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<book id="USBDeviceDriver">
 <bookinfo>
  <title>Writing USB Device Drivers</title>

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```

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<toc></toc>
```

```
  <chapter id="intro">
      <title>Introduction</title>
  <para>
```

The Linux USB subsystem has grown from supporting only two different
types of devices in the 2.2.7 kernel (mice and keyboards), to over 20
different types of devices in the 2.4 kernel. Linux currently supports
almost all USB class devices (standard types of devices like keyboards,
mice, modems, printers and speakers) and an ever-growing number of
vendor-specific devices (such as USB to serial converters, digital
cameras, Ethernet devices and MP3 players). For a full list of the
different USB devices currently supported, see Resources.

```
  </para>
  <para>
```

The remaining kinds of USB devices that do not have support on Linux are
almost all vendor-specific devices. Each vendor decides to implement a
custom protocol to talk to their device, so a custom driver usually needs
to be created. Some vendors are open with their USB protocols and help
with the creation of Linux drivers, while others do not publish them, and
developers are forced to reverse-engineer. See Resources for some links
to handy reverse-engineering tools.

```
  </para>
  <para>
```

Because each different protocol causes a new driver to be created, I have
written a generic USB driver skeleton, modeled after the pci-skeleton.c
file in the kernel source tree upon which many PCI network drivers have
been based. This USB skeleton can be found at drivers/usb/usb-skeleton.c
in the kernel source tree. In this article I will walk through the basics
of the skeleton driver, explaining the different pieces and what needs to
be done to customize it to your specific device.

```
  </para>
  </chapter>
```

```
  <chapter id="basics">
      <title>Linux USB Basics</title>
  <para>
```

If you are going to write a Linux USB driver, please become familiar with
the USB protocol specification. It can be found, along with many other
useful documents, at the USB home page (see Resources). An excellent
introduction to the Linux USB subsystem can be found at the USB Working
Devices List (see Resources). It explains how the Linux USB subsystem is
structured and introduces the reader to the concept of USB urbs
(USB Request Blocks), which are essential to USB drivers.

```
  </para>
  <para>
```

The first thing a Linux USB driver needs to do is register itself with
the Linux USB subsystem, giving it some information about which devices
the driver supports and which functions to call when a device supported
by the driver is inserted or removed from the system. All of this
information is passed to the USB subsystem in the usb_driver structure.
The skeleton driver declares a usb_driver as:

　　</para>
　　<programlisting>

```
static struct usb_driver skel_driver = {
        .name        = "skeleton",
        .probe       = skel_probe,
        .disconnect  = skel_disconnect,
        .fops        = &amp;skel_fops,
        .minor       = USB_SKEL_MINOR_BASE,
        .id_table    = skel_table,
};
```

　　</programlisting>
　　<para>
　　　　The variable name is a string that describes the driver. It is used in
　　　　informational messages printed to the system log. The probe and
　　　　disconnect function pointers are called when a device that matches the
　　　　information provided in the id_table variable is either seen or removed.
　　</para>
　　<para>
　　　　The fops and minor variables are optional. Most USB drivers hook into
　　　　another kernel subsystem, such as the SCSI, network or TTY subsystem.
　　　　These types of drivers register themselves with the other kernel
　　　　subsystem, and any user-space interactions are provided through that
　　　　interface. But for drivers that do not have a matching kernel subsystem,
　　　　such as MP3 players or scanners, a method of interacting with user space
　　　　is needed. The USB subsystem provides a way to register a minor device
　　　　number and a set of file_operations function pointers that enable this
　　　　user-space interaction. The skeleton driver needs this kind of interface,
　　　　so it provides a minor starting number and a pointer to its
　　　　file_operations functions.
　　</para>
　　<para>
　　　　The USB driver is then registered with a call to usb_register, usually in
　　　　the driver's init function, as shown here:
　　</para>
　　<programlisting>

```
static int __init usb_skel_init(void)
{
        int result;

        /* register this driver with the USB subsystem */
        result = usb_register(&amp;skel_driver);
        if (result &lt; 0) {
                err(&quot;usb_register failed for the &quot;__FILE__
&quot;driver.&quot;
                    &quot;Error number %d&quot;, result);
                return -1;
        }

        return 0;
}
module_init(usb_skel_init);
```

　　</programlisting>
　　<para>
　　　　When the driver is unloaded from the system, it needs to deregister
　　　　itself with the USB subsystem. This is done with the usb_deregister
　　　　function:

```
   </para>
   <programlisting>
static void __exit usb_skel_exit(void)
{
        /* deregister this driver with the USB subsystem */
        usb_deregister(&amp;skel_driver);
}
module_exit(usb_skel_exit);
   </programlisting>
   <para>
      To enable the linux-hotplug system to load the driver automatically when
      the device is plugged in, you need to create a MODULE_DEVICE_TABLE. The
      following code tells the hotplug scripts that this module supports a
      single device with a specific vendor and product ID:
   </para>
   <programlisting>
/* table of devices that work with this driver */
static struct usb_device_id skel_table [] = {
        { USB_DEVICE(USB_SKEL_VENDOR_ID, USB_SKEL_PRODUCT_ID) },
        { }                             /* Terminating entry */
};
MODULE_DEVICE_TABLE (usb, skel_table);
   </programlisting>
   <para>
      There are other macros that can be used in describing a usb_device_id for
      drivers that support a whole class of USB drivers. See usb.h for more
      information on this.
   </para>
   </chapter>


   <chapter id="device">
       <title>Device operation</title>
   <para>
      When a device is plugged into the USB bus that matches the device ID
      pattern that your driver registered with the USB core, the probe function
      is called. The usb_device structure, interface number and the interface ID
      are passed to the function:
   </para>
   <programlisting>
static int skel_probe(struct usb_interface *interface,
    const struct usb_device_id *id)
   </programlisting>
   <para>
      The driver now needs to verify that this device is actually one that it
      can accept. If so, it returns 0.
      If not, or if any error occurs during initialization, an errorcode
      (such as <literal>-ENOMEM</literal> or <literal>-ENODEV</literal>)
      is returned from the probe function.
   </para>
   <para>
      In the skeleton driver, we determine what end points are marked as bulk-in
      and bulk-out. We create buffers to hold the data that will be sent and
      received from the device, and a USB urb to write data to the device is
      initialized.
   </para>
   <para>
```

Conversely, when the device is removed from the USB bus, the disconnect function is called with the device pointer. The driver needs to clean any private data that has been allocated at this time and to shut down any pending urbs that are in the USB system.
    </para>
    <para>
Now that the device is plugged into the system and the driver is bound to the device, any of the functions in the file_operations structure that were passed to the USB subsystem will be called from a user program trying to talk to the device. The first function called will be open, as the program tries to open the device for I/O. We increment our private usage count and save a pointer to our internal structure in the file structure. This is done so that future calls to file operations will enable the driver to determine which device the user is addressing. All of this is done with the following code:
    </para>
    <programlisting>
/* increment our usage count for the module */
++skel->open_count;

/* save our object in the file's private structure */
file->private_data = dev;
    </programlisting>
    <para>
After the open function is called, the read and write functions are called to receive and send data to the device. In the skel_write function, we receive a pointer to some data that the user wants to send to the device and the size of the data. The function determines how much data it can send to the device based on the size of the write urb it has created (this size depends on the size of the bulk out end point that the device has). Then it copies the data from user space to kernel space, points the urb to the data and submits the urb to the USB subsystem. This can be seen in the following code:
    </para>
    <programlisting>
/* we can only write as much as 1 urb will hold */
bytes_written = (count > skel->bulk_out_size) ? skel->bulk_out_size : count;

/* copy the data from user space into our urb */
copy_from_user(skel->write_urb->transfer_buffer, buffer, bytes_written);

/* set up our urb */
usb_fill_bulk_urb(skel->write_urb,
                  skel->dev,
                  usb_sndbulkpipe(skel->dev, skel->bulk_out_endpointAddr),
                  skel->write_urb->transfer_buffer,
                  bytes_written,
                  skel_write_bulk_callback,
                  skel);

/* send the data out the bulk port */
result = usb_submit_urb(skel->write_urb);
if (result) {
        err("Failed submitting write urb, error %d", result);
}
    </programlisting>

〈para〉
　　When the write urb is filled up with the proper information using the
　　usb_fill_bulk_urb function, we point the urb's completion callback to call
our
　　own skel_write_bulk_callback function. This function is called when the
　　urb is finished by the USB subsystem. The callback function is called in
　　interrupt context, so caution must be taken not to do very much processing
　　at that time. Our implementation of skel_write_bulk_callback merely
　　reports if the urb was completed successfully or not and then returns.
〈/para〉
〈para〉
　　The read function works a bit differently from the write function in that
　　we do not use an urb to transfer data from the device to the driver.
　　Instead we call the usb_bulk_msg function, which can be used to send or
　　receive data from a device without having to create urbs and handle
　　urb completion callback functions. We call the usb_bulk_msg function,
　　giving it a buffer into which to place any data received from the device
　　and a timeout value. If the timeout period expires without receiving any
　　data from the device, the function will fail and return an error message.
　　This can be shown with the following code:
〈/para〉
〈programlisting〉

```
/* do an immediate bulk read to get data from the device */
retval = usb_bulk_msg (skel->dev,
                       usb_rcvbulkpipe (skel->dev,
                       skel->bulk_in_endpointAddr),
                       skel->bulk_in_buffer,
                       skel->bulk_in_size,
                       &amp;count, HZ*10);
/* if the read was successful, copy the data to user space */
if (!retval) {
        if (copy_to_user (buffer, skel->bulk_in_buffer, count))
                retval = -EFAULT;
        else
                retval = count;
}
```

〈/programlisting〉
〈para〉
　　The usb_bulk_msg function can be very useful for doing single reads or
　　writes to a device; however, if you need to read or write constantly to a
　　device, it is recommended to set up your own urbs and submit them to the
　　USB subsystem.
〈/para〉
〈para〉
　　When the user program releases the file handle that it has been using to
　　talk to the device, the release function in the driver is called. In this
　　function we decrement our private usage count and wait for possible
　　pending writes:
〈/para〉
〈programlisting〉

```
/* decrement our usage count for the device */
--skel->open_count;
```

〈/programlisting〉
〈para〉
　　One of the more difficult problems that USB drivers must be able to handle
　　smoothly is the fact that the USB device may be removed from the system at
</para>

    any point in time, even if a program is currently talking to it. It needs
    to be able to shut down any current reads and writes and notify the
    user-space programs that the device is no longer there. The following
    code (function <function>skel_delete</function>)
    is an example of how to do this: </para>
  <programlisting>

```
static inline void skel_delete (struct usb_skel *dev)
{
    kfree (dev->bulk_in_buffer);
    if (dev->bulk_out_buffer != NULL)
        usb_free_coherent (dev->udev, dev->bulk_out_size,
            dev->bulk_out_buffer,
            dev->write_urb->transfer_dma);
    usb_free_urb (dev->write_urb);
    kfree (dev);
}
```

  </programlisting>
  <para>
    If a program currently has an open handle to the device, we reset the flag
    <literal>device_present</literal>. For
    every read, write, release and other functions that expect a device to be
    present, the driver first checks this flag to see if the device is
    still present. If not, it releases that the device has disappeared, and a
    -ENODEV error is returned to the user-space program. When the release
    function is eventually called, it determines if there is no device
    and if not, it does the cleanup that the skel_disconnect
    function normally does if there are no open files on the device (see
    Listing 5).
  </para>
  </chapter>

  <chapter id="iso">
      <title>Isochronous Data</title>
  <para>
    This usb-skeleton driver does not have any examples of interrupt or
    isochronous data being sent to or from the device. Interrupt data is sent
    almost exactly as bulk data is, with a few minor exceptions. Isochronous
    data works differently with continuous streams of data being sent to or
    from the device. The audio and video camera drivers are very good examples
    of drivers that handle isochronous data and will be useful if you also
    need to do this.
  </para>
  </chapter>

  <chapter id="Conclusion">
      <title>Conclusion</title>
  <para>
    Writing Linux USB device drivers is not a difficult task as the
    usb-skeleton driver shows. This driver, combined with the other current
    USB drivers, should provide enough examples to help a beginning author
    create a working driver in a minimal amount of time. The linux-usb-devel
    mailing list archives also contain a lot of helpful information.
  </para>
  </chapter>

  <chapter id="resources">

　　　　〈title〉Resources〈/title〉
　　〈para〉
　　　The Linux USB Project: 〈ulink
url="http://www.linux-usb.org"〉http://www.linux-usb.org/〈/ulink〉
　　〈/para〉
　　〈para〉
　　　Linux Hotplug Project: 〈ulink
url="http://linux-hotplug.sourceforge.net"〉http://linux-hotplug.sourceforge.net/
〈/ulink〉
　　〈/para〉
　　〈para〉
　　　Linux USB Working Devices List: 〈ulink
url="http://www.qbik.ch/usb/devices"〉http://www.qbik.ch/usb/devices/〈/ulink〉
　　〈/para〉
　　〈para〉
　　　linux-usb-devel Mailing List Archives: 〈ulink
url="http://marc.theaimsgroup.com/?l=linux-usb-devel"〉http://marc.theaimsgroup.c
om/?l=linux-usb-devel〈/ulink〉
　　〈/para〉
　　〈para〉
　　　Programming Guide for Linux USB Device Drivers: 〈ulink
url="http://usb.cs.tum.edu/usbdoc"〉http://usb.cs.tum.edu/usbdoc〈/ulink〉
　　〈/para〉
　　〈para〉
　　　USB Home Page: 〈ulink url="http://www.usb.org"〉http://www.usb.org〈/ulink〉
　　〈/para〉
　　〈/chapter〉

〈/book〉