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Linux Device Driver Basics

By

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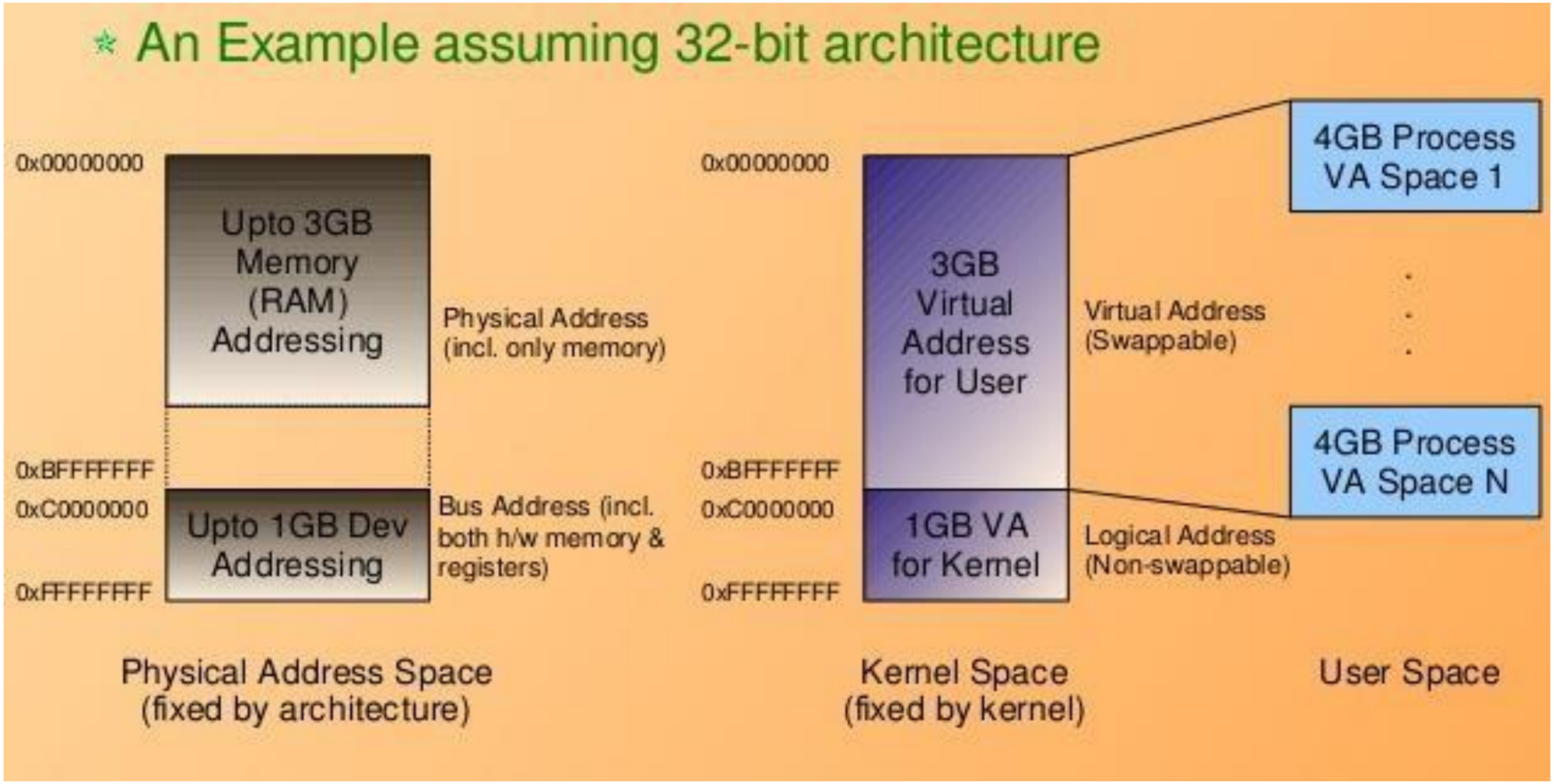
Session-4

Low-level Accesses

What to Expect?

- After this session, you would know
  - Various Address Spaces in Linux
  - Role of Memory Manager in Linux
  - Accessing the Memory in Kernel Space
  - Accessing the Device or Hardware
    - Memory
    - Registers
  - Low-level Access in Drivers

Address Spaces in Linux



Linux Memory Manager

- Provides Access Control to h/w & memory resources
- Provides Dynamic Memory to kernel sub-system
  - Drivers
  - File Systems
  - Stacks
- Provides Virtual Memory to Kernel & User space
  - Kernel & User Processes run in their own virtual address spaces
  - Providing the various features of a Linux system
    - System reliability, Security
    - Communication
    - Program Execution Support

Kernel Space Memory Access

- Virtual Address for Physical Address
  - Header: <linux/gfp.h>
    - unsigned long __get_free_pages(flags, order); etc
    - void free_pages(addr, order); etc
  - Header: <linux/slab.h>
    - void *kmalloc(size_t size, gfp_t flags);
      - GFP_USER, GFP_KERNEL, GFP_DMA
    - void kfree(void *obj);
  - Header: <linux/vmalloc.h>
    - void *vmalloc(unsigned long size);
    - void vfree(void *addr);

Memory allocations in Kernel

kmalloc and kfree:

- Basic allocators, kernel equivalents of glibc's malloc and free.
- #include <linux/slab.h>
- static inline void *kmalloc(size_t size, int flags);

  size: number of bytes to allocate

  flags: priority (see next page)
- void kfree (const void *objp);
- Example: struct mem *ptr;

```
ptr = kmalloc(sizeof(struct mem), GFP_KERNEL);
if (!ptr)
/* handle error ... */
...
kfree(ptr);
```

Memory allocations in Kernel.

Kmalloc features:

- Quick (unless it's blocked waiting for memory to be freed).
- Doesn't initialize the allocated area.
  You can use kcalloc or kzalloc to get zeroed memory.
- The allocated area is contiguous in physical RAM.
- Allocates by 2^n sizes, and uses a few management bytes.
  So, don't ask for 1024 when you need 1000! You'd get 2048!
- Caution: drivers shouldn't try to kmalloc
  more than 128 KB (upper limit in some architectures).
- Minimum allocation: 32 or 64 bytes (page size dependent).

Memory allocations in Kernel..

Kmalloc main flags:

Defined in include/linux/gfp.h (GFP: __get_free_pages)

- GFP_KERNEL

  Standard kernel memory allocation. May block. Fine for most needs.

- GFP_ATOMIC

  Allocated RAM from interrupt handlers or code not triggered by user processes. Never blocks.

- GFP_USER

  Allocates memory for user processes. May block. Lowest priority.

Memory allocations in Kernel…

- vmalloc can be used to obtain big chunk of memory in virtual address space (that means pages allocated are not contiguous in RAM, but the kernel sees them as one block).

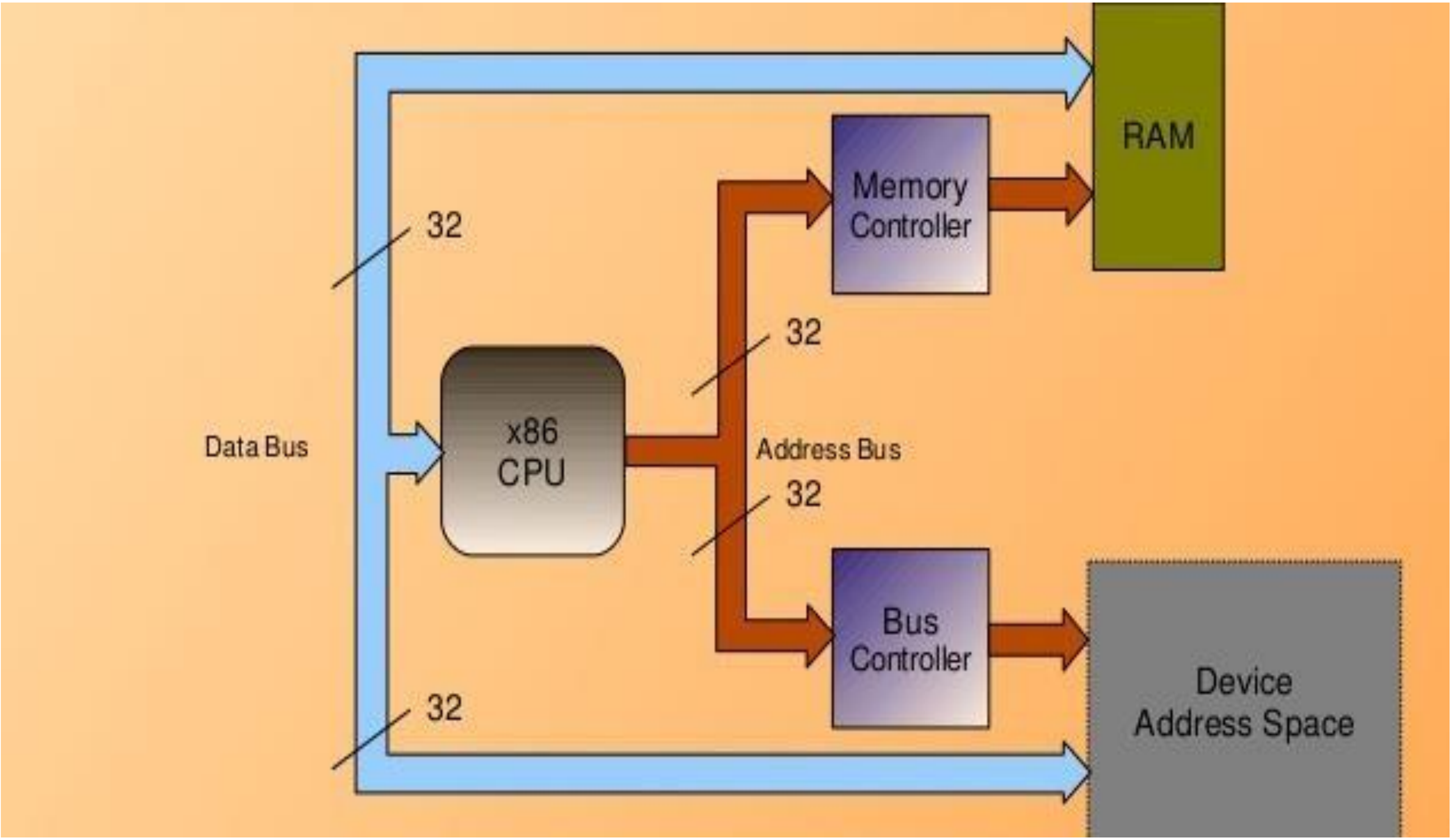
- May block if free pages are not available.
  - void *vmalloc(unsigned long size);
  - void vfree(void *addr);
- Example:

```
char *buf;
buf = vmalloc(16 * PAGE_SIZE); /* get 16 pages */
if (!buf)
/* error! failed to allocate memory */
/* buf now points to at least a 16*PAGE_SIZE bytes * of virtually contiguous block of memory */
vfree(buf);
```

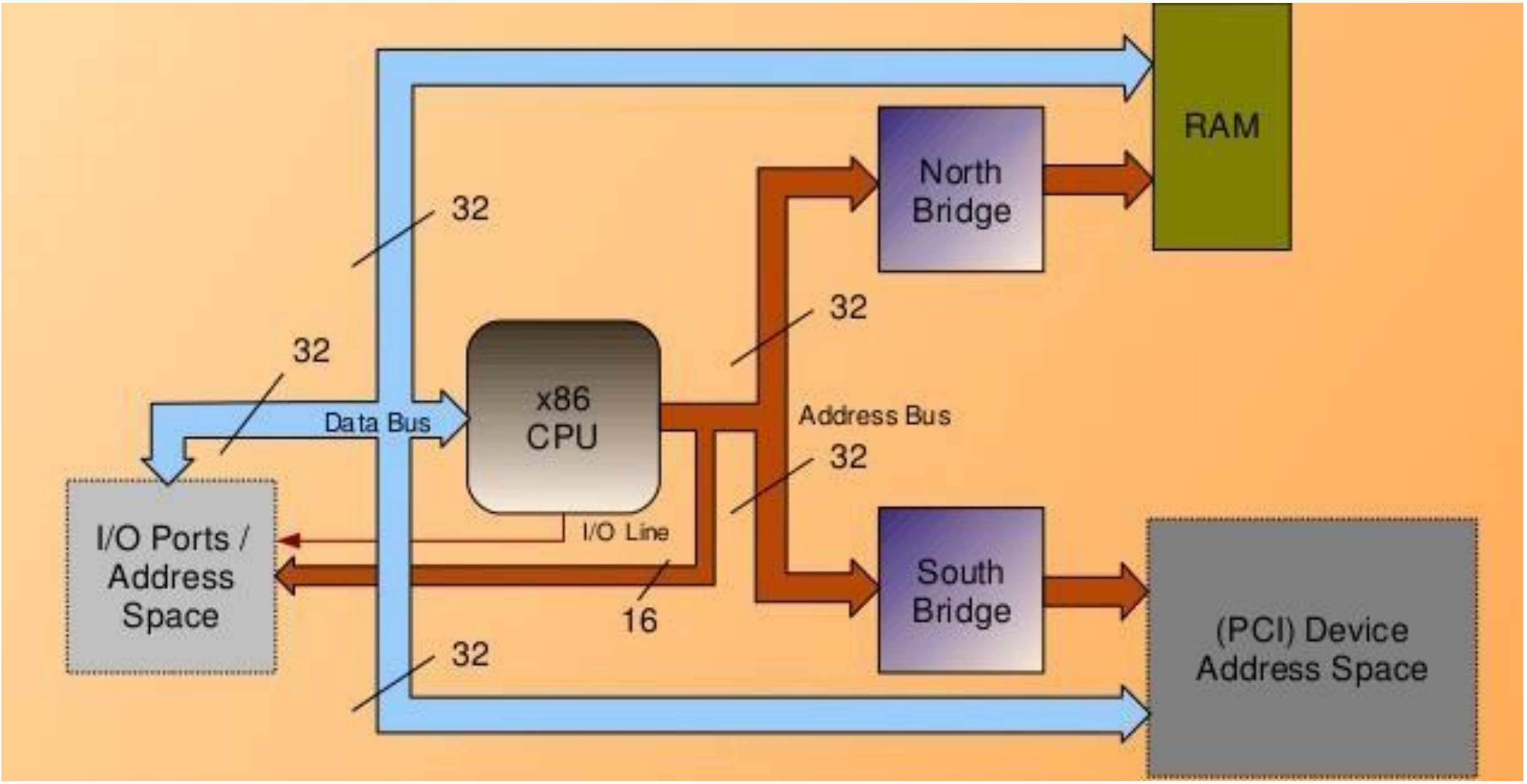
Kernel Space Device Access

- Virtual Address for Bus/IO Address
  - Header: <asm/io.h>
    - void *ioremap(phys_addr_t bus_addr, unsigned long size);
    - void iounmap(void *addr);
- I/O Memory Access
  - Header: <asm/io.h>
    - u[8|16|32] ioread[8|16|32](void *addr);
    - void iowrite[8|16|32](u[8|16|32] value, void *addr);
- Kernel Window: /proc/iomem
- Access Permissions
  - Header: <linux/ioport.h>
    - struct resource *request_mem_region(resource_size_t start, resource_size_t size, label);
    - void release_mem_region(resource_size_t start, resource_size_t size);

x86 Memory & Device Access



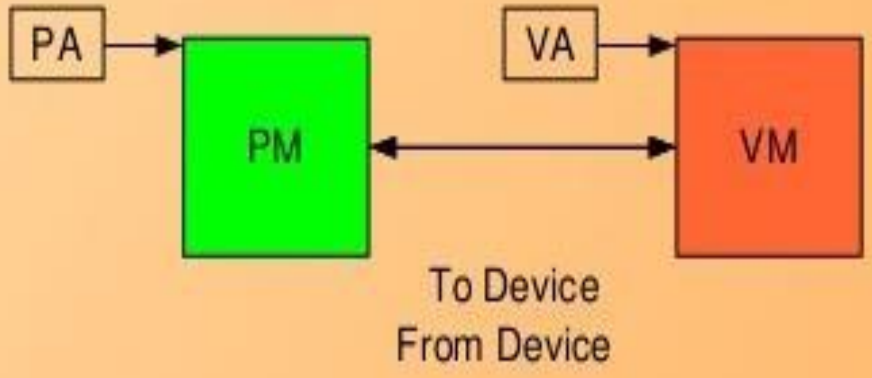
x86 Hardware Architecture
complete



I/O Access (x86* specific)

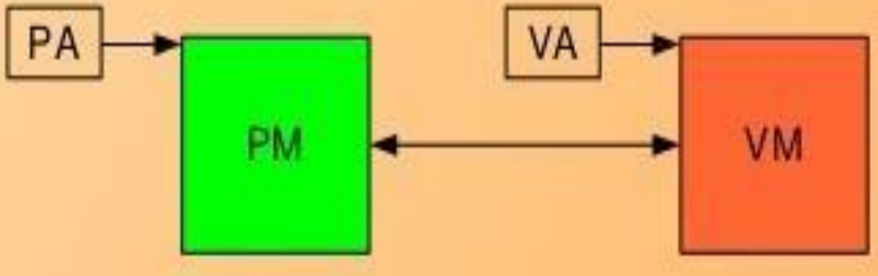
- I/O Port Access
  - u8 inb(unsigned long port);
  - u16 inw(unsigned long port);
  - u32 inl(unsigned long port);
  - void outb(u8 value, unsigned long port);
  - void outw(u16 value, unsigned long port);
  - void outl(u32 value, unsigned long port);
- Header: <asm/io.h>
- Kernel Window: /proc/ioports
- Access Permissions
  - Header: <linux/ioport.h>
    - struct resource *request_region(resource_size_t start, resource_size_t size, label);
    - void release_region(resource_size_t start, resource_size_t size);

DMA Mapping



- APIs
  - dma_addr_t dma_map_single(struct device *, void *, size_t, enum dma_data_direction);
  - void dma_unmap_single(struct device *, dma_addr_t, size_t, enum dma_data_direction);
  - Directions
    - DMA_BIDIRECTIONAL
    - DMA_TO_DEVICE
    - DMA_FROM_DEVICE
    - DMA_NONE
- Header: <linux/dma-mapping.h>

DMA Allocation



- APIs
  - void *dma_alloc_coherent(struct device *, size_t, dma_addr_t *, gfp_t);
  - void dma_free_coherent(struct device *, size_t, void *, dma_addr_t);
  - int dma_set_mask(struct device *, u64 mask);
- Header: <linux/dma-mapping.h>

Barriers

- Heard about Processor Optimization?
- void barrier(void);
  - For surrounding instructions
  - Header: <linux/kernel.h>
- void [r|w|]mb(void);
  - For surrounding read/write instructions
  - Header: <asm/system.h>

Memory & Character Driver

- Dynamic Memory Experiments
  - Preserve latest write in /dev/memory
  - Control the preserve size using ioctl
  - Implement seek

Hardware & Character Driver

- Digital/Analog I/O Control on the Board
- Figure out
  - Operation Relevant Registers
  - Hardware Access Addresses
  - Relevant low-level access APIs to be used
- Driver for I/O access over /dev/io

What all have we learnt?

- Various Address Spaces in Linux
- Role of Memory Manager in Linux
- Accessing the Memory in Kernel Space
- Accessing the Device or Hardware
  - Memory
  - Registers
- Barriers
- Low-level Access in Drivers

Any Queries?

Optional Slides for Session-4 Low-Level Access

Linux Kernel Interrupt handling

Interrupts:

- Asynchronous events triggered by devices to notify some change.
- ISR routine will be executed when interrupt occurs.
- Driver should implement ISR routine and register with Kernel Interrupt subsystem.
- Routines to register&unregister the ISR:

  int request_irq(unsigned int irq, irq_handler_t handler, unsigned long flags, const char *name, void *dev);

  void free_irq(unsigned int irq, void *dev_id);

Linux Kernel Interrupt handling.

Example: For Keyboard ISR registration.

```
static unsigned int upcode;    //global var to update the scancode.
request_irq(KB_INT, /1 *  The number of the keyboard IRQ on PCs*/
            irq_handler, /* our handler */
            SA_SHIRQ,"test_keyboard_irq_handler", (void *)(data));
 free_irq(KB_INT, &data);
 irq_handler(int irq, void *dev_id, struct pt_regs *regs)
{
  unsigned char scancode;
  scancode = read_kbd_input();
  printk(“scancode = %d\n”, scancode);
  upcode = scancode;
  wake_up_interruptable(&my_kb_queue);
  return 0;
}
```

Device Control Interfaces

Device drivers Basic Interface functions:

While writing a drivers for particular device, we should consider below

- Actual functionality implementation.
- Implementation to control the device.

1. Functionality Interface routines

   – Implements actual functionality of device

   -- Ex: Camera device

   Enable --- Open()

   Disable --- close()

   Capture --- Read()

   Display --- write()

2. Control Interface routines

   -- Implements control of device

   -- Ex: resolution , zoom , brightness setting etc --- ioctl()

Device Control Interfaces

Ioctl() - IO control

- All the Device control operations should be implemented using ioctl()
- Ioctl() implementation is unique for each device.
- Ioctl() function can support 255 control interfaces.
- Ioctl() is a part of file operation structure.
- Each Driver ioctl() function should export ioctl request commands to user space.
- U-space apps can use these request commands & u-space ioctl() API to control the device.

Device Control Interfaces

Ioctl() - IO control - from u-space

- U-space App can make use of ioctl() API to initiate device specific functionality.

  Header file :

  #include <sys/ioctl.h>

  API:

  int ioctl(int fd, int request, …)

  arg1: file descriptor

  arg2: ioctl request command.

  arg3: untied pointer – depends of request command type

  Ex: ret_val = ioctl(fd, TICAM_BRIGHTNESS_SET, data)

  ret_val = ioctl(fd, TEST_FILL_CHAR, a)

Device Control Interfaces

Ioctl() - IO control - K-space implementation

- Identify Control operations offered by the device
- Declare a unique ioctl request command for each control operation. Take one header file generate ioctl commands & export the header file to u-spce.
- Implement an ioctl routine in a driver to process ioctl requests.

Device Control Interfaces

Ioctl() - IO control - K-space implementation

Kernel provides Macro’s to generate unique ioctl request commands in <linux/ioctl.h>.

- _IO(type, n)
- _IOW(type, n, dataitem)
- _IOR(type, n, dataitem)
- _IOWR(type, n, dataitem)

Which one to use depends on

- Type or magic num
- Sequence num – 8-bit wide
- Direction – reading or writing
- Size – of user data (int size or char size)

Device Control Interfaces

Ioctl() - IO control - K-space implementation

Assume we are writing driver – assume 1024 bytes of RAM as a device for us.

Now we will implement driver ioctl() to fill the data in that 1024 bytes.

In header file:

```
#define TEST_IOCTL_MAGIC   SP
//commands
#define TEST_FILL_ZERO     _IO(TEST_IOCTL_MAGIC, 1)
#define TEST_FILL_CHAR     _IOW(TEST_IOCTL_MAGIC, 2, char)
#define TEST_SET_SIZE   _IOW(TEST_IOCTL_MAGIC, 3, uint)
#define TEST_GET_SIZE _IOR(TEST_IOCTL_MAGIC, 4, uint)

#define TEST_MAX_COMMANDS   5
#define TEST_MAX_LEN 1024
```

Device Control Interfaces

Ioctl() - IO control - K-space implementation

Implementation of drivers ioctl():

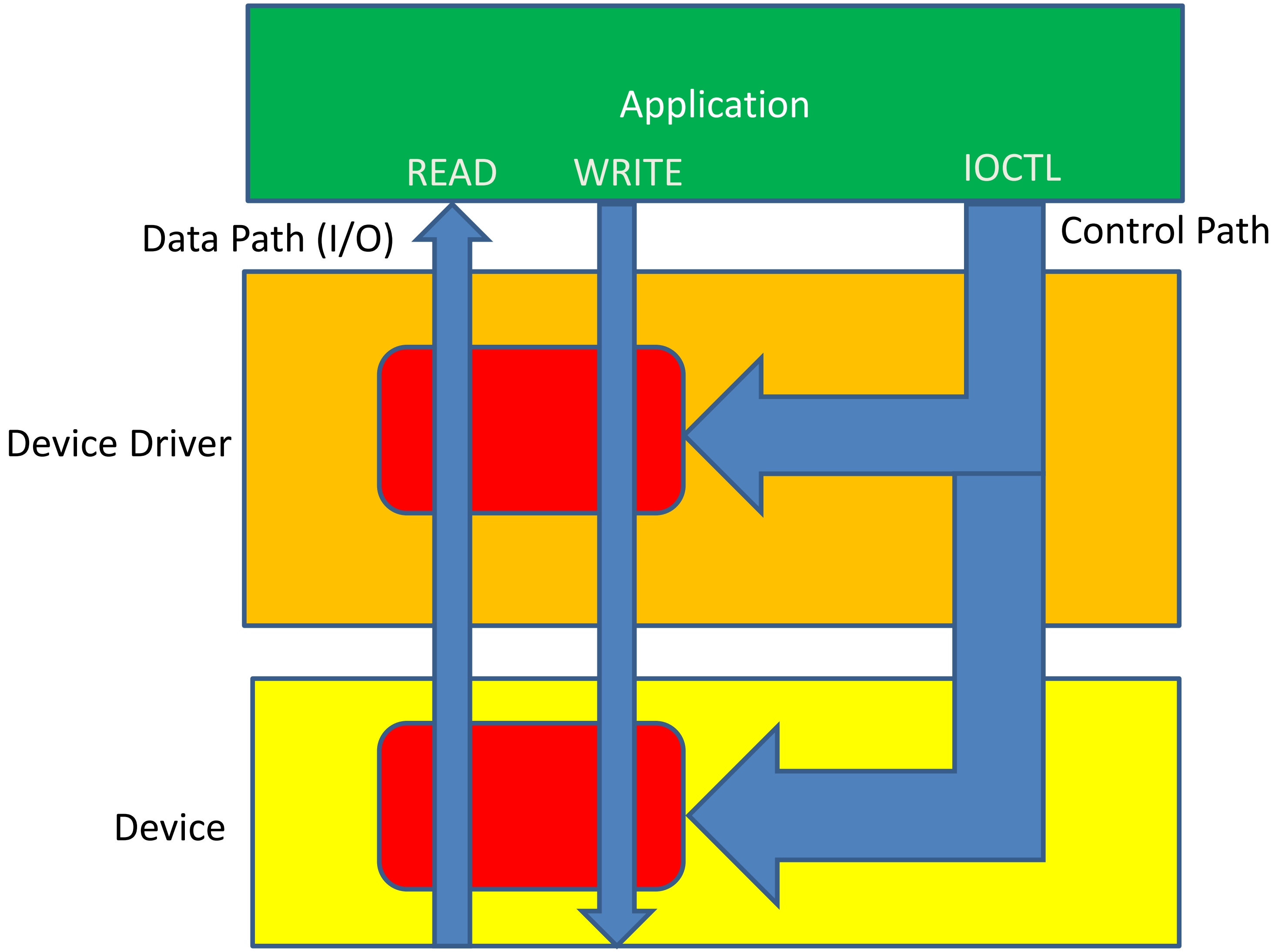
```
Int    test_char_dev_ioctl(struct inode *inode, struct file *filp
             unsigned int cmd, unsigned long arg)
{
   unsigned int i, size;
   char c;
   int bytes;
   if(_IOC_TYPE(cmd) != TEST_IOCTL_MAGIC)//to  validate magic num
     return –EWRONG;
   if(_IOC_NR(cmd) > TEST_MAX_COMMANDS)   //to  validate seq num
      return –EWRONG;
   switch(cmd){
            case TEST_FILL_ZERO:
        for(i=0;i<TEST_MAX_LENGTH;i++)
            char_dev_buf[i] = 0;
             break;
}
```

IOCTL Command Format

32-bit unsigned int

2-bits	14-bits	8-bits	8-bits
Direction	Arg Size (in Bytes)	Magic Number	Command Number

IOCTL – Control Path



Kernel source management tools.

1.Cscope:

http://cscope.sourceforge.net/

- Tool to browse source code (mainly C, but also C++ or Java).
- Can be used from editors like vim and emacs.

2.Kscope:

http://kscope.sourceforge.net

- A graphical front-end to Cscope
- Makes it easy to browse and edit the Linux kernel sources
- Can display a function call tree
- Nice editing features: symbol completion, spelling checker, automatic indentation...

3.Source navigator:

4.Source insight:

Books for Ref..

Books:

- Understanding the Linux Kernel, D. P. Bovet and M. Cesati, O'Reilly & Associates, 2000.
- Linux Core Kernel – Commentary, In-Depth Code Annotation, S. Maxwell, Coriolis Open Press, 1999.
- The Linux Kernel, Version 0.8-3, D. A Rusling, 1998.
- Linux Kernel Internals, 2nd edition, M. Beck et al., Addison-Wesley, 1998.
- Linux Kernel, R. Card et al., John Wiley & Sons, 1998.
- Linux Device Drivers, 3rd Edition, Jonathan Corbet, Alessandro Rubini, and Greg Kroah-Hartman Published by O'Reilly Media, Inc., 1005

Questions ??

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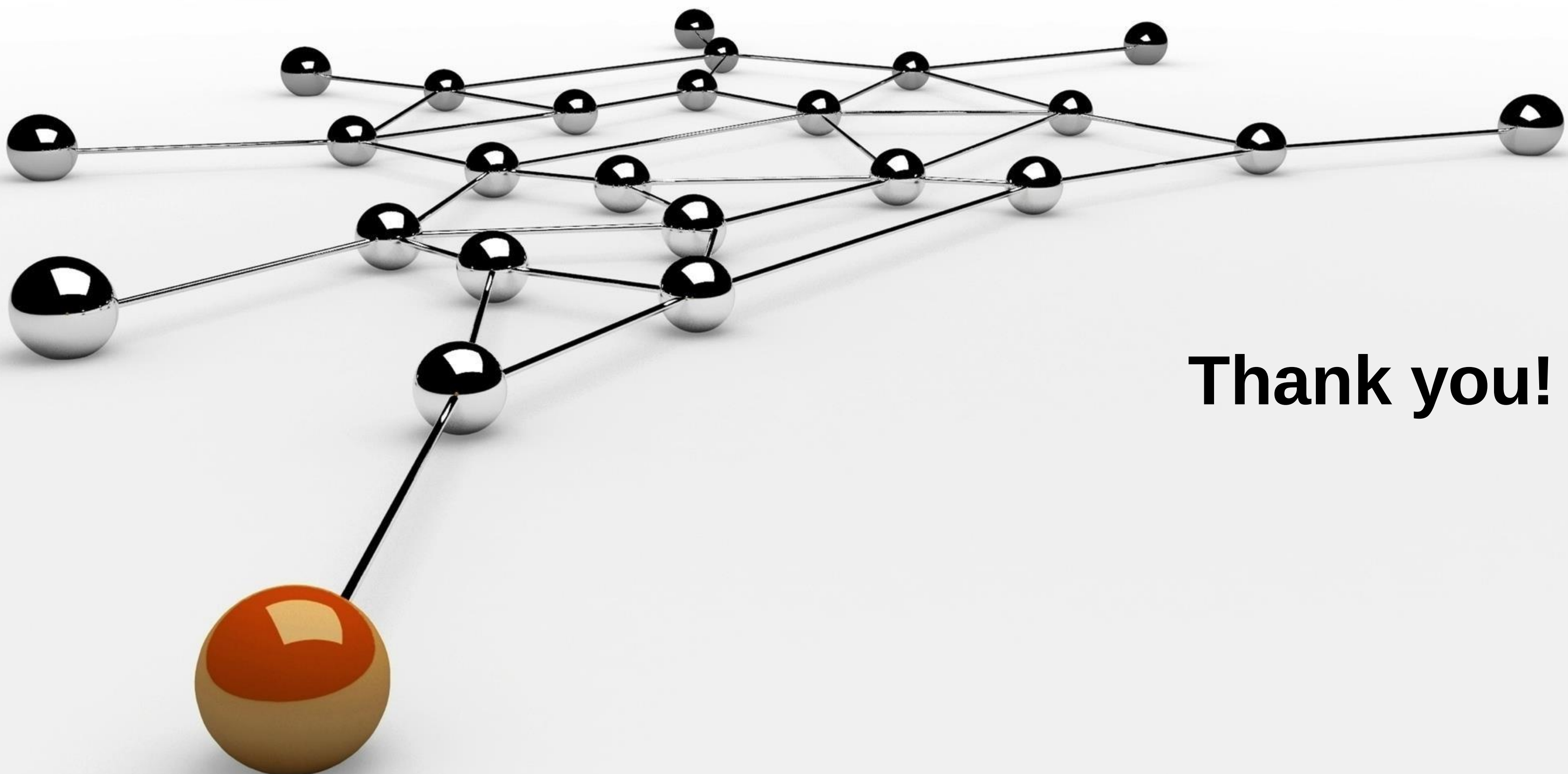

Thank you!

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