國立臺北科技大學
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Department of Computer Science and Information Engineering

Linux Driver & Driver Framework

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Course Schedule

No class on school exam week.

W	Date	Lecture	Notes	Homework
1	Sept. 14	Lec01: Introduction		HW00
2	Sept. 21	Teacher Official Leave	No Class	
3	Sept. 28	Lec02: The Big Picture		
4	Oct. 5	Lec03: Linux and Real time		
5	Oct. 12	Lec04: The Linux Kernel		
6	Oct. 19	Lec05: Kernel Arch for Device Drivers & Kernel Initialization		
7	Oct. 26	Lec06: Driver Allocation, Input Subsystem & Memory		
8	Nov. 2	Lec07: Direct Memory Access & misc		
9	Nov. 9	School Midterm Exam	No Class	
10	Nov. 16	Lec08: Flash Memory		
11	Nov. 23	Midterm on Nov. 23	Open book + Physical + Paper/Pen	
12	Nov. 30	Lec09: Flash Memory		
13	Dec. 7	Lec10: USB Device		
14	Dec. 14	Lec11: I2C		
15	Dec. 21	Lec12: Kernel Framework & PCI		
16	Dec. 28	Final Presentation	Online	
17	Jan. 14	Final Presentation	Online	
18	Jan. 11	School Final Exam	No Class	

Kernel Arch for Device Drivers

- User space sees three main types of devices:

1. Character devices
   - The most common type of devices.
   - Initially for devices implementing streams of bytes, it is now used for a wide range of devices: serial ports, framebuffers, video capture devices, sound devices, input devices, I2C and SPI gateways, etc.
2. Block devices
   - for storage devices like hard disks, CD-ROM drives, USB keys, SD/MMC cards, etc.
3. Network devices
   - for wired or wireless interfaces, network connections and others

Accessing the devices

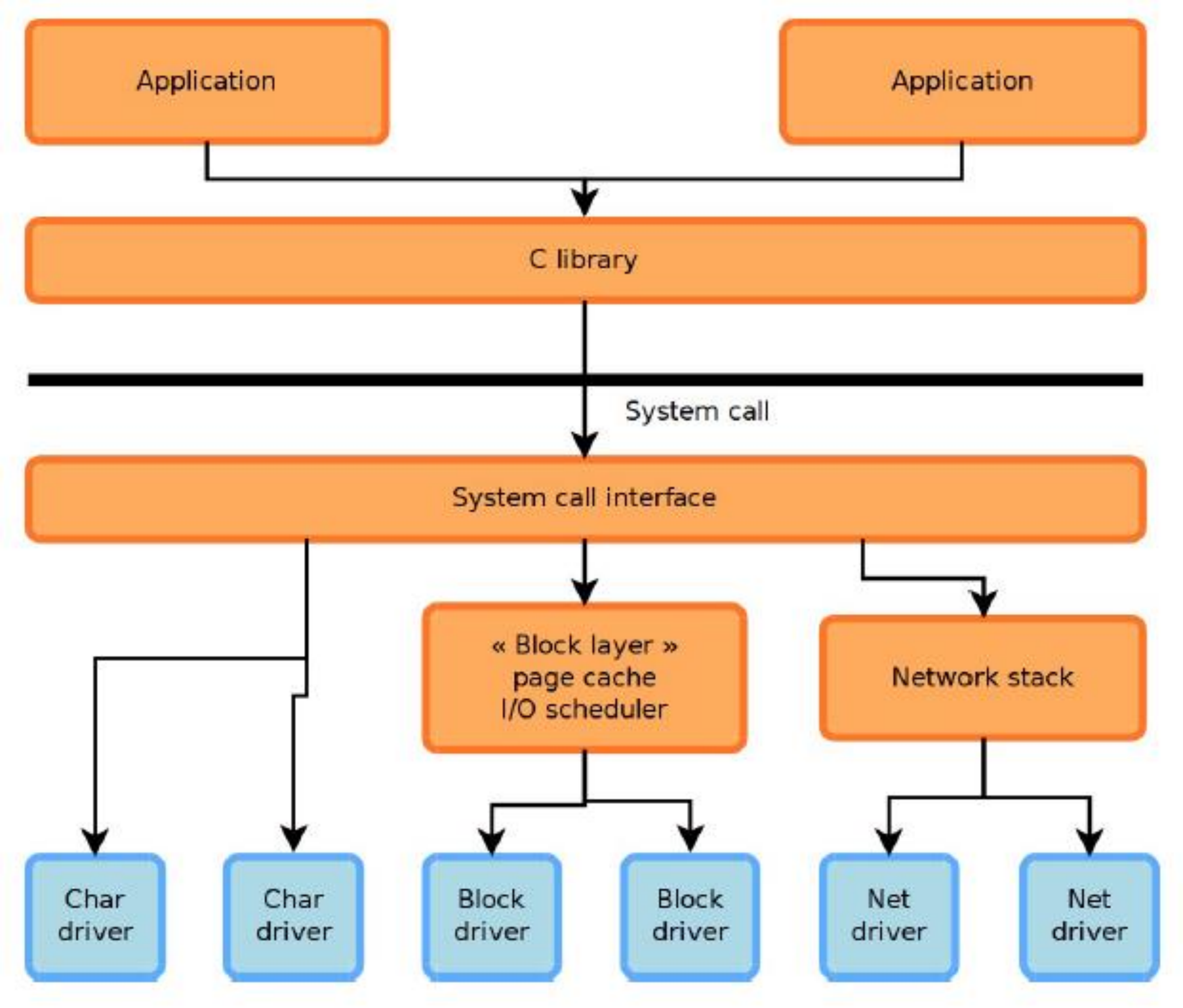
- Network devices are accessed through network-specic APIs and tools (socket API of the standard C library, tools such as ifconfig, route, etc.)
- Block and character devices are represented for user space applications as files than can be manipulated using the traditional file API (open(), read(), write(), close(), etc.)
  - Special file types for block and character devices, associating a name with a couple (major, minor)
  - The kernel only cares about the (type, major, minor), which is the unique identifier of the device
  - Special files traditionally located in /dev, created by mknod, either manually or automatically by udev

Inside the Kernel

- Device drivers must register themselves to the core kernel and implement a set of operations specific to their type:
  - **Character drivers** must instantiate and register a cdev structure and implement file_ operations
  - **Block drivers** must instantiate and register a gendisk structure and implement block_device_operations and a special make_request function
  - **Network drivers** must instantiate and register a net_device structure and implement net_device_ops

- For the following, we will first focus on character devices as an example of device drivers.

General architecture



File operations

- The file operations are generic to all types of files: regular files, directories, character devices, block devices, etc.

```
struct file_operations {
    struct module *owner;
    loff_t (*llseek) (struct file *, loff_t, int);
    ssize_t (*read) (struct file *, char __user *, size_t, loff_t *);
    ssize_t (*write) (struct file *, const char __user *, size_t, loff_t *);
    ssize_t (*aio_read) (struct kiocb *, const struct iovec *, unsigned long, loff_t);
    ssize_t (*aio_write) (struct kiocb *, const struct iovec *, unsigned long, loff_t);
    int (*readdir) (struct file *, void *, filldir_t);
    unsigned int (*poll) (struct file *, struct poll_table_struct *);
    int (*ioctl) (struct inode *, struct file *, unsigned int, unsigned long);
    int (*mmap) (struct file *, struct vm_area_struct *);
    int (*open) (struct inode *, struct file *);
    int (*flush) (struct file *, fl_owner_t id);
    int (*release) (struct inode *, struct file *);
    int (*fsync) (struct file *, struct dentry *, int datasync);
    int (*fasync) (int, struct file *, int);
    int (*flock) (struct file *, int, struct file_lock *);
    [...]
};
```

Character Driver Skeleton

- Implement the read() and write() operations, and instantiate the file_operations structure.

```
static ssize_t demo_write(struct file *f, const char __user *buf,
                          size_t len, loff_t *off)
{
        [...]
}

static ssize_t demo_read(struct file *f, char __user *buf,
                         size_t len, loff_t *off)
{
        [...]
}

static struct file_operations demo_fops =
{
        .owner = THIS_MODULE,
        .read = acme_read,
        .write = acme_write
};
```

Character Driver Skeleton

- Register and unregister the driver to the kernel using
  - register_chrdev_region & unregister_chrdev_region
  - cdev_add & cdev_del

```
static dev_t demo_dev = MKDEV(202,128);
static struct cdev demo_cdev;

static int __init demo_init(void)
{
    register_chrdev_region(demo_dev, 1, \demo");
    cdev_init(&demo_cdev, &demo_fops);
    cdev_add(&demo_cdev, demo_dev, demo_count);
}

static void __exit demo_exit(void)
{
    cdev_del(&demo_cdev);
    unregister_chrdev_region(demo_dev, 1);
    iounmap(demo_buf);
}

module_init(demo_init);
module_exit(demo_exit);
```

Driver Usage in Userspace

- Making it accessible to userspace application by creating a device node:
- mknod /dev/demo c 202 128
- Using normal the normal file API :

```
fd = open("/dev/demo", O_RDWR);

ret = read(fd, buf, bufsize);

ret = write(fd, buf, bufsize);
```

From the Syscall to Your Driver

- In fs/read write.c

```
SYSCALL_DEFINE3(read, unsigned int, fd, char __user *, buf, size_t, count)
{
        struct file *file;
        ssize_t ret = -EBADF;
        int fput_needed;

        file = fget_light(fd, &fput_needed);
        if (file) {
                loff_t pos = file_pos_read(file);
                ret = vfs_read(file, buf, count, &pos);
                file_pos_write(file, pos);
                fput_light(file, fput_needed);
        }

        return ret;
}
```

From the Syscall to Your Driver

- In fs/read write.c

```
ssize_t vfs_read(struct file *file, char __user *buf, size_t count, loff_t *pos)
{
        ssize_t ret;

        if (!(file->f_mode & FMODE_READ))
                return -EBADF;
        if (!file->f_op || (!file->f_op->read && !file->f_op->aio_read))
                return -EINVAL;
        if (unlikely(!access_ok(VERIFY_WRITE, buf, count)))
                return -EFAULT;

        ret = rw_verify_area(READ, file, pos, count);
        if (ret >= 0) {
                count = ret;
                if (file->f_op->read)
                        ret = file->f_op->read(file, buf, count, pos);
                else
                        ret = do_sync_read(file, buf, count, pos);
                if (ret > 0) {
                        fsnotify_access(file->f_path.dentry);
                        add_rchar(current, ret);
                }
                inc_syscr(current);
        }

        return ret;
}
```

ioctl mechanism

- The file operations set of operations, while being sufficient for regular files, isn't sufficient as an API to the wide range of character and block devices
- Device-specific operations such as changing the speed of a serial port, setting the volume on a soundcard, configuring video-related parameters on a framebuffer are not handled by the file operations
- One of the operations, ioctl() allows to extend the capabilities of a driver with driver-specific operations
- In user space: `int ioctl(int d, int request, ...);`
  - d, the file descriptor
  - request, a driver-specific integer identifying the operation
  - ..., zero or one argument.
- In kernel space: `int (*ioctl) (struct inode *, struct file *, unsigned int, unsigned long);`

Kernel

- Implement the demo ioctl() operation and reference it in the file_operations structure:

```
static int demo_ioctl(struct inode *inode,
      struct file *file,
      unsigned int cmd,
      unsigned long arg)

{
        char __user *argp = (char __user *)arg;

        switch (cmd) {

               case DEMO_CMD1:
                         /* Something */
                         return 0;

               default:
                         return -ENOTTY;
        }
}

static const struct file_operations demo_fops =
{
        [...]
        .ioctl = demo_ioctl,
        [...]
};
```

ioctl example, userspace side

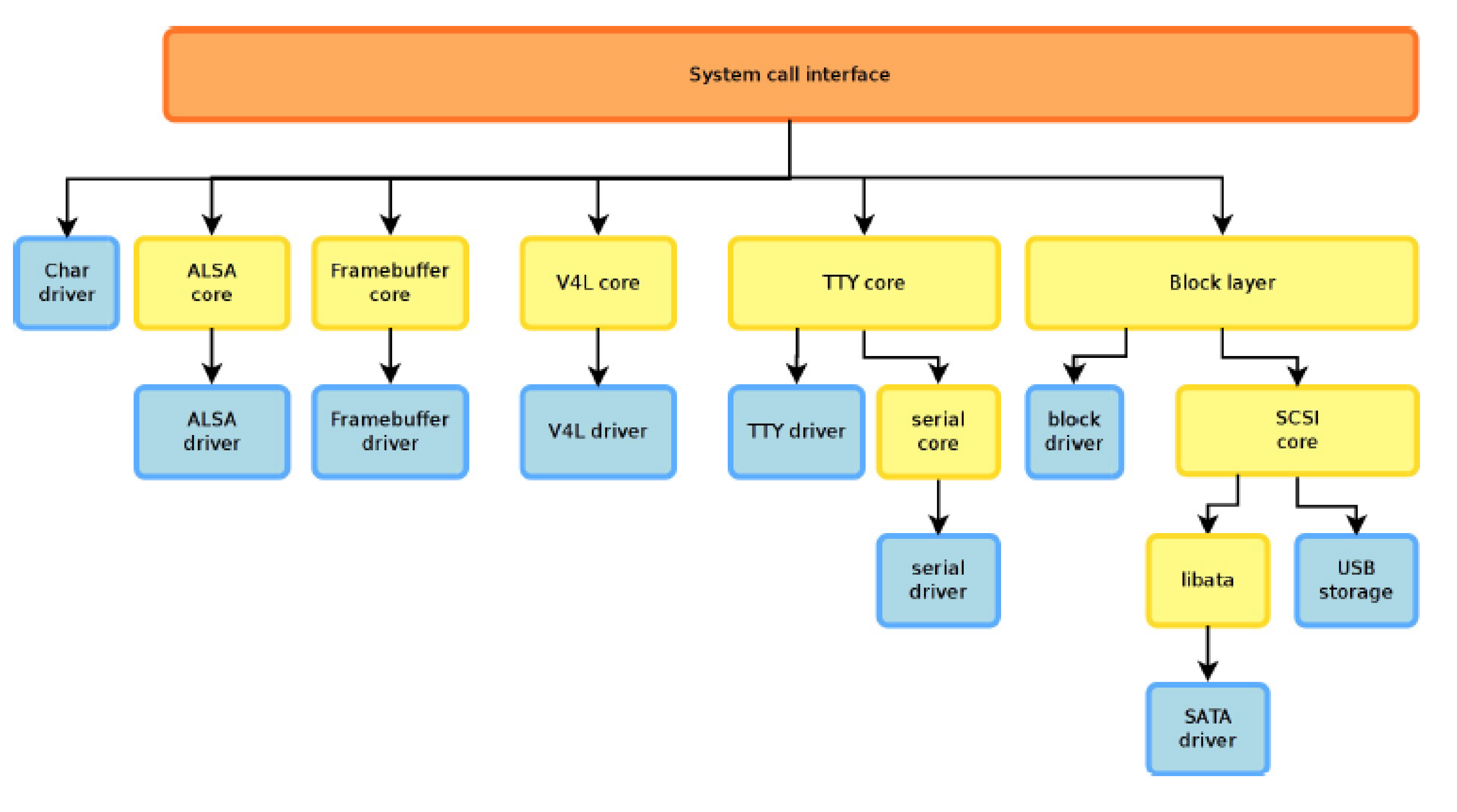
- Use the ioctl() system call.

```
int fd, val;

fd = open("/dev/demo", O_RDWR);

ioctl(fd, DEMO_CMD1, & val);
```

Kernel Framework

- Most device drivers are not directly implemented as character devices or block devices
- They are implemented under a framework, specific to a device type (framebuffer, V4L, serial, etc.)
  - The framework allows to factorize the common parts of drivers for the same type of devices
  - From user space, they are still seen as normal character devices
  - The framework allows to provide a coherent user space interface (ioctl numbering and semantic, etc.) for every type of device, regardless of the driver

Example of frameworks



Example of the framebuffer framework

- Kernel option CONFIG_FB
- Implemented in drivers/video/
  - fb.c, fbmem.c, fbmon.c, fbcmap.c, fbsysfs.c, modedb.c, fbcvt.c
- Implements a single character driver (through file operations), registers the major number and allocates minors, allocates and implements the user/kernel API
  - First part of include/linux/fb.h
- Defines the set of operations a framebuffer driver must implement and helper functions for the drivers
  - struct fb_ops
  - Second part of include/linux/fb.h

The framebuffer Driver

- Must implement some or all operations defined in struct fb_ops. Those operations are framebuffer-specfic.
  - xxx_open(), xxx _ read(), xxx_write(), xxx_release(), xxx_checkvar(), xxx_setpar(), xxx_setcolreg(), xxx_blank(), xxx_pan_display(), xxx_fillrect(), xxx_copyarea(), xxx_imageblit(), xxx_cursor(), xxx_rotate(), xxx_sync(), xxx get_caps(), etc.
- Must allocate a fb_info structure with framebuffer_alloc(), set the ->fbops field to the operation structure, and register the framebuer device with register framebuffer()

Skeleton example

```
static int xxx_open(struct fb_info *info, int user) {}
static int xxx_release(struct fb_info *info, int user) {}
static int xxx_check_var(struct fb_var_screeninfo *var, struct fb_info *info) {}
static int xxx_set_par(struct fb_info *info) {}

static struct fb_ops xxx_ops = {
        .owner          = THIS_MODULE,
        .fb_open        = xxxfb_open,
        .fb_release     = xxxfb_release,
        .fb_check_var   = xxxfb_check_var,
        .fb_set_par     = xxxfb_set_par,
        [...]
};

init()
{
    struct fb_info *info;
    info = framebuffer_alloc(sizeof(struct xxx_par), device);
    info->fbops = &xxxfb_ops;
    [...]
    register_framebuffer(info);
}
```

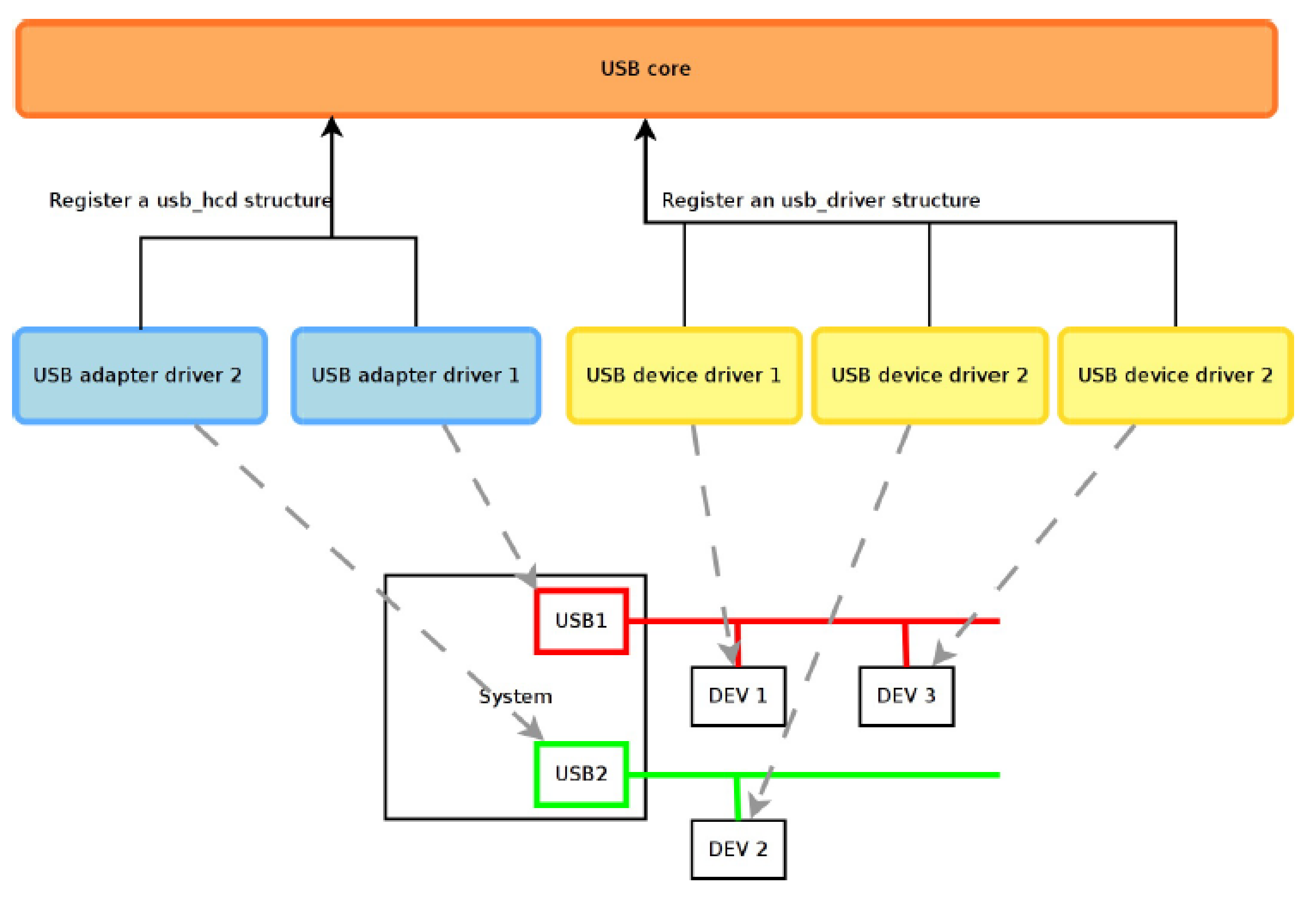
Other example of framework: serial driver

- 1. The driver registers a single uart_driver structure, that contains a few informations such as major, starting minor, number of supported serial ports, etc.
  - Functions uart register driver() and uart unregister driver()
- 2. For each serial port detected, the driver registers a uart_port structure, which points to a uart_ops structure and contains other informations about the serial port
  - Functions uart_add_one_port() and uart_remove_one_port()
- 3. The driver implements some or all of the methods in the uart ops structure
  - tx empty(), set mctrl(), get mctrl(), stop tx(), start tx(), send xchar(), stop rx(), enable ms(), break ctl(), startup(), shutdown(), flush buffer(), set termios(), etc.
  - All these methods receive as argument at least a uart port structure, the device on which the method applies. It is similar to the this pointer in object-oriented languages

Device and Driver model

- One of the features that came with the 2.6 kernel is a unified device and driver model
- Instead of different ad-hoc mechanisms in each subsystem, the device model unions the vision of the devices, drivers, their organization and relationships
- Allows to minimize code duplication, provide common facilities, more coherency in the code organization
- Defines base structure types: struct device, struct driver, struct bus type
- Is visible in userspace through the sysfs filesystem, traditionally mounted under /sys

Adapter, Bus and Device Drivers



Example of Device Driver

- To illustrate how drivers are implemented to work with the device model, we will use an USB network adapter driver. We will therefore limit ourselves to device drivers and won't cover adapter drivers.

Device Identifiers

- Defines the set of devices that this driver can manage, so that the USB core knows which devices this driver can handle.
- The MODULE_DEVICE_TABLE macro allows depmod to extract at compile the relation between device identifiers and drivers, so that drivers can be loaded automatically by udev.
- See /lib/modules/$(uname -r)/modules. {falias,usbmapg}

```
static struct usb_device_id rtl8150_table[] = {
        {USB_DEVICE(VENDOR_ID_REALTEK, PRODUCT_ID_RTL8150)},
        {USB_DEVICE(VENDOR_ID_MELCO, PRODUCT_ID_LUAKTX)},
        {USB_DEVICE(VENDOR_ID_MICRONET, PRODUCT_ID_SP128AR)},
        {USB_DEVICE(VENDOR_ID_LONGSHINE, PRODUCT_ID_LCS8138TX)},
        {USB_DEVICE(VENDOR_ID_OQO, PRODUCT_ID_RTL8150)},
        {USB_DEVICE(VENDOR_ID_ZYXEL, PRODUCT_ID_PRESTIGE)},
        {}
};
MODULE_DEVICE_TABLE(usb, rtl8150_table);
```

Device identifiers

- Instantiates the usb_driver structure. This structure is a specialization of struct_driver dened by the driver model. We have an example of inheritance here.

```
static struct usb_device_id rtl8150_table[] = {
        {USB_DEVICE(VENDOR_ID_REALTEK, PRODUCT_ID_RTL8150)},
        {USB_DEVICE(VENDOR_ID_MELCO, PRODUCT_ID_LUAKTX)},
        {USB_DEVICE(VENDOR_ID_MICRONET, PRODUCT_ID_SP128AR)},
        {USB_DEVICE(VENDOR_ID_LONGSHINE, PRODUCT_ID_LCS8138TX)},
        {USB_DEVICE(VENDOR_ID_OQO, PRODUCT_ID_RTL8150)},
        {USB_DEVICE(VENDOR_ID_ZYXEL, PRODUCT_ID_PRESTIGE)},
        {}
};
MODULE_DEVICE_TABLE(usb, rtl8150_table);
```

Instantiation of usb_driver

- Instantiates the usb_driver structure. This structure is a specialization of struct driver defined by the driver model. We have an example of inheritance here.

```
static struct usb_driver rtl8150_driver = {
        .name =         "rtl8150",
        .probe =        rtl8150_probe,
        .disconnect =   rtl8150_disconnect,
        .id_table =     rtl8150_table,
        .suspend =      rtl8150_suspend,
        .resume =       rtl8150_resume
};
```

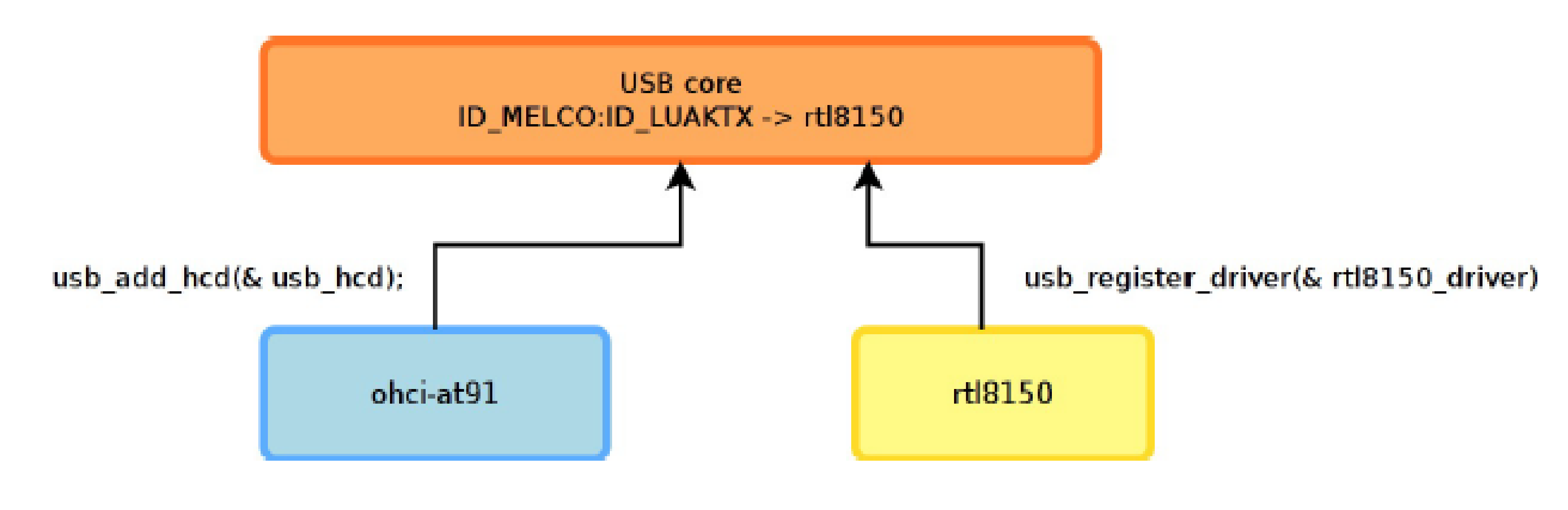
Registration of the Driver

- When the driver is loaded and unloaded, it simply registers and unregisters itself as an USB device driver.

```
static int __init usb_rtl8150_init(void)
{
        return usb_register(&rtl8150_driver);
}

static void __exit usb_rtl8150_exit(void)
{
        usb_deregister(&rtl8150_driver);
}

module_init(usb_rtl8150_init);
module_exit(usb_rtl8150_exit);
```

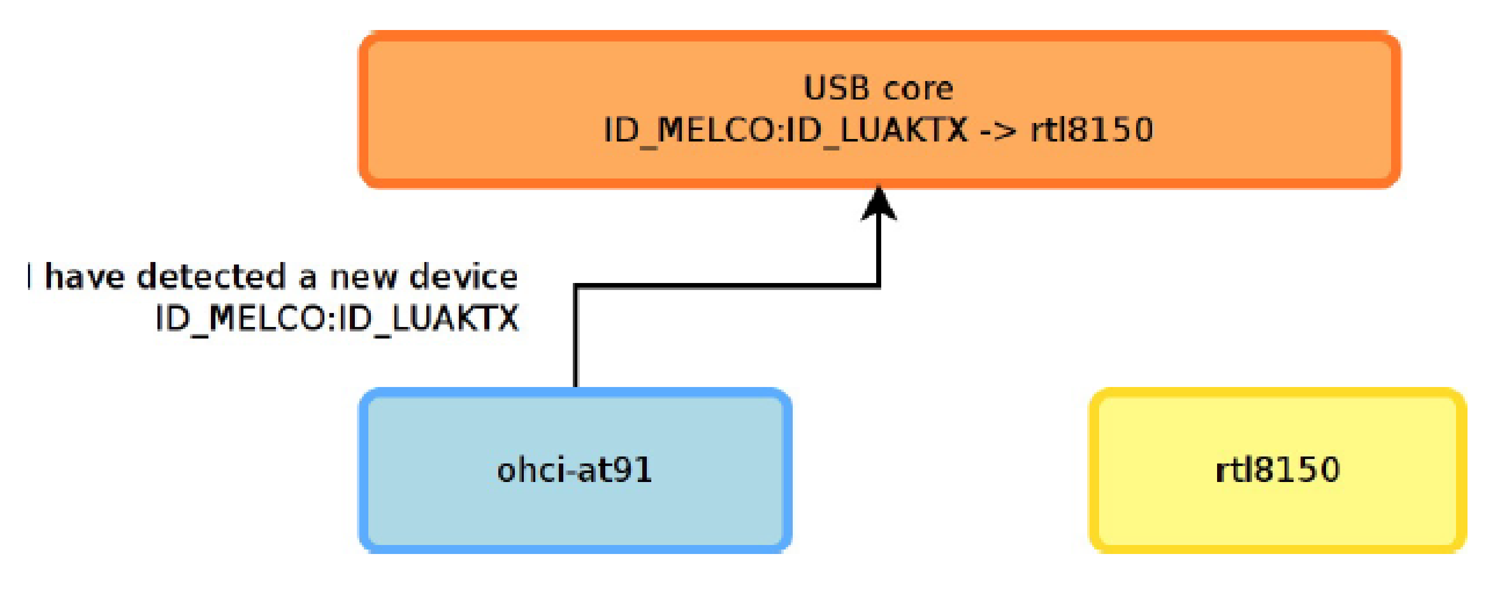
Probe Call Sequence (1/3)

- At boot time, the USB device driver registers itself to the generic BUS infrastructure



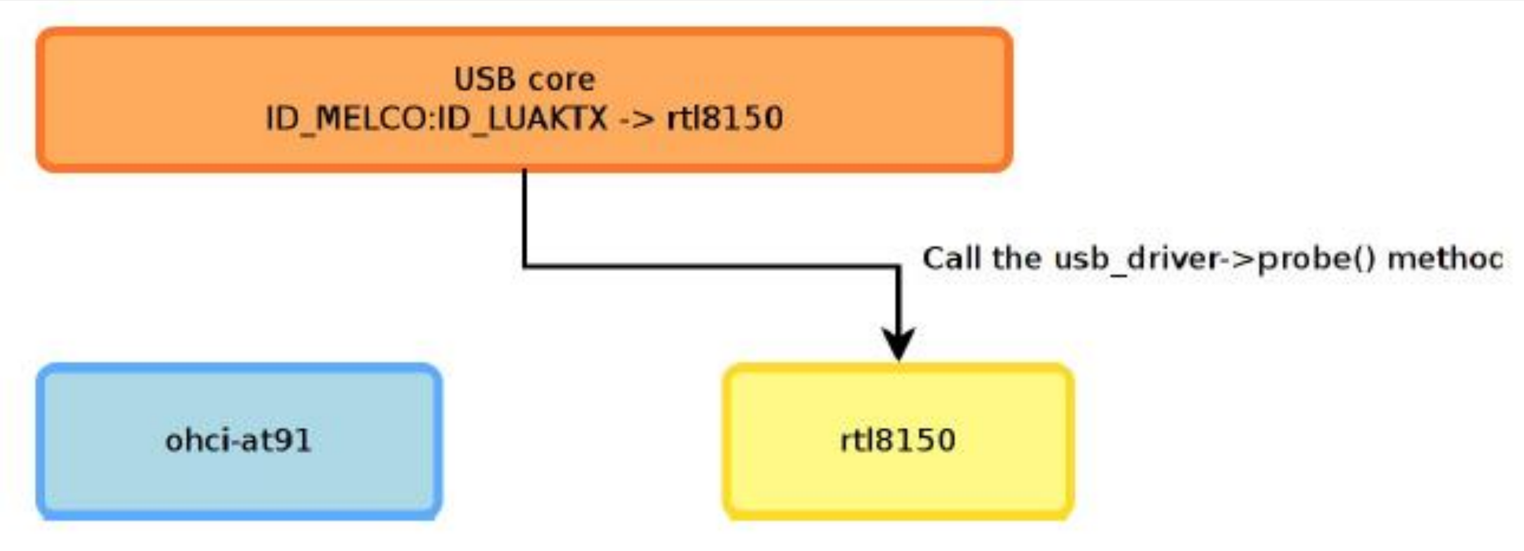
Probe Call Sequence (2/3)

- When a bus adapter driver detects a device, it notifies the generic USB bus infrastructure



Probe Call Sequence (3/3)

- The generic USB bus infrastructure knows which driver is capable of handling the detected device. It calls the probe() method of that driver



Probe Method

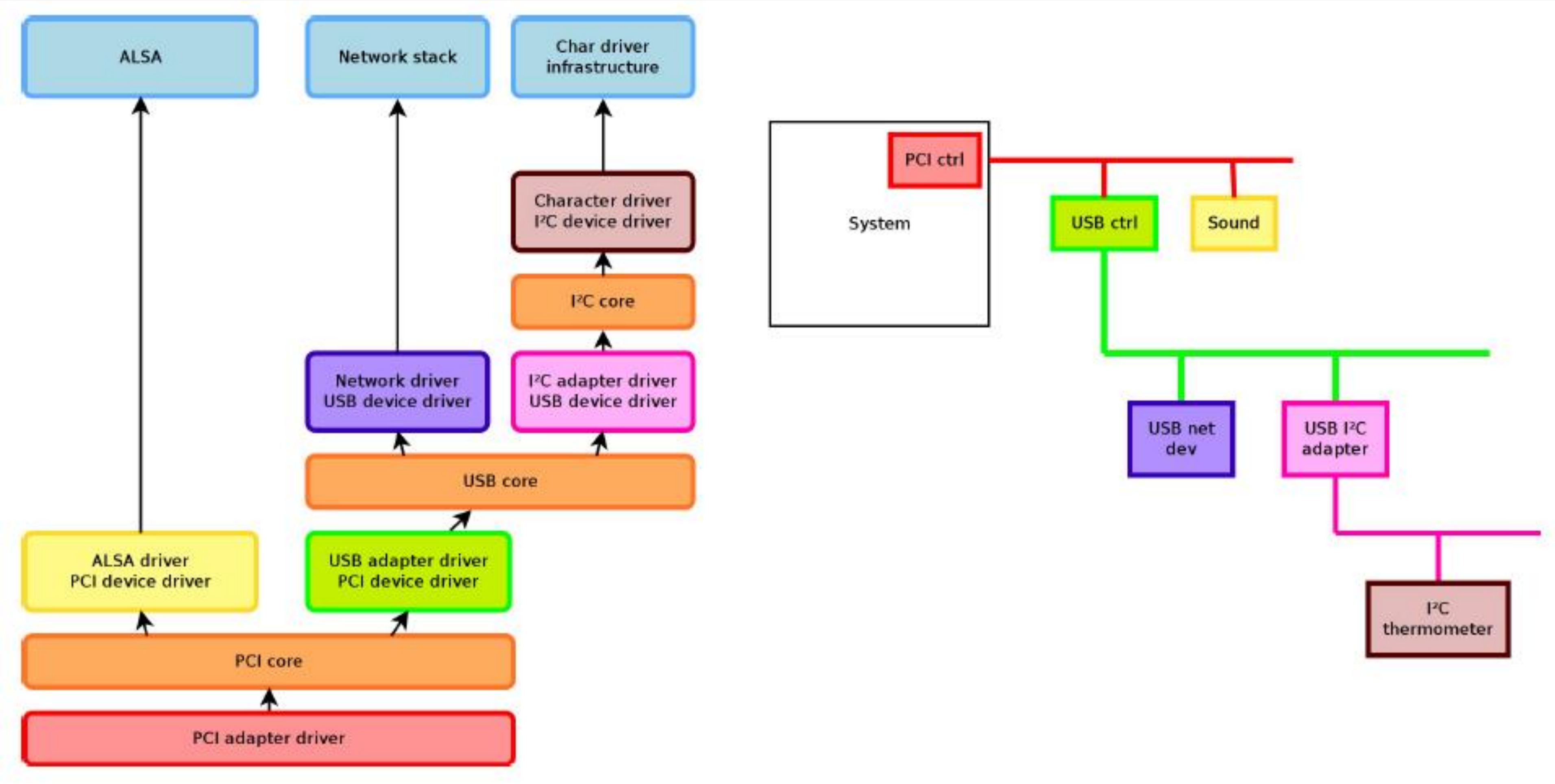
- The probe() method receives as argument a structure describing the device, usually specialized by the bus infrastructure (pci_dev, usb_interface, etc.)
- This function is responsible for
  - Initializing the device, mapping I/O memory, registering the interrupt handlers. The bus infrastructure provides methods to get the addresses, interrupts numbers and other device-specific information.
  - Registering the device to the proper kernel framework, for example the network infrastructure.

rtl8150 probe

```
static int rtl8150_probe(struct usb_interface *intf,
                         const struct usb_device_id *id)
{
        rtl8150_t *dev;
        struct net_device *netdev;

        netdev = alloc_etherdev(sizeof(rtl8150_t));

        dev = netdev_priv(netdev);
        tasklet_init(&dev->tl, rx_fixup, (unsigned long)dev);
        spin_lock_init(&dev->rx_pool_lock);

        netdev->netdev_ops = &rtl8150_netdev_ops;
        alloc_all_urbs(dev);

        usb_set_intfdata(intf, dev);
        SET_NETDEV_DEV(netdev, &intf->dev);
        register_netdev(netdev);

        return 0;
}
```

Device Model is Recursive

- Drivers can be connected to another driver



Platform Drivers

- On embedded systems, devices are often not connected through a bus allowing enumeration, hotplugging, and providing unique identifiers for devices.
- <u>However, we still want the devices to be part of the device model.</u>
- The solution to this is the platform driver / platform device infrastructure.
- The platform devices are the devices that are directly connected to the CPU, without any kind of bus.

Initialization of a Platform Driver

- Example of the iMX serial port driver, in drivers/serial/imx.c. The driver instantiates a platform driver structure:

```
static struct platform_driver serial_imx_driver = {
        .probe          = serial_imx_probe,
        .remove         = serial_imx_remove,
        .driver         = {
                .name   = "imx-uart",
                .owner  = THIS_MODULE,
        },
};
```

- And registers/unregisters it at init/cleanup:

```
static int __init imx_serial_init(void)
{
        platform_driver_register(&serial_imx_driver);
}
static void __ext imx_serial_cleanup(void)
{
        platform_driver_unregister(&serial_imx_driver);
}
```

Initialization of a Platform Device

- As platform devices cannot be detected dynamically, they are statically defined:
  - by direct instantiation of platform_device structures, as done on ARM
  - by using a device tree, as done on PowerPC
- Example on ARM, where the instantiation is done in the board specific code (arch/arm/mach-imx/mx1ads.c)

```
static struct platform_device imx_uart1_device = {
        .name             = "imx-uart",
        .id               = 0,
        .num_resources    = ARRAY_SIZE(imx_uart1_resources),
        .resource         = imx_uart1_resources,
        .dev = {
                .platform_data = &uart_pdata,
        }
};
```

- The matching between a device and the driver is simply done using the name.

Registration of Platform Devices

- The device is part of a list:

```
static struct platform_device *devices[] __initdata = {
        &cs89x0_device,
        &imx_uart1_device,
        &imx_uart2_device,
};
```

- And the list of devices is added to the system during the board initialization

```
static void __init mx1ads_init(void)
{
        [...]
        platform_add_devices(devices, ARRAY_SIZE(devices));
        [...]
}

MACHINE_START(MX1ADS, "Freescale MX1ADS")
        [...]
        .init_machine    = mx1ads_init,
MACHINE_END
```

The resource mechanism

- Each device managed by a particular driver typically uses different hardware resources: different addresses for the I/O registers, different DMA channel, different IRQ line, etc.
- These information can be represented using the kernel struct resource, and an array of resources is associated to a platform device definition.

```
static struct resource imx_uart1_resources[] = {
        [0] = {
                .start  = 0x00206000,
                .end    = 0x002060FF,
                .flags  = IORESOURCE_MEM,
        },
        [1] = {
                .start  = (UART1_MINT_RX),
                .end    = (UART1_MINT_RX),
                .flags  = IORESOURCE_IRQ,
        },
};
```

The platform_data mechanism

- In addition to the well-defined resources, some driver require driver-specific configuration for each platform device
- These can be specified using the platform_data field of the struct device
- As it is a void * pointer, it can be used to pass any type of data to the driver
- In the case of the iMX driver, the platform data is a struct imxuart_platform_data structure, referenced from the platform_device structure

```
static struct imxuart_platform_data uart_pdata = {
        .flags = IMXUART_HAVE_RTSCTS,
};
```

Driver-specific data structure

- Typically, device drivers **subclass** the type-specific data structure that they must instantiate to register their device to the upper layer framework
- For example, serial drivers subclass uart_port, network drivers subclass netdev, framebuffer drivers subclass fb_info
- This **inheritance** is done by aggregation or by reference

```
struct imx_port {
        struct uart_port        port;
        struct timer_list       timer;
        unsigned int            old_status;
        int                     txirq,rxirq,rtsirq;
        unsigned int            have_rtscts:1;
        unsigned int            use_irda:1;
        unsigned int            irda_inv_rx:1;
        unsigned int            irda_inv_tx:1;
        unsigned short          trcv_delay; /* transceiver delay */
        struct clk              *clk;
};
```

probe() method for Platform Devices

- Just like the usual probe() methods, it receives the platform_device pointer, uses different utility functions to find the corresponding resources, and registers the device to the corresponding upper layer.

```
static int serial_imx_probe(struct platform_device *pdev)
{
        struct imx_port *sport;
        struct imxuart_platform_data *pdata;
        void __iomem *base;
        struct resource *res;

        sport = kzalloc(sizeof(*sport), GFP_KERNEL);
        res = platform_get_resource(pdev, IORESOURCE_MEM, 0);
        base = ioremap(res->start, PAGE_SIZE);

        sport->port.dev = &pdev->dev;
        sport->port.mapbase = res->start;
        sport->port.membase = base;
        sport->port.type = PORT_IMX,
        sport->port.iotype = UPIO_MEM;
        sport->port.irq = platform_get_irq(pdev, 0);
        sport->rxirq = platform_get_irq(pdev, 0);
        sport->txirq = platform_get_irq(pdev, 1);
        sport->rtsirq = platform_get_irq(pdev, 2);

        [...]
```

probe() method for Platform Devices

```
        sport->port.fifosize = 32;
        sport->port.ops = &imx_pops;

        sport->clk = clk_get(&pdev->dev, "uart");
        clk_enable(sport->clk);
        sport->port.uartclk = clk_get_rate(sport->clk);

        imx_ports[pdev->id] = sport;

        pdata = pdev->dev.platform_data;
        if (pdata && (pdata->flags & IMXUART_HAVE_RTSCTS))
                sport->have_rtscts = 1;

        ret = uart_add_one_port(&imx_reg, &sport->port);
        if (ret)
                goto deinit;
        platform_set_drvdata(pdev, &sport->port);

        return 0;
}
```

Other non-dynamic busses

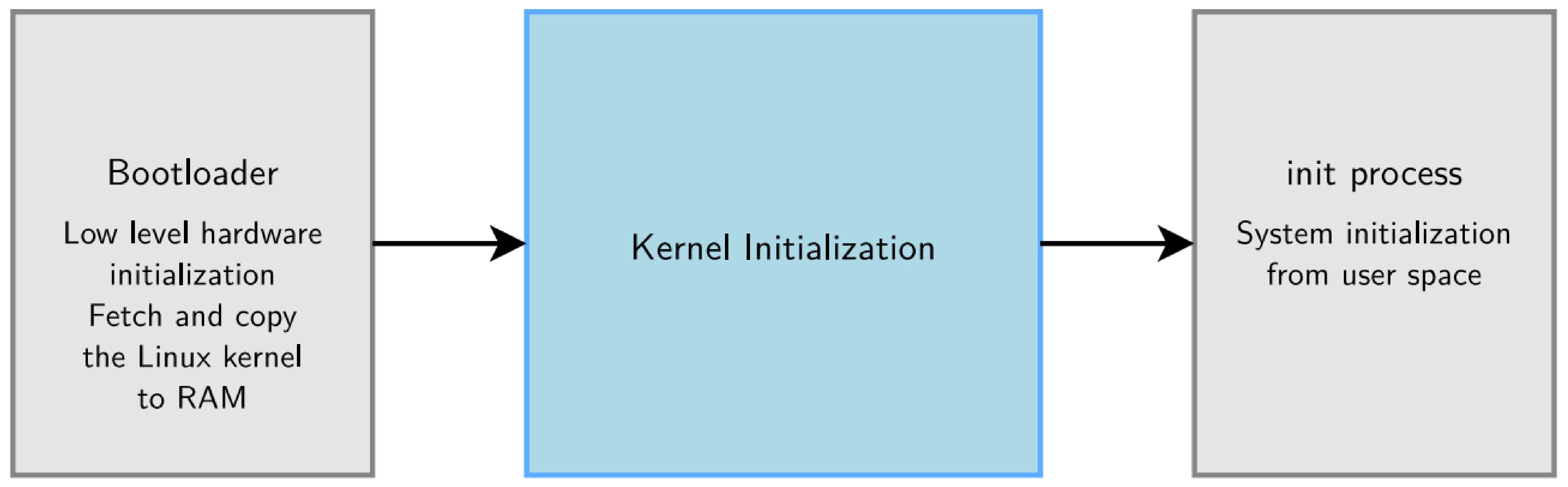
- In addition to the special platform bus, there are some other busses that do not support dynamic enumeration and identification of devices. For example: I2C and SPI.
- For these busses, a list of devices connected to the bus is hardcoded into the board-specific information and is registered using i2c_register_board_info() or spi_register_board_info(). The binding between the device is also done using a string identifier.

```
static struct i2c_board_info pcm038_i2c_devices[] = {
        {       I2C_BOARD_INFO("at24", 0x52),
                .platform_data = &board_eeprom,  },
        {       I2C_BOARD_INFO("pcf8563", 0x51), },
        {       I2C_BOARD_INFO("lm75", 0x4a),    }
};

static void __init pcm038_init(void) {
        [...]
        i2c_register_board_info(0, pcm038_i2c_devices,
                                ARRAY_SIZE(pcm038_i2c_devices));
        [...]
}
```

Typical Organization of a Driver

- A driver typically
  - Defines a **driver-specific data structure** to keep track of per-device state, this structure often subclass the type-specific structure for this type of device
  - Implements a set of **helper functions**, interrupt handlers, etc.
  - Implements some or all of the **operations**, as specified by the framework in which the device will be subscribed
  - Instantiate the **operation table**
  - Defines a probe() **method** that allocates the "state" structure, initializes the device and registers it to the upper layer framework. Similarly defines a corresponding remove() method
  - Instantiate a SOMEBUS_driver **structure** that references the probe() and remove() methods and give the bus infrastructure some way of binding a device to this driver (by name, by identifier, etc.)
  - In the **driver initialization function**, register as a device driver to the bus-specific infrastructure. In the **driver cleanup function**, unregister from the bus-specific infrastructure

Kernel Initialization : From Bootloader to User Space



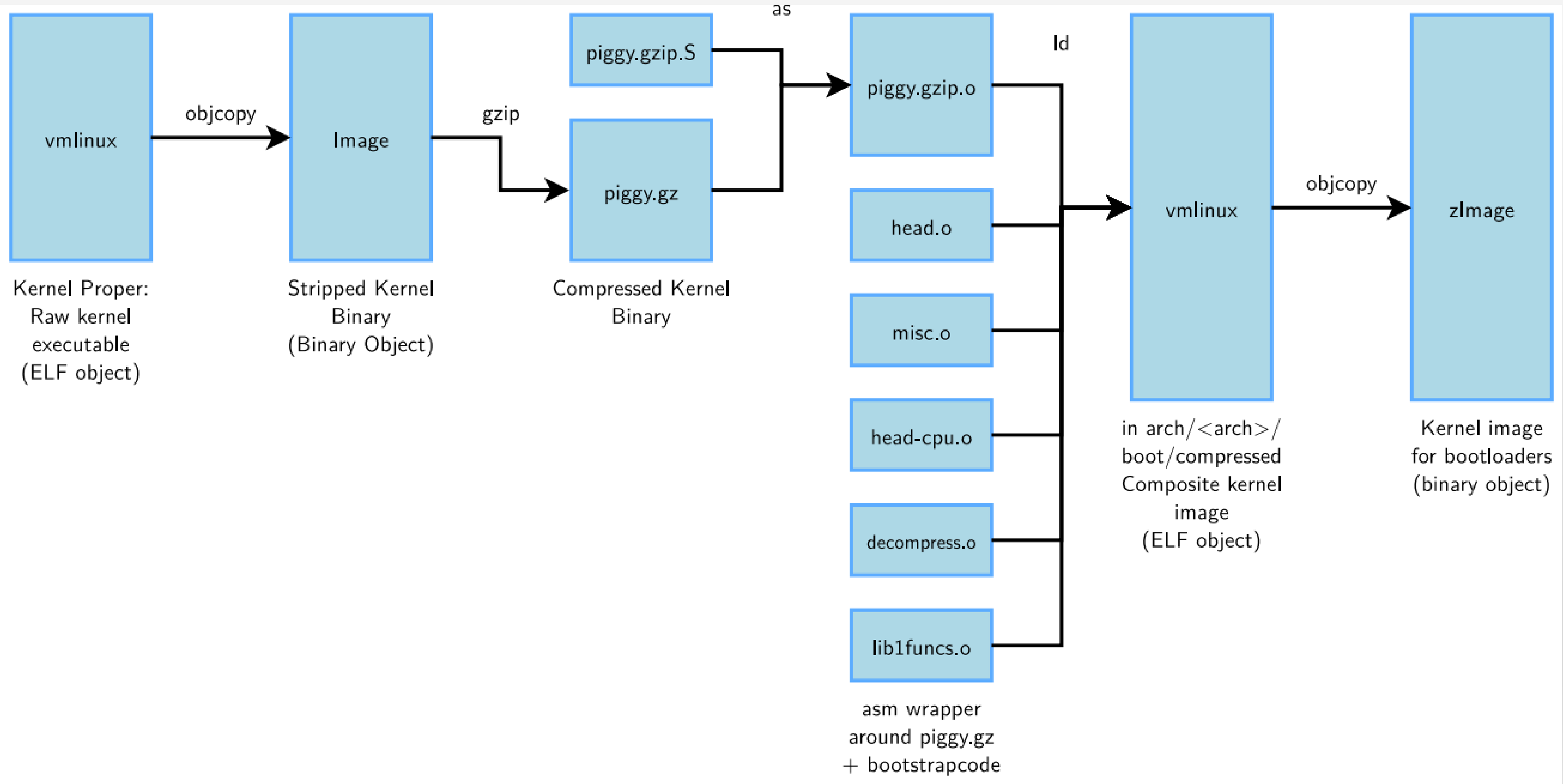
- Upon power-on, the bootloader in an embedded system is the first software to get processor control for low-level hardware initialization.
- Then, the control is passed to the Linux kernel

Kernel Bootstrap

- How the kernel bootstraps itself appears in kernel building. Example on ARM (pxa cpu) in Linux 2.6.36:
  - make ARCH=arm CROSS_COMPILE=xscale_be- zImage

```
...     < many build steps omitted for clarity>
   LD          vmlinux
   SYSMAP    System.map
   SYSMAP    .tmp_System.map
   OBJCOPY arch/arm/boot/Image
   Kernel: arch/arm/boot/Image is ready
   AS          arch/arm/boot/compressed/head.o
   GZIP       arch/arm/boot/compressed/piggy.gz
   AS          arch/arm/boot/compressed/piggy.o
   CC          arch/arm/boot/compressed/misc.o
   AS          arch/arm/boot/compressed/head-xscale.o
   AS          arch/arm/boot/compressed/big-endian.o
   LD          arch/arm/boot/compressed/vmlinux
   OBJCOPY arch/arm/boot/zImage
   Kernel: arch/arm/boot/zImage is ready
```

Kernel Bootstrap



Bootstrap Code for Compressed Kernels

- Located in arch/<arch>/boot/compressed
  - head.o
    - Architecture specific initialization code.
    - This is what is executed by the bootloader
  - head-cpu.o (here head-xscale.o)
    - CPU specific initialization code
  - decompress.o, misc.o
    - Decompression code
  - piggy.o
    - The kernel itself
  - Responsible for uncompressing the kernel itself and jumping to its entry point.

Architecture-specific Initialization Code

- The uncompression code jumps into the main kernel entry point, typically located in arch/<arch>/kernel/head.S, whose job is to:
  - Check the architecture, processor and machine type.
  - Configure the MMU, create page table entries and enable virtual memory.
  - Calls the start_kernel function in init/main.c.
  - Same code for all architectures.
  - Anybody interested in kernel startup should study this file!

start_kernel Main Actions

- Calls setup_arch(&command_line)
  - Function defined in arch/<arch>/kernel/setup.c
  - Copying the command line from where the bootloader left it.
  - On arm, this function calls setup_processor (in which CPU information is displayed) and setup_machine(locating the machine in the list of supported machines).
- Initializes the console as early as possible (to get error messages)
- Initializes many subsystems (see the code)
- Eventually calls rest_init.

rest_init: Starting the Init Process

```c
static noinline void __init_refok rest_init(void)
	__releases(kernel_lock)
{
	int pid;

	rcu_scheduler_starting();
	/*
	 * We need to spawn init first so that it obtains pid 1, however
	 * the init task will end up wanting to create kthreads, which, if
	 * we schedule it before we create kthreadd, will OOPS.
	 */
	kernel_thread(kernel_init, NULL, CLONE_FS | CLONE_SIGHAND);
	numa_default_policy();
	pid = kernel_thread(kthreadd, NULL, CLONE_FS | CLONE_FILES);
	rcu_read_lock();
	kthreadd_task = find_task_by_pid_ns(pid, &init_pid_ns);
	rcu_read_unlock();
	complete(&kthreadd_done);

	/*
	 * The boot idle thread must execute schedule()
	 * at least once to get things moving:
	 */
	init_idle_bootup_task(current);
	preempt_enable_no_resched();
	schedule();
	preempt_disable();

	/* Call into cpu_idle with preempt disabled */
	cpu_idle();
```

kernel_init

- kernel_init does two main things:
  - Call do_basic_setup

```
static void __init do_basic_setup(void)
{
    cpuset_init_smp();
    usermodehelper_init();
    init_tmpfs();
    driver_init();
    init_irq_proc();
    do_ctors();
    do_initcalls();
}
```

  - Once kernel services are ready, start device initialization (Linux 2.6.36 code excerpt):
  - Call init_post

do_initcalls

- Calls pluggable hooks registered with the macros below. Advantage: the generic code doesn't have to know about them

```
/*
 * A "pure" initcall has no dependencies on anything else, and purely
 * initializes variables that couldn't be statically initialized.
 *
 * This only exists for built-in code, not for modules.
 */
#define pure_initcall(fn)               __define_initcall("0",fn,1)

#define core_initcall(fn)               __define_initcall("1",fn,1)
#define core_initcall_sync(fn)          __define_initcall("1s",fn,1s)
#define postcore_initcall(fn)           __define_initcall("2",fn,2)
#define postcore_initcall_sync(fn)      __define_initcall("2s",fn,2s)
#define arch_initcall(fn)               __define_initcall("3",fn,3)
#define arch_initcall_sync(fn)          __define_initcall("3s",fn,3s)
#define subsys_initcall(fn)             __define_initcall("4",fn,4)
#define subsys_initcall_sync(fn)        __define_initcall("4s",fn,4s)
#define fs_initcall(fn)                 __define_initcall("5",fn,5)
#define fs_initcall_sync(fn)            __define_initcall("5s",fn,5s)
#define rootfs_initcall(fn)             __define_initcall("rootfs",fn,rootfs)
#define device_initcall(fn)             __define_initcall("6",fn,6)
#define device_initcall_sync(fn)        __define_initcall("6s",fn,6s)
#define late_initcall(fn)               __define_initcall("7",fn,7)
#define late_initcall_sync(fn)          __define_initcall("7s",fn,7s)
```

Defined in `include/linux/init.h`

initcall example

From `arch/arm/mach-pxa/lpd270.c` (Linux 2.6.36)

```c
static int __init lpd270_irq_device_init(void)
{
    int ret = -ENODEV;
    if (machine_is_logicpd_pxa270()) {
        ret = sysdev_class_register(&lpd270_irq_sysclass);
        if (ret == 0)
            ret = sysdev_register(&lpd270_irq_device);
    }
    return ret;
}

device_initcall(lpd270_irq_device_init);
```

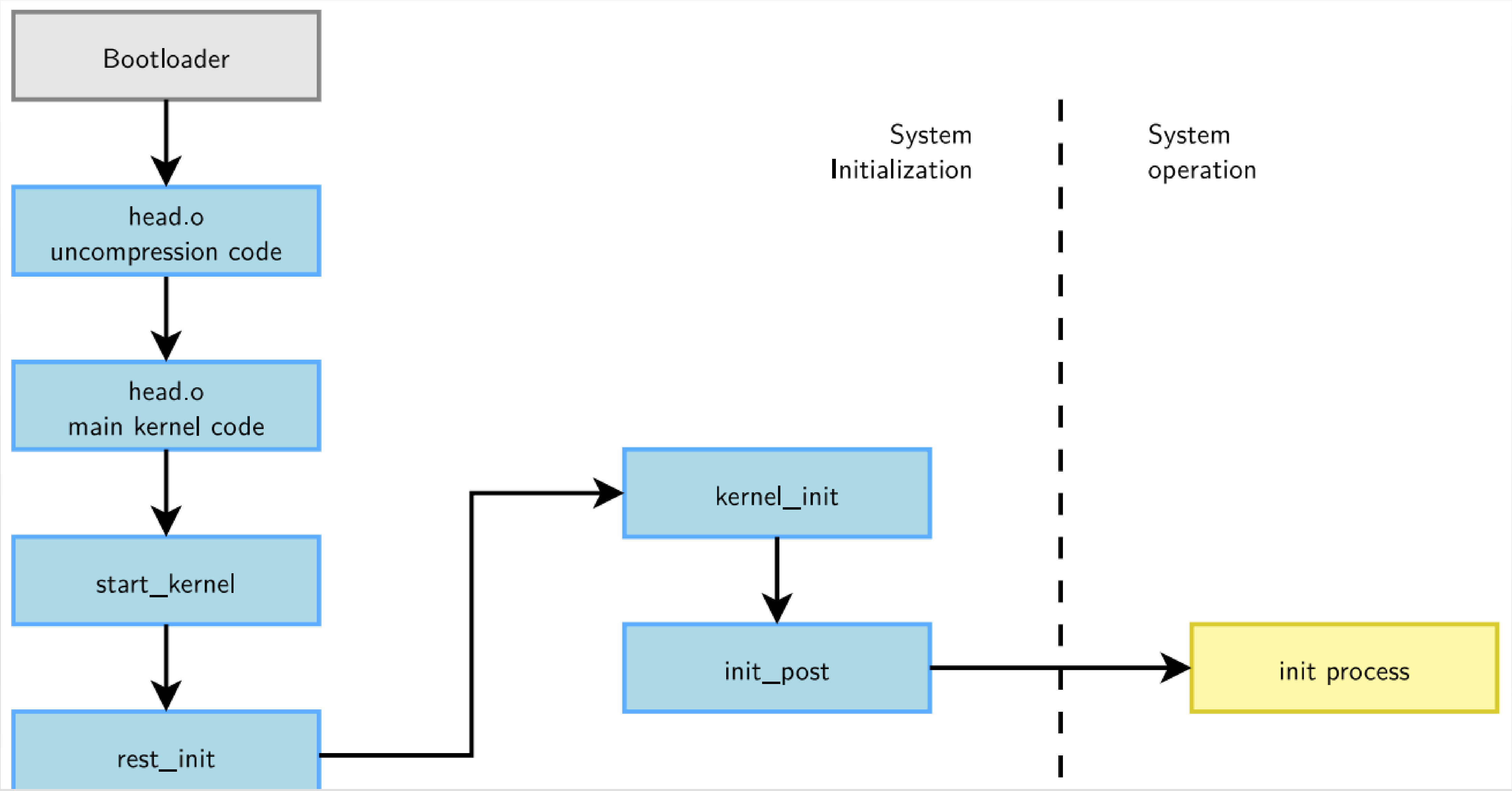
init_post

- The last step of Linux booting
  - First tries to open a console
  - Then tries to run the init process, effectively turning the current kernel thread into the user space init process

init_post Code: init/main.c

```c
static noinline int init_post(void) __releases(kernel_lock) {
    /* need to finish all async __init code before freeing the memory */
    async_synchronize_full();
    free_initmem();
    mark_rodata_ro();
    system_state = SYSTEM_RUNNING;
    numa_default_policy();

    current->signal->flags |= SIGNAL_UNKILLABLE;
    if (ramdisk_execute_command) {
        run_init_process(ramdisk_execute_command);
        printk(KERN_WARNING "Failed to execute %s\n", ramdisk_execute_command);
    }

    /* We try each of these until one succeeds.
     * The Bourne shell can be used instead of init if we are
     * trying to recover a really broken machine. */
    if (execute_command) {
        run_init_process(execute_command);
        printk(KERN_WARNING "Failed to execute %s.  Attempting defaults...\n", execute_command);
    }
    run_init_process("/sbin/init");
    run_init_process("/etc/init");
    run_init_process("/bin/init");
    run_init_process("/bin/sh");

    panic("No init found. Try passing init= option to kernel. See Linux Documentation/init.txt");
}
```

Kernel Initialization Graph



Kernel Initialization - Summary

- The bootloader executes bootstrap code.
- Bootstrap code initializes the processor and board, and uncompresses the kernel code to RAM, and calls the kernel’s start_kernel function.
- Copies the command line from the bootloader.
- Identifies the processor and machine.
- Initializes the console.
- Initializes kernel services (memory allocation, scheduling, file cache...)
- Creates a new kernel thread (future init process) and continues in the idle loop.
- Initializes devices and execute initcalls

That's all for today.