CS 423
Operating System Design: Midterm Review

Tianyin Xu (almost back!)

Midterm Details

- In-Class or Online, March 12th (75 minutes).
- **Close book**: No textbooks, no paper notes, no printed sheets. No Internet!
  - I will be the "Internet" – ask me questions if you don't remember something.
- **Content**: All lecture and text material covered prior to before the exam (including memory I).

Midterm Details

- No need to memorize anything.
- Ask me during the exam, if you forget some names or abbreviation.
  - Demo: "What is MLFQ"?
- If you really want to have a sample problem, here is one:
  - In x86-64 virtual memory design, the huge pages are 2MB and 1GB (the regular page is 4KB). Can we support other sizes like 4MB and 16MB? Why or why not?
  - Note that huge pages is out of scope of the exam (that's why I use it as an example)

COVID concerns

- We will support remote exam if you are worried about the virus – we hope to create an environment that you are free of fear in doing the exam.
  - There's a rumor of two potential cases (not confirmed)
- Currently, it's a personal decision – the university has not make anything remote.
- You are still welcome to come to the class.
  - I will be there.

Midterm Details

- If you want to do it remotely, please pay extra efforts.
- We need you to setup a Zoom webcam that shows both your laptop screen and your upper body.
  - You have to register (Piazza posts) to let us know if you have that before tomorrow.
  - We will let you test Zoom setup by opening a Zoom session.
  - Failures of the right setups leads to INVALID results.
  - If you don’t register, you are required to take the physical midterm.
  - Ask questions on Piazza.

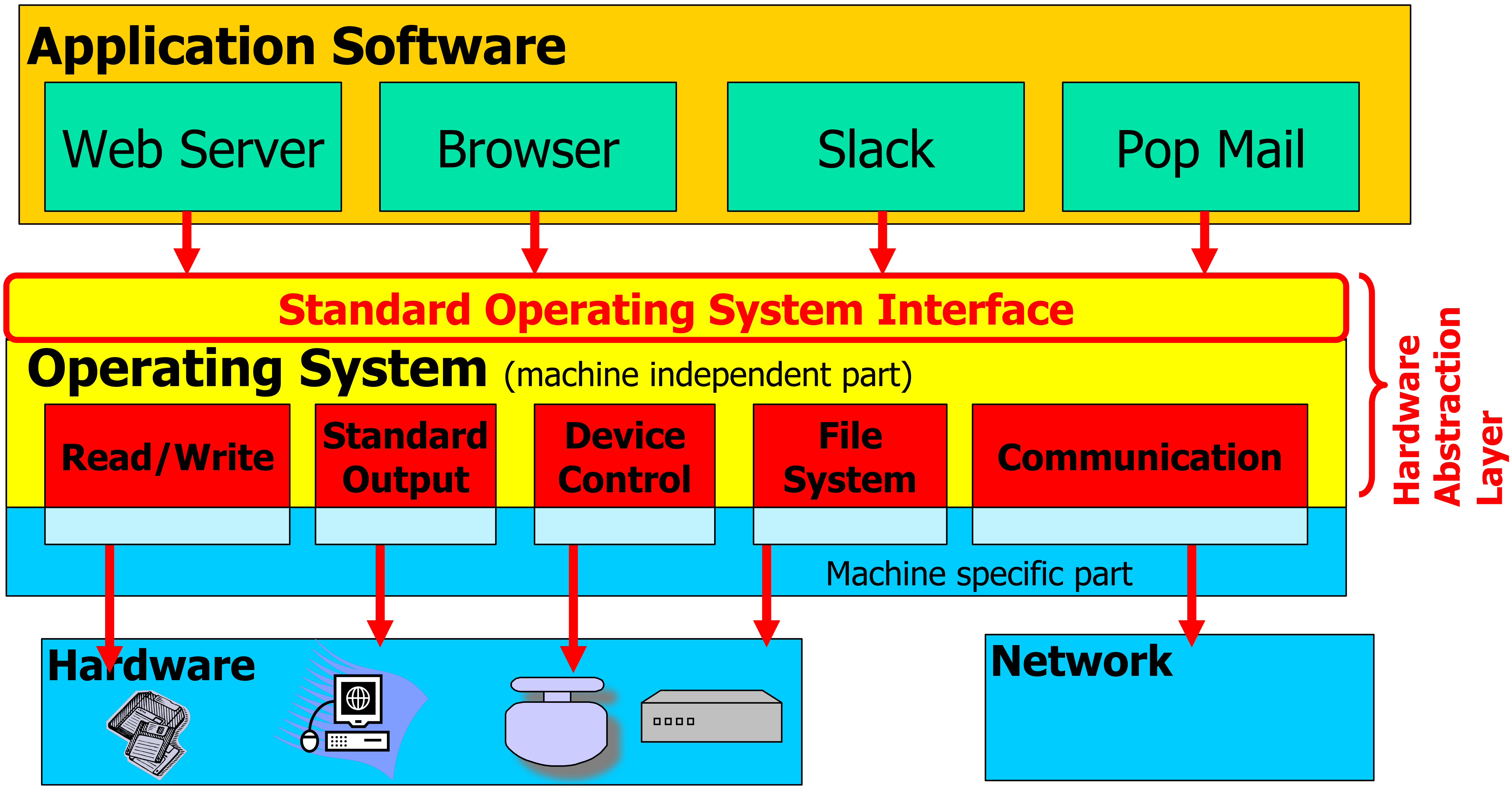
More Q&A

Remainder of these slides

- <u>This is not a study guide</u>
- I prepared these by walking the lecture slides from start to finish and sampling important concepts
- Slides intended to prompt discussion and questions
- Test is written at this point, but this deck leaks minimal information; don't try to read into which slides I did/didn't copy over to here.
- There are no memory slides since we just covered it, but obviously there will be questions about memory on the exam.

Overview: OS Stack

OS Runs on Multiple Platforms while presenting the same Interface:



Overview: OS Roles

Role #1: Referee

- Manage resource allocation between users and applications
- Isolate different users and applications from one another
- Facilitate and mediate communication between different users and applications

Role #2: Illusionist

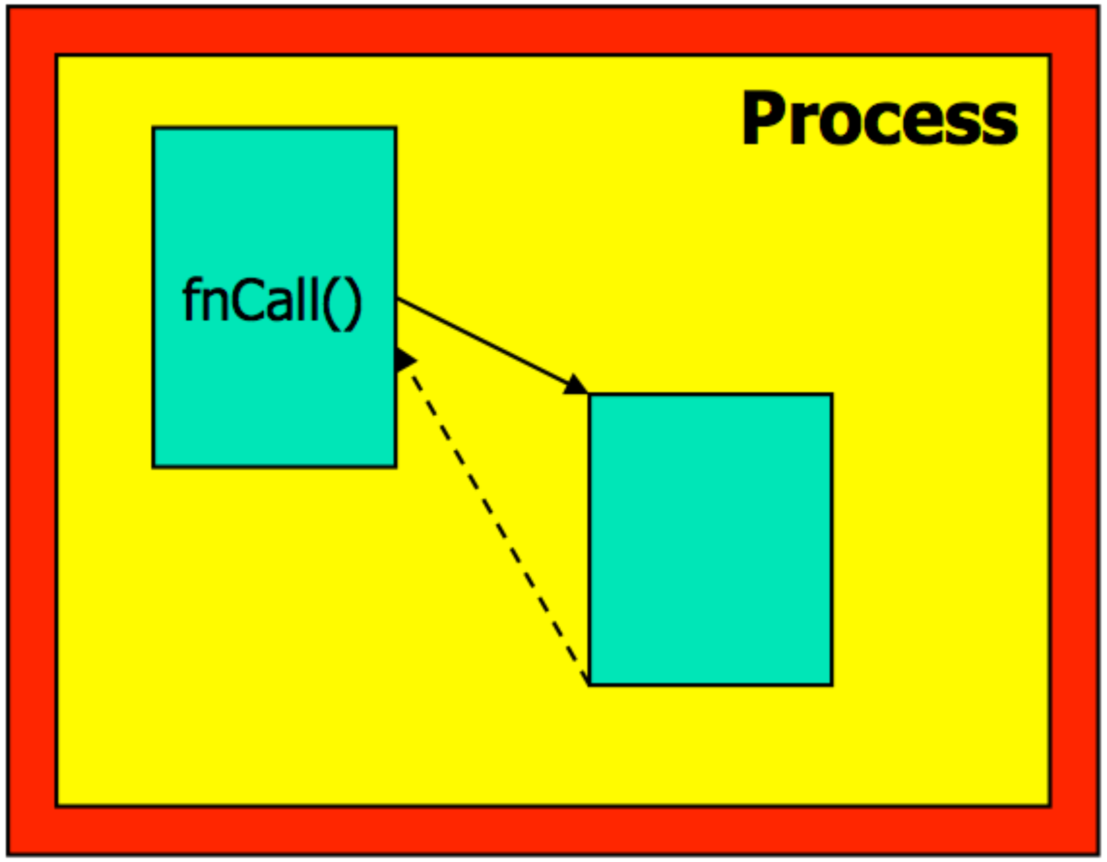
- Allow each application to believe it has the entire machine to itself
- Create the appearance of an Infinite number of processors, (near) infinite memory
- Abstract away complexity of reliability, storage, network communication…

Role #3: Glue

- Manage hardware so applications can be machine-agnostic
- Provide a set of common services that facilitate sharing among applications
- **Examples of “Glue” OS Services?**

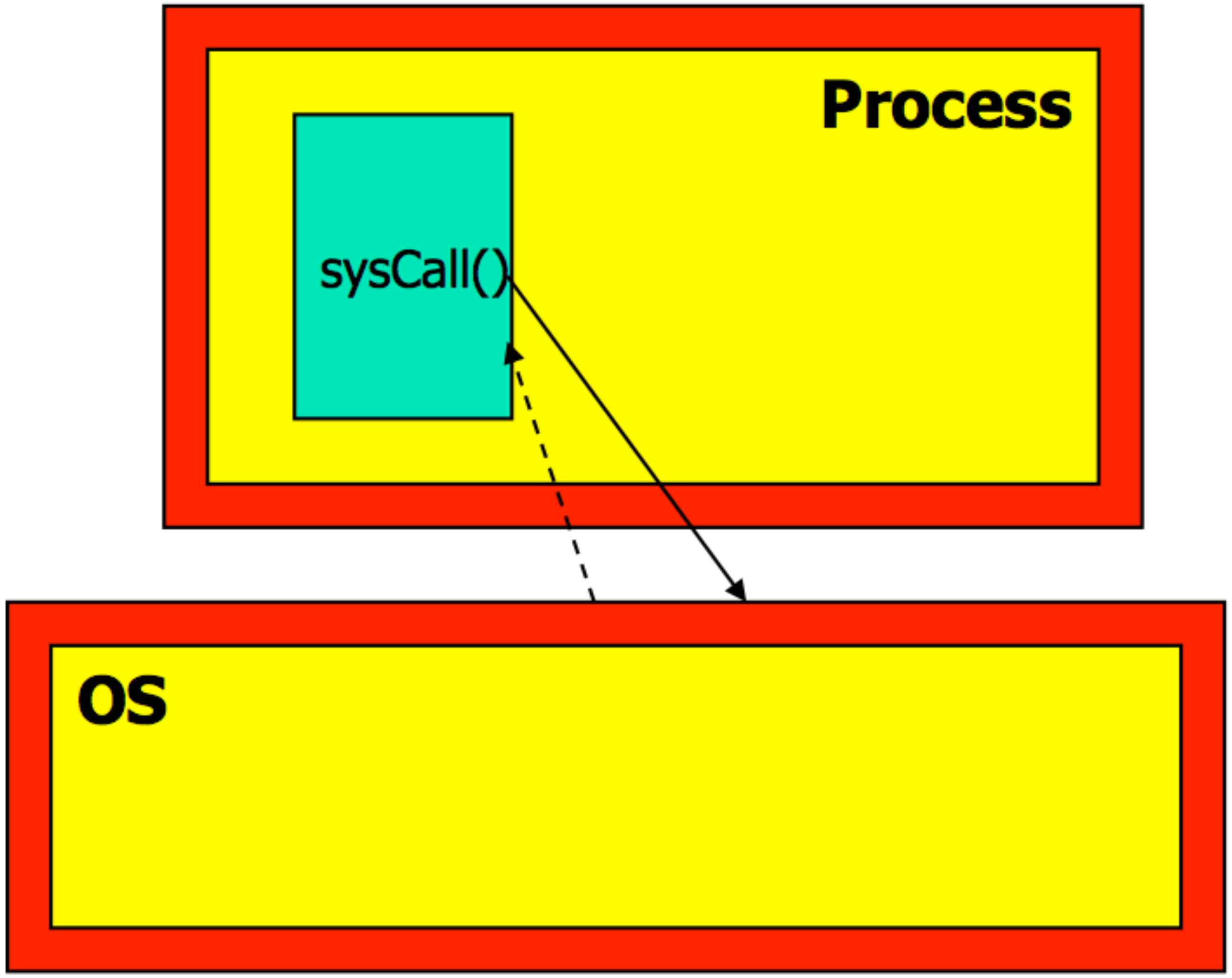
Review: System Calls

Function Calls



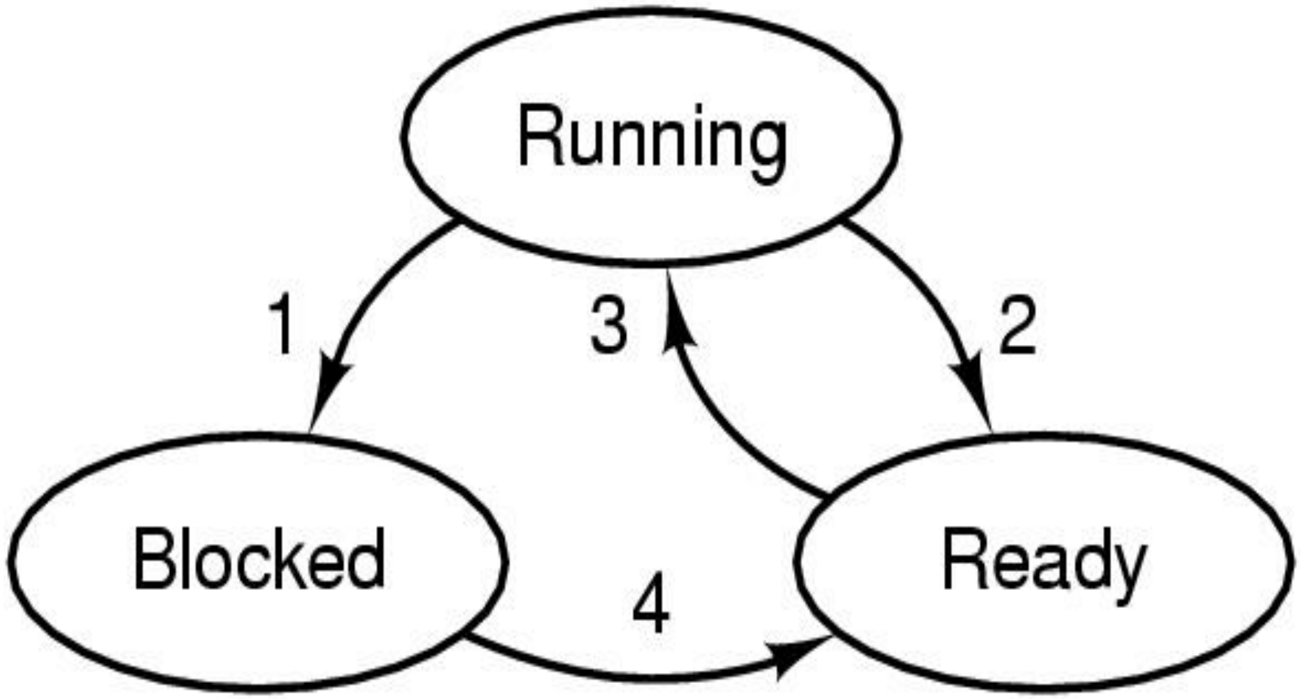
Caller and callee are in the same Process
- Same user
- Same "domain of trust"

System Calls



- OS is trusted; user is not.
- OS has super-privileges; user does not
- Must take measures to prevent abuse

Review: Process Abstraction

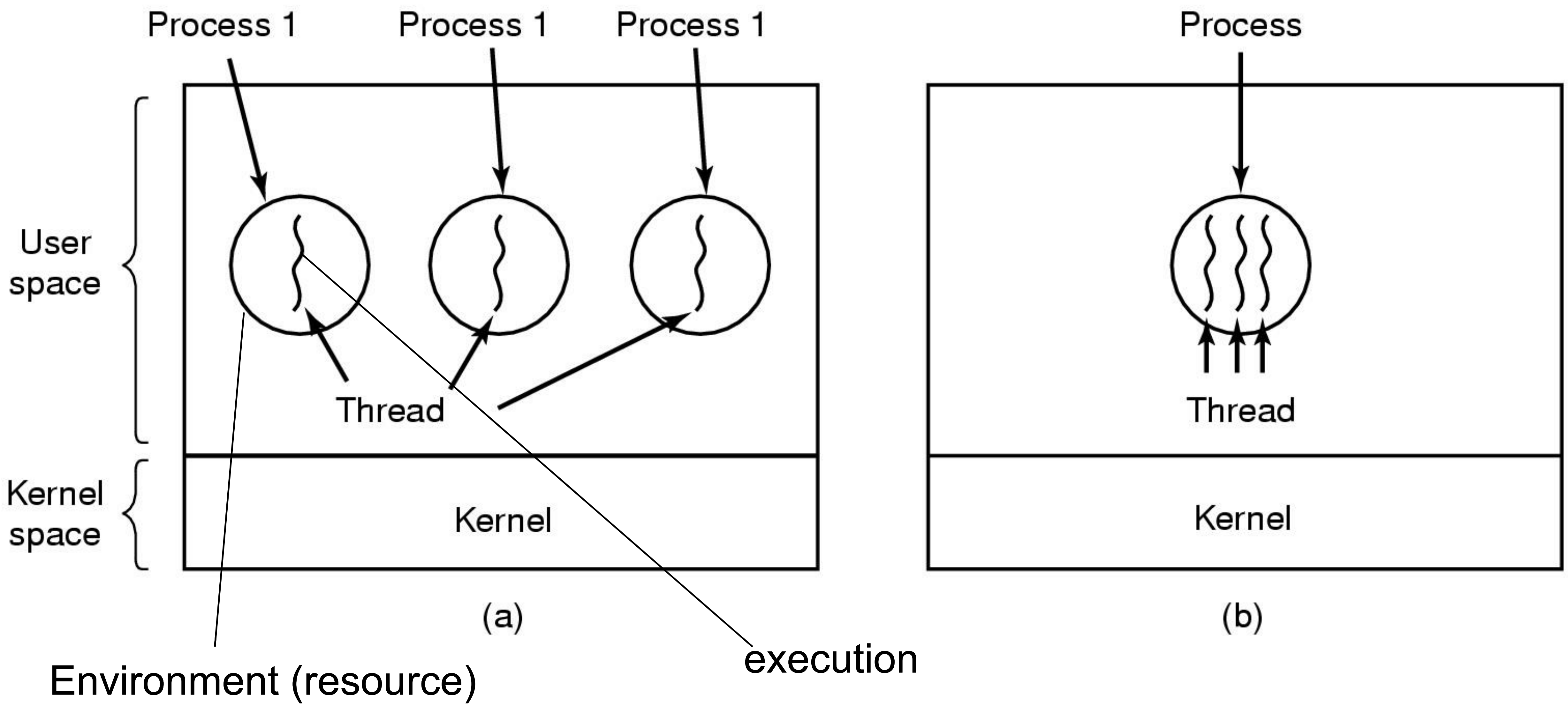


1. Process blocks for input
2. Scheduler picks another process
3. Scheduler picks this process
4. Input becomes available

- Possible process states
  - Running (occupy CPU)
  - Blocked
  - Ready (does not occupy CPU)
  - Other states: suspended, terminated

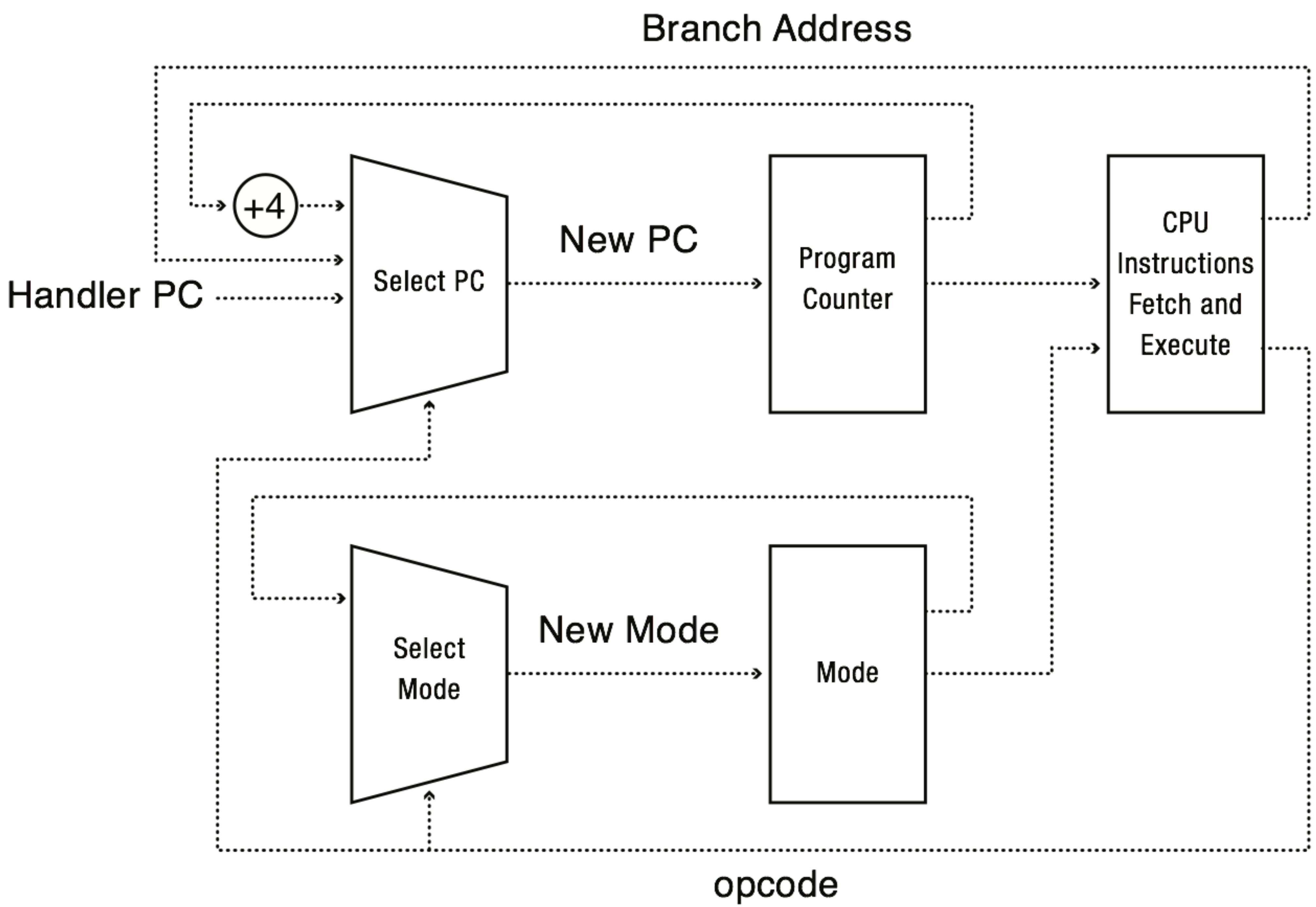
Question: in a single processor machine, how many process can be in running state?

Review: Threads

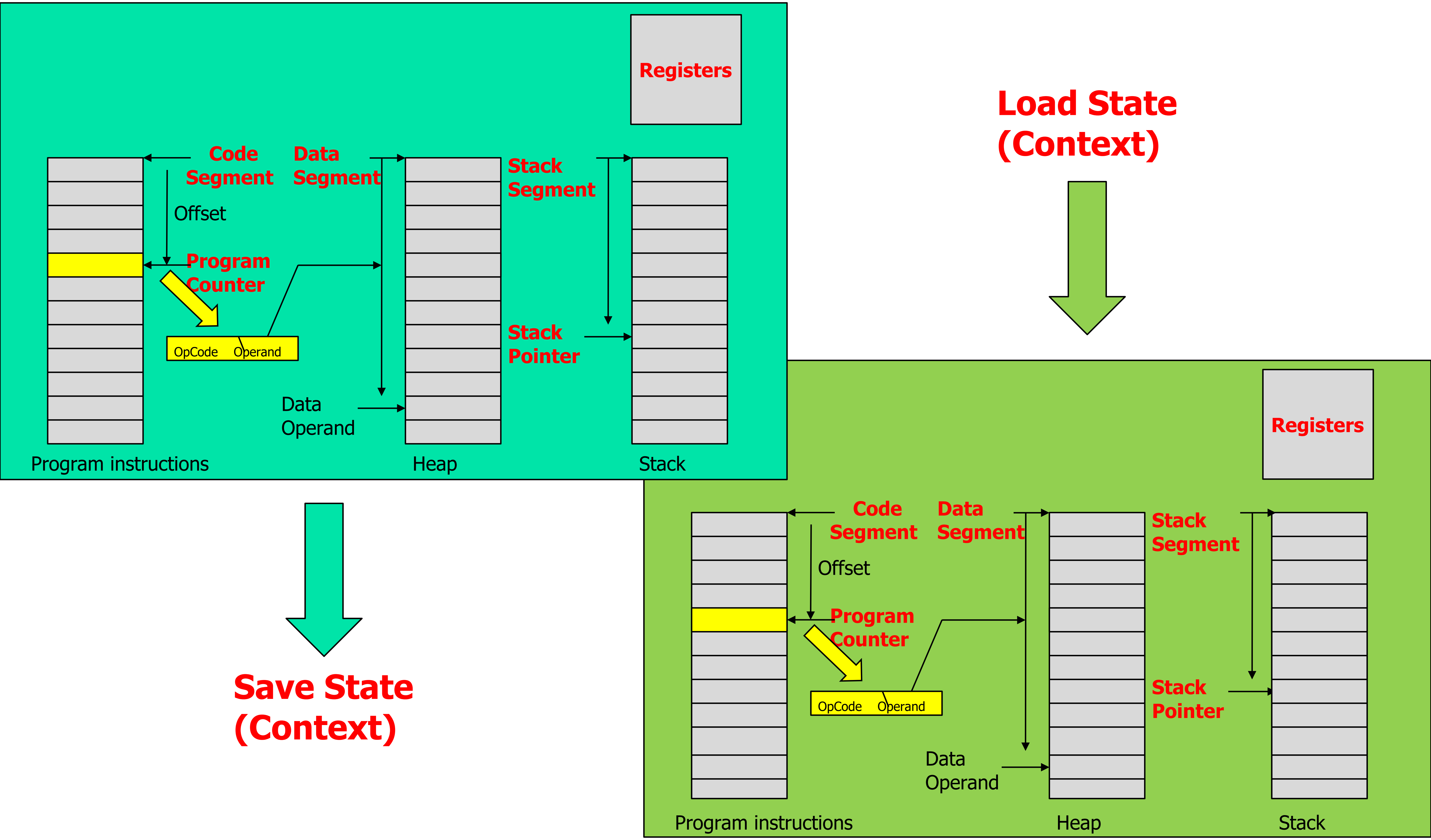


- (a) Three processes each with one thread
- (b) One process with three threads

Kernel Abstraction: HW Support

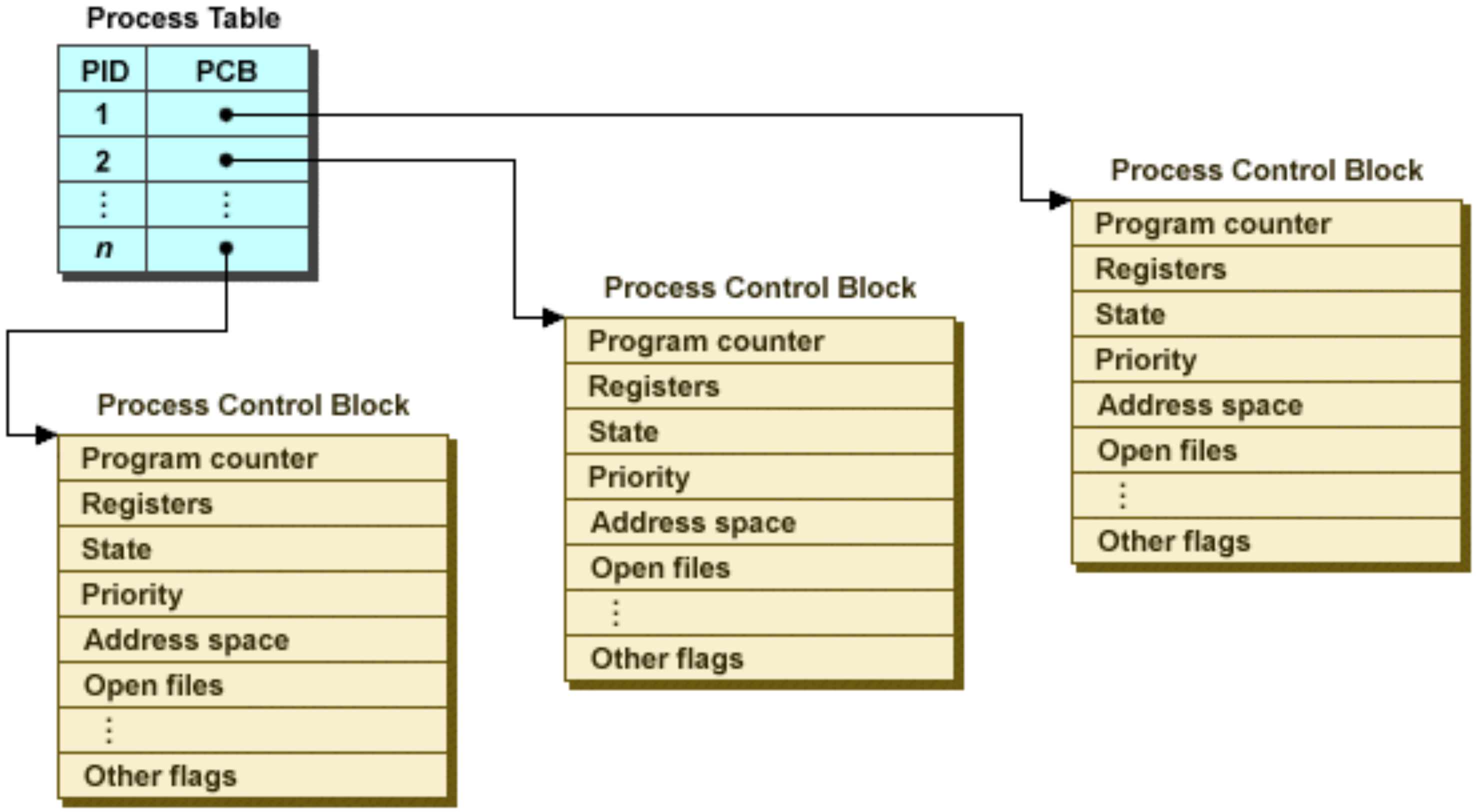


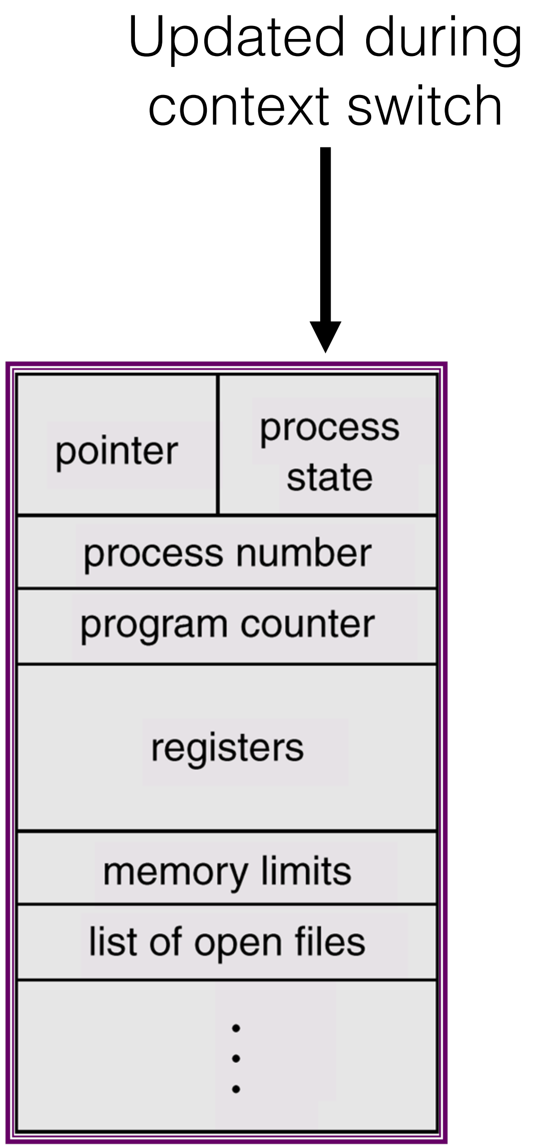
Kernel Abstraction: CTX Switch



Kernel Abstraction: PCBs

The state for processes that are not running on the CPU are maintained in the Process Control Block (PCB) data structure



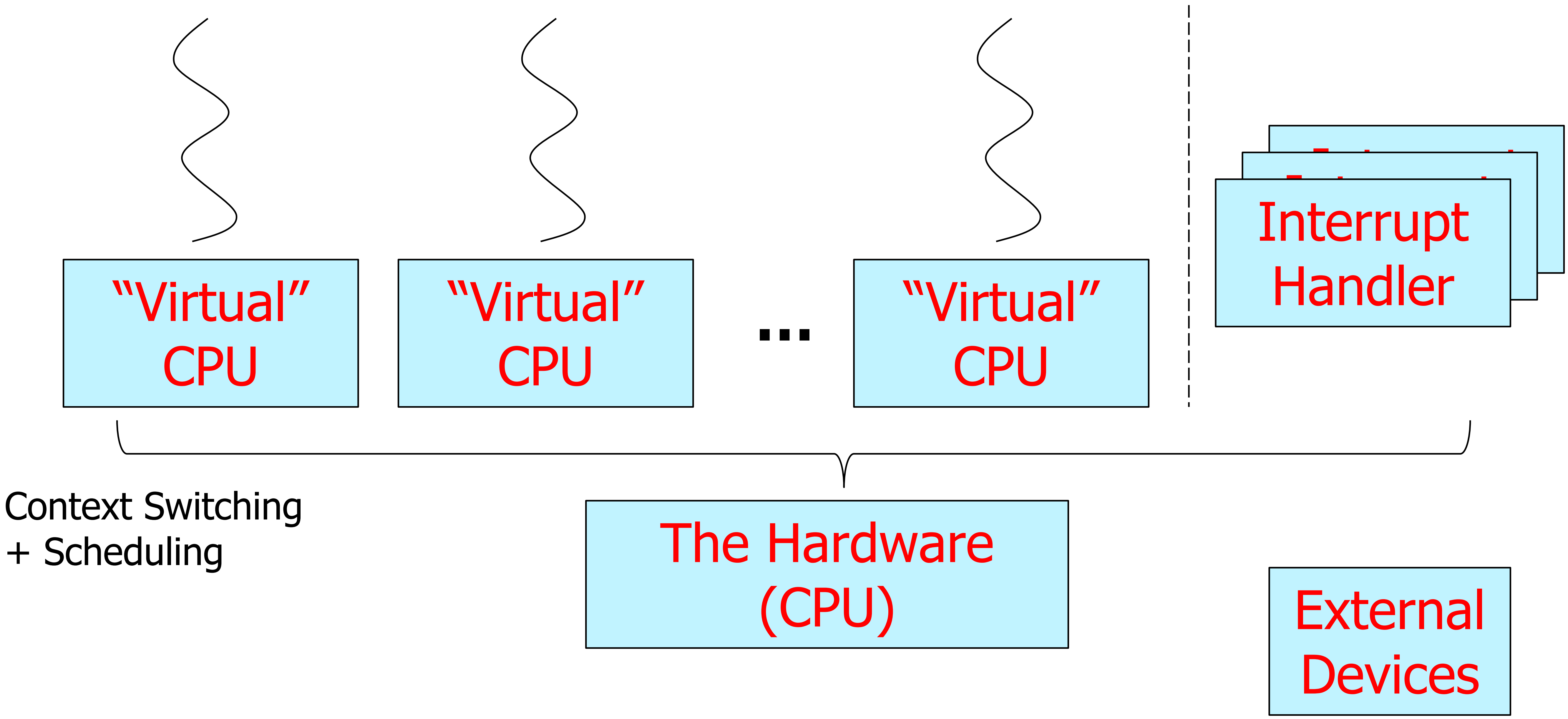


An alternate PCB diagram

Interrupts: Model

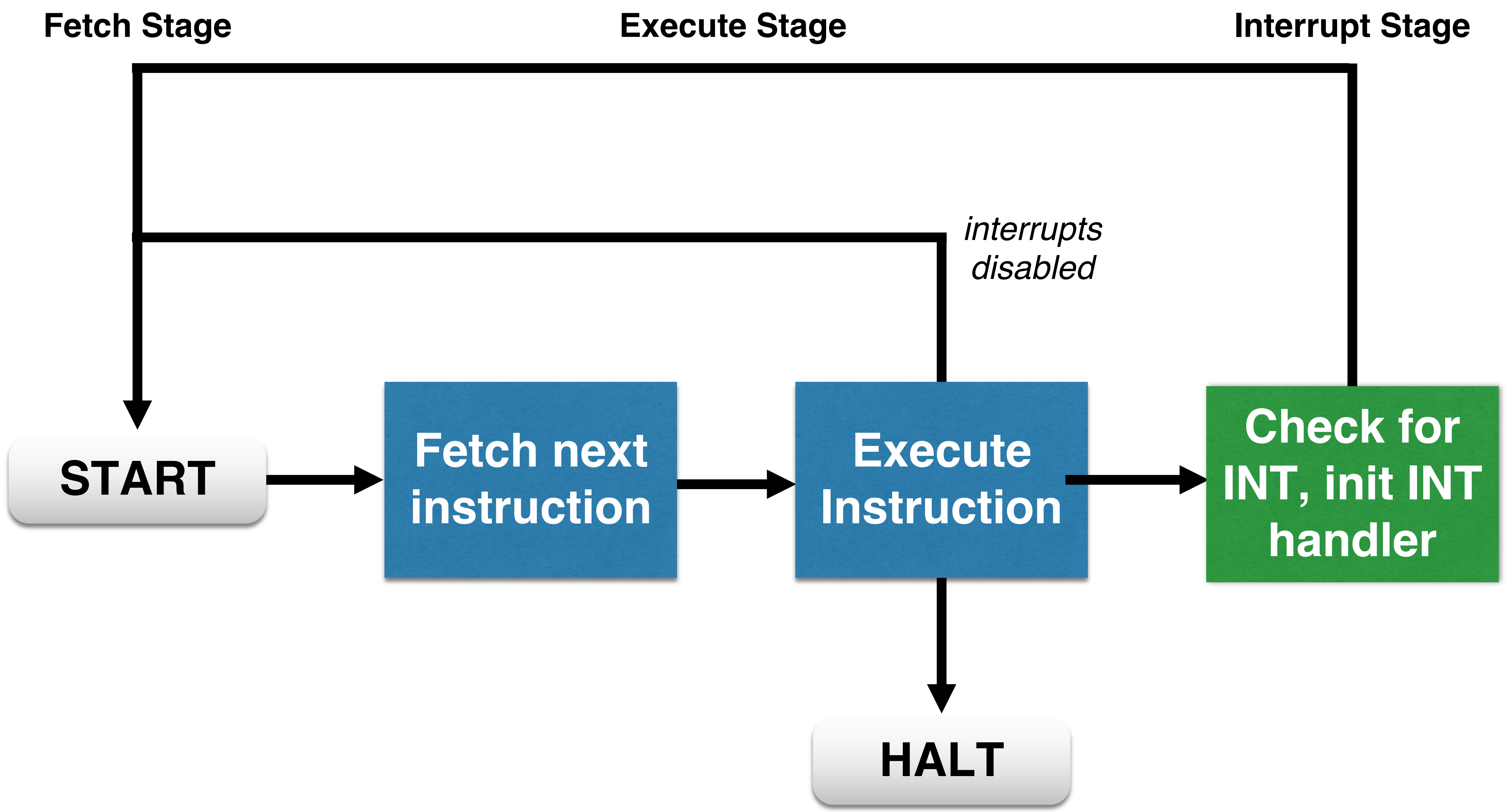
Interrupts to drive scheduling decisions!

Interrupt handlers are also tasks that share the CPU.



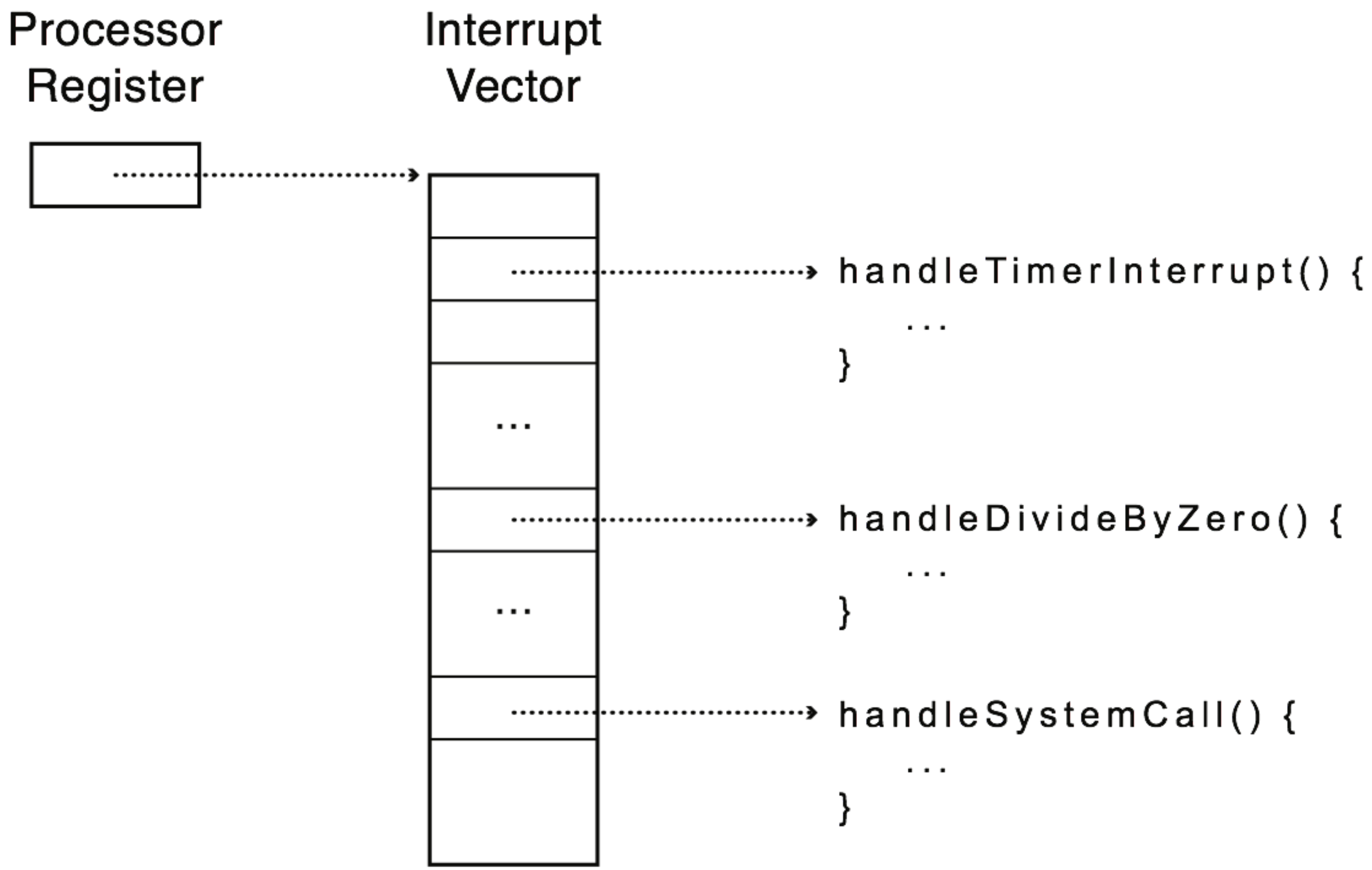
Interrupts: Handling

How does interrupt handling change the instruction cycle?



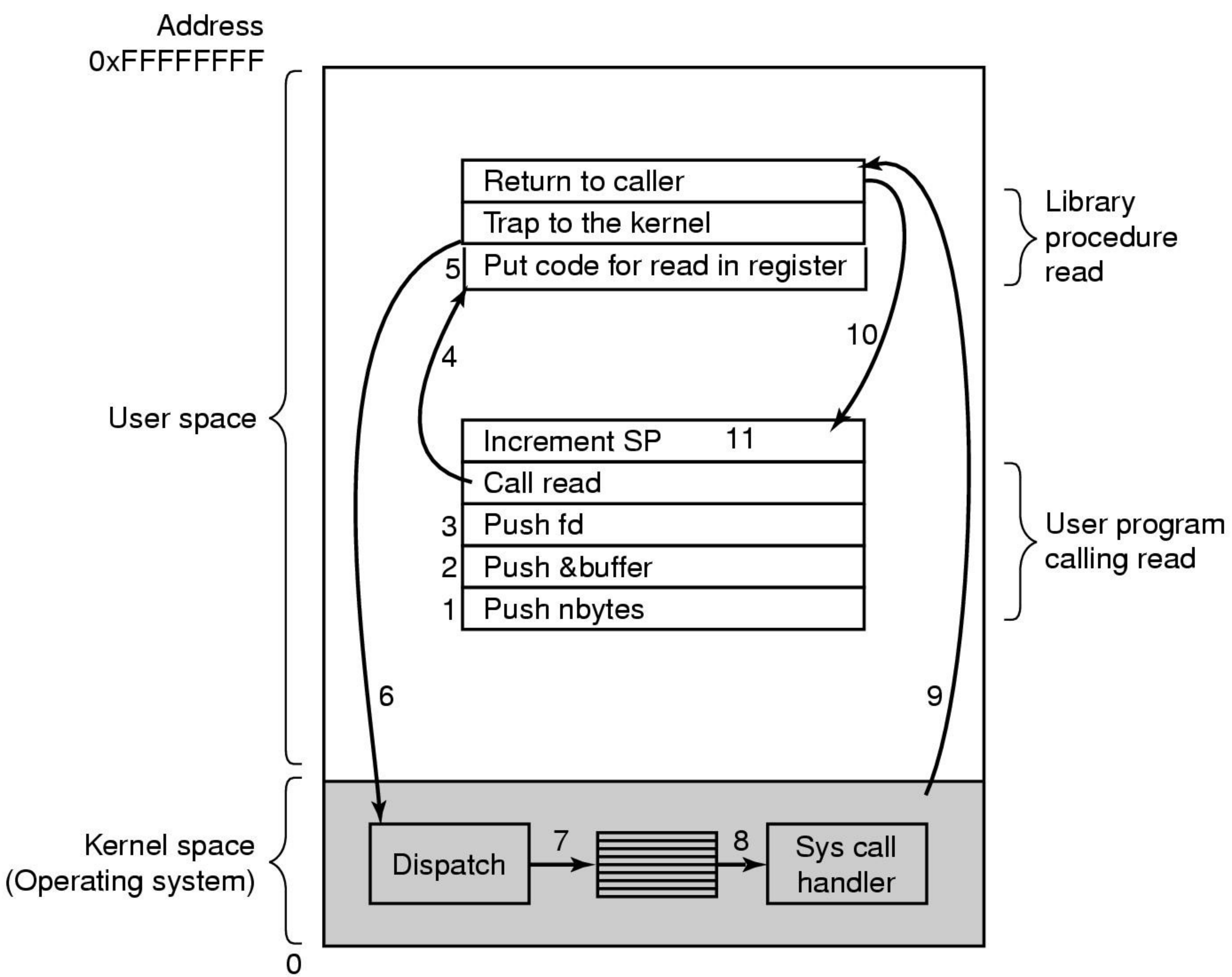
Interrupts: Handling

Table set up by OS kernel; pointers to code to run on different events

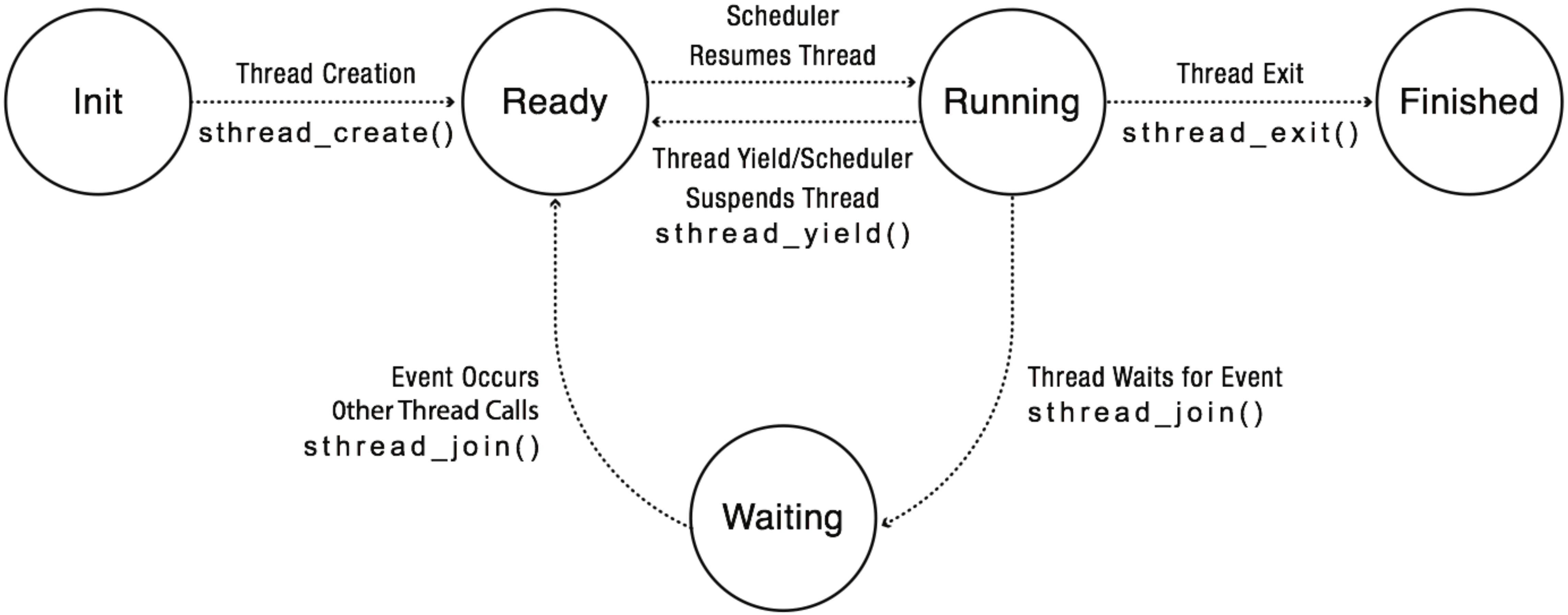


System Calls: Under the Hood

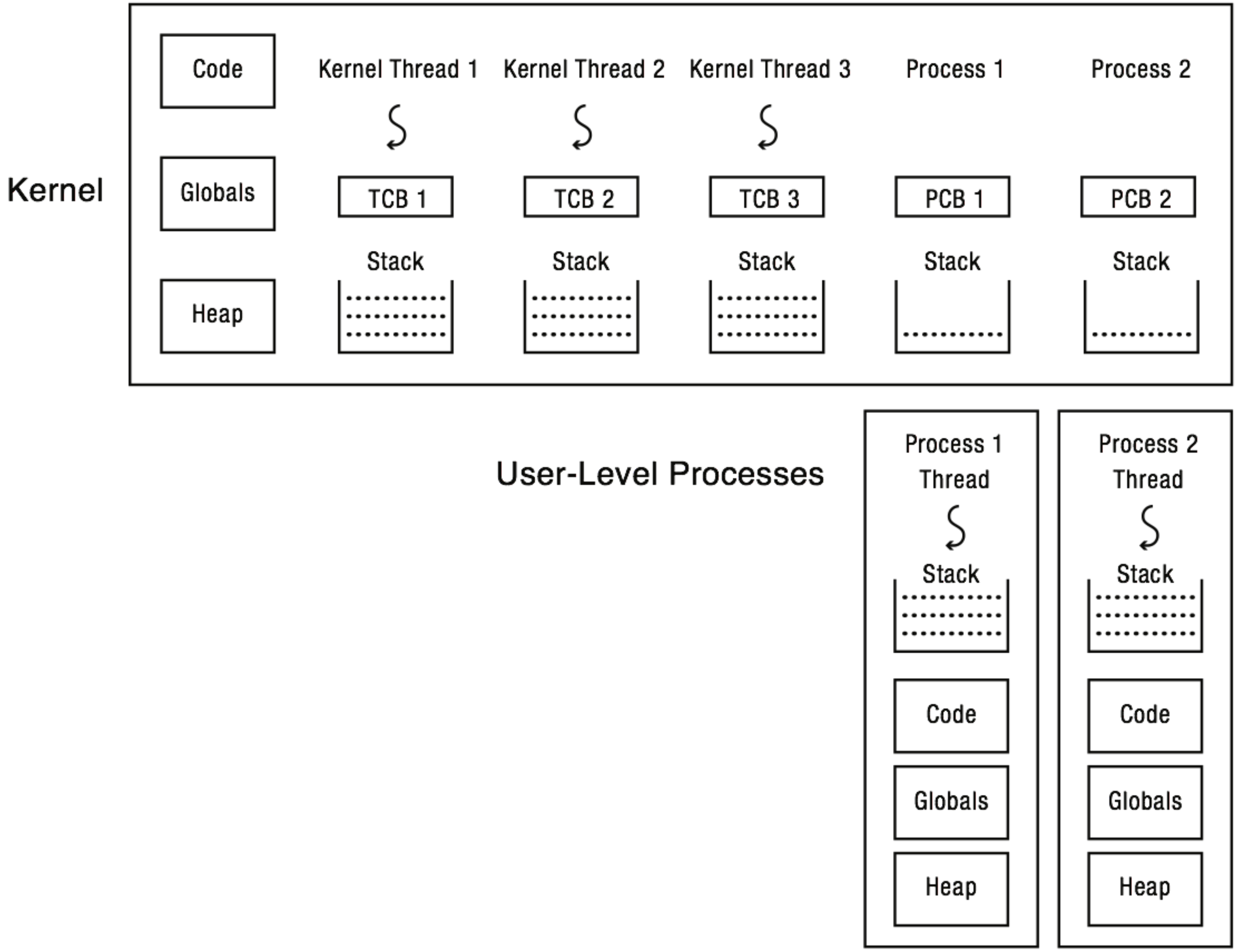
read (fd, buffer, nbytes)



Concurrency: Thread Lifecycle



Concurrency: Thread State



Synchronization: Principals

Concurrent Applications

Shared Objects

Bounded Buffer   Barrier

Synchronization Variables

Semaphores   Locks   Condition Variables

Atomic Instructions

Interrupt Disable   Test-and-Set

Hardware

Multiple Processors   Hardware Interrupts

Queueing Lock Implementation (1 Proc)

```
Lock::acquire() {
    disableInterrupts();
    if (value == BUSY) {
        waiting.add(myTCB);
        myTCB->state = WAITING;
        next = readyList.remove();
        switch(myTCB, next);
        myTCB->state = RUNNING;
    } else {
        value = BUSY;
    }
    enableInterrupts();
}
```

```
Lock::release() {
    disableInterrupts();
    if (!waiting.Empty()) {
        next = waiting.remove();
        next->state = READY;
        readyList.add(next);
    } else {
     value = FREE;
    }
    enableInterrupts();
}
```

Multiprocessor Sync Tool!

- Read-modify-write (RMW) instructions
  - Atomically read a value from memory, operate on it, and then write it back to memory
  - Intervening instructions prevented in hardware
- Examples
  - Test and set
  - Intel: xchgb, lock prefix
  - Compare and swap
- Any of these can be used for implementing locks and condition variables!

Test-and-set

- The **test-and-set** instruction is an instruction used to write 1 (set) to a memory location and return its old value as a single **atomic** (i.e., non-interruptible) operation. If multiple processes may access the same memory location, and if a process is currently performing a test-and-set, no other process may begin another test-and-set until the first process's test-and-set is finished.
- Please implement a lock using test-and-set (5 minutes)

```
lock:acquire() {

}

lock:release() {

}
```

Synchronization: Locks

- Lock::acquire
  - wait until lock is free, then take it
- Lock::release
  - release lock, waking up anyone waiting for it

1. At most one lock holder at a time (safety)
2. If no one holding, acquire gets lock (progress)
3. If all lock holders finish and no higher priority waiters, waiter eventually gets lock (progress)

Synchronization: Condition Variables

- Waiting inside a critical section
  - Called only when holding a lock

- CV::Wait — atomically release lock and relinquish processor
  - Reacquire the lock when wakened

- CV::Signal — wake up a waiter, if any

- CV::Broadcast — wake up all waiters, if any

Synchronization: Spinlocks

- A spinlock is a lock where the processor waits in a loop for the lock to become free
  - Assumes lock will be held for a short time
  - Used to protect the CPU scheduler and to implement locks

```
Spinlock::acquire() {
   while (testAndSet(&lockValue) == BUSY)
      ;
}

Spinlock::release() {
   lockValue = FREE;
  memorybarrier();
}
```

Semaphores

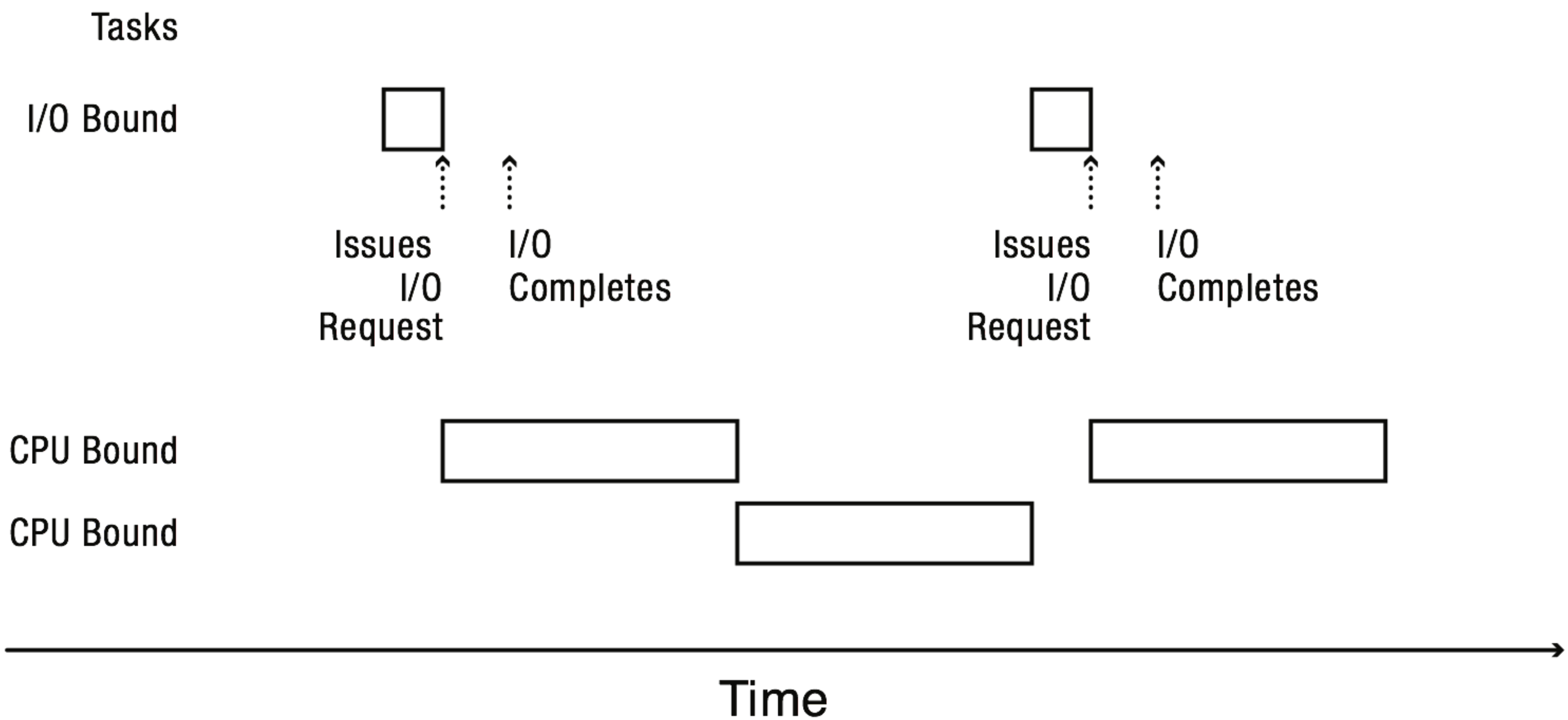
- Semaphore has a non-negative integer value
  - P() atomically waits for value to become > 0, then decrements
  - V() atomically increments value (waking up waiter if needed)
- Semaphores are like integers except:
  - Only operations are P and V
  - Operations are atomic
    - If value is 1, two P's will result in value 0 and one waiter

Scheduling: Principals

- Basic scheduling algorithms
  - FIFO (FCFS)
  - Shortest job first
  - Round Robin

- What is an optimal algorithm in the sense of maximizing the number of jobs finished (i.e., minimizing average response time)?

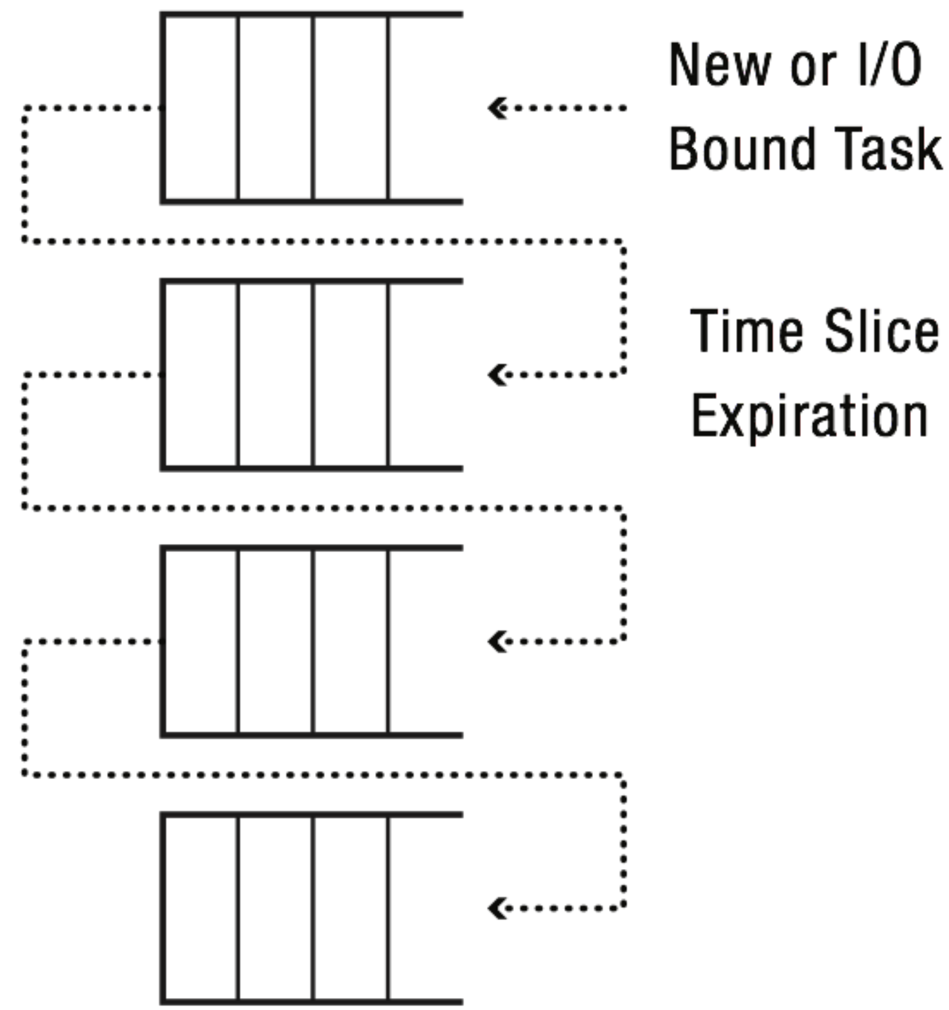
Scheduling: Mixed Workloads??



Scheduling: MFQ

Priority	Time Slice (ms)
1	10
2	20
3	40
4	80

Round Robin Queues



Scheduling: Early Linux

- Linux 1.2: circular queue w/ round-robin policy.
  - Simple and minimal.
  - Did not meet many of the aforementioned goals

- Linux 2.2: introduced scheduling classes (real-time, non-real-time).

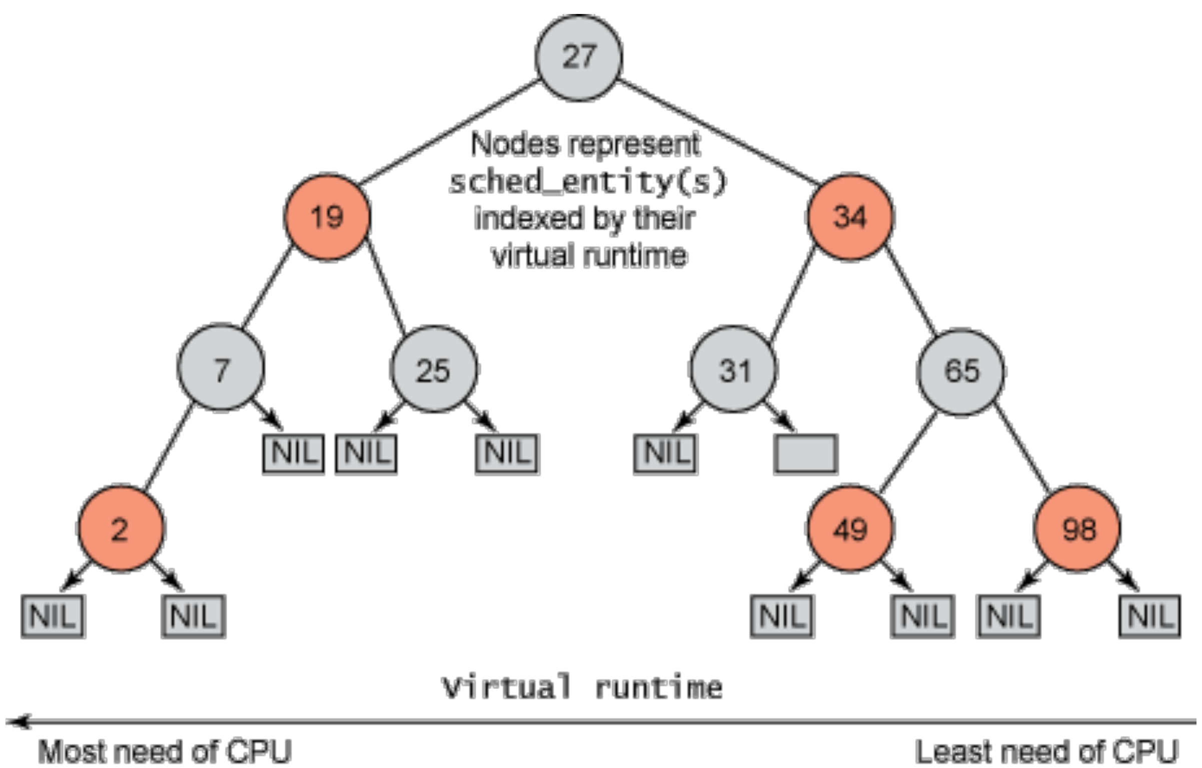
```
/* Scheduling Policies
*/
#define SCHED_OTHER  0 // Normal user tasks (default)
#define SCHED_FIFO   1 // RT: Will almost never be preempted
#define SCHED_RR     2 // RT: Prioritized RR queues
```

Scheduling: CFS

- Merged into the 2.6.23 release of the Linux kernel and is the default scheduler.
- Scheduler maintains a red-black tree where nodes are ordered according to received virtual execution time
- Node with smallest virtual received execution time is picked next
- Priorities determine accumulation rate of virtual execution time
  - Higher priority → slower accumulation rate

Scheduling: Red-Black Trees

- CFS dispenses with a run queue and instead maintains a time-ordered **red-black tree**. Why?



An RB tree is a BST w/ the constraints:

1. Each node is red or black
2. Root node is black
3. All leaves (NIL) are black
4. If node is red, both children are black
5. Every path from a given node to its descendent NIL leaves contains the same number of black nodes

Takeaway: In an RB Tree, the path from the root to the farthest leaf is no more than twice as long as the path from the root to the nearest leaf.

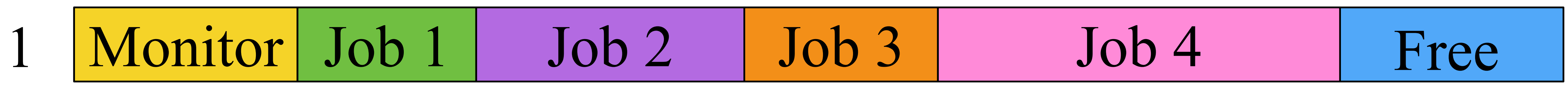
Scheduling: Multi-Processor

- CPU affinity would seem to necessitate a multi-queue approach to scheduling… but how?
- Asymmetric Multiprocessing (AMP): One processor (e.g., CPU 0) handles all scheduling decisions and I/O processing, other processes execute only user code.
- Symmetric Multiprocessing (SMP): Each processor is self-scheduling. Could work with a single queue, but also works with private queues.
  - Potential problems?

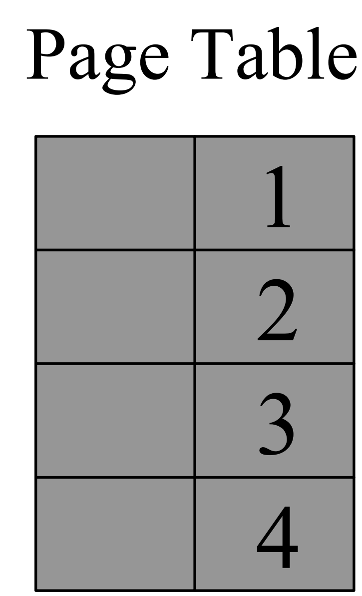
Virtual Memory

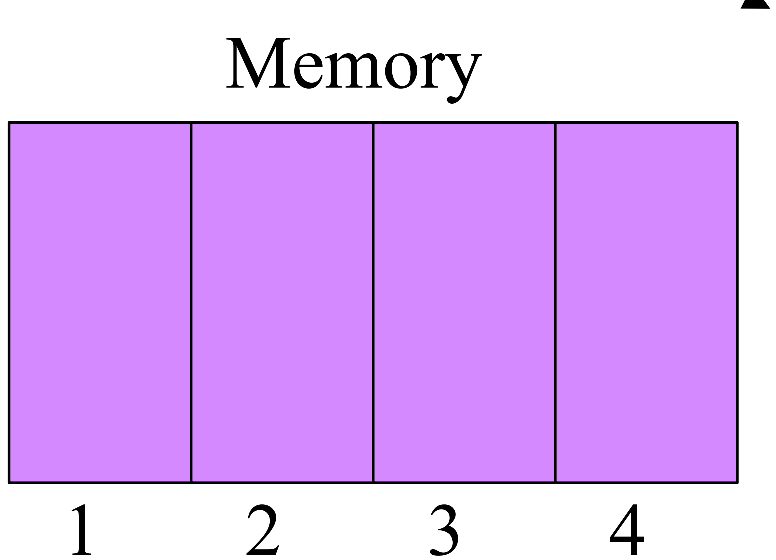
- Provide user with virtual memory that is as big as user needs
- Store virtual memory on disk
- Cache parts of virtual memory being used in real memory
- Load and store cached virtual memory without user program intervention

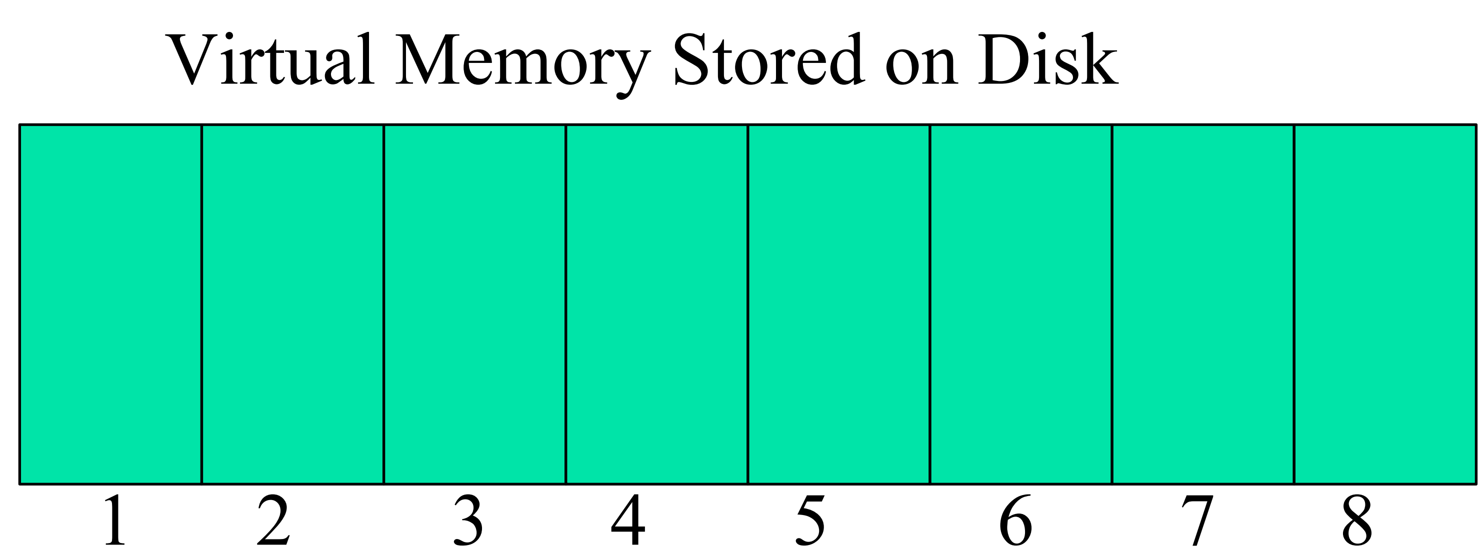
Virtual Memory Systems



- Fixed partitions
  - Internal fragmentation
- Segmentation (variable partition)
  - External fragmentation
- Paging







Page Faults

- Occur when we access a virtual page that is not mapped into any physical page
  - A fault is triggered by hardware
- Page fault handler (in OS's VM subsystem)
  - Find if there is any free physical page available
    - If no, evict some resident page to disk (swapping space)
  - Allocate a free physical page
  - Load the faulted virtual page to the prepared physical page
  - Modify the page table