FREEBSD® DEVICE DRIVERS

A GUIDE FOR THE *INTREPID*

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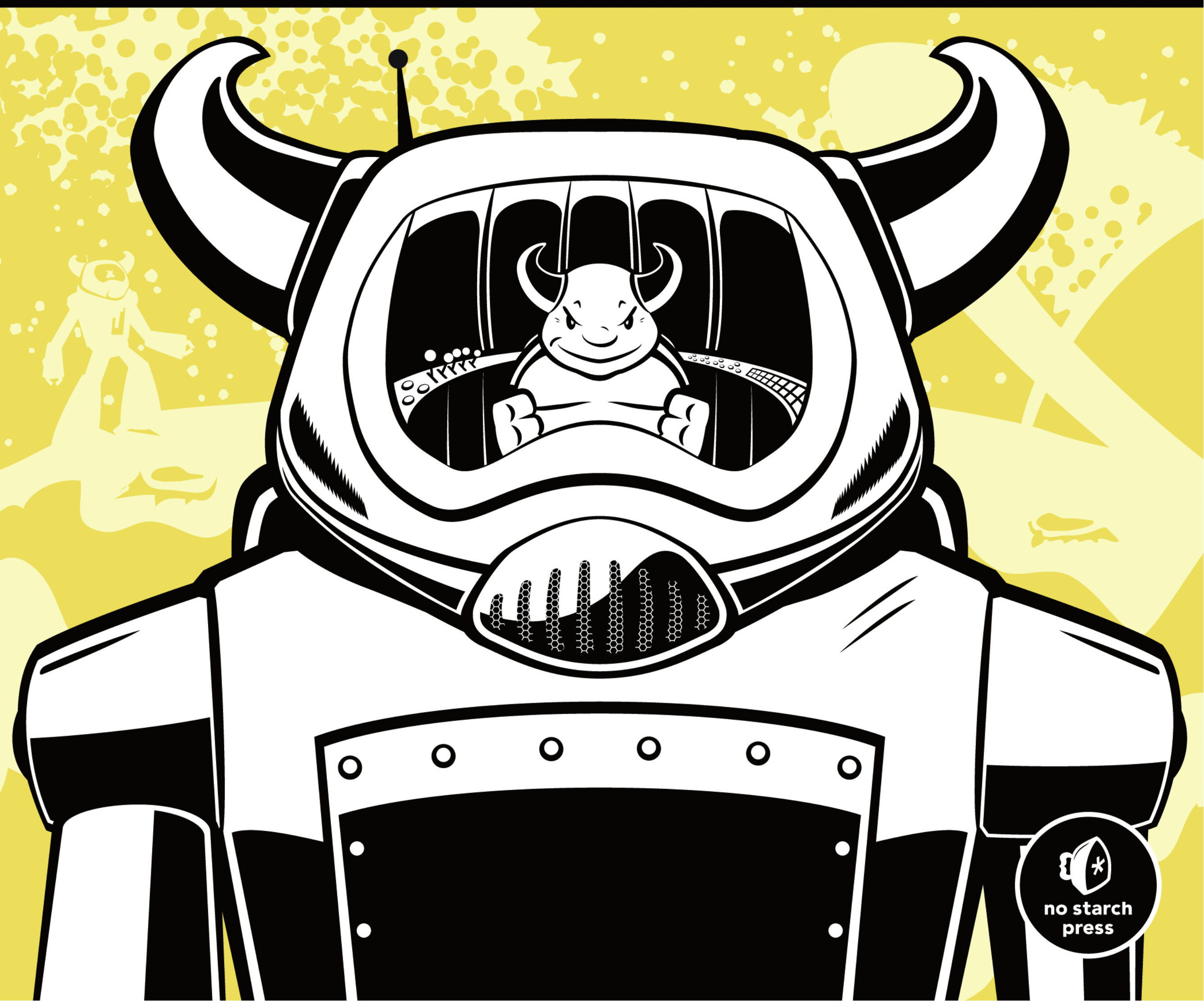

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BRIEF CONTENTS

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NEWBUS AND RESOURCE ALLOCATION

Until now, we've examined only pseudo-devices, which provide a superb introduction to driver writing. However, most drivers need to interact with real hardware. This chapter shows you how to write drivers that do just that.

I'll start by introducing *Newbus*, which is the infrastructure used in FreeBSD to manage the hardware devices on the system (McKusick and Neville-Neil, 2005). I'll then describe the basics of a Newbus driver, and I'll conclude this chapter by talking about hardware resource allocation.

Autoconfiguration and Newbus Drivers

Autoconfiguration is the procedure carried out by FreeBSD to enable the hardware devices on a machine (McKusick and Neville-Neil, 2005). It works by systematically probing a machine's I/O buses in order to identify their child devices. For each identified device, an appropriate Newbus driver is assigned to configure and initialize it. Note that it's possible for a device to be unidentifiable or unsupported. As a result, no Newbus driver will be assigned.

A *Newbus driver* is any driver in FreeBSD that controls a device that is bound to an I/O bus (that is, roughly every driver that is not a pseudo-device driver).

In general, three components are common to all Newbus drivers:

- The `device_foo` functions
- A device method table
- A `DRIVER_MODULE` macro call

device_foo Functions

The `device_foo` functions are, more or less, the operations executed by a Newbus driver during autoconfiguration. Table 7-1 briefly introduces each `device_foo` function.

Table 7-1: device_foo Functions

Function	Description
`device_identify`	Add new device to I/O bus
`device_probe`	Probe for specific device(s)
`device_attach`	Attach to device
`device_detach`	Detach from device
`device_shutdown`	Shut down device
`device_suspend`	Device suspend requested
`device_resume`	Resume has occurred

The `device_identify` function adds a new device (instance) to an I/O bus. This function is used only by buses that cannot directly identify their children. Recall that autoconfiguration begins by identifying the child devices on each I/O bus. Modern buses can directly identify the devices that are connected to them. Older buses, such as ISA, have to use the `device_identify` routine provided by their associated drivers to identify their child devices (McKusick and Neville-Neil, 2005). You'll learn how to associate a driver with an I/O bus shortly.

All identified child devices are passed to every Newbus driver's `device_probe` function. A `device_probe` function tells the kernel whether its driver can handle the identified device.

Note that there may be more than one driver that can handle an identified child device. Thus, `device_probe`'s return value is used to specify how well its driver matches the identified device. The `device_probe` function that returns the highest value denotes the best Newbus driver for the identified device. The following excerpt from <sys/bus.h> shows the constants used to indicate success (that is, a match):

```
#define BUS_PROBE_SPECIFIC      0       /* Only I can use this device. */
#define BUS_PROBE_VENDOR        (-10)   /* Vendor-supplied driver. */
#define BUS_PROBE_DEFAULT       (-20)   /* Base OS default driver. */
#define BUS_PROBE_LOW_PRIORITY  (-40)   /* Older, less desirable driver. */
#define BUS_PROBE_GENERIC       (-100)  /* Generic driver for device. */
#define BUS_PROBE_HOOVER        (-500)  /* Driver for all devices on bus. */
#define BUS_PROBE_NOWILDCARD    (-2000000000) /* No wildcard matches. */
```

As you can see, success codes are values less than or equal to zero. The standard UNIX error codes (that is, positive values) are used as failure codes.

Once the best driver has been found to handle a device, its `device_attach` function is called. A `device_attach` function initializes a device and any essential software (for example, device nodes).

The `device_detach` function disconnects a driver from a device. This function should set the device to a sane state and release any resources that were allocated during `device_attach`.

A Newbus driver's `device_shutdown`, `device_suspend`, and `device_resume` functions are called when the system is shut down, when its device is suspended, or when its device returns from suspension, respectively. These functions let a driver manage its device as these events occur.

Device Method Table

A device method table, `device_method_t`, specifies which `device_foo` functions a Newbus driver implements. It is defined in the <sys/bus.h> header.

Here is an example device method table for a fictitious PCI device:

```
static device_method_t foo_pci_methods[] = {
        /* Device interface. */
        DEVMETHOD(device_probe,         foo_pci_probe),
        DEVMETHOD(device_attach,        foo_pci_attach),
        DEVMETHOD(device_detach,        foo_pci_detach),
        { 0, 0 }
};
```

As you can see, not every `device_foo` function has to be defined. If a `device_foo` function is undefined, the corresponding operation is unsupported.

Unsurprisingly, the `device_probe` and `device_attach` functions must be defined for every Newbus driver. For drivers on older buses, the `device_identify` function must also be defined.

DRIVER_MODULE Macro

The DRIVER_MODULE macro registers a Newbus driver with the system. This macro is defined in the <sys/bus.h> header. Here is its function prototype:

```
#include <sys/param.h>
#include <sys/kernel.h>
#include <sys/bus.h>
#include <sys/module.h>

DRIVER_MODULE(name, busname, driver_t driver, devclass_t devclass,
    modeventhand_t evh, void *arg);
```

The arguments expected by this macro are as follows.

name

The name argument is used to identify the driver.

busname

The busname argument specifies the driver's I/O bus (for example, isa, pci, usb, and so on).

driver

The driver argument expects a filled-out driver_t structure. This argument is best understood with an example:

```
static driver_t foo_pci_driver = {
        ❶"foo_pci",
        ❷foo_pci_methods,
        ❸sizeof(struct foo_pci_softc)
};
```

Here, ❶ "foo_pci" is this example driver's official name, ❷ foo_pci_methods is its device method table, and ❸ sizeof(struct foo_pci_softc) is the size of its software context.

devclass

The devclass argument expects an uninitialized devclass_t variable, which will be used by the kernel for internal bookkeeping.

evh

The evh argument denotes an optional module event handler. Generally, we'll always set evh to 0, because DRIVER_MODULE supplies its own module event handler.

arg

The arg argument is the void * argument for the module event handler specified by evh. If evh is set to 0, arg must be too.

Tying Everything Together

You now know enough to write your first Newbus driver. Listing 7-1 is a simple Newbus driver (based on code written by Murray Stokely) for a fictitious PCI device.

NOTE *Take a quick look at this code and try to discern some of its structure. If you don't understand all of it, don't worry; an explanation follows.*

```
#include <sys/param.h>
#include <sys/module.h>
#include <sys/kernel.h>
#include <sys/systm.h>

#include <sys/conf.h>
#include <sys/uio.h>
#include <sys/bus.h>

#include <dev/pci/pcireg.h>
#include <dev/pci/pcivar.h>

❶ struct foo_pci_softc {
        ❷device_t       device;
        ❸struct cdev    *cdev;
};

static d_open_t         foo_pci_open;
static d_close_t        foo_pci_close;
static d_read_t         foo_pci_read;
static d_write_t        foo_pci_write;

❹ static struct cdevsw foo_pci_cdevsw = {
        .d_version =    D_VERSION,
        .d_open =       foo_pci_open,
        .d_close =      foo_pci_close,
        .d_read =       foo_pci_read,
        .d_write =      foo_pci_write,
        .d_name =       "foo_pci"
};

❺ static devclass_t foo_pci_devclass;

static int
foo_pci_open(struct cdev *dev, int oflags, int devtype, struct thread *td)
{
        struct foo_pci_softc *sc;

        sc = dev->si_drv1;
        device_printf(sc->device, "opened successfully\n");
        return (0);
}
```

```
static int
foo_pci_close(struct cdev *dev, int fflag, int devtype, struct thread *td)
{
        struct foo_pci_softc *sc;

        sc = dev->si_drv1;
        device_printf(sc->device, "closed\n");
        return (0);
}

static int
foo_pci_read(struct cdev *dev, struct uio *uio, int ioflag)
{
        struct foo_pci_softc *sc;

        sc = dev->si_drv1;
        device_printf(sc->device, "read request = %dB\n", uio->uio_resid);
        return (0);
}

static int
foo_pci_write(struct cdev *dev, struct uio *uio, int ioflag)
{
        struct foo_pci_softc *sc;

        sc = dev->si_drv1;
        device_printf(sc->device, "write request = %dB\n", uio->uio_resid);
        return (0);
}

static struct _pcsid {
        uint32_t        type;
        const char      *desc;
} pci_ids[] = {
        { 0x1234abcd, "RED PCI Widget" },
        { 0x4321fedc, "BLU PCI Widget" },
        { 0x00000000, NULL }
};

static int
foo_pci_probe(device_t dev)
{
        uint32_t type = pci_get_devid(dev);
        struct _pcsid *ep = pci_ids;

        while (ep->type && ep->type != type)
                ep++;
        if (ep->desc) {
                device_set_desc(dev, ep->desc);
                return (BUS_PROBE_DEFAULT);
        }

        return (ENXIO);
}
```

```
static int
foo_pci_attach(device_t dev)
{
        struct foo_pci_softc *sc = device_get_softc(dev);
        int unit = device_get_unit(dev);

        sc->device = dev;
        sc->cdev = ❻make_dev(&foo_pci_cdevsw, unit, UID_ROOT, GID_WHEEL,
            0600, "foo_pci%d", unit);
        sc->cdev->si_drv1 = sc;

        return (0);
}

static int
foo_pci_detach(device_t dev)
{
        struct foo_pci_softc *sc = device_get_softc(dev);

        destroy_dev(sc->cdev);
        return (0);
}

static device_method_t foo_pci_methods[] = {
        /* Device interface. */
        DEVMETHOD(device_probe,         foo_pci_probe),
        DEVMETHOD(device_attach,        foo_pci_attach),
        DEVMETHOD(device_detach,        foo_pci_detach),
        { 0, 0 }
};

static driver_t foo_pci_driver = {
        "foo_pci",
        foo_pci_methods,
        sizeof(struct foo_pci_softc)
};

❼ DRIVER_MODULE(foo_pci, pci, foo_pci_driver, ❽foo_pci_devclass, 0, 0);
```

Listing 7-1: foo_pci.c

This driver begins by defining its ❶ software context, which will maintain a ❷ pointer to its device and the ❸ cdev returned by the ❻ make_dev call.

Next, its ❹ character device switch table is defined. This table contains four d_foo functions named foo_pci_open, foo_pci_close, foo_pci_read, and foo_pci_write. I'll describe these functions in "d_foo Functions" on page 121.

Then a ❺ devclass_t variable is declared. This variable is passed to the ❼ DRIVER_MODULE macro as its ❽ devclass argument.

Finally, the d_foo and device_foo functions are defined. These functions are described in the order they would execute.

foo_pci_probe Function

The `foo_pci_probe` function is the `device_probe` implementation for this driver. Before I walk through this function, a description of the `pci_ids` array (found around the middle of Listing 7-1) is needed.

```
static struct _pcsid {
      ❶uint32_t       type;
      ❷const char     *desc;
} pci_ids[] = {
        { 0x1234abcd, "RED PCI Widget" },
        { 0x4321fedc, "BLU PCI Widget" },
        { 0x00000000, NULL }
};
```

This array is composed of three `_pcsid` structures. Each `_pcsid` structure contains a ❶ PCI ID and a ❷ description of the PCI device. As you might have guessed, `pci_ids` lists the devices that Listing 7-1 supports.

Now that I've described `pci_ids`, let's walk through `foo_pci_probe`.

```
static int
foo_pci_probe(device_t ❶dev)
{
        uint32_t type = ❷pci_get_devid(dev);
        struct _pcsid *ep = ❸pci_ids;

      ❹while (ep->type && ep->type != type)
                ep++;
        if (ep->desc) {
              ❺device_set_desc(dev, ep->desc);
              ❻return (BUS_PROBE_DEFAULT);
        }

        return (ENXIO);
}
```

Here, ❶ `dev` describes an identified device found on the PCI bus. So this function begins by ❷ obtaining the PCI ID of `dev`. Then it ❹ determines if `dev`'s PCI ID is listed in ❸ `pci_ids`. If it is, `dev`'s verbose description is ❺ set and the success code `BUS_PROBE_DEFAULT` is ❻ returned.

NOTE *The verbose description is printed to the system console when* `foo_pci_attach` *executes.*

foo_pci_attach Function

The `foo_pci_attach` function is the `device_attach` implementation for this driver. Here is its function definition (again):

```
static int
foo_pci_attach(device_t ❶dev)
{
        struct foo_pci_softc *sc = ❷device_get_softc(dev);
```

```
        int unit = ❸device_get_unit(dev);

        sc->device = ❹dev;
        sc->cdev = ❺make_dev(&foo_pci_cdevsw, unit, UID_ROOT, GID_WHEEL,
            0600, "foo_pci%d", unit);
        sc->cdev->si_drv1 = ❻sc;

        return (0);
}
```

Here, ❶ dev describes a device under this driver's control. Thus, this function starts by getting dev's ❷ software context and ❸ unit number. Then a character device node is ❺ created and the variables sc->device and sc->cdev->si_drv1 are set to ❹ dev and ❻ sc, respectively.

NOTE *The d_foo functions (described next) use `sc->device` and `cdev->si_drv1` to gain access to `dev` and `sc`.*

d_foo Functions

Because every d_foo function in Listing 7-1 just prints a debug message (that is to say, they're all basically the same), I'm only going to walk through one of them: foo_pci_open.

```
static int
foo_pci_open(struct cdev ❶*dev, int oflags, int devtype, struct thread *td)
{
        struct foo_pci_softc *sc;

      ❷sc = dev->si_drv1;
      ❸device_printf(sc->device, "opened successfully\n");
        return (0);
}
```

Here, ❶ dev is the cdev returned by the make_dev call in foo_pci_attach. So, this function first ❷ obtains its software context. Then it ❸ prints a debug message.

foo_pci_detach Function

The foo_pci_detach function is the device_detach implementation for this driver. Here is its function definition (again):

```
static int
foo_pci_detach(device_t ❶dev)
{
        struct foo_pci_softc *sc = ❷device_get_softc(dev);

      ❸destroy_dev(sc->cdev);
        return (0);
}
```

Here, ❶ dev describes a device under this driver's control. Thus, this function simply obtains dev's ❷ software context to ❸ destroy its device node.

Don't Panic

Now that we've discussed Listing 7-1, let's give it a try:

```
$ sudo kldload ./foo_pci.ko
$ kldstat
Id Refs Address    Size     Name
 1    3 0xc0400000 c9f490   kernel
 2    1 0xc3af0000 2000     foo_pci.ko
$ ls -l /dev/foo*
ls: /dev/foo*: ❶No such file or directory
```

Of course, it ❶ fails miserably, because foo_pci_probe is probing for fictitious PCI devices. Before concluding this chapter, one additional topic bears mentioning.

Hardware Resource Management

As part of configuring and operating devices, a driver might need to manage hardware resources, such as interrupt-request lines (IRQs), I/O ports, or I/O memory (McKusick and Neville-Neil, 2005). Naturally, Newbus includes several functions for doing just that.

```
#include <sys/param.h>
#include <sys/bus.h>

#include <machine/bus.h>
#include <sys/rman.h>
#include <machine/resource.h>

struct resource *
bus_alloc_resource(device_t dev, int type, int *rid, u_long start,
    u_long end, u_long count, u_int flags);

struct resource *
bus_alloc_resource_any(device_t dev, int type, int *rid,
    u_int flags);

int
bus_activate_resource(device_t dev, int type, int rid,
    struct resource *r);

int
bus_deactivate_resource(device_t dev, int type, int rid,
    struct resource *r);

int
bus_release_resource(device_t dev, int type, int rid,
    struct resource *r);
```

The bus_alloc_resource function allocates hardware resources for a specific device to use. If successful, a struct resource pointer is returned; otherwise, NULL is returned. This function is normally called during device_attach. If it is called during device_probe, all allocated resources must be released (via bus_release_resource) before returning. Most of the arguments for bus_alloc_resource are common to the other hardware resource management functions. These arguments are described in the next few paragraphs.

The dev argument is the device that requires ownership of the hardware resource(s). Before allocation, resources are owned by the parent bus.

The type argument represents the type of resource dev wants allocated. Valid values for this argument are listed in Table 7-2.

Table 7-2: Symbolic Constants for Hardware Resources

Constant	Description
SYS_RES_IRQ	Interrupt-request line
SYS_RES_IOPORT	I/O port
SYS_RES_MEMORY	I/O memory

The rid argument expects a resource ID (RID). If bus_alloc_resource is successful, a RID is returned in rid that may differ from what you passed. You'll learn more about RIDs later.

The start and end arguments are the start and end addresses of the hardware resource(s). To employ the default bus values, simply pass 0ul as start and ~0ul as end.

The count argument denotes the size of the hardware resource(s). If you used the default bus values for start and end, count is used only if it is larger than the default bus value.

The flags argument details the characteristics of the hardware resource. Valid values for this argument are listed in Table 7-3.

Table 7-3: bus_alloc_resource Symbolic Constants

Constant	Description
RF_ALLOCATED	Allocate hardware resource, but don't activate it
RF_ACTIVE	Allocate hardware resource and activate resource automatically
RF_SHAREABLE	Hardware resource permits contemporaneous sharing; you should always set this flag, unless the resource cannot be shared
RF_TIMESHARE	Hardware resource permits time-division sharing

The bus_alloc_resource_any function is a convenience wrapper for bus_alloc_resource that sets start, end, and count to their default bus values.

The bus_activate_resource function activates a previously allocated hardware resource. Naturally, resources must be activated before they can be used. Most drivers simply pass RF_ACTIVE to bus_alloc_resource or bus_alloc_resource_any to avoid calling bus_activate_resource.

The `bus_deactivate_resource` function deactivates a hardware resource. This function is primarily used in bus drivers (so we'll never call it).

The `bus_release_resource` function releases a previously allocated hardware resource. Of course, the resource cannot be in use on release. If successful, `0` is returned; otherwise, the kernel panics.

NOTE *We'll cover an example that employs IRQs in Chapters 8 and 9, and I'll go over an example that requires I/O ports and I/O memory in Chapters 10 and 11.*

Conclusion

This chapter introduced you to the basics of Newbus driver development—working with real hardware. The remainder of this book builds upon the concepts described here to complete your understanding of Newbus.