CS 423
Operating System Design: Midterm Review

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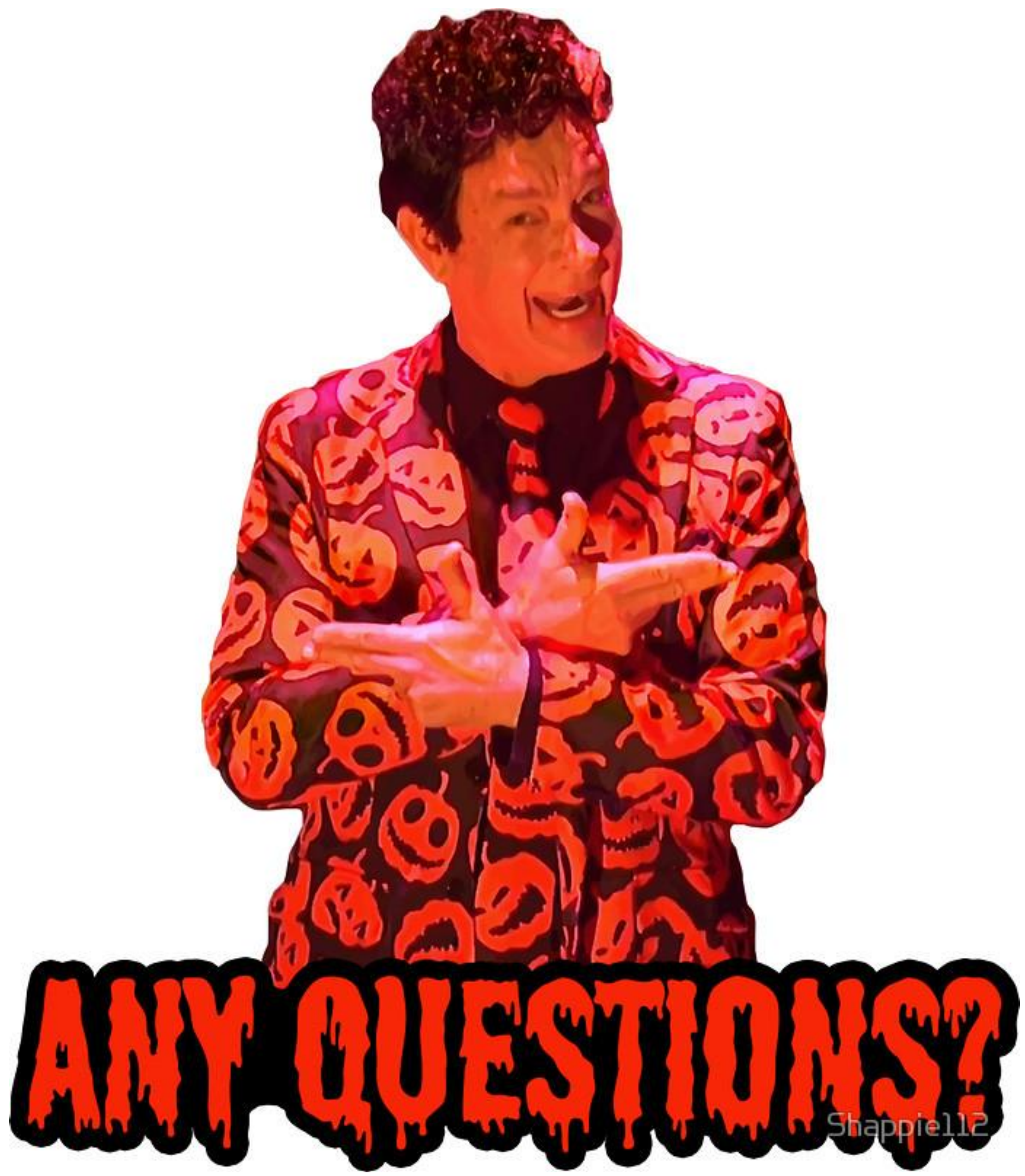
Midterm Details

- In-Class, Oct 18^{th} (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 memory I&II).

Midterm Details

- No need to memorize terms.
- Ask me during the exam, if you forget some names or abbreviation.
  - Demo: “What is MLFQ”?
- Mostly short answers + small coding questions
  - Review MP1!
- 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?

More Q&A

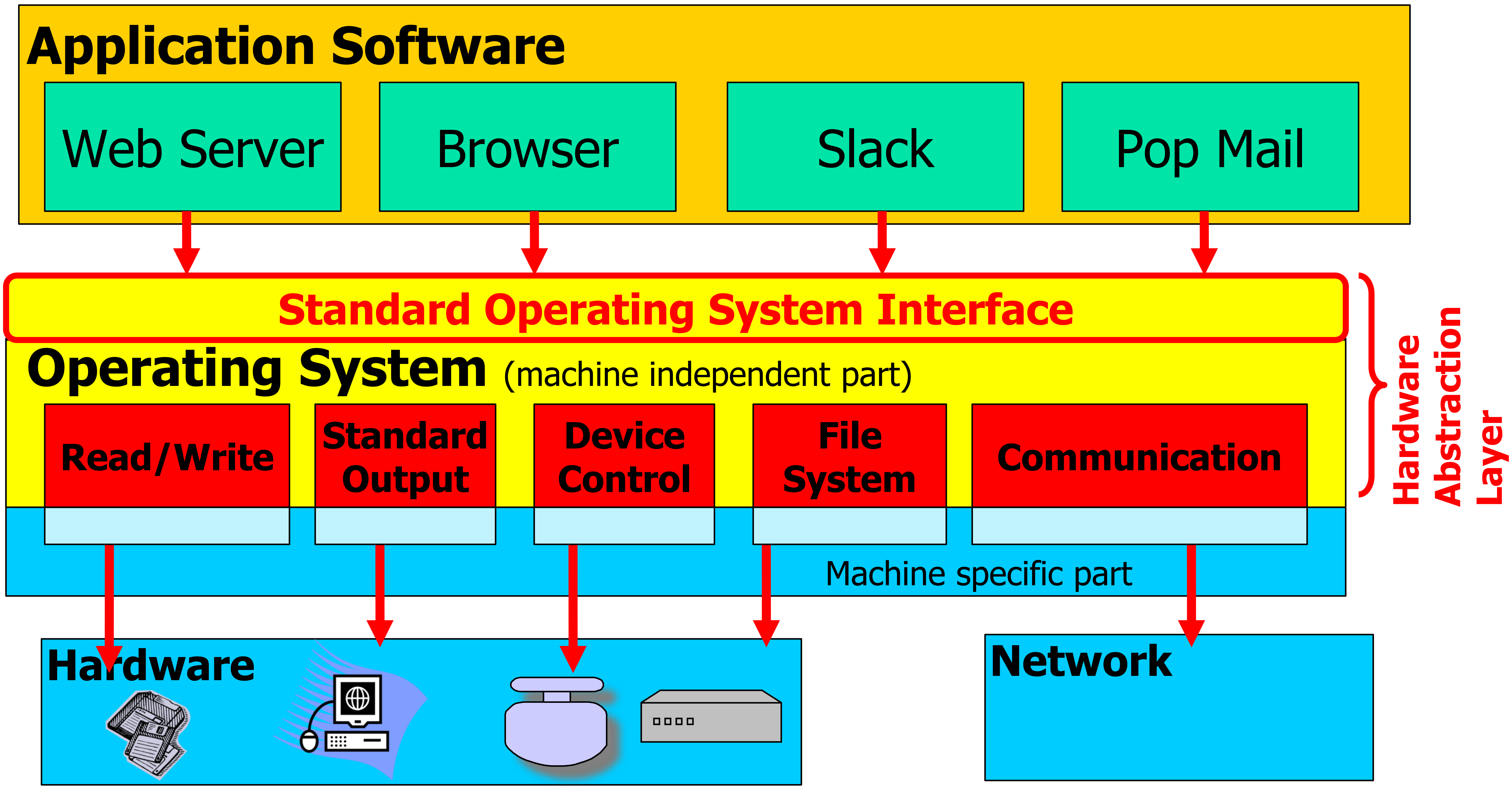


Remainder of these slides

- <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

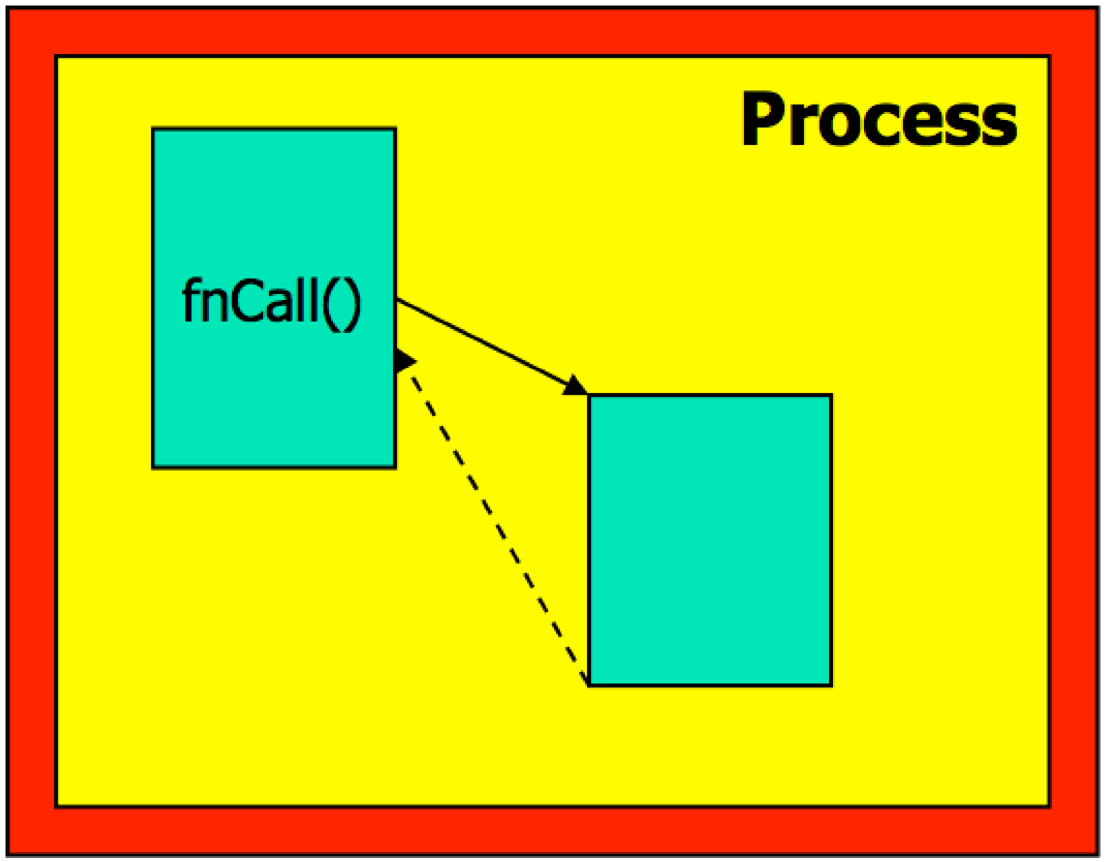
Role #1: Referee
- Manage resource allocation between users and applications
- Isolate different users and applications from one another
- Facilitate and mediate communication between different users and applications

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?**

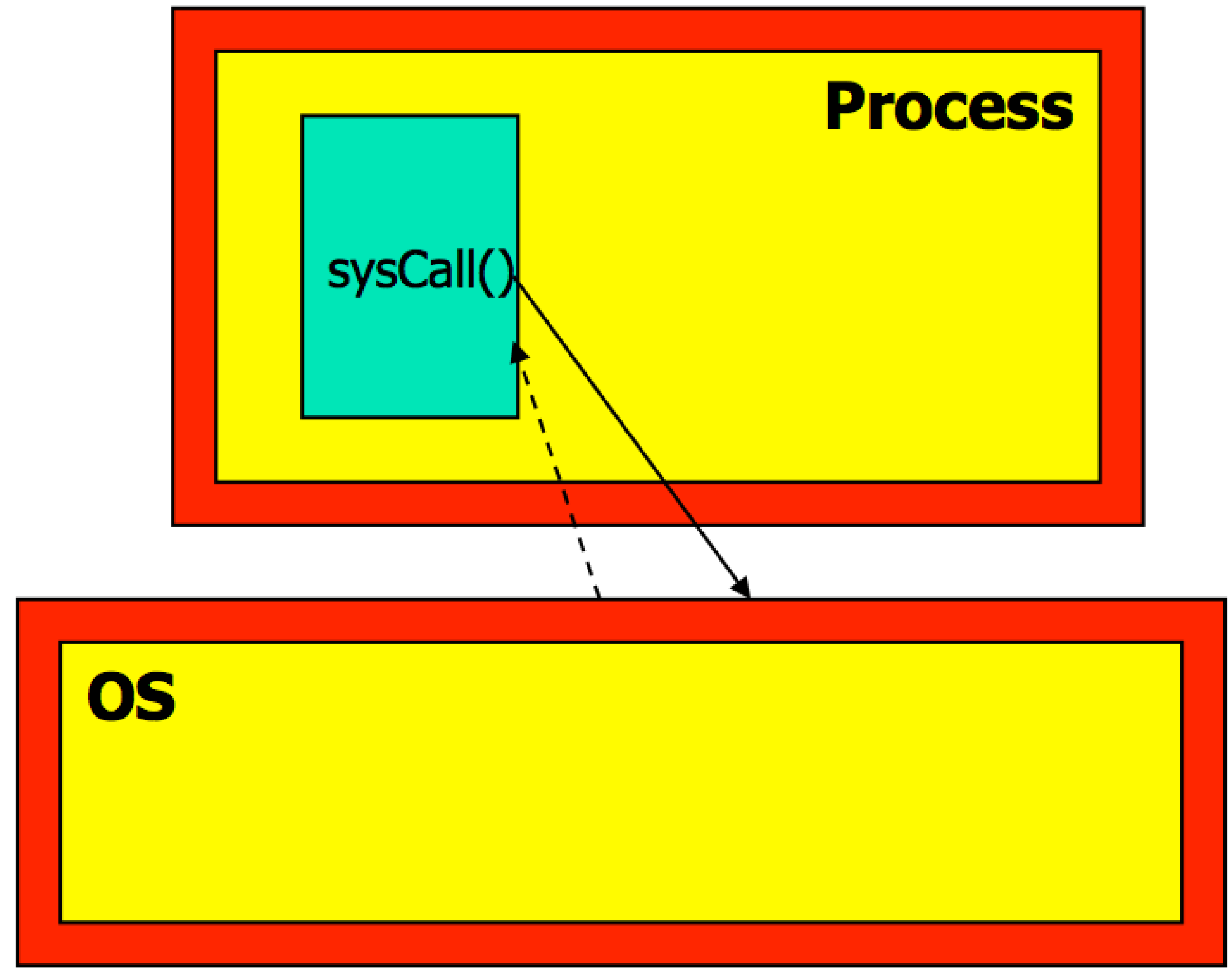
Review: System Calls

Function Calls



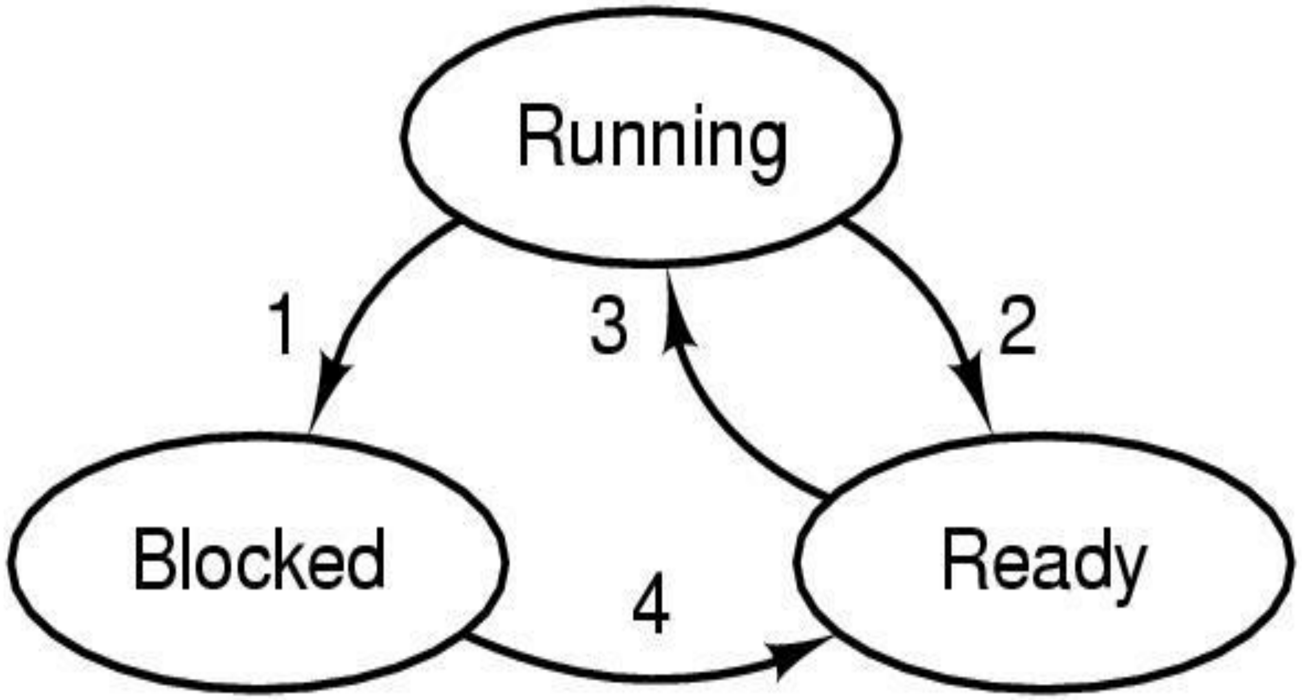
Caller and callee are in the same Process
- Same user
- Same "domain of trust"

System Calls



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

Review: Process Abstraction

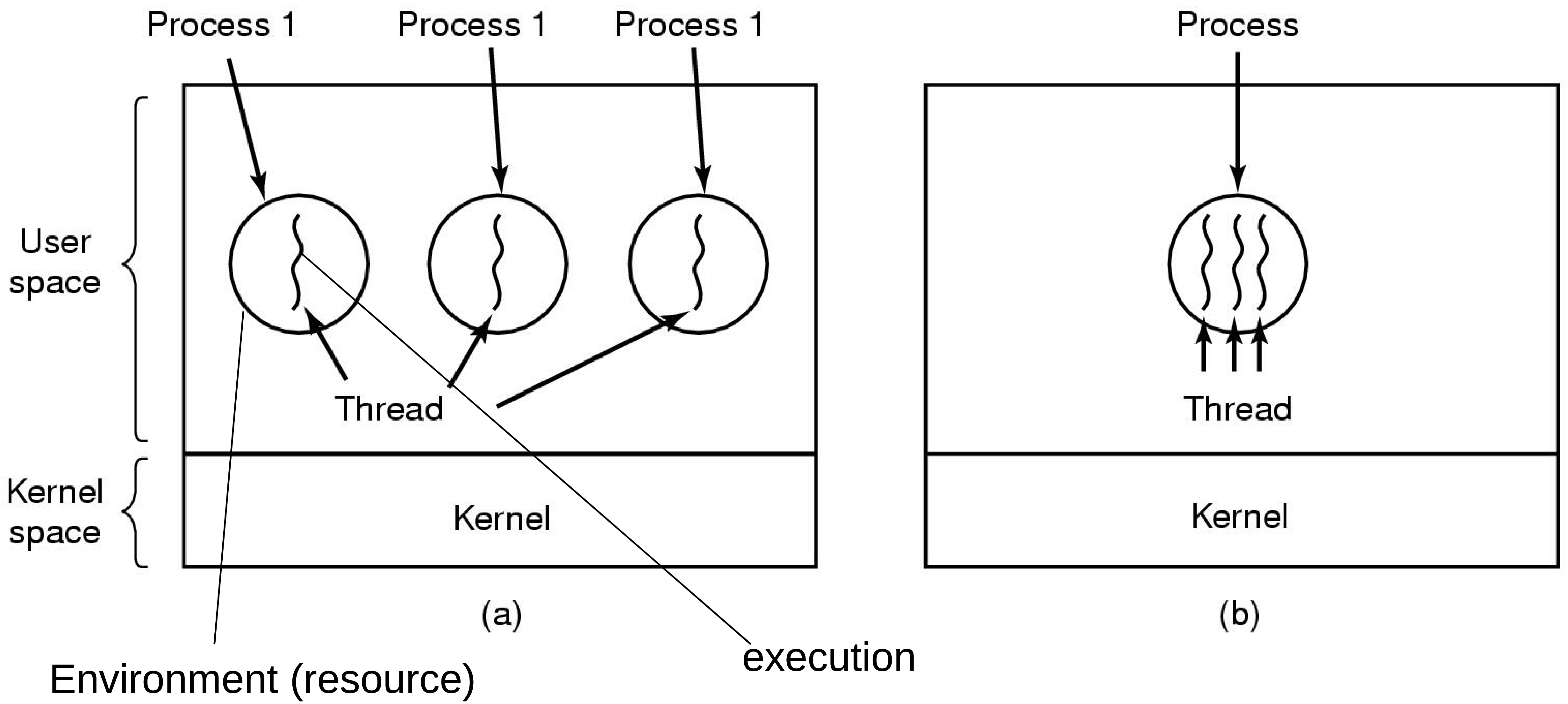


1. Process blocks for input
2. Scheduler picks another process
3. Scheduler picks this process
4. Input becomes available

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

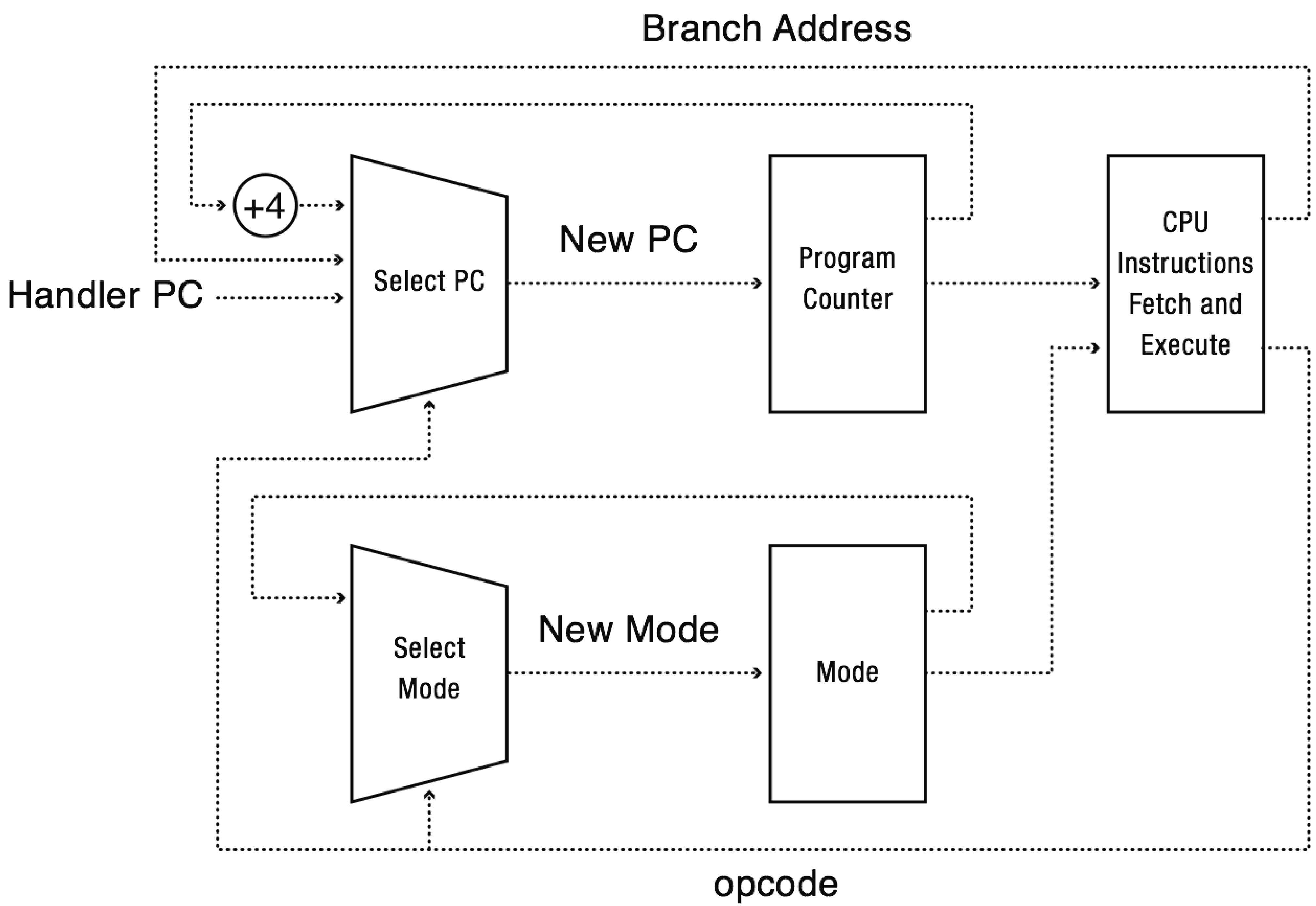
Question: in a single processor machine, how many process can be in running state?

Review: Threads

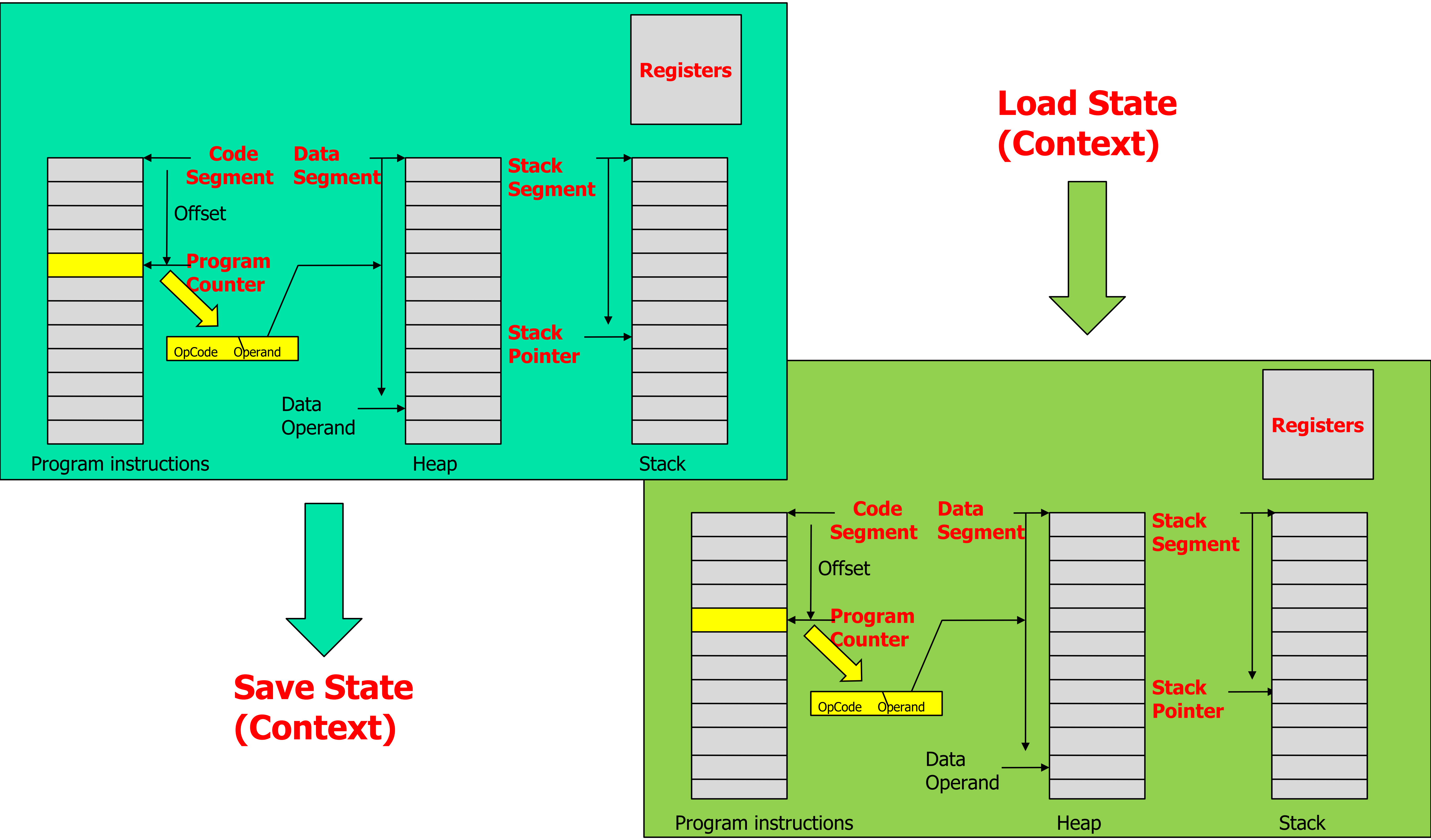


- (a) Three processes each with one thread
- (b) One process with three threads

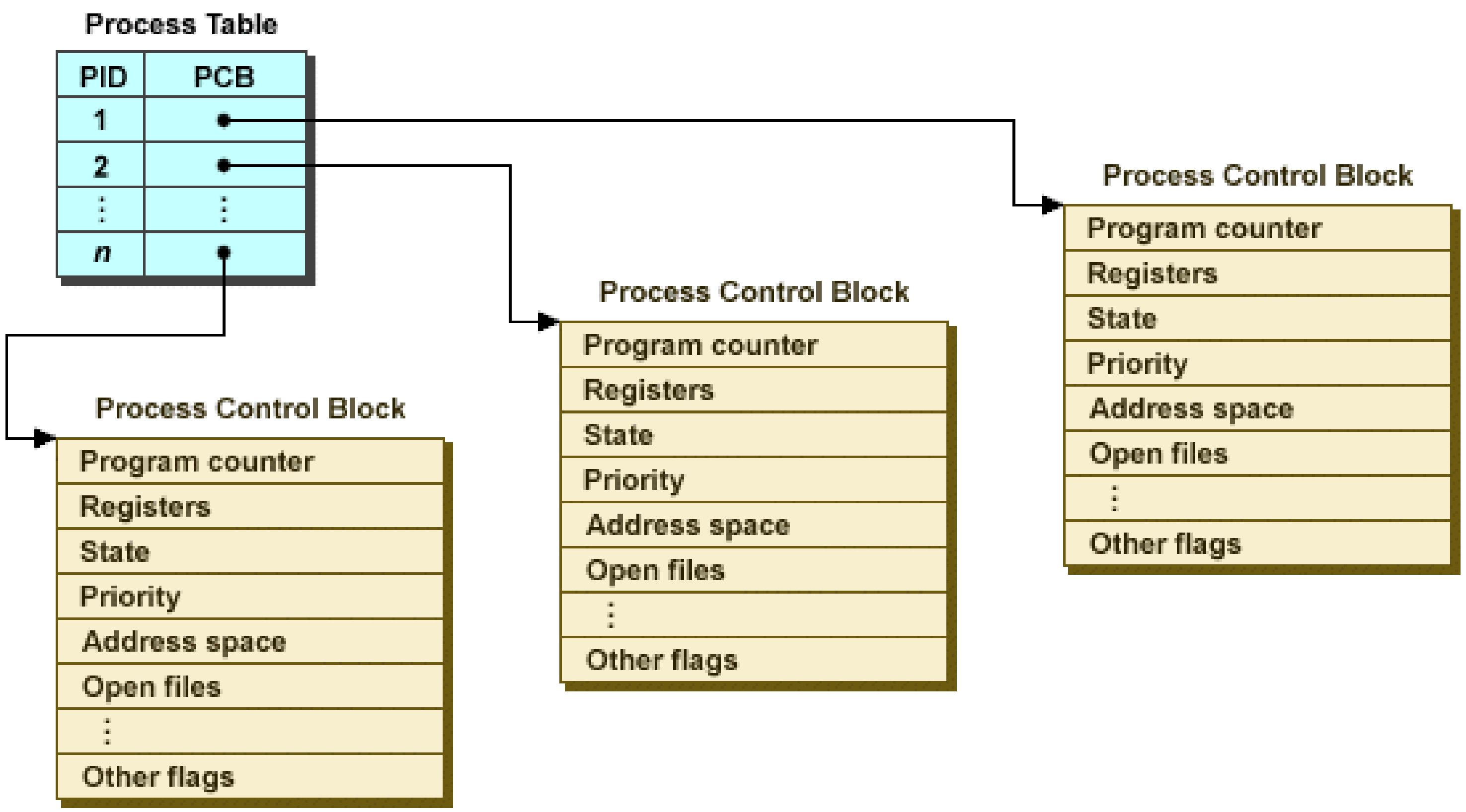
Kernel Abstraction: HW Support



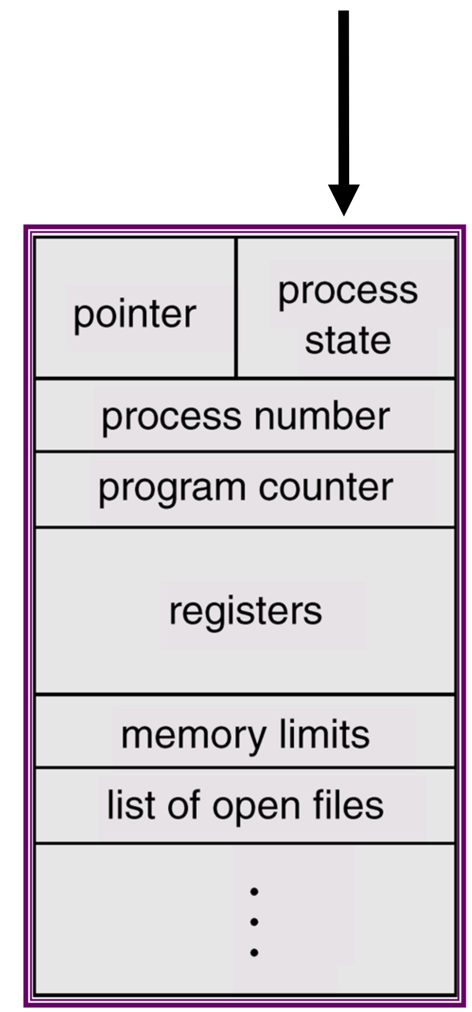
Kernel Abstraction: CTX Switch



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



Updated during context switch

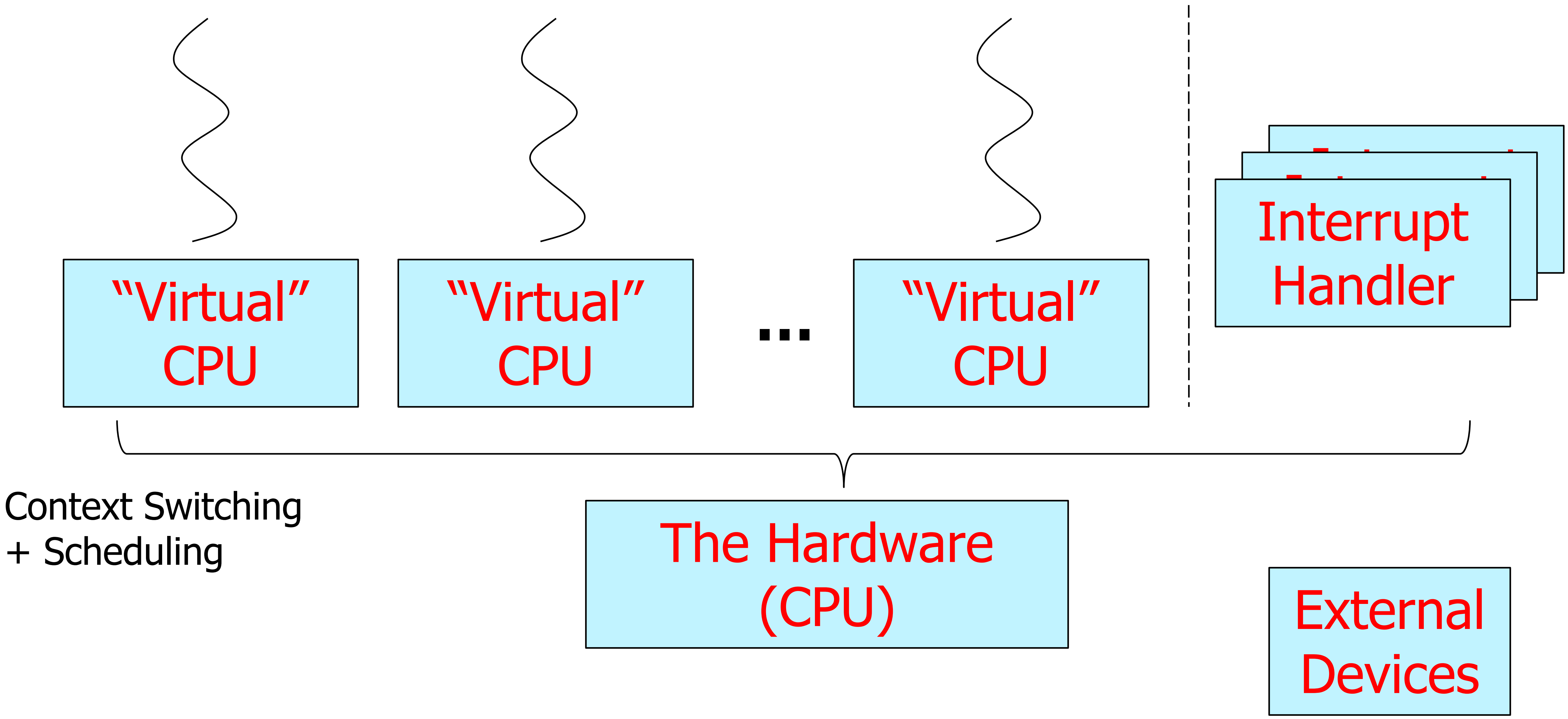


An alternate PCB diagram

Interrupts: Model

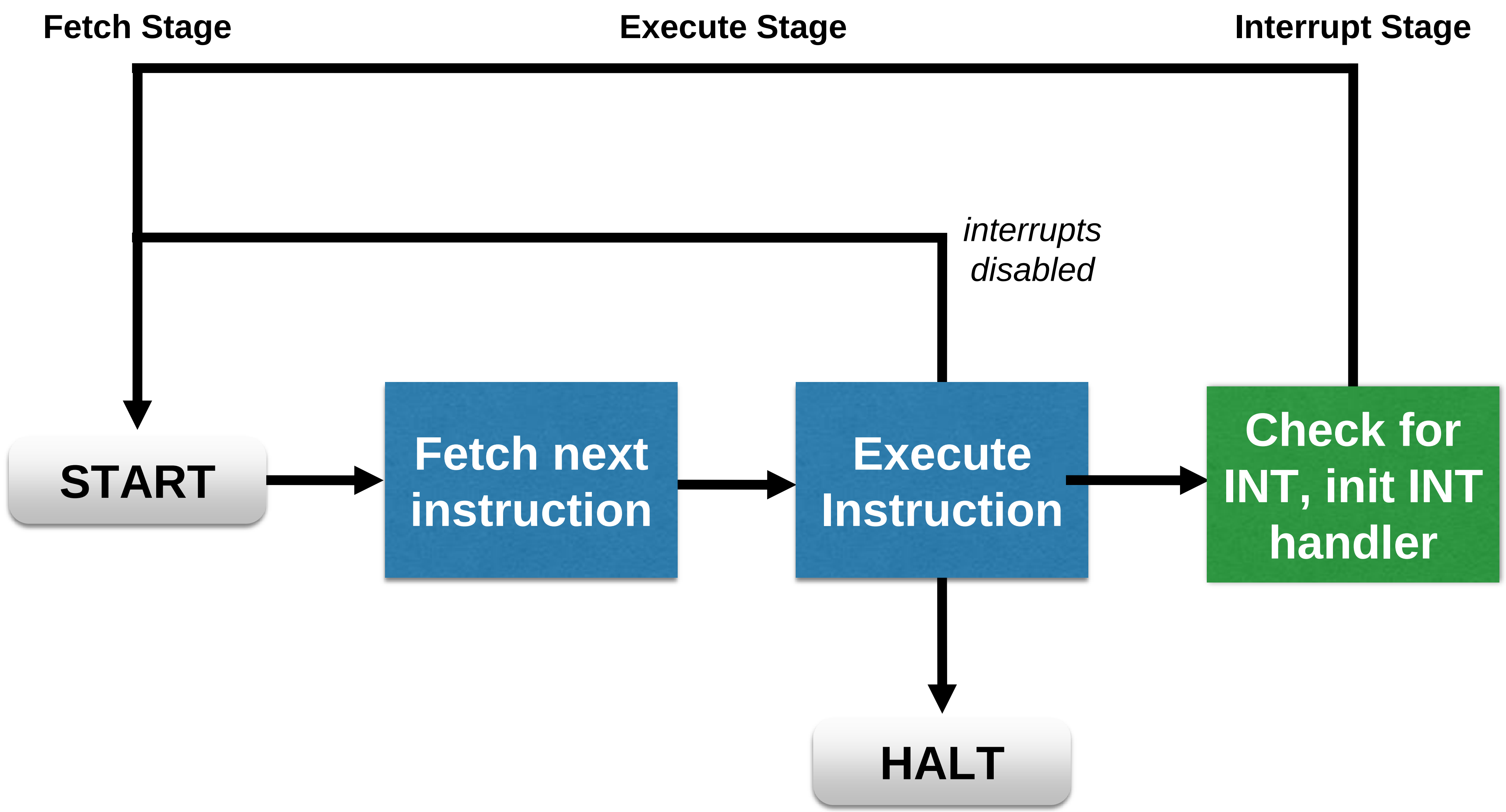
Interrupts to drive scheduling decisions!

Interrupt handlers are also tasks that share the CPU.



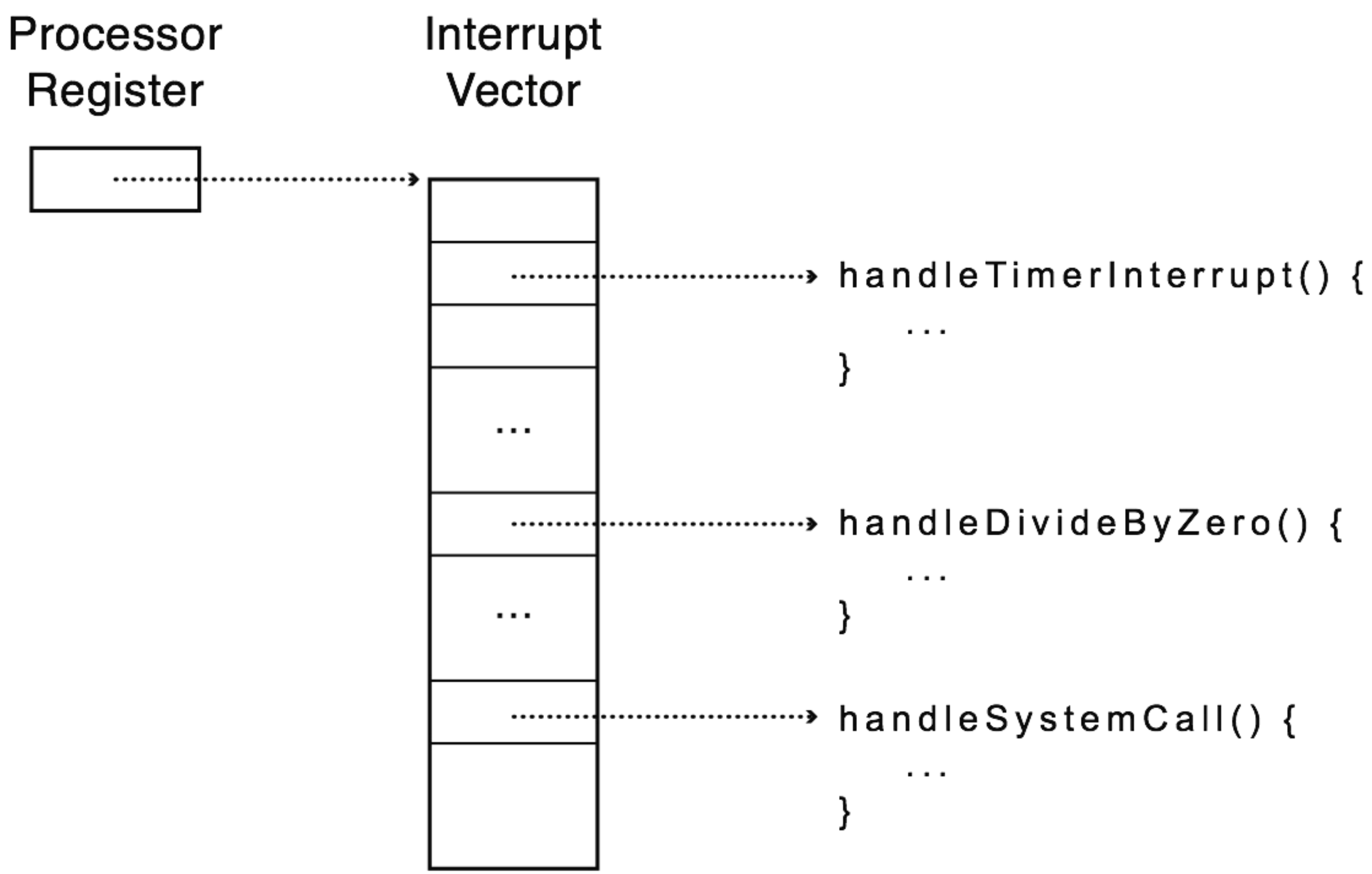
Interrupts: Handling

How does interrupt handling change the instruction cycle?



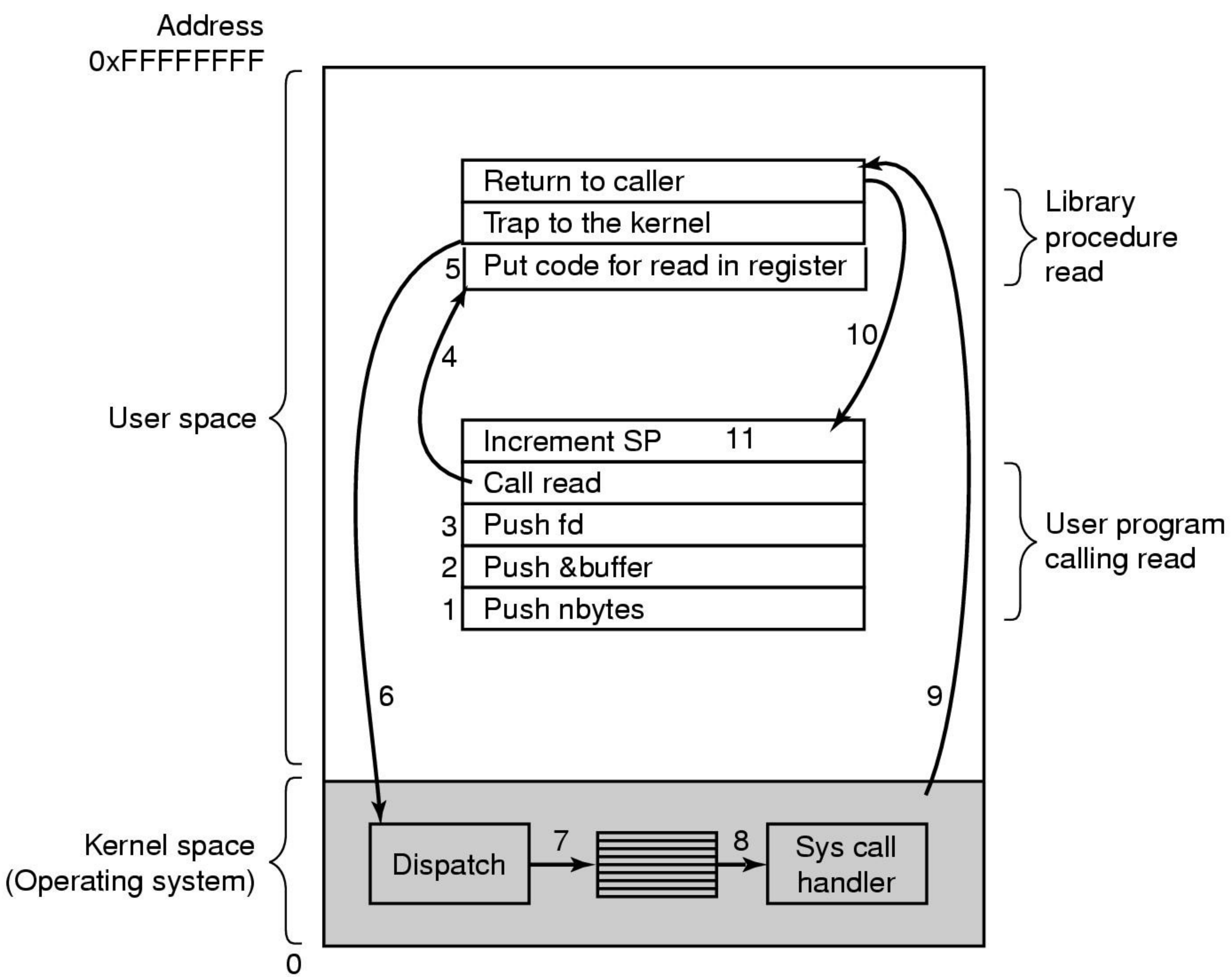
Interrupts: Handling

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

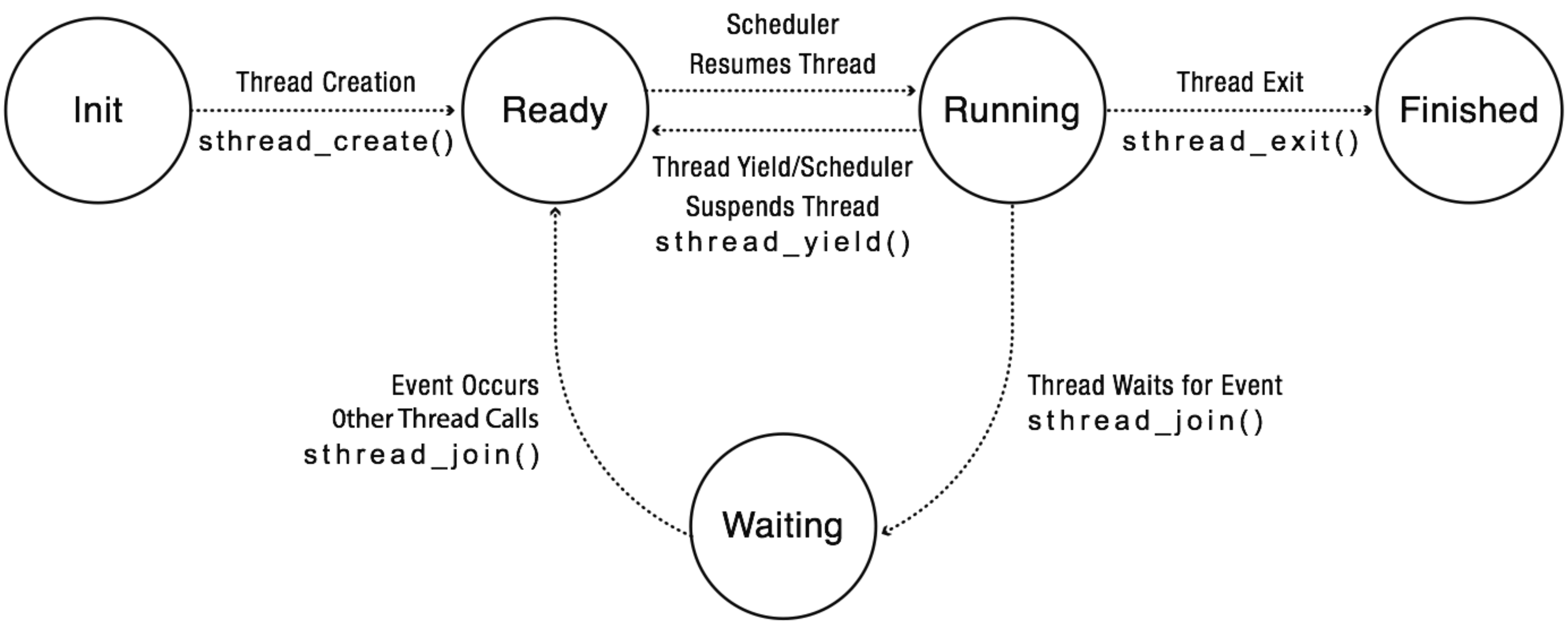


System Calls: Under the Hood

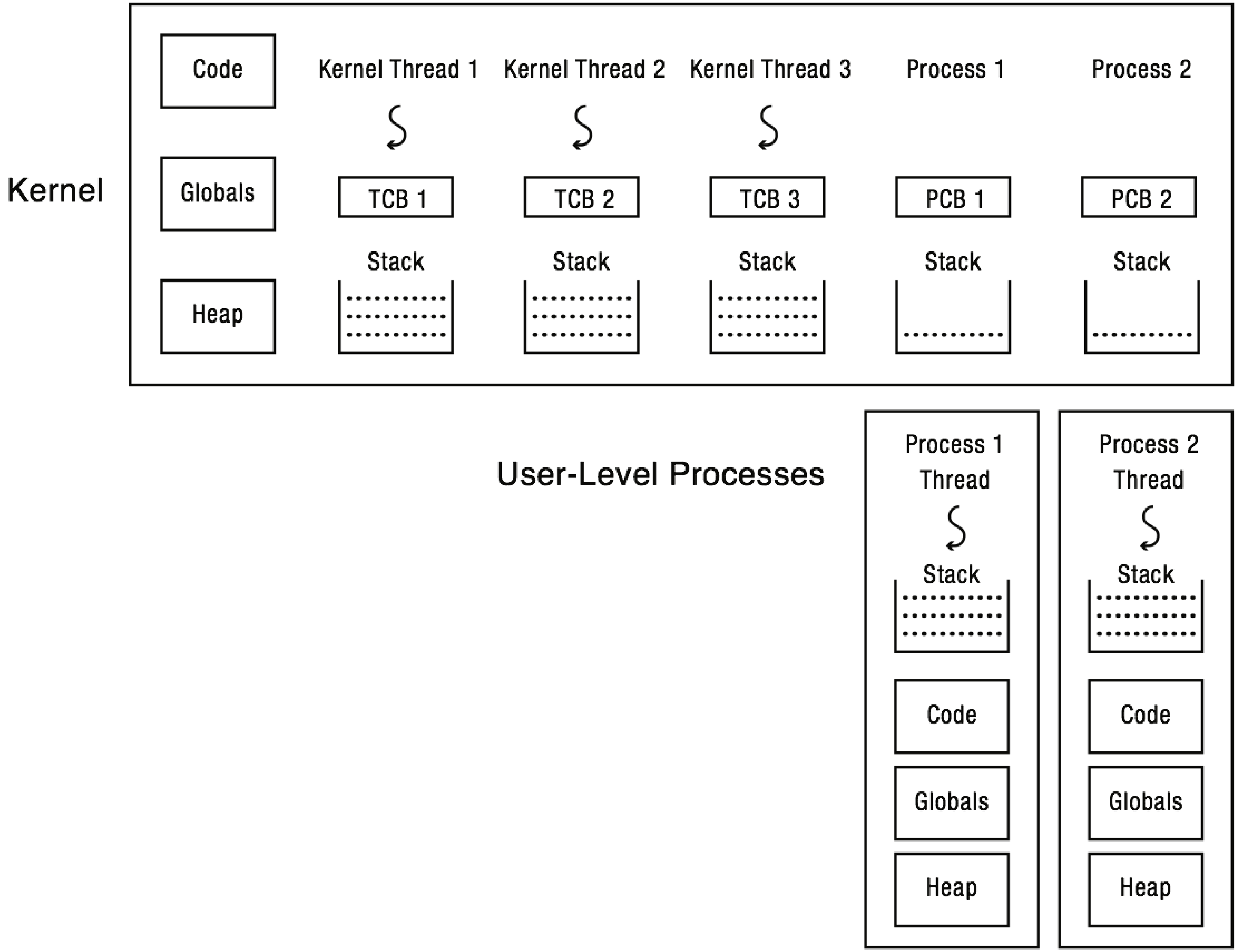
read (fd, buffer, nbytes)



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

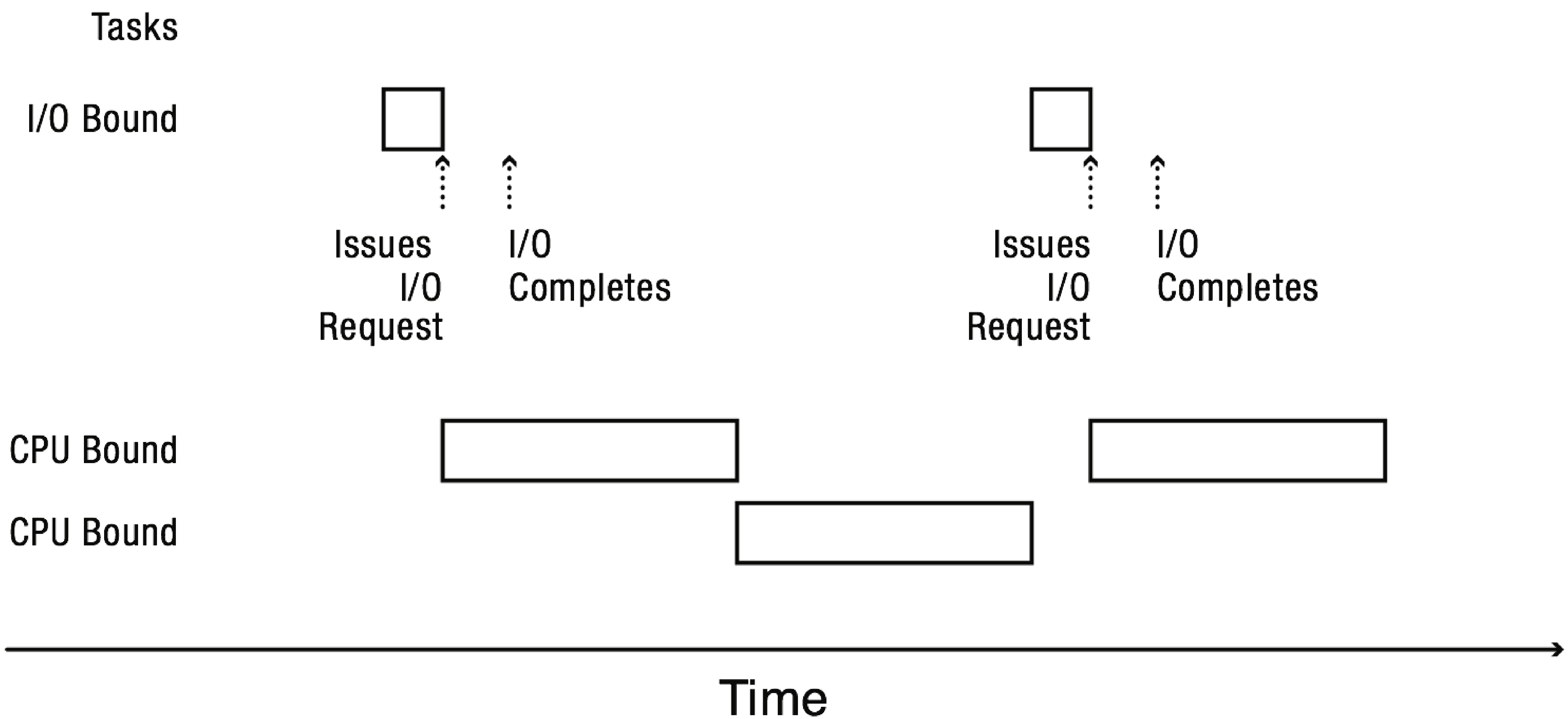
- Semaphore has a non-negative integer value
  - P() atomically waits for value to become > 0, then decrements
  - V() atomically increments value (waking up waiter if needed)
- Semaphores are like integers except:
  - Only operations are P and V
  - Operations are atomic
    - If value is 1, two P's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

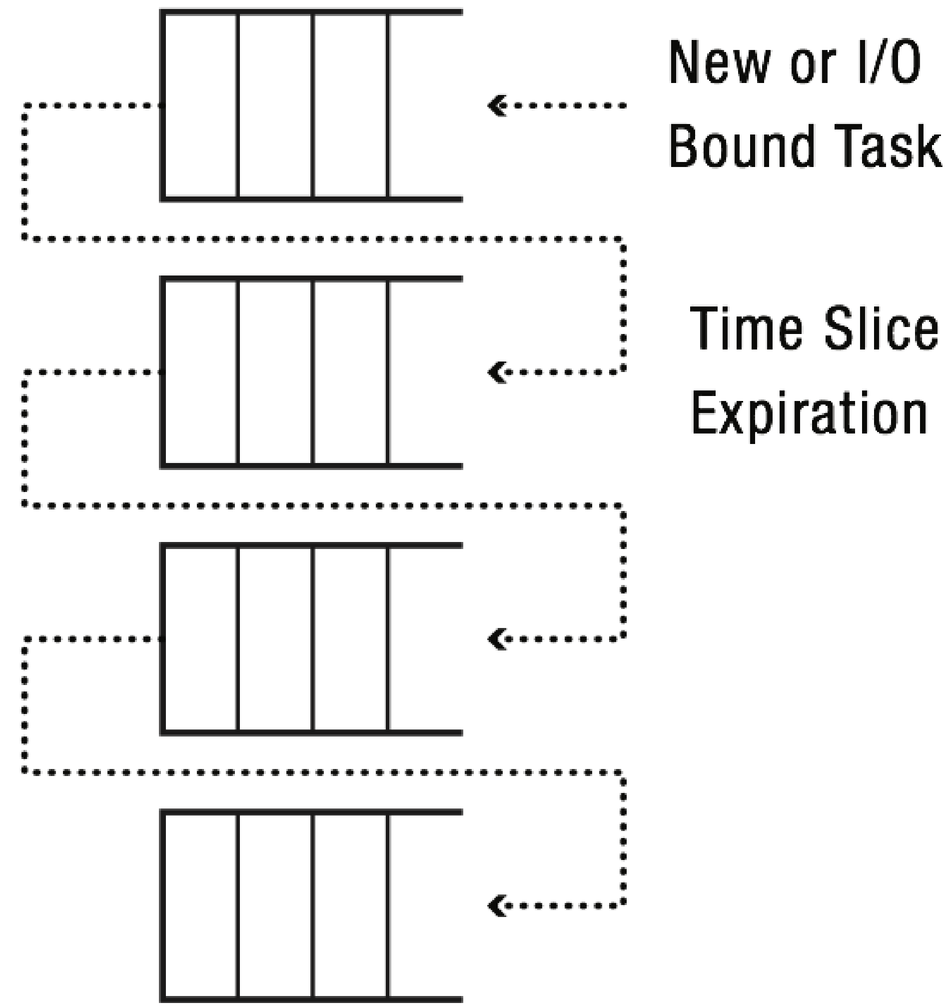
Scheduling: Mixed Workloads??



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).

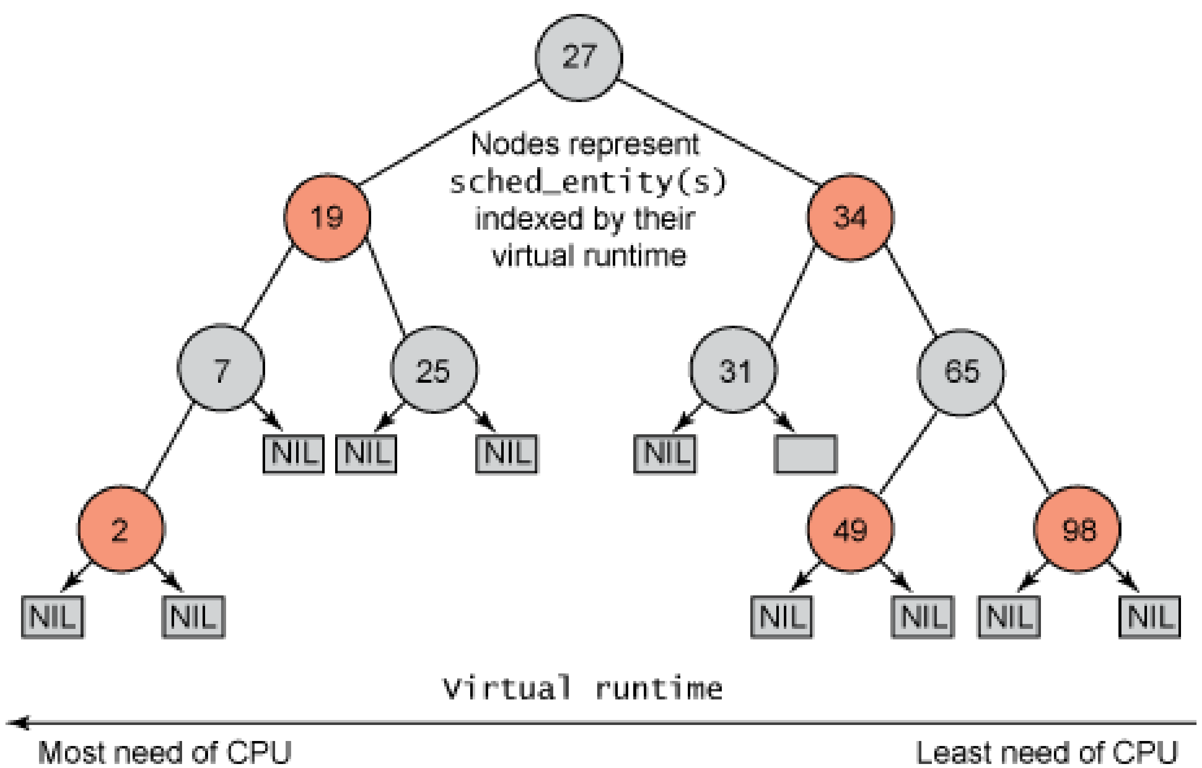
```
/* Scheduling Policies
*/
#define SCHED_OTHER  0 // Normal user tasks (default)
#define SCHED_FIFO   1 // RT: Will almost never be preempted
#define SCHED_RR     2 // RT: Prioritized RR queues
```

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.

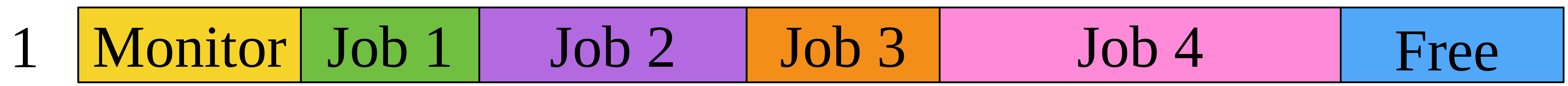
Scheduling: Multi-Processor

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

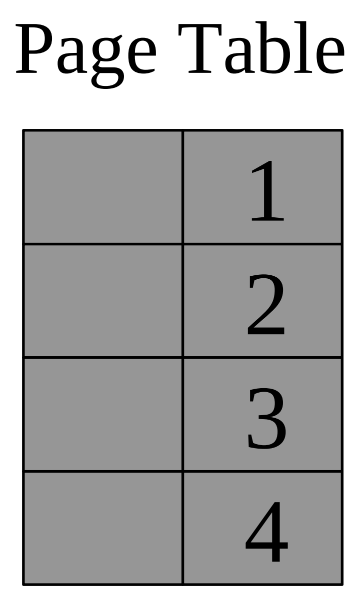
Virtual Memory

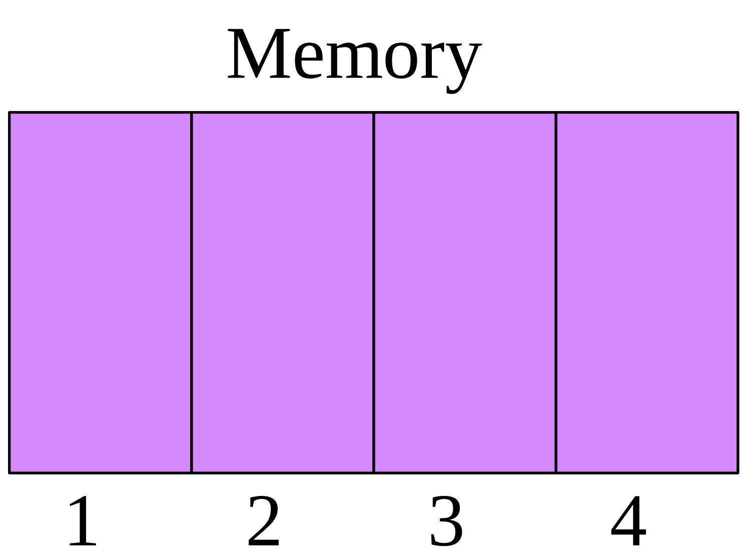
- Provide user with virtual memory that is as big as user needs
- Store virtual memory on disk
- Cache parts of virtual memory being used in real memory
- Load and store cached virtual memory without user program intervention

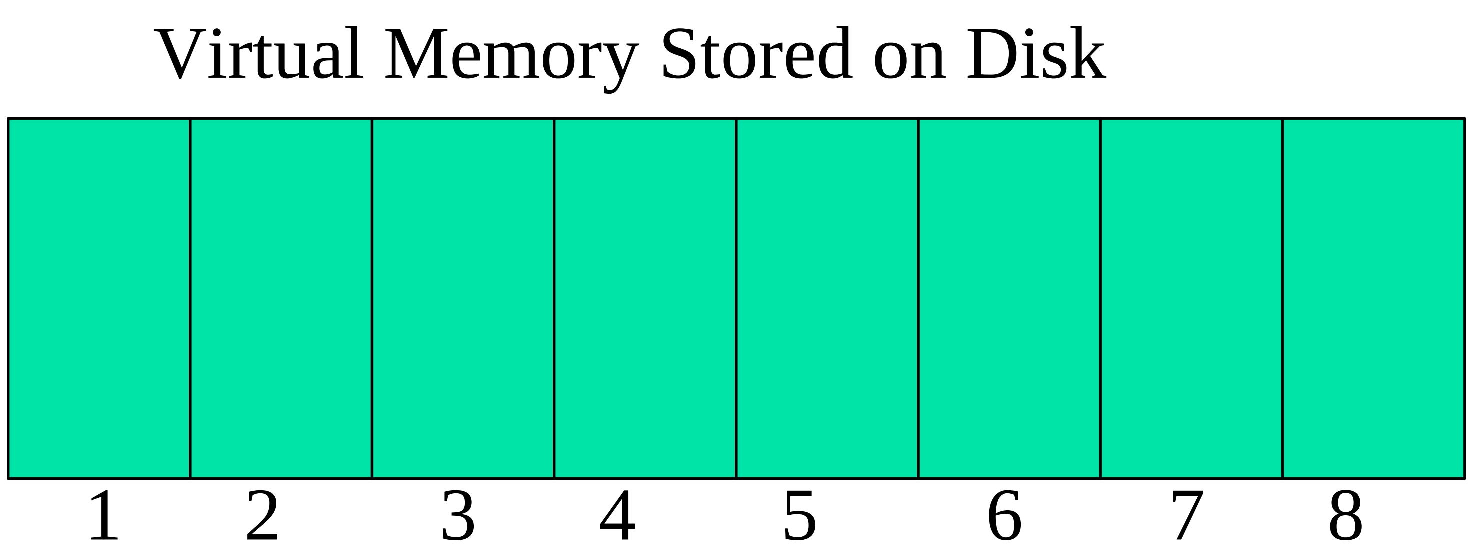
Virtual Memory Systems



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



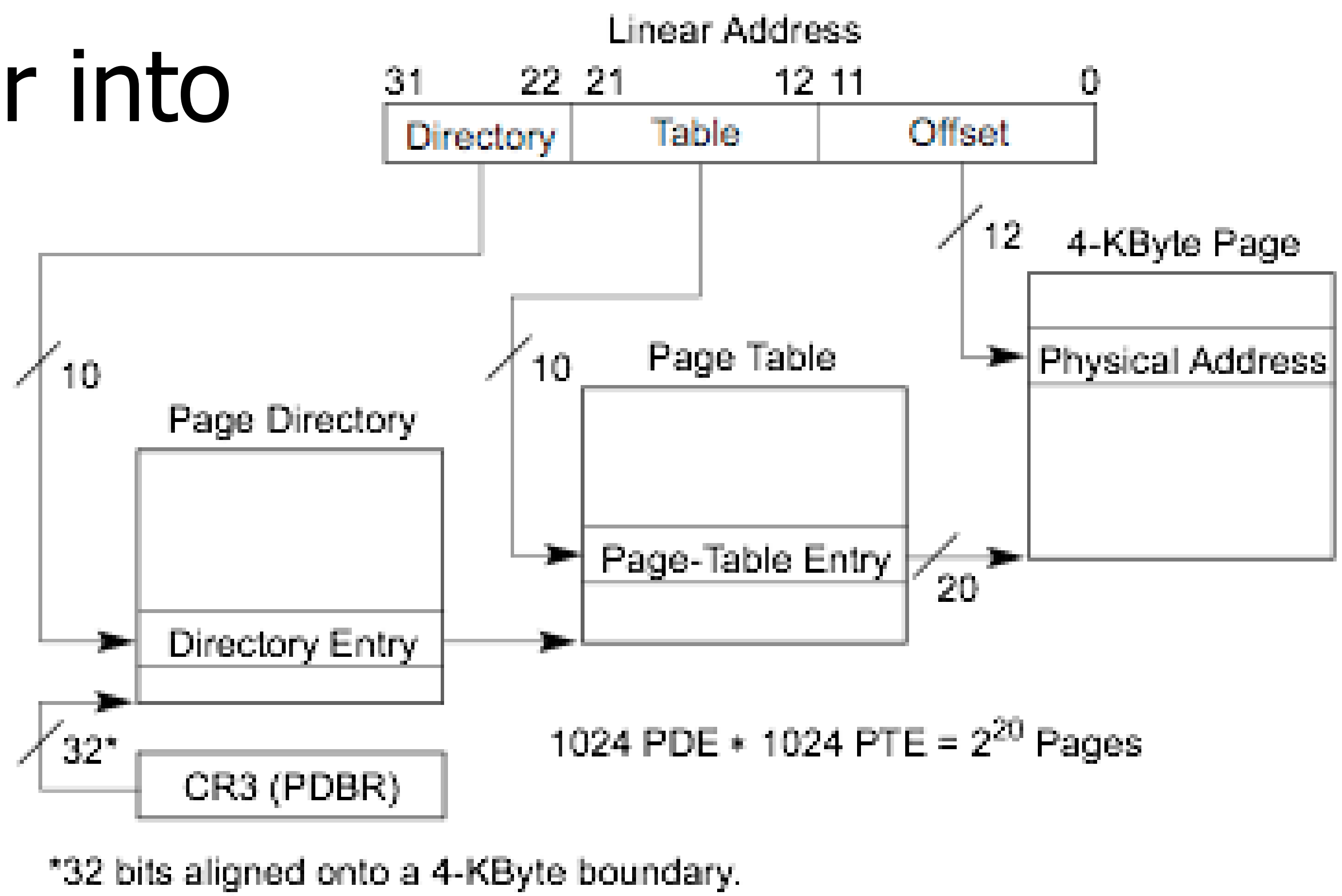




Multi-level Page Tables

Example: Addressing in a Multi-level Page Table system.

- A logical address (on 32-bit x86 with 4k page size) is divided into
  - A page number consisting of 20 bits
  - A page offset consisting of 12 bits
- Divide the page number into
  - A 10-bit page directory
  - A 10-bit page number



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