Linux Kernel Porting Overview

PART 1 - Boston Linux Users Group, November 2006

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Obligatory biography

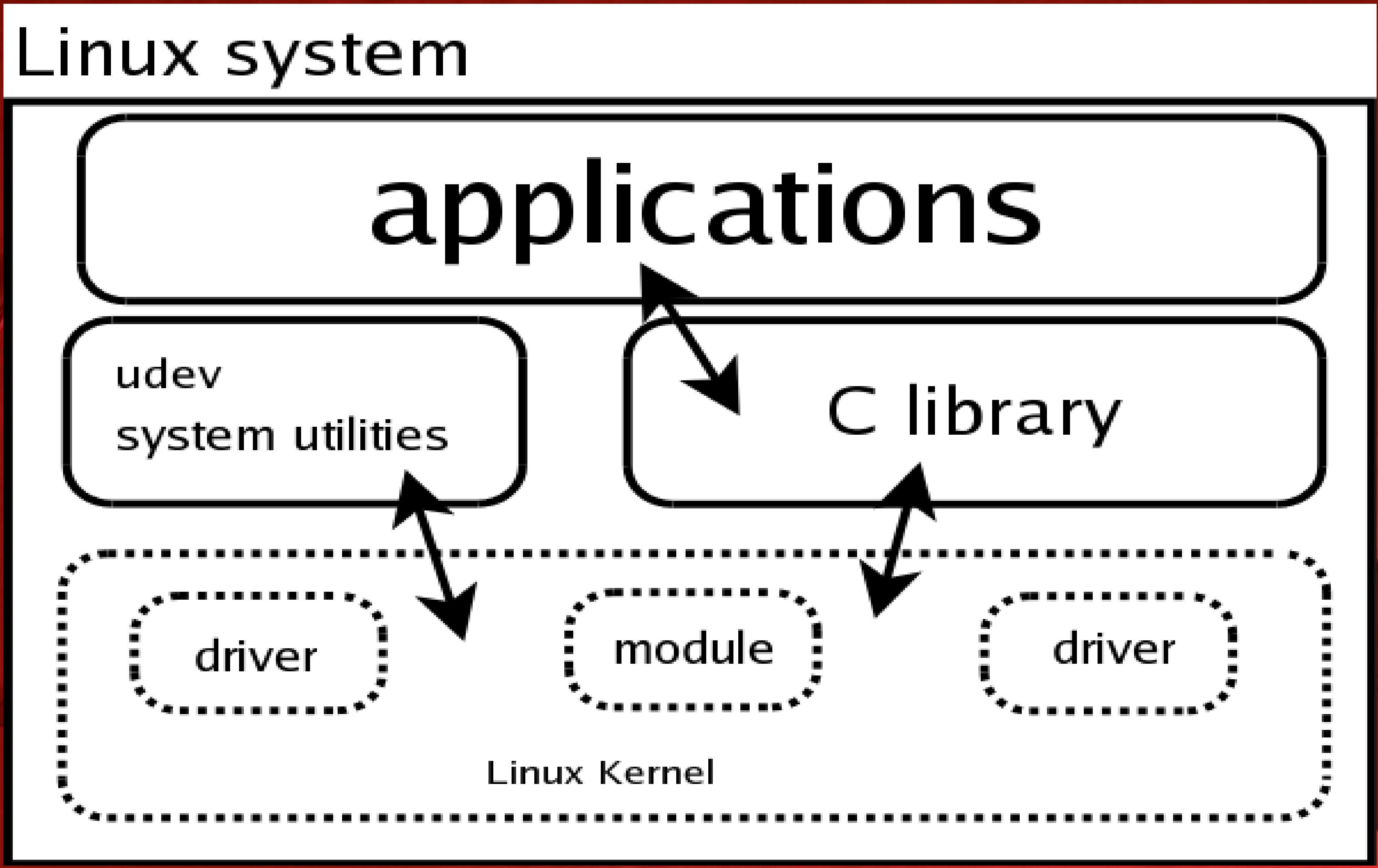
- Long time enthusiast
- Embedded Linux
- Enterprise Linux
- Articles, books, etc.
- Works on kernel tools at Red Hat

Overview

- Linux system architecture
- Introducing the Linux kernel
- What is kernel portability?
- Porting the Linux kernel
- Building a complete system
- Q&A

Linux system architecture

Linux System Architecture



Applications

- Applications include GNOME Desktop
- Make use of system C library functions
- Library functions are usually wrappers
- Library abstracts user-kernel interface
- User-kernel interface remains stable

System call demo

```
/*
 * syscall demo
 */

#include <stdio.h>
#include <linux/unistd.h>
#include <sys/types.h>

_syscall0(uid_t,getuid);

int main(int argc, char **argv) {
        printf("user ID: %d\n",getuid());
        return 0;
}
```

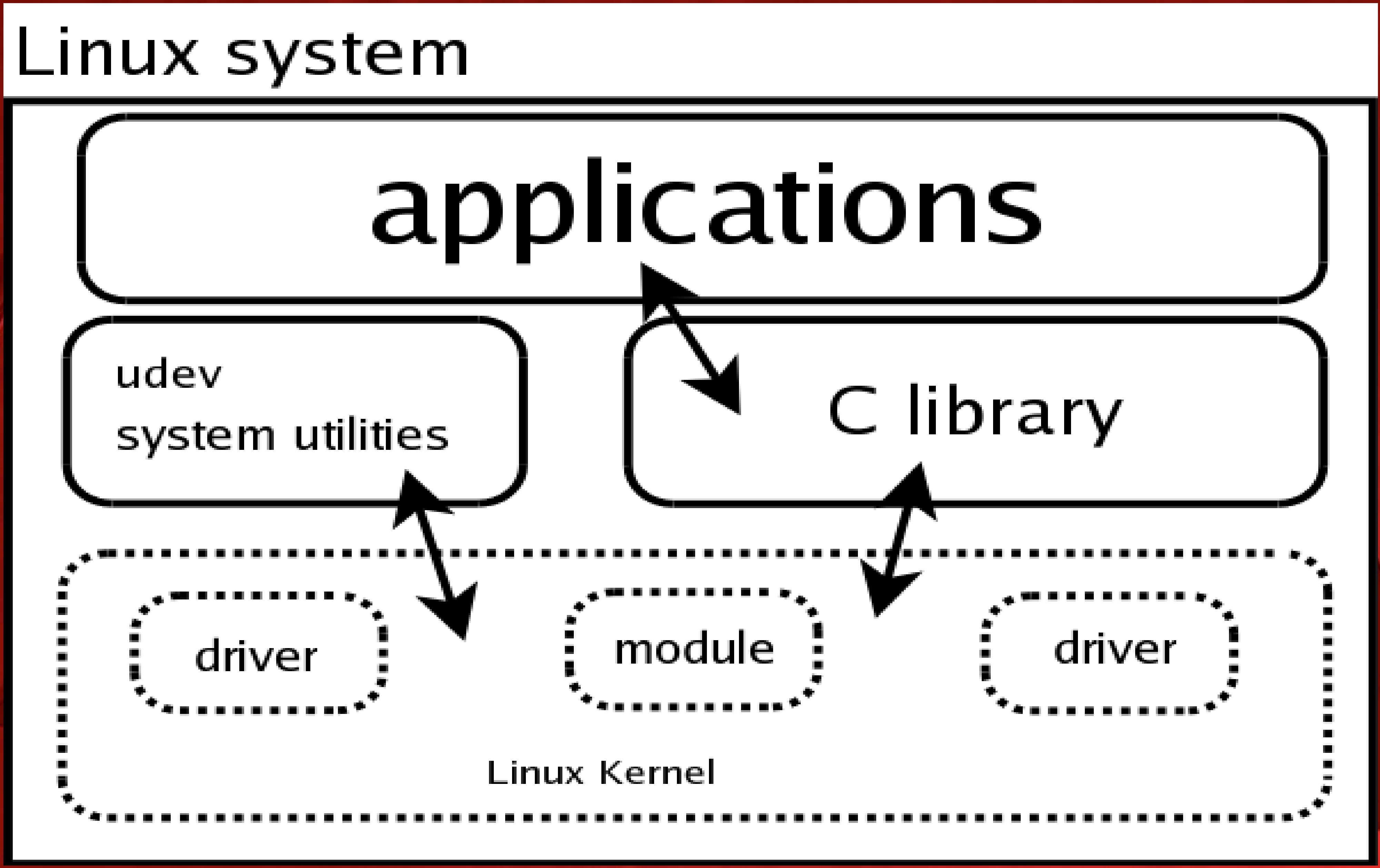
System call demo

You can build the example as follows:

```
[jcm@maple ~]$ gcc -Wall -o syscall syscall.c
[jcm@maple ~]$ ./syscall
user ID: 500
```

The current user ID (500) is displayed.

Linux System Architecture

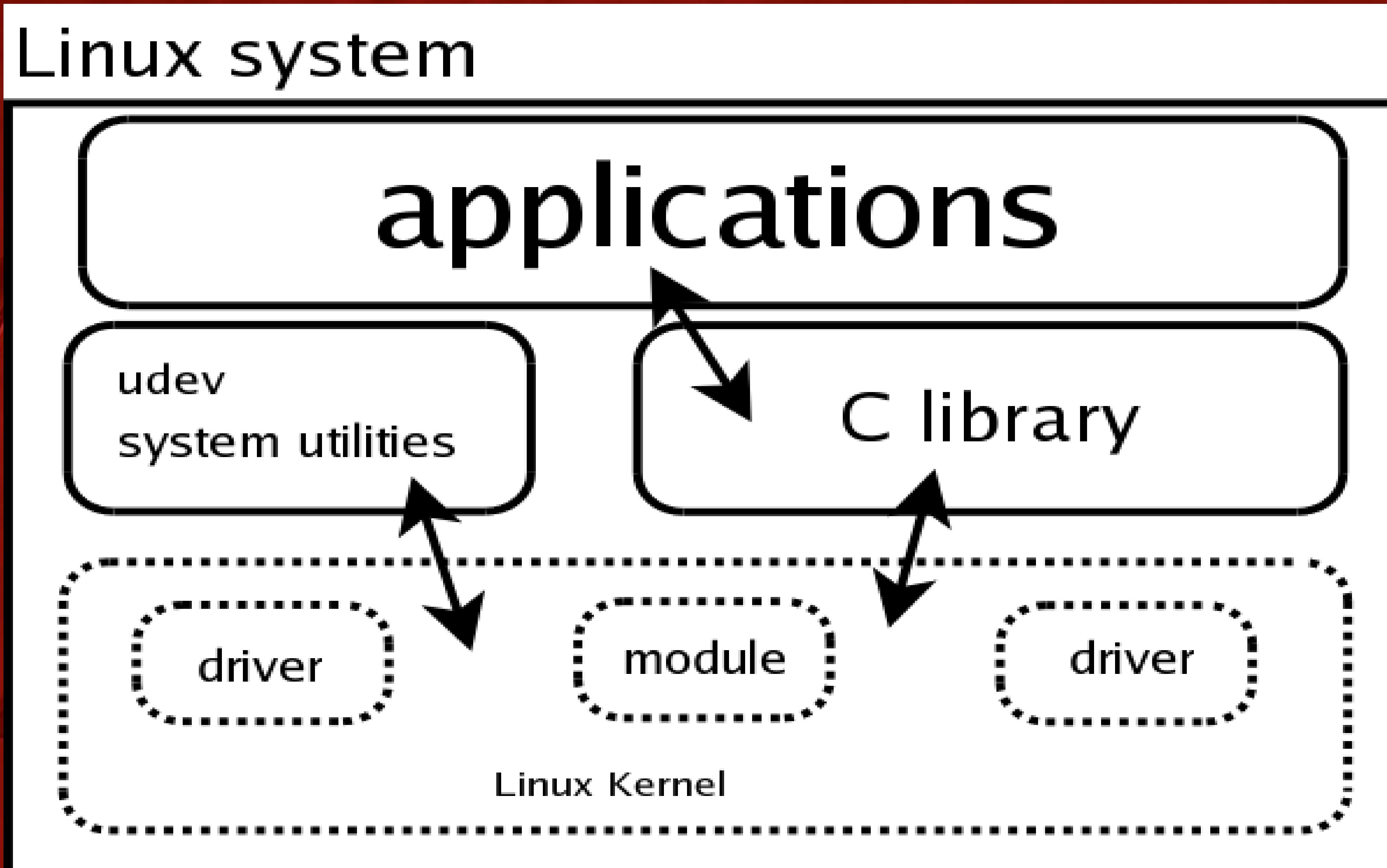


System call demo

You can trace the example using strace:

```
$ strace ./syscall
execve("./syscall", ["./syscall"], [/* 39 vars */]) = 0
brk(0)                                  = 0x10011000
mmap(NULL, 4096, PROT_READ|PROT_WRITE, MAP_PRIVATE|
  MAP_ANONYMOUS, -1, 0) = 0x30000000
...
getuid()                                = 500
...
exit_group(0)                           = ?
Process 10054 detached
```

Linux System Architecture



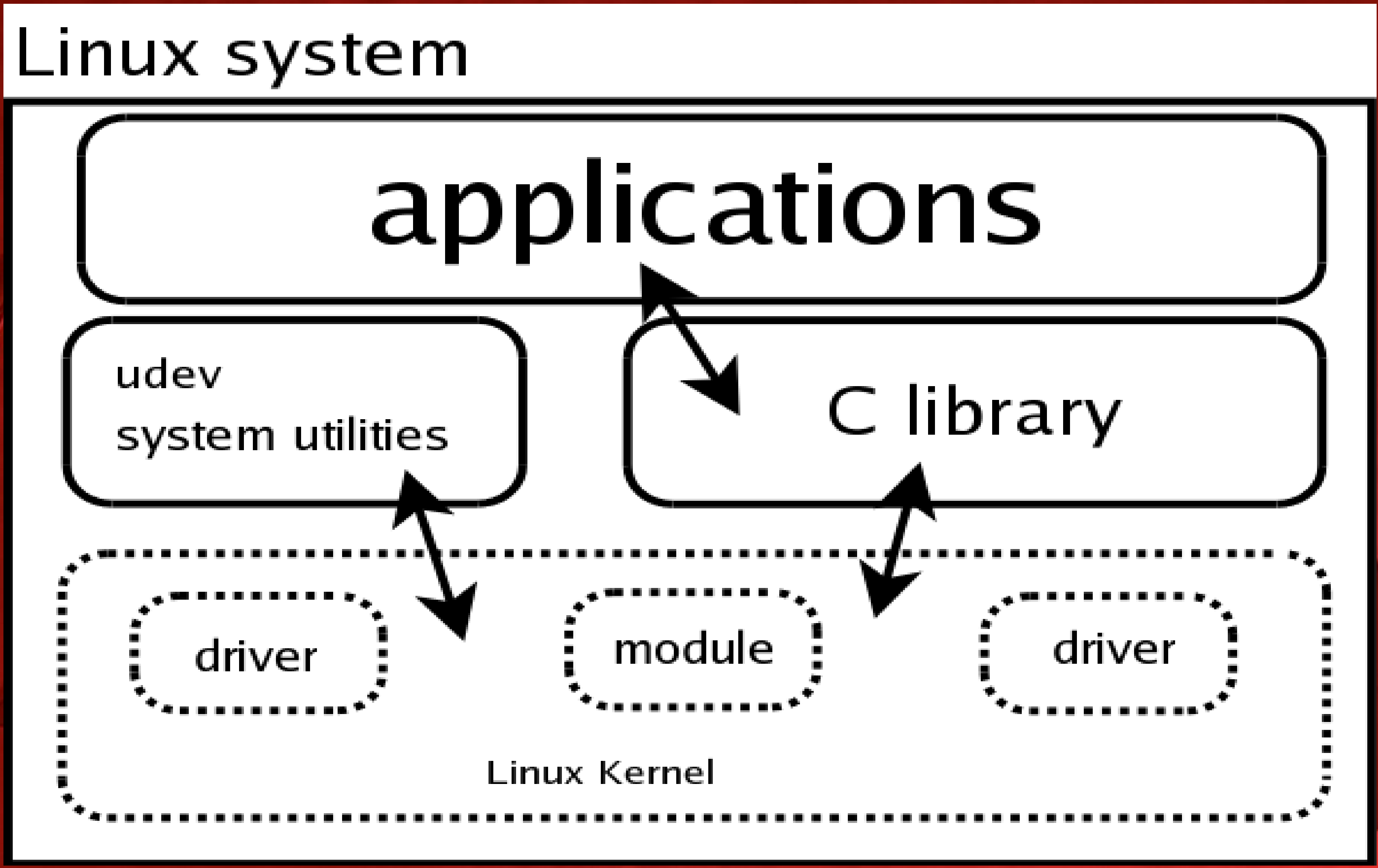
System tools and utilities

- Kernel provides enhanced functionality
- Events allow for user space notification
- ioctl()s enable control over special devices
- Many other tools using sysfs, etc.

USB Example

- Insert USB stick
- Kernel driver detects new device
- Kernel notifies udev of new device
- udev loads USB storage driver
- udev notifies the GNOME hald
- hald notifies gvm (over D-BUS)

Linux System Architecture



Introducing the Linux kernel

A brief history of the Linux kernel

- First written for Linus' 80386 in 1991
  - M68K, SPARC, Tivo, Mobile Phones...
- Now supports 20 architectures in upstream
  - Relatively easy to add more
- Kernel module support added early on
  - Use insmod/modprobe at runtime
- Evolving documentation, news sites...

Getting Linux kernel sources

- http://www.kernel.org/
- Two ways to get the source
  - Current official stable release (2.6.18.2)
  - Download the tarball/tar.bz2 file and unpack

```
arch      Documentation  ipc          Makefile        REPORTING-BUGS  usr
block     drivers        Kbuild       mm              scripts         vmlinux
COPYING   fs             kernel       Module.symvers  security
CREDITS   include        lib          net             sound
crypto    init           MAINTAINERS  README          System.map
```

Tracking development with git

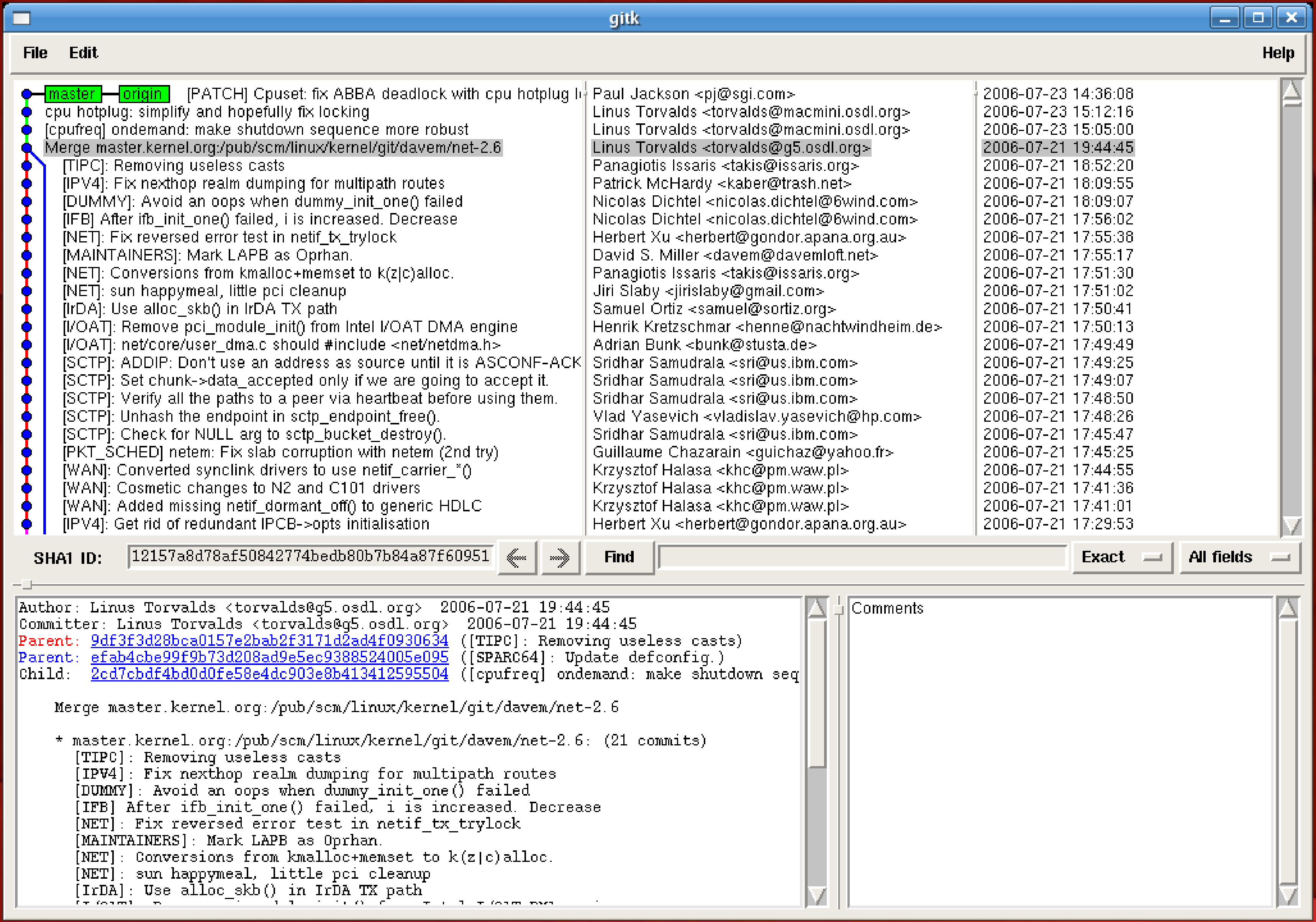
- Track kernel development with git:
  - clone the official Linux kernel tree:

  git clone http://path.to.official.source linus_26

  (see http://www.kernel.org/git for sources)

  - Update daily using git pull
  - Follow regular development via lkml.org, LWN and gitk

Visualizing source changes with gitk



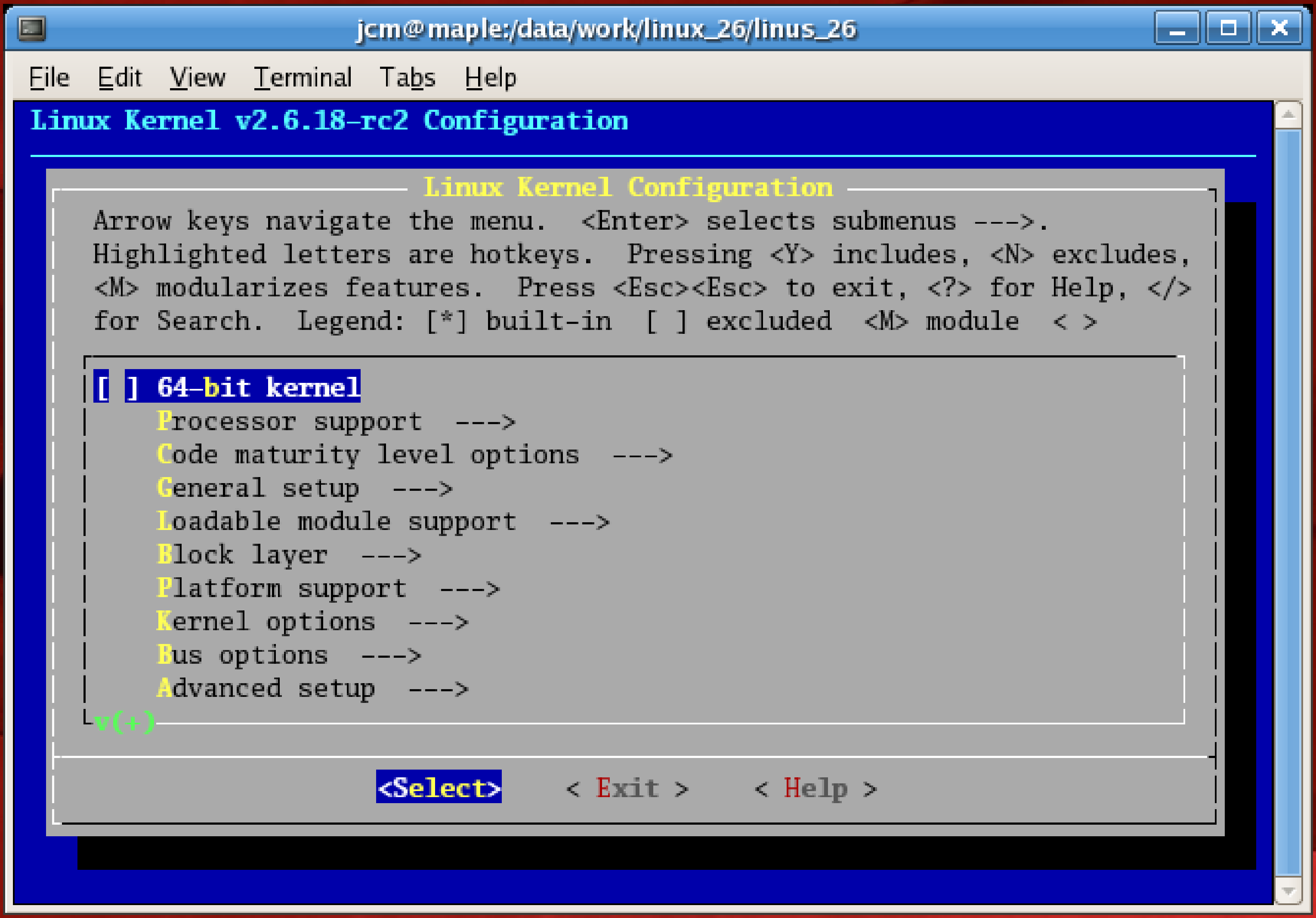
Vendor sources

- Various patches, not useful for porting to new systems
- Good for writing drivers against specific vendor systems
- Good for building drivers against specific vendor systems
- apt/yum/etc. on a typical desktop system

- For example:
  - /usr/src/kernels/2.6.18-1.2766.fc6-ppc

Configuring a Linux kernel

- Configure using make menuconfig:



Building a Linux kernel

- Build the kernel using make:

```
[jcm@maple linus_26]$ make
scripts/kconfig/conf -s arch/powerpc/Kconfig
  CHK     include/linux/version.h
  CHK     include/linux/utsrelease.h
  CC      init/main.o
  CHK     include/linux/compile.h
  LD      init/built-in.o
  CC      arch/powerpc/kernel/idle.o
  CC      arch/powerpc/kernel/time.o
arch/powerpc/kernel/time.c: In function ‘get_freq’:
arch/powerpc/kernel/time.c:874: warning: left shift count >= width of
   type
  CC      arch/powerpc/kernel/setup-common.o
  CC      arch/powerpc/kernel/setup_32.o
...
```

Installing a Linux kernel

- Install modules using make modules_install
- Install kernel image in e.g. /boot
- Install System.map in e.g. /boot
- Possibly make an initial ramdisk
- Follow your distribution guide.

Extending the Linux kernel

- Linux supports runtime extension via LKMs.
- Can add new driver/filesystem/etc.
- Cannot change core kernel.
- Sometimes have to modify kernel itself.

Adding your own kernel module

```c
/*
 * hello.c - An example kernel module.
 */
#include <linux/module.h>
#include <linux/init.h>

int hello_world(void)
{
        printk("Hello, World!\n");
        return 0;
}

int __init hello_init(void)
{
        printk("Loaded module.\n");
        return 0;
}

void __exit hello_exit(void)
{
        printk("Unloaded module.\n");
}
```

```c
/* Module Metadata */

MODULE_AUTHOR("Jon Masters <jcm@redhat.com>");
MODULE_DESCRIPTION("module example");
MODULE_LICENSE("GPL");


module_init(hello_init);

module_exit(hello_exit);


/* Exported Functions */

EXPORT_SYMBOL_GPL(hello_world);
```

Figure: hello.c source code

Building your own kernel module

Add the following to a Kbuild file:

```
obj-m               := hello_module.o
hello_module-y      += hello.o
```

Build the module against an existing kernel:

```
[jcm@maple test-1.0]$ make -C /usr/src/kernels/2.6.18-1.2766.fc6-ppc M=$PWD
make: Entering directory `/usr/src/kernels/2.6.18-1.2766.fc6-ppc'
  LD      /home/jcm/test-1.0/built-in.o
  CC [M]  /home/jcm/test-1.0/hello.o
  LD [M]  /home/jcm/test-1.0/hello_module.o
  Building modules, stage 2.
  MODPOST
  CC      /home/jcm/test-1.0/hello_module.mod.o
  LD [M]  /home/jcm/test-1.0/hello_module.ko
make: Leaving directory `/usr/src/kernels/2.6.18-1.2766.fc6-ppc'
```

Installing your own kernel module

Install the module into global /lib/modules:

```
[jcm@maple test-1.0]$ sudo make -C /usr/src/kernels/2.6.18-1.2766.fc6-ppc modules_install M=$PWD
Password:
make: Entering directory `/usr/src/kernels/2.6.18-1.2766.fc6-ppc'
  INSTALL /home/jcm/test-1.0/hello_module.ko
  DEPMOD  2.6.18-1.2766.fc6
make: Leaving directory `/usr/src/kernels/2.6.18-1.2766.fc6-ppc'
```

Rebuild global module dependencies:

```
[jcm@maple test-1.0]$ sudo /sbin/depmod -a
```

Loading and unloading your kernel module

Load the module:

```
[jcm@maple test-1.0]$ sudo /sbin/modprobe hello_module
```

Check kernel ringbuffer:

```
[jcm@maple test-1.0]$ dmesg|tail
Loaded module.
```

Unload the module:

```
[jcm@maple test-1.0]$ sudo /sbin/modprobe -r hello_module
```

Linux Kernel Architecture

Linux Kernel Architecture

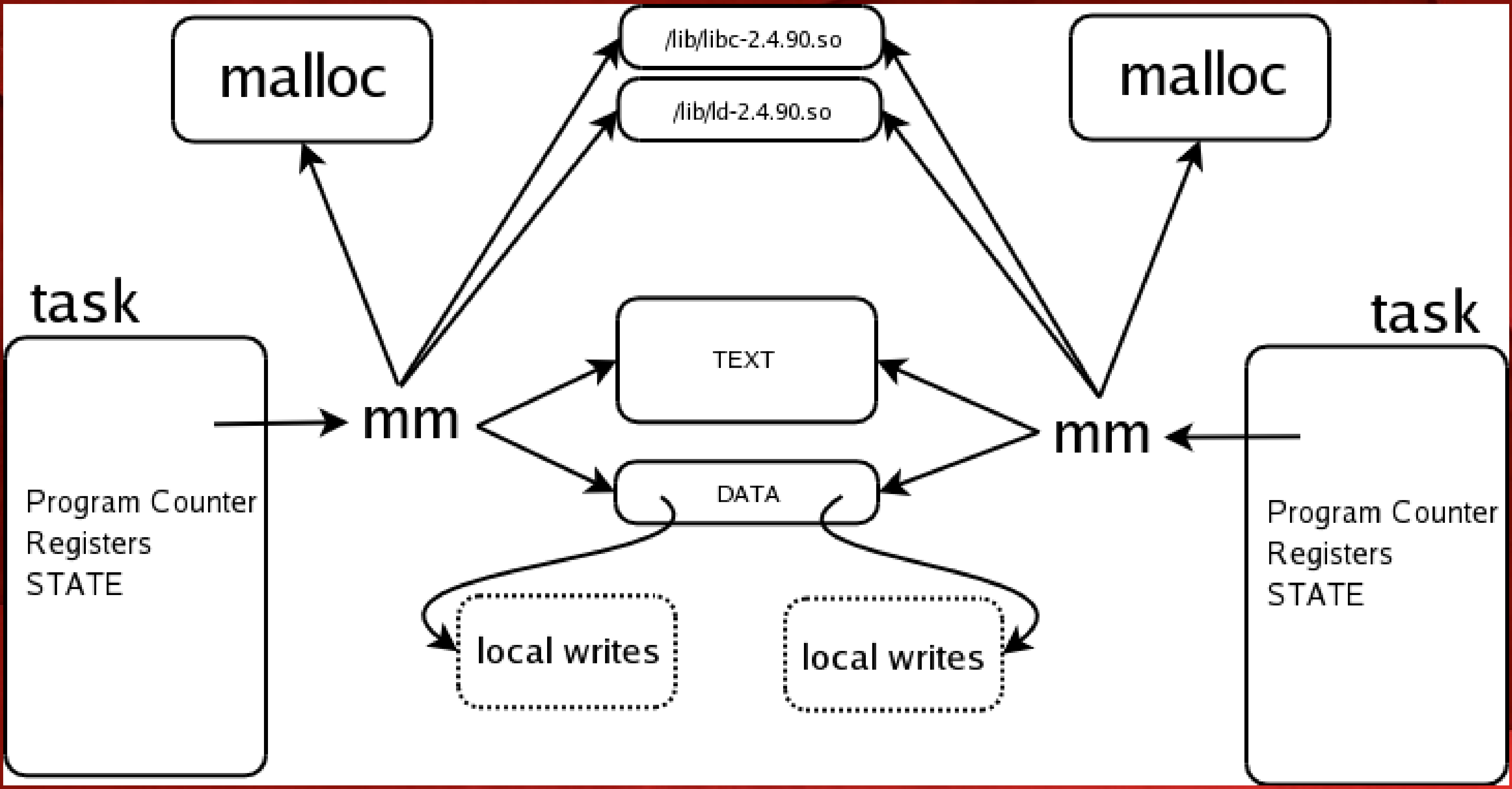
- The kernel as a privileged software library
- Asynchronous entry
  - Interrupts
    (timer, hard disk, network...)
- Synchronous entry
  - System calls
    (open, read, write, ptrace...)

The kernel as a privileged library

- The kernel is not magical
- Performs tasks on our behalf
- Mains fundamental software abstraction
- Limits access to shared resources
- Is there to help us, not to hinder us

The process abstraction

- Every running program represented by process.
  - Referred to within the kernel as a task.



Asynchronous Kernel Entry

- Things that happen involving hardware
- Hardware defined trap in response:

```
/* 0x1000 - Programmable Interval Timer (PIT) Exception */
START_EXCEPTION(0x1000, Decrementer)
NORMAL_EXCEPTION_PROLOG
lis         r0,TSR_PIS@h
mtspr       SPRN_TSR,r0                 /* Clear the PIT exception */
addi        r3,r1,STACK_FRAME_OVERHEAD
EXC_XFER_LITE(0x1000, timer_interrupt)
```

Synchronous Kernel Entry

- Things that we caused to happen directly
- System Calls
  - depending upon architecture
- Program Exceptions
- Data Access Exceptions
  - stack growth, paging
- Emulation
  - traps for VMs, FP...

Kernel Sources

arch crypto **include** **kernel** mm

scripts block **Documentation** init lib

net security COPYING **drivers** ipc

MAINTAINERS README sound CREDITS fs

Kbuild Makefile **REPORTING-BUGS** usr

What is kernel portability?

What is portability?

- “Writing software that can be more easily ported from one architecture (or platform) to another without rewriting it from scratch”.
- Abstract away 64/32-bit, endian issues, etc.
- Linux has no official HAL
  - No generic “Linux Driver Model” either.

Architecture Ports

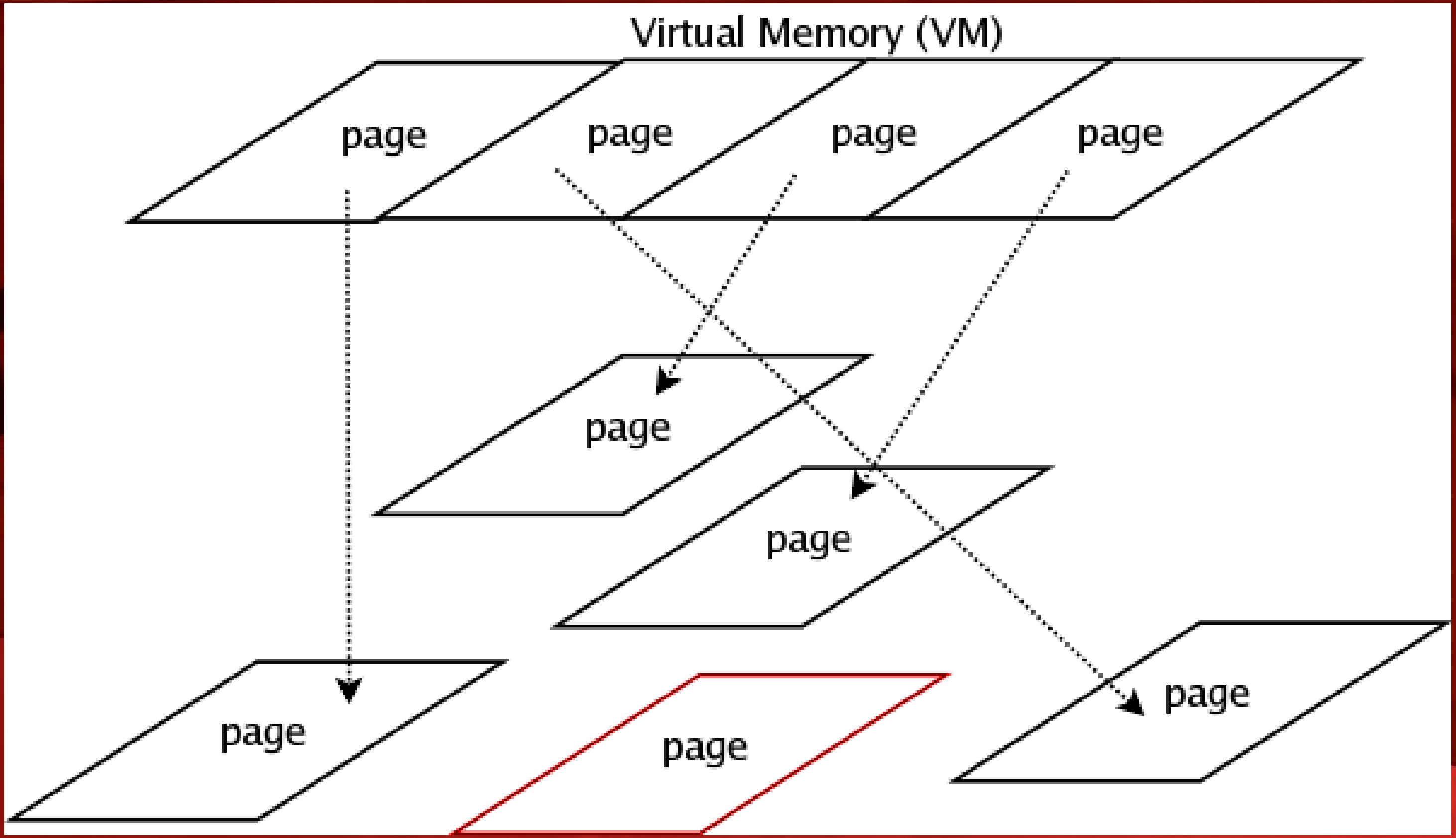
- What's a machine architecture?
- Linux on whole new type of hardware
  - Intel IA32 (“x86”), IA64, POWER, PowerPC, SPARC, etc.
- Typically done by hardware vendors
  - Vested interest in getting support in order to drive sales.
- May require lots of funky hardware
  - Debuggers
- Need to first port GCC, other tools

Examples of architectural differences

- What is virtual memory?
- Why does it differ between architectures?
- How does Linux implement virtual memory?
- Examples

What is virtual memory?

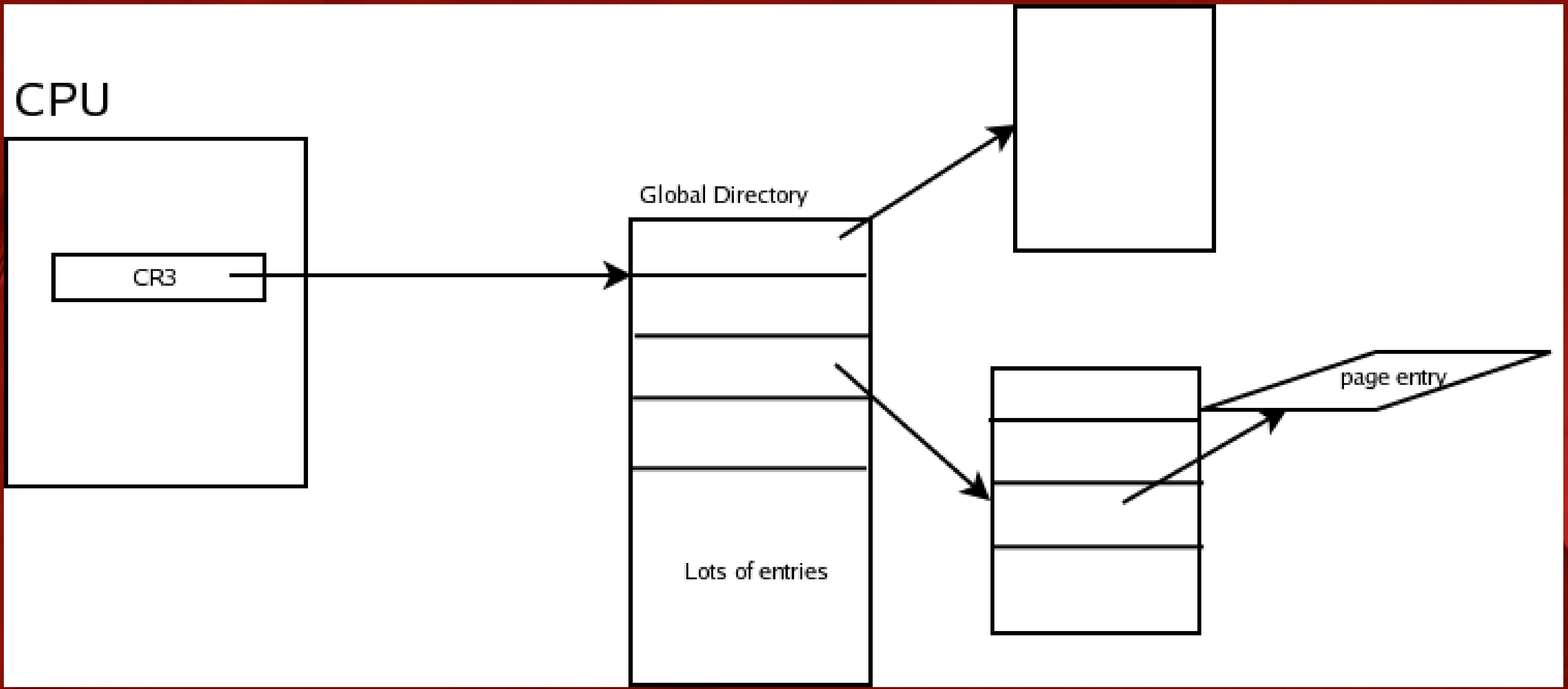
- Abstraction designed to manage memory.
- Group physical memory into pages:



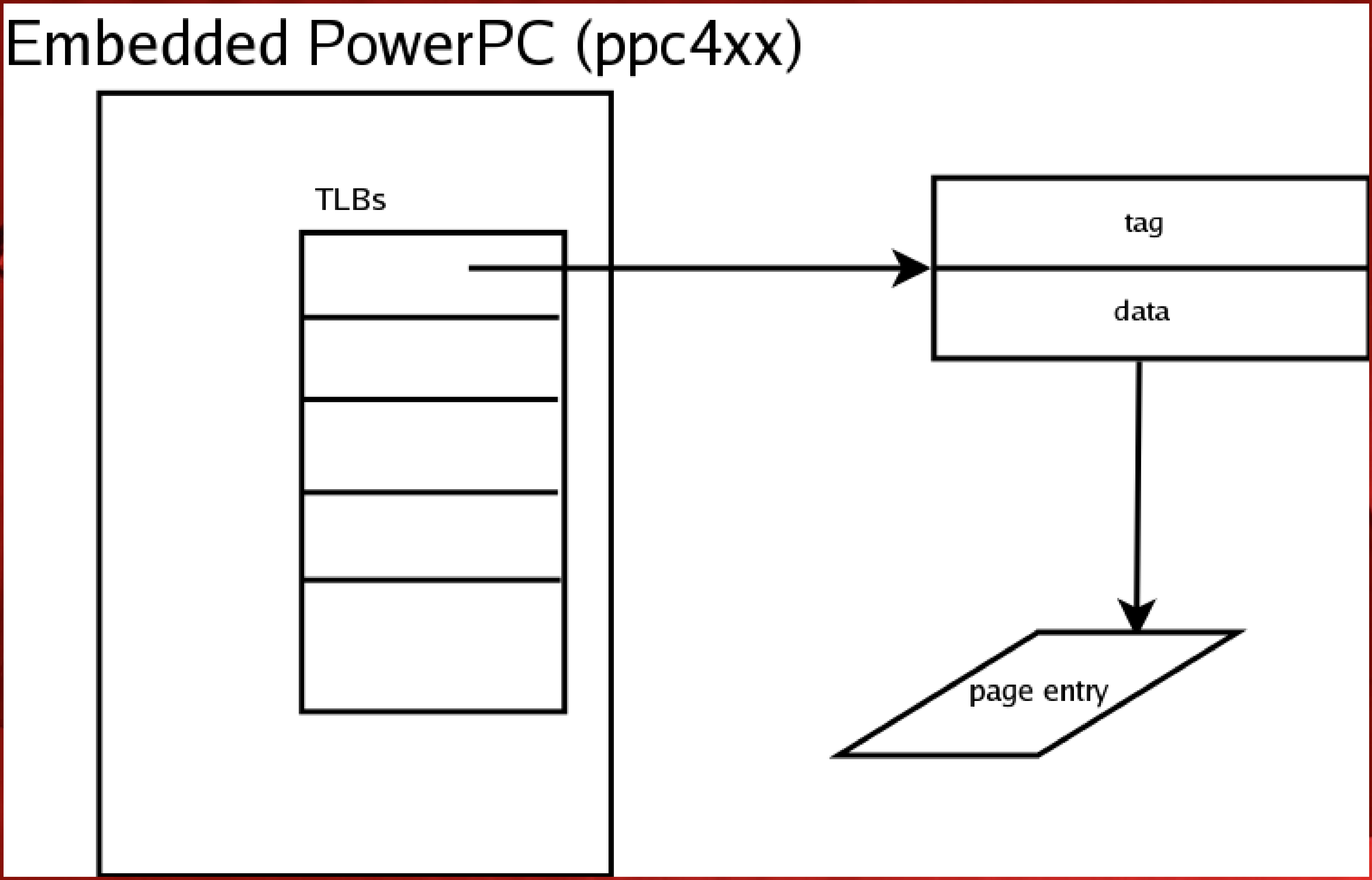
Virtual Memory (VM) architectural differences

- Virtual memory is just a concept.
- Everyone implements it differently.
- Intel giant page table directory.
- PowerPC giant hash table.
- PowerPC self-managed TLBs.

Intel virtual memory...



Embedded PowerPC virtual memory...



Tools needed to build the kernel

- Need a compiler to build a kernel.
- Binutils provides many ELF binary tools
- Check out dummy build/link build hacks
- Need a lot of documentation/expertise
- Try running objdump on your kernel.

objdump -x -D -S vmlinux...

```
/data/work/linux_26/linus_26/vmlinux:     file format elf32-powerpc
/data/work/linux_26/linus_26/vmlinux
architecture: powerpc:common, flags 0x00000112:
EXEC_P, HAS_SYMS, D_PAGED
start address 0xc0000000

Program Header:
    LOAD off    0x00010000 vaddr 0xc0000000 paddr 0xc0000000 align 2**16
         filesz 0x003b0000 memsz 0x003ffcb8 flags rwx
   STACK off    0x00000000 vaddr 0x00000000 paddr 0x00000000 align 2**2
         filesz 0x00000000 memsz 0x00000000 flags rwx

Sections:
Idx Name          Size      VMA       LMA       File off  Algn
  0 .text         002a3000  c0000000  c0000000  00010000  2**5
                  CONTENTS, ALLOC, LOAD, READONLY, CODE
  1 .rodata       00057580  c02a3000  c02a3000  002b3000  2**3
                  CONTENTS, ALLOC, LOAD, READONLY, DATA
  2 .pci_fixup    00000470  c02fa580  c02fa580  0030a580  2**2
                  CONTENTS, ALLOC, LOAD, READONLY, DATA
  3 __ksymtab     00004c18  c02fa9f0  c02fa9f0  0030a9f0  2**2
                  CONTENTS, ALLOC, LOAD, DATA
```

objdump -x -D -S vmlinux...

```
c0000000 <_start>:
c0000000:    60 00 00 00    nop
c0000004:    60 00 00 00    nop
c0000008:    60 00 00 00    nop

c000000c <__start>:
c000000c:    2c 05 00 00    cmpwi   r5,0
c0000010:    41 82 00 0c    beq-    c000001c <__start+0x10>
c0000014:    48 32 51 05    bl      c0325118 <prom_init>
c0000018:    7f e0 00 08    trap
c000001c:    3f e0 42 6f    lis     r31,17007
c0000020:    63 ff 6f 58    ori     r31,r31,28504
c0000024:    7c 03 f8 00    cmpw    r3,r31
c0000028:    40 82 00 0c    bne-    c0000034 <__start+0x28>
c000002c:    48 32 e0 09    bl      c032e034 <bootx_init>
c0000030:    7f e0 00 08    trap
c0000034:    7c 7f 1b 78    mr      r31,r3
c0000038:    7c 9e 23 78    mr      r30,r4
c000003c:    3b 00 00 00    li      r24,0
c0000040:    48 32 3e 79    bl      c0323eb8 <early_init>
c0000044:    48 00 39 21    bl      c0003964 <mmu_off>
```

objdump -x -D -S vmlinux...

```
c0003800 <start_here>:
c0003800:   3c 40 c0 34   lis     r2,-16332
c0003804:   60 42 e0 50   ori     r2,r2,57424
c0003808:   3c 82 40 00   addis   r4,r2,16384
c000380c:   38 84 01 d0   addi    r4,r4,464
c0003810:   7c 93 43 a6   mtsprg  3,r4
c0003814:   38 60 00 00   li      r3,0
c0003818:   7c 72 43 a6   mtsprg  2,r3
c000381c:   3c 20 c0 3a   lis     r1,-16326
c0003820:   38 21 00 00   addi    r1,r1,0
c0003824:   38 00 00 00   li      r0,0
c0003828:   94 01 1f f0   stwu    r0,8176(r1)
c000382c:   7f e3 fb 78   mr      r3,r31
c0003830:   7f c4 f3 78   mr      r4,r30
c0003834:   48 32 06 ed   bl      c0323f20 <machine_init>
c0003838:   48 00 a3 2d   bl      c000db64 <__save_cpu_setup>
c000383c:   48 32 54 d1   bl      c0328d0c <MMU_init>
c0003840:   3c 80 c0 00   lis     r4,-16384
c0003844:   60 84 38 5c   ori     r4,r4,14428
c0003848:   3c 84 40 00   addis   r4,r4,16384
c000384c:   38 60 10 02   li      r3,4098
c0003850:   7c 9a 03 a6   mtsrr0  r4
```

Architecture Ports

- Machine defined hardware entry
  - Linux kernel provides head.S, entry.S|.c, etc.
  - See arch/$my_arch/kernel
- Machine defined interrupts and exceptions
  - What's an exception?
- Machine defined Virtual Memory
  - Huh?
- End up at start_kernel eventually

Platform Ports

- What's a platform anyway?
- Based on standard architecture
  - Much more common than arch. ports
  (run Linux on your own hardware based on COTS parts)
- Use application-dependent devices
- Different memory layout
- Huh?

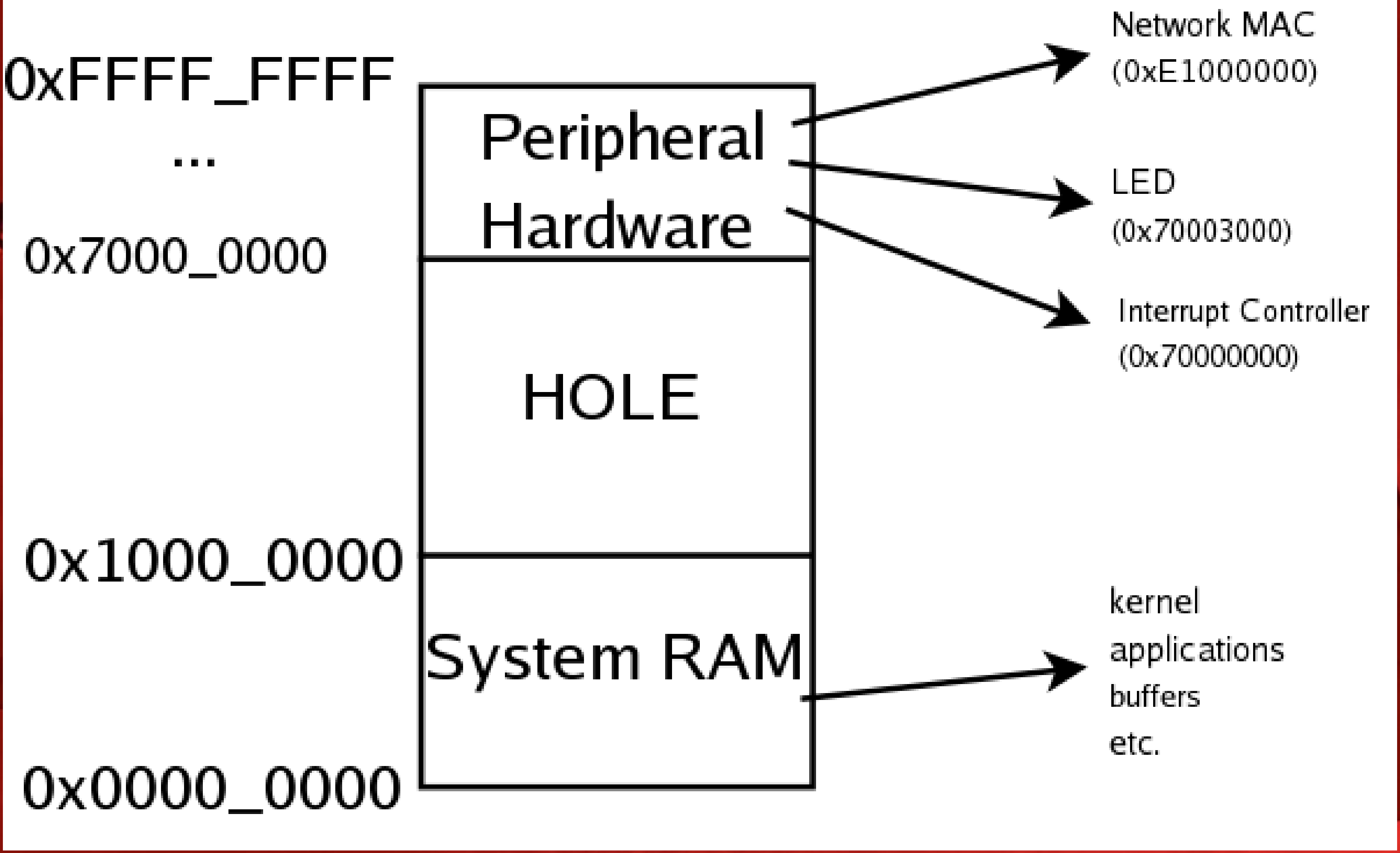
Platform Example - PowerPC

- Tivo PVR runs Linux on PowerPC platform
- Powerbooks Linux on a PowerPC platform
- Industrial Linux on a PowerPC platform
- GameCube Linux on a PowerPC platform
- All Based on a standard architecture

Platform Example - ARM

- PDA running Linux on an ARM platform
- iPod running Linux on an ARM platform
- Broadcom WiFi on an ARM platform
- Your cell phone (running Linux yet?)
- All Based on a standard architecture

Platform Example



Porting the Linux kernel

Determining the hardware platform

- Select a hardware platform
  - Processor/architecture requirements
  - Memory, storage, other requirements
- Acquire necessary hardware tools
  - Hardware debugger (e.g. BDI2000)

Acquire necessary software tools

- You'll need a good toolchain
  - for x86 (IA32), grab one from your distro.
  - otherwise, you need to build/find one.
- Dan Kegel's crosstool is the most popular:
  - http://www.kegel.com/crosstool/
- Vendors sell tools with proprietary gloss.
  - Can buy Eclipse based tools.

Get a good book

- You need to understand the kernel
  - Understanding the Linux Kernel (O'Reilly)
  - Linux Kernel Development (Novell)
  - Linux Device Drivers (O'Reilly)
- If you're working on embedded devices:
  - Building Embedded Linux Systems

Bringing up the system

- Need a workable firmware/BIOS.
  - e.g. uboot, redboot, LinuxBIOS, etc.
- Port firmware to device if needed.
- Ensure necessary toolchain available.
  - What's a toolchain?
- Ensure debugging tools available.
- Spend a lot of time hacking code.

Porting the Linux kernel

(by reusing existing code)

Follow the standard formula

- Most systems are variants of existing ones
- Copy the base platform files and modify
- Add drivers for custom hardware devices

PowerPC Example

- PowerPC architecture/platform files in:
  include/asm-ppc and arch/ppc
  (ongoing work to replace ppc with powerpc)
- System boots through to platform_init()
- We supply platform_init and use it to:
  - Educate Linux about hardware
  - Setup the kernel environment
  - Workaround any known issues

Platform Porting – PowerPC Example

```
/* Clock Defines
 */
#define MY_PLATFORM_SYSCLK          (300000000)
/* 300MHz Clock */


/****************************
 * MYPLATFORM Phyiscal memory map *
 ***************************
 */


#define MYPLATFORM_BRAM_BASE_PADDR     0xFFFFC000
#define MYPLATFORM_LED_BASE_PADDR      0x70003000
#define MYPLATFORM_UART0_BASE_PADDR    0x70002000
#define MYPLATFORM_BUTTON_BASE_PADDR   0x70001000
#define MYPLATFORM_XINTC0_BASE_PADDR   0x70000000
```

Platform Porting – PowerPC Example

- arch/ppc/platforms/my_platform.c:
- Void __init platform_init()
  - Called by the kernel early on to setup low-level hardware
  - Registers contain pointers to board info (binfo), initrd, etc.
- Save board information from bootloader
- Setup initrd
- Produce some debugging output (no printk)

Platform Porting – PowerPC Example

- plaform_init also sets up board functions:
  - ppc_md.setup_arch
  - ppc_md.show_percpuinfo
  - ppc_md.init_IRQ
  - ppc_md.get_irq
  - ppc_md.restart
  - ppc_md.time_init
  - ppc_md.find_end_of_memory
  - ppc_md.setuo_io_mappings
- Kernel will use these functions as callbacks later

Platform Porting – Device Drivers

- Most platforms are very similar
  - Different memory layout, devices, etc.
- Drivers often very different
  - proprietary?!!!
- Use generic PCI/USB/other subsystems
- Add support for device to existing driver
- User-space device drivers?

Building a complete system

Integration

- System is more than a kernel
- Need a working userland (distribution)
- Need to handle software updates

Need a userland

- System is useless without init/bash/something.
  - did you want a webserver with that?
- Can build your own distribution from scratch.
- Can use an existing vendor distribution.
- Can use PTXdist/busybox as a base.
- Experiment!

Handling Updates

- Probably should think about updates

- Build your system with a web server
  - everyone else does.

- Design platform for durability
  - keep a “known good” configuration.
  - keep a spare flash image/kernel.

Jon's Personal Experiences

- Linux in NMR
- Supporting Embedded Linux
- Hobbyist Homebrew

Q&A

- See also:
  - http://www.lwn.net/
  - http://www.lkml.org/
- Mail me with stuff we can't cover here.
- Obligatory legal disclaimer.