The Kernel Abstraction

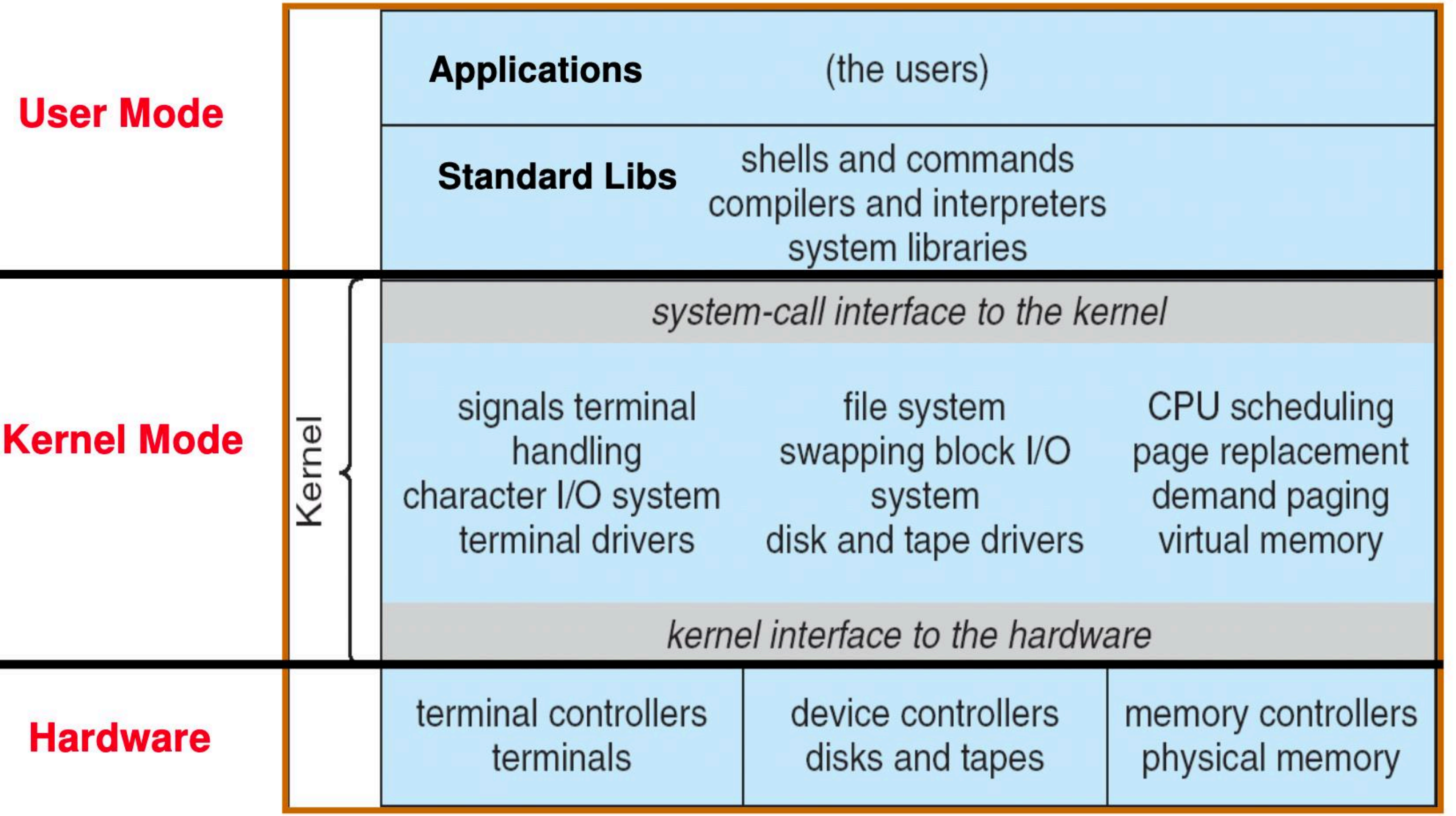
Slides adopted from CSE 451 class at UW, CS162 class at Berkeley and CSE 421/521 class at UB

What is an OS…

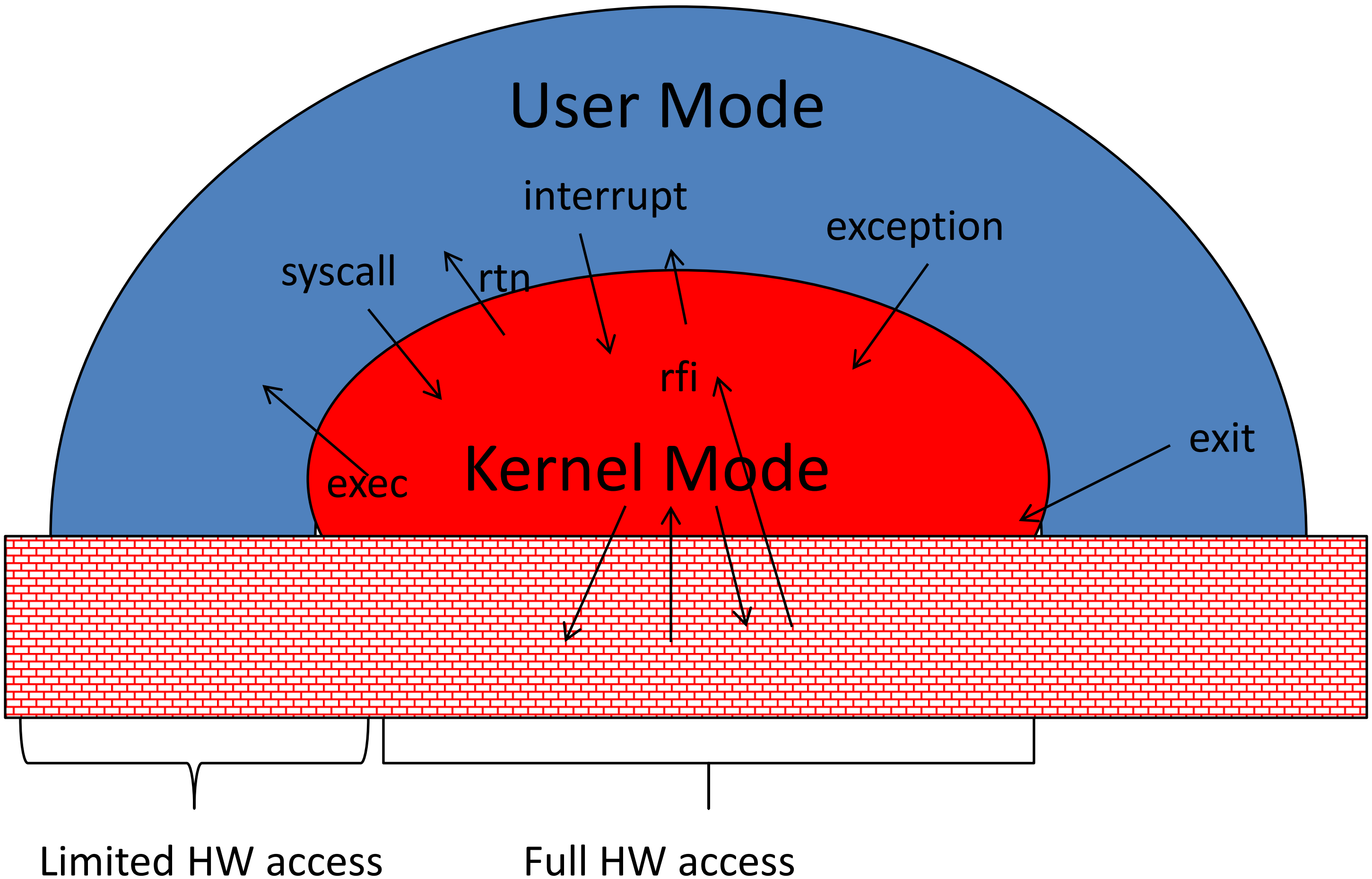
- Hiding Complexity

- **Kernel** is the part of the OS that running all the time on the computer

UNIX Structure



User/Kernel (Privileged) Mode



One of the major goals of OS is…

- Protecting **Process** and the **Kernel**
  - Running multiple programs
    - Keep them from interfering with the OS – kernel
    - Keep them from interfering with each other

Protection: WHY?

เวลา 10 นาที

Protection: How? (HW/SW)

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Hardware Support: Dual-Mode Operation

- Kernel mode
  - Execution with the full privileges of the hardware
  - Read/write to any memory, access any I/O device, read/write any disk sector, send/read any packet
- User mode
  - Limited privileges
  - Only those granted by the operating system kernel
- On the x86, mode stored in EFLAGS register
- On the MIPS, mode in the status register

โจทย์

- ในปัจจุบัน น.ศ. คิดว่า HW (CPU) supports การทำ Dual-mode Operation อย่างไรบ้าง

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Hardware Support: Dual-Mode Operation

- Privileged instructions
  - Available to kernel
  - Not available to user code
- Limits on memory accesses
  - To prevent user code from overwriting the kernel
- Timer
  - To regain control from a user program in a loop
- Safe way to switch from user mode to kernel mode, and vice versa

Privileged instructions

- Examples?

- What should happen if a user program attempts to execute a privileged instruction?

User Mode

- Application program
  - Running in process

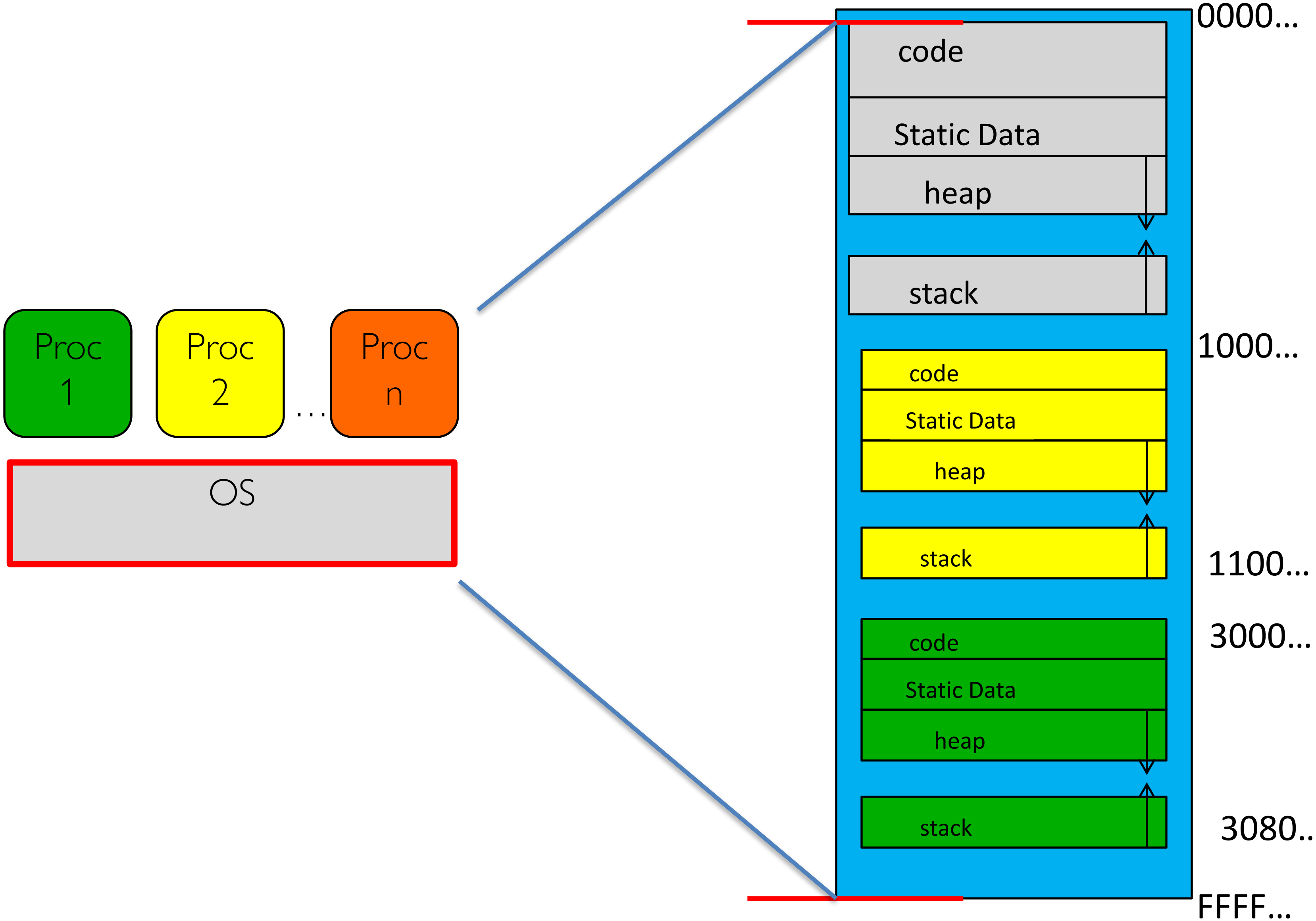
Virtual Machine:VM

- Software emulation of an abstract machine
  - Give programs illusion they own the machine
  - Make it look like HW has feature you want
- 2 types of VM
  - Process VM
    - Supports the execution of a single program (one of the basic function of the OS)
  - System VM
    - Supports the execution of an entire OS and its applications

Process VMs

- GOAL:
  - Provide an isolation to a program
  - Portability

Kernel mode & User mode

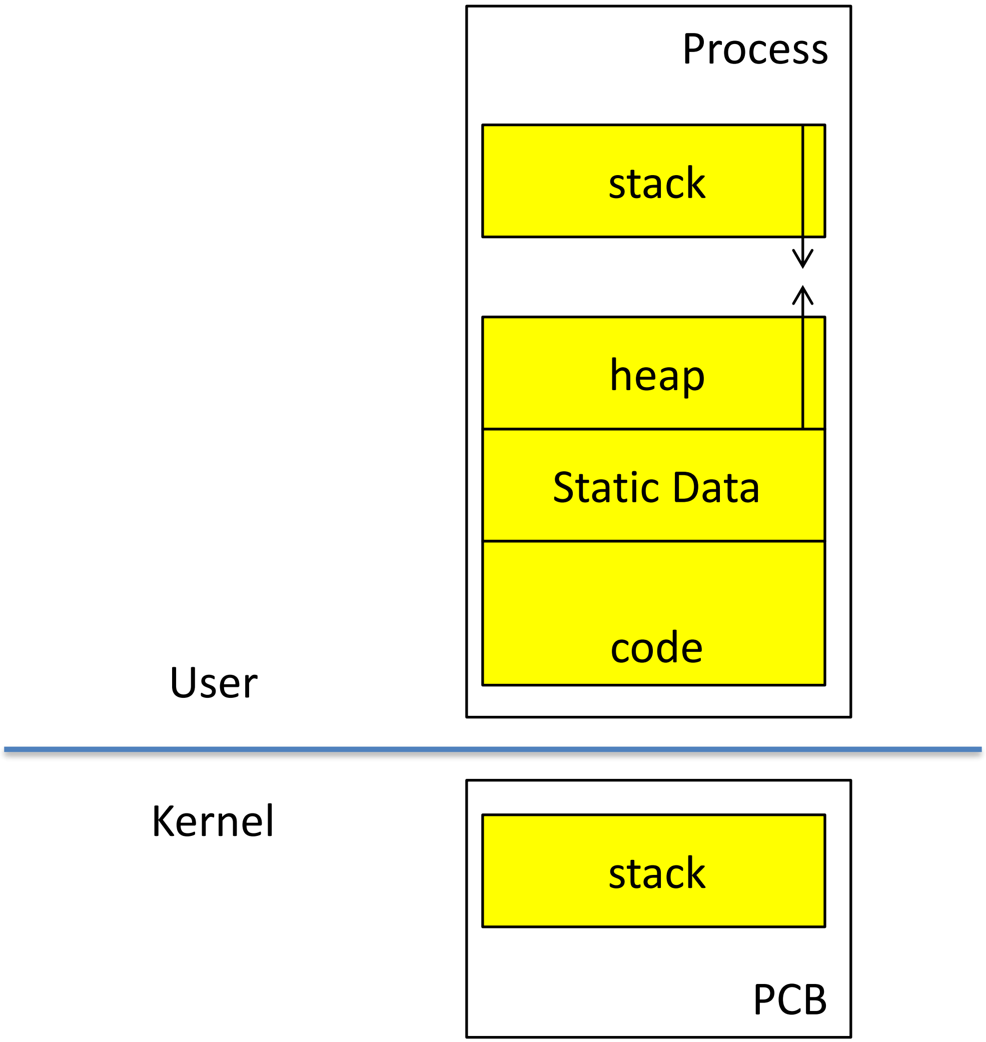


Process Abstraction

- Process: an *instance* of a program, running with limited rights
  - Thread: a sequence of instructions within a process
    - Potentially many threads per process (for now 1:1)
  - Address space: set of rights of a process
    - Memory that the process can access
    - Other permissions the process has (e.g., which system calls it can make, what files it can access)

Process

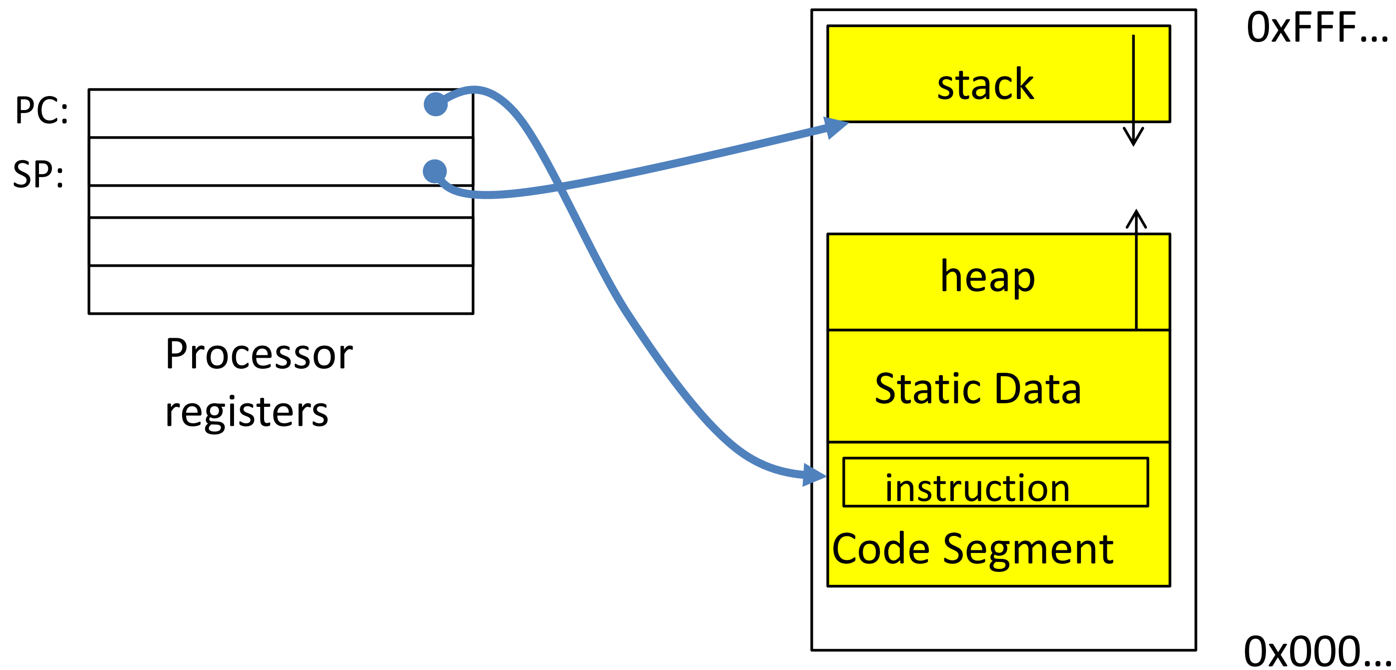
- 2 parts
  - PCB in kernel
  - Others in user



Process Control Block: PCB

- 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

Address Space: In a Picture



Break

Main Points

- Process concept
  - A process is the OS abstraction for executing a program with limited privileges
- Dual-mode operation: user vs. kernel
  - Kernel-mode: execute with complete privileges
  - User-mode: execute with fewer privileges
- Safe control transfer
  - How do we switch from one mode to the other?

Mode Switch

- From user mode to kernel mode
  - Interrupts
    - Triggered by timer and I/O devices
  - Exceptions
    - Triggered by unexpected program behavior
    - Or malicious behavior!
  - System calls (aka protected procedure call)
    - Request by program for kernel to do some operation on its behalf
    - Only limited # of very carefully coded entry points

Mode Switch

- From kernel mode to user mode
  - New process/new thread start
    - Jump to first instruction in program/thread
  - Return from interrupt, exception, system call
    - Resume suspended execution
  - Process/thread context switch
    - Resume some other process
  - User-level upcall (UNIX signal)
    - Asynchronous notification to user program

Implementing Safe Kernel Mode Transfers

- *Carefully* constructed kernel code packs up the user process state and sets it aside
- Must handle weird/buggy/malicious user state
  - Syscalls with null pointers
  - Return instruction out of bounds
  - User stack pointer out of bounds
- Should be impossible for buggy or malicious user program to cause the kernel to corrupt itself
- User program should not know interrupt has occurred *(transparency)*

Device Interrupts

- OS kernel needs to communicate with physical devices
- Devices operate asynchronously from the CPU
  - Polling: Kernel waits until I/O is done
  - Interrupts: Kernel can do other work in the meantime
- Device access to memory
  - Programmed I/O: CPU reads and writes to device
  - Direct memory access (DMA) by device
  - Buffer descriptor: sequence of DMA's
    - E.g., packet header and packet body
  - Queue of buffer descriptors
    - Buffer descriptor itself is DMA'ed

Device Interrupts

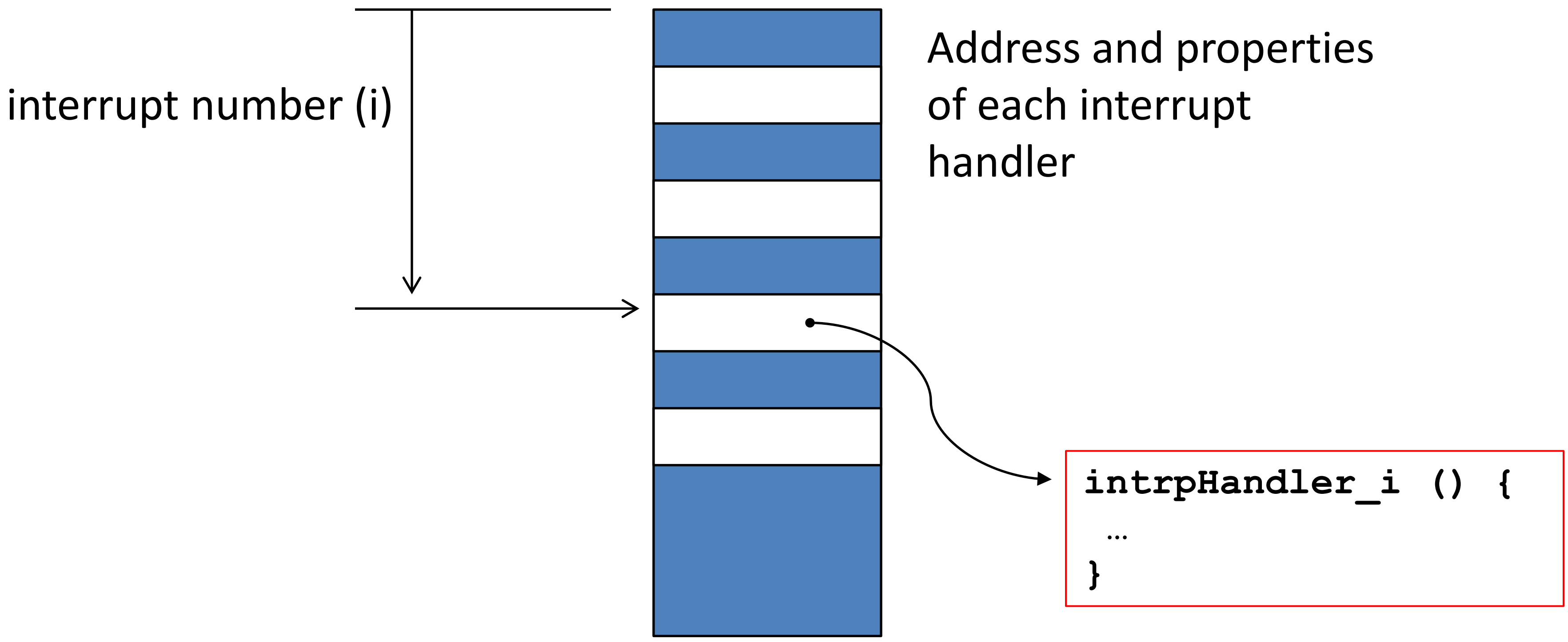
- How do device interrupts work?
  - Where does the CPU run after an interrupt?
  - What stack does it use?
  - Is the work the CPU had been doing before the interrupt lost forever?
  - If not, how does the CPU know how to resume that work?

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

Where do mode transfers go?

- Solution: ***Interrupt Vector***



The Kernel Stack

- Interrupt handlers want a stack
- System call handlers want a stack
- Can't just use the user stack [why?]

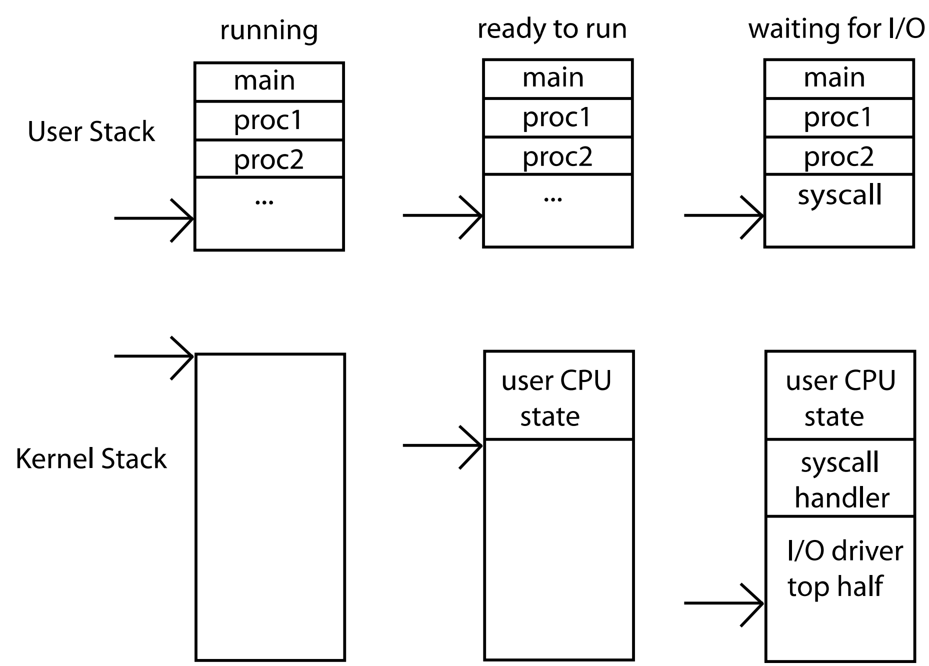
The Kernel Stack

- Solution: two-stack model
  – Each OS thread has kernel stack (located in kernel memory) plus user stack (located in user memory)
- Place to save user registers during interrupt

ชิ้นส่วนของ process ที่อยู่ใน kernel

PCB, stack

รูป



พอมีการ switch ตัว stack

กำลังรัน process A แล้วเกิด inte

ตัว interrupt routine จะย้ายไป

รัน stack ชิ้น

Interrupt Stack

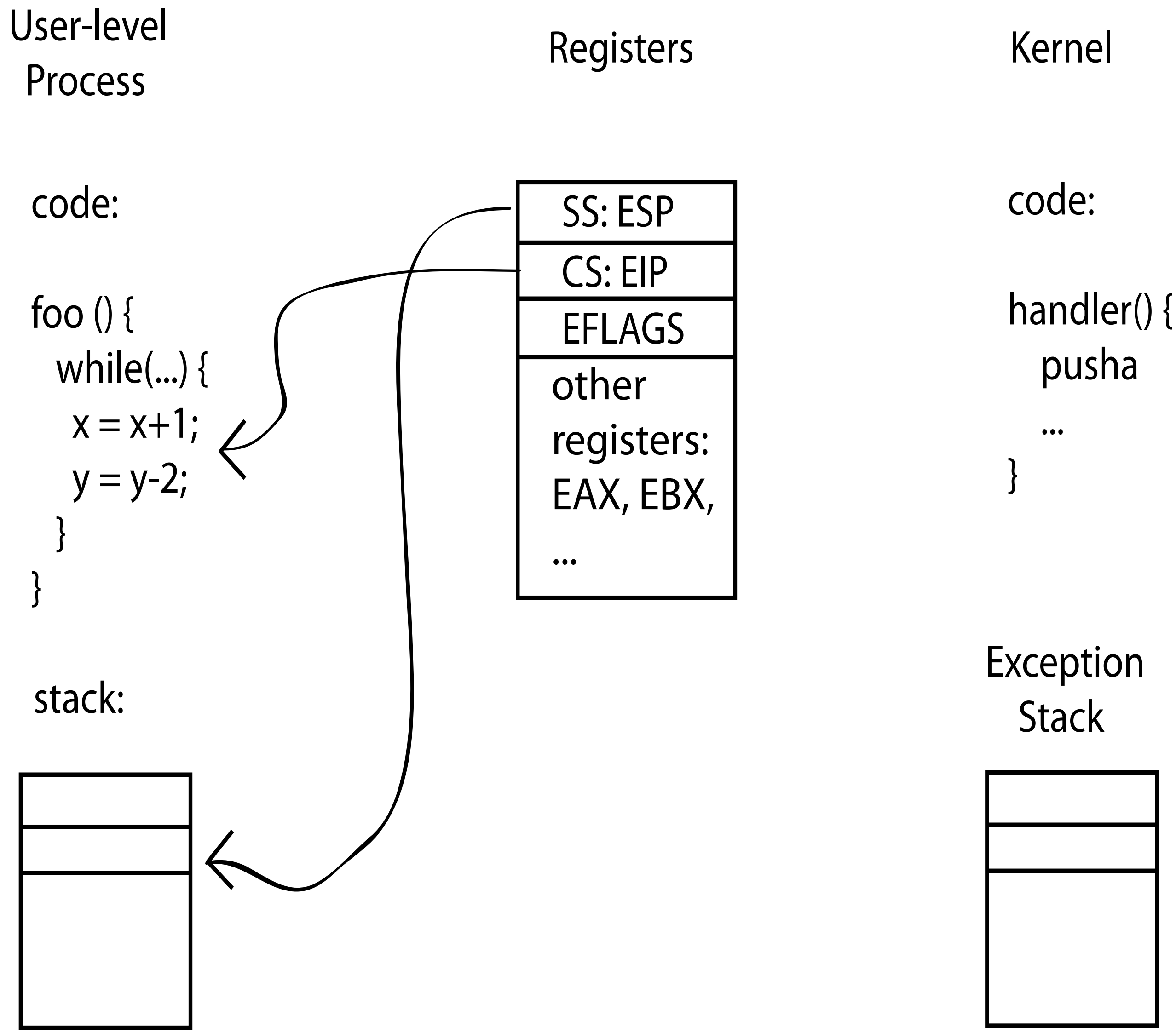
- Per-processor, located in kernel (not user) memory
  - Usually a process/thread has both: kernel and user stack
- Why can’t the interrupt handler run on the stack of the interrupted user process?

Case Study: x86 Interrupt

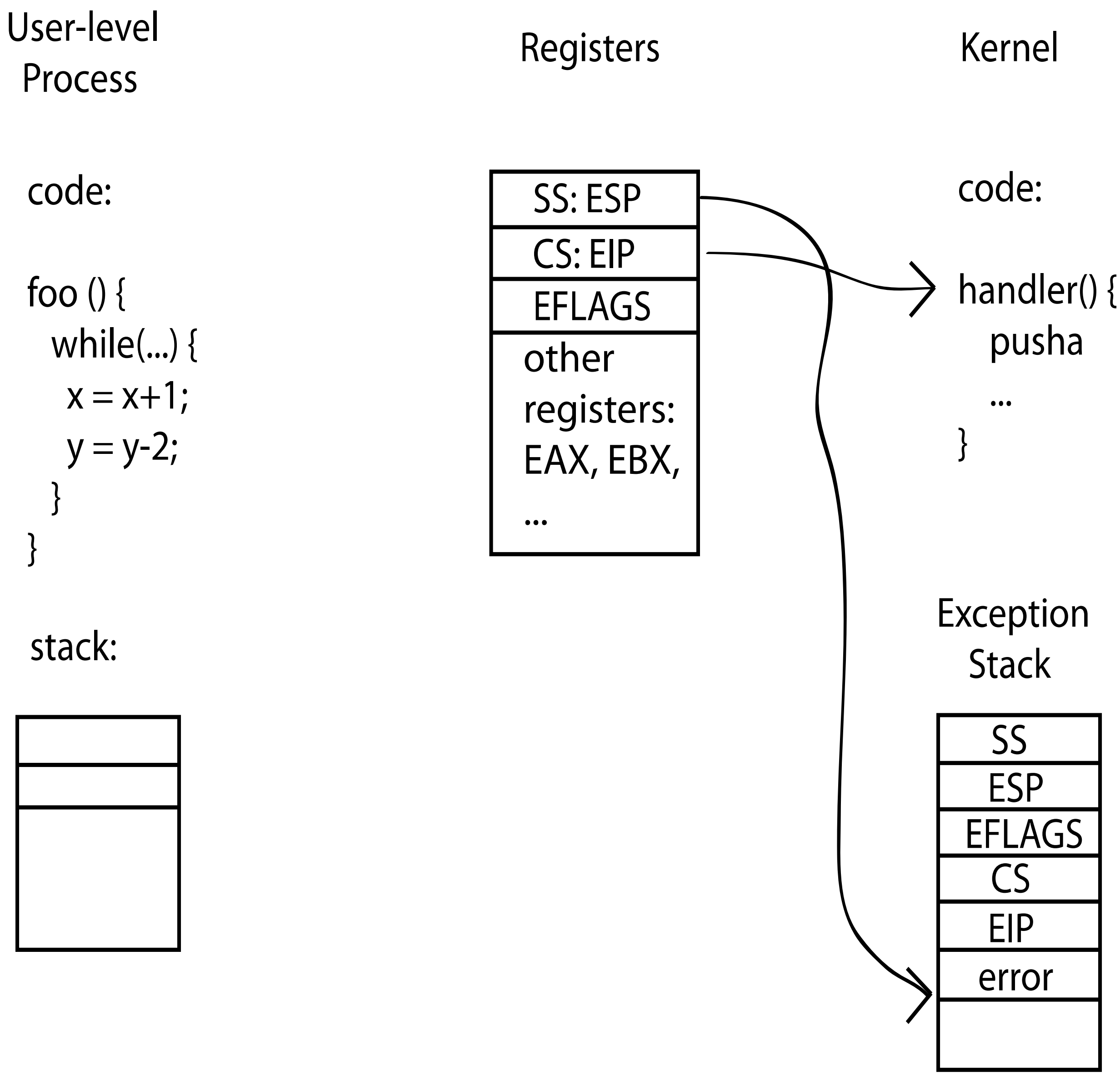
เมื่อเกิดการ interrupt

- Save current stack pointer
- Save current program counter
- Save current processor status word (condition codes)
- Switch to kernel stack; put SP, PC, PSW on stack
- Switch to kernel mode
- Vector through interrupt table
- Interrupt handler saves registers it might clobber

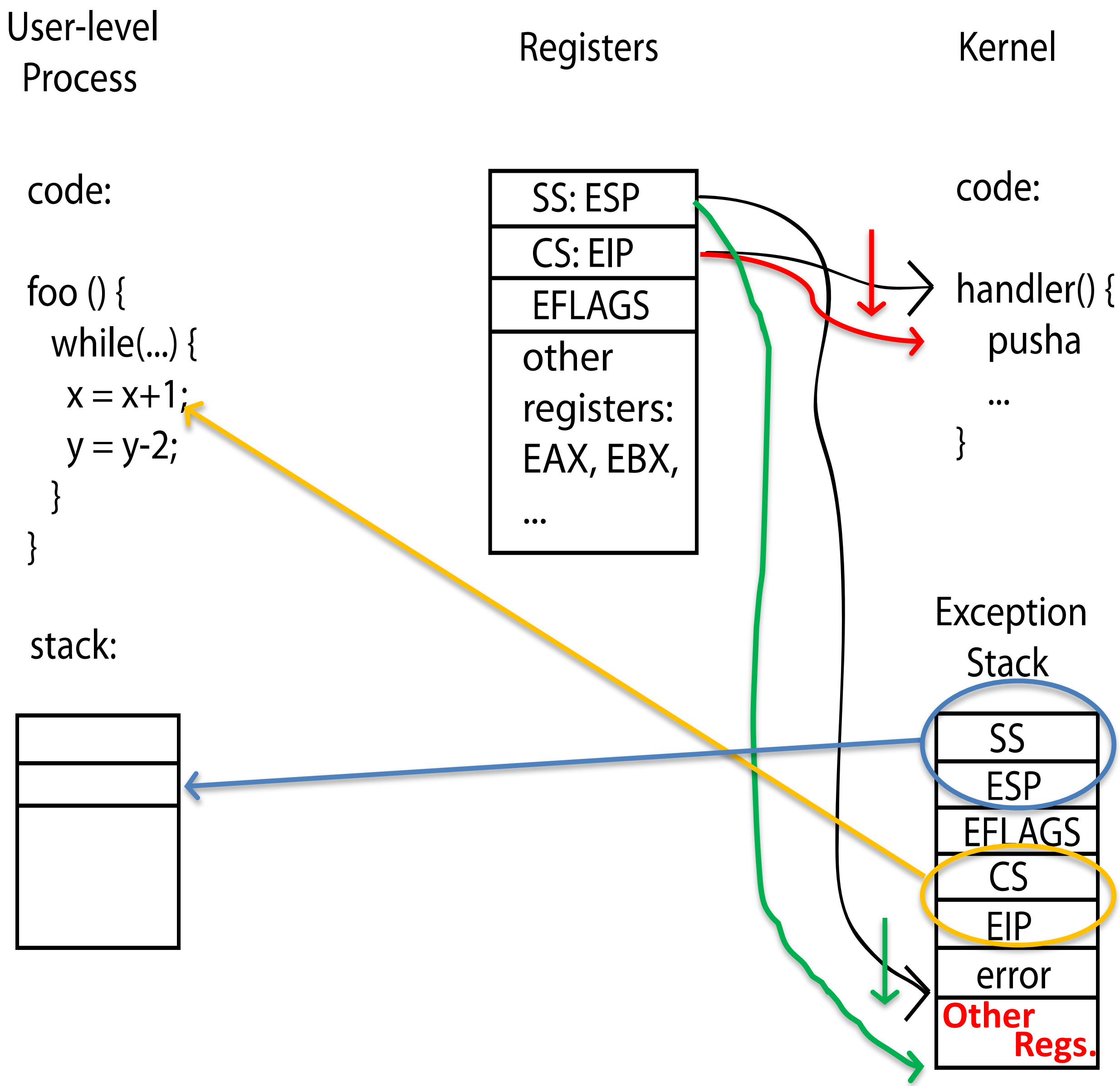
Before Interrupt



During Interrupt



After Interrupt



At end of handler

การบ้าน

ทำความเข้าใจชิ้น

- Handler restores saved registers
- Atomically return to interrupted process/thread
  - Restore program counter
  - Restore program stack
  - Restore processor status word/condition codes
  - Switch to user mode

Interrupt Masking

- Interrupt handler runs with interrupts off
  - Re-enabled when interrupt completes
- OS kernel can also turn interrupts off
  - Eg., when determining the next process/thread to run
  - On x86
    - CLI: disable interrrupts
    - STI: enable interrupts
    - Only applies to the current CPU (on a multicore)
- We'll need this to implement synchronization in chapter 5

Hardware support: Interrupt Control

hardware ฮินทรอปในเรื่องอะไรบ้าง

- 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

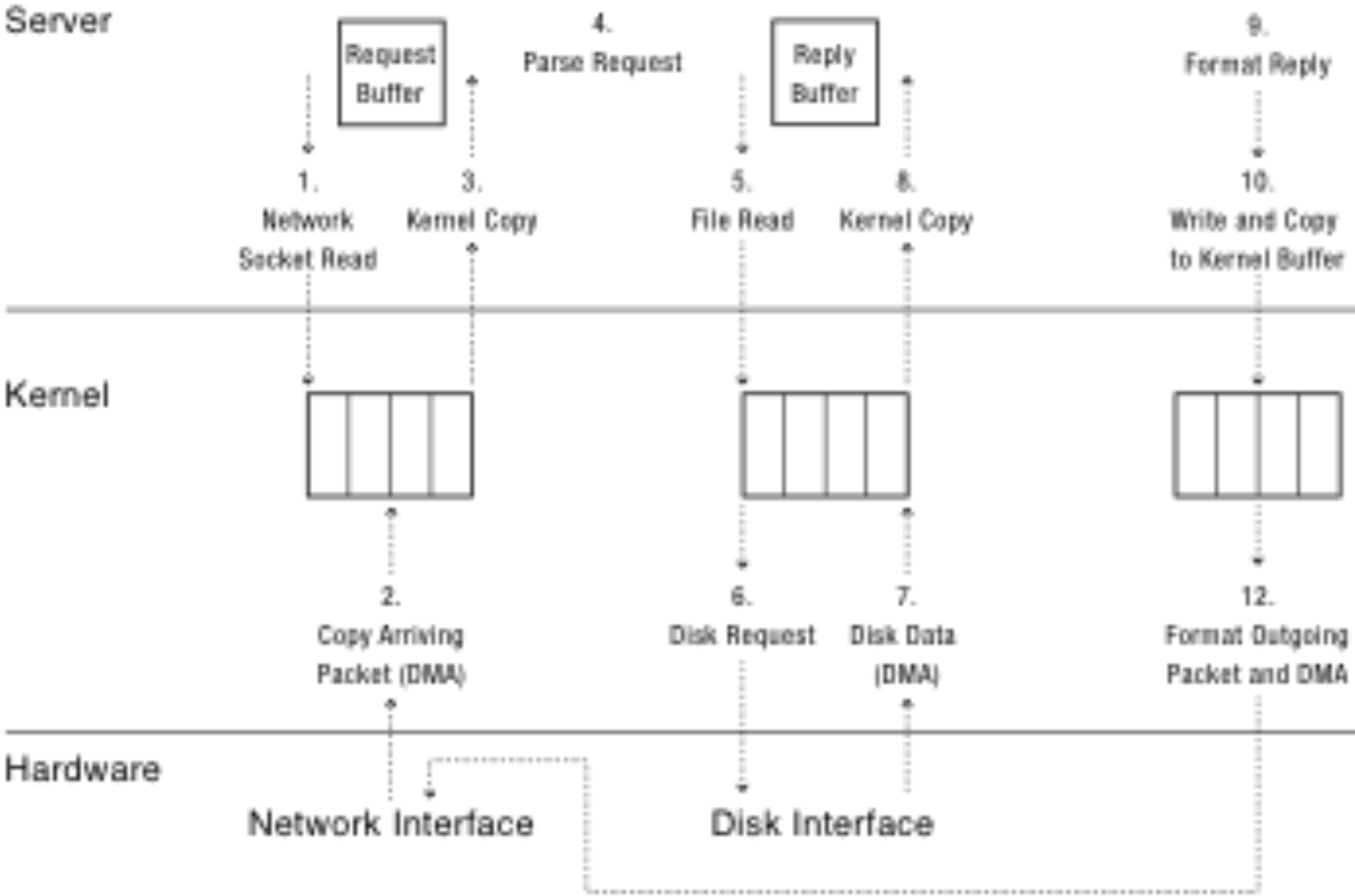
- HW may have multiple levels of interrupts
  - Mask off (disable) certain interrupts, eg., lower priority
  - Certain Non-Maskable-Interrupts (NMI)
    - e.g., kernel segmentation fault
    - Also: Power about to fail!

BREAK

Kernel System Call Handler

↳ การทำงานคล้าย interrupt และ แต่มาจาก software

- 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 – carefully checking locations!
  - Protect kernel from malicious code evading checks
- Validate arguments
  - Protect kernel from errors in user code
- Copy results back
  - Into user memory – carefully checking locations!



Server
Request Buffer
4. Parse Request
Reply Buffer
9. Format Reply
1. Network Socket Read
3. Kernel Copy
5. File Read
8. Kernel Copy
10. Write and Copy to Kernel Buffer
Kernel
2. Copy Arriving Packet (DMA)
6. Disk Request
7. Disk Data (DMA)
12. Format Outgoing Packet and DMA
Hardware
Network Interface
Disk Interface

Today: Four Fundamental OS Concepts

ดูแค่ how do we interrup switch

สรุปว่าพูดถึงอะไร

- **Thread: Execution Context**
  - Program Counter, Registers, Execution Flags, Stack
- **Address space** (with **translation)**
  - Program's view of memory is distinct from physical machine
- **Process: an instance of a running program**
  - Address Space + One or more Threads
- **Dual mode operation / Protection**
  - Only the “system” can access certain resources
  - Combined with translation, isolates programs from each other