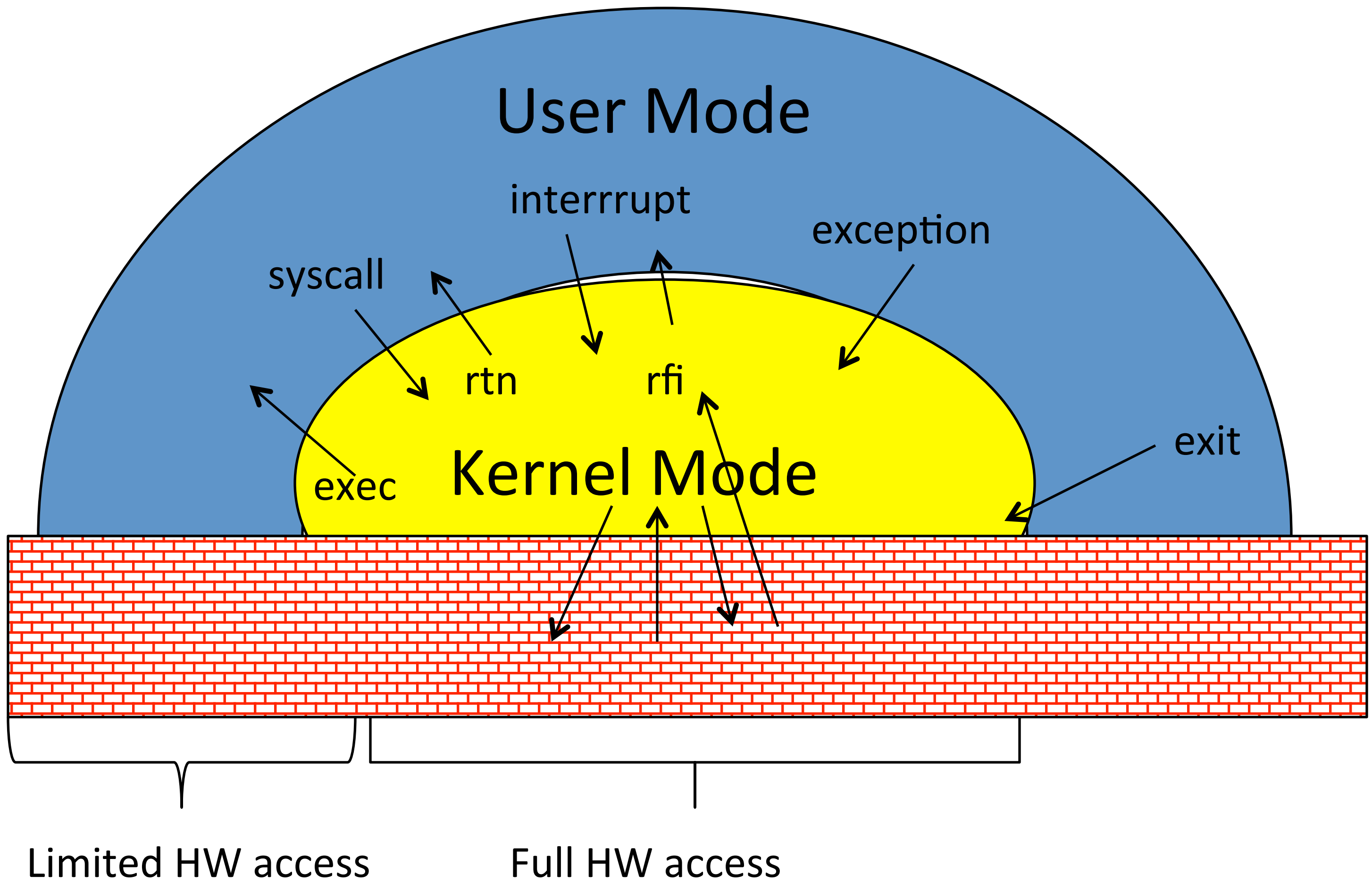
Finish – Introduction to Process

Introduction to File Systems

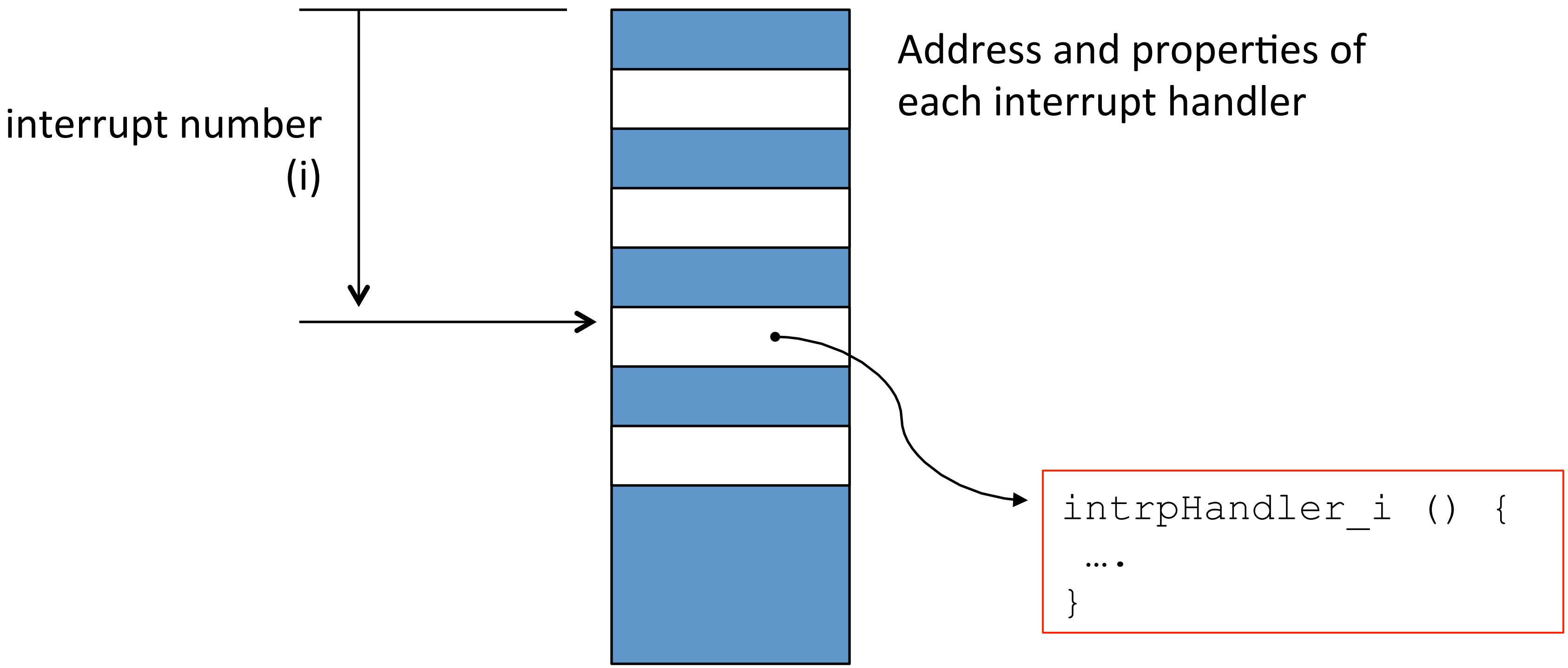
David E. Culler
CS162 – Operating Systems and Systems Programming
Lecture 2’ & 3
Sept 5, 2014

Reading: A&D 3.1-3, 11.1-2
HW: 0 out, due 9/8

Recall:User/Kernal(Priviledged) Mode

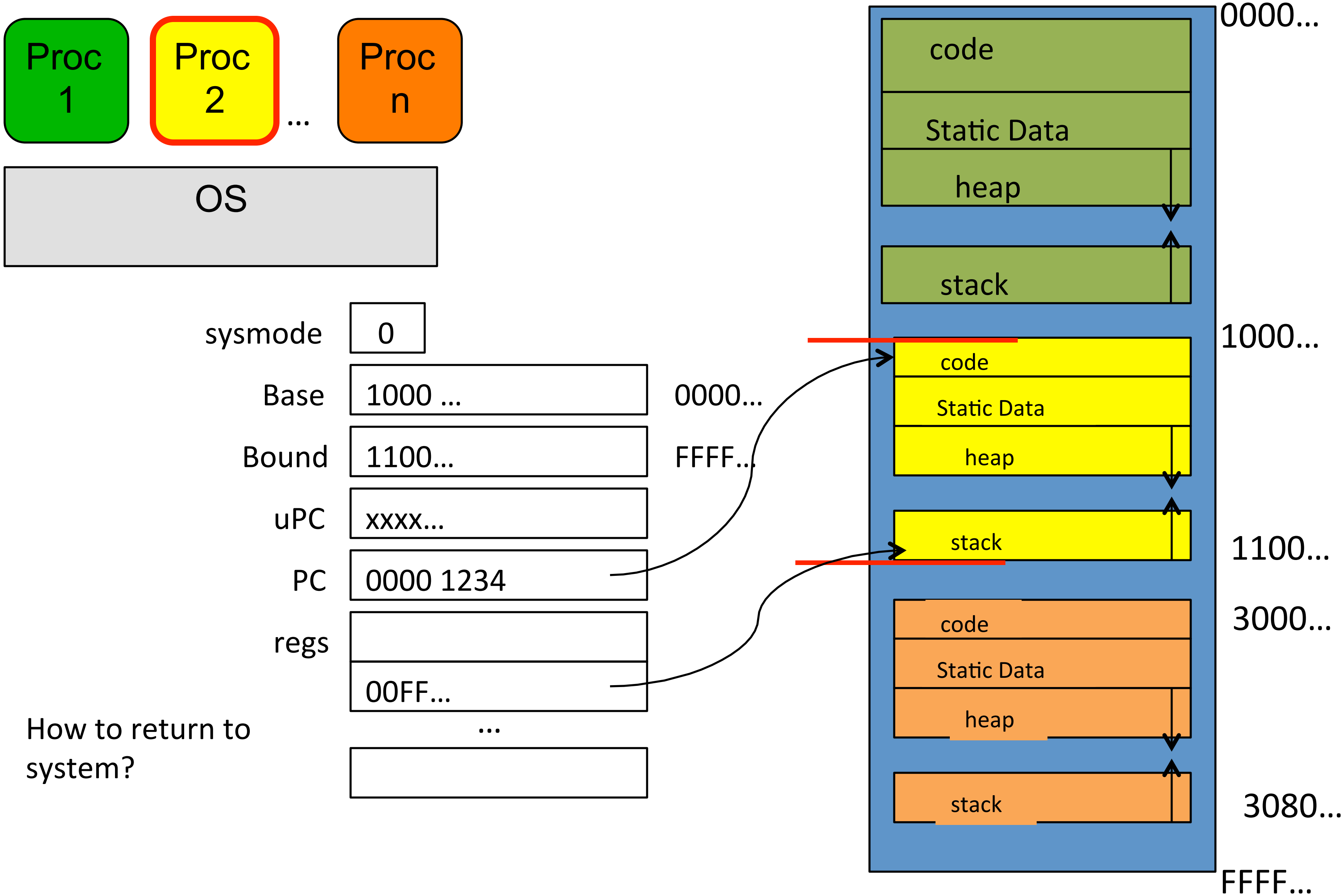


Recall: Interrupt Vector



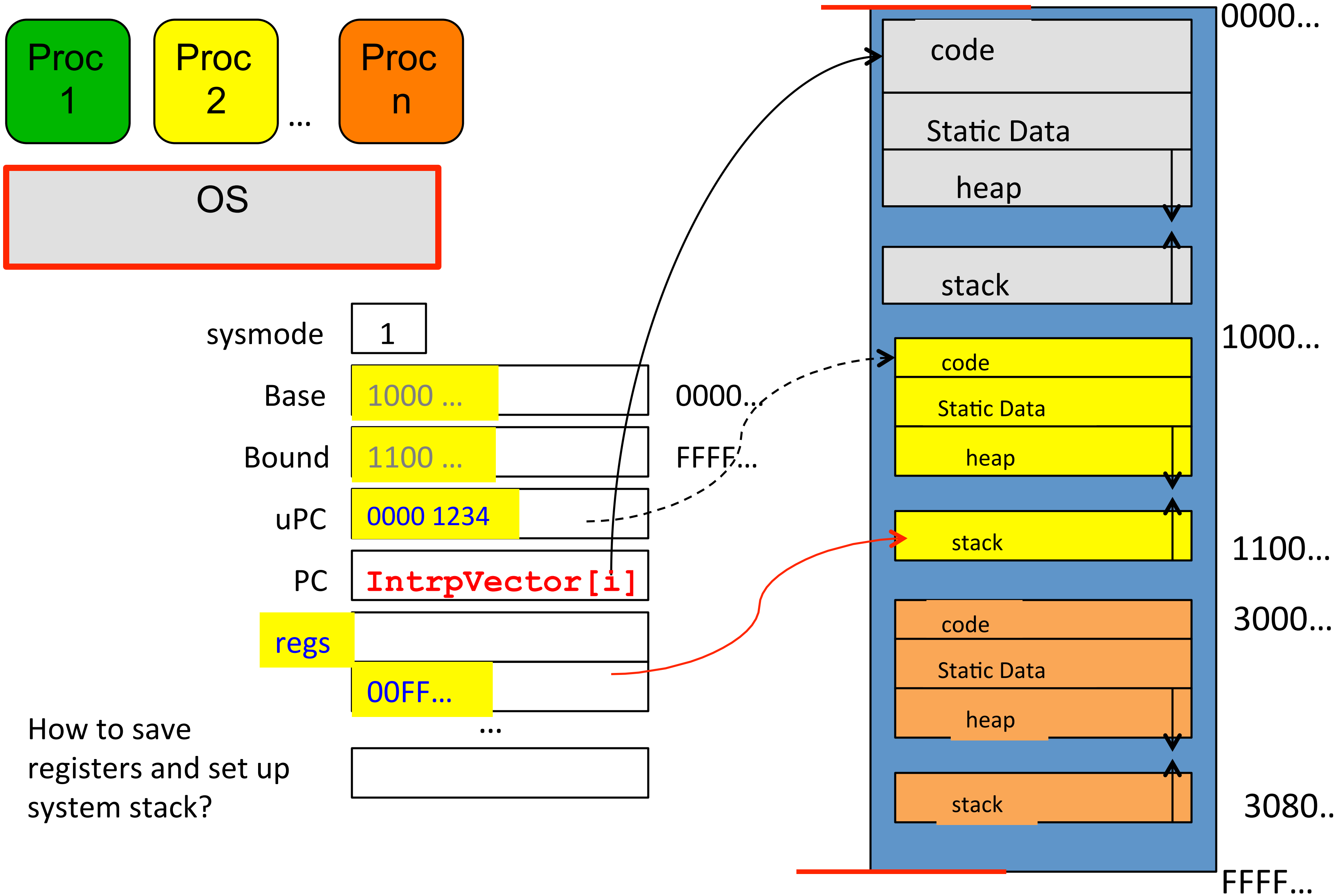
- Where else do you see this dispatch pattern?

Simple B&B: User => Kernel



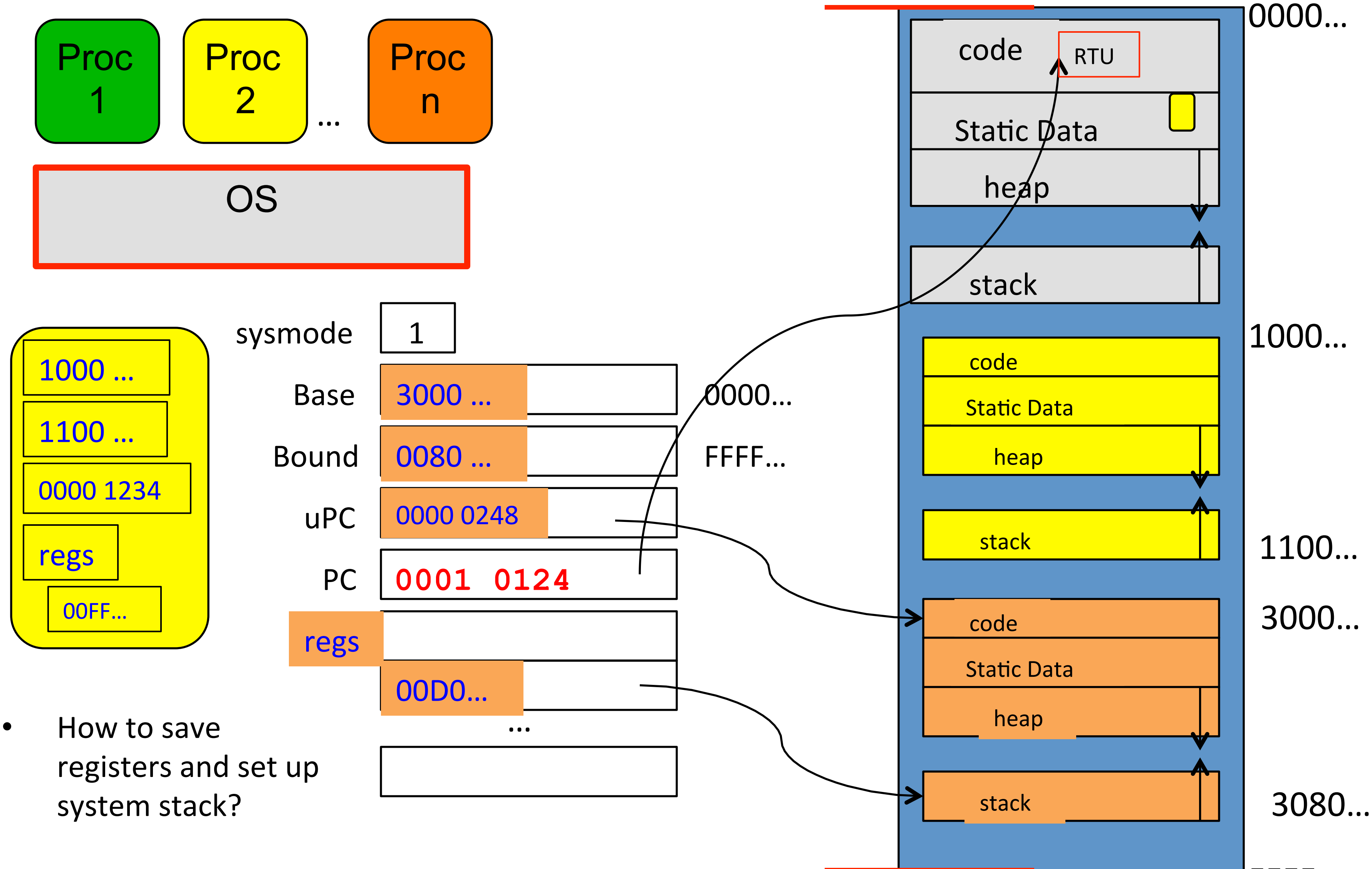
- How to return to system?

Simple B&B: Interrupt



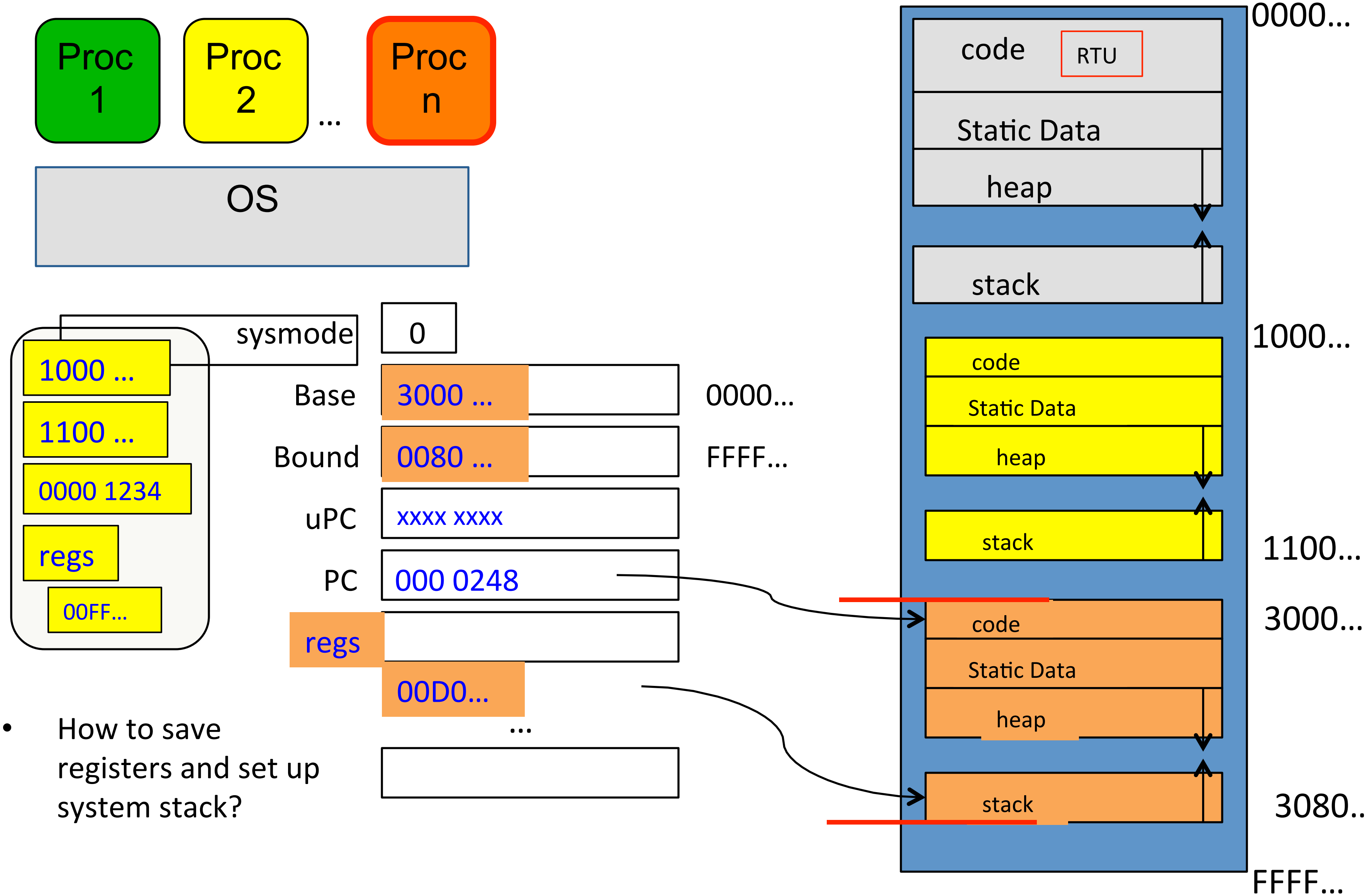
- How to save registers and set up system stack?

Simple B&B: Switch User Process



- How to save registers and set up system stack?

Simple B&B: “resume”

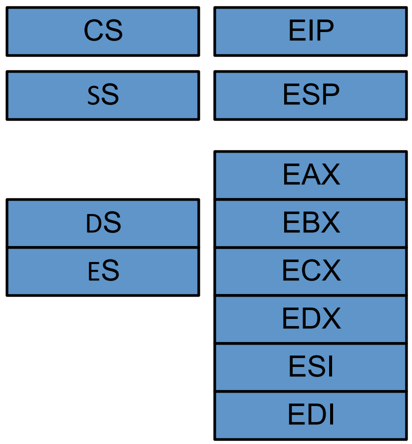


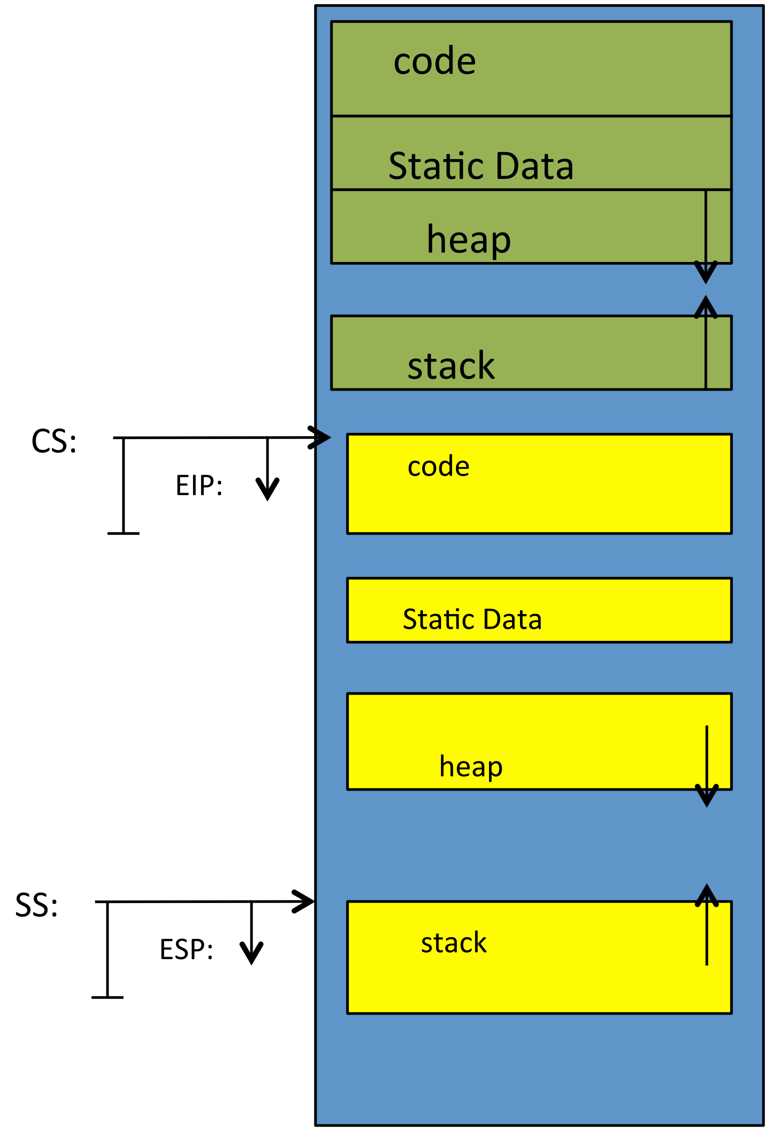
- How to save registers and set up system stack?

What's wrong with this simplistic address translation mechanism?

x86 – segments and stacks

Processor Registers





Start address, length and access rights associated with each segment

Virtual Address Translation

- Simpler, more useful schemes too!
- Give every process the illusion of its own BIG FLAT ADDRESS SPACE
  - Break it into pages
  - More on this later

Running Many Programs ???

- We have the basic mechanism to
  - switch between user processes and the kernel,
  - the kernel can switch among user processes,
  - Protect OS from user processes and processes from each other
- Questions ???
- How do we decide which user process to run?
- How do we represent user processes in the OS?
- How do we pack up the process and set it aside?
- How do we get a stack and heap for the kernel?
- Aren't we wasting are lot of memory?
- …

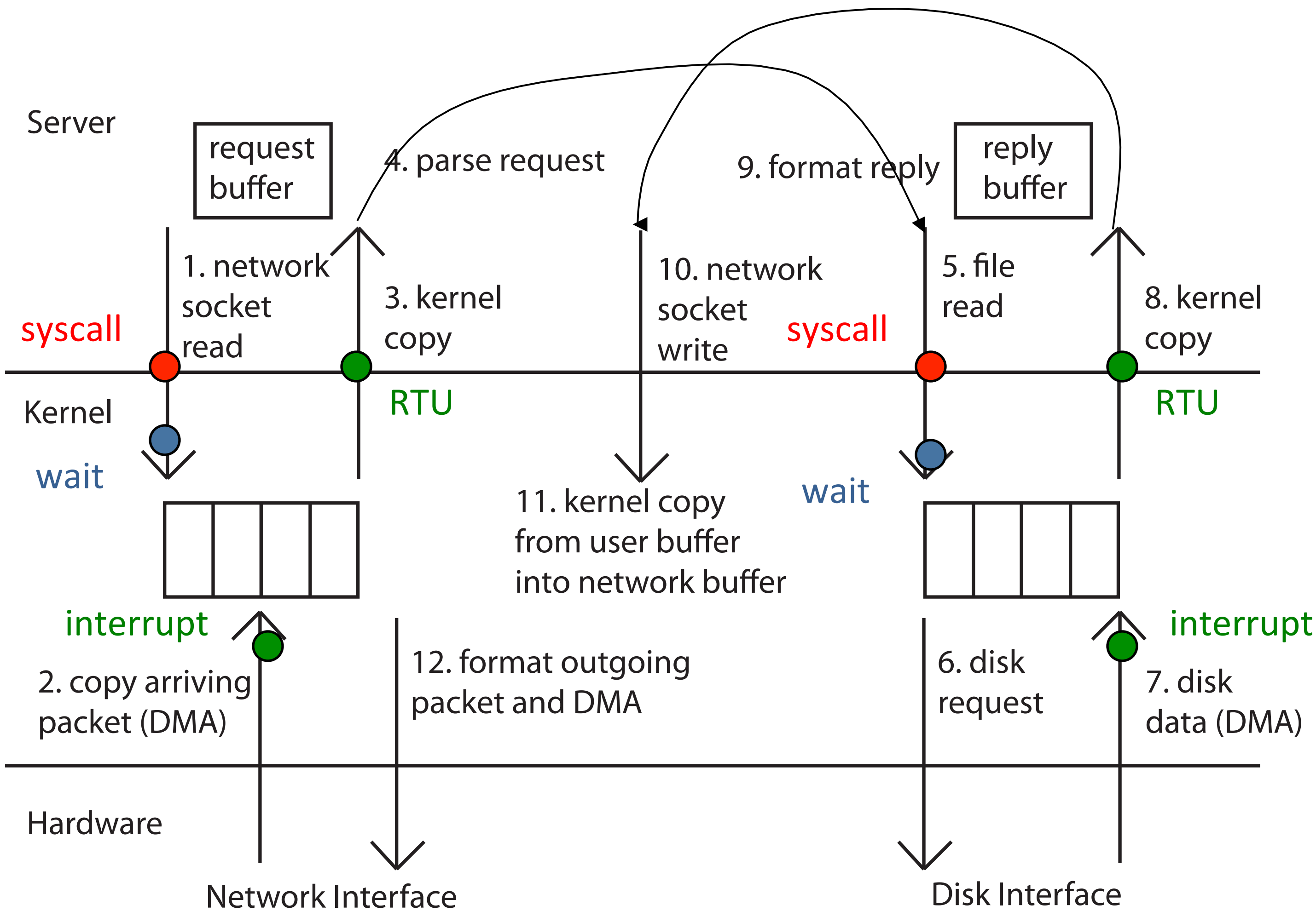
Process Control Block

- Kernel represents each process as a process control block (PCB)
  – Status (running, ready, blocked, …)
  – Register state (when not ready)
  – Process ID (PID), User, Executable, Priority, …
  – Execution time, …
  – Memory space, translation, …
- Kernel Scheduler maintains a data structure containing the PCBs
- Scheduling algorithm selects the next one to run

Scheduler

```
if ( readyProcesses(PCBs) ) {
    nextPCB = selectProcess(PCBs);
    run( nextPCB );
} else {
    run_idle_process();
}
```

Putting it together: web server



4 OS concepts working together

- Privilege/User Mode
  - The hardware can operate in two modes, with only the "system" mode having the ability to access certain resources.
- Address Space
  - Programs execute in an *address space* that is distinct from the memory space of the physical machine
- Process
  - An instance of an executing program is *a process consisting of an address space and one or more threads of control*
- Protection
  - The OS and the hardware are protected from user programs and user programs are isolated from one another by *controlling the translation* from program virtual addresses to machine physical addresses

Introduction to File Systems

David E. Culler

CS162 – Operating Systems and Systems Programming

Lecture 3

Sept 5, 2014

Reading: A&D 3.1-3, 11.1-2

HW: 0 out, due 9/8

Objective of this lecture

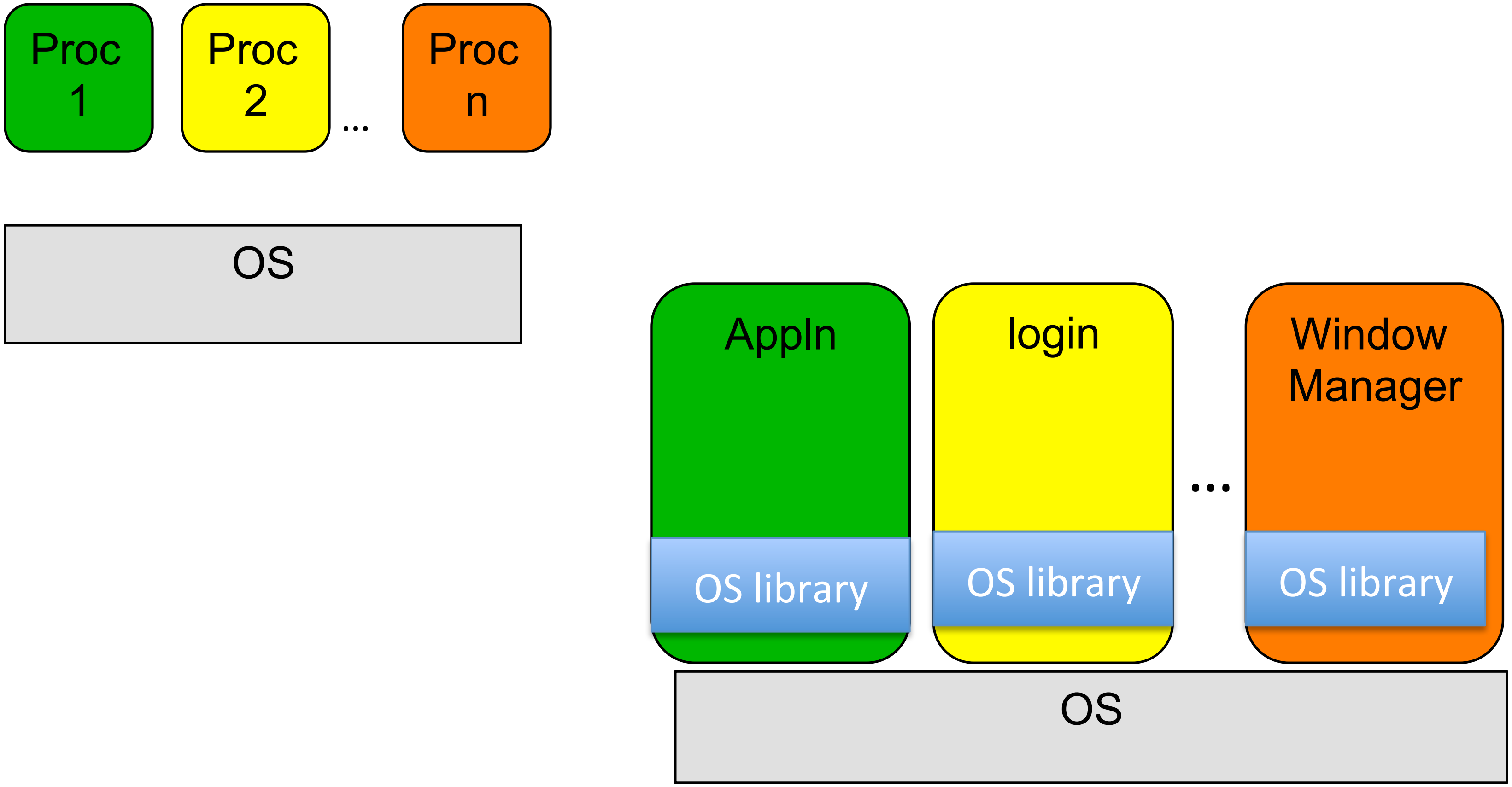
- Show how Operating System functionality distributes across layers in the system.
- Introduce I/O & storage services – i.e., file systems

Reflecting on the process intro

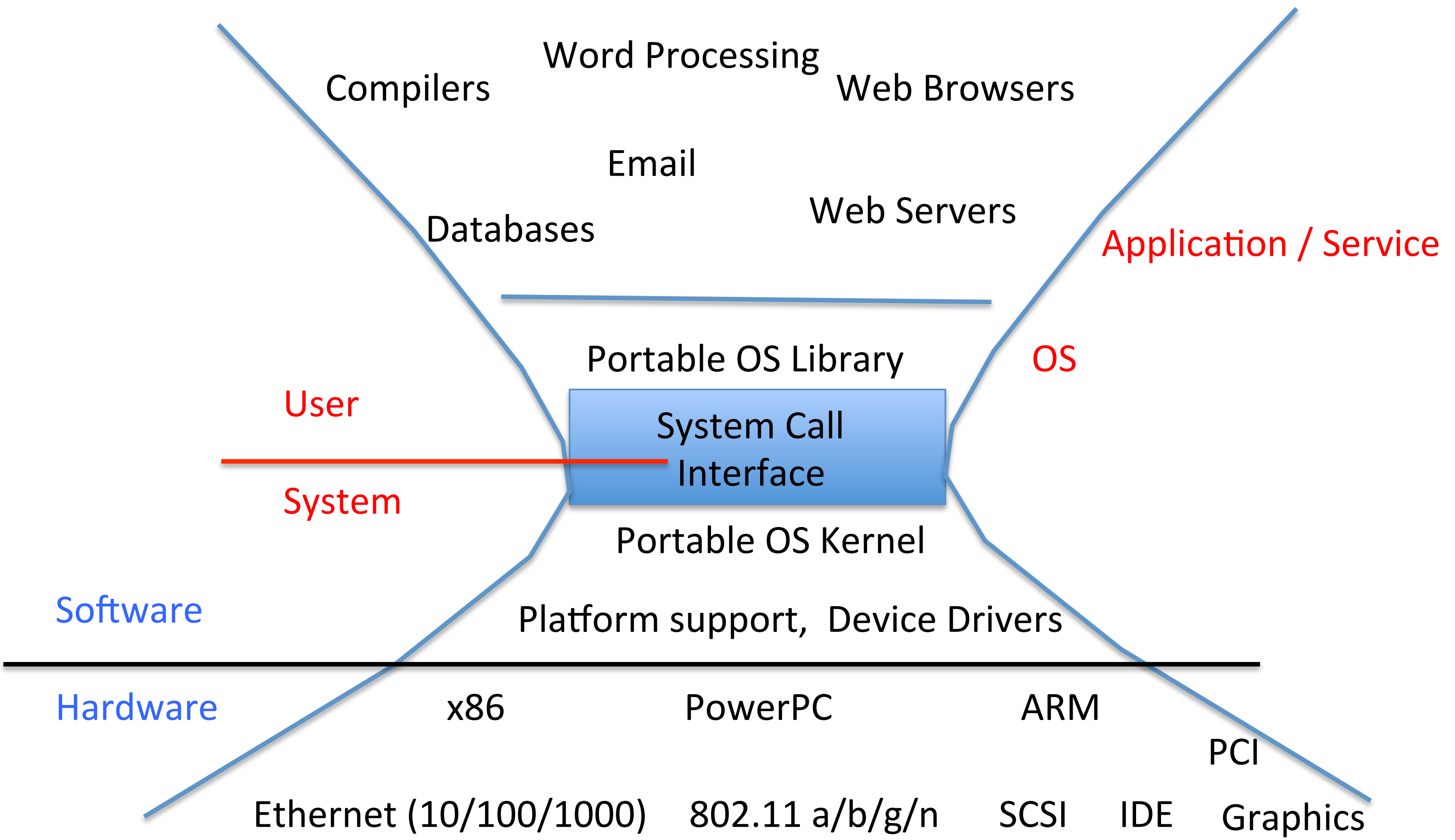
- You said that applications request services from the operating system via ***syscall***, but …
- I've been writing all sort of useful applications and I never ever saw a "syscall" !!!

- That's right.
- It was buried in the programming language runtime library (e.g., libc.a)
- … Layering

OS run-time library



A Kind of Narrow Waist

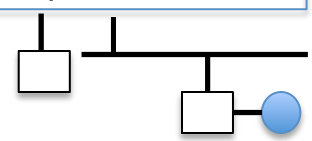


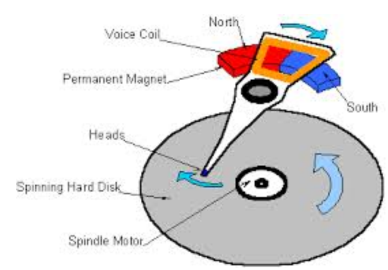
Key Unix I/O Design Concepts

- Uniformity
  - file operations, device I/O, and interprocess communication through open, read/write, close
  - Allows simple composition of programs
    - find | grep | wc …
- Open before use
  - Provides opportunity for access control and arbitration
  - Sets up the underlying machinery, i.e., data structures
- Byte-oriented
  - Even if blocks are transferred, addressing is in bytes
- Kernel buffered reads
  - Streaming and block devices looks the same, read blocks yielding processor to other task
- Kernel buffered writes
  - Completion of out-going transfer decoupled from the application, allowing it to continue
- Explicit close

I/O & Storage Layers

Application / Service

Layer	
High Level I/O	*streams*
Low Level I/O	*handles*
Syscall	*registers*
File System	*descriptors*
I/O Driver	*Commands and Data Transfers*
	*Disks, Flash, Controllers, DMA*

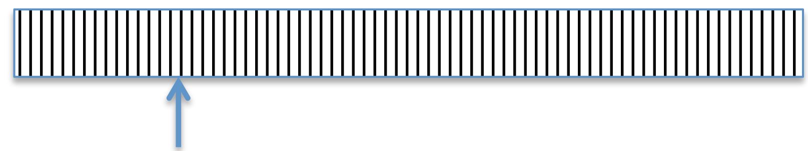


The file system abstraction

- File
  - Named collection of data in a file system
  - File data
    - Text, binary, linearized objects
  - File Metadata: information about the file
    - Size, Modification Time, Owner, Security info
    - Basis for access control
- Directory
  - "Folder" containing files & Directories
  - Hierachical (graphical) naming
    - Path through the directory graph
    - Uniquely identifies a file or directory
      - /home/ff/cs162/public_html/fa14/index.html
  - Links and Volumes (later)

C high level File API – streams (review)

- Operate on "streams" - sequence of bytes, whether text or data, with a position



```
#include <stdio.h>
FILE *fopen( const char *filename, const char *mode );
int fclose( FILE *fp );
```

Mode Text	Binary	Descriptions
r	rb	Open existing file for reading
w	wb	Open for writing; created if does not exist
a	ab	Open for appending; created if does not exist
r+	rb+	Open existing file for reading & writing.
w+	wb+	Open for reading & writing; truncated to zero if exists, create otherwise
a+	ab+	Open for reading & writing. Created if does not exist. Read from beginning, write as append

Don't forget to flush

Connecting Processes, Filesystem, and Users

- Process has a 'current working directory'
- Absolute Paths
  - /home/ff/cs152
- Relative paths
  - index.html, ./index.html - current WD
  - ../index.html - parent of current WD
  - ~, ~cs152 - home directory

C API Standard Streams

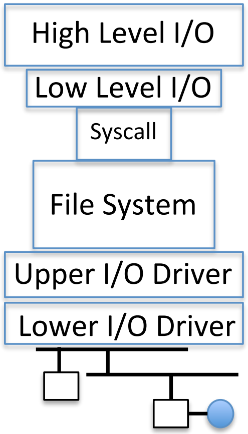
- Three predefined streams are opened implicitly when the program is executed.
  - `FILE *stdin` – normal source of input, can be redirected
  - `FILE *stdout` – normal source of output, can too
  - `FILE *stderr` – diagnostics and errors
- STDIN / STDOUT enable composition in Unix

C high level File API – stream ops

```
#include <stdio.h>
// character oriented
int fputc( int c, FILE *fp );              // rtn c or EOF on err
int fputs( const char *s, FILE *fp );    // rtn >0 or EOF

int fgetc( FILE * fp );
char *fgets( char *buf, int n, FILE *fp );

// block oriented
size_t fread(void *ptr, size_t size_of_elements,
             size_t number_of_elements, FILE *a_file);

size_t fwrite(const void *ptr, size_t size_of_elements,
             size_t number_of_elements, FILE *a_file);

// formatted
int fprintf(FILE *restrict stream, const char *restrict
format, ...);
int fscanf(FILE *restrict stream, const char *restrict
format, ... );
```

C Stream API positioning

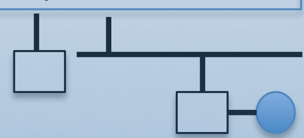
```
int fseek(FILE *stream, long int offset, int whence);
long int ftell (FILE *stream)
void rewind (FILE *stream)
```

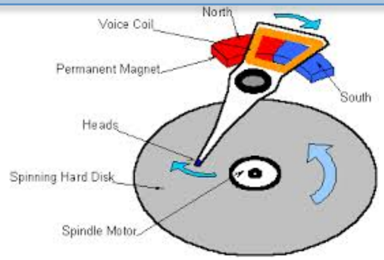


- Preserves high level abstraction of a uniform stream of objects

What's below the surface ??

Application / Service

High Level I/O	*streams*
Low Level I/O	*handles*
Syscall	*registers*
File System	*descriptors*
I/O Driver	*Commands and Data Transfers*
	*Disks, Flash, Controllers, DMA*



C Low level I/O

- Operations on File Descriptors – as OS object representing the state of a file
  – User has a “handle” on the descriptor

```
#include <fcntl.h>
#include <unistd.h>
#include <sys/types.h>

int open (const char *filename, int flags [, mode_t mode])
int creat (const char *filename, mode_t mode)
int close (int filedes)
```

Bit vector of:

- Access modes (Rd, Wr, …)
- Open Flags (Create, …)
- Operating modes (Appends, …)

Bit vector of Permission Bits:

- User|Group|Other X R|W|X

http://www.gnu.org/software/libc/manual/html_node/Opening-and-Closing-Files.html

C Low Level: standard descriptors

```
#include <unistd.h>

STDIN_FILENO -  macro has value 0
STDOUT_FILENO - macro has value 1
STDERR_FILENO - macro has value 2

int fileno (FILE *stream)

FILE * fdopen (int filedes, const char *opentype)
```

- Crossing levels: File descriptors vs. streams
- Don’t mix them!

C Low Level Operations

```
ssize_t read (int filedes, void *buffer, size_t maxsize)
 - returns bytes read, 0 => EOF, -1 => error
ssize_t write (int filedes, const void *buffer, size_t size)
 - returns bytes written

off_t lseek (int filedes, off_t offset, int whence)

int fsync (int fildes) – wait for i/o to finish
void sync (void) – wait for ALL to finish
```

- When write returns, data is on its way to disk and can be read, but it may not actually be permanent!

And lots more !

- TTYs versus files
- Memory mapped files
- File Locking
- Asynchronous I/O
- Generic I/O Control Operations
- Duplicating descriptors

```
int dup2 (int old, int new)
int dup (int old)
```

What’s below the surface ??

Application / Service

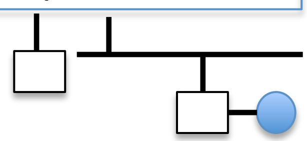
High Level I/O — *streams*

Low Level I/O — *handles*

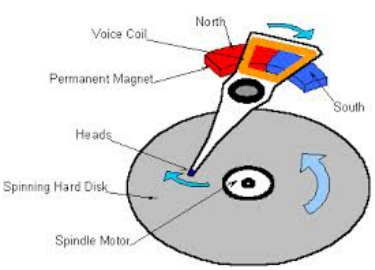
Syscall — *registers*

File System — *descriptors*

I/O Driver — *Commands and Data Transfers*



Disks, Flash, Controllers, DMA



SYSCALL

syscalls.kernelgrok.com

BCal | UCB | CS162 | cullermayeno | Wikipedia | Yahoo! | News | Popular | Imported From Safari

Linux Syscall Reference

Show 10 entries | Search:

#	Name	Registers						Definition
		eax	ebx	ecx	edx	esi	edi	
0	**sys_restart_syscall**	0x00	-	-	-	-	-	**kernel/signal.c:2058**
1	**sys_exit**	0x01	int error_code	-	-	-	-	**kernel/exit.c:1046**
2	**sys_fork**	0x02	**struct pt_regs ***	-	-	-	-	**arch/alpha/kernel/entry.S:716**
3	**sys_read**	0x03	unsigned int fd	char __user *buf	size_t count	-	-	**fs/read_write.c:391**
4	**sys_write**	0x04	unsigned int fd	const char __user *buf	size_t count	-	-	**fs/read_write.c:408**
5	**sys_open**	0x05	const char __user *filename	int flags	int mode	-	-	**fs/open.c:900**
6	**sys_close**	0x06	unsigned int fd	-	-	-	-	**fs/open.c:969**
7	**sys_waitpid**	0x07	pid_t pid	int __user *stat_addr	int options	-	-	**kernel/exit.c:1771**
8	**sys_creat**	0x08	const char __user *pathname	int mode	-	-	-	**fs/open.c:933**
9	**sys_link**	0x09	const char __user *oldname	const char __user *newname	-	-	-	**fs/namei.c:2520**

Showing 1 to 10 of 338 entries — First Previous 1 2 3 4 5 Next Last

Generated from Linux kernel 2.6.35.4 using Exuberant Ctags, Python, and DataTables. Project on GitHub. Hosted on GitHub Pages.

- Low level lib parameters are set up in registers and syscall instruction is issued

Internal OS File Descriptor

- Internal Data Structure describing everything about the file
  - Where it resides
  - Its status
  - How to access it

lxr.free-electrons.com/source/include/linux/fs.h#L747

```
struct file {
        union {
                struct llist_node       fu_llist;
                struct rcu_head         fu_rcuhead;
        } f_u;
        struct path             f_path;
#define f_dentry        f_path.dentry
        struct inode            *f_inode;       /* cac
        const struct file_operations    *f_op;

        /*
         * Protects f_ep_links, f_flags.
         * Must not be taken from IRQ context.
         */
        spinlock_t              f_lock;
        atomic_long_t           f_count;
        unsigned int            f_flags;
        fmode_t                 f_mode;
        struct mutex            f_pos_lock;
        loff_t                  f_pos;
        struct fown_struct      f_owner;
        const struct cred       *f_cred;
        struct file_ra_state    f_ra;

        u64                     f_version;
#ifdef CONFIG_SECURITY
        void                    *f_security;
#endif
        /* needed for tty driver, and maybe others */
        void                    *private_data;

#ifdef CONFIG_EPOLL
        /* Used by fs/eventpoll.c to link all the hook
        struct list_head        f_ep_links;
        struct list_head        f_tfile_llink;
#endif /* #ifdef CONFIG_EPOLL */
        struct address_space    *f_mapping;
} __attribute__((aligned(4)));  /* lest something weir
```

File System: from syscall to 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;
}
```

Low Level Driver

- Associated with particular hardware device
- Registers / Unregisters itself with the kernel
- Handler functions for each of the file operations

```
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 *);
    [...]
};
```

So what happens when you fgetc?

Application / Service

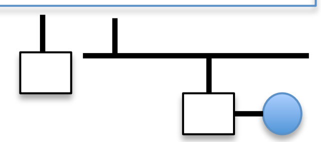
High Level I/O — *streams*

Low Level I/O — *handles*

Syscall — *registers*

File System — *descriptors*

I/O Driver — *Commands and Data Transfers*



Disks, Flash, Controllers, DMA