devices can contain chips that use a byte-ordering convention different from that used by the system on which they are installed. The Intel 82586, for example, supports little-endian byte-ordering conventions, making it compatible with Multibus-based, but not VMEbus-based, machines. Drivers for such peripheral devices must swap bytes without inadvertently reordering the bits in any control fields greater than 16 bits in length. See `swab`(9F) for more information.

The 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.

Two separate boot PROMs are briefly discussed here: the Open Boot PROM version 2 (OBP), used on machines with an SBus, and the PROM Monitor (SunMon) available on Sun-4 machines.

The PROM has several purposes; it serves to:

- Bring the machine up from power on, or from a hard reset (OBP `reset` command, or SunMon `k2` command).
- Provide an interactive tool for examining and setting memory, device registers, and memory mappings.

- Boot SunOS 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 essential system devices, such as the keyboard.

Examples in this section use a *bwtwo* (monochrome) frame buffer on a SPARCstation IPC. Using PROM commands to modify video memory on this frame buffer provides a visual indication that something is happening when PROM commands are executed.

Open Boot PROM 2.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-4c; other architectures may require new commands to map memory, among other things.

The Open Boot PROM is currently used on Sun machines with an SBus. It is more powerful than the older SunMon ("The Sun Monitor" on page 34). The Open Boot PROM uses an "`ok`" prompt rather than the "`>`" prompt used by SunMon. However, many Open Boot PROM machines present the old-style interface by default. The '`n`' command switches an OBP from the old mode to the new mode.

```
Type b (boot), c (continue), or n (new command mode)
>n
Type help for more information
ok
```

Note – 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).

To make the machine come up in new mode by default, set the environment variable `sunmon-compat?` to *false*.

```
ok setenv sunmon-compat? false
sunmon-compat? =      false
```

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 walk 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 is left 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 a SPARCstation IPC.

```
ok cd /
```

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

```
ok ls
ffec8760 options
ffec5ce0 fd@1,f7200000
ffebab64 virtual-memory@0,0
ffeba958 memory@0,0
ffeb9084 sbus@1,f8000000
ffeb9020 auxiliary-io@1,f7400003
ffeb8fb8 interrupt-enable@1,f5000000
ffeb8f54 memory-error@1,f4000000
ffeb8ed0 counter-timer@1,f3000000
ffeb8e5c eeprom@1,f2000000
ffeb8de8 audio@1,f7201000
ffeb8cf8 zs@1,f0000000
ffeb8c54 zs@1,f1000000
ffeb8c04 openprom
ffeb7b5c packages
```

The full node name can be used:

```
ok cd sbus@1,f8000000
ok ls
ffecd450 bwtwo@3,0
ffecc2f0 le@0,c00000
ffec9b38 esp@0,800000
ffec9af4 dma@0,400000
```

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 *bwtwo* device is in slot 3 and starts at offset 0. If an SBus device shows up in this tree, the device has been recognized by the PROM.

The `.attributes` command displays the PROM properties of a device. These can be examined to determine what 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 57 for related information.

```
ok cd bwtwo
ok .attributes
monitor-sense            00 00 00 03
intr                     00 00 00 07 00 00 00 00
reg                      00 00 00 03 00 00 00 00 01 00 00 00
device_type              display
model                    SUNW,501-1561
...
```

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 *bwtwo* 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 three steps:

1. Determine the physical address of the SBus slot the device is in. Table 2-8 displays the physical addresses of various SBus slots on a SPARCstation 1 and SPARCstation 1+:

Table 2-8 SBus physical addresses

SBus Slot Number	Physical Address Space
SBus slot #0	0 (internal slot)
SBus slot #1	0x2000000
SBus slot #2	0x4000000
SBus slot #3	0x6000000

   In this example, the *bwtwo* device is located in slot 3. Consequently, the physical address space for the device is 0x6000000.

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

   The offset used is specific to the device. In the *bwtwo* example, the video memory happens to start at offset 0x800000 within the *bwtwo* space. As a result, the actual offset to be mapped is 0x6800000.

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

   The `map-sbus` *word* takes an *offset* and a *size* as arguments to map. Like the offset, the size of the byte transfer is specific to the device. In the *bwtwo* example, the size is set to 20000 bytes.

In the code example below, the offset and size values for the frame buffer are displayed as arguments to the `map-sbus` word. Notice that the virtual address to use is left on top of the stack. The stack is then shown using the `.s` word. It can be assigned a name with the `constant` operation.

```
ok 6800000 20000 map-sbus
ok .s
ffe7f000
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 ffe8000 c!
```

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

```
ok ffe80000 c@
ok .s
77
```

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

```
ok ffe80000 c?
77
```

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 ffee0000 c@
Data Access Exception
ok ffee0000 cprobe
ok .s
0
ok ffe80000 cprobe
ok .s
0 ffffffff
```

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 *bwtwo* to display simple patterns based on the byte passed.

```
ok 6800000 20000 map-sbus
ok constant fb
ok fb 20000 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.

The Sun Monitor

Normally, the Sun Monitor is used on Sun-4 architectures with a VMEbus. For complete documentation on SunMon, see the *PROM User's Guide*.

Mapping the Device

To test the device, it must be mapped into memory. The PROM can then be used to verify proper operation by using data-transfer commands to transfer bytes, words, and long words. If the device can be made to operate 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:

1. Select an appropriate virtual address for the testing of the device.
2. Determine the physical address of the device, as well as the address space that it occupies.
3. Use the monitor to map the system's virtual address to the device's physical address.

Selecting a Virtual Address

When mapping a virtual address to a physical address, the MMU is actually mapping to a page of physical memory and an offset within that page. The low-order bits of a virtual address, those that specify the offset, *are not mapped*. See Figure 2-2 on page 35.

The mapping mechanism is essentially the same for all systems, though the details of the address size and page mapping differ.

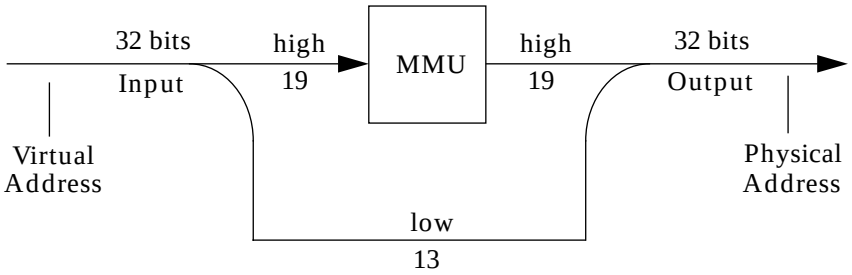


Figure 2-2 Sun-4 architecture address mapping

The easiest way to select a virtual address for testing is to use one between 0x4000 and 0x100000. Addresses in this range are unused by the PROM in Sun-4 architecture machines and are available. Be aware that these addresses, while convenient for testing, are not those that the kernel chooses when the driver is finally installed.

It is most convenient to select a virtual address that has only zeros in its low-order bits. This way, the first address in a virtual page is selected. The low-order bits in the chosen address remain unchanged. With 'X' representing the unmapped low-order bits (13 on an 8K page Sun-4) the test address 0x4000 is, in binary:

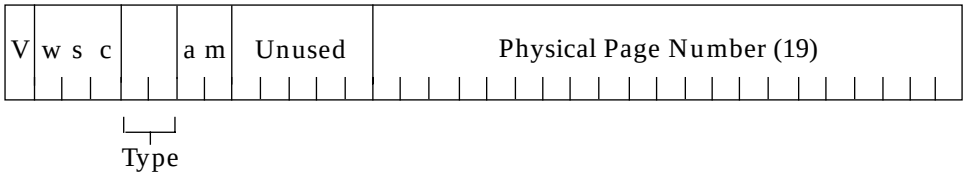
```
0000 0000 0000 0000 010X XXXX XXXX XXXX
```

Finding a Physical Address

The device may be preconfigured to some address. If it is, then that address should be used unless it conflicts with the address of an already installed device. If it conflicts, an unused physical address must be found. To do so, examine the hardware configuration files in `/kernel/drv` and `/usr/kernel/drv` on the test system. See `driver.conf(4)` for more information on hardware configuration files and `vme(4)` for specific information on configuration files for VMEbus devices.

Creating a Page Table Entry

The link between the virtual and physical address is the MMU. The MMU contains a page table to keep track of which virtual pages map to which physical pages. Entries in this table are called page table entries (PTE). To create a mapping, a page table entry must be constructed. On a Sun-4, PTEs are 32-bit numbers with the following structure:

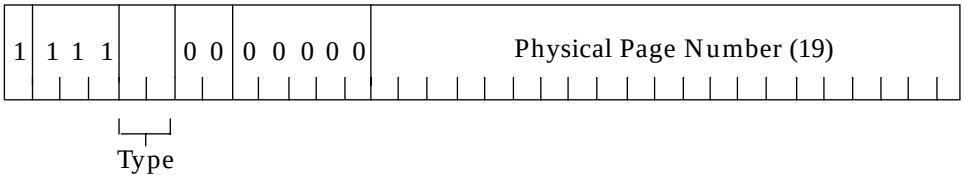


Note – This discussion is for informational and debugging use only. Device drivers must not manipulate page table entries.

The following is a “template” bit mask that can be used to construct standard PTEs. An acceptable mask assumes values as follows:

V (valid) = 1
w / s (write ok / supervisor only) = 11
c (don’t cache) = 1
(a / m) accessed / modified = 00
unused = 00000

A one in the *don’t cache* position only disables caching if the type is zero, since other types of pages are never cached. Substituting the above values, the template looks like this:



This results in a mask of 0xF0000000 (assuming that the type field is 00). Thus, the four masks for the four types of memory are:

Table 2-9 PTE masks

Type	Description	Mask
0	On Board Memory	0xF0000000
1	On Board I/O Space	0xF4000000
2	`vme16d16`	0xF8000000
2	`vme24d16`	0xF8000000
2	`vme32d16`	0xF8000000
3	`vme16d32`	0xFC000000
3	`vme24d32`	0xFC000000
3	`vme32d32`	0xFC000000

To determine the value to be plugged into the PTE, the appropriate mask is added to the physical page number, resulting in the full 32-bit PTE. Following are some rules for generating PTEs with the correct template, based on the address space the device is in and assuming an 8K page size:

If *the device is in* vme16d16, vme24d16, *or* vme32d16
Use Type-2 Template

If *the device is in* vme16d32, vme24d32, *or* vme32d16
Use Type-3 Template

If *the device is in* vme32d16 *or* vme32d32
Physical Page Number = Physical Address >> 13

If *the device is in* vme24d16 *or* vme24d32
Physical Page Number = (Physical Address + 0xFF000000) >> 13

If *the device is in* vme16d16 *or* vme16d32
Physical Page Number = (Physical Address + 0xFFFF0000) >> 13

Example One

A device is attached at physical address 0x280008 in bus type vme24d16, which will be mapped into virtual memory at address 0xE000000. What is the corresponding PTE?

Answer: 0xF807F940

Explanation: Because the device is being mapped into vme24d16, 0xF8000000 is used as the template. Adding the physical address to 0xFF000000 yields 0xFF280008. In binary, this is:

```
1111 1111 0010 1000 0000 0000 0000 1000
```

Shifting this right by 13 yields:

```
XXXX XXXX XXXX X111 1111 1001 0100 0000
```

Adding the 0xF8000000 template results in values for the 13 bits that are undefined from the shift. The PTE is:

```
1111 1000 0000 0111 1111 1001 0100 0000
```

In hexadecimal, this is 0xF807F940.

The resulting PTE maps the virtual page beginning at 0xE000000 to the physical page containing 0x280008. To get the virtual address to access the device, it is necessary to take the lower 13 bits of the physical installation address—the bits that are just passed through the MMU— and add them to virtual address 0xE000000. The lower 13 bits of physical address 0x280008 are 0008; adding them to 0xE000000 yields 0xE000008, the virtual address by which the device can be accessed.

Example Two

A device at physical address 0xEE48 on bus type vme16d32 will be mapped to virtual address 0xE000000. What is the PTE?

Answer: 0xFC07FFFF

Explanation: Because the device is being mapped into vme16d32, 0xFC000000 is used as the template. Adding the physical address to 0xFFFF0000 yields 0xFFFFEE48. In binary, this is:

```
1111 1111 1111 1111 1110 1110 0100 1000
```

Shifting this right by 13 yields:

```
XXXX XXXX XXXX X111 1111 1111 1111 1111
```

Adding the 0xFC000000 template results in values for the 13 bits that are undefined from the shift. The PTE is:

```
1111 1100 0000 0111 1111 1111 1111 1111
```

This is 0xFC07FFFF in hexadecimal.

To get the virtual address to access the device at physical address 0xEE48, add its lower 13 bits, 0xE48, to 0xE000000. This yields 0xE000E48.

Sun 4/110 Considerations

The Sun-4/110 MMU does not store bits 28-31. For the VMEbus, which uses 32 bits of physical addressing, bits 28-31 are generated by sign-extending bit 27. When the PTE is read back, these upper bits are always set to zero. This essentially creates a hole in the address space that is not addressable.

When entering page table entries on a Sun-4/110 to test hardware from the PROM, use a virtual address less than 0x800000. Virtual addresses at or above 0x800000 are not set up by the PROM for use.

When mapping the device to vme16, vme24, or the top half of the vme32 address space, after entering the PTE the top five bits of the physical page number are zero because the Sun-4/110 physical address space is split with 128 megabytes at the bottom and 128 megabytes at the top. Whenever the physical address goes above 128 megabytes, the high bit is sign extended so that the address lies within the top 128 megabytes. Sign extending the high bit into the next five bits should result in the previously calculated physical page number.

In this example, instead of using 0xE000000 as the starting address, the value 0xE0000 could be used successfully.

Mapping Commands

1. Issue the PROM command that puts the CPU into supervisor data state:

```
> s B
```

2. Calculate the PTE appropriate to the chosen physical address.

3. Map the virtual address to the device. The PROM p command will do this, given a virtual address:

```
> p F32000
```

This command takes the virtual address 0xF32000 as its argument and displays the PTE for it. It also displays a ?, which indicates that a new value may be typed in to replace the one displayed. Note that all virtual addresses within a page select the same PTE. Type any non-hexadecimal character to stop.

4. Repeat step 3 for each page to map.

Reading and Writing

The format of the data transfer commands are

```
command [address] [value]
```

Valid commands are:

- `o` open a byte
- `e` open a word (4 bytes)
- `l` open a longword (4 bytes)

When using the `o`, `e`, or `l` commands to open a location, the monitor reads the present contents of that location and displays it before giving the option to rewrite it. To do the write without the read (because the device does something else when the read occurs), pass a value after the address argument; this is known as a *blind write.*

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 SunOS 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 containing subroutines and data responsible for managing low-level I/O operations for a particular hardware device. Device drivers can also be software-only, emulating a device such as a RAM disk or a pseudo-terminal that only exists in software. 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. There are two types of character device drivers: 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 make the device transfer the specified block. The main interface to the file system is the `strategy`(9E) routine. See Chapter 9, “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 8, “Drivers for Character Devices” for more information.

Byte-Stream I/O

The main job of any device driver is to perform I/O, and many character device drivers do what is called *bytestream* 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 bytestream I/O for standard character drivers. See “I/O Request Handling” on page 153 for more information.

I/O Control

Many devices have characteristics and behaviors 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. The baud rate of a serial communications port, for example, is usually configurable in this way.

The I/O control interface is open ended, allowing device drivers to define special commands for the device. The definition of the commands is entirely up to 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 2.4 Reference Manual AnswerBook*. For example, `fbio`(7) documents the I/O controls that frame buffers must support, and `dkio`(7) documents standard disk I/O controls. See "Miscellaneous I/O Control" on page 165 for more information on I/O control.

Note – The I/O control commands in section 7 are not part of the Solaris 2.x DDI/DKI.

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 `mmap`(9E) entry points. See Chapter 11, "Device Context Management" for details.

Drivers that define an `mmap`(9E) entry point usually do not define `read`(9E) and `write`(9E) entry points, since application programs perform I/O directly to the devices after calling `mmap`(2). See Chapter 11, "Device Context Management", for more information on I/O control.

Device Polling

The `poll`(2) system call allows application programs to monitor or *poll* a set of file descriptors for certain conditions or *events*. `poll`(2) is 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 since 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 device. 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 Programmer's Guide* for additional information on how to write STREAMS drivers.

Device Issues

Accessing Device Registers

There are two common ways of accessing device registers: through *memory-mapping* and *I/O ports*. The preferred method depends on the device; it is not generally software-configurable. For example, SBus and VMEbus devices do not provide I/O ports, but some ISA, MCA, and EISA devices may provide both access methods.

Memory-mapped Access

In memory-mapped access, device registers appear in memory address space and are treated as normal memory. Just as the driver needs a kernel virtual address to access physical memory, the driver also needs a virtual address to

access any device registers. To get a virtual address, the driver must map the device registers into kernel virtual memory. The Solaris 2.x DDI/DKI provides this ability with the `ddi_map_regs`(9F) function.

```
volatile char *reg_addr;
ddi_map_regs(..., (caddr_t) &reg_addr, ...);
```

Once the registers are successfully mapped, they can be accessed as any other memory. The following example writes one byte to the first location mapped (hexadecimal notation is usually used when writing bits):

```
*reg_addr = 0x10;
```

I/O Port Access

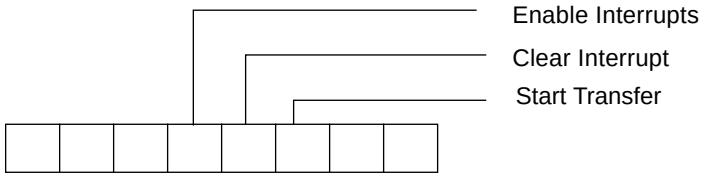
In I/O port access, the device registers appear in I/O address space. Each addressable element of the I/O address space is called an I/O port. Device registers are accessed through I/O *port numbers*, which are defined by the hardware. These port numbers can refer to 8, 16, or 32-bit registers. Reading from a port is accomplished with one of the `inb`(9F) family of routines. Writing to a port is performed with an `outb`(9F) routine.

On x86 systems, device registers are typically accessed through I/O ports. Large buffers, on the other hand, are accessed using memory mapping.

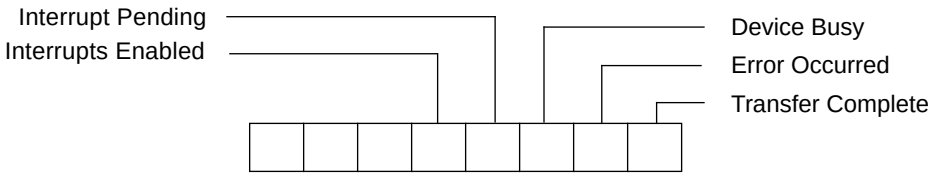
Example Device Registers

Most of the examples in this manual use a fictitious device that has an 8-bit command/status register (csr), followed by an 8-bit data register. The command/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 completed might look like this:

```
if (*reg_addr & TRANSFER_COMPLETE) {
    data = *(reg_addr + 1); /* read data */
}
```

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

```
struct device_reg {
    volatile u_char csr;
    volatile u_char data;
};
```

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

```
struct device_reg *regp;

...
ddi_map_regs(..., (caddr_t) &regp, ... );
...
```

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

```
if (regp->csr & TRANSFER_COMPLETE)
    data = regp->data;
```

Structure Padding

A device that has a one-byte command/status register followed by a four-byte data register might lead to the following structure layout:

```
struct device_reg {
    u_char  csr;
    u_int   data;
};
```

The above 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 byte-alignment for the `csr` field, but four-byte alignment for the `data` field. This results in three unused bytes between the two fields. Using this structure, the driver would be three bytes off when accessing the data register.

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 3-1 Structure padding

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

struct device_reg {
    u_char  csr;
    u_int   data;
};
```

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

Here is a sample compilation with SPARCompilers 2.0.1 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 2.4 Reference Manual AnswerBook*. 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 an `mmap`(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 `identify`(9E), `attach`(9E), and `getinfo`(9E)). Drivers may also support the optional autoconfiguration entry

points for probe(E) and detach(9E). All device drivers must support the entry point getinfo(9E). Most drivers have open(9E) and close(9E) entry points to control access to their devices. See Chapter 8, “Drivers for Character Devices,” Chapter 9, “Drivers for Block Devices,” and Chapter 5, “Autoconfiguration,” for details about these entry points.

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

Note – In SunOS 5.x, only the loadable module routines must be visible outside the driver object module. Everything else 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).

These routines have kernel context.

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 up to the driver.

Autoconfiguration Routines

```
static int xxidentify(dev_info_t *dip);
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);
```

The driver is single-threaded on a per-device basis when the kernel calls these routines, 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 may occur concurrently.

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).

These routines have kernel context.

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);
```

These routines have kernel context.

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, int arg, int mode,
           cred_t *credp, int *rvalp);
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);
```

With the exception of `prop_op`(9E), all these routines have user context. `prop_op`(9E) has kernel context.

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 timeout 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 do to certain things. In the case of DMA routines, a callback function must return a value indicating whether the callback function wants to be rescheduled in case of a failure.

Callback functions execute as a separate thread. They must consider all the usual multithreading issues.

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

3

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 or in a hardware configuration file. See `sbus`(4), `vme`(4), and“Properties” on page 59 for more information.

Since the internal implementation of interrupts is an architectural detail, special *interrupt cookies* are used to allow 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) and “Registering Interrupts” on page 99 for more information.

Interrupt-Block 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.

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 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. Since 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, driver interrupt routines added for that interrupt with `ddi_add_intr`(9F) run in high-level interrupt context. See “Handling High-Level Interrupts” on page 113 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 what label will be printed:

`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 detail.

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 application 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

State Structure

For each device that the driver handles, the driver must keep some state information. At the 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 devices mapped registers
- Flags (such as *busy*)

The initial state structure the examples in this book use is given in Code Example 3-2:

Code Example 3-2 Initial State Structure

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

Subsequent chapters may require new fields. Each chapter will list any additions to the state structure.

3

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 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 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 only needs to call `ddi_get_soft_state`(9F) to retrieve the pointer.

See “Loadable Driver Interface” on page 89 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 `ddi_prop_create`(9F).

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

- A boolean property, which has no length; it either exists or does not exist.
- An integer property, which has length four and has an integer value
- A long property, which has an arbitrary length, and whose value is a series of bytes

---

Note – Strictly speaking, ddi 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 may ask its parent. The driver can control whether the request can go higher than its parent.

For example, the “esp” driver maintains an integer-sized property called `target`*X*`-sync-speed`. 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>.
...
```

The property interface can be used to:

- Create a property with `ddi_prop_create`(9F). This usually is performed in `attach`(9E).
- Retrieve a property with `ddi_prop_op`(9F), or one of the following more specific routines:
  - `ddi_getproplen`(9F) to retrieve the length of a property
  - `ddi_getprop`(9F) for boolean and integer properties
  - `ddi_getlongprop`(9F) and `ddi_getlongprop_buf`(9F) for other property sizes
- `ddi_prop_modify`(9F) – Change the value of a property
- `ddi_prop_undefine`(9F) - Explicitly undefine, but not remove, a property
- `ddi_prop_remove`(9F) – Remove a property.
- `ddi_prop_remove_all`(9F) - Remove all properties associated with a device.

prop_op( )

To report the values of device properties to the system, drivers must fill in the entry point in the `cb_ops`(9S) structure with their own `prop_op`(9E) entry point or the `ddi_prop_op`(9F) routine. A `prop_op`(9E) routine is only necessary if more control is needed over property management. For example, if the value of a property changes frequently, it may be more efficient for the driver to maintain it locally, updating a variable representing the property

value whenever it changes. If a caller requests the value of the property, the driver's prop_op(9E) modifies the property using ddi_prop_modify(9F) and then calls ddi_prop_op(9F) to retrieve it.

Providing a prop_op(9E) entry point does not mean that the driver must manage *all* properties locally. If a property is modified dynamically, it should be maintained by the driver in prop_op(9E). If a property is static (set only once), it is easier for the driver to use ddi_prop_create(9F) to create it and allow ddi_prop_op(9F) to retrieve it. The prop_op(9E) entry point would just intercept some property requests and pass all others to ddi_prop_op(9F). 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 3-3, the prop_op(9E) intercepts requests for the nblocks 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 get the new value. 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 "State Structure" on page 57 for more information.

```
    int     nblocks; /* number of blocks in block device */
```

Code Example 3-3 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)
{
    int     instance;
    struct xxstate *xsp;
```

```
    if (dev == DDI_DEV_T_ANY)
        goto skip;
    instance = getminor(dev);
    xsp = ddi_get_soft_state(statep, instance);
    if (xsp == NULL)
        return (DDI_PROP_NOTFOUND);
    if (strcmp(name, "nblocks") == 0) {
        ddi_prop_modify(dev, dip, “nblocks”, flags,
            &xsp->nblocks, sizeof(int));
    }
    other cases
skip:
    return (ddi_prop_op(dev, dip, prop_op, flags, name,
        valuep, lengthp));
}
```

Driver Layout

This section suggests a structure for device drivers. The following sections describe the example driver layout in detail.

The code for a device driver is usually divided into the following files:

- headers (`.h` files)
- source files (`.c` files)
- possibly a configuration file (`.conf` file)

Note – This is a suggested layout only. It is not required, 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 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 3-4, and Code Example 3-5 show the layout of these headers.

Code Example 3-4 `xximpl.h` Header File

```
/*
 * xximpl.h
 */
struct device_reg {
     /* fields... */
};
/*
 * #define bits of the device registers...
 */
struct xxstate {
    /* fields */
};
/*
 * related #define statements
 */
```

Code Example 3-5 `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 3-6 shows the layout of an *xx*`.c` file:

Code Example 3-6 *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
xxidentify(dev_info_t *dip)
{
    /* 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 */
}
static int
xxwrite(dev_t dev, struct uio *uiop, cred_t *credp)
{
    /* definition */
}
```

```
static int
xxioctl(dev_t dev, int cmd, int arg, int mode, cred_t *credp,
    int *rvalp)
{
    /* definition */
}
/*
 * for memory-mapped character-oriented devices
 */
static int
xxmmap(dev_t dev, off_t off, int prot)
{
    /* 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 */
}
/*
 * other driver routines, such as xxintr()
 */
```

The C Language and Compiler Modes

The SPARCworks 2.0.1 and ProWorks 2.0.1 C compilers are ANSI C compilers. They support several compilation modes, a number of new keywords and function prototypes.

Compiler Modes

The following compiler modes are of interest to driver writers:

-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. This is the default mode.

-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 will be the default mode in the future.

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

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 a function takes a pointer, casting NULL to that pointer type is no longer necessary. Prototypes are provided for most Solaris 2.x DDI/DKI functions, provided the driver includes the proper header file (documented in the manual page for the function).

New Keywords

There are a few new keywords available in ANSI C. The following keywords are of interest to driver writers:

`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. Since 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 now catch it.

`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, do 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)
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 is an example of the first use. There are two writes to a device required to begin a transfer:

```
struct device_reg *regp;

regp->csr = ENABLE_INTERRUPTS;
regp->csr = START_TRANSFER;
```

A highly optimizing compiler may determine that the value of `regp->csr` is not used between the first and the second assignment, and could remove the first assignment. Such a compiler might also determine that reordering the instructions would provide better performance, causing the device to be programmed in the incorrect order. If the `csr` field is declared volatile, it is not allowed to do so.

Following is an example of the second use of 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. The `busy` flag should be declared volatile, forcing 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 79 instead of 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 u_char csr;
    volatile u_char data;
};
struct device_reg *regp;
```

is recommended over:

```
struct device_reg {
    u_char csr;
    u_char 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.

3

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 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 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 completes. 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.

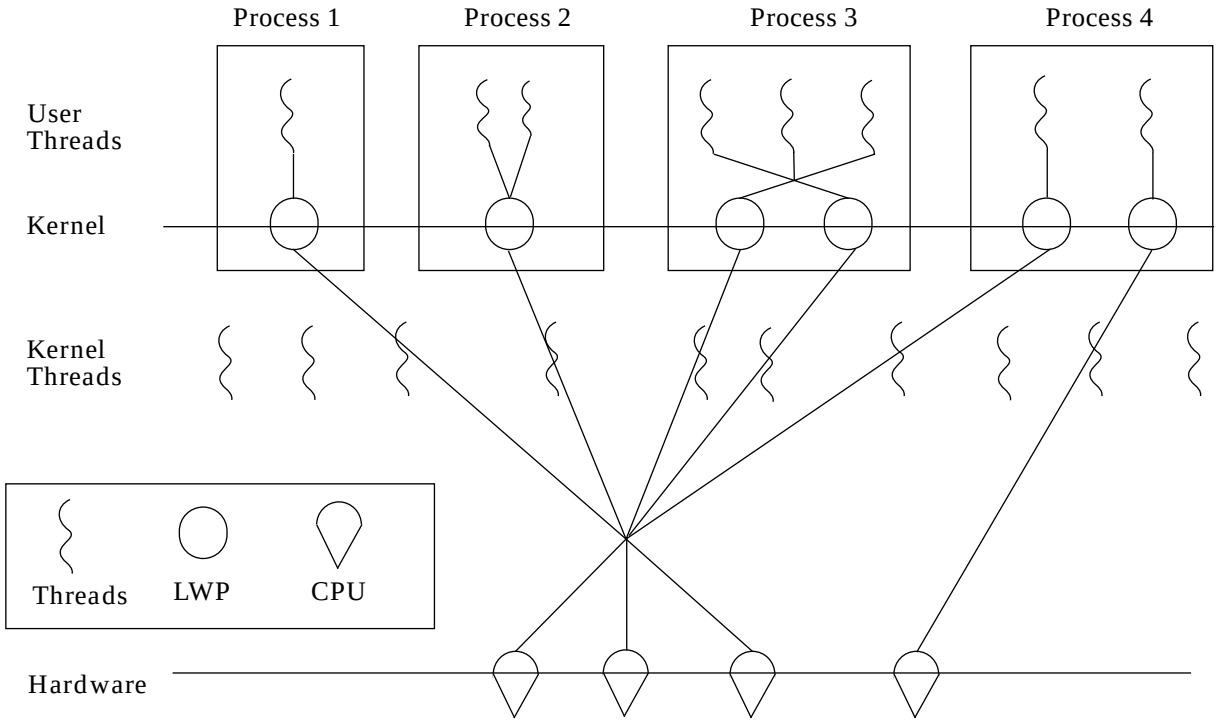
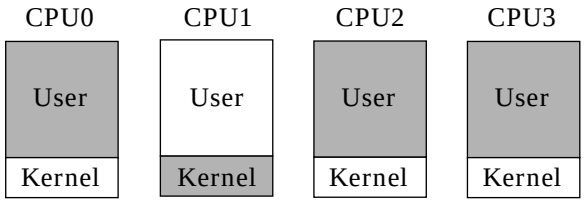


Figure 4-1 Threads and lightweight processes

A multithreaded kernel requires programmers to consider two issues: *locking primitives* and *thread synchronization*.

Multiprocessing Changes Since SunOS 4.x

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 wanted 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 SunOS 5.x, 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, 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.

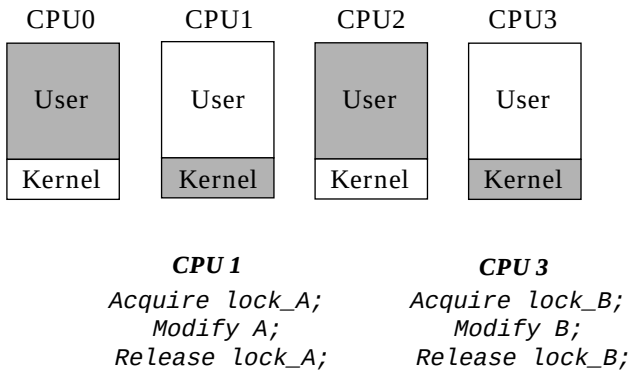


Figure 4-3 SunOS 5.x on a multiprocessor

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. Since 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 may need to take explicit steps to control access to the data.

Automatic (Stack) Data

Since 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 may need to lock this type of data at times.

Kernel Heap Data

Kernel heap data, such as data allocated by `kmem_alloc`(9F), may be shared by any number of threads in the driver. If this data *is* shared, the driver may need to protect it at times.

State Structure

This section adds the following field to the state structure. See “State Structure” on page 57 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)`	Initialize a mutex.
`mutex_destroy(9F)`	Release any associated storage.
`mutex_enter(9F)`	Acquire mutex.
`mutex_tryenter(9F)`	Acquire mutex if available; but do not block.
`mutex_exit(9F)`	Release mutex.
`mutex_owned(9F)`	Test if 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 B, “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)	Initialize a condition variable.
cv_destroy(9F)	Destroy a condition variable.
cv_wait(9F)	Wait for condition.
cv_timedwait(9F)	Wait for condition or timeout.
cv_wait_sig(9F)	Wait for condition or return zero on receipt of a signal.
cv_timedwait_sig(9F)	Wait for condition or timeout or signal.
cv_signal(9F)	Signal one thread waiting on the condition variable
cv_broadcast(9F)	Signal 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, "xx cv", CV_DRIVER, NULL);
...
```

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

Using Condition Variables

On the code path waiting for the condition take the following steps:

- Acquire the mutex guarding the condition.
- Test the condition.

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

On the code path signaling the condition take the following steps:

- Acquire the mutex guarding the condition.
- Set the condition.
- Signal the blocked thread with `cv_signal`(9F).
- Release the mutex.

Code Example 4-1 uses a busy flag, mutex and condition variable 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);
    do the read
}
static u_int
xxintr(caddr_t arg);
{
    struct xxstate *xsp = (caddr_t) 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_signal`(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. 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 signalled 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);

    do the read

}

static u_int
xxintr(caddr_t arg);
{
    struct xxstate *xsp = (caddr_t) 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 81), 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 on 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 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 cheaper 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.

For more information on locking schemes, see Appendix B, "Advanced Topics". Also see *Multithreaded Programming Guide* for more detail on multithreading operations.

4

Autoconfiguration 5

This chapter describes the support a driver must provide for 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. These processes are discussed in more detail in "Loadable Driver Interface" on page 89 and "Device Configuration" on page 93. The autoconfiguration process begins when the device is put into use.

State Structure

This section adds the following fields to the state structure. See "State Structure" on page 57 for more information.

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

5

Data Structures

Figure 5-1 shows an overview of the driver data structures that are accessed directly by the kernel for loading the driver, configuring devices, and providing access to devices. The figure is divided into 3 sections; the first two are discussed in this chapter. The third section is discussed in Chapter 8, “Drivers for Character Devices” and Chapter 9, “Drivers for Block Devices”.

Figure 5-1 shows the relationship between the autoconfiguration structures and the driver entry points.

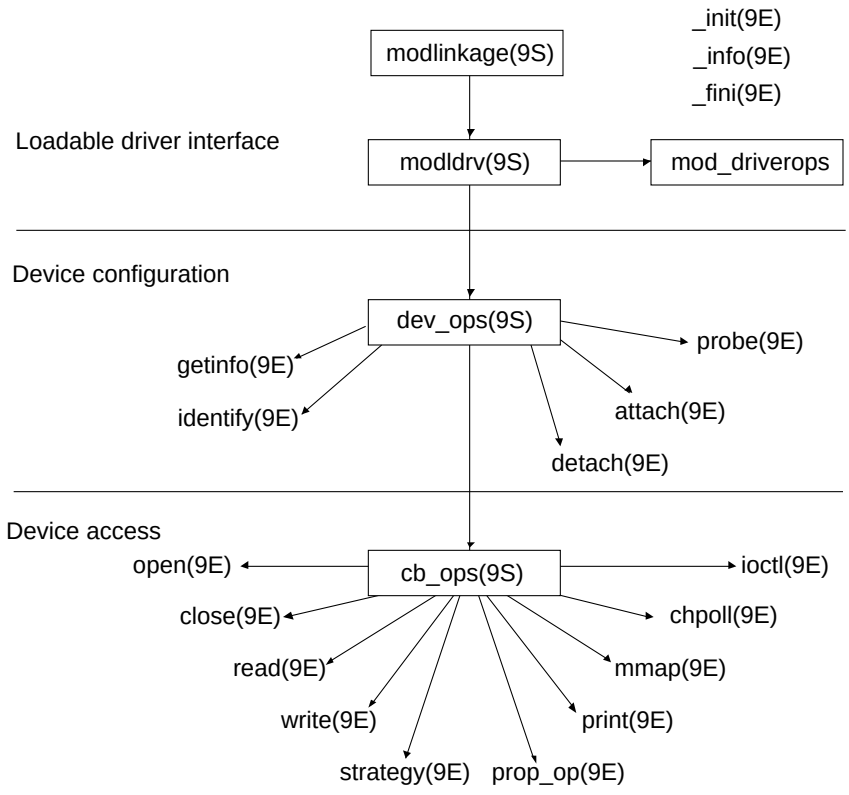


Figure 5-1 Autoconfiguration Data Structures

The structures in this diagram 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);
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:

- If a probe(9E) routine is not needed, use nulldev(9F).
- nodev(9F) can be used in devo_detach to prevent the driver from being unloaded.
- devo_reset should be set to nodev(9F).

The devo_cb_ops member should contain 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, int arg, int mode,
            cred_t *credp, int *rvalp);
int     (*cb_devmap)();
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;
```

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).

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, so `cb_str` *must* be set to `NULL`. The `cb_flag` member indicates whether the driver is safe for multithreading (`D_MP`) and whether it is a new-style driver (`D_NEW`). 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 also 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.

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 88 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,
    xxidentify,
    xxprobe,
    xxattach,
    xxdetach,
    nodev,
```

```
    &xx_cb_ops,
    (struct bus_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), none of the data structures hanging off of the modlinkage(9S) structure should be changed by the driver, as the system may make copies of them or change them.

Device Configuration

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

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

Every device driver must have an identify(9E), 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.

identify( )

The system calls identify(9E) to find out whether the driver drives the device specified by dip.

Code Example 5-2 identify(9E) routine

```
static int
xxidentify(dev_info_t *dip)
{
```

```
    if (strcmp(ddi_get_name(dip), "xx") == 0)
        return (DDI_IDENTIFIED);
    else
        return (DDI_NOT_IDENTIFIED);
}
```

If the device is known by several different names, `identify`(9E) should check for a match with each name before failing. The names must also have been passed with *aliases* to `add_drv`(1M) when the driver was installed. See Chapter 12, "Loading and Unloading Drivers."

`identify`(9E) should *not* maintain a device count, since the system does not guarantee that `identify`(9E) will be called for all device instances before `attach`(9E) is called for any device instance, nor does the system make any guarantees about the number of times `identify`(9E) will be called for any given device.

Instance Numbers

In SunOS 4.x, drivers counted the calls to `identify(9E)` and used the current value of this number as an instance number in a later call to `attach()`. *However, drivers must not do this in Solaris 2.x*. The system now assigns an instance number to each device this number is 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, VMEbus, ISA, EISA, and MCA devices. Non-self-identifying device drivers provide this in the hardware configuration file. See `sbus`(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).

The driver should retrieve the particular instance number that has been assigned by calling `ddi_get_instance`(9F). See Code Example 5-4 on page 95 for an example.

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.

probe( )

For non-self-identifying devices (see “Device Identification” on page 14) 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 OR
`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. Code Example 5-3 is an example of `probe`(9E).

Code Example 5-3 `probe`(9E) routine

```
static int
xxprobe(dev_info_t *dip)
{
    int        instance;
    volatile 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_map_regs(dip, rnumber, &reg_addr, offset, len) != 0)
        return (DDI_PROBE_FAILURE);
    if (ddi_peekc(dip, reg_addr, NULL) != DDI_SUCCESS)
        goto failed;
    free allocated resources
    ddi_unmap_regs(dip, rnumber, &reg_addr, offset, len);
    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_unmap_regs(dip, rnumber, &reg_addr, offset, len);
    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).

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.

The `ddi_peek`(9F) and `ddi_poke`(9F) family of routines must be used to access the device registers, as they cope correctly with the faults that may occur if the access fails, for example, because the device is not there.

attach( )

The system calls attach(9E) to *attach* a device instance to the system. 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

Code Example 5-4 is 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;

    switch (cmd) {
    case DDI_ATTACH:
        /*
         * get assigned instance number
         */
        instance = ddi_get_instance(dip);

        /*
         * this device requires DMA capability
         * make sure the bus slot allows this
         */
        if (ddi_slaveonly(dip) == DDI_SUCCESS)
            return(DDI_FAILURE);

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

        xsp = ddi_get_soft_state(statep, instance);

        /*
         * set up interrupt handler for the device
         */
        if (ddi_add_intr(dip, inumber, &xsp->iblock_cookie,
            &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_map_regs(dip, rnumber, (caddr_t *)&xsp->regp, offset,
            sizeof(struct device_reg)) != DDI_SUCCESS) {
            ddi_remove_intr(dip, inumber, xsp->iblock_cookie);
            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);
        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 (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);
    default:
        return (DDI_FAILURE);
    }
failed:
    free allocated resources
    ddi_unmap_regs(dip, rnumber, (caddr_t *)&xsp->regp, offset,
        sizeof(struct device_reg));
    ddi_remove_intr(dip, inumber, xsp->iblock_cookie);
    cv_destroy(&xsp->cv);
    mutex_destroy(&xsp->mu);
```

```
    ddi_soft_state_free(statep, instance);
    return (DDI_FAILURE);
}
```

attach(9E) first checks for the DDI_ATTACH command, which is the only one it handles. Future releases may support additional commands; consequently, it is important that drivers return DDI_FAILURE for all the commands they do not recognize. attach(9E) 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. The example also requires DMA capability, so ddi_slaveonly(9F) is called to check if the slot is capable of DMA. The section “SBus Slots” on page 18 discusses one example of such SBus hardware.

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_unmap_regs(dip, rnumber, (caddr_t)&xsp->regp, offset,
        sizeof(struct device_reg));
```

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

Registering Interrupts

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 an interrupt block cookie in xsp->iblock_cookie for use in calls to mutex_init(9F); it also 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 111 for a solution to this problem.

Mapping Device Drivers

In the `ddi_map_regs`(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) and `sbus`(4)). `ddi_map_regs`(9F) maps a device register set (register specification) and returns a kernel virtual address 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 filesystem.

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 (CDROM)
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_PSEUDO	General pseudo devices

The node types DDI_NT_BLOCK, DDI_NT_BLOCK_CHAN, DDI_NT_CD and DDI_NT_CD_CHAN causes 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) is the inverse operation to `attach`(9E). It is called for each device instance, receiving a command of `DDI_DETACH`, when the system attempts to unload a driver module. The system only calls the `DDI_DETACH` case of `detach`(9E) for a device instance if the device instance is not open. No calls to other driver entry points for that device instance occurs during `detach`(9E), although interrupts and time-outs may occur.

The main purpose 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.

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);
            ddi_unmap_regs(dip, rnumber, (caddr_t)&xsp->regp,
                offset, sizeof(struct device_reg));
            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);
        default:
            return (DDI_FAILURE);
        }
}
```

In the call to ddi_unmap_regs(9F), *rnumber* and *offset* are the same values passed to ddi_map_regs(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 only critical 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 cancelled, and callbacks that must run to completion.

Callbacks that can be cancelled 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 cancelled.

Table 5-2 Example of functions with callbacks that can be cancelled.

Function	Cancelling function
timeout(9F)	untimeout(9F)
bufcall(9F)	unbufcall(9F)
esbbcall(9F)	unbufcall(9F)

Some callbacks cannot be cancelled—for these it is necessary to wait until the callback has been called. In some cases, such as `ddi_dma_setup`(9F), the callback must also be prevented from rescheduling itself. See “Cancelling DMA Callbacks” on page 140 for an example.

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

- `esballoc`(9F)
- `ddi_dma_setup`(9F)
- `ddi_dma_addr_setup`(9F)
- `ddi_dma_buf_setup`(9F)
- `scsi_dmaget`(9F)
- `scsi_resalloc`(9F)
- `scsi_pktalloc`(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.

Code Example 5-1 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);
}
```

5

Interrupt Handlers 6

This chapter describes the interrupt handling mechanisms of the Solaris 2.x DDI/DKI. This includes registering, servicing, and removing interrupts.

Overview

An interrupt is a hardware signal from a device to the CPU. It tells the CPU that the device needs attention, and the CPU should drop whatever it is doing and respond to the device. If the CPU is available (it is not doing something that is 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 whatever 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 device interrupts before they can receive and service interrupts.

Example

On x86 platforms, a device requests an interrupt by asserting an interrupt request line (IRQ) on the system bus. The bus implements multiple IRQ lines, and a particular device may be able to generate interrupts on one or more of them. Multiple devices may share a common IRQ line.

The bus IRQ lines are connected to an interrupt controller that arbitrates between interrupt requests. The kernel programs the interrupt controller to select which interrupts should be enabled at any particular time. When the interrupt controller determines that an interrupt should be delivered, it raises a request to the CPU. If processor interrupts are enabled, the CPU acknowledges the interrupt and causes the kernel to begin interrupt handler processing.

Interrupt Specification

An *interrupt specification* is the information the system needs in order to link an interrupt handler with a given interrupt. It describes the information provided by the hardware to the system when making an interrupt request. Interrupt specifications typically includes a *bus-interrupt level*. For *vectored interrupts* it includes an *interrupt vector*. On x86 platforms the `driver.conf`(4) file specifies the relative priority of the devices interrupt. See `isa(4)`, `eisa(4)`, `mca(4)`, `sbus`(4), and `vme`(4) for specific information on interrupt specifications for these buses.

Interrupt Number

When registering interrupts the driver must provide the system with an *interrupt number*. This identifies which interrupt specification the driver is registering a handler for. Most devices have one interrupt, interrupt number 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.

Bus-Interrupt Levels

Buses prioritize device interrupts at one of several *bus-interrupt levels*. These bus interrupt levels are then associated with different processor-interrupt levels. For example, SBus devices that interrupt at SBus level 7 interrupt at SPARC level 9 on SPARCstation 2 systems, but interrupt at SPARC level 13 on SPARCstation 10 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 function `ddi_intr_hilevel`(9F), given an interrupt number, returns a value indicating whether the interrupt is high-level.

The driver can choose whether or not to support high-level interrupts, but it *always* has to check —it *cannot* assume that its interrupts are not high-level. For information on checking for high-level interrupts see “Registering Interrupts” on page 111.

Types of Interrupts

There are two common ways to request for an interrupt: *vectored* and *polled*. Both methods commonly specify a bus-interrupt priority level. Their only difference is that vectored devices also specify an interrupt vector, but polled devices do not.

Vectored Interrupts

Devices that use vectored interrupts are assigned an *interrupt vector*. This is a number that identifies that 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 its bus-interrupt priority level. When a handler is registered, the system adds the handler to list of potential interrupt handlers for the bus-interrupt level. When an interrupt occurs, the system must determine which device, of all the devices at that level, actually interrupted. It does this by calling all the interrupt handlers for that bus-interrupt level until one of them *claims* the interrupt.

The SBus supports 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 be very quick, since they may suspend other system activity while running (particularly in high-level interrupt handlers). For example, they may prevent lower-priority interrupts from occurring while they run. For this reason, hardware interrupt handlers should do the minimum amount of work needed to service the device.

Software interrupt handlers run at a lower priority than hardware interrupt handlers, so they can do more work without seriously impacting the performance of the system. Additionally, if the hardware interrupt handler is high-level, it is severely restricted in what it can do. In this case, it is a good idea to simply trigger a software interrupt in the high-level handler and put all possible processing in the lower-level software interrupt handler.

Software interrupt handlers must not assume that 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 can receive and service interrupts, it must register them with the system by calling `ddi_add_intr`(9F). This 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 handlers responsibility to determine if it should handle the interrupt, and claim it if so.

The following steps are usually performed in `attach`(9E):

- 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`. Code Example 6-1 on page 110 does this.

- Add the interrupt.

- Initialize any associated mutexes.
  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.

  The solution to this problem is to use `ddi_add_intr`(9F) to add an interrupt handler that never claims the interrupt. This allows the driver to get the interrupt block cookie for the interrupt, which it can then use to initialize any mutexes. Once the mutexes are initialized, the temporary interrupt handler can be removed, and the real one installed. `nulldev`(9F) can be used as the temporary handler, though it needs to be cast properly. See Code Example 6-1 for an example.

Code Example 6-1 `attach`(9E) routine with temporary interrupt handler

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

    if (cmd != DDI_ATTACH)
        return (DDI_FAILURE);

    ...
    if (ddi_intr_hilevel(dip, inumber) != 0){
        cmn_err(CE_CONT,
            “xx: high-level interrupts are not supported\n”);
        return (DDI_FAILURE);
    }

    /*
     * The interrupt routine will grab the mutex, so a null */
     * handler is required.
     */
    if (ddi_add_intr(dip, inumber, &xsp->iblock_cookie,
        NULL, (u_int (*)(caddr_t))nulldev, NULL) != DDI_SUCCESS){
        cmn_err(CE_WARN, "xx: cannot add interrupt handler.");
        return (DDI_FAILURE);
    }

    mutex_init(&xsp->mu, "xx mutex", MUTEX_DRIVER,
        (void *) xsp->iblock_cookie);

    ddi_remove_intr(dip, inumber, xsp->iblock_cookie);

    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;
    }
    cv_init(&xsp->cv, "xx cv", CV_DRIVER, NULL);
    return (DDI_SUCCESS);

failed:
    remove interrupt handler if necessary, destroy mutex
    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. **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 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 been serviced yet.

3. **Perform any I/O request related processing.**
   Devices interrupt for different reasons, such as *transfer done* or *transfer error.* This step may involve reading the device's data buffer, examining the device's error register, and setting the status field in a data structure accordingly.

   Interrupt dispatching and processing is relatively expensive. 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 Interrupt routine

```
static u_int
xxintr(caddr_t arg)
{
```

```
    struct xxstate *xsp = (struct xxstate *) arg;
    u_char     status, temp;

    /*
     * Claim or reject the interrupt.This example assumes
     * that the device's CSR includes this information.
     */
    mutex_enter(&xsp->mu);
    status = xsp->regp->csr;
    if (!(status & INTERRUPTING)) {
        mutex_exit(&xsp->mu);
        return (DDI_INTR_UNCLAIMED);
    }
    /*
     * 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 write
     * operation makes it to the device before the interrupt service
     * returns. For example, reading the CSR, if it does not result in
     * unwanted effects, can ensure this.
     */
    xsp->regp->csr = CLEAR_INTERRUPT | ENABLE_INTERRUPTS;
    temp = 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);
}
```

On an architecture that does not support vectored hardware interrupts, when the system detects an interrupt, 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 model 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 be 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 learn how 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 “State Structure” on page 57 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 them. 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 just 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.

Example

In the model presented here, the high-level mutex (`xsp->high_mu`) is only used 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`) is used to protect 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)) {
        /* add null high-level handler */
        if (ddi_add_intr(dip, inumber, &xsp->high_iblock_cookie,
            NULL, (u_int (*)(caddr_t))nulldev, NULL) != DDI_SUCCESS)
            goto failed;

        mutex_init(&xsp->high_mu, "xx high mutex", MUTEX_DRIVER,
            (void *)xsp->high_iblock_cookie);

        ddi_remove_intr(dip, inumber, 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;
```

```
        /* add null low-level handler */
        if (ddi_add_softintr(dip, DDI_SOFTINT_HI, &xsp->id,
            &xsp->low_iblock_cookie, NULL,
            (u_int (*)(caddr_t))nulldev, NULL))
            != DDI_SUCCESS)
            goto failed;
        mutex_init(&xsp->low_mu, "xx low mutex", MUTEX_DRIVER,
            (void *) xsp->low_iblock_cookie);
        ddi_remove_softintr(xsp->id);
        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.

Code Example 6-4 High-level interrupt routine

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


    mutex_enter(&xsp->high_mu);
    /* read status */
    status = xsp->regp->csr;
```

```
    if (!(status & INTERRUPTING)) {
        mutex_exit(&xsp->high_mu);
        return (DDI_INTR_UNCLAIMED); /* device isn't interrupting */
    }
    xsp->regp->csr = CLEAR_INTERRUPT;
    /* Flush store buffers */
    temp = 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.

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);
}
```

6

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 describes transfers between a device and memory only.

The DMA Model

The Solaris 2.x DDI/DKI provides a high-level, architecture-independent model for DMA. This allows the framework (the DMA routines) to hide architecture-specific details such 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 DMA setup call. The DMA handle can be used in successive DMA subroutine calls to refer to the DMA object.

- DMA Window

  A DMA window describes all or a portion of a DMA object that is ready to accept data transfers.

- DMA Segment

  A DMA segment is a contiguous portion of a DMA window that is entirely addressable by the device.

- DMA Cookie

  A `ddi_dma_cookie`(9S) structure (`ddi_dma_cookie_t`) describes a DMA segment. 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

Figure 7-1 shows the relationship between the DMA object, the DMA handle, and the DMA windows, segments, and cookies.

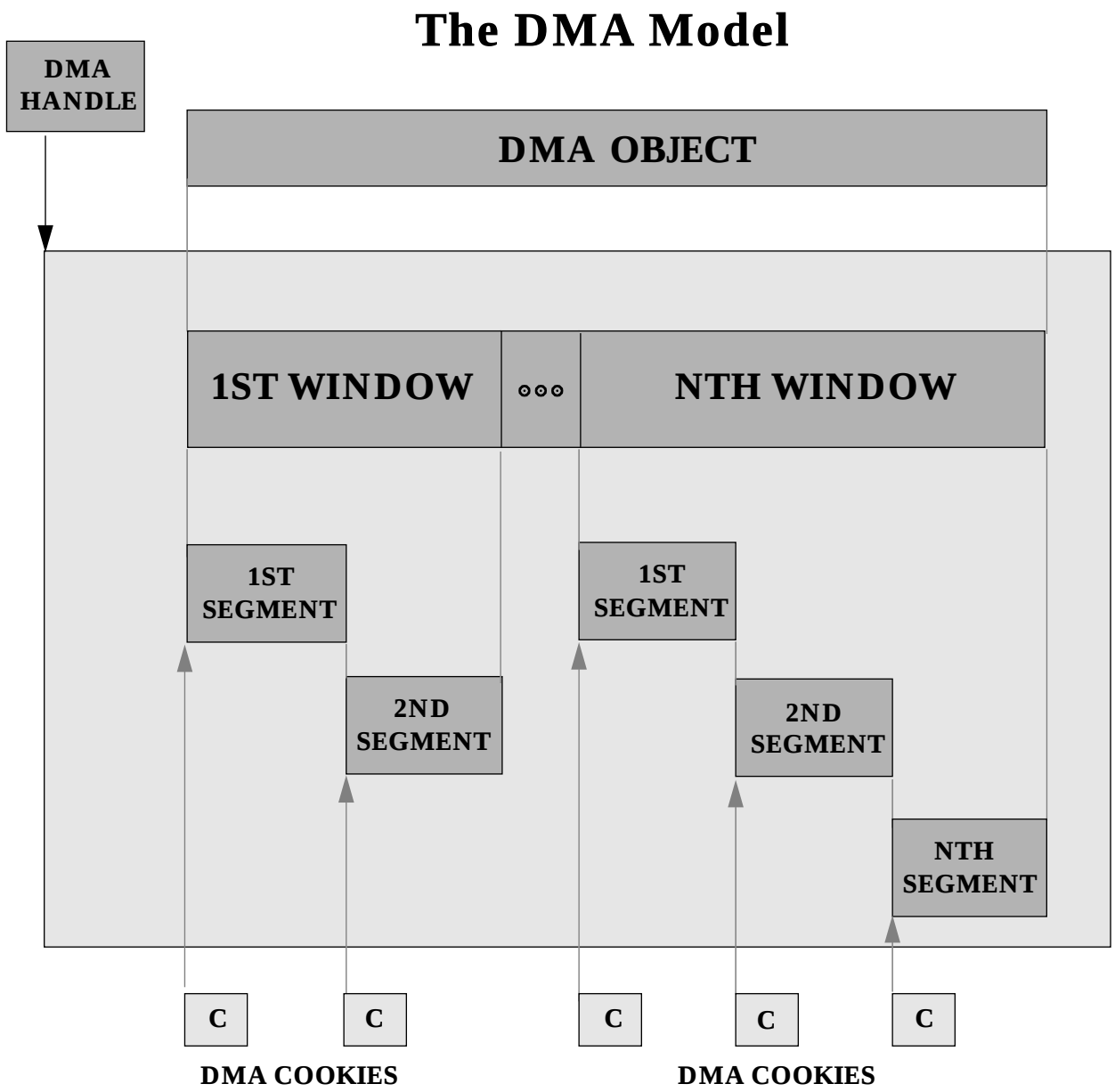


Figure 7-1 The DMA Model

7

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, then the driver should program the device's DMA registers directly. The transfer address and count is obtained from the 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 such 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 device is provided with a physical address by the system 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. In order to deal with the discontiguous memory, devices for these platforms

usually have some kind of scatter/gather DMA capability. Typically the system that supports x86 platforms provides physical addresses for direct memory transfers.

On platforms that support DVMA, the device is provided with a virtual address by the system in order to perform transfers. In this case, the underlying platform provides some form of MMU which 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 virtual pages. Devices that operate in these platforms don't need scatter/gather DMA capability. Typically the system which supports SPARC platforms provides virtual addresses for direct memory transfers.

Handles, Windows, Segments and Cookies

A DMA handle is an opaque pointer representing an object (usually a memory buffer or address) where a device can perform DMA transfer. The handle is used in several different calls to DMA routines to identify the DMA resources allocated for the object.

An object represented by a DMA handle is completely covered by one or more *DMA windows*. The system uses the information in the DMA limit structure, and the memory location and alignment of the target object, to decide how to divide an object into multiple windows in order to fit the request within system resource limitations. The `ddi_dma_nextwin`(9F) function takes a DMA handle obtained from a DMA setup function and a previous window (or NULL for the first window) and passes back the next (or first) window of the object. An active DMA window may represent allocated resources, such as intermediate buffers. The resources will be released upon the next call to `ddi_dma_nextwin`(9F) or when the DMA resources are freed using `ddi_dma_free`(9F).

A DMA window can span several discontiguous pages of system memory. If the DMA engine does not have a memory map, a DMA window might have to be broken into multiple *DMA segments*, each representing a contiguous piece of memory to or from which the DMA engine can transfer data. The `ddi_dma_nextseg`(9F) function takes a DMA window obtained from `ddi_dma_nextwin`(9F) and a previous segment (or NULL for the first segment) and returns the next (or first) segment in the window. A segment represents a contiguous object that is completely addressable in one DMA cookie.

The DMA cookie is a data structure that contains information (such as the transfer address and count) needed to program the DMA engine (see `ddi_dma_cookie`(9S)). The `ddi_dma_segtocookie`(9F) function takes a DMA segment obtained from `ddi_dma_nextseg`(9F) and passes back a DMA cookie for that segment.

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_nextseg`(9F) and `ddi_dma_segtocookie`(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 segments combined.

DMA Operations

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

Bus-master DMA

In general, here are the steps that must be followed to perform bus-master DMA.

1. Describe the device limitations. This allows the routines to ensure that the device will be able to access the buffer.
2. Lock the DMA objects 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.

---

3. Allocate DMA resources for the object.
4. Retrieve the next DMA window with `ddi_dma_nextwin`(9F).
5. Retrieve the next segment in the window with `ddi_dma_nextseg`(9F).
6. Get a DMA cookie for the segment with `ddi_dma_segtocookie`(9F).

7. Program the DMA engine on the device and start it (this is device-specific).

When the transfer is complete, continue the bus master operation:

8. Perform any required object synchronizations.
9. Transfer the rest of the window by repeating from Step 5.
10. Transfer the rest of the object by repeating from Step 4.
11. Release the DMA resources.

First-party DMA

In general, here are the steps that must be performed to perform first-party DMA.

1. Allocate a DMA channel.
2. Configure the channel with `ddi_dmae_1stparty`(9F).
3. Lock the DMA objects in memory. 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. Retrieve the next DMA window with `ddi_dma_nextwin`(9F).
6. Retrieve the next segment in the window with `ddi_dma_nextseg`(9F).
7. Get a DMA cookie for the segment with `ddi_dma_segtocookie`(9F).

Program the DMA engine and start it. When the transfer is complete, continue the DMA operation:

8. Perform any required object synchronizations.
9. Transfer the rest of the window by repeating from Step 6.
10. Transfer the rest of the object by repeating from Step 5.
11. Release the DMA resources.
12. Deallocate the DMA channel.

Third-party DMA

In general, here are the steps that must be performed to perform third-party DMA.

1. Allocate a DMA channel.
2. Retrieve the system's DMA engine limitations with `ddi_dmae_getlim`(9F).
3. Lock the DMA objects in memory. 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. Retrieve the next DMA window with `ddi_dma_nextwin`(9F).
6. Retrieve the next segment in the window with `ddi_dma_nextseg`(9F).
7. Get a DMA cookie for the segment with `ddi_dma_segtocookie`(9F).
8. Program the system DMA engine to perform the transfer with `ddi_dmae_prog`(9F).
9. Perform any required object synchronizations.
10. Transfer the rest of the window by repeating from Step 6.
11. Transfer the rest of the object by repeating from Step 5.
12. Stop the DMA engine with `ddi_dmae_stop`(9F).
13. Release the DMA resources.
14. Deallocate the DMA channel.

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 the `attach()` section on page 95.

Device limitations

Device limitations describe the built-in restrictions of a DMA engine. These limits include:

- 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_lim`(9S) structure. The system may impose additional restrictions on the device attributes, but it never removes any of the driver-supplied restrictions.

DMA Limits

All DMA resource-allocation routines take a pointer to a DMA limit structure as an argument (see Code Example 7-1 on page 134). This structure is currently processor-architecture dependant.

ddi_dma_lim_sparc

The SPARC DMA limit structure contains the following members:

```
typedef struct ddi_dma_lim_t {
    u_long  dlim_addr_lo;  /* lower bound of address range  */
    u_long  dlim_addr_hi;  /* inclusive upper bound of address range  */
    u_int   dlim_minxfer;  /* minimum effective DMA transfer size  */
    u_int   dlim_cntr_max; /* inclusive upper bound of address register  */
    u_int   dlim_burstsizes;/* bitmask encoded DMA burst sizes  */
    u_int   dlim_dmaspeed; /* average DMA data rate (KB/s) */
} ddi_dma_lim_t;
```

`dlim_addr_lo` is the lowest address that the DMA engine can access.

`dlim_addr_hi` is the highest address that the DMA engine can access.

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

`dlim_cntr_max` 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, `dlim_cntr_max` would be set to `0x00FFFFFF`; this prevents the system from crossing a 24-bit segment boundary when establishing mappings to the object.

dlim_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 bitmask encoding of the burst sizes. 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. If the device is an SBus device and can take advantage of a 64-bit SBus, the lower 16 bits are used to specify the burst size for 32-bit transfers, and the upper 16 bits are used to specify the burst size for 64-bit transfers.

dlim_dmaspeed is the average speed of the DMA engine in KBytes/second. This is intended to be a hint for the resource allocation routines, but is optional and may be zero.

ddi_dma_lim_x86

The x86 DMA limit structure contains the following members:

```
typedef struct ddi_dma_lim {
    u_long  dlim_addr_lo;  /*  lower bound of address range  */
    u_long  dlim_addr_hi;  /*  inclusive upper bound of address range  */
    u_int   dlim_cntr_max; /*  set to 0 */
    u_int   dlim_burstsizes;/*  set to 1  */
    u_int   dlim_minxfer;  /*  minimum DMA transfer size  */
    u_int   dlim_dmaspeed; /*  set to 0  */
    u_int   dlim_version;  /*  version number of this structure */
    u_int   dlim_adreg_max;/* inclusive upper bound of incrementing address */
                           /* register  */
    u_int   dlim_ctreg_max;/*  maximum transfer count - 1  */
    u_int   dlim_granular; /*  granularity of transfer count */
    u_int   dlim_sgllen;   /* length of DMA scatter/gather list */
    u_int   dlim_reqsize;  /*  maximum transfer size (bytes) of a single I/O  */
} ddi_dma_lim_t;
```

dlim_addr_lo is the lowest address that the DMA engine can access.

dlim_addr_hi is the highest address that the DMA engine can access.

dlim_minxfer is the minimum transfer size the DMA engine can perform. It also influences alignment and padding restrictions. It should be set to DMA_UNIT_8, DMA_UNIT_16, or DMA_UNIT_32 to indicate 1, 2, or 4 byte transfers.

dlim_version specifies the version number of this structure. It should be set to DMALIM_VER0.

`dlim_adreg_max` 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, `dlim_cntr_max` would be set to `0x00FFFFFF`; this prevents the system from crossing a 24-bit segment boundary when establishing mappings to the object.

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

`dlim_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.

`dlim_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.

`dlim_reqsize` 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 (`dlim_ctreg_max +1) * dlim_sgllen`. If the DMA engine has no particular limitation, this field should be set to `0xFFFFFFFF`.

Here are some examples specifying device limitations:

Example One

A DMA engine on a SPARC SBus device has the following limitations:

- It can only access addresses ranging from `0xFF000000` to `0xFFFFFFFF`.
- It has a 32-bit address register.
- It supports 1, 2 and 4-byte burst sizes.
- It has a minimum effective transfer size of 1 byte.
- The system should not make optimizations related to transfer speed.

The average speed is not known, so the `dlim_dmaspeed` field is set to zero. The resulting limit structure is:

```
static ddi_dma_lim_t limits = {
    0xFF000000,    /* low address */
    0xFFFFFFFF,    /* high address */
    0xFFFFFFFF,    /* address register maximum */
    0x7,           /* burst sizes: 0x1 | 0x2 | 0x4 */
    0x1,           /* minimum transfer size */
    0              /* speed */
};
```

Example Two

A DMA engine on a SPARC VMEbus device has the following limitations:

- It can address the full 32-bit range.
- It has a 24-bit address register.
- 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 an average transfer speed of 10 Mbytes per second.

The resulting limit structure is:

```
static ddi_dma_lim_t limits = {
    0x00000000,    /* low address */
    0xFFFFFFFF,    /* high address */
    0xFFFFFF,      /* address register maximum */
    0x1FE,         /* burst sizes */
    2,             /* minimum transfer size */
    10240          /* speed */
};
```

Example Three

A DMA engine on an x86 ISA bus device has the following limitations:

- It only access the first 16 megabytes of memory.
- It can perform transfers to segments up to 32k in size.
- It can hold up to 17 scatter/gather transfers.
- It operates on units of 512 bytes.
- It has a minimum effective transfer size of 2 bytes.
- It has an average transfer speed of 10 Mbytes per second.

The resulting limit structure is:

```
static ddi_dma_lim_t limits = {
    0x00000000,    /* low address */
    0x00FFFFFF,    /* high address */
    0,             /* must be 0 */
    1,             /* must be 1 */
    DMA_UNIT_8,    /* minimum transfer size */
    0              /* must be 0 */
    DMALIM_VER0,   /* version */
    0xFFFFFF,      /* address register maximum */
    0x007FFF,      /* maximum transfer - 1 */
    512,           /* granularity */
    17,            /* scatter/gather length */
    0xFFFFFFFF     /* request size */
};
```

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_mem_alloc`(9F) or `ddi_iopb_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 “DMA Transfers” on page 158 for an example.

Allocating DMA Resources

Two interfaces are recommended for allocating DMA resources:

`ddi_dma_buf_setup`(9F) Recommended for use with buffer structures.

`ddi_dma_addr_setup`(9F) Recommended for use 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_mem_alloc`(9F), or `ddi_iopb_alloc`(9F)	`ddi_dma_addr_setup(9F)`
Requests from the file system through `strategy`(9E)	`ddi_dma_buf_setup(9F)`
Memory in user space that has been locked down using `physio`(9F)	`ddi_dma_buf_setup(9F)`

All resource allocation routines return a DMA handle for use in subsequent calls to DMA-related functions. DMA resources are usually allocated in the driver's `xxstart( )` routine, if it has one. See "Asynchronous Data Transfers" on page 184 for discussion of `xxstart( )`.

```
int ddi_dma_addr_setup(dev_info_t *dip,
    struct as *as, caddr_t addr,
    u_int len, u_int flags, int (*waitfp)(caddr_t), caddr_t arg,
    ddi_dma_lim_t *lim, ddi_dma_handle_t *handlep);

int ddi_dma_buf_setup(dev_info_t *dip,
    struct buf *bp,
    u_int flags, int (*waitfp)(caddr_t), caddr_t arg,
    ddi_dma_lim_t *lim, ddi_dma_handle_t *handlep);
```

`ddi_dma_addr_setup`(9F) and `ddi_dma_buf_setup`(9F) take the following two arguments:

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

the object to allocate resources for

For `ddi_dma_addr_setup`(9F), the object is described by an address range:

- `as` is a pointer to an address space structure (this must be `NULL`).
- `addr` is the base kernel address of the object.
- `len` is the length of the object.

For ddi_dma_buf_setup(9F), the object is described by a buf(9S) structure:

- bp is a pointer to a buf(9S) structure.

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_req(9S) for a complete discussion of the allowed flags.

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

arg is the argument to pass to the callback function.

lim is a pointer to a ddi_dma_lim(9S) structure as described in "Device limitations" on page 128.

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 wish 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.

State Structure

This section adds the following fields to the state structure. See "State Structure" on page 57 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:

```
volatile caddr_t    dma_addr;   /* starting address for DMA */
volatile u_int      dma_size;   /* amount of data to transfer */
volatile 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. */
```

Callback Example

In Code Example 7-1 `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.

Since `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 0 if it fails to allocate resources (and needs to be called again later) or 1 indicating success (so no further callback is necessary).

See `ddi_dma_req`(9S) for a discussion of DMA callback responsibilities.

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_setup(xsp->dip, xsp->bp, flags, xxstart,
        (caddr_t)xsp, &limits, &xsp->handle) != DDI_DMA_MAPPED) {
        /* really should check all return values in a switch */
        return (0);
    }
    ...
    program the DMA engine
    ...
    return (1);
}
```

Burst Sizes

SPARC device drivers specify the burst sizes their device supports in the `dlim_burstsizes` field of the `ddi_dma_lim`(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_setup(xsp->dip, xsp->bp, flags, xxstart,
        (caddr_t)xsp, &limits, &xsp->handle) != 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 driver traverses the returned DMA window and finds the first segment. Code Example 7-2 is a simple example of this.

Code Example 7-2 Traversing windows and segments

```
ddi_dma_win_t  win, nwin;
ddi_dma_seg_t  seg, nseg;
int     retw, rets;

for (win = NULL;
    (retw = ddi_dma_nextwin(xsp->handle,win,&nwin))!=DDI_DMA_DONE;
    win = nwin) {
    if (retw != DDI_SUCCESS) {
        /* do error handling */
    } else {
        for (seg = NULL;
            (rets = ddi_dma_nextseg(nwin,seg,&nseg))!=DDI_DMA_DONE;
            seg = nseg) {
            if (rets != DDI_SUCCESS) {
                /* do error handling */
            } else {
                ddi_dma_segtocookie(nseg, &off, &len, &cookie);
                program the DMA engine
            }
        }
    }
}
```

The device must then be programmed to transfer this segment. 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 a given segment by calling `ddi_dma_segtocookie`(9F).

This function takes the segment and fills in a *DMA cookie* and the offset and length of the segment. A cookie is of type `ddi_dma_cookie`(9S) and has the following fields:

```
unsigned long  dmac_address;  /* unsigned 32 bit address */
u_int          dmac_size;     /* unsigned 32 bit size */
u_int          dmac_type;     /* bus-specific type bits */
```

Upon return from `ddi_dma_segtocookie`(9F), the `dmac_address` field of the cookie contains the DMA transfer's starting address and `dmac_size` contains the transfer count. Depending on the bus architecture, the third field in the cookie may be required by the driver.

The exact shape of `dmac_address` is device specific—the driver should know how to interpret it. There is an implementation-specific agreement on the shape of the cookie. The driver should not perform any manipulations, such as logical or arithmetical, on the cookie.

Freeing the DMA Resources

After a DMA transfer completes (usually in the interrupt routine), the DMA resources may be released by calling `ddi_dma_free(9F)`.

As described in "Synchronizing Memory Objects" on page 142," `ddi_dma_free`(9F) calls `ddi_dma_sync`(9F), eliminating the need for any explicit synchronization. After calling `ddi_dma_free`(9F), the DMA handle becomes invalid, and further references to the handle have undefined results. Code Example 7-3 shows how to use `ddi_dma_free`(9F).

Code Example 7-3 Freeing DMA resources

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

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

```
    if (!(status & INTERRUPTING)) {
        mutex_exit(&xsp->mu);
        return (DDI_INTR_UNCLAIMED);
    }
    xsp->regp->csr = CLEAR_INTERRUPT;
    /* for store buffers */
    temp = xsp->regp->csr;
    ddi_dma_free(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 is 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).

Cancelling DMA Callbacks

DMA callbacks cannot be cancelled. This requires some additional code in the drivers `detach`(9E) routine, since it must not return `DDI_SUCCESS` if there are any outstanding callbacks. 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 7-4 Cancelling 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_setup(xsp->dip, xsp->bp,
        flags, xxdmacallback, (caddr_t)xsp, &limits, &xsp->handle);
    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 (1);    /* tell framework for this callback */
                       /* routine not to 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_setup(xsp->dip, xsp->bp,
            flags, DDI_DMA_DONTWAIT, NULL, &limits, &xsp->handle);
        if (error == DDI_DMA_MAPPED) {
            ...
            program the DMA engine
            ...
            xsp->callback_count--;
            mutex_exit(&xsp->callback_mutex);
            return (1);
        }
        if (error != DDI_DMA_NORESOURCES) {
            xsp->callback_count--;
            mutex_exit(&xsp->callback_mutex);
            return (1);
        }
        mutex_exit(&xsp->callback_mutex);
        return (0);
    }
```

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).

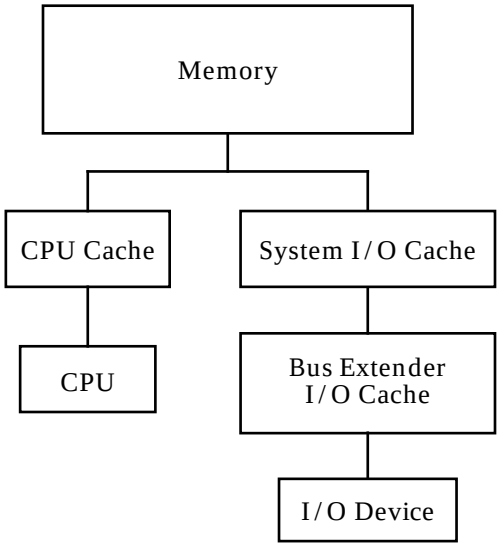


Figure 7-2 Caches

When an attempt is made to read data from main memory, the associated cache first checks to see if it contains the requested data. If so, it very 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 very 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 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_free(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,
    u_int 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_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.

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. Two interfaces are provided for allocating memory for DMA transfers: `ddi_iopb_alloc`(9F) and `ddi_mem_alloc`(9F).

`ddi_iopb_alloc()`

`ddi_iopb_alloc`(9F) should be used if the device accesses in a non-sequential fashion, or if synchronization steps using `ddi_dma_sync`(9F) should be as lightweight as possible (due to 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 using `ddi_iopb_alloc`(9F). `ddi_iopb_free`(9F) is used to free the memory allocated by `ddi_iopb_alloc`(9F).

On x86 systems, `ddi_iopb_alloc`(9F) can be used to allocate memory that is physically contiguous as well as consistent.

Code Example 7-5 is an example of 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 7-5 Using `ddi_iopb_alloc`(9F)

```
if (ddi_iopb_alloc(xsp->dip, &limits, size, &xsp->iopb_array)
    != DDI_SUCCESS) {
    error handling
    goto failure;
}
if (ddi_dma_addr_setup(xsp->dip, NULL, xsp->iopb_array, size,
    DDI_DMA_READ | DDI_DMA_CONSISTENT, DDI_DMA_SLEEP,
    NULL, &limits, &xsp->iopb_handle) != DDI_DMA_MAPPED) {
    error handling
    ddi_iopb_free(xsp->iopb_array);
    goto failure;
}
```

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ddi_mem_alloc( )

ddi_mem_alloc(9F) should be used 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.

In SPARC, ddi_mem_alloc(9F) obeys the alignment and padding constraints specified by the dlim_minxfer and dlim_burstsizes fields in the passed DMA limit structure to get the most effective hardware support for large transfers. 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_mem_alloc(9F) will round the size to a multiple of the cache line to avoid data corruption.

In x86, ddi_mem_alloc(9F) obeys the alignment specified by the dlim_minxfer fields in the passed DMA limit structure. In addition, the physical address of the allocated memory will be within the dlim_addr_lo and dlims_addr_hi of the DMA limit structure.

ddi_mem_free(9F) is used to free the memory allocated by ddi_mem_alloc(9F).

Note – If the memory is not properly aligned, the transfer will succeed but the system will pick a different (and possibly less efficient) transfer mode that requires less restrictions. For this reason, ddi_mem_alloc(9F) is preferred over kmem_alloc(9F) when allocating memory for the device to access.

Code Example 7-6 is an example of how to allocate memory for streaming access.

Code Example 7-6 Using ddi_mem_alloc(9F)

```
if (ddi_mem_alloc(xsp->dip, &limits, size, 0,
    &memp, &real_length) != DDI_SUCCESS) {
    error handling
    goto failure;
}
if (ddi_dma_addr_setup(xsp->dip, NULL, memp, real_length,
    DDI_DMA_READ, DDI_DMA_SLEEP, NULL, &limits, &mem_handle)
    != DDI_DMA_MAPPED) {
    error handling
```

```
        ddi_mem_free(memp);
        goto failure;
}
```

ddi_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_setup(9F) requires the actual length.

ddi_dma_devalign( )

After allocating DMA resources for private data buffers, ddi_dma_devalign(9F) should be used to determine the minimum required data alignment and minimum effective transfer size.

Although the starting address for the DMA transfer will be aligned properly, the offset passed to ddi_dma_htoc(9F) allows the driver to start a transfer anywhere within the object, eventually bypassing alignment restrictions. The driver should therefore check the alignment restrictions prior to initiating a transfer and align the offset appropriately.

The driver should also check the minimum effective transfer size. The minimum effective transfer size indicates, for writes, how much of the mapped object will be affected by the minimum access. For reads it indicates how much of the mapped object will be accessed.

For memory allocated with ddi_iopb_alloc(9F), the minimum transfer size will usually be one byte. This means that positioning randomly within the mapped object is possible. For memory allocated with ddi_mem_alloc(9F), the minimum transfer size is usually larger as caches might be activated that only operate on entire cache lines (line size granularity).

Example

```
if (ddi_dma_devalign(xsp->handle, &align, &mineffect) ==
    DDI_FAILURE) {
    error handling
    goto failure;
}
align = max(align, mineffect);
/* adjust offset for ddi_dma_htoc(9F) */
```

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Drivers for Character Devices 8

This chapter describes the structure of a character device driver. The entry points of a character device driver are the main focus, and the use of `physio`(9F) in `read`(9E) and `write`(9E) is also explained.

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, and must be set by the driver. Table 8-1 lists the character device driver entry points.

Table 8-1 Character Driver 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)	Identifies if the device driver supports a physical device.
`probe`(9E)	Determines if a device is present.
`attach`(9E)	Performs device-specific initialization.
`detach`(9E)	Removes device-specific state.
`getinfo`(9E)	Gets device driver information.

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Table 8-1 Character Driver Entry Points

Entry Point	Description
`open`(9E)	Gains access to a device.
`close`(9E)	Relinquishes access to a device.
`read`(9E)	Read data from device.
`write`(9E)	Write data to device.
`ioctl`(9E)	Perform arbitrary operation.
`prop_op`(9E)	Manages arbitrary driver properties.
`mmap`(9E)	Checks virtual mapping for a memory mapped device.
`segmap`(9E)	Maps device memory into user space.
`chpoll`(9E)	Poll device for events.

Note – Some of these entry points may be replaced by `nodev`(9F) or `nulldev`(9F) as appropriate.

Autoconfiguration

The `attach`(9E) routine should perform the common initialization tasks that all devices require. Typically, these tasks include:

- Allocating per-instance state structures
- Mapping the device's registers
- Registering device interrupts
- Initializing mutex and condition variables
- Creating minor nodes

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 8-1 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 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);
    default:
        return (DDI_FAILURE);
    }
}
```

For a description of the autoconfiguration process see Chapter 5, "Autoconfiguration."

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.

Code Example 8-2 Character driver open(9E) routine.

```
static int
xxopen(dev_t *devp, int flag, int otyp, cred_t *credp)
{
    int     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);
}
```

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 chooses the minor number dynamically, 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. Threads issuing the open(2) can also request exclusive access to the device (FEXCL) or specify that the open should

not block for any reason (FNDELAY), but it is up to the driver 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.

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:

- Wait for I/O to drain from output buffers before returning.
- Rewind a tape (tape device).
- Hang 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 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" for more information about the uio(9S) structure).

A 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 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 313 and "uio(9S) Handling" on page 352 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 the driver to user space, and copyin(9F) to copy data from user space to the driver. 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 describing one end of the transfer (the other end is the device). Below is a list of uio(9S) structure members that are important to character drivers.

```
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. See NOTES.*/
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 a noncontiguous area 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 that the application wants to begin the transfer at. 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 intrepret either uio_offset or uio_loffset (but not both). The driver determines the offset used according to the settings of the flags field in the cp_ops(9S) structure.

The uio_resid field starts out as the amount of data to be transferred (the sum of all the iov_len fields in uio_iov), and *must* be set by the driver to the amount of data *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) and physio(9F) update the uio(9S) structure directly. If they are used, no driver adjustments are necessary.

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Driver Operations

The read(9E) or write(9E) entry point is called when a user thread issues the corresponding system call. It is the responsibility of these routines to perform the desired transfer, then return an indication of success or failure.

Programmed I/O Transfers.

Programmed I/O (PIO) devices rely on the CPU to perform the data transfer. PIO data transfers are identical to other device register read and write operations. An assignment statement is used to move a value from one variable or structure to another.

uiomove( )

This kind of device may allow the driver to use uiomove(9F). 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. The following example is one way to write the ramdisk read(9E) routine, and relies on the following fields being present in the ramdisk state structure:

```
caddr_t    ram;       /* base address of ramdisk */
int        ramsize;   /* size of the ramdisk */
```

Code Example 8-3 Ramdisk read(9E) routine using uiomove(9F)

```
static int
rd_read(dev_t dev, struct uio *uiop, cred_t *credp)
{
    int instance;
    rd_devstate_t *rsp;

    instance = getminor(dev);
    rsp = ddi_get_soft_state(rd_statep, instance);
    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 might be a driver writing data directly to the device's memory, which must be performed one byte at a time. 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 8-4 Programmed I/O write(9E) routine using uwritec(9F).

```
static int
xxwrite(dev_t dev, struct uio *uiop, cred_t *credp)
{
    int     instance;
    int     value;
    struct xxstate *xsp;
    struct device_reg *regp;

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

    regp = xsp->regp;
    while (uiop->uio_resid > 0) {
        /*
         * do the PIO access
         */
        value = uwritec(uiop);
        if (value == -1)
            return (EFAULT);
        regp->data = (u_char)value;
        regp->csr = START_TRANSFER;
        /* this device requires a ten microsecond delay */
        /* between writes */
        drv_usecwait(10);
    }
    return (0);
}
```

DMA Transfers

Many character drivers (especially those with DMA capabilities) use `physio`(9F) to do most of the work.

```
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 a `strategy`(9E) entry point (though it does not get placed in the `cb_ops`(9S) structure). `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.

Code Example 8-5 `read`(9E) and `write`(9E) routines using `physio`(9F)

```
static int
xxread(dev_t dev, struct uio *uiop, cred_t *credp)
{
    int instance;
    struct xxstate *xsp;

    instance = getminor(dev);
    xsp = ddi_get_soft_state(statep, instance);

    if (xsp == NULL)
        return (ENXIO);
    return (physio(xxstrategy, NULL, dev, B_READ, xxminphys, uiop));
}

static int
xxwrite(dev_t dev, struct uio *uiop, cred_t *credp)
{
    int instance;
    struct xxstate *xsp;

    instance = getminor(dev);
    xsp = ddi_get_soft_state(statep, instance);

    if (xsp == NULL)
        return (ENXIO);
    return (physio(xxstrategy, NULL, dev, B_WRITE, xxminphys,uiop));
}
```

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. The return value of physio(9F) is determined by the strategy(9E) routine.

minphys( )

xxminphys is a pointer to a function to be called by physio(9F) to ensure that the size of the requested transfer does not exceed a driver-imposed limit. If the user requests a larger transfer, physio(9F) calls xxstrategy() repeatedly, requesting no more than the imposed limit at a time. This is important for DMA transfers because there is only finite amount of DMA resources available. Drivers for slow devices, such as printers, should be careful because they tie up resources for a long time.

Usually, a driver passes a pointer to the kernel function minphys(9F), but it can define its own xxminphys() routine instead. The job of minphys(9F) 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 minphys routine should call the system minphys(9F) routine before returning.

Code Example 8-6 minphys(9F) routine

```
#define XXMINVAL (124 << 10)

static void
xxminphys(struct buf *bp)
{
    if (bp->b_bcount > XXMINVAL)
        bp->b_bcount = XXMINVAL
    minphys(bp);
}
```

8

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 this example, the strategy(9E) routine for a character-oriented DMA device allocates DMA resources for the data transfer and starts the command by programming the device register (see Chapter 7, "DMA," for a detailed description). Note that strategy(9E) does not receive a device number (dev_t) as a parameter, this is instead retrieved from the b_edev field of the buf(9S) structure.

Code Example 8-7 strategy(9E) routine supporting physio(9F)

```
static int
xxstrategy(struct buf *bp)
{
    int     instance;
    struct xxstate *xsp;
    ddi_dma_cookie_t   cookie;

    instance = getminor(bp->b_edev);
    xsp = ddi_get_soft_state(statep, instance);
    ...
    set up DMA resources with ddi_dma_buf_setup(9F)

    xsp->bp = bp; /* remember bp */

    program DMA engine and start command

    return (0);
}
```

Though strategy(9E) is declared to return an int, it should always return zero. strategy(9E) indicates an error to physio(9F) by setting the B_ERROR bit in the b_flags member of the buf(9S) structure, and placing the appropriate error number in the b_error field. physio(9F) will then return zero to indicate success, or the value of the b_error field if an error occurs.

After calling strategy(9E), physio(9F) waits until the driver finishes with the buf(9S) structure (the transfer fails or is complete) by calling biowait(9F). A call to biodone(9F) must later be made by the driver or physio(9F) will wait forever. For example, strategy(9E) must call biodone(9F) when an error occurs.

Transfer Completion

On completion of the DMA transfer, the device generates an interrupt. Eventually, the interrupt routine will be called. In this example, xxintr() receives a pointer to the state structure for the device that might have issued the interrupt. The most important function in the interrupt routine is to notify physio(9F) that the transfer is complete, which is accomplished by the call to biodone(9F). If the driver does not notify physio(9F) that the transfer is complete, physio(9F) will not return, and the thread will hang.

Code Example 8-8 Interrupt routine using physio(9F)

```
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_free(9F))

    /* wake up waiting thread in physio(9F) */
    biodone (xsp->bp);

    return (DDI_INTR_CLAIMED);
}
```

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 mmap(9E) entry point. A typical example is a frame buffer driver that implements the mmap(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 all memory mapped devices usually use ddi_segmap(9F) as the entry point rather than define their own segmap(9E) routine.

mmap( )

```
int xxmmap(dev_t dev, off_t off, int prot);
```

This routine is called as a result of an mmap(2) system call, and also as the result of a page fault. mmap(9E) is called to translate the device offset off to the corresponding page frame number. Code Example 8-9 allows a user thread to memory map the device registers.

Code Example 8-9 mmap(9E) routine

```
static int
xxmmap(dev_t dev, off_t off, int prot)
{
    int     instance;
    struct xxstate *xsp;

    if (prot & PROT_WRITE)
        return (-1);

    instance = getminor(dev);
    xsp = ddi_get_soft_state(statep, instance);
    if (xsp == NULL)
        return (-1);

    if (off is invalid)
        return (-1);
    return (hat_getkpfnum(xsp->regp->csr + off));
}
```

dev is the device number and off is the offset into the device's memory. prot specifies the kind of access requested, such as PROT_READ and PROT_WRITE A value of PROT_WRITE for prot would be invalid on a read-only device. See mmap(9E) and mmap(2).

hat_getkpfnum(9F) returns the page frame number for the memory that should be mapped. xsp->regp->csr is the kernel virtual address of the device memory determined in attach(9E) by calling ddi_map_regs(9F) and stored in the state structure.

In Code Example 8-9 the whole address range up to off must be mapped using ddi_map_regs(9F). This can use a lot of system resources for devices that have a large mappable memory area, and is a waste of resources if the driver only needs the mapping so it can call hat_getkpfnum(9F). A better way to get the page frame number for a given offset is to just map that individual page, retrieve the page frame number, then unmap the page before returning. Since the page frame number refers to a page on the device, it will not change when the page is unmapped.

Code Example 8-10 mmap(9E) routine using less resources.

```
static int
xxmmap(dev_t dev, off_t off, int prot)
{
    int     kpfn = -1;
    caddr_t kva;

    ...
    if (ddi_map_regs(xsp->dip, rnumber, &kva, off, ptob(1)) ==
        DDI_SUCCESS) {
        kpfn = hat_getkpfnum(kva);
        ddi_unmap_regs(xsp->dip, rnumber, &kva, off, ptob(1));
    }
    return (kpfn);
}
```

If the mappable memory of the device is physically contiguous, converting off to the number of pages and adding it to the base page frame number will give the same result as getting the page frame number of a mapped page. In this case, only the first page of the device's memory needs to be mapped:

```
        return (hat_getkpfnum(xsp->regp->csr) + btop(off));
```

For an example showing how to access a memory mapped device from a user program see "Using Existing Drivers" on page 243.

8

Multiplexing I/O on File Descriptors

A thread sometimes wants to handle I/O on more than one file descriptor. One example is an application program that wants 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 files 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.

State Structure

This section adds the following field to the state structure. See “State Structure” on page 57 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 wish to support polling.

In `chpoll`(9E), the driver must follow the following 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 8-11, 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.

  The following two examples show how to implement the polling discipline and how to use `pollwakeup`(9F).

Code Example 8-11 `chpoll`(9E) routine

```
static int
xxchpoll(dev_t dev, short events, int anyyet,
    short *reventsp,struct pollhead **phpp)
{
    int    instance;
    u_char status;
    short  revent;
    struct xxstate *xsp;

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

    revent = 0;
    /*
     * Valid events are:
     * POLLIN | POLLOUT | POLLPRI | POLLHUP | POLLERR
     * This example checks only for POLLIN and POLLERR.
     */
    status = 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 this example, 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 8-12 Interrupt routine supporting `chpoll`(9E)

```
static u_int
xxintr(caddr_t arg)
{
    struct xxstate *xsp = (struct xxstate *) arg;
    u_char  status, temp;
    normal interrupt processing
    ...
    status = 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, since it could cause the chpoll(9E) routine to be entered, causing 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(9E)

```
int xxioctl(dev_t dev, int cmd, int 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)

#define XX_GET_STATE  (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 know 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 8-13 `ioctl`(9E) routine

```
static int
xxioctl(dev_t dev, int cmd, int arg, int mode,
    cred_t *credp,int *rvalp)
{
    int     instance;
    u_char      csr;
    struct xxstate *xsp;

    instance = getminor(dev);
    xsp = ddi_get_soft_state(statep, instance);
    if (xsp == NULL) {
        return (ENXIO);
    }
    switch (cmd) {
    case XX_GET_STATUS:
        csr = xsp->regp->csr;
        if (ddi_copyout(&csr, (caddr_t) arg, sizeof(u_char),
            mode) != 0) {
            return (EFAULT);
        }
        break;
    case XX_SET_CMD:
        if (ddi_copyin((caddr_t) arg, &csr, sizeof(u_char),
            mode) != 0) {
            return (EFAULT);
        }
        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 8-13, for the case of an `XX_GET_STATUS` request the contents of `xsp->regp->csr` is 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 negative values indicate failure.

An application that uses the I/O controls above could look like the following:

Code Example 8-14 Using `ioctl`(2)

```
#include <sys/types.h>
#include “xxio.h”

int main(void)
{
    u_char  status;
    .......
    /*
     * read the device status
     */
    if (ioctl(fd, XX_GET_STATUS, &status) == -1) {
        /* error handling */
    }
    printf("device status %x\n", status);
    exit(0);
}
```

8

Drivers for Block Devices 9

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 B, "Advanced Topics."

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.

9

State Structure

This chapter adds the following fields to the state structure. See "State Structure" on page 57 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 9-1 lists the block driver entry points.

Table 9-1 Block Driver Entry Points

Entry Point	Description
`_init`(9E)	Initialize a loadable driver module.
`_info`(9E)	Return information on a loadable driver module.
`_fini`(9E)	Prepare a loadable driver module for unloading.
`identify`(9E)	Determine if the device driver supports a given physical device.
`probe`(9E)	Determine if a device is present.
`attach`(9E)	Perform device-specific initialization.
`detach`(9E)	Remove device-specific state.
`getinfo`(9E)	Get device driver information.
`dump`(9E)	Dump memory to the device during system failure.
`open`(9E)	Gain access to a device.
`close`(9E)	Relinquish access to a device.
`prop_op`(9E)	Manage arbitrary driver properties.
`print`(9E)	Print error message on driver failure.
`strategy`(9E)	I/O interface for block data.

Note – Some of the above entry points may 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 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 59 for details.

Code Example 9-1 shows a typical `attach`(9E) entry point with emphasis on creating the device's minor node and the `nblocks` property.

Code Example 9-1 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 the devices 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_create(makedevice(DDI_MAJOR_T_UNKNOWN,
                instance), dip, DDI_PROP_CANSLEEP,
                "nblocks", (caddr_t)&xsp->nblocks, sizeof (int))
                != 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);
        default:
            return (DDI_FAILURE);
        }
    }
```

Properties are associated with device numbers. In Code Example 9-1, 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 8, "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 171 for more information.

The open(9E) entry point should make the following checks:

- The device can be opened: for example, it is on-line 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 9-2 Block driver open(9E) routine

```
static int
xxopen(dev_t *devp, int flags, int otyp, cred_t *credp)
{
    int     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`, though `close`(9E) will only be called once 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 `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 the example, close(9E) must determine when the device can really be closed based on the number of block opens and layered opens.

Code Example 9-3 Block device close(9E) routine

```
static int
xxclose(dev_t dev, int flag, int otyp, cred_t *credp)
{
    int     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 */
    /* wait for I/O to drain */
    mutex_exit(&xsp->mu);

    return (0);
}
```

9

Data Transfers

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* comes from 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.

The buf *Structure*

Below is a list of buf structure members that 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 */
unsigned int    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 */
unsigned int    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) in preference to setting B_ERROR.

Caution – Drivers should never clear b_flags.

av_forw and av_back are pointers that can be used to manage a list of buffers by the driver. See “Asynchronous Data Transfers” on page 184 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 virtual address of the data buffer when it is mapped into the kernel.

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 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 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 due to an error. See Code Example 9-8 on page 185 for an example of setting b_resid. The b_resid member is overloaded: it is also used by disksort(9F).

b_error is set by the driver an error number 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) in preference to setting b_error directly.

b_private is used exclusivly 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 data is not directly accessible

by the driver. 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.

Synchronous Data Transfers

This section discusses a simple method for performing synchronous I/O transfers. It is assumes that the hardware is a simple disk device that can transfer only one data buffer at a time using DMA**.** The device driver's `strategy`(9E) routine waits for the current request to complete before accepting a new one. The device interrupts the CPU when the transfer completes 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 to see if:

   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. Set up the buffer for DMA

Prepare the data buffer for a DMA transfer using `ddi_dma_buf_setup`(9F). See Chapter 7, “DMA,” for information on setting up DMA resources and related data structures.

4. 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.

Code Example 9-4 Synchronous block driver `strategy`(9E) routine

```
static int
xxstrategy(struct buf *bp)
{
    struct xxstate *xsp;
    struct device_reg *regp;
    u_char  temp;
    int     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);
```

set up DMA resources with ddi_dma_buf_setup(9F)
retrieve the DMA cookie from the handle returned.

```
    xsp->bp = bp;
    /* Set up device DMA engine from the cookie. */
    regp = xsp->regp;
    regp->dma_addr = cookie.dmac_address;
    regp->dma_size = cookie.dmac_size;
    regp->csr = ENABLE_INTERRUPTS | START_TRANSFER;
    /* Read the csr to flush any hardware store buffers */
    temp = regp->csr;
    return (0);
}
```

5. Handle the interrupting device

When the device finishes the data transfer it generates an interrupt, which eventually results in the 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 111). 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 9-5 Synchronous block driver interrupt routine

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

    mutex_enter(&xsp->mu);

    status = 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;
        bp->b_error = EIO;
        bp->b_flags |= B_ERROR;
    } else {
        /* success */
        bp->b_resid = 0;
    }
```

```
    xsp->regp->csr = CLEAR_INTERRUPT;
    /* Read the csr to flush any hardware store buffers */
    temp = xsp->regp->csr;
    /* The transfer has finished, successfully or not */
    biodone(bp);
    release any resources used in the transfer, such as DMA resources (ddi_dma_free(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 180 for more details.

2. Enqueue the request

Unlike synchronous data transfers, the asynchronous driver does not wait for the current data transfer 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.

This example is designed to allow multiple threads access to the drivers 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 9-6 Asynchronous block driver `strategy`(9E) routine.

```
static int
xxstrategy(struct buf *bp)
{
    struct xxstate *xsp;
    int    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->ist_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 all requests, regardless of the state of the device (busy or free), are processed by `start( )`.

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 non-empty 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. The example is written as if it will also be used as a DMA callback (though 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 135 for more information about DMA callback routines.

Code Example 9-7 Block driver start() routine.

```
static int
xxstart(caddr_t arg)
{
    struct xxstate *xsp = (struct xxstate *)arg;
    struct device_reg *regp;
    struct buf *bp;
    u_char     temp;

    /* start() should never be called with the mutex held. */
    /* just in case, though... */
    ASSERT(!mutex_owned(&xsp->mu));

    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);

    set up DMA resources with ddi_dma_buf_setup(9F)

    xsp->bp = bp;

    /* Set up device DMA engine from the cookie. */
    regp = xsp->regp;
    regp->dma_addr = cookie.dmac_address;
    regp->dma_size = cookie.dmac_size;
    regp->csr = ENABLE_INTERRUPTS | START_TRANSFER;

    /* Read the csr to flush any hardware store buffers */
    temp = regp->csr;

    return (0);
}
```

4. Handle the interrupting Device

The interrupt routine is very 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 9-8 Asynchronous block driver interrupt routine.

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

    mutex_enter(&xsp->mu);
```

```
    status = 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;
    }
    xsp->regp->csr = CLEAR_INTERRUPT;
    /* Read the csr to flush any hardware store buffers */
    temp = xsp->regp->csr;
    /* The transfer has finished, successfully or not */
    biodone(bp);
```

release any resources used in the transfer, such as DMA resources (ddi_dma_free(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 dump a portion of virtual address space directly to the specified device in the case of a system failure.

```
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 to start the dump at, blkno is the beginning block to dump to, and nblk is the number of blocks to dump. The example depends on the existing driver working properly. It creates a buf(9S) request to pass to strategy(9E). Interrupts are not necessarily enabled at this point, so xxdump( ) calls a special version of strategy(9E) (not shown) that only does polled I/O (non-interrupt driven).

Code Example 9-9 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_KERNBUF;
    bp->b_blkno = blkno;

    disable interrupts

    (void) xxstrategy_poll(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);
}
```

SCSI Target Drivers 10

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 – Target driver developers may be interested in SCSI HBA driver information. A SCSI HBA chapter in progress (`SCSIHBA.PS`) is included as a .ps file in the DDK. It is located in this path: `opt/SUNWddk/doc`

Overview

The Solaris 2.4 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 SCSI HBA 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” as defined in SCSI specifications.

10

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 information on setting global SCSI options see Appendix B, “Advanced Topics.”

For a pointer to SCSI driver sample code see Appendix D, “Sample Driver Source Code Listings”.

Sun Common SCSI Architecture Overview

The Sun Common SCSI Architecture (SCSA) is the Solaris 2.4 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 that is 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.

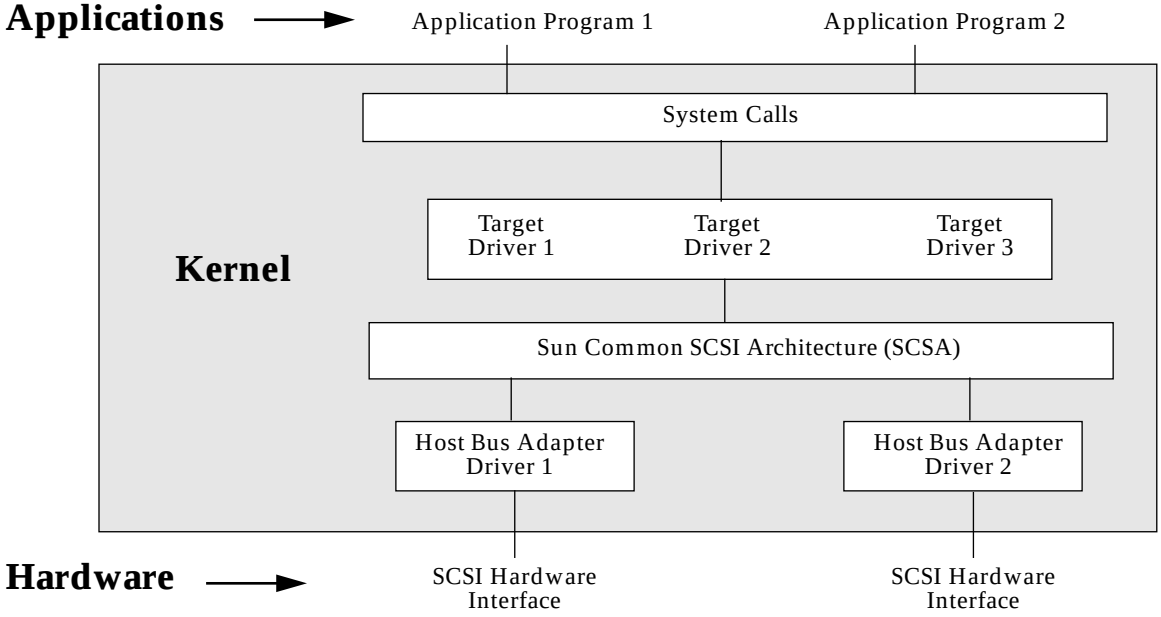

Figure 10-1 SCSA Block Diagram

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)

The target driver is completely responsible for the generation of the proper SCSI commands required to execute the desired function.

General Flow of Control

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) to encode the request into a `buf`(9S) structure and call 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 CDB using the `makecom`(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 completes.

4. After the target sends completion status and disconnects, the host bus adapter driver notifies the target driver by calling the completion function which 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 in order to retrieve the sense data in the event of a check condition.

6. If either the command 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 may call `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 allows the execution of target driver functions on host bus adapter drivers using SCSI bus adapters of varying degrees of intelligence.

10

SCSA Functions

SCSA defines a number of functions, listed in Table 10-1, which manage the allocation and freeing of resources, the sensing and setting of control states, and the transport of SCSI commands:

Table 10-1 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)`	
`makecom_g0(9F)`	CDB initialization functions
`makecom_g1(9F)`	
`makecom_g0_s(9F)`	
`makecom_g5(9F)`	

SCSA Compatibility Functions

The functions listed in Table 10-2 are maintained for both source and binary compatibility with previous releases. However, new drivers should use the new functions listed in Table 10-1.

Table 10-2 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)	

SCSI Target Drivers

Hardware Configuration File

Since 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 allows 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.

10

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 202.

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);
long        pkt_flags;
u_long      pkt_time;
u_char      *pkt_scbp;
u_char      *pkt_cdbp;
long        pkt_resid;
u_long      pkt_state;
u_long      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 may 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, 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 parity (`FLAG_NOPARITY`). See `scsi_pkt`(9S) for details.

`pkt_time` is a timeout value (in seconds). If the command does not complete 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 understands.

`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 due to 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 completes, the target driver should examine the pkt_scbp field for a check condition status. See scsi_pkt(9S) for more information.

State Structure

This section adds the following fields to the state structure. See "State Structure" on page 57 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), _info(9E), and identify(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 or not the expected type of device is present and responding.

10

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.

Since 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 10-1 shows a typical probe(9E) routine. It uses the ddi_getprop(9F) routine to retrieve the device's SCSI target and logical unit numbers so that it can print them in messages. It also retrieves its scsi_device(9S) structure from the private field of its dev_info structure. 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 check to see 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 10-1 SCSI target driver probe(9E) routine

```
static int
xxprobe(dev_info_t *dip)
{
    struct scsi_device *sdp;
    int rval, target, lun;

    /*
     * Get the SCSI target/lun properties. DDI_PROP_DONTPASS
     * prevents ddi_getprop from looking beyond this node for the
     * properties.
     */
    target = ddi_getprop(DDI_DEV_T_ANY, dip, DDI_PROP_DONTPASS,
         “target”, -1);
    lun = ddi_getprop(DDI_DEV_T_ANY, dip, DDI_PROP_DONTPASS,
```

```
    “lun”, -1);
if ((target == -1) || (lun == -1))
    return (DDI_FAILURE);
/*
 * Get a pointer to the scsi_device(9S) structure
 */
sdp = (struct scsi_device *) ddi_get_driver_private(dip);
/*
 * 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 useable.
     */
    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 and creates minor device node information. See “attach( )” on page 95 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 makecom_g0(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 syncing 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. makecom_g0(9F) creates a SCSI Command Descriptor Block (CDB), in this case creating a SCSI Request Sense command.

Code Example 10-2 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);
```

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
     */
    makecom_g0(rqpkt, devp, FLAG_NOPARITY, SCMD_REQUEST_SENSE,
        0, SENSE_LENGTH);
    /*
     * 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
    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.

Code Example 10-3 SCSI target driver detach(9E) routine

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

```
    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
    return (DDI_SUCCESS);
}
```

getinfo( )

The getinfo(9E) routine for SCSI target drivers is much the same as for other drivers; see “getinfo( )” on page 102 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 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 10-4 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, *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 (CDB) 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 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 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 dmar_flag set. The pkt_resid(9E) field of the scsi_pkt(9S) structure may be returned with a non-zero residual, indicating the number of bytes for which scsi_init_pkt() 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_sync_pkt`(9F) routine can be used to synchronize any cached data after a transfer, when a target driver wants to reuse a `scsi_pkt` for another command. This may be done either in the command completion routine or before calling `scsi_transport`(9F) for the command a second time.

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).

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 which 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 202 and “detach( )” on page 204 for examples.

10

Building and Transporting a Command

The host bus adapter driver is responsible for transmitting the command to the device and taking care of 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 `makecom`(9F) family of functions:

```
makecom_g0(pkt, sdp, flags, SCMD_READ, bp->b_blkno,
    bp->b_bcount >> DEV_BSHIFT);
```

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 fourth parameter (`SCMD_READ`).
- The target device's logical unit number (bits 5-7 of byte 1) is set using `sd_address` field of `sdp`.
- The `pkt_flags` field is set from the `flags` parameter.
- 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.

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.

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.
- TRAN_BADPKT - The host adapter driver rejected this packet.
- 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.

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. A simple completion routine is given in Code Example 10-5.

Code Example 10-5 SCSI driver completion routine

```
static void
xxcallback(struct scsi_pkt *pkt)
{
    struct buf     *bp;
    struct xxstate *xsp;
    int            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);
        }
    }
}
```

This is a very simple completion callback routine. It checks to see whether the command completed and if it did not, gives up immediately. If the target was busy it gives up, or if it returned a “check condition” status, it sends a Request Sense command.

Otherwise, the command succeeded. If this is the end of processing for the command, it destroys the packet and calls `biodone`(9F).

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 B, “Advanced Topics” for further information.

10

Device Context Management 11

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 context for a process is managed by the device driver 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. Since 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 allow a device driver to be notified when a user processes accesses memory-mapped regions of the device and to control accesses to the device's hardware. Synchronization and management of the various device contexts is the responsibility 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 on a mapping:

- Access to a mapping by a user process
- Duplication of a mapping by a user process
- Freeing of a mapping by a user process

Figure 11-1 is a snapshot of multiple user processes that have memory mapped a device. Process B has been granted access to the device by the driver, and the driver no longer requires notification by process B. However, the driver *does* require notification if either process A or process C access the device.

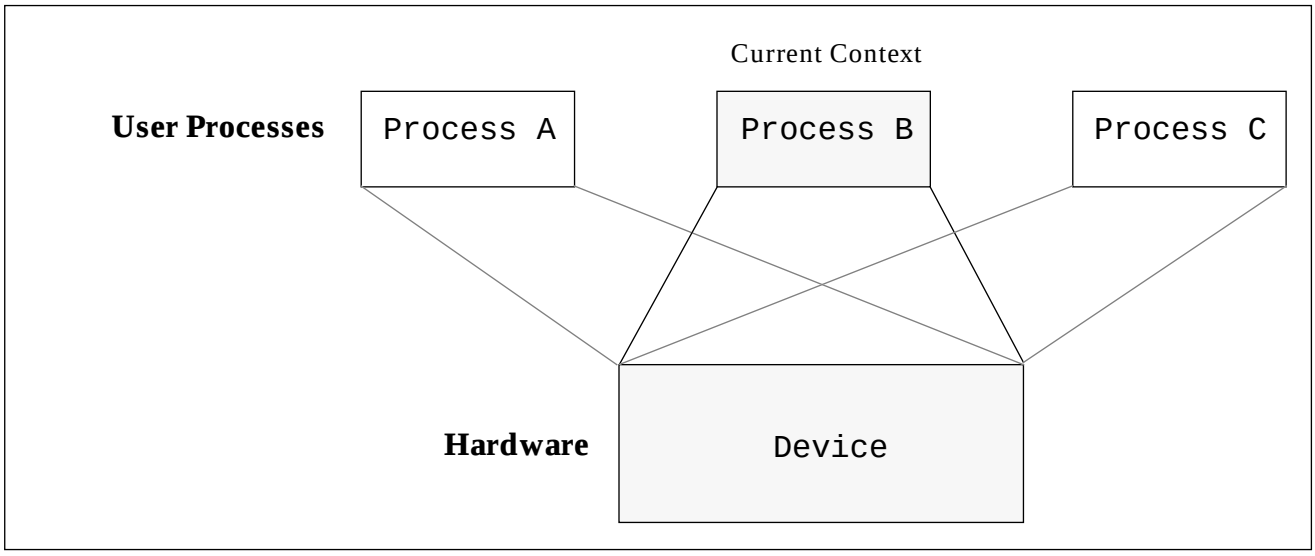

Figure 11-1 Device context management

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 restores the device context of process A and grants access to process A. This is illustrated in Figure 11-2. At this point, the device driver requires notification if either process B or process C access the device.

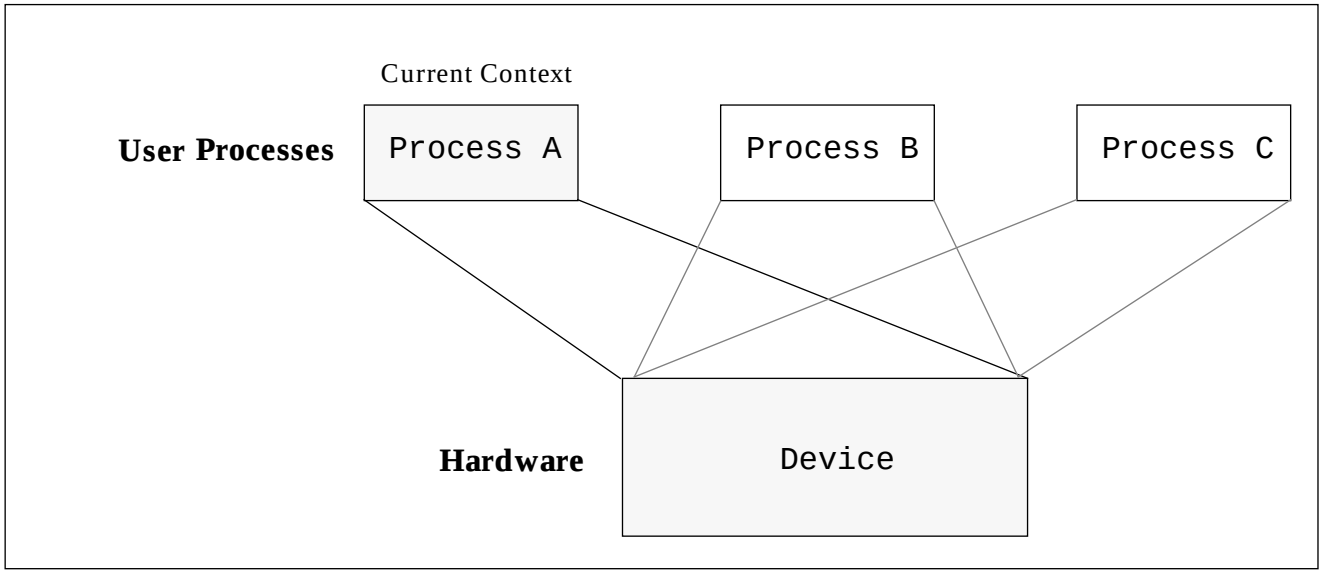

Figure 11-2 Device context switched to user process A

Multiprocessor Considerations

On a multiprocessor machine, multiple processes could be attempting to access the device at the same time. This can cause thrashing. The kernel prevents this from happening by guaranteeing 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 at least one clock tick.

However, some devices require more time to restore a device context than others. To prevent more CPU time from being used to restore a device context than to actually use that device context, the time that a process needs to have access to the device must be increased. If more time than one click tick is

required, the driver can block new access to the device for an additional predetermined amount of time using the standard thread synchronization function calls. See “Thread Synchronization” on page 79 for more information.

Context Management Operation

In general, here are the steps for performing device context management:

1. Define a `ddi_mapdev_ctl`(9S) structure.
2. Allocate space to save device context if necessary.
3. Set up user mappings to the device and driver notifications with `ddi_mapdev`(9F).
4. Manage user access to the device with `ddi_mapdev_intercept`(9F) and `ddi_mapdev_nointercept`(9F).
5. Free the device context structure if needed.

State Structure

This section adds the following fields to the state structure. See “State Structure” on page 51 for more information.

```
kmutex_t            ctx_lock;
struct xxctx        *current_ctx;
```

The structure `xxctx` is the driver private device context structure for the examples used in this section. It looks like this:

```
struct xxctx {
    ddi_mapdev_handle_t    handle;
    char                   context[XXCTX_SIZE];
    struct xxstate         *xsp;
};
```

The `context` field stores the actual device context. In this case, it is simply a chunk of memory; in other cases, it may actually be a series of structure fields corresponding to device registers.

Declarations and Data Structures

Device drivers that use the device context management interfaces must include the following declaration:

```
char _depends_on[] = "misc/seg_mapdev";
```

ddi_mapdev_ctl()

The device driver must allocate and initialize a `ddi_mapdev_ctl`(9S) structure to inform the system of its device context management entry point routines.

This structure contains the following fields:

```
struct ddi_mapdev_ctl {
    int mapdev_rev;
    int (*mapdev_access)(ddi_mapdev_handle_t handle,
        void *private, off_t offset);
    void (*mapdev_free)(ddi_mapdev_handle_t handle, void
        *private);
    int (*mapdev_dup)(ddi_mapdev_handle_t oldhandle,
        void *oldprivate, ddi_mapdev_handle_t newhandle,
        void **newprivate);
};
```

`mapdev_rev` is the version number of the `ddi_mapdev_ctl`(9S) structure. It must be set to `MAPDEV_REV`.

`mapdev_access` must be set to the address of the driver's `mapdev_access`(9E) entry point.

`mapdev_free` must be set to the address of the driver's `mapdev_free`(9E) entry point.

`mapdev_dup` must be set to the address of the driver's `mapdev_dup`(9E) entry point.

Associating Devices with User Mappings

When a user process requests a mapping to a device with `mmap`(2), the device's `segmap`(9E) entry point is called. The device must use `ddi_mapdev`(9F) when setting up the memory mapping if it wants to manage device contexts. Otherwise the device driver must use `ddi_segmap`(9F) to set up the mapping.

Unlike, ddi_segmap(9E), ddi_mapdev(9F) can not be used directly as an entry point in the cb_ops(9S) structure. You must define a segmap(9E) entry point to use ddi_mapdev(9F).

```
int ddi_mapdev(dev_t dev, off_t offset, struct as *asp,
        caddr_t *addrp, off_t len, u_int prot, u_int maxprot,
        u_int flags, cred_t *cred, struct ddi_mapdev_ctl *m_ops,
        ddi_mapdev_handle_t *handlep, void *private_data);
```

ddi_mapdev(9F) is similar to ddi_segmap(9F) in that they both allow a user to map device space. In addition to establishing a mapping, ddi_mapdev(9F) informs the system of the ddi_mapdev_ctl(9S) entry points and creates a handle to the mapping in *handlep. This *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.

To ensure that a device driver can distinguish between the various user processes that have memory-mapped the device, only mappings of type MAP_PRIVATE can be used with ddi_mapdev(9F).

The dev, offset, asp, addrp, len, prot, maxprot, flags, and cred arguments are passed into the segmap(9E) entry point and should be passed on to ddi_mapdev(9F) unchanged. ddi_mapdev(9F) also takes the driver-defined structure ddi_mapdev_ctl(9S) and a pointer to device private data. This pointer is passed into each entry point and is usually a pointer to the device context structure.

Code Example 11-1 segmap(9E) entry point

```
static struct ddi_mapdev_ctl xx_mapdev_ctl = {
    MAPDEV_REV,
    xxmapdev_access,
    xxmapdev_free,
    xxmapdev_dup
};
```

```
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;
    int     instance = getminor(dev);
    struct xxstate *xsp = ddi_get_soft_state(statep, instance);
    struct xxctx *newctx;

    /* Create a new context for this mapping */
    newctx = kmem_alloc(sizeof (struct xxctx), KM_SLEEP);
    newctx->xsp = xsp;
    /* Set up mapping */
    error = ddi_mapdev(dev, off, asp, addrp, len, prot,
        maxprot, flags, credp, &xx_mapdev_ctl, &newctx->handle,
        newctx);
    if (error)
        kmem_free(newctx, sizeof (struct xxctx));
    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 `ddi_mapdev_intercept`(9F) and `ddi_mapdev_nointercept`(9F) are used to invalidate and validate mapping translations.

```
int ddi_mapdev_intercept(ddi_mapdev_handle_t handle,
    off_t offset, off_t len);
```

`ddi_mapdev_intercept`(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 mapdev_access(9E) entry point.

```
int ddi_mapdev_nointercept(ddi_mapdev_handle_t handle,
    off_t offset, off_t len);
```

ddi_mapdev_nointercept(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 allow accesses to proceed without notifying the device driver.

ddi_mapdev_nointercept(9F) must be called with the offset and the handle of the mapping that generated the access event for the access to complete. If ddi_mapdev_nointercept(9F) is not called on this handle, the mapping translations will not be validated and the process will receive a SIGBUS.

For both functions, requests affect the entire page containing the offset and all the pages up to and including the entire page containing the last byte as indicated by offset + len. The device driver must make sure 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:

mapdev_access()

```
int xxmapdev_access(ddi_mapdev_handle_t handle, void *devprivate,
    off_t offset);
```

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 ddi_mapdev(9F) in response to mmap(2), duplicated by fork(2), or explicitly invalidated by a call to ddi_mapdev_intercept(9F).

`handle` represents 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.

In general, `mapdev_access`(9E) should call `ddi_mapdev_intercept`(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 `mapdev_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 `ddi_mapdev_nointercept`(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 `ddi_mapdev_nointercept`(9F) do not generate a call to `mapdev_access`(9E). A subsequent call to `ddi_mapdev_intercept`(9F) will invalidate the mapping translations and allows `mapdev_access`(9E) to be called again.

If either `ddi_mapdev_intercept`(9F) or `ddi_mapdev_nointercept`(9F) return an error, `mapdev_access`(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, `mapdev_access`(9E) should return zero. A return of other than zero from `mapdev_access`(9E) will cause a `SIGBUS` or `SIGSEGV` to be sent to the process.

Code Example 11-2 shows how to manage a one-page device context.

Code Example 11-2 `mapdev_access`(9E) routine

```
static int
xxmapdev_access(ddi_mapdev_handle_t handle, void *devprivate,
    off_t offset)
{
    int error;
    struct xxctx   *ctxp = devprivate;
    struct xxstate *xsp = ctxp->xsp;
```

```
    mutex_enter(&xsp->ctx_lock);
    /* enable access callback for the current mapping */
    if (xsp->current_ctx != NULL) {
        if ((error = ddi_mapdev_intercept(xsp->current_ctx->handle,
            offset, 0)) != 0) {
                xsp->current_ctx = NULL;
                mutex_exit(&xsp->ctx_lock);
                return (error);
        }
    }
    /* Switch device context - device dependent*/
    if (xxctxsave(xsp->current_ctx) < 0) {
        xsp->current_ctx = NULL;
        mutex_exit(&xsp->ctx_lock);
        return (-1);
    }
    if (xxctxrestore(ctxp) < 0){
        xsp->current_ctx = NULL;
        mutex_exit(&xsp->ctx_lock);
        return (-1);
    }
    xsp->current_ctx = ctxp;
    /* Disable access callback for handle and return */
    error = ddi_mapdev_nointercept(handle, offset, 0);
    if (error)
        xsp->current_ctx = NULL;
    mutex_exit(&xsp->ctx_lock);
    return(error);
}
```

mapdev_free()

```
void xxmapdev_free(ddi_mapdev_handle_t handle, void *devprivate);
```

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. Partial unmappings are not supported and will cause the munmap(2) system call to fail with EINVAL.

handle is the handle of the mapping being freed.

devprivate is a pointer to the driver private data associated with the mapping.

The mapdev_free(9E) routine is expected to free any driver-private resources that were allocated when this mapping was created, either by ddi_mapdev(9F) or by mapdev_dup(9E).

There is no need to call ddi_mapdev_intercept(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 mapdev_access(9E), the device driver should make sure that its representation of the current mapping is set to “no current mapping”.

Code Example 11-3 mapdev_free(9E) routine

```
static void
xxmapdev_free(ddi_mapdev_handle_t handle, void *devprivate)
{
    struct xxctx   *ctxp = devprivate;
    struct xxstate *xsp = ctxp->xsp;

    mutex_enter(&xsp->ctx_lock);
    if (xsp->current_ctx == ctxp)
        xsp->current_ctx = NULL;
    mutex_exit(&xsp->ctx_lock);
    kmem_free(ctxp, sizeof (struct xxctx));
}
```

mapdev_dup()

```
int xxmapdev_dup(ddi_mapdev_handle_t handle, void *devprivate,
    ddi_mapdev_handle_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 a pointer to the mapping being duplicated

new_handle is a pointer to the new 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 mapdev_dup(9E) will, by default, have their mapping translations invalidated. This will force a call to the mapdev_access(9E) entry point the first time the mapping is accessed.

Code Example 11-4 mapdev_dup(9E) routine

```
static int
xxmapdev_dup(ddi_mapdev_handle_t handle, void *devprivate,
    ddi_mapdev_handle_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);

    mutex_enter(&xsp->ctx_lock);
    newctx->xsp = xsp;
    bcopy(ctxp->context, newctx->context, XXCTX_SIZE);
    newctx->handle = new_handle;
    *new_devprivate = newctx;
    mutex_exit(&xsp->ctx_lock);
    return(0);
}
```

Loading and Unloading Drivers 12

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 drivers module name must either match the name of the device nodes, or the system must be informed that other names should be managed by this driver. 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.

Compile and Link 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, other than 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 SPARCompilers 2.0.1 and ProCompilers 2.0.1, 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.

Write 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), isa(4), pseudo(4), sbus(4), scsi(4) and vme(4) for more information on hardware configuration files.

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.

Copy the Driver to a Module Directory

The driver and its configuration file must be copied to a `drv` directory in the module path. Usually, this is `/usr/kernel/drv`:

```
$ su
# cp xx /usr/kernel/drv
# cp xx.conf /usr/kernel/drv
```

During development, it may be convenient to add the development directory to the module path that the kernel searches by adding a line to `/etc/system`:

`moddir: /kernel:/usr/kernel:/`*new-mod-dir*

Optionally Edit `/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.

Run `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 Programmer's 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 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) like this 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
```

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Debugging 13

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, how to use existing memory driver, and also some hints for coding the device driver. It also introduces system debugging tools that are available, and gives hints on how to test the device driver.

Note – The information presented in this chapter is specific to the release of the operating system, and is subject to change.

Machine Configuration

Setting Up a `tip`*(1) Connection*

The serial ports on one system (the host system) can be used to connect to a driver debugging and test machine using `tip`(1). This allows 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 SunOS device driver. It is only required for the use of `tip`(1).

Using a tip window is very helpful:

- It lets the window system to assist in interactions with the boot PROM or kadb. For example, the window can keep a log of the session, which is very handy if the driver crashes the test system.
- It allows the test machine to be remote. It is reached 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

A simple setup for connecting serial port A on the host (running Solaris 2.x) to serial port A on the test machine (a SPARC system with an Open Boot PROM) is:

1. Connect the host system to the test machine using either serial port; the example in this section uses port A. This connection must be made with a *null modem* cable, which connects the signal Receive to Transmit, and Ground to Ground. This cable can be constructed by the developer, or a null modem adaptors can be found at electronics stores.

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. Solaris 2.x comes with the correct entry for serial port B, but one must be added for serial port A:

```
debug:\
    :dv=/dev/term/a:br#9600:el=^C^S^Q^U^D:ie=%$:oe=^D:
```

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* directed to the test machine.

Setting Up the Test System

A quick way to set up the test machine is to unplug its keyboard before turning it on. It then automatically uses serial port A as the console. Another way to do this is to use boot PROM commands to make serial port A the console:

1. On the test machine, enter the boot PROM (`ok` prompt). Direct I/O to the serial line, indicating the correct serial port. In this example, the test machine is using serial port A, so the command is **`ttya io`**. Pressing Return in the tip window should get a boot PROM prompt.

Caution – Do not use L1-A on the host machine to send a break to stop the test machine. This actually stops the host machine. To send a break to the test machine, type ~# in the tip window. Tilde 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.

---

2. 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
```

On x86 platforms, the test machine needs to `set console = 1` in `/etc/system`. This causes a switch to COM1 during reboot.

Preparing for the Worst

It is possible that the driver will render the system unbootable; this is most likely if the driver is for the boot device. If a complete system reinstallation is to be avoided, some advance work must be done to prepare for this possibility.

Boot Off a Backup Root Partition

One way to deal with this is to have another bootable root file system. Use `format`(1M) to make a partition the exact size of the original, then (from SunOS) use `dd`(1M) to copy it. Do this from single-user mode so that there is as little file system activity as possible, and 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 filesystem as the root filesystem.

Boot Off the Network.

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.

Critical System Files

There are a number of driver-related system files that are difficult, if not impossible, to reconstruct. Files such as `/etc/name_to_major` could 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.

Recreating `/devices` *and* `/dev`

If the `/devices` or `/dev` directories are damaged (most likely if the driver crashes during `attach`(9E)), they may be recreated in the following way. Boot the system from somewhere else (another disk, an installation CD, or the network), and run `fsck`(1M) to repair the damaged root filesystem. Then, mount the root filesystem and recreate `/devices` 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.

For example, if the damaged disk is /dev/dsk/c0t3d0s0, and an alternate boot disk is /dev/disk/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 5.4 Version Generic [UNIX(R) System V Release 4.0]
Copyright (c) 1983-1994, 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 of information (such as system core dumps) before reinstalling the system.

Booting an Alternate Kernel

A kernel other than /kernel/unix can be booted by specifying it as the boot file. In fact, backup copies of all the system drivers in /kernel can be made and used in the event the originals fail (this is probably more useful if more than one driver is being debugged). For example:

```
# cp -r /kernel /kernel.orig
```

To boot the original system, boot `/kernel.orig/unix`. By default, the first module directory in the module directory path is the one the kernel resides in. By booting `/kernel.orig/unix`, the module directory path becomes "`/kernel.orig /usr/kernel`".

```
ok boot disk1 /kernel.orig/unix
...
Rebooting with command: disk1 /kernel.orig/unix
Boot device: /sbus/esp@0,800000/sd@1,0  File and args:/kernel.orig/unix
SunOS Release 5.4 Version Generic [UNIX(R) System V Release 4.0]
Copyright (c) 1983-1994, Sun Microsystems, Inc.
...
```

For more complete control, boot with the ask (`-a`) option; this allows alternate files to be specified (such as `/etc/system.orig` if that is the original "clean" system file).

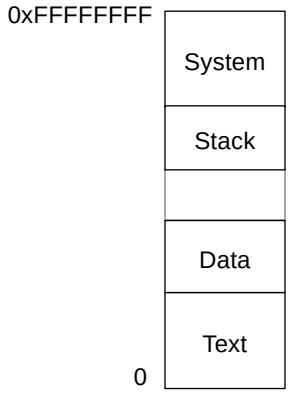
```
ok boot disk1 -a
...
Rebooting with command: disk1 -a
Boot device: /sbus/esp@0,800000/sd@1,0   File and args: -a
Enter filename [/kernel/unix]: /kernel.orig/unix
SunOS Release 5.4 Version Generic [UNIX(R) System V Release 4.0]
Copyright (c) 1983-1994, Sun Microsystems, Inc.
Name of system file [etc/system]:  etc/system.orig
Name of default directory for modules [/kernel.orig /usr/kernel]: <CR>
root filesystem type [ufs]: <CR>
Enter physical name of root device
[/sbus@1,f8000000/esp@0,800000/sd@1,0:a]: <CR>
```

Coding Hints

During development, debugging the driver should be a constant consideration. Since the driver is operating much closer to the hardware, without the protection of the operating system, debugging kernel code is harder than debugging user-level code. 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

SunOS 5.x operating system processes follow the definition given in the *System V Application Binary Interface, SPARC Processor Supplement* (also known as the ABI). A standard process looks similar to this:



The ABI specifies the system portion of a process' virtual address space is in the high end, and may occupy no more than 512 megabytes. In other words, all kernel addresses will be `0xE0000000` or higher. Some implementations may use less kernel space, and so begin at a higher address. This fact can be used when debugging: if pointers point below the address 0xE0000000, they probably are user addresses.

System Support

The system provides a number of routines that can aid in debugging; they are documented in Section 9F of the *man Pages(9F): DDI and DKI Kernel Functions*.

`cmn_err( )`

`cmn_err`(9F) is the function to use to print messages to the console from the kernel. See `cmn_err`(9F) and "Printing Messages" on page 55 for more information on its use.

Note – Though printf() and uprintf() currently exist, they should not be used if the driver is to be Solaris DDI-compliant.

An example from the probe(9E) routine might be to print a message if the device is not found. Normally, probe(9E) routines should not print messages if the device is not there.

```
if (ddi_pokec(dip, &regp->csr, ENABLE_INTERRUPTS) != DDI_SUCCESS) {
     cmn_err(CE_NOTE, "%s not found.", ddi_get_name(dip));
     return (DDI_PROBE_FAILURE);
}
```

A handy format for printing device register bits is %b. See cmn_err(9F) for information on how to use it.

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, and what it does depends on whether or not the symbol DEBUG is defined (from <sys/debug.h>). 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 and the system panics.

For example, if at a point in the driver a pointer should be non-NULL—and if it is not, something is seriously wrong—the following assertion could be used:

```
ASSERT(ptr != NULL);
```

If compiled with DEBUG defined, and the assertion fails, a panic occurs:

```
panic: assertion failed: ptr != NULL, file: driver.c, line: 56
```

Note – Because ASSERT(9F) uses DEBUG, it is suggested that any conditional debugging code should also be based on DEBUG, rather than with 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, and 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 mu mutex held */
    ASSERT(mutex_owned(&xsp->mu));
    ...
}
```

Future releases of Solaris may only support the use of mutex_owned(9F) within ASSERT(9F) by not defineing mutex_owned(9F) unless the preprocessor symbol DEBUG is defined.

Conditional Compilation and Variables

There are two common ways to place debugging code in a driver: conditionally compiling code based on a preprocessor symbol such as DEBUG, or 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 run time, such as by setting a debugging level at run time 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
    ...
    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, and have it use `vsprintf`(9F) or `vcmn_err`(9F) to handle variable argument lists.

The Optimizer and `volatile`

The `volatile` keyword must be used when declaring any variable that will reference a device register, or the optimizer may optimize important accesses away. This is very important since not using `volatile` can result in bugs that are very difficult to track down. See “volatile” on page 69 for more information.

Using Existing Drivers

Using existing drivers with a user program is a good way to see if the kernel sees the device. This allows the device to be debugged without the need for the device-specific driver, and separates device debugging from driver debugging. Depending on the driver and device, `mmap(2)`, or `read(2)` and `write(2)` (possibly with `lseek(2)`) may be used.

The “mem” and “kmem” drivers access physical memory and kernel memory, respectively. `/dev/mem` is used to provide a core memory image to debuggers such as `adb`(1).

To examine kernel memory from a user program, consider using the libkvm routines (see section `kvm_open`(3K)) for a (slightly) portable way. Be aware that kernel structures change frequently, so any code that examines the kernel is likely to need changes in future releases or on other platforms.

For devices, there are two bus space drivers, “vmemem” and “sbusmem”. These allow access to devices on the bus without a driver. After verifying that the device is accessible through the PROM (see “The PROM on SPARC Machines” on page 26), these drivers can verify that it is accessible by SunOS. However, special handling requiring knowledge of the device (such as interrupt handling and DMA) can not be performed by these drivers. Be careful to not compromise system security (such as by giving non-root users access to the special files for these drivers), or system integrity (by accessing other devices).

This program opens the “sbusmem” driver for the slot the bwtwo is in and performs the same operations that were done previously with the PROM (see “Reading and Writing” on page 33).

Code Example 13-1 Accessing bwtwo with the “sbusmem” driver

```
#include <sys/types.h>
#include <sys/mman.h>
#include <sys/stat.h>
#include <fcntl.h>
#include <stdio.h>

void
fill(char *base, int count, char val)
{
    register int i;


    for(i=0; i < count; i++)
        *base++ = val;
    sleep(2);
}

int
main(int argc, char *argv[])
{
    int     fd;
    caddr_t base;
    size_t  fb_len = 0x20000;
    off_t   fb_offset = 0x800000;

    fd = open("/devices/sbus@1,f8000000/sbusmem@3,0:slot3",
        O_RDWR);
    if (fd == -1) {
        perror("open /devices/sbus@1,f8000000/sbusmem@3,0:slot3");
        return (1);
    }
    base = mmap(NULL, fb_len, PROT_READ | PROT_WRITE, MAP_SHARED,
        fd, fb_offset);
    if (base == (caddr_t)-1) {
        perror("mmap of SBus slot 3");
        return (1);
    }
    close(fd);

    fill(base, 0x20000, 0xff);
    fill(base, 0x20000, 0);
    fill(base, 0x18000, 0x55);
    fill(base, 0x15000, 0x3);
    fill(base, 0x10000, 0x5);
    fill(base, 0x5000, 0xf9);

    return (0);
}
```

Debugging Tools

This section describes some programs and files that can be used to debug the driver at run time.

/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.

The path the kernel uses when looking for modules can be set by changing the *moddir* variable in the system file. If the driver module is in a working area, such as `/home/driver`, the following example adds that directory to the module path:

```
moddir: /kernel /usr/kernel /home/driver
```

Caution – Do not allow non-root users to write to the module directory.

The `set` command is used to set integer variables. To set module variables, the module name must also be specified:

```
set module:variable=value
```

For example, 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 ORing 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` is a bit field that controls the module loading process. See `<sys/modctl.h>` for all its possible values. Here are a few useful ones:

`0x80000000` – Print messages to the console when loading/unloading modules.

`0x40000000` – Give more detailed error messages

`0x20000000` – Print more detail when loading/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.

`modload` *and* `modunload`

Since 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 may unload it subsequently, but `modload`(1M) may be used to insure 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 – `modload`(1M) and `modunload`(1M) may be removed in a future release.

Saving System Core Dumps

When the system panics, it writes the interesting portions of memory to the dump device (which is usually the swap device). This is a system core dump, similar to the core dumps generated by applications.

To save a core dump, there must be enough space in the swap area to contain it. To be safe, the primary swap area should be at least the size of main memory (all the information is in main memory, though not all of it is dumped).

`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 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 -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 -p /var/crash/`uname -n`
fi
                echo ‘checking for crash dump...\c ‘
savecore /var/crash/`uname -n`
                echo ‘’
```

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. The file will appear larger than it actually is, since it contains holes, so 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.

adb(1) is a very terse debugger. It does not normally prompt for input (though kadb(1M) does).

Starting adb

The command for starting adb to debug a kernel core dump is:

```
% adb -k /var/crash/hostname/unix.n /var/crash/hostname/vmcore.n
```

To start adb on a live system, use (as root)::

```
# adb -k /dev/ksyms /dev/mem
```

/dev/ksyms is a special driver that provides an image of the kernel's symbol table. This can be used to examine the debugging information (traces) the driver has left in the memory.

When adb(1) responds with 'physmem XXX', it is ready for a command.

Starting kadb

The system must be booted under kadb(1M) before kadb(1M) can be used. From the Open Boot PROM, use:

```
ok boot kadb
...
Boot device: /sbus/esp@0,800000/sd@3,0   File and args: kadb
kadb: /kernel/unix
Size: 673348+182896+46008 bytes
/kernel/unix loaded - 0x125000 bytes used
SunOS Release 5.4 Version Generic [UNIX(R) System V Release 4.0]
Copyright (c) 1983-1994, 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. This 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: 673348+182896+46008 bytes
/kernel/unix loaded - 0x125000 bytes used
kadb[0]:
```

At this point you can set break points or continue with the :c command.

Note – kadb(1M) passes on 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, or by ~# 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. Halting the system will also drop to a kadb(1M) prompt.

Warning – Before rebooting or shutting 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, make sure to flush buffers with `sync` (on the OBP), or `'g 0'` (on SunMon).

To continue back to SunOS, 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
```

kadb(1M) can be continued by typing `go` (on the OBP) or `c` (on SunMON).

Warning – No other commands can be performed from the PROM if the system is to be continued. PROM commands other than `:c` (continue) may change system state that SunOS depends on.

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 ('.' also stands for 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:

`?`	Print locations starting at *address* in the executable.
`/`	Print locations starting at *address* in the core file.
`=`	Print the value of *address* itself.
`>`	Assign a value to a variable or register.
`<`	Read a value from a variable or register.
RETURN	Repeat the previous command with a count of 1. Increment '.'.

With `?`, `/`, and `=`, output format specifiers can be used. Lowercase letters normally print 2 bytes, uppercase letters print 4 bytes:

`o, O`	Octal
`d,D`	Decimal
`x,X`	Hexadecimal
`u,U`	Unsigned decimal
`f,F`	4,8 byte floating point

`c`	Print the addressed character
`C`	Print the addressed character using ^ escape notation.
`s`	Print the addressed string.
`S`	Print the addressed string using ^ escape notation.
`i`	Print as machine instructions (disassemble)
`a`	Print the value of `.' in symbolic form.
`w,W`	Write a 2/4 byte value

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 OR in the desired bit.

```
kadb[0]: moddebug/X
moddebug:
moddebug:    0
kadb[0]: moddebug/W 0x80000000
moddebug:    0x0 = 0x80000000
```

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. The output has been formatted for readability:

```
kadb[0]: strcmp,4?i
strcmp:
strcmp: ba      strcmp + 0x20
        ldsb    [%o1], %o5
        add     %o0, 0x1, %o0
        orcc    %g0, %o5, %g0
```

To show the addresses also, specify symbolic notation with the '**a**' command:

```
kadb[0]: strcmp,4?ai
strcmp: strcmp: ba      strcmp + 0x20
strcmp+4:       ldsb    [%o1], %o5
strcmp+8:       add     %o0, 0x1, %o0
strcmp+0xc:     orcc    %g0, %o5, %g0
```

Register Identifiers

Machine or kadb(1M) internal registers are identified with the '<' command, followed by the register of interest. 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.

`g7` always contains the current thread pointer. For more information on how these registers are normally used, see *The SPARC Architecture Manual, Version 8,* and the *System V Application Binary Interface, SPARC Processor Supplement*.

The following command displays the PSR as a 4-byte hexadecimal value:

```
kadb[0]: <psr=X
                400cc3
```

The individual bits of the PSR are defined in <sys/psw.h>. More information is available in *The SPARC Architecture Manual, Version 8* and *The SPARC Assembly Language Reference Manual.*

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.

'$c' is very useful with crash dumps: it shows the call trace and arguments at the time of the crash. It is also useful in kadb(1M) when a breakpoint is reached, but is usually not useful if kadb(1M) is entered at a random time. The number of arguments to print can be passed following the '$c' ('$c 2' for two arguments).

Breakpoints

In kadb(1M), breakpoints can be set, which will automatically drop back into kadb when reached. The standard form of a breakpoint command is:

```
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. 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

Here is an example of setting a breakpoint in a commonly used routine, `scsi_transport`(9F). 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 scsi_transport: save %sp, -0x60, %sp
kadb[0]: $c
scsi_transport(0xff09c400,0x3,0x3,0x1,0xff09c534,0xff0a0690)
sdstrategy(0xff0a0690,0x3,0xff09c440,0x170,0xff09c534,0xff09c400) + 3d8
bwrite(0xff0a0690,0xff1ed400,0x1,0xb,0xff0a06f0,0xf017d9d8) + bc
sbupdate(0xf00dcfe8,0xff20f400,0xff0a0690,0x400,0x0,0xff03b000)+ 9c
ufs_update(0xff034c80,0x3,0xff034cac,0xff2ac764,0xff03b000,0xf00dfe8) + 198
ufs_sync(0x0,0x10000,0xff007980,0x1e,0xf00d8e38,0xf00d8e38) + 8
fsflush(0xf00dd330,0xf00e0830,0x1af,0x2,0xf00f3ab8,0xf00b8254) + 568
kadb[0]: :s
stopped at scsi_transport+4: ld [%i0 + 0x4], %o0
kadb[0]: $b
breakpoints
count   bkpt           command
1       scsi_transport
kadb[0]: scsi_transport:d
kadb[0]: :c
```

Conditional Breakpoints

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 header file).

To force the breakpoint to be reached, the `prtvtoc`(1M) command is used. It known to issue this I/O control:

```
# prtvtoc /dev/rdsk/c0t3d0s0
breakpoint sdioctl+4: mov %i0, %o0
kadb[0]: $c
sdioctl(0x800018,0x40b,0xeffffc24,0x1,0xff22fa80,0xf01e9918) + 4
ioctl(0xf01e9e90,0xf01e9918,0x1,0x40b,0xff2ab380,0xff0894b4) + 1ec
syscall(0xf00c1c54) + 4d4
.syscall(0x3) +8c
?(?) + 7fffffff
Syssize(0x3,0xeffffc24,0xeffffd6c,0x5403148,0x0,0x5452ea0) + 20338
Syssize(0x3,0xefffff7c,0xeffffc24,0x80,0x3,0x0)+ fb70
Syssize(0xefffff7c,0x2000,0x1,0x1,0x1,0x3) + f51c
Syssize(0x2,0xeffffee4,0xeffffef0,0x22c00,0x0,0xffffffff) + eb8c
```

`kadb`(1M) cannot always determine where the bottom of the stack is. In the above example, the calls to `Syssize` and `?(?)` are not part of the stack.

Macros

adb(1) and kadb(1M) support macros. adb(1) macros are in /usr/kvm/lib/adb, while kadb(1M)'s macros are built-in 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(1).

Macros are used in the form:

```
[ address ] $<macroname
```

threadlist is a useful macro that displays the stacks of all the threads in the system. This macro that does not take an address, and can generate a lot of output, so be ready to use Control-S and Control-Q to start/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 f0141ee0
?() + 1e
data address not found
       thread_id f0165ee0
?(0xf00e24e0,0xf00e24e0,0xff004000,0xc,0x0,0x4000e0) + 1e
callout_thread(0xff004090,0xf00d7d9a,0xf00e24e0,0xf00ac6c0,0x0,0xf004000) + 2c
       thread_id f016bee0
?(0xf00e04d0,0xf00e04d0,0x80b5f7ff,0x1,0x0,0x4000e0) + 1e
background(0x0,0x0,0x0,0xf00e23ac,0x0,0xf00e04d0) + 64
       thread_id f016eee0
?(0xf00dd884,0xf00dd884,0x80b777ff,0x1,0x0,0x4000e0) + 1e
freebs(0x0,0x0,0xf00e2388,0xff21d270,0xf00e24a0,0xf00dd884) + 2c
^C
```

Another useful macro is `thread`. Given a thread ID, it 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
0xf0141ee0:
       link    stk         stksize
       0       f0141ee0    ee0
0xf0141eec:
       affinity   affcnt  bind_cpu
       1          1       -1
...
```

Note – There is no type information kept in the kernel, so using a macro on an inappropriate object will result 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 – The driver should have knowledge only of headers and structures listed in Section 9S of the *man Pages(9S): DDI and DKI Data Structures*, even though interesting knowledge may be uncovered while debugging.

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 247), the system is rebooted. The crash is then recreated 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 ac0
```

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 very helpful initially, since 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—in this case 9—which is a `T_DATA_FAULT` trap (from `<sys/trap.h>`). See *The SPARC Architecture, Version 8* manual for more information.

The second argument to `trap`() is a pointer to a `regs` structure containing the state of the registers at the time of the trap.

```
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 PC was `ff2dd8b0` when the trap occurred. The next step is to determine which routine that is in:

```
ff2dd8b0/i
rd_write+0x2c: ld [%o2 + 0x4], %o3
```

That 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 `ld` (load) 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 0xE0000000 by the ABI, so this address is probably a user one. The ramdisk does not deal with user addresses though, so this is something the ramdisk write routine should not be dereferencing.

Now, where this occurs in relation to the complete routine must be determined, so that the assembly language can be matched to the C code. To do this, the routine is disassembled up to the problem instruction, which occurs 2c bytes into the routine. 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). Examining the ramdisk.c source file these 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) (since 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 – Most data fault panics are 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
/kernel/unix loaded - 0x125000 bytes used
kadb[0]::c
SunOS Release 5.4 Version Generic [UNIX(R) System V Release 4.0]
Copyright (c) 1983-1994, Sun Microsystems, Inc.
...
```

After the rest of the kernel has loaded, moddebug is patched to see if loading is the problem (since it got to rd_write() before, it is probably not the problem, 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
load '/usr/kernel/drv/ramdisk' id 61 loaded @ 0xff335000 size 3304
installing ramdisk, module id 61.
```

It loads fine, 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
```

It hangs. At this point, `kadb`(1M) is entered and the stack examined:

```
~stopped at 0xfbd01028: ta 0x7d
kadb[0]: $c
_end() + bc1eb40
debug_enter(0xfbd01000,0xff1a7054,0x0,0x0,0xb,0xff1a7000) + 88
zs_high_intr(0xff1a0230) + 19c
_level1(0xf0141ee0) + 404
idle(0x0,0x0,0x0,0xf0171ee0,0x0,0x1) + 28
```

It does not look like the current thread is the problem, so the entire thread list is checked for hung threads:

```
kadb[0]: $<threadlist
       thread_id f0141ee0
?(0xfbd01000,0xff1a7054,0x0,0x0,0xb,0xff1a7000)+ 1e
zs_high_intr(0xff1a0230) + 19c
_level1(0xf0141ee0) + 404
idle(0x0,0x0,0x0,0xf0171ee0,0x0,0x1) + 28
       thread_id f0165ee0
?(?) + 1e
cv_wait(0xf00e24e0,0xf00e24e0,0xff004000,0xb,0x0,0x4000e4)
callout_thread(0xff004090,0xf00d7d9a,0xf00e24e0,0xf00ac6c0,0x0,0xff004000) + 2c
       thread_id f016bee0
...
       thread_id ff11c600
?(?) + 1e
biowait(0xf01886d0,0x0,0x7fe00,0x200,0xf00e085c,0x3241c)
physio(0xff196120,0xf01886d0,0xf01888a4,0x3241c,0x0,0xf0188878)+ 338
rd_write(0x1180000,0xf0188878,0xff19b680,0xff19b680,0x2,0xff335884) + 8c
rdwr(0xff1505c0,0xf0188878,0xf0188918,0x0,0x0,0xff24dd04) + 138
rw(0xf0188e90,0xf0188918,0x2,0xf01888a4,0xf0188e90,0x3241c) + 11c
syscall(0xf00c1c54) + 4d4
```

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]: f01886d0$<buf
0xf01886d0: flags
            129
0xf01886d4: forw      back       av_forw    av_back
            ff24dd04  72616d64   69736b3a   302c7261
0xf01886e8: count     bufsize    error      edev
            512       770        0          1180000
0xf01886ec: addr      blkno      resid      proc
            3241c     3ff        0          ff26f000
0xf0188714: iodone    vp         pages
            0         f01888a4   effffff68
```

The `resid` field is 0, which indicates that the transfer is complete. `physio`(9F) is still blocked, however. Examining the `physio`(9F) manual page 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 very important, and is a part of the test process. Once the driver is working on a simple, or default, configuration, additional configurations should be tested. Depending on 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 on 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, providing the configuration code allows it to work at all. On the other hand, a special I/O control call may have different effects depending on 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 run through configuration testing, all of its functionality should be thoroughly tested. This requires exercising the operation of all of 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 of 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 mmap(9E), poll(9E) and ioctl(9E), if applicable. The ioctl(9E) tests may 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 may 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 in order to cause several threads to execute the same code simultaneously. The way this should be done depends on the driver; some drivers will require special testing applications, but starting several UNIX commands in the background will be suitable for others. It depends on 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, and whether the driver correctly claims its own interrupts and otherwise operates correctly under the stress tests described above should be tested. 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, that could indicate that the network driver is causing the rest of the system to encounter interrupt latency problems.

Performance of a driver 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 2.4 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 2.4 Reference Manual AnswerBook* are used.

In addition, the Solaris 2.4 Driver Developer Kit (DDK) now 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. SunSoft recommends that all drivers be written to pass DDICT. After the DDK has been installed, the DDICT can be found in:

```
/opt/SUNWddk/driver_dev/bin/ddict
```

A new manual page describing DDICT is available in:

```
/opt/SUNWddk/driver_dev/ddict/man/man1/ddict.1
```

Installation and Packaging Testing

Drivers are delivered to customers in *packages*. A package can be added and removed from the system using a standard, documented mechanism (see the *SunOS 5.4 Application Packaging and Installation 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 may be made about where standard kernel files are kept, however. It is a good idea to test the 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

Since 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(7)); all of 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 be exercising 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 of 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 speed communication will help test the reliability of the driver. Running uucp(1C) over the line also provides some exercise; note, however, that uucp(1C) performs its own error handling, so 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 various commands should be run by multiple processes. Heavy network loading means:

- There is a lot of traffic to the test machine.
- There is heavy traffic among all machines on the network.

Network cables should be unplugged while the tests are executing, and the driver should recover 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 machine with the driver being tested. 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 Device Driver to SunOS 5.4

A

This chapter is a guide to the differences between SunOS 4.x and SunOS 5.x device drivers. Some simple drivers can be ported easily, but to properly handle the multithreaded environment, most drivers will need to be rethought and rewritten.

Before Starting the Conversion

Review Existing Functionality

Make sure 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 you have access to the SunOS 5.4 Reference Manuals.

A

ANSI C

The unbundled Sun C compiler is now ANSI C compliant. Most ANSI C changes are beyond the scope of this book. There are a number of good ANSI C books available from local bookstores. The following two books are good references:

- Kernighan and Ritchie, *The C Language*, Second Edition, 1988, Prentice-Hall
- Harbison and Steele, *C: A Reference Manual*, Second Edition, 1987, Prentice-Hall

Development Environment

DDI/DKI

The 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 man Pages(9): DDI and DKI Overview*, it is called Solaris 2.4 DDI/DKI-compliant. A Solaris 2.4 DDI/DKI-compliant driver is likely to be binary compatible across Sun Solaris platforms with the same processor (SPARC), and binary compatible with future releases of Solaris on platforms the driver works on.

Things to Avoid

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 man Pages(9S): DDI and DKI Data Structures*. 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, since the size of a `buf`(9S) structure may change in future releases.

System V Release 4

SunOS 5.x 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 Solaris 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 Solaris 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. This is either part of SPARCworks 2.0.1 (for SPARC systems) or ProWorks 2.0.1 (for x86 systems). See Chapter 12, "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 `-Xa` and `-D_KERNEL` options.

When building a loadable driver module from the object modules, use `ld`(1) with the `-r` flag.

A

Debugging Tools

`adb`(1), `kadb`(1M), and `crash`(1M) are essentially the same as they were in SunOS 4.x, 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 245, for more information.

ANSI C

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 a new ANSI C keyword. It is used to prevent the optimizer from removing what it thinks are unnecessary accesses to objects. All device registers should be declared `volatile`. As an example, if the device has a control register that requires two consecutive writes to get it to do something, the optimizer could decide that the first write is unnecessary since the value is unused if there is no intervening read access.

Note – It is not an error to declare something `volatile` unnecessarily.

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 man Pages(9): DDI and DKI Overview*. 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.

Overview of Changes

Autoconfiguration

Under SunOS 4.1.2 or later, the system initialized all the drivers in the system before starting `init`(8). The advent of loadable module technology allowed some device drivers to be added and removed manually at later times in the life of the system.

SunOS 5.X 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 `identify`(9E), `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 SunOS 4.x 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).
- It is no longer guaranteed that `identify`(9E) is called once before `attach`(9E). It may now be called any number of times, and may be called at any time. *Do not count device units.* See `ddi_get_instance`(9F) for more information.

- The SunOS 5.x `probe`(9E) is not the same as `probe`(9E) in SunOS 4.x. 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 `identify(9E),` then `probe(9E),` then `attach`(9E) for example), these drivers will break in some future release.

Instance Numbers

In SunOS 4.x, drivers used to count the number of devices that they found, and assign a unit number to each (in the range 0 to the number of units found less one). Now, these are called instance numbers, and are assigned to devices by the system.

Instances can be thought of as a shorthand name for a particular instance of a device (`foo0` could name instance 0 of device `foo`). They are assigned and remembered by the system, 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 (since 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 may not be available (the device may not be attached).

`/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 SunOS 4.x, special device files were created using `mknod` (or by an installation script running `mknod`) by the administrator. Now, entries are advertised to the kernel by device drivers 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.

/dev

In SunOS 4.x, device special files lived (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 backwards compatibility with SunOS 4.X applications, a shorthand for the real `/devices` name, or a way to identify a device without having to know where it is in the `/devices` tree (`/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 Chapter 5, “Autoconfiguration” and *Application Packaging Developer’s Guide* for more information.

Multithreading

SunOS 5.x supports multiple *threads* in the kernel, and multiple CPUs. A thread is a sequence of instructions being executed by a program. In SunOS 5.x, 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 top-half and bottom-half of a driver than there was in SunOS 4.x. 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.

A

Locking

Under SunOS 4.1.2 or later, 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 wants 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 SunOS 5.x, 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, the possibility exists 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 deal with this in SunOS 4.x, 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 SunOS 4.x.

Both of these cases are similar to situations present in SunOS 4.x, 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 SunOS 4.x, a driver had to be careful when accessing data shared between the top-half and the interrupt routine. Since 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 SunOS 5.x, 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, SunOS 5.x provides:

1. A uniform module of execution—even interrupts run as threads. This blurs the distinction between the top-half and the bottom-half, as effectively every routine is a bottom-half 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 SunOS 4.X is that, because everything is run by kernel threads, the interrupt routine needs to explicitly acquire and release the mutex. In SunOS 4.x, this was implicit since the interrupt handler automatically ran at an elevated priority.

See “Locking Primitives” on page 76 for more information on locking.

Condition Variables

In SunOS 4.X, when the driver wanted 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. Since 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 13-2 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);
}
```

SunOS 5.X 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 which protects the condition variable before blocking the thread. The mutex is then released before the thread is blocked (similar to blocking / unblocking interrupts in SunOS 4.X)

Code Example 13-3 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 SunOS 4.x).

Note – There is no equivalent to the dispatch priority passed to sleep( ).

Though the sleep( ) and wakeup( ) calls exist, please do not use them, since the result would be an MT-unsafe driver.

See “Thread Synchronization” on page 79 for more information.

Catching Signals

There is always the possibility that either the driver accidentally waits for an event that will never occur, or the event will not happen for a long time. In either case, the user may 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 on the driver.

In SunOS 4.x, whether the sleep( ) was signal-interruptible depended on 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 back to the user, without letting the driver know 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 SunOS 5.x, 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 SunOS 4.x 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 SunOS 5.x, but the same thing may be accomplished with `cv_timedwait`(9F). An absolute time to wait for is passed to `cv_timedwait`(9F), and which will return zero if the time is reached and the event has not occurred. See Code Example 4-3 on page 81 for an example usage of `cv_timedwait`(9F). Also see "cv_timedwait_sig( )" on page 84 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, and add more depending on the abilities of the device. See "Choosing a Locking Scheme" on page 85 and Appendix B, "Advanced Topics," for more information.

Interrupts

In SunOS 4.x, 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 SunOS 5.x, 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 111 and “Responsibilities of an Interrupt Handler” on page 113 for more information.

DMA

In SunOS 4.x, 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, then freed the mapping. This was accomplished in a sequence like:

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 want to do DMA to large objects, and the DMA routines can be informed of device limitations (such as 24-bit addressing).

The normal sequence for DMA is similar to SunOS 4.x. Commit DMA resources using one of the `ddi_dma_setup`(9F) routines, retrieve the DMA address from the handle to do the DMA, then free the mapping with `ddi_dma_free`(9F). The new sequence is something like this:

1. `ddi_dma_buf_setup`(9F) - allocate resources
2. `ddi_dma_nextwin`(9F) - to get the first DMA window
3. `ddi_dma_nextseg`(9F) - to get the first DMA segment
4. `ddi_dma_segtocookie` - retrieve address from the returned cookie
5. *program the device and start the DMA*
6. *Perform the transfer.*

Note – If the transfer involves several segments or windows (or both), you can call `ddi_dma_nextseg`(9F) or `ddi_dma_nextwin`(9F) (or both) to move to subsequent segments and windows.

---

7. `ddi_dma_free`(9F) - free mapping when DMA is complete

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 SunOS 4.x, 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 want 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()`

SunOS 4.x:

```
int xxidentify(name)
char *name;
```

SunOS 5.x

```
int xxidentify(dev_info_t *dip)
```

The *name* property is no longer passed to `identify`(9E). `ddi_get_name`(9F) must be used to retrieve the name from the `dev_info_t` pointer argument.

Note – The unit counting is now handled by the framework. To get the unit number in any routine, call `ddi_get_instance`(9F). *Do not count units anywhere.*

`identify`(9E) is no longer guaranteed to be called for all units before `attach`(9E) is ever called. However, `identify`(9E) *is* guaranteed be called before `attach`(9E) on a per-instance basis.

`probe()`

SunOS 4.x:

```
int xxprobe(reg, unit)
caddr_t reg;
int     unit;
```

SunOS 5.x

```
int xxprobe(dev_info_t *dip)
```

`probe`(9E) is still expected to determine if a device is there or not, but now it may be called any number of times, so it must be *stateless* (free anything it allocates).

`attach()`

SunOS 4.x: VMEbus

```
int xxattach(md)
struct mb_device *md;
```

SBus

```
int xxattach(devinfo)
struct dev_info *devinfo;
```

SunOS 5.x

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

As noted in `identify`(9E), 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 which used to pass in the config file (such as *flags*) should now be passed as properties.

getinfo()

SunOS 5.x:

```
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:

```
int xxopen(dev, flag)
dev_t   dev;
int     flag;
```

SunOS 5.x

```
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 59 for more information.

read() *and* write()

SunOS 4.x:

```
int xxread(dev, uio)
int xxwrite(dev, uio)
dev_t   dev;
struct uio *uio;
```

SunOS 5.x

```
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), since 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:

```
int xxioctl(dev, cmd, data, flag)
dev_t   dev;
int     cmd, flag;
caddr_t data;
```

SunOS 5.x

```
int xxioctl(dev_t dev, int cmd, int arg, int mode,
    cred_t *credp, int *rvalp);
```

In SunOS 4.x, `ioctl( )` command arguments were defined as follows:

```
#define XXIOCTL1  _IOR(m, 1, u_int)
```

The `_IOR( )`, `_IOW( )`, and `_IOWR( )` macros 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 which means something (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:

```
int xxstrategy(buf)
struct buf *bp;
```

SunOS 5.x

```
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 interesting ways at other times). Use the `b_edev` field instead.

If the driver used to allocate buffers uncached, it should now use `ddi_dma_sync`(9F) whenever consistent view of the buffer is required.

`mmap( )`

SunOS 4.x:

```
int xxmmap(dev, off, prot)
dev_t   dev;
off_t   off;
int     prot;
```

SunOS 5.x

```
int xxmmap(dev_t dev, off_t off, int prot);
```

Building a page table entry manually is no longer allowed. The driver must use `hat_getkpfnum`(9F) to retrieve the PTE information from a virtual address. See “Mapping Device Memory” on page 161 for more information.

If the driver used to check for root privileges using `suser`(), it should now use `drv_priv`(9F). Because there is no credential pointer passed to `mmap`(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 162, for details.

SunOS 4.1.x to SunOS 5.4 Differences

This table compares device driver routines on SunOS 4.1.x versus SunOS 5.4. 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 5.4 Kernel Support Routines

SunOS 4.1.x	SunOS 5.4	Description
`ASSERT()`	`ASSERT()`	expression verification
`CDELAY()`	-	conditional busy-wait
`DELAY()`	`drv_usecwait()`	busy-wait for specified interval
`OTHERQ()`	`OTHERQ()`	get pointer to queue’s partner queue
`RD()`	`RD()`	get pointer to the read queue
`WR()`	`WR()`	get pointer to the write queue

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Table A-1 SunOS 4.1.x and SunOS 5.4 Kernel Support Routines

SunOS 4.1.x	SunOS 5.4	Description
`add_intr()`	`ddi_add_intr()`	add an interrupt handler
`adjmsg()`	`adjmsg()`	trim bytes from a message
`allocb()`	`allocb()`	allocate a message block
`backq()`	`backq()`	get pointer to queue behind the current queue
`bcmp()`	`bcmp()`	compare two byte arrays
`bcopy()`	`bcopy()`	copy data between address locations in kernel
`biodone()` `iodone()`	`biodone()`	indicate I/O is complete
`biowait()` `iowait()`	`biowait()`	wait for I/O to complete
`bp_mapin()`	`bp_mapin()`	allocate virtual address space
`bp_mapout()`	`bp_mapout()`	deallocate virtual address space
`brelse()`	`brelse()`	return buffer to the free list
`btodb()`	-	convert bytes to disk sectors
`btop()`	`btop()` `ddi_btop()`	convert size in bytes to size in pages (round down)
`btopr()`	`btopr()` `ddi_btopr()`	convert size in bytes to size in pages (round up)
`bufcall()`	`bufcall()`	call a function when a buffer becomes available
`bzero()`	`bzero()`	zero out memory
`canput()`	`canput()`	test for room in a message queue
`clrbuf()`	`clrbuf()`	erase the contents of a buffer
`copyb()`	`copyb()`	copy a message block
`copyin()`	`ddi_copyin()`	copy data from a user program to a driver buffer
`copymsg()`	`copymsg()`	copy a message

Table A-1 SunOS 4.1.x and SunOS 5.4 Kernel Support Routines

SunOS 4.1.x	SunOS 5.4	Description
`copyout()`	`ddi_copyout()`	copy data from a driver to a user program
`datamsg()`	`datamsg()`	test whether a message is a data message
`delay()`	`delay()`	delay execution for a specified number of clock ticks
`disksort()`	`disksort()`	single direction elevator seek sort for buffers
`dupb()`	`dupb()`	duplicate a message block descriptor
`dupmsg()`	`dupmsg()`	duplicate a message
`enableok()`	`enableok()`	reschedule a queue for service
`esballoc()`	`esballoc()`	allocate a message block using caller-supplied buffer
`esbbcall()`	`esbbcall()`	call function when buffer is available
`ffs()`	`ddi_ffs()`	find first bit set in a long integer
`fls()`	`ddi_fls()`	find last bit set in a long integer
`flushq()`	`flushq()`	remove messages from a queue
`free_pktiopb()`	`scsi_free_consistent_buf()`	free a SCSI packet in the iopb map
`freeb()`	`freeb()`	free a message block
`freemsg()`	`freemsg()`	free all message blocks in a message
`get_pktiopb()`	`scsi_alloc_consistent_buf()`	allocate a SCSI packet in the iopb map
`geterror()`	`geterror()`	get buffer's error number
`getlongprop()`	`ddi_getlongprop()`	get arbitrary size property information
`getprop()`	`ddi_getprop()`	get boolean and integer property information
`getproplen()`	`ddi_getproplen()`	get property information length
`getq()`	`getq()`	get the next message from a queue
`gsignal()`	-	send signal to process group
`hat_getpkfnum()`	`hat_getkpfnum()`	get page frame number for kernel address

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Table A-1 SunOS 4.1.x and SunOS 5.4 Kernel Support Routines

SunOS 4.1.x	SunOS 5.4	Description
`index()`	`strchr()`	return pointer to first occurrence of character in string
`insq()`	`insq()`	insert a message into a queue
`kmem_alloc()`	`kmem_alloc()`	allocate space from kernel free memory
`kmem_free()`	`kmem_free()`	free previously allocated kernel memory
`kmem_zalloc()`	`kmem_zalloc()`	allocate and clear space from kernel free memory
`linkb()`	`linkb()`	concatenate two message blocks
`log()`	`strlog()`	log kernel errors
`machineid()`	-	get host ID from EPROM
`major()`	`getmajor()`	get major device number
`makecom_g0()`	`makecom_g0()`	make packet for SCSI group 0 commands
`makecom_g0_s()`	`makecom_g0_s()`	make packet for SCSI group 0 sequential commands
`makecom_g1()`	`makecom_g1()`	make packet for SCSI group 1 commands
`makecom_g5()`	`makecom_g5()`	make packet for SCSI group 5 commands
`mapin()` `map_regs()`	`ddi_map_regs()`	map physical to virtual space
`mapout()` `unmap_regs()`	`ddi_unmap_regs()`	remove physical to virtual mappings
`max()`	`max()`	return the larger of two integers
`mb_mapalloc()`	`ddi_dma_buf_setup()`	setup system DMA resources
`mb_mapfree()`	`ddi_dma_free()`	release system DMA resources
`mballoc()`	-	allocate a main bus buffer
`mbrelse()`	-	free main bus resources
`mbsetup()`	-	set up use of main bus resources
`min()`	`min()`	return the lesser of two integers
`minor()`	`getminor()`	get minor device number

Table A-1 SunOS 4.1.x and SunOS 5.4 Kernel Support Routines

SunOS 4.1.x	SunOS 5.4	Description
`minphys()`	`minphys()`	limit transfer request size to system maximum
`mp_nbmapalloc()`	`ddi_dma_addr_setup()`	setup system DMA resources
`MBI_ADDR()`	`ddi_dma_htoc()`	retrieve DMA address
`msgdsize()`	`msgdsize()`	return the number of bytes in a message
`nodev()`	`nodev()`	error function returning ENXIO
`noenable()`	`noenable()`	prevent a queue from being scheduled
`nulldev()`	`nulldev()`	function returning zero
`ovbcopy()`	-	copy overlapping byte memory regions
`panic()`	`cmn_err()`	reboot at fatal error
`peek()`	`ddi_peeks()`	read a short value from a location
`peekc()`	`ddi_peekc()`	read a byte value from a location
`peekl()`	`ddi_peekl()`	read a long value from a location
`physio()`	`physio()`	limit transfer request size
`pkt_transport()`	`scsi_transport()`	request by a SCSI target driver to start a command
`poke()`	`ddi_pokes()`	write a short value to a location
`pokec()`	`ddi_pokec()`	write a byte value to a location
`pokel()`	`ddi_pokel()`	write a long value to a location
`printf()`	`cmn_err()`	display an error message or panic the system
`pritospl()`	-	convert priority level
`psignal()`	-	send a signal to a process
`ptob()`	`ptob()` `ddi_ptob()`	convert size in pages to size in bytes
`pullupmsg()`	`pullupmsg()`	concatenate bytes in a message
`put()`	`put()`	call a STREAMS put procedure
`putbq()`	`putbq()`	place a message at the head of a queue
`putctl()`	`putctl()`	send a control message to a queue

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Table A-1 SunOS 4.1.x and SunOS 5.4 Kernel Support Routines

SunOS 4.1.x	SunOS 5.4	Description
`putctl1()`	`putctl1()`	send a control message with one-byte parameter to a queue
`putnext()`	`putnext()`	send a message to the next queue
`putq()`	`putq()`	put a message on a queue
`qenable()`	`qenable()`	enable a queue
`qreply()`	`qreply()`	send a message on a stream in the reverse direction
`qsize()`	`qsize()`	find the number of messages on a queue
`remintr()`	`ddi_remove_intr()`	remove an interrupt handler
`report_dev()`	`ddi_report_dev()`	announce a device
`rmalloc()`	`rmallocmap()` `rmalloc()`	allocate resource map allocate space from a resource map
`rmalloc(iopbmap)`	`ddi_iopb_alloc()`	allocate consistent memory
`rmfree()`	`rmfreemap()` `rmfree()`	free resource map free space back into a resource map
`rmfree(iopbmap)`	`ddi_iopb_free()`	free consistent memory
`rmvb()`	`rmvb()`	remove a message block from a message
`rmvq()`	`rmvq()`	remove a message from a queue
`scsi_abort()`	`scsi_abort()`	abort a SCSI command
`scsi_dmafree()`	`scsi_destroy_pkt()`	free DMA resources for SCSI command
`scsi_dmaget()`	`scsi_init_pkt()`	allocate DMA resources for SCSI command
`scsi_ifgetcap()`	`scsi_ifgetcap()`	get SCSI transport capability
`scsi_ifsetcap()`	`scsi_ifsetcap()`	set SCSI transport capability
`scsi_pktalloc()`	`scsi_pktalloc()`	allocate packet resources for SCSI command
`scsi_pktfree()`	`scsi_pktfree()`	free packet resources for SCSI command
`scsi_poll()`	`scsi_poll()`	run a polled SCSI command
`scsi_resalloc()`	`scsi_init_pkt()`	prepare a complete SCSI packet

Table A-1 SunOS 4.1.x and SunOS 5.4 Kernel Support Routines

SunOS 4.1.x	SunOS 5.4	Description
`scsi_reset()`	`scsi_reset()`	reset a SCSI bus or target
`scsi_resfree()`	`scsi_destroy_pkt()`	free an allocated SCSI packet
`scsi_slave()`	`scsi_probe()`	probe for a SCSI target
`selwakeup()`	`pollwakeup()`	inform a process that an event has occurred
`slaveslot()`	`ddi_slaveonly()`	tell if device is installed in a slave-only slot
`sleep()`	`cv_wait()`	suspend calling thread and exit mutex atomically
`spl`*`n`*`()`	`mutex_enter()`	set CPU priority level
`splr()` `splx()`	`mutex_exit()`	reset priority level
`splstr()`	-	set processor level for STREAMS
`strcmp()`	`strcmp()`	compare two null-terminated strings
`strcpy()`	`strcmp()`	copy a string from one location to another
`suser()`	`drv_priv()`	verify superuser
`swab()`	`swab()`	swap bytes in 16-bit halfwords
`testb()`	`testb()`	check for an available buffer
`timeout()`	`timeout()`	execute a function after a specified length of time
`uiomove()`	`uiomove()`	copy kernel data using uio(9S) structure
`unbufcall()`	`unbufcall()`	cancel an outstanding bufcall request
`unlinkb()`	`unlinkb()`	remove a message block from the head of a message
`untimeout()`	`untimeout()`	cancel previous timeout function call
`uprintf()`	`cmn_err()`	kernel print to controlling terminal
`ureadc()`	`ureadc()`	add character to a uio structure
`useracc()`	`useracc()`	verify whether user has access to memory

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Table A-1 SunOS 4.1.x and SunOS 5.4 Kernel Support Routines

SunOS 4.1.x	SunOS 5.4	Description
`usleep()`	`drv_usecwait`	busy-wait for specified interval
`uwritec()`	`uwritec()`	remove a character from a uio structure
`wakeup()`	`cv_broadcast()`	signal condition and wake all blocked threads

Advanced Topics B

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 reentrant 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 a lot of 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

- 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 may sound obvious, but blindly 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 reentrant 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 down, and usually even more so since the code paths are rarely so straightforward. Also, it doesn't always happen, as it depends on the relative timing of threads one and two.

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 reentrant by the same thread. If you already own the mutex, you cannot own it again. Doing this leads to the above panic.

`panic: mutex_adaptive_exit: mutex not held by thread`

Releasing a mutex that the current thread does not hold causes the above panic.

`panic: lock_set: lock held and only one CPU`

This 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 may 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 B-1 lists the mandatory Sun disk I/O controls.

Table B-1 Mandatory Sun Disk I/O Controls

I/O Control	Description
DKIOCINFO	Return information describing the disk controller.
DKIOCGAPART	Return a disk's partition map.
DKIOCSAPART	Set a disk's partition map.
DKIOCGGEOM	Return a disk's geometry.
DKIOCSGEOM	Set a disk's geometry.
DKIOCGVTOC	Return a disk's Volume Table of Contents.
DKIOCSVTOC	Set 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 B-2 lists optional Sun disk ioctls:

Table B-2 Optional Sun Disk Ioctls

I/O Control	Description
HDKIOCGTYPE	Return the disk's type.
HDKIOCSTYPE	Set the disk's type.

Table B-2 Optional Sun Disk Ioctls

I/O Control	Description
HDKIOCGBAD	Return the bad sector map of the device.
HDKIOCSBAD	Set the bad sector map for the device.
HDKIOCGDIAG	Return 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 184 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 which can be manipulated by the driver. 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. It is up to the driver to set 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 runs into bus-wide problems. There is one global data variable that 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>`, and have the following meanings when set:

Table B-3 SCSA Options

Option	Description
SCSI_OPTIONS_DR	enable global disconnect/reconnect
SCSI_OPTIONS_SYNC	enable global synchronous transfer capability
SCSI_OPTIONS_PARITY	enable global parity support
SCSI_OPTIONS_TAG	enable global tagged queuing support
SCSI_OPTIONS_FAST	enable global FAST SCSI support: 10MB/sec transfers, as opposed to 5 MB/sec
SCSI_OPTIONS_WIDE	enable 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 2.4 Reference Manual AnswerBook* 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 queueing refer to the SCSI-2 specification. To support tagged queueing, first check the *scsi_options* flag SCSI_OPTIONS_TAG to see if tagged queueing is enabled globally. Next, check to see if the target is a SCSI-2 device and whether it has tagged queueing enabled. If this is all true, attempt to enable tagged queueing by using `scsi_ifsetcap`(9F). Code Example B-1 shows an example of supporting tagged queueing.

Code Example B-1 Supporting SCSI Tagged Queueing

```
#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 / 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 is queue full).

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. However, some 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 cas, 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 B-2 is an example of enabling auto request sense.

Code Example B-2 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 B-3 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_long             sts_rqpkt_state;/* state of command */
u_long             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 B-3 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 B-4 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
         */
        ....
    }
    ...
}
```

The sample SCSI drivers in appendixes E and F show in more detail how to interpret the auto request sense data structure.

B

Summary of Solaris 2.4 DDI/DKI Services

C

This chapter discusses, by category, the interfaces provided by the Solaris 2.4 DDI/DKI. After each category 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:

STREAMS interfaces are not discussed here; to learn about them, see the *STREAMS Programmer's 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. See Chapter 9, "Drivers for Block Devices," and Chapter 8, "Drivers for Character Devices" for more information.

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);

bioreset(9F) is used to 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 completes. 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 complete.

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 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 177 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 a 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(long 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 which 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 which 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 program.

void bcopy(caddr_t from, caddr_t 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(caddr_t userbuf, caddr_t driverbuf,
size_t cn);

copyin(9F) copies data from an application program'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(caddr_t driverbuf, caddr_t 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(caddr_t buf, caddr_t 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 through directly from the `mode` argument of `ioctl` (9E) untranslated.

int ddi_copyout(caddr_t driverbuf, caddr_t 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_copy`out (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_copy`out (9F) behaves like `bcopy` (9F). Otherwise `buf` is interpreted as a user buffer address, and `ddi_copyin` (9F) behaves like `copy`out(9F).

The value of the `flags` argument to `ddi_copy`out(9F) should be passed through 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. Only use drv_priv(9F) 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 intended to be 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 14). 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. ddi_get_name(9F) should be called in the identify(9E) entry point and the result compared to the name of the device.

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 and release DMA resources for devices capable of directly accessing system memory. The family of setup functions are all wrappers around the main setup function, ddi_dma_setup(9F). The wrappers make it easier to allocate DMA resources for use with kernel virtual addresses (ddi_dma_addr_setup(9F)), and buf(9S) structures (ddi_dma_buf_setup(9F)). The setup functions pass back a pointer to a DMA handle, which identifies the allocated DMA resources in future calls to other DMA handling functions.

The DMA setup functions take a pointer to a DMA limits structure as an argument. The DMA limits structure allows any constraints which the device's DMA controller may impose on DMA transfers to be specified, such as a limited transfer size.

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_addr_setup(dev_info_t *dip,
      struct as *as, caddr_t addr, u_int len,
      u_int flags, int (*waitfp)(caddr_t),
      caddr_t arg, ddi_dma_lim_t *lim,
      ddi_dma_handle_t *handlep);
```

ddi_dma_addr_setup(9F) allocates resources for an object of length len at kernel address addr, subject to any constraints specified by lim. waitfp is a pointer to a callback function to be called later if the DMA resources cannot be allocated right away. If the resources are allocated successfully, ddi_dma_addr_setup(9F) passes back the DMA handle for the mapping in the location pointed to by handlep. NULL should be passed for as.

```
int ddi_dma_buf_setup(dev_info_t *dip, struct buf *bp,
      u_int flags, int (*waitfp)(caddr_t),
      caddr_t arg, ddi_dma_lim_t *lim,
      ddi_dma_handle_t *handlep);
```

ddi_dma_buf_setup(9F) allocates resources for an object described by a buf(9F) structure pointed to by bp, subject to constraints specified by lim. waitfp is a pointer to a callback function to be called later if the DMA resources cannot be allocated right away. If the resources are allocated successfully, ddi_dma_buf_setup(9F) passes back the DMA handle for the resources in the location pointed to by handlep.

```
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 two-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_coff(ddi_dma_handle_t handle,
      ddi_dma_cookie_t *cookiep, off_t *offp);
```

ddi_dma_coff(9F) passes back, in the location pointed to by offp, an offset into a DMA object. The mapping is specified by handle, and the offset offp is derived from the DMA cookie referred to by cookiep. ddi_dma_coff(9F) can be used after a DMA transfer is complete to find out where the DMA controller stopped.

```
int ddi_dma_curwin(ddi_dma_handle_t handle,
      off_t *offp, u_int *lenp);
```

ddi_dma_curwin(9F) passes back the offset and length of the current DMA window in the locations pointed to by offp and lenp, respectively.

```
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_htoc(ddi_dma_handle_t handle, off_t off,
      ddi_dma_cookie_t *cookiep);
```

ddi_dma_htoc(9F) passes back a DMA cookie in the location pointed to by cookiep that represents a DMA transfer starting at off in the DMA resources identified by handle. The DMA cookie is described in ddi_dma_cookie(9S) that contains information about a potential DMA transfer. The field dmac_address contains the transfer address for the DMA controller.

```
int ddi_dma_movwin(ddi_dma_handle_t handle,
      off_t *offp, u_int *lenp,
      ddi_dma_cookie_t *cookiep);
```

ddi_dma_movwin(9F) moves the current DMA window in the mapping identified by handle. The new window offset and length are passed back in the locations pointed to by offp and lenp, respectively. If a pointer to a DMA cookie structure is passed in cookiep, ddi_dma_movwin(9F) calls ddi_dma_htoc(9F) passes back a new DMA cookie in the location pointed to by cookiep.

```
int ddi_dma_nextseg(ddi_dma_win_t win,
      ddi_dma_seg_t seg, ddi_dma_seg_t *nseg);
```

ddi_dma_nextseg(9F) gets the next DMA segment within the specified window win. If the current segment is NULL, the first DMA segment within the window is returned.

```
int ddi_dma_nextwin(ddi_dma_handle_t handle,
      ddi_dma_win_t win, ddi_dma_win_t *nwin);
```

ddi_dma_nextwin(9F) shifts the current DMA window win within the object referred to by handle to the next DMA window nwin. If the current window is NULL, the first window within the object is returned.

```
int ddi_dma_segtocookie(ddi_dma_seg_t seg,
      off_t *offp, off_t *lenp,
      ddi_dma_cookie_t *cookiep);
```

ddi_dma_segtocookie(9F) takes a DMA segment and fills in the cookie pointed to by cookiep with the appropriate address, length, and bus type to be used to program the DMA engine. ddi_dma_segtocookie(9F) also fills in *offp and *lenp, which specify the range within the object.

```
int ddi_dma_setup(dev_info_t *dip,
      struct ddi_dma_req *dmareqp,
      ddi_dma_handle_t *handlep);
```

ddi_dma_setup(9F) is the main DMA resource allocation function. It allocates resources based on the DMA request structure pointed to by dmareqp, and passes back a DMA handle that identifies the mapping in the location pointed to by handlep.

```
int ddi_dma_free(ddi_dma_handle_t handle);
```

ddi_dma_free(9F) calls ddi_dma_sync(9F) and frees the resources associated with the DMA mapping identified by handle.

```
int ddi_dma_sync(ddi_dma_handle_t handle, off_t off,
      u_int length, u_int type);
```

ddi_dma_sync(9F) assures 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_segtocookie(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_getlim(dev_info_t *dip,
ddi_dma_lim_t *limitsp);

The ddi_dmae_getlim(9F) function fills in the DMA limit structure, pointed to by limitsp, with the DMA limits of the system DMA engine. This limit structure must be passed to the DMA setup routines so that they will know how to break the DMA request into windows and segments. 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 the DMA setup routines. The driver must not relax any of the restrictions embodied in the structure after it is filled in by ddi_dmae_getlim(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_iopb_alloc(dev_info_t *dip,
ddi_dma_lim_t *limits, u_int length,
caddr_t *iopbp);

ddi_iopb_alloc(9F) allocates a block of length bytes of memory, subject to constraints specified by limits. A block of memory so allocated is commonly called an "I/O parameter block", or IOPB, and is usually used to encode a device command. This block of consistent memory can be directly accessed by the device. A pointer to the allocated IOPB is passed back in the location pointed to by iopbp.

void ddi_iopb_free(caddr_t iopb);

ddi_iopb_free(9F) frees the I/O parameter block pointed to by iopb, which must have been allocated previously by ddi_iopb_alloc(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 every so often to check on the status of the device, and possibly issue an error message if some strange condition is detected.

Note – The detach(9E) entry point must assure 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, long 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 non-zero 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 allow 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 land 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) allows 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 be 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.

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.

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. 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 signalling 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_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 59 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_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_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.

Register and Memory Mapping

These interfaces support the mapping of device memory and device registers into kernel memory so a device driver can address them.

`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_map_regs(dev_info_t *dip, u_int rnumber,`
`caddr_t *kaddrp, off_t offset, off_t len);`

`ddi_map_regs`(9F) maps the register specification identified by `rnumber` on the device identified by `dip` into kernel memory starting at `offset` bytes from the base of the register specification. `ddi_map_regs`(9F) then passes back in the location pointed to by `kaddrp` a pointer to the base of the register specification plus `offset`.

`void ddi_unmap_regs(dev_info_t *dip, u_int rnumber,`
`caddr_t *kaddrp, off_t offset, off_t len);`

`ddi_unmap_regs`(9F) unmaps the register specification identified by `rnumber` on the device identified by `dip`. The associated mapping resources are freed, and the driver may no longer address the registers.

`int ddi_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_segmap`(9F) supports the `mmap`(2) system call, which allows application programs to map device memory into their address spaces. `ddi_segmap`(9F) should be used as the `segmap`(9E) entry in the `cb_ops`(9S) structure.

```
int ddi_mapdev(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,
      struct ddi_mapdev_ctl *ctl,
      ddi_mapdev_handle_t *handle, void *devprivate);
```

ddi_mapdev(9F) sets up user mappings to device space in the same manner as ddi_segmap(9F). However, unlike mappings created with ddi_segmap(9F), mappings created with ddi_mapdev(9F) have a set of driver entry points and a mapping handle associated with them. The driver is notified via these entry points in response to user events on the mappings.

```
int ddi_mapdev_intercept(ddi_mapdev_handle_t *handle,
      off_t offset, off_t len);
int ddi_mapdev_intercept(ddi_mapdev_handle_t *handle,
      off_t offset, off_t len);
```

ddi_mapdev_intercept(9F) and ddi_mapdev_nointercept(9F) control whether or not user accesses to the device mappings created by ddi_mapdev(9F) in the specified range will generate an access event notification to the device driver.

ddi_mapdev_intercept(9F) tells the system to intercept mapping accesses and invalidates the mapping translations. ddi_mapdev_nointercept(9F) prevents the system from intercepting mapping accesses and validates the mapping translations.

I/O Port Access

These interfaces support the accessing of device registers from the device driver.

```
unsigned char inb(int port);
unsigned short inw(int port);
unsigned long inl(int port);
void repinsb(int port, unsigned char *addr, int count);
void repinsw(int port, unsigned short *addr,
     int count);
void repinsd(int port, unsigned long *addr, int count);
```

These routines read data of various sizes from the I/O port with the address specified by `port`.

The `inb`(9F), `inw`(9F), and `inl`(9F) functions read 8 bits, 16 bits, and 32 bits of data respectively, returning the resulting values.

The `repinsb`(9F), `repinsw`(9F), and `repinsd`(9F) functions read multiple 8-bit, 16-bit, and 32-bit values, respectively. `count` specifies the number of values to be read. `addr` is a pointer to a buffer that will receive the input data. The buffer must be long enough to hold `count` values of the requested size.

```
void outb(int port, unsigned char value);
void outw(int port, unsigned short value);
void outl(int port, unsigned long value);
void repoutsb(int port, unsigned char *addr,
     int count);
void repoutsw(int port, unsigned short *addr,
     int count);
void repoutsd(int port, unsigned long *addr,
     int count);
```

These routines write data of various sizes to the I/O port with the address specified by `port`.

The `outb`(9F), `outw`(9F), and `outl`(9F) functions write 8 bits, 16 bits, and 32 bits of data respectively, writing the data specified by `value`.

The repoutsb(9F), repoutsw(9F), and repoutsd(9F) functions write multiple 8-bit, 16-bit, and 32-bit values, respectively. count specifies the number of values to be written. addr is a pointer to a buffer from which the output values are fetched.

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 10, "SCSI Target Drivers."

```
struct scsi_pkt *get_pktiopb(struct scsi_address *ap,
      caddr_t *datap, int cdblen, int statuslen,
      int datalen, int readflag,
      int (*callback)(void));
```

get_pktiopb(9F) allocates a SCSI packet structure with a small data area in the system IOPB (I/O parameter block) map for the target device denoted by ap. get_pktiopb(9F) calls scsi_dmaget(9F) to allocate the data area, and calls scsi_resalloc(9F) to allocate the scsi_pkt(9S) structure itself. If func is not NULL_FUNC and resources cannot be allocated right away, the function pointed to by func will be called when resources may have become available. func can call get_pktiopb(9F) again. If callback is SLEEP_FUNC, scsi_dmaget(9F) may block waiting for resources.

Target drivers often use get_pktiopb( ) to allocate packets for the REQUEST SENSE or INQUIRY SCSI commands, which need a small amount of cache-consistent memory. Use IOPB packets sparingly, though, because they are allocated from scarce DMA memory resources.

```
void free_pktiopb(struct scsi_pkt *pkt, caddr_t datap,
      int datalen);
```

free_pktiopb(9F) frees a scsi_pkt(9S) structure and related DMA resources previously allocated by get_pktiopb(9F).

```
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 non-sequential 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 non-sequential 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,
     int datalen, ulong bflags,
     int (*callback)(caddr_t), caddr_t arg);
```

scsi_alloc_consistent_buf(9F) allocates a buffer header and the associated data buffer for direct memory access (DMA) transfer. This buffer is allocated from the IOPB space, which is considered consistent memory. If bp is NULL, a new buffer header will be allocated using getrbuf(9F). If datalen is non-zero, a new buffer will be allocated using ddi_iopb_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) may 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) may block waiting for resources.

void scsi_dmafree(struct scsi_pkt *pkt);

scsi_dmafree(9F) frees the DMA resources previously allocated by scsi_dmaget(9F) for the scsi_pkt(9S) structure pkt.

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_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);

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) may 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.

```
struct scsi_pkt *scsi_pktalloc(
     struct scsi_address *ap, int cmdlen,
     int statuslen, int (*callback)(void));
```

scsi_pktalloc(9F) allocates and returns a pointer to a SCSI command packet for the target at the SCSI address pointed to by ap. cmdlen and statuslen tell scsi_pktalloc(9F) what size command descriptor block (CDB) and status completion block (SCB) to allocate. Use scsi_pktalloc(9F) only for commands that do no actual I/O. Use scsi_resalloc(9F) for I/O commands.

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. If callback is SLEEP_FUNC, scsi_pktalloct(9F) may block waiting for resources.

void scsi_pktfree(struct scsi_pkt *pkt);

scsi_pktfree(9F) frees the scsi_pkt(9S) structure pointed to by pkt that was previously allocated by scsi_pktalloc(9F).

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/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) may block waiting for resources.

struct scsi_pkt *scsi_resalloc(struct scsi_address *ap, int cmdlen, int statuslen, opaque_t dmatoken, int (*callback)(void));

scsi_resalloc(9F) allocates and returns a pointer to a SCSI command packet for the target at the SCSI address pointed to by ap. cmdlen and statuslen tell scsi_resalloc(9F) what size command descriptor block (CDB) and

status completion block (SCB) to allocate. Pass in `dmatoken` a pointer to the `buf`(9S) structure encoding the original I/O request. Use `scsi_pktalloc`(9F) for commands that do no actual I/O.

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. If `callback` is `SLEEP_FUNC`, `scsi_resalloc`(9F) may 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.

`void scsi_resfree(struct scsi_pkt *pkt);`

`scsi_resfree`(9F) frees the `scsi_pkt`(9S) structure pointed to by `pkt` and related DMA resources that were previously allocated by `scsi_resalloc`(9F).

`char *scsi_rname(u_char reason);`

`scsi_rname`(9F) decodes the packet completion reason code reason, and returns the corresponding reason string.

`int scsi_slave(struct scsi_device *devp, int (*callback)(void));`

`scsi_slave`(9F) issues, to the device indicated by *devp*, a `TEST UNIT READY` command, one or more `REQUEST SENSE` commands, and an `INQUIRY` command to determine whether the target is present and ready. It returns a code indicating the state of the target.

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_slave`(9F) may block waiting for resources.

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 command. 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).

void scsi_unslave(struct scsi_device *devp);

scsi_unslave(9F) is used to free any resources that were allocated on the driver's behalf during scsi_slave(9F).

Soft State Management

These interfaces comprise the soft state structure allocator, a facility that simplifies the management of state structures for driver instances. These routines are the recommended way 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 assure 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 non-zero 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 non-zero 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 assure 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 assure 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.

C

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 long parm,
     unsigned long *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 allow 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 doing this 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, long 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, long 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_add_intr(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 non-zero 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 non-zero.

void rw_destroy(krwlock_t *rwlp);

rw_destroy(9F) releases the resources associated with the readers / 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/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 non-zero 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 non-zero 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(long 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 deal with moving data using the uio(9S) data structure.

int uiomove(caddr_t address, long nbytes,
enum uio_rw rwflag, struct uio *uio_p);

uiomove(9F) copies data between the address 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 the 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 driver may use.

void ASSERT(EX);

The ASSERT(9F) macro does nothing if EX evaluates to non-zero. 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(char *s1, char *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 non-zero 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(caddr_t addr, size_t bytes);

bzero(9F) zeroes bytes 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);

ddi_set_driver_private(9F) sets the driver-private data of the dev_info node identified by dip to the value data.

int ddi_peekc(dev_info_t *dip, char *addr,
char *valuep);

ddi_peekc(9F) reads a character from the address addr to the location pointed to by valuep.

```
int ddi_peeks(dev_info_t *dip, short *addr,
      short *valuep);
```

ddi_peeks(9F) reads a short integer from the address addr to the location pointed to by valuep.

```
int ddi_peekl(dev_info_t *dip, long *addr,
      long *valuep);
```

ddi_peekl(9F) reads a long integer from the address addr to the location pointed to by valuep.

```
int ddi_peekd(dev_info_t *dip, longlong_t *addr,
      longlong_t *valuep);
```

ddi_peekd(9F) reads a double long integer from the address addr to the location pointed to by valuep.

```
int ddi_pokec(dev_info_t *dip, char *addr, char value);
```

ddi_pokec(9F) writes the character in value to the address addr.

```
int ddi_pokes(dev_info_t *dip, short *addr,
      short value);
```

ddi_pokes(9F) writes the short integer in value to the address addr.

```
int ddi_pokel(dev_info_t *dip, long *addr, long value);
```

ddi_pokel(9F) writes the long integer in value to the address addr.

```
int ddi_poked(dev_info_t *dip, longlong_t *addr,
      longlong_t value);
```

ddi_poked(9F) writes the double long integer 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 *man Pages(9E): DDI and DKI Driver Entry Points* 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 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 on the DDK. Sample driver names and driver descriptions are provided. Sample drivers are located in the following DDK path:

```
/opt/SUNWddk/driver_dev
```

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 device driver
pio	Simple programmed I/O driver
dma	Simple DMA character device driver
ramdisk	Simple RAM disk pseudo-device driver

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