CS162
Operating Systems and Systems Programming
Lecture 3

Processes (con't), Fork, Introduction to I/O

August 29th, 2018

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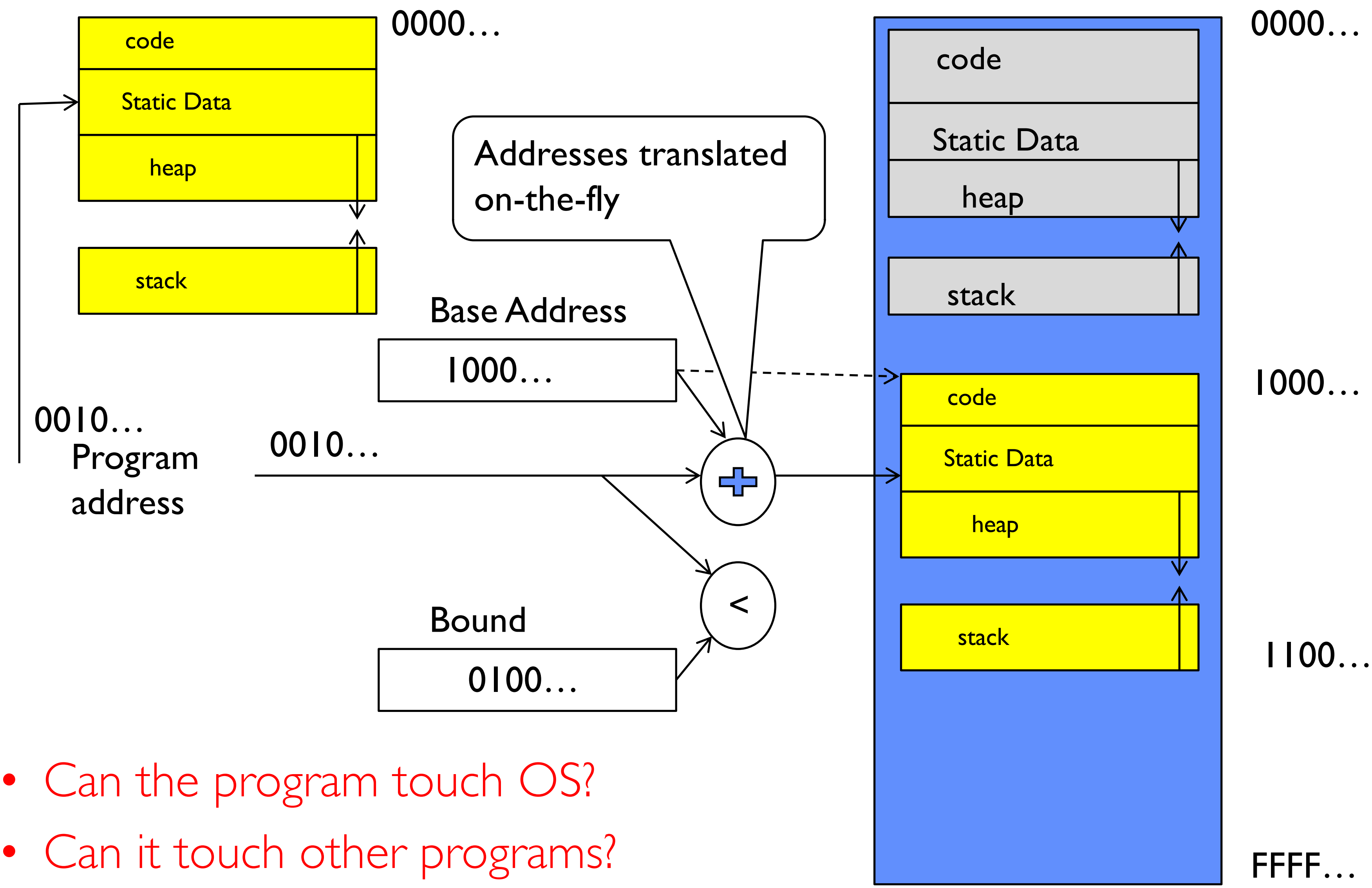
Recall: Four fundamental OS concepts

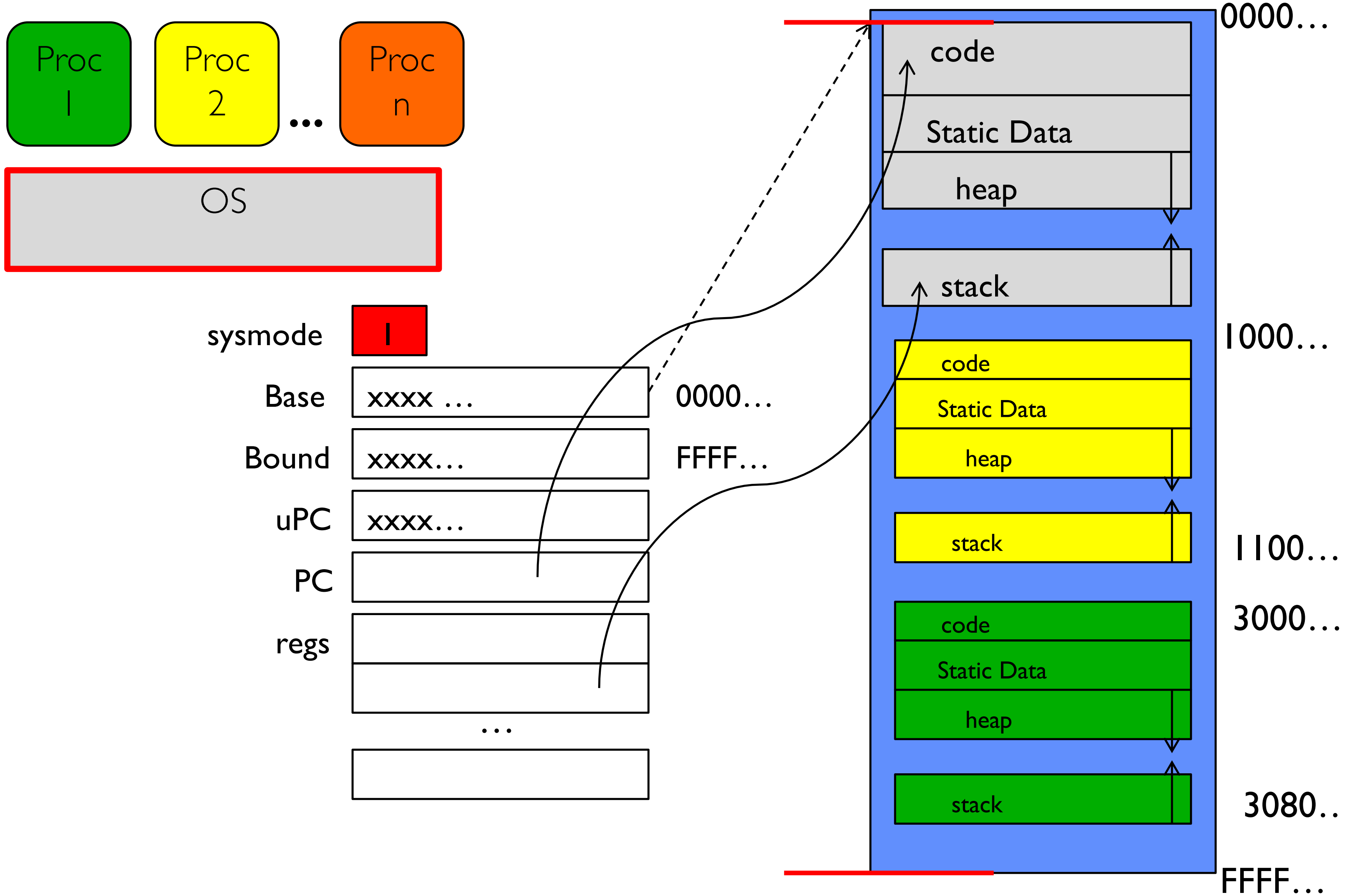
- **Thread**
  - Single unique execution context
  - Program Counter, Registers, Execution Flags, Stack
- **Address Space** w/ translation
  - Programs execute in an *address space* that is distinct from the memory space of the physical machine
- **Process**
  - An instance of an executing program is *a process consisting of an address space and one or more threads of control*
- **Dual Mode** operation/protection
  - Only the "system" has the ability to access certain resources
  - 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

Recall: A simple address translation w/ Base & Bound

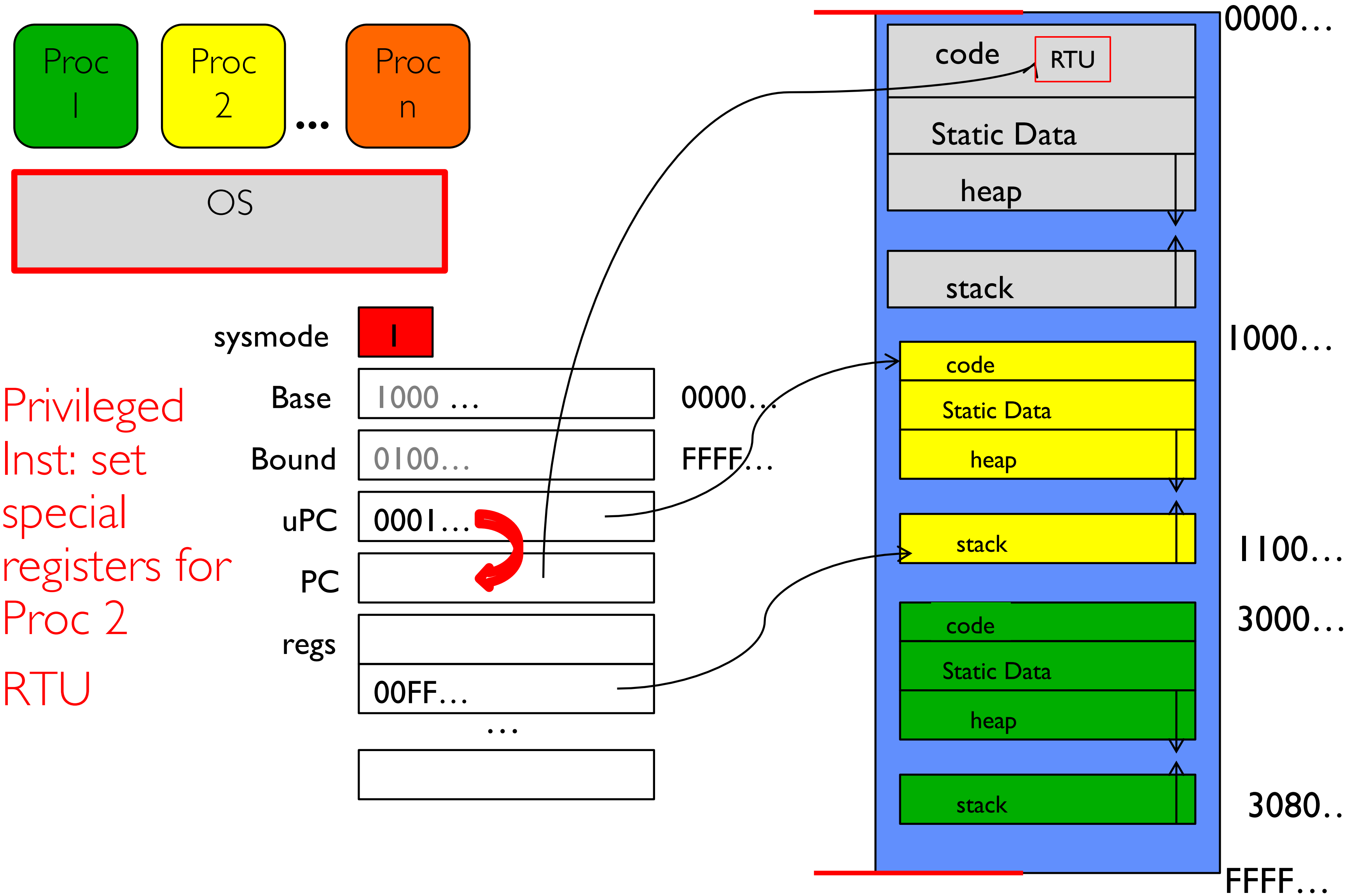


- Can the program touch OS?
- Can it touch other programs?

Tying it together: Simple B&B: OS loads process

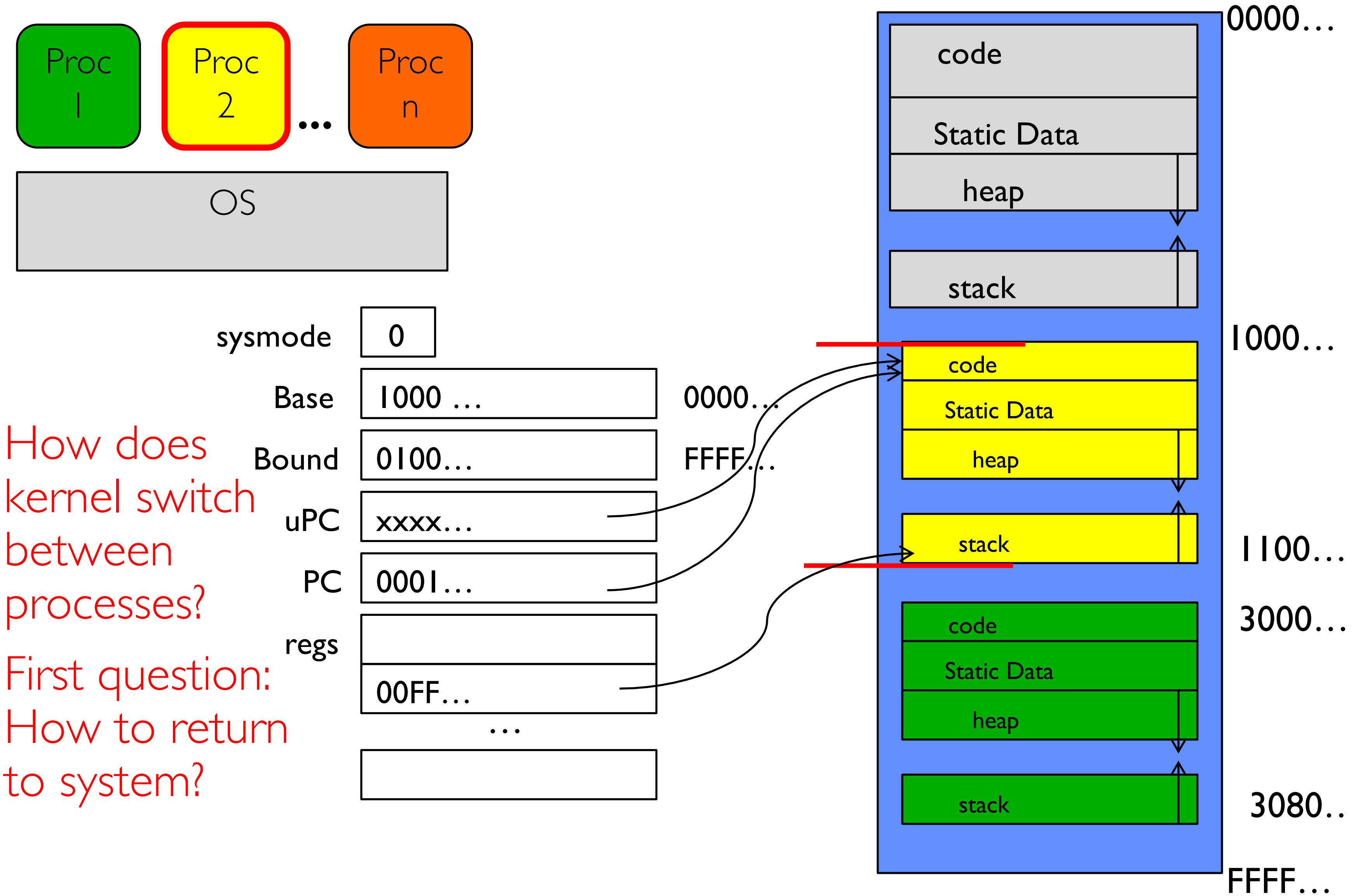


Simple B&B: OS gets ready to execute process



- Privileged Inst: set special registers for Proc 2
- RTU

Simple B&B: User Code Running



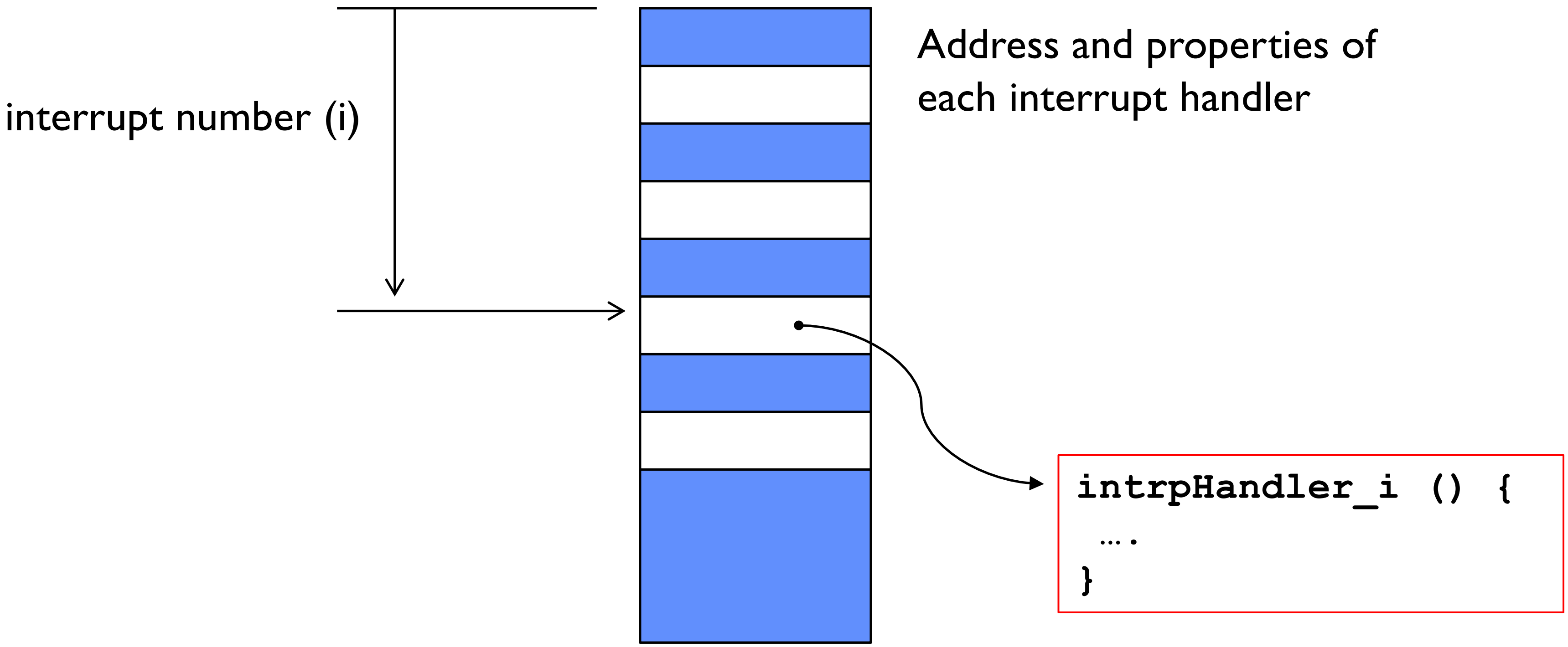
- How does kernel switch between processes?
- First question: How to return to system?

3 types of Mode Transfer

- Syscall
  – Process requests a system service, e.g., exit
  – Like a function call, but "outside" the process
  – Does not have the address of the system function to call
  – Marshall the syscall id and args in registers and exec syscall
- Interrupt
  – External asynchronous event triggers context switch
  – e. g., Timer, I/O device
  – Independent of user process
- Trap or Exception
  – Internal synchronous event in process triggers context switch
  – e.g., Protection violation (segmentation fault), Divide by zero, …
- All 3 are an UNPROGRAMMED CONTROL TRANSFER

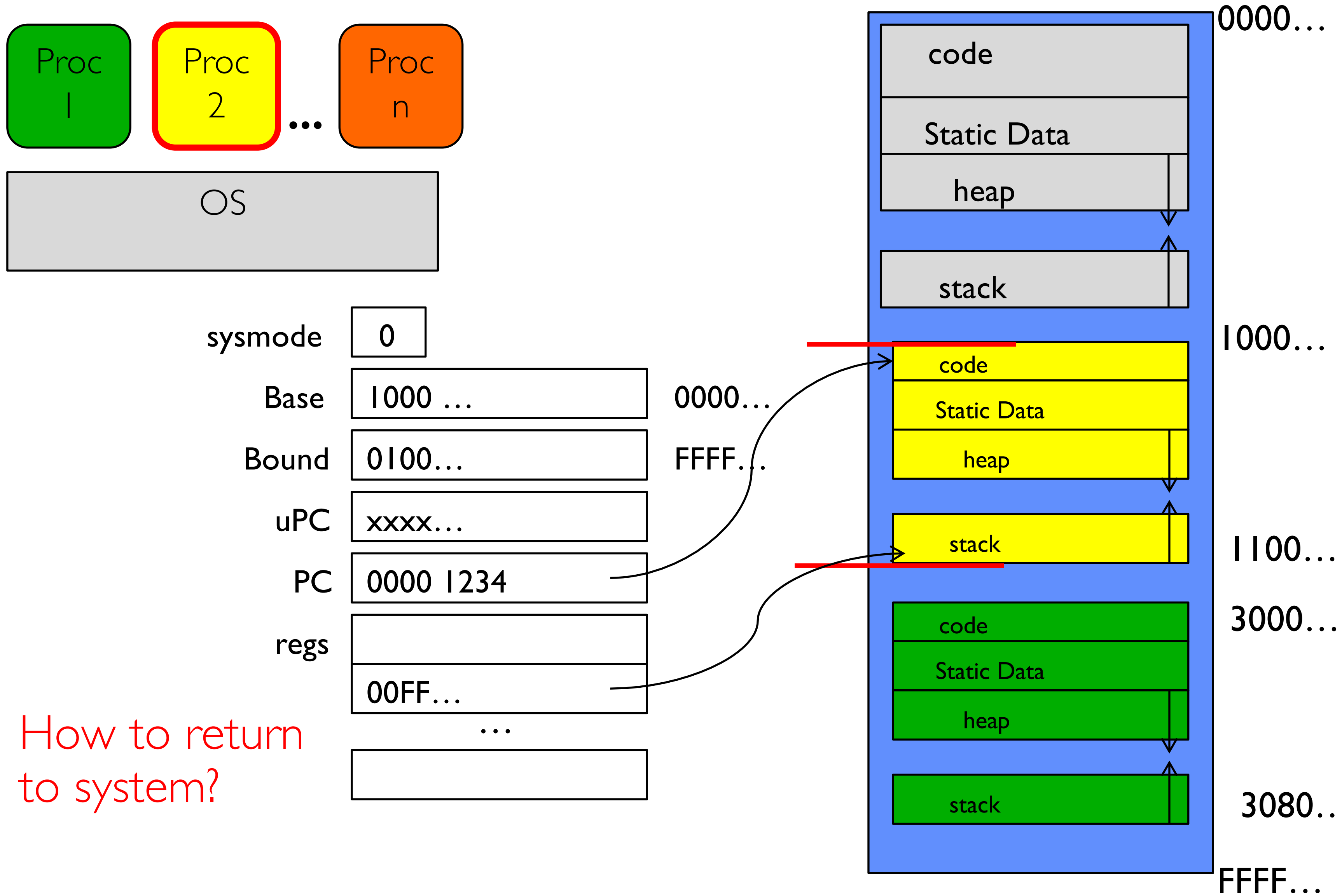
How do we get the system target address of the "unprogrammed control transfer?"

Example: Interrupt Vector



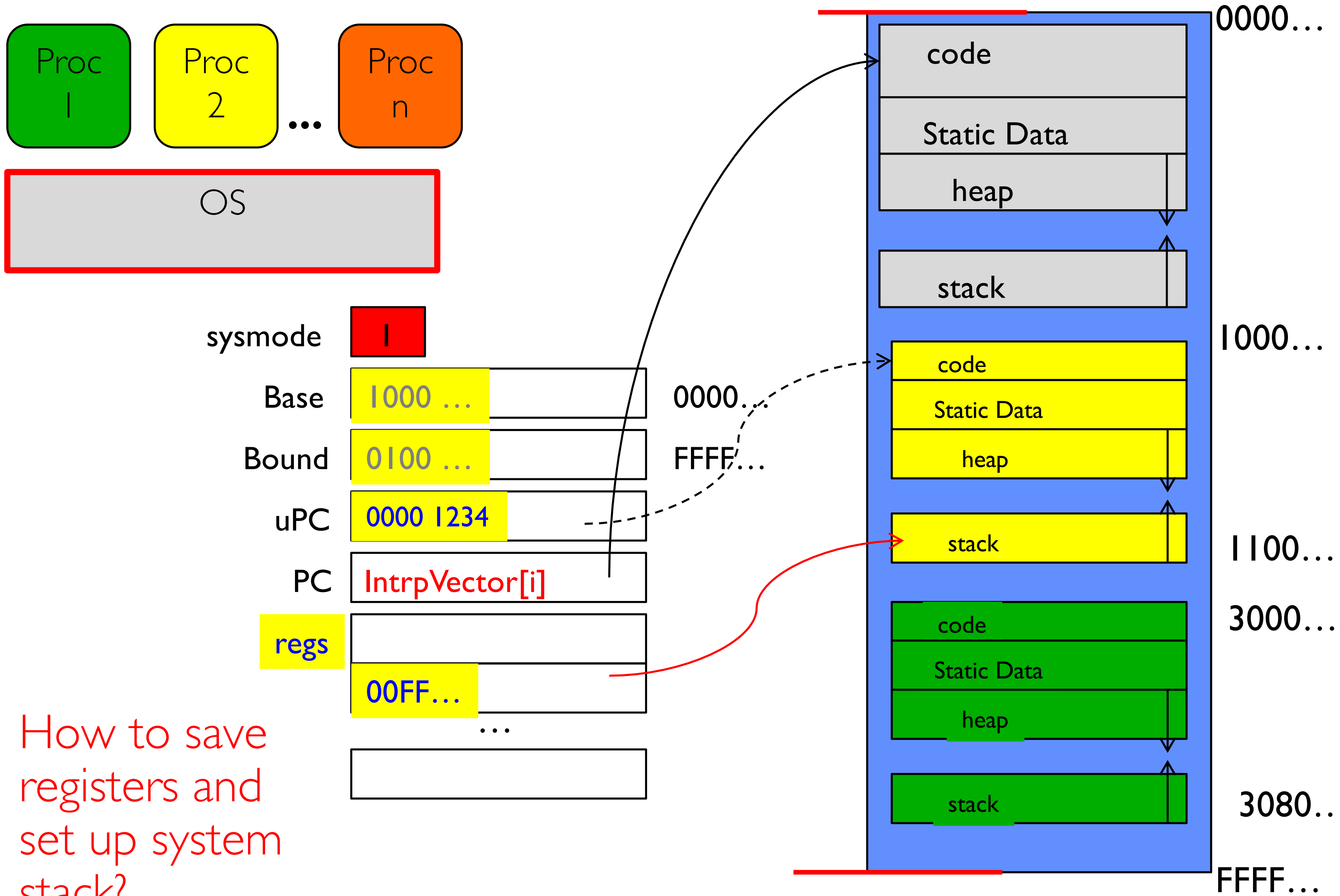
- Where else do you see this dispatch pattern?

Simple B&B: User => Kernel



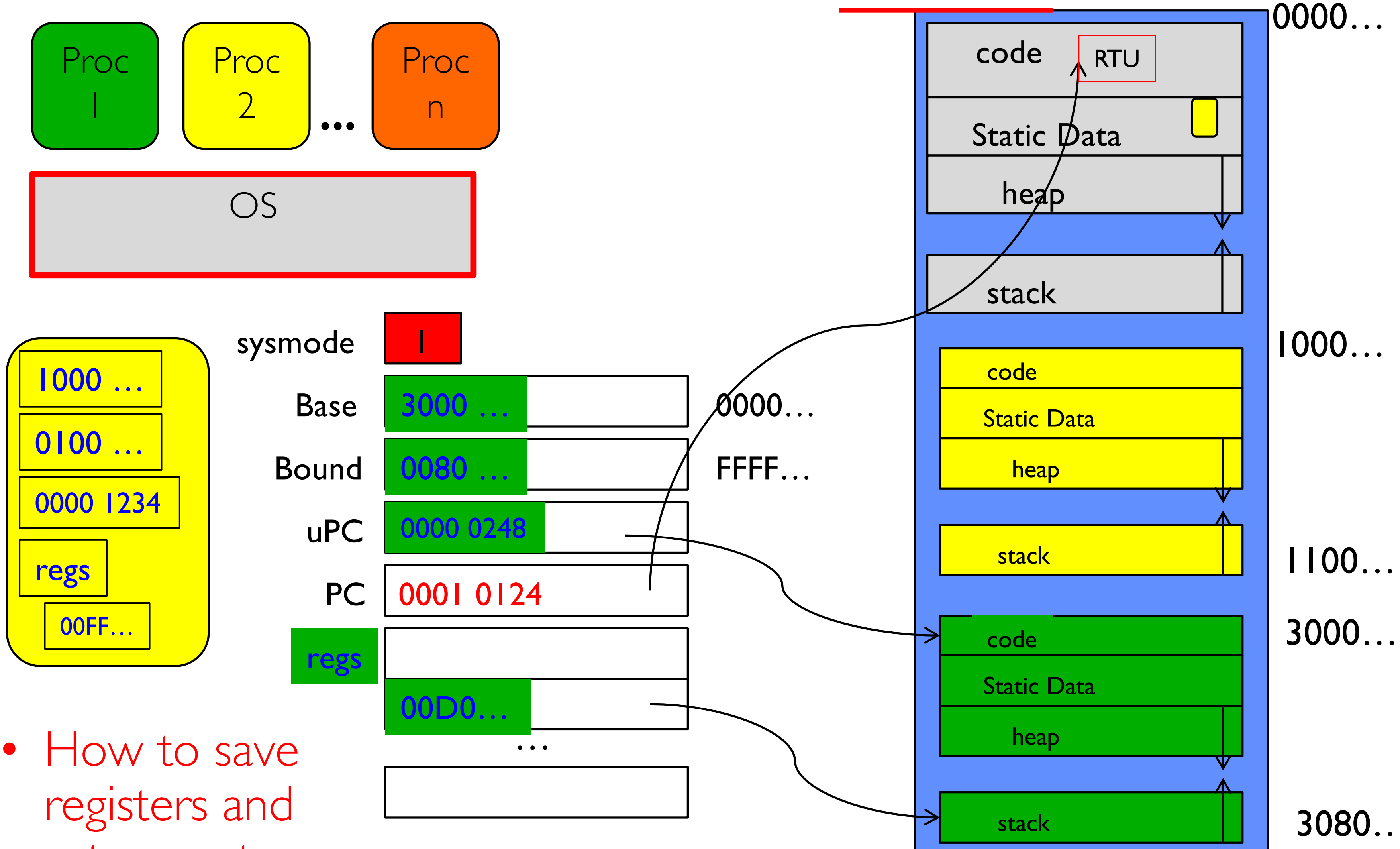
- How to return to system?

Simple B&B: Interrupt



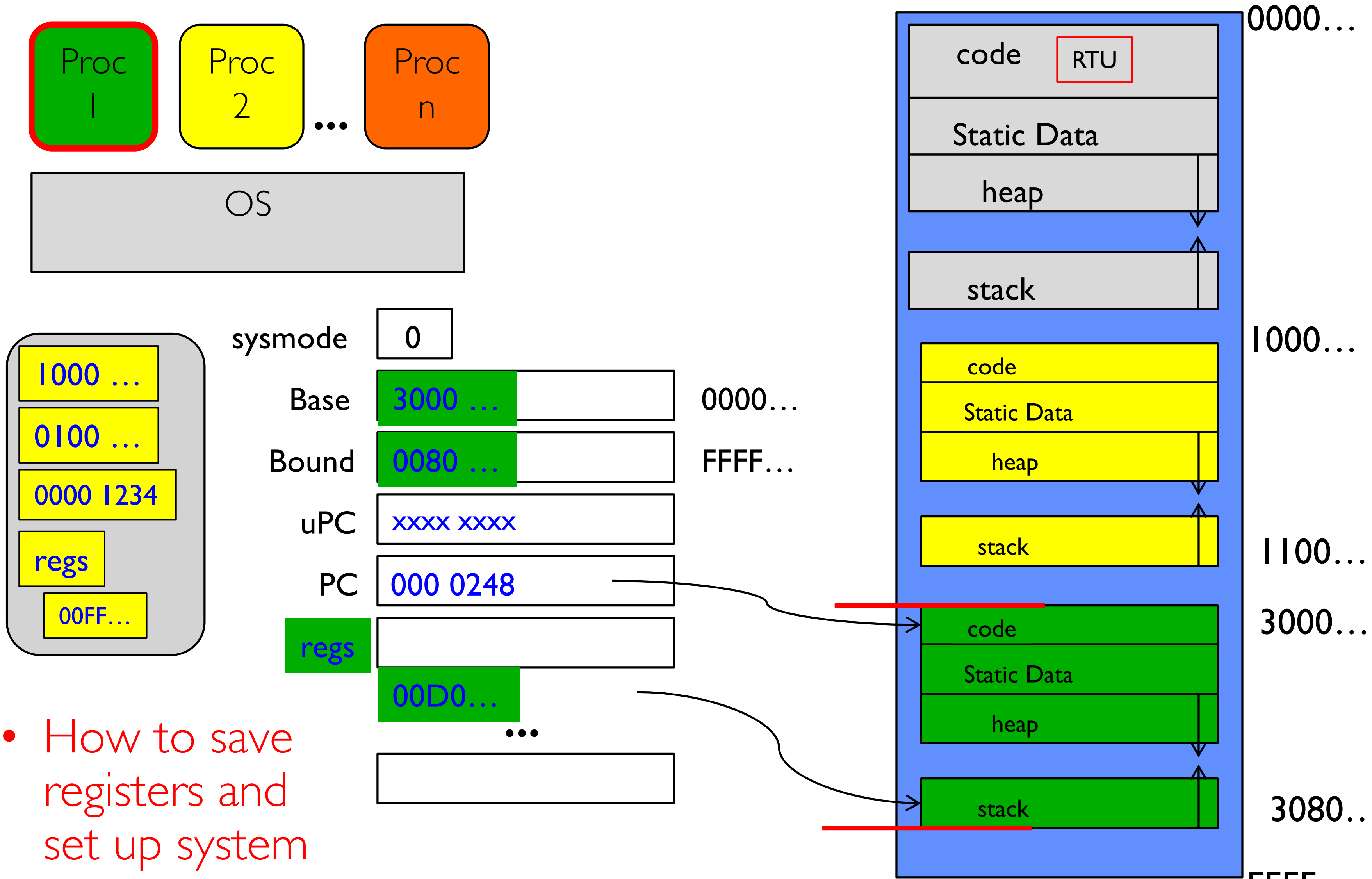
- How to save registers and set up system stack?

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?

Process Control Block

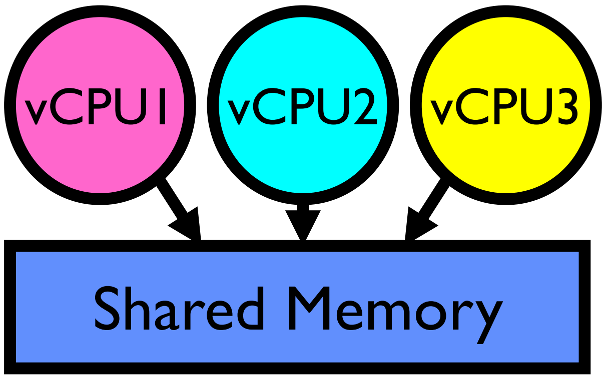
(Assume single threaded processes for now)

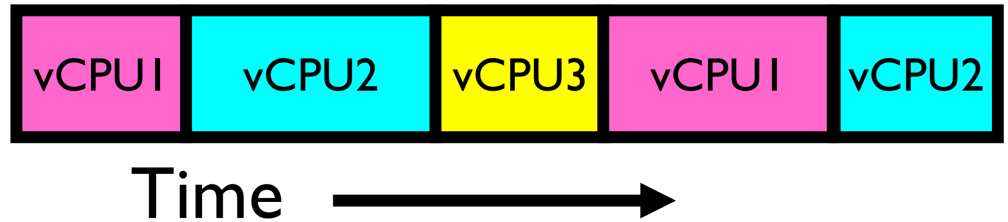
- Kernel represents each process as a process control block (PCB)
  – Status (running, ready, blocked, …)
  – Registers, SP, … (when not running)
  – Process ID (PID), User, Executable, Priority, …
  – Execution time, …
  – Memory space, translation tables, …

- Kernel Scheduler maintains a data structure containing the PCBs

- Scheduling algorithm selects the next one to run

Recall: give the illusion of multiple processors?

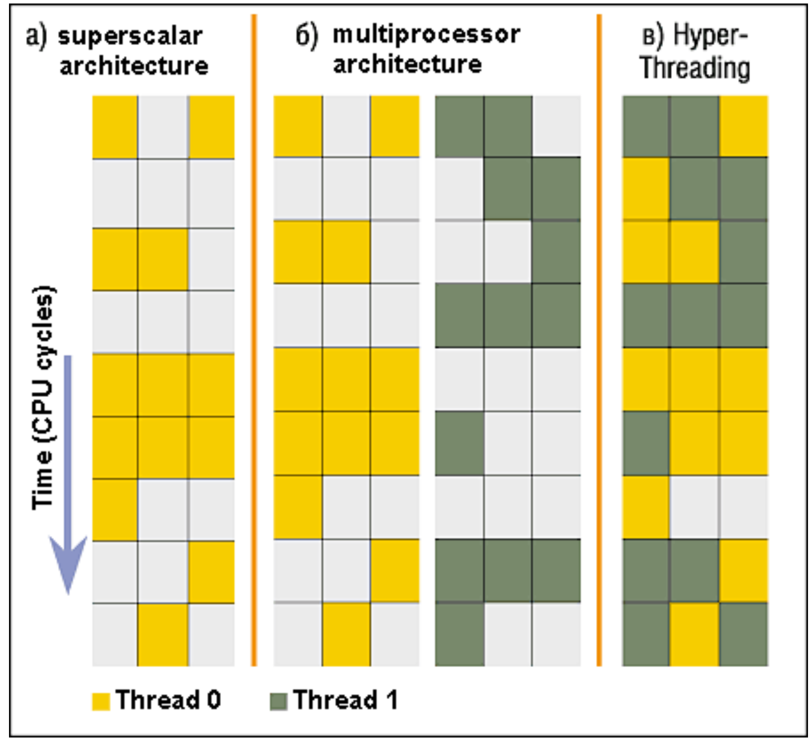




- Assume a single processor. How do we provide the *illusion* of multiple processors?
  – Multiplex in time!
  – Multiple "virtual CPUs"
- Each virtual "CPU" needs a structure to hold, i.e., PCB:
  – Program Counter (PC), Stack Pointer (SP)
  – Registers (Integer, Floating point, others…?)
- How switch from one virtual CPU to the next?
  – Save PC, SP, and registers in current PCB
  – Load PC, SP, and registers from new PCB
- What triggers switch?
  – Timer, voluntary yield, I/O, other things

Simultaneous MultiThreading/Hyperthreading

- Hardware technique
  – Superscalar processors can execute multiple instructions that are independent
  – Hyperthreading duplicates register state to make a second "thread," allowing more instructions to run
- Can schedule each thread as if were separate CPU
  – But, sub-linear speedup!



Colored blocks show instructions executed

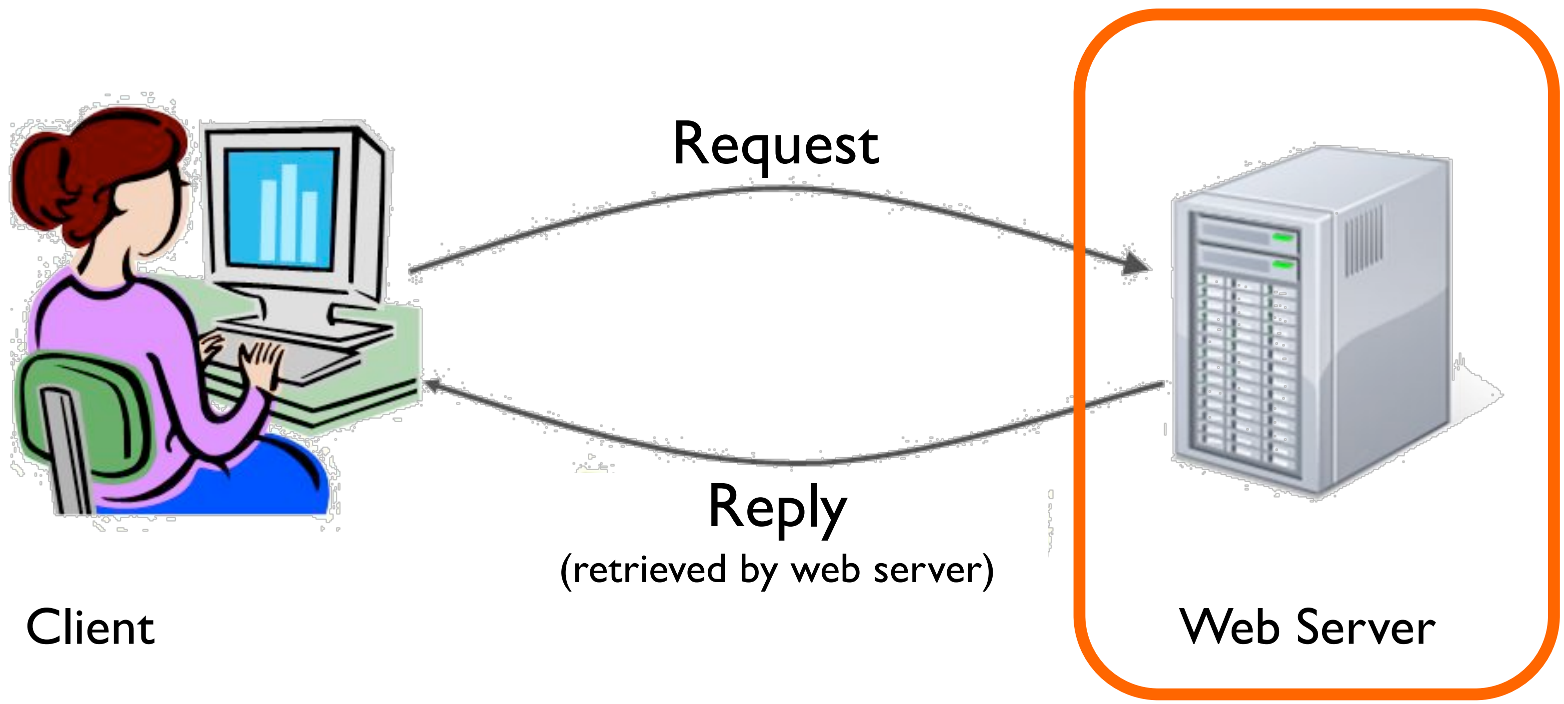
- Original technique called "Simultaneous Multithreading"
  – http://www.cs.washington.edu/research/smt/index.html
  – SPARC, Pentium 4/Xeon ("Hyperthreading"), Power 5

Scheduler

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

- Scheduling: Mechanism for deciding which processes/threads receive the CPU
- Lots of different scheduling policies provide …
  – Fairness or
  – Realtime guarantees or
  – Latency optimization or ..

Putting it together: web server



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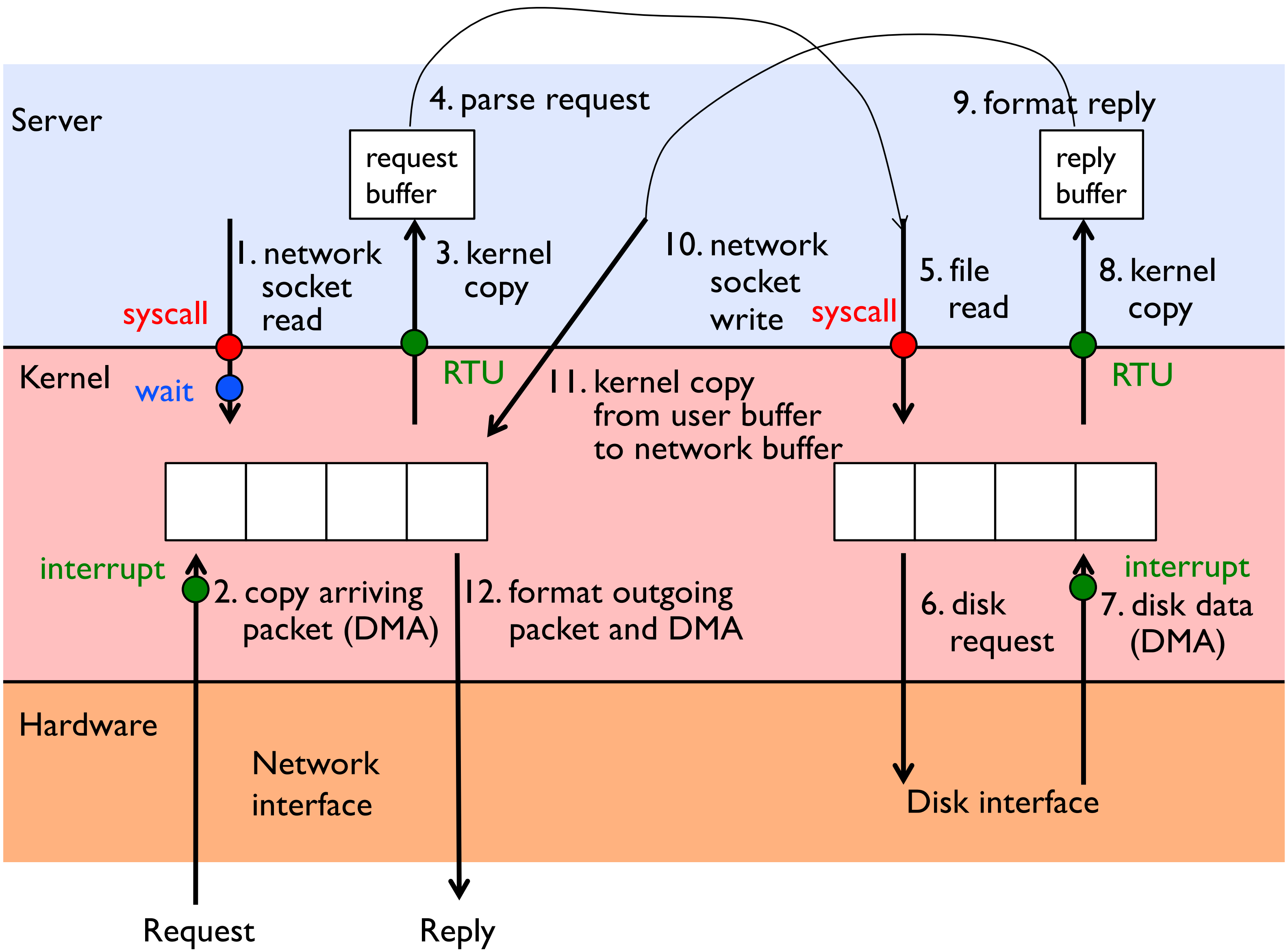
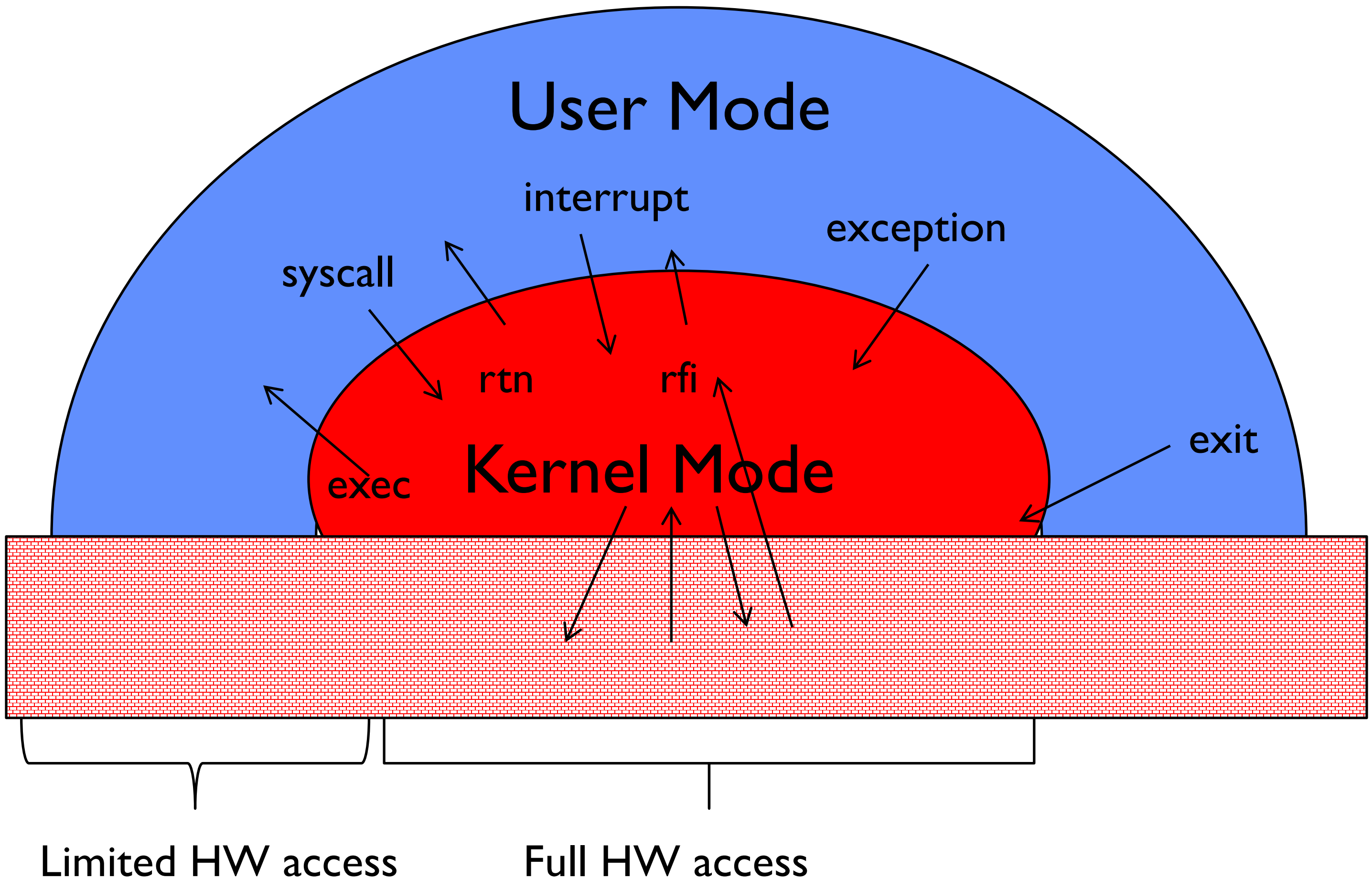


Recall: User/Kernel (Privileged) Mode



Implementing Safe Kernel Mode Transfers

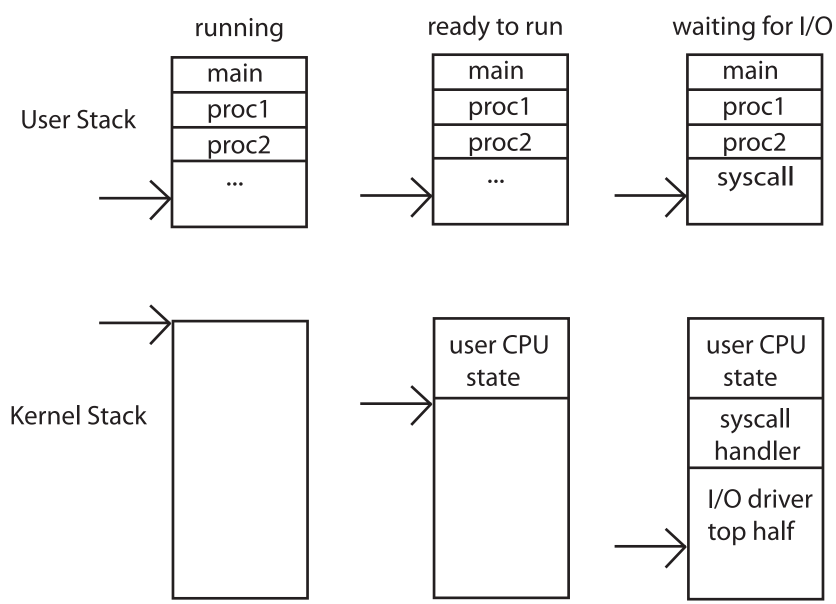
- Important aspects:
  - Controlled transfer into kernel (e.g., syscall table)
  - Separate kernel stack

- Carefully constructed kernel code packs up the user process state and sets it aside
  - Details depend on the machine architecture

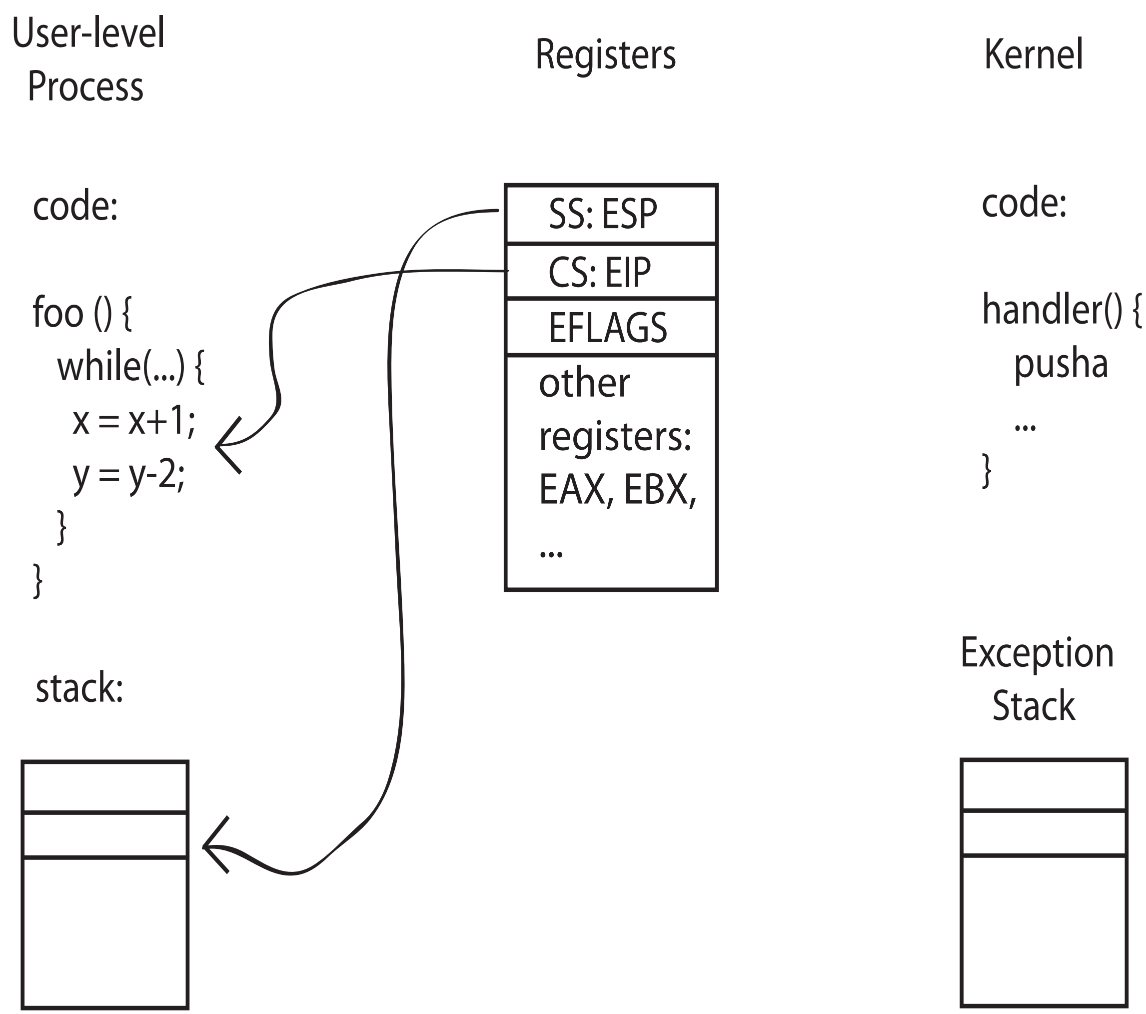
- Should be impossible for buggy or malicious user program to cause the kernel to corrupt itself

Need for Separate Kernel Stacks

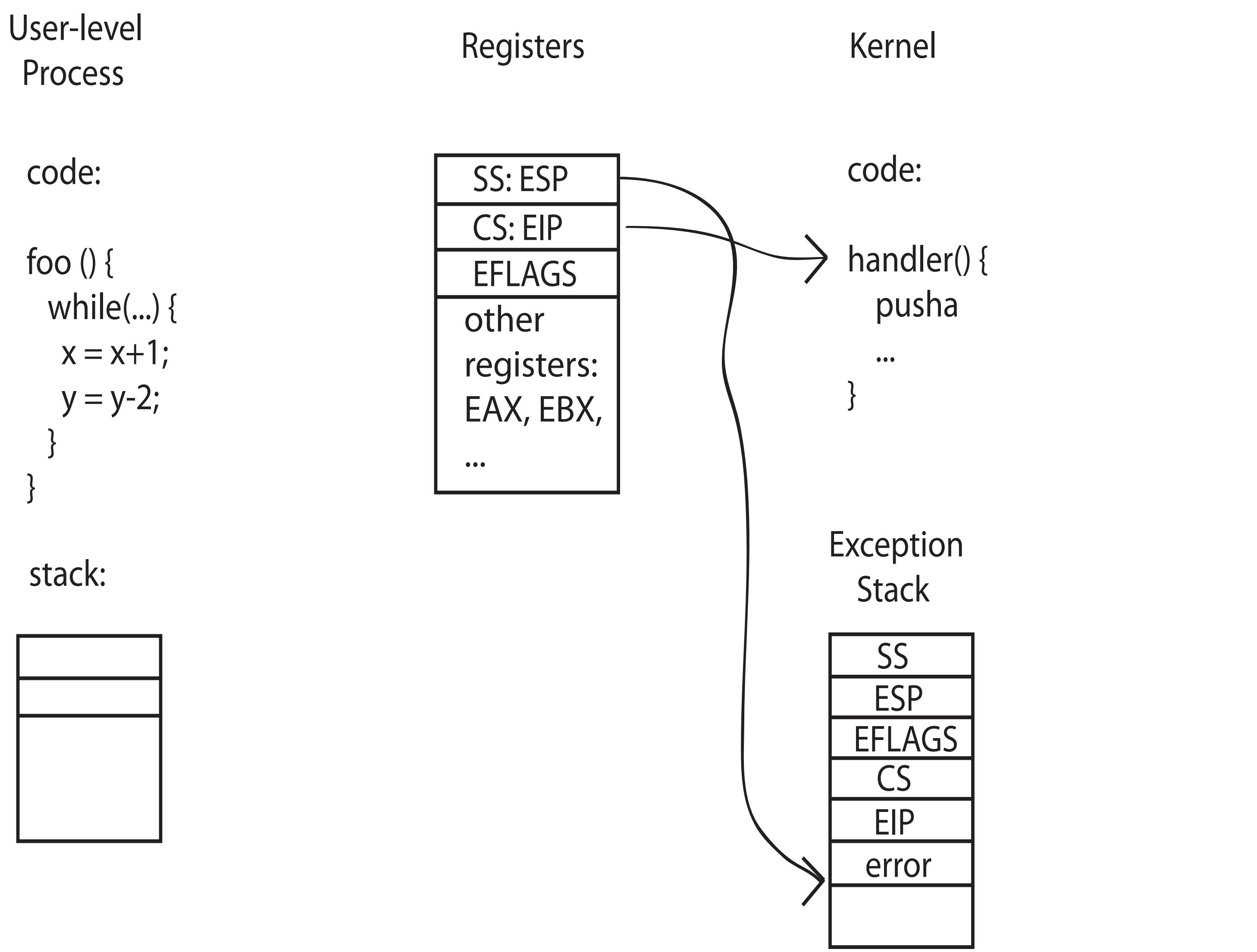
- Kernel needs space to work
- Cannot put anything on the user stack (Why?)
- Two-stack model
  – OS thread has interrupt stack (located in kernel memory) plus User stack (located in user memory)
  – Syscall handler copies user args to kernel space before invoking specific function (e.g., open)
  – Interrupts (???)



Before


User-level Process
code:
foo () {
while(...) {
x = x+1;
y = y-2;
}
}
stack:
Registers
SS: ESP
CS: EIP
EFLAGS
other registers: EAX, EBX, ...
Kernel
code:
handler() {
pusha
...
}
Exception Stack

During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Kernel
code:
handler() {
pusha
...
}
Exception Stack
SS
ESP
EFLAGS
CS
EIP
error

Kernel System Call Handler

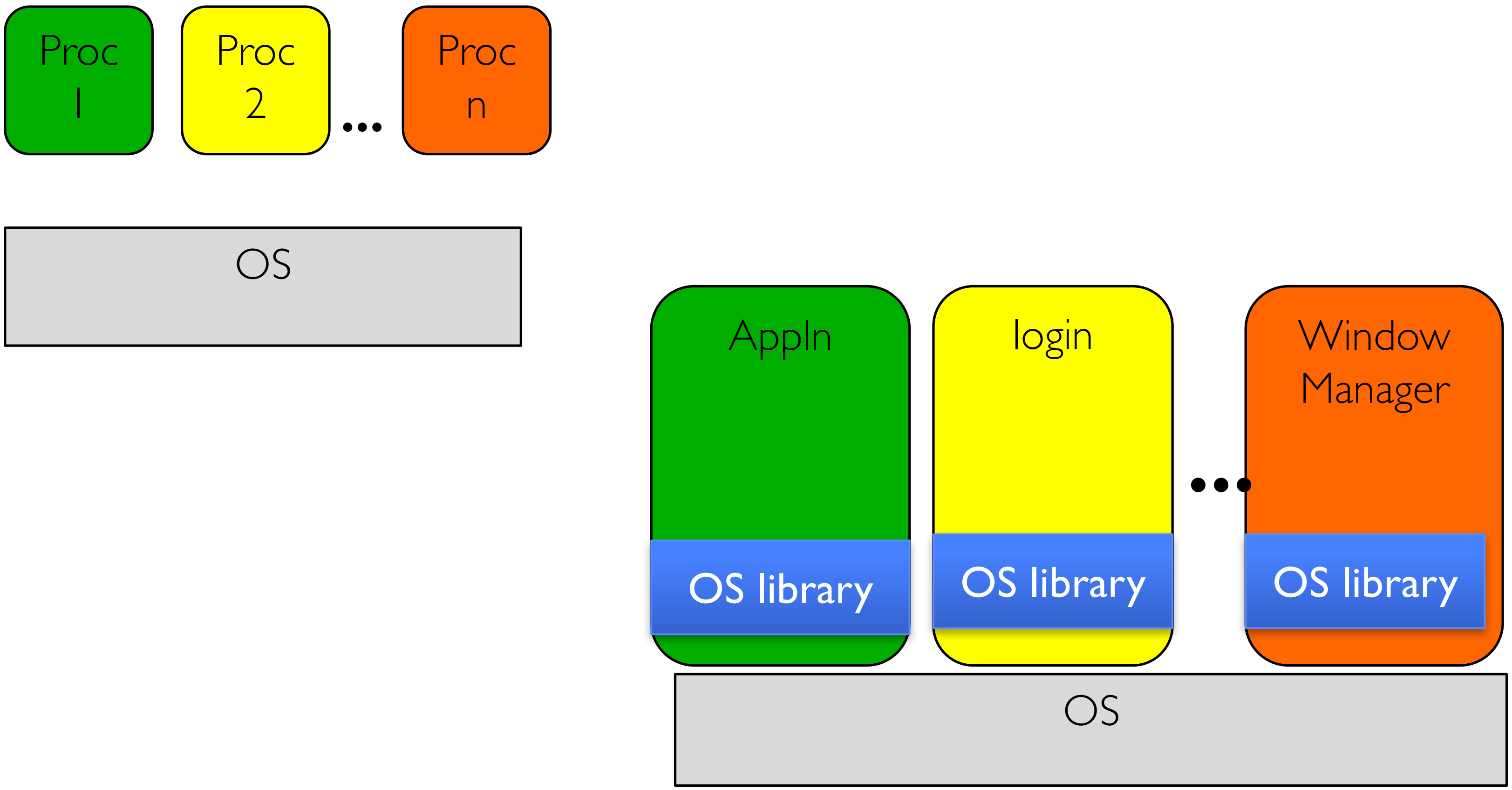
- Vector through well-defined syscall entry points!
  - Table mapping system call number to handler
- Locate arguments
  - In registers or on user (!) stack
- Copy arguments
  - From user memory into kernel memory
  - Protect kernel from malicious code evading checks
- Validate arguments
  - Protect kernel from errors in user code
- Copy results back
  - Into user memory

How Does the Kernel Provide Services?

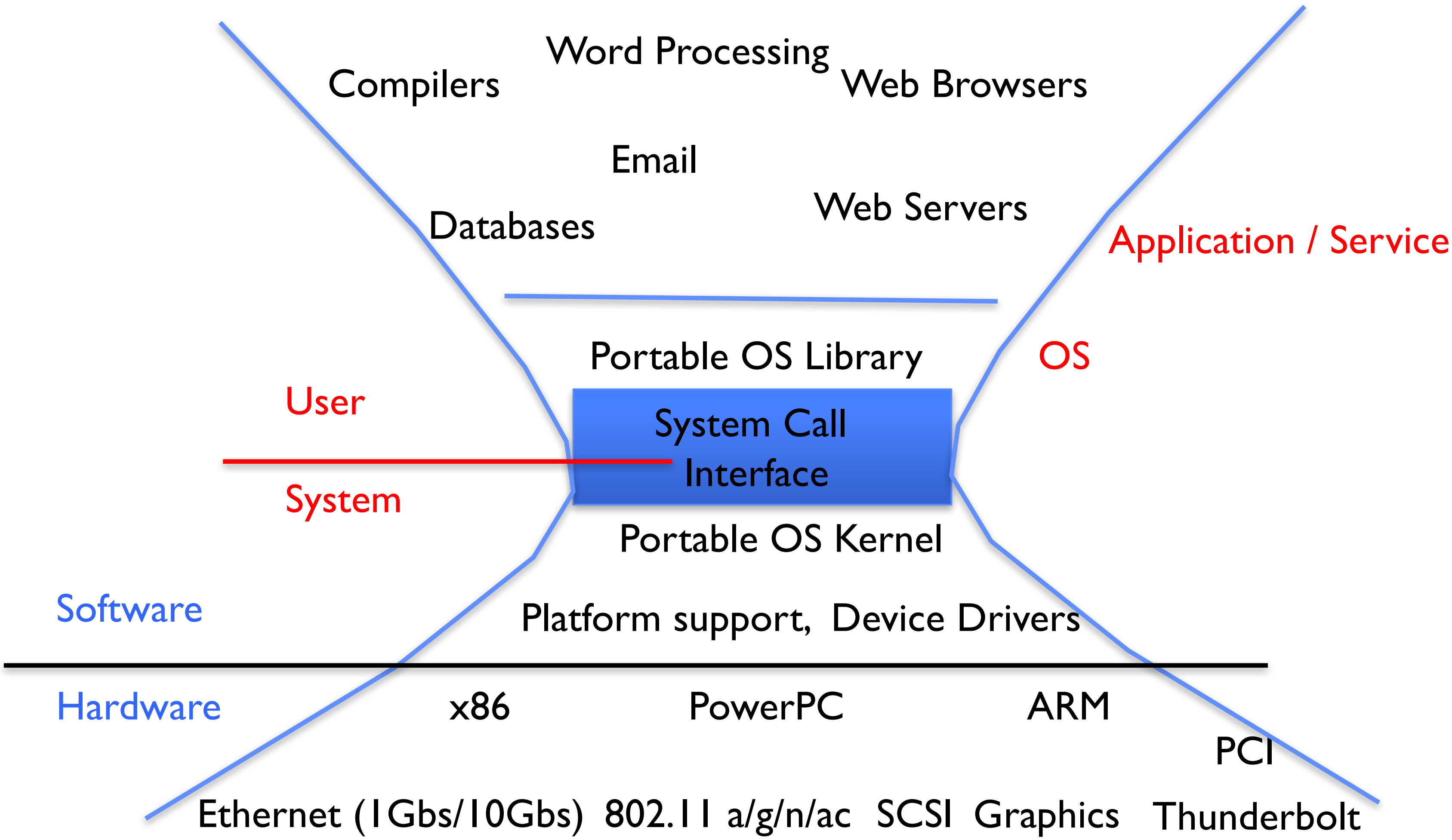
- You said that applications request services from the operating system via **syscall**, but …
- I've been writing all sort of useful applications and I never ever saw a "syscall" !!!

- 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



Administrivia: Getting started

- **THIS** Friday (8/31) is early drop day! Very hard to drop afterwards…

- Work on Homework 0 due on Tuesday!
  – Get familiar with all the cs162 tools
  – Submit to autograder via git

- Participation: Attend section! Get to know your TA!

- Group sign up via autograder then TA form next week
  – Get finding groups of 4 people ASAP
  – Priority for same section; if cannot make this work, keep same TA

5 min break

Hardware support: Interrupt Control

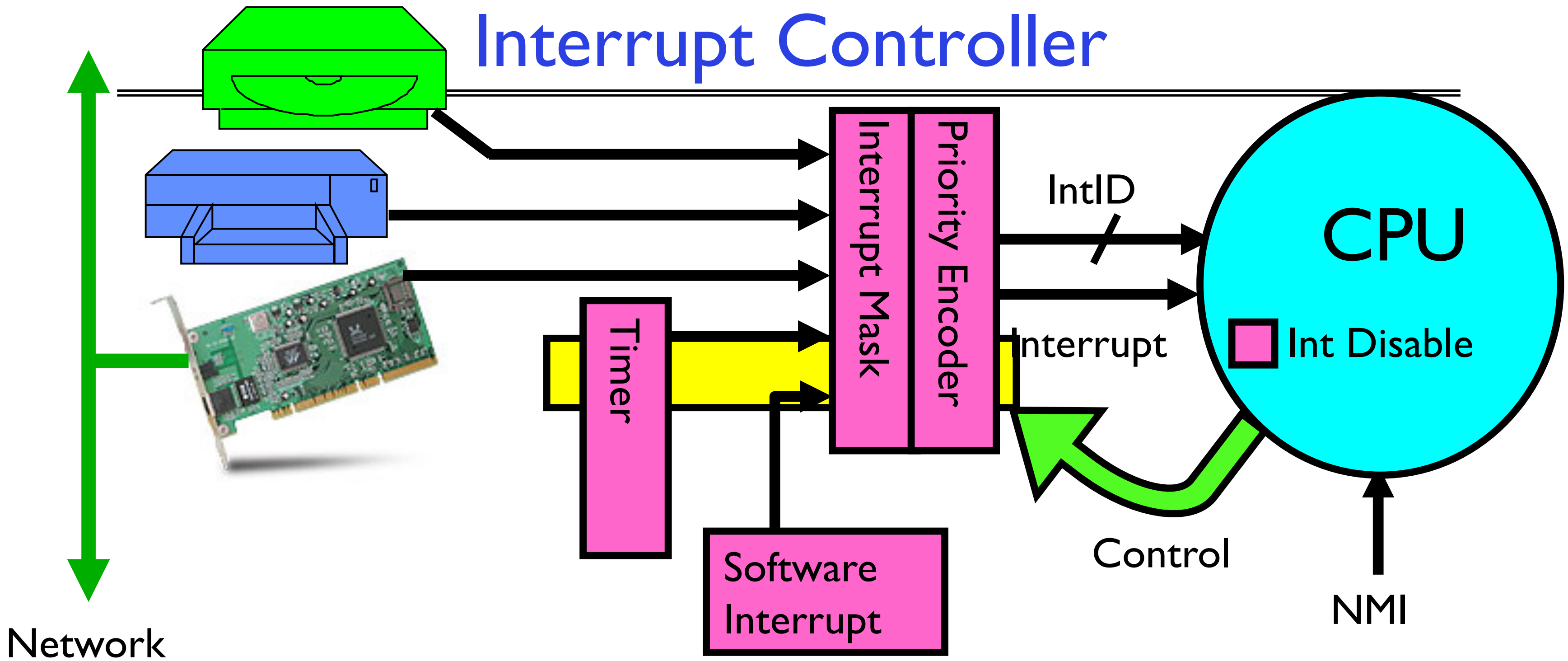
- Interrupt processing not visible to the user process:
  - Occurs between instructions, restarted transparently
  - No change to process state
  - What can be observed even with perfect interrupt processing?
- Interrupt Handler invoked with interrupts 'disabled'
  - Re-enabled upon completion
  - Non-blocking (run to completion, no waits)
  - Pack up in a queue and pass off to an OS thread for hard work
    - » wake up an existing OS thread

Hardware support: Interrupt Control

- OS kernel may enable/disable interrupts
  - On x86: CLI (disable interrupts), STI (enable)
  - Atomic section when select next process/thread to run
  - Atomic return from interrupt or syscall

- HW may have multiple levels of interrupts
  - Mask off (disable) certain interrupts, eg., lower priority
  - Certain Non-Maskable-Interrupts (NMI)
    - » e.g., kernel segmentation fault

Interrupt Controller



- Interrupts invoked with interrupt lines from devices
- Interrupt controller chooses interrupt request to honor
  - Interrupt identity specified with ID line
  - Mask enables/disables interrupts
  - Priority encoder picks highest enabled interrupt
  - Software Interrupt Set/Cleared by Software
- CPU can disable all interrupts with internal flag
- Non-Maskable Interrupt line (NMI) can't be disabled

How do we take interrupts safely?

- Interrupt vector
  – Limited number of entry points into kernel
- Kernel interrupt stack
  – Handler works regardless of state of user code
- Interrupt masking
  – Handler is non-blocking
- Atomic transfer of control
  – "Single instruction"-like to change:
    » Program counter
    » Stack pointer
    » Memory protection
    » Kernel/user mode
- Transparent restartable execution
  – User program does not know interrupt occurred

Can a process create a process ?

- Yes! Unique identity of process is the "process ID" (or PID)
- **fork()** system call creates a *copy* of current process with a new PID
- Return value from **fork()**: integer
  - When > 0:
    - » Running in (original) Parent process
    - » return value is pid of new child
  - When = 0:
    - » Running in new Child process
  - When < 0:
    - » Error! Must handle somehow
    - » Running in original process
- All state of original process duplicated in both Parent and Child!
  - Memory, File Descriptors (next topic), etc…

fork1.c

```
#include <stdlib.h>
#include <stdio.h>
#include <string.h>
#include <unistd.h>
#include <sys/types.h>

#define BUFSIZE 1024
int main(int argc, char *argv[])
{
  char buf[BUFSIZE];
  size_t readlen, writelen, slen;
  pid_t cpid, mypid;
  pid_t pid = getpid();         /* get current processes PID */
  printf("Parent pid: %d\n", pid);
  cpid = fork();
  if (cpid > 0) {                    /* Parent Process */
    mypid = getpid();
    printf("[%d] parent of [%d]\n", mypid, cpid);
  }  else if (cpid == 0) {          /* Child Process */
    mypid = getpid();
    printf("[%d] child\n", mypid);
  } else {
    perror("Fork failed");
    exit(1);
  }
  exit(0);
}
```

fork2.c

```
int status;
pid_t = tcpid;
…
cpid = fork();
if (cpid > 0) {                         /* Parent Process */
  mypid = getpid();
  printf("[%d] parent of [%d]\n", mypid, cpid);
  tcpid = wait(&status);
  printf("[%d] bye %d(%d)\n", mypid, tcpid, status);
}  else if (cpid == 0) {                /* Child Process */
  mypid = getpid();
  printf("[%d] child\n", mypid);
}
…
```

Process Races: fork3.c

```
int i;
cpid = fork();
if (cpid > 0) {
    mypid = getpid();
    printf("[%d] parent of [%d]\n", mypid, cpid);
    for (i=0; i<10; i++) {
      printf("[%d] parent: %d\n", mypid, i);
      // sleep(1);
    }
  }  else if (cpid == 0) {
    mypid = getpid();
    printf("[%d] child\n", mypid);
    for (i=0; i>-10; i--) {
      printf("[%d] child: %d\n", mypid, i);
      // sleep(1);
    }
  }
```

- Question: What does this program print?
- Does it change if you add in one of the sleep() statements?

UNIX Process Management

- UNIX `fork` – system call to create a copy of the current process, and start it running
  - No arguments!

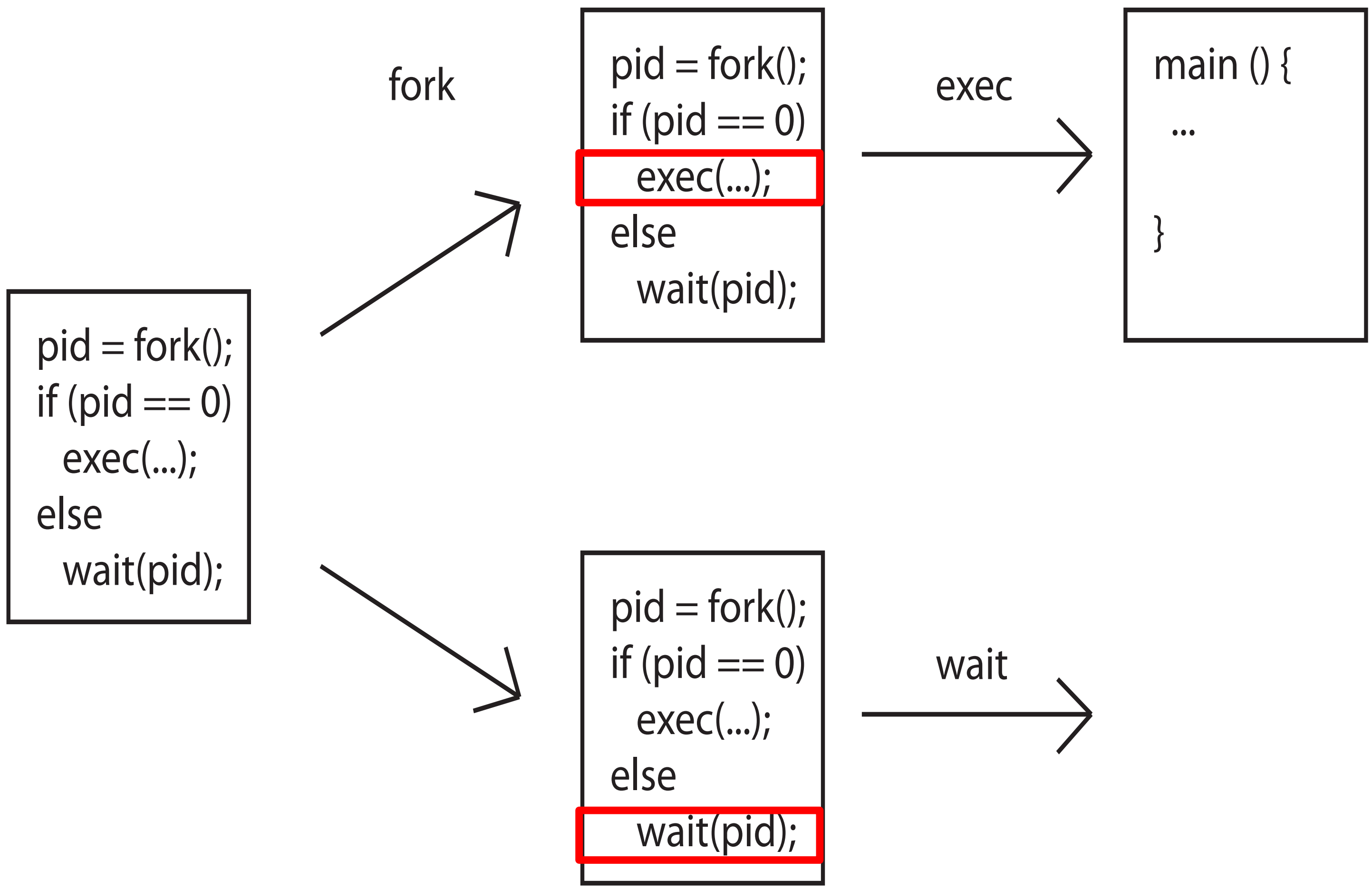
- UNIX `exec` – system call to *change the program* being run by the current process

- UNIX `wait` – system call to wait for a process to finish

- UNIX `signal` – system call to send a notification to another process

- UNIX man pages: `fork`(2), `exec`(3), `wait`(2), `signal`(3)

UNIX Process Management



Shell

- A shell is a job control system
  - Allows programmer to create and manage a set of programs to do some task
  - Windows, MacOS, Linux all have shells

- Example: to compile a C program

  cc –c sourcefile1.c

  cc –c sourcefile2.c

  ln –o program sourcefile1.o sourcefile2.o

  ./program

HW1

Signals – infloop.c

```
#include <stdlib.h>
#include <stdio.h>
#include <sys/types.h>

#include <unistd.h>
#include <signal.h>

void signal_callback_handler(int signum)
{
  printf("Caught signal %d - phew!\n",signum);
  exit(1);
}

int main() {
  signal(SIGINT, signal_callback_handler);

  while (1) {}
}
```

Got top?

Summary

- Process: execution environment with Restricted Rights
  - Address Space with One or More Threads
  - Owns memory (address space)
  - Owns file descriptors, file system context, …
  - Encapsulate one or more threads sharing process resources
- Interrupts
  - Hardware mechanism for regaining control from user
  - Notification that events have occurred
  - User-level equivalent: Signals
- Native control of Process
  - Fork, Exec, Wait, Signal