Part 2: Processes and Threads

- **Process Concept**
- Process Scheduling
- Operation on Processes
- Interprocess Communication
- Threads

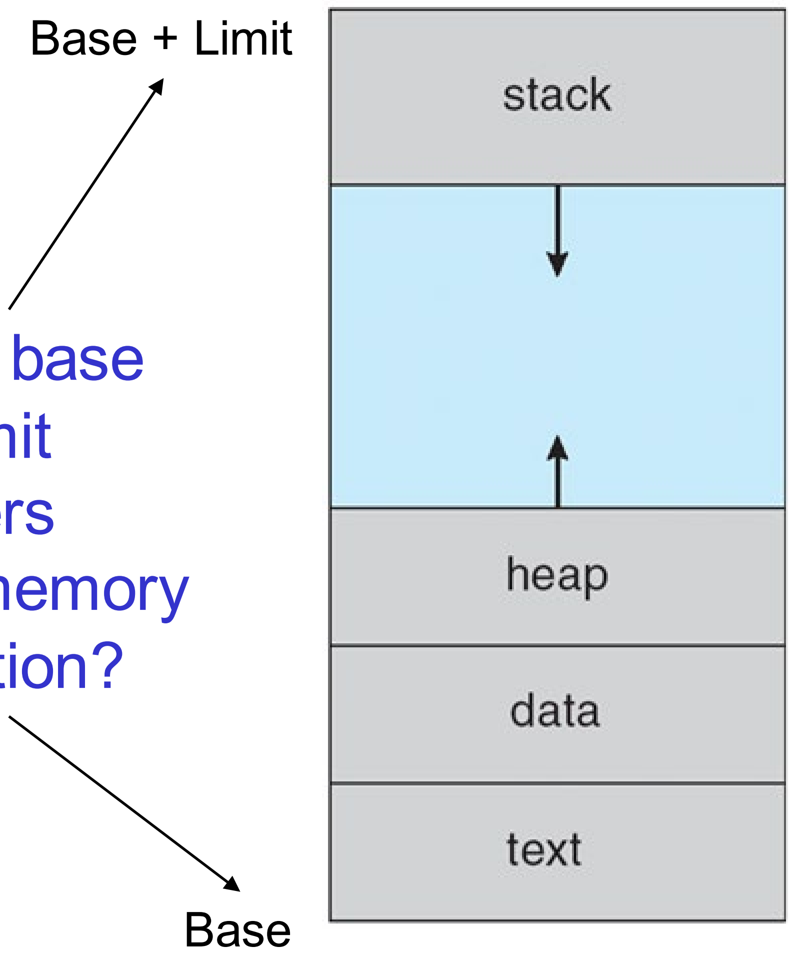
Process Concept

- Process: **A program in execution**; process execution must progress in a sequential fashion

- An operating system executes a variety of processes
  - Batch system – jobs
  - Time-sharing system – user programs & commands

- Textbook uses the terms *job* and *process* almost interchangeably (Job = Process)

Process in Memory



(parameters and local variables in a function)

(all dynamically allocated variables, e.g., a=new int[10])

(global parameters)

(code section, program)

Recall base and limit registers from memory protection?

Process State

As a process executes, it changes *state*

1. New: The process is being created

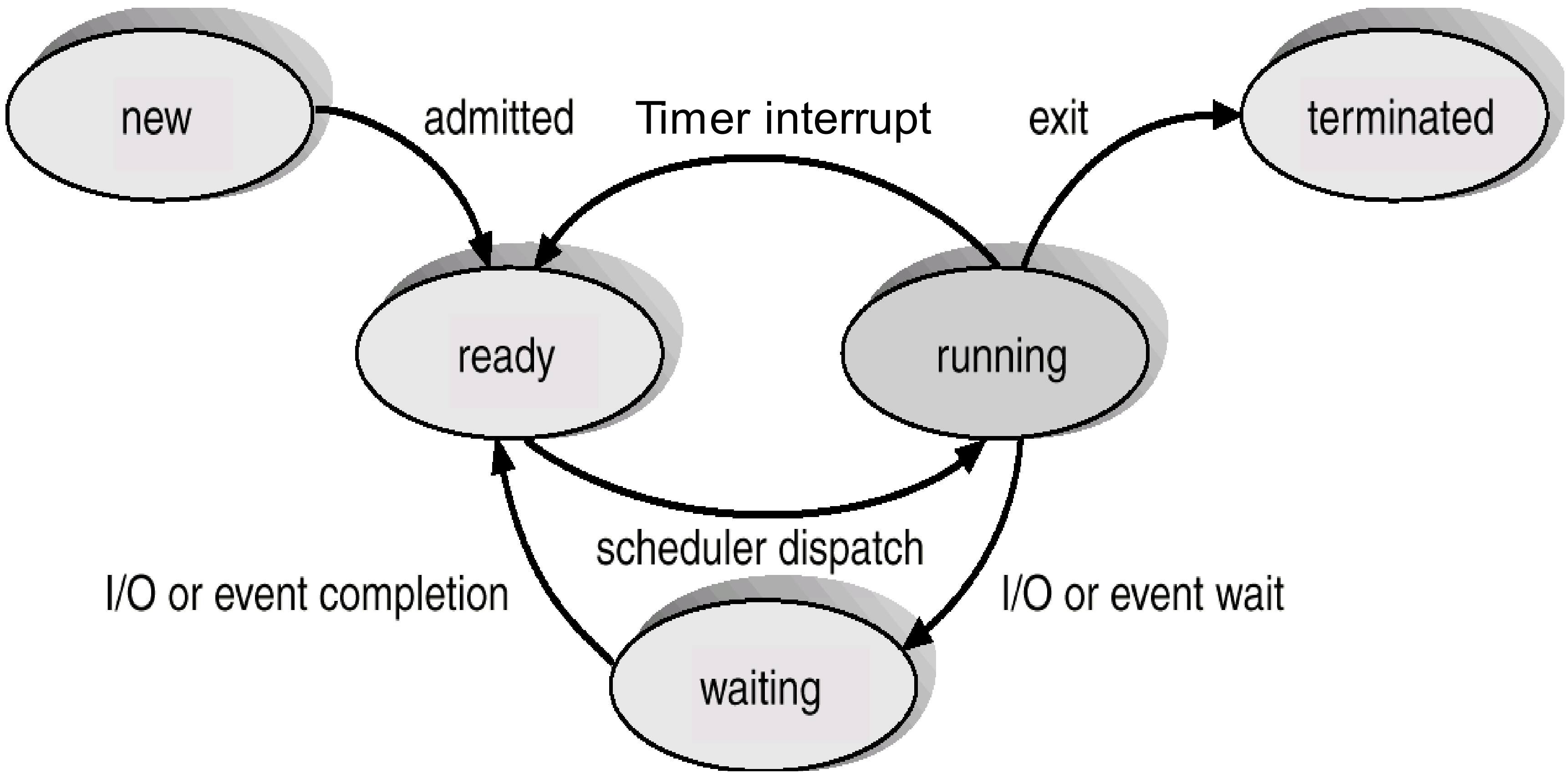
2. Running: Instructions are being executed

3. Waiting: The process is waiting for I/O or event

4. Ready: The process is ready to run, but is waiting to be assigned to the CPU

5. Terminated: The process has completed

Diagram of Process State Transitions



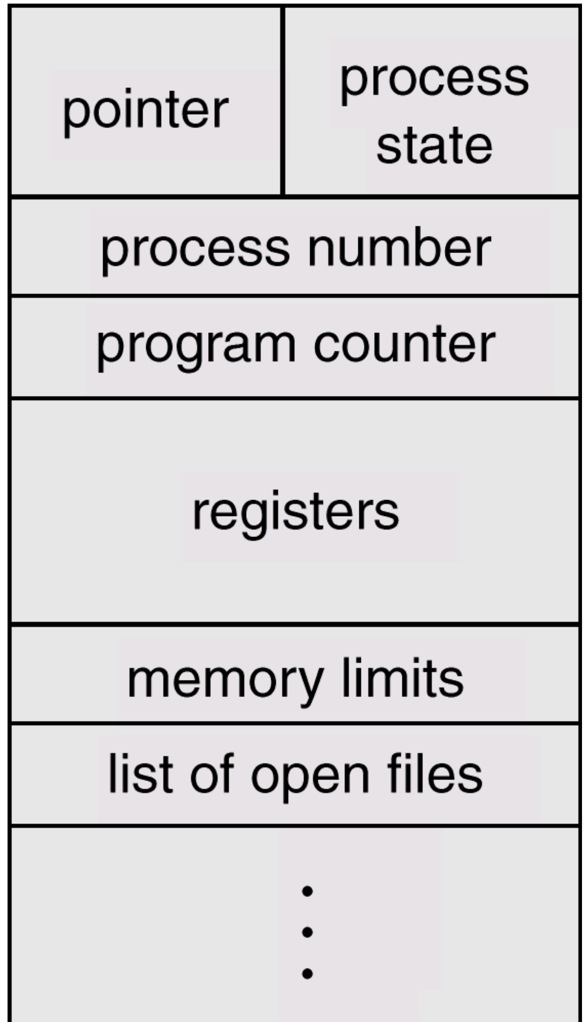
Timer interrupt is used in multiprogramming systems to switch between ready processes

Process Control Block (PCB)

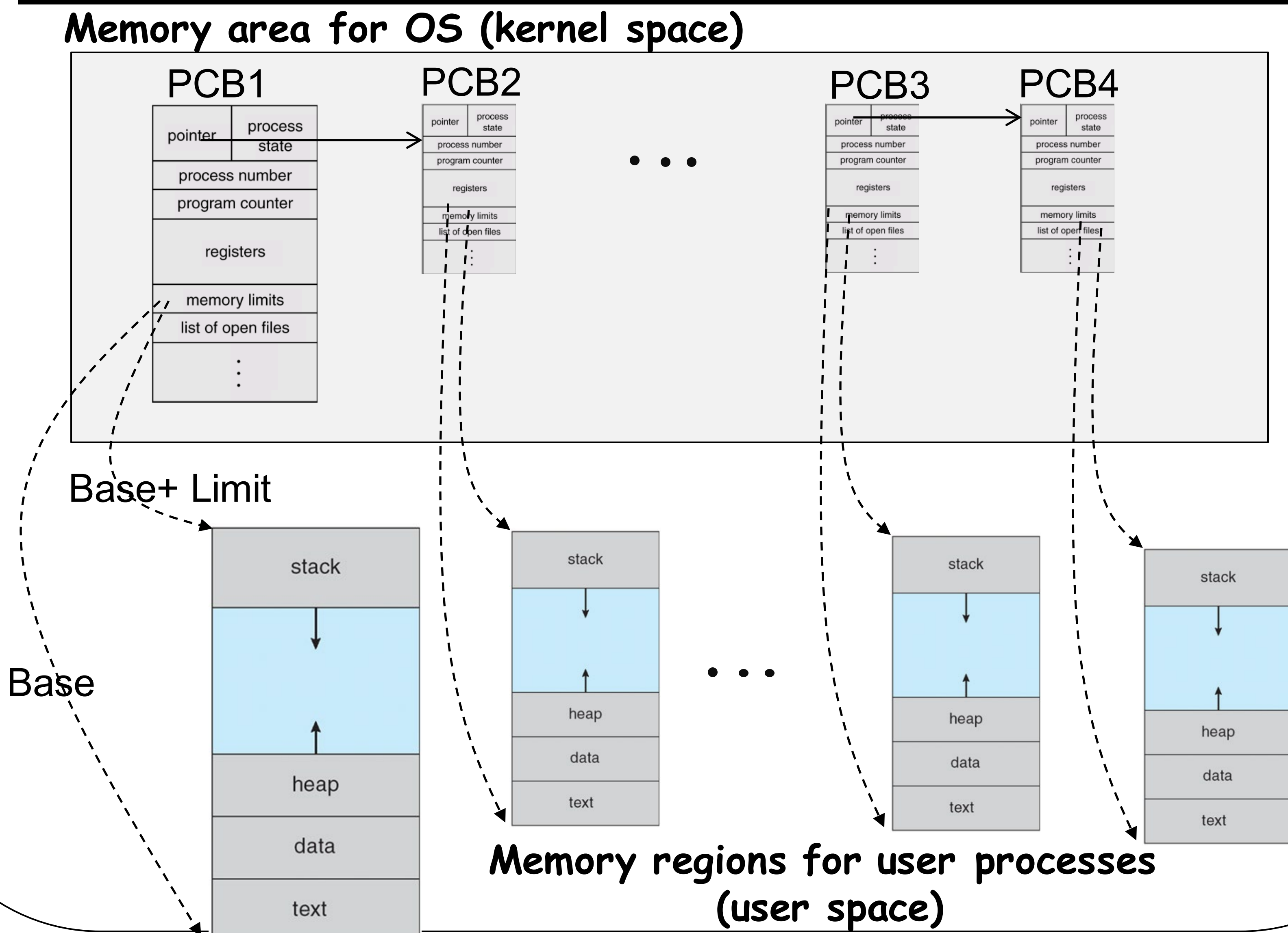
Keeps information associated with each process

1. Pointer to other PCBs (PCBs are maintained in a queue/list structure)
2. Process state
3. Process number (process id)
4. Program counter (pointer to the next instruction)
5. CPU registers
6. Process priority (used in process scheduling)
7. Memory management information (e.g., base and limit register values)
8. Information regarding files (e.g., list of open files)

Process Control Block (PCB)



PCB and Processes in Main Memory



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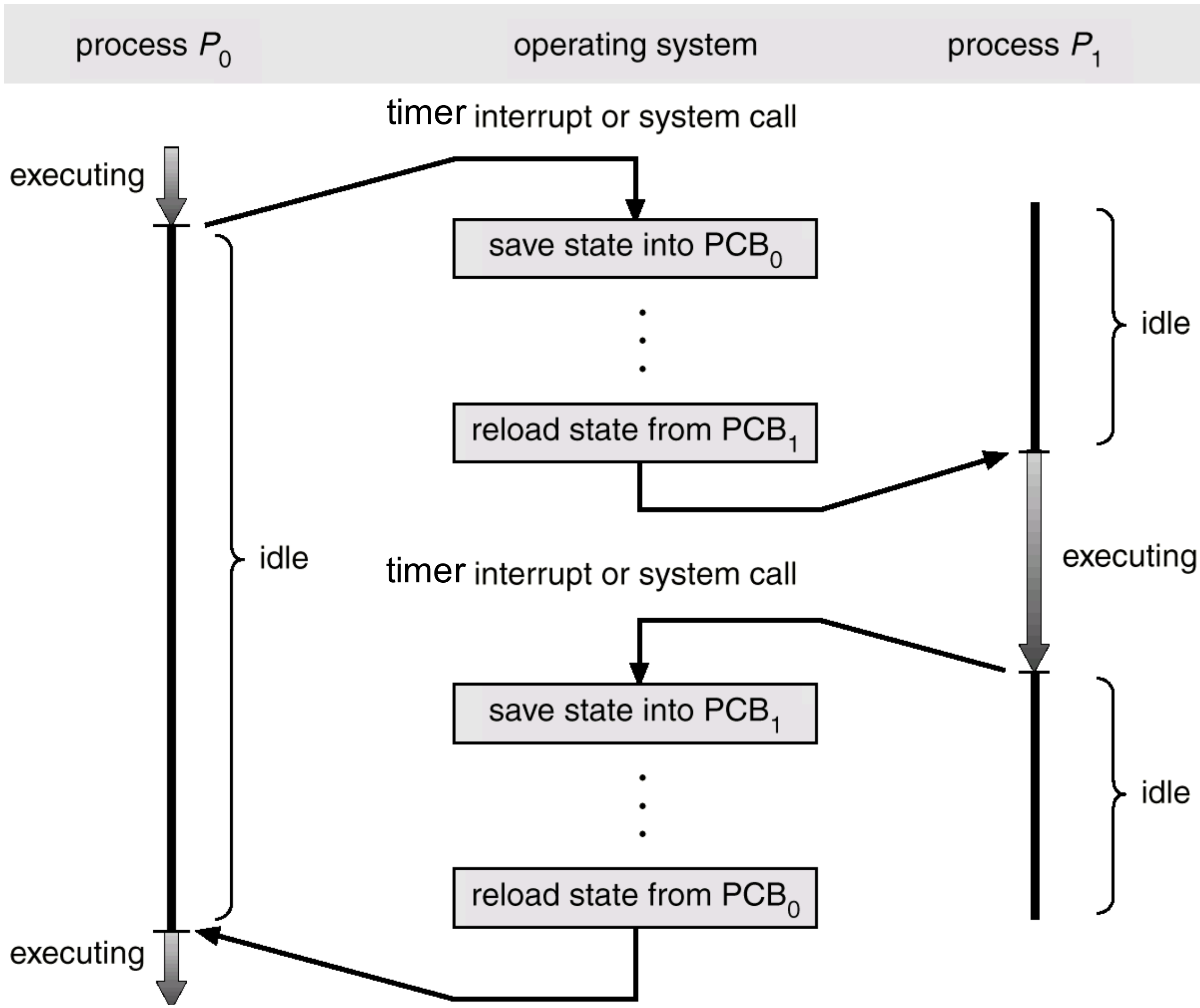
Context Switch Between Processes



Context Switch

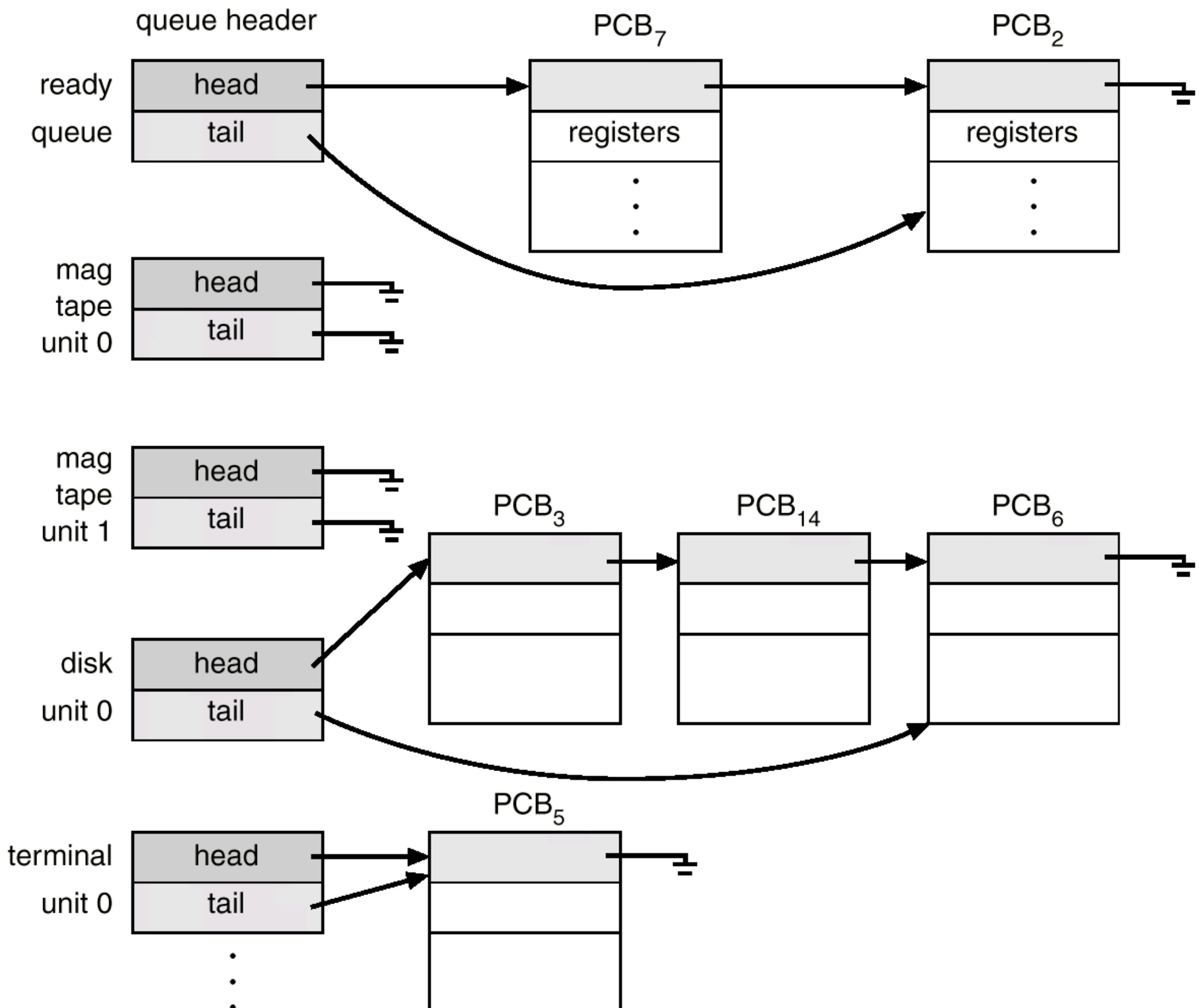
- When CPU switches to another process, the system must save the context (i.e., information) of the old process and load the saved context for the new process

- Context switch time is overhead: The system does NO useful work while switching between processes

Process Scheduling Queues

- Job queue: Set of all processes *with the same state* in the system
  - Ready queue (processes in ready state), device queue (processes in waiting state and waiting for a specific I/O device), etc.
- All the queues are stored in main memory (kernel memory space)
- Process migrates between queues when its state changes

Ready Queue And Various I/O Device Queues



Process Schedulers

- We need multiple schedulers for different purposes
  1. Long-term scheduler (or job scheduler): Selects processes from disk and loads them into main memory for execution
  2. Short-term scheduler (or CPU scheduler): Selects from among the processes that are ready to execute, and allocates the CPU to one of them
  3. Medium-term scheduler:
     - When the system load is heavy, swaps out a partially executed process from memory to hard disk
     - When the system load is light, such processes can be swapped back into main memory

Process Schedulers (Cont.)

- Short-term scheduler is invoked frequently (e.g., 100 milliseconds) in a multiprogrammed system for responsiveness and efficiency purposes
- Long-term scheduler is invoked infrequently (e.g., seconds or minutes)
- The degree of multiprogramming is initially controlled by the long-term scheduler, *and* thereafter by the medium-term scheduler

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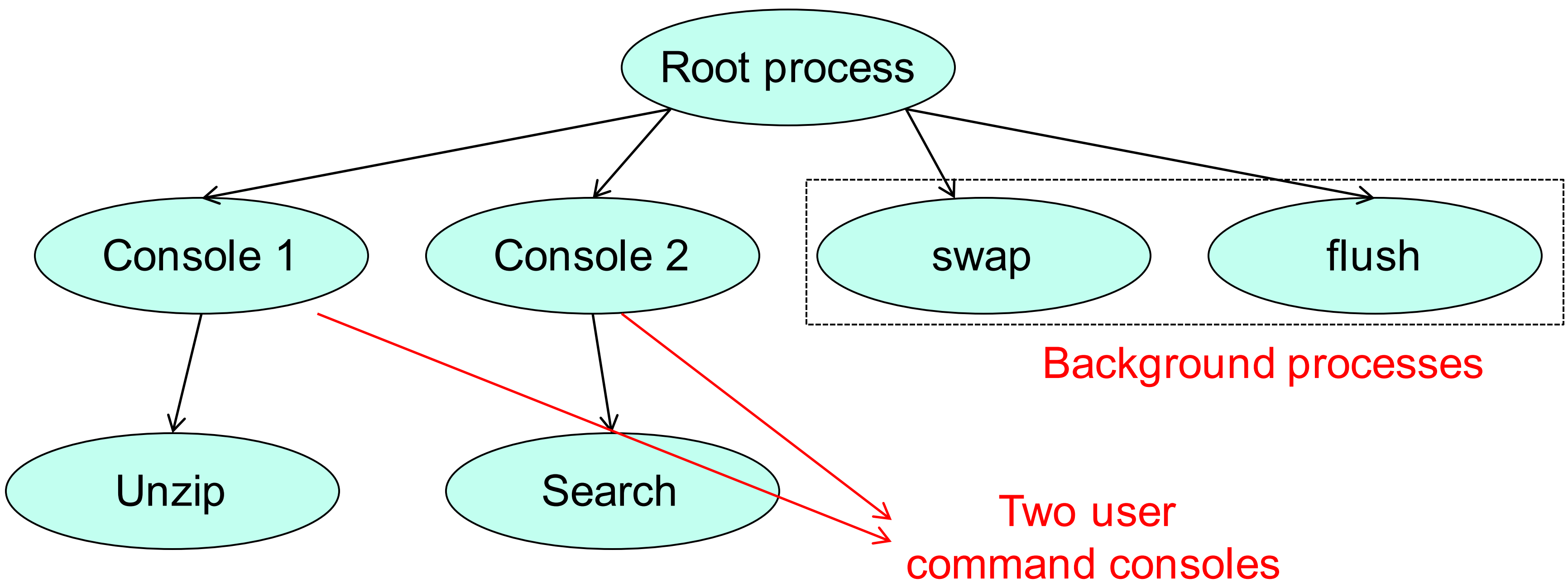
Process Creation

- Parent process creates children processes, which, in turn create other processes, forming a tree of processes (**fork**)



Process Creation (Cont.)

- Two possible execution orders
  1. Parent and children execute concurrently (and independently)
  2. Parent waits until all children terminate (**wait(),join()**)

- Examples
  - Many web browsers nowadays fork a new process when we access a new page in a "tab"
  - OS may create background processes for monitoring and maintenance tasks

Process Termination

- Two possible ways to terminate a process
  - Exit: Process executes last statement and asks the OS to delete it
    - A child may output return data to its parent
    - Process resources are de-allocated by the OS
  - Abort: Parent may terminate execution of children processes at any time
    - Child has exceeded allocated resources
    - Task assigned to child is no longer required
    - Parent is exiting

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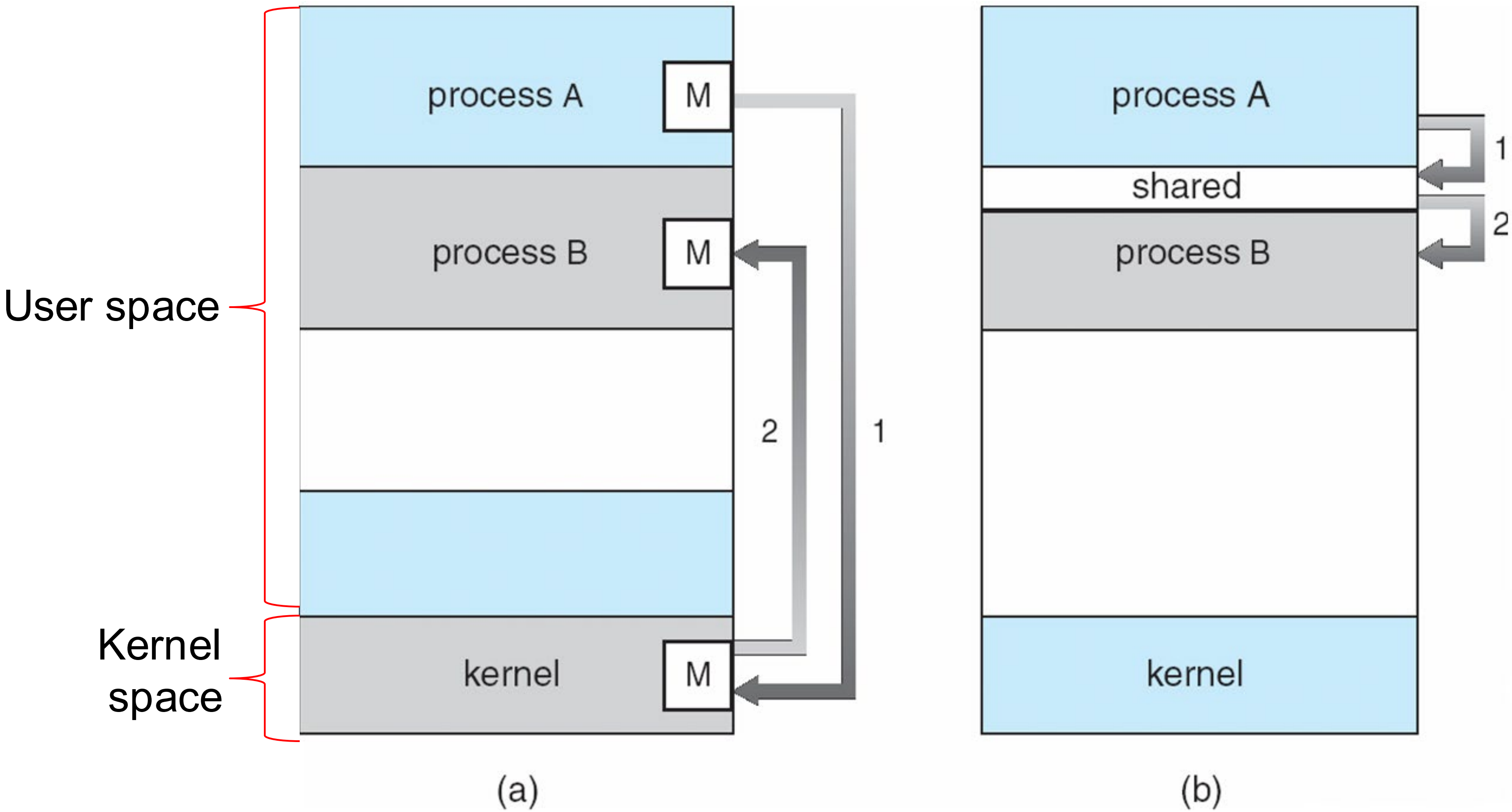
Cooperating Processes

- An *independent* process cannot affect or be affected by the execution of other processes

- A *cooperating* process on the other hand can affect or be affected by the execution of other processes
  - Such processes have to communicate with each other to share data
  - Two models of Inter-Process Communication (IPC)
    - **Message passing**
    - **Shared memory**

IPC Models



Message Passing

Shared Memory

IPC – Message Passing

- Processes communicate and synchronize their actions without resorting to shared variables

- Two operations (system calls) are required
  - **send**(*message*) – message size fixed or variable
  - **receive**(*message*)

- If two processes wish to communicate, they need to
  - Establish a *communication link* between them
  - Exchange messages via send/receive

Direct vs. Indirect Message Passing

- **Direct:** Processes must name each other explicitly
  - send (*P,message*): Send a message to process P
  - receive(*Q,message*): Receive a message from process Q
- **Indirect:** Messages are sent to or received from mailboxes (also referred to as ports)
  - Mailbox is an object into which messages are placed and removed (like a queue)
  - Primitives are:
    - send(*A,message*): Send a message to mailbox *A*
    - receive(*A,message*): Receive a message from mailbox *A*

Producer-Consumer Process Paradigm

- Classical paradigm for cooperating processes
  - *Producer* process produces information that is consumed by a *consumer* process
  - Shared buffer used for storing information

- Two models for shared buffer
  1. *unbounded-buffer* places no practical limit on the size of the buffer
  2. *bounded-buffer* assumes that there is a fixed buffer size

Producer-Consumer: Bounded Buffer

//declare a *mailbox* with capacity of B messages (buffer size B)

? Does this example use direct or indirect communication

```
void producer(void)
{
   message m;
   while (1) {
         //pre-processing…
         while(mailbox is full) wait;
         send(mailbox, m);
   }
}
```

```
void consumer(void)
{
   message m;
   while (1) {
         while(mailbox is empty) wait;
         receive(mailbox, m);
         //post-processing…
         }
}
```

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Threads

- This part is for **self-learning**

- **About Labs**
  - Nachos uses term "thread", but means "process"
  - All concepts and mechanisms that we learnt about processes are also applicable to Nachos threads
    - Thread control block = Process control block
    - Thread state = Process state
    - System calls: fork, exit, etc.

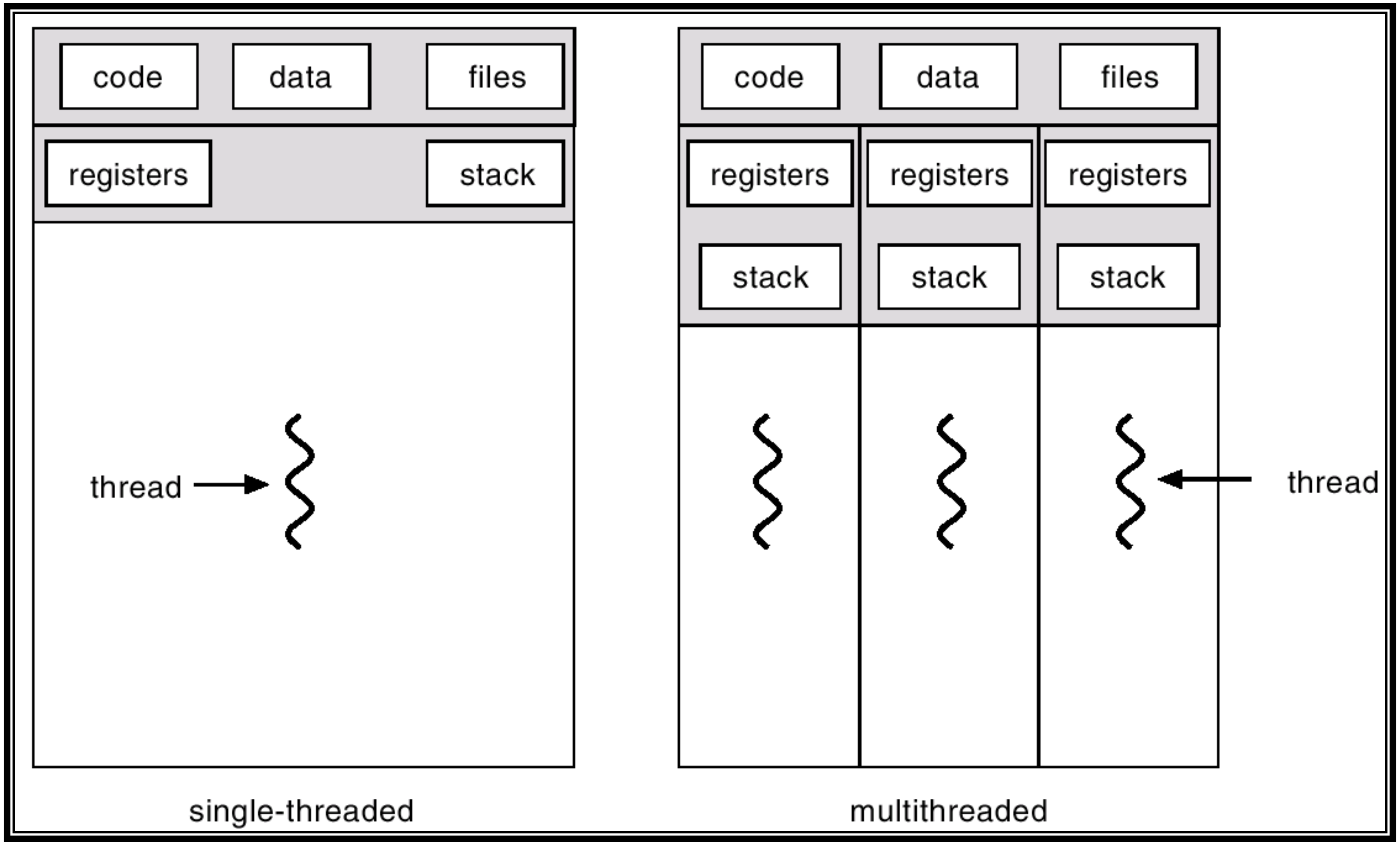
Threads

- Overview
- Single vs Multithreading Process
- Benefits of threads
- Types of threads
- Multithreading models

Overview

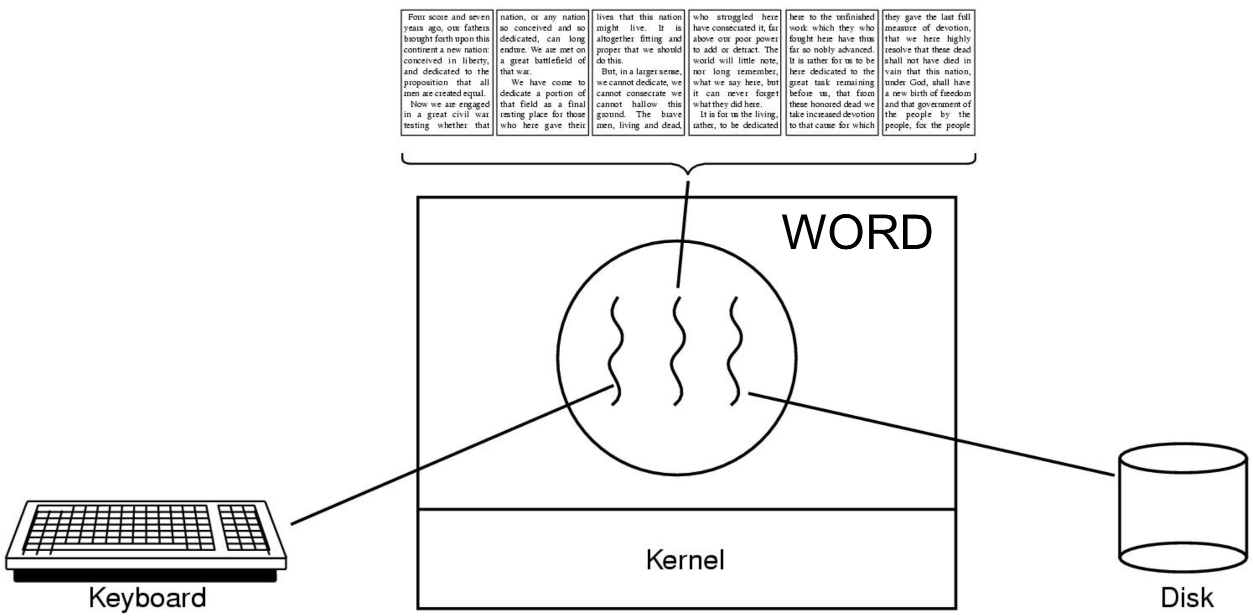
- A thread (or lightweight process) is a basic unit of CPU utilization; it consists of:
  - Thread id
  - Program counter
  - Register set
  - Stack space
- A thread shares with its peer threads in the same process:
  - Code and data sections
  - Operating system resources (open files, etc.)
- A traditional or heavyweight process is an executing program with a single thread of control

Single vs Multithreaded Processes

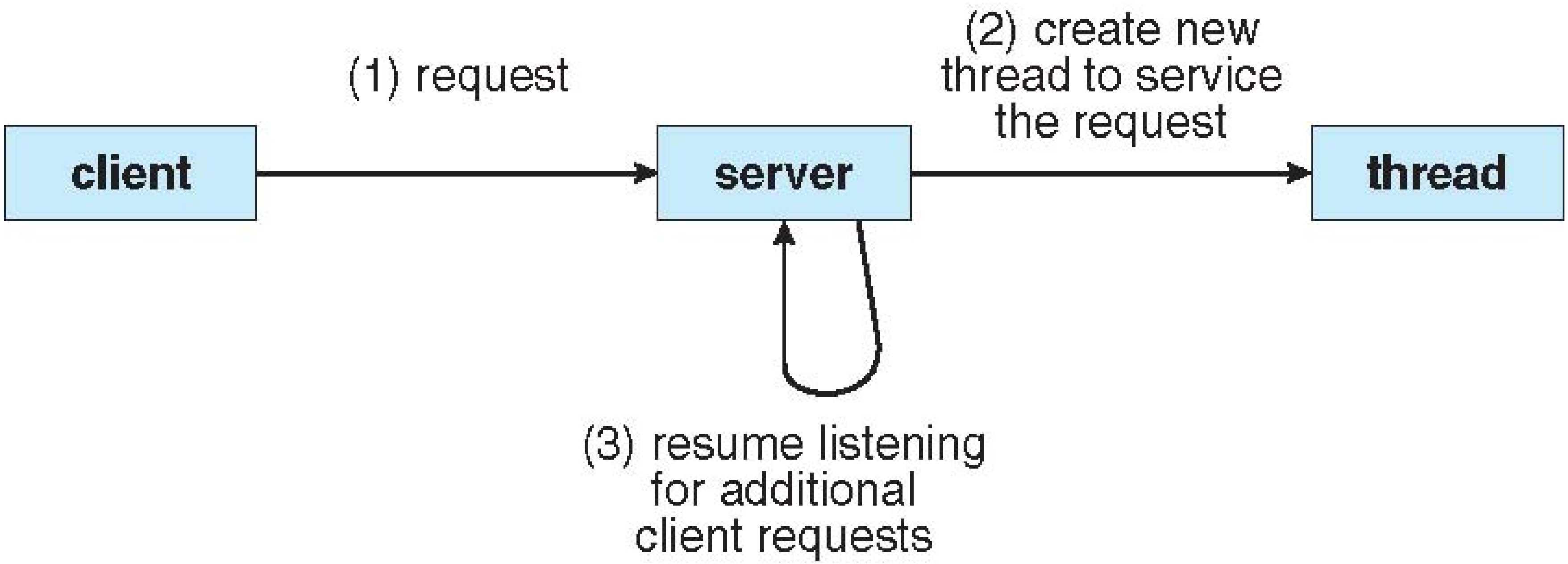


Advantage of Multithreaded Processes

- In a multithreaded process, while one thread is blocked and waiting, a second thread can run
  - Cooperation of multiple threads in the same process results in higher throughput



Example: Multithreaded Server



Thread Implementation Models

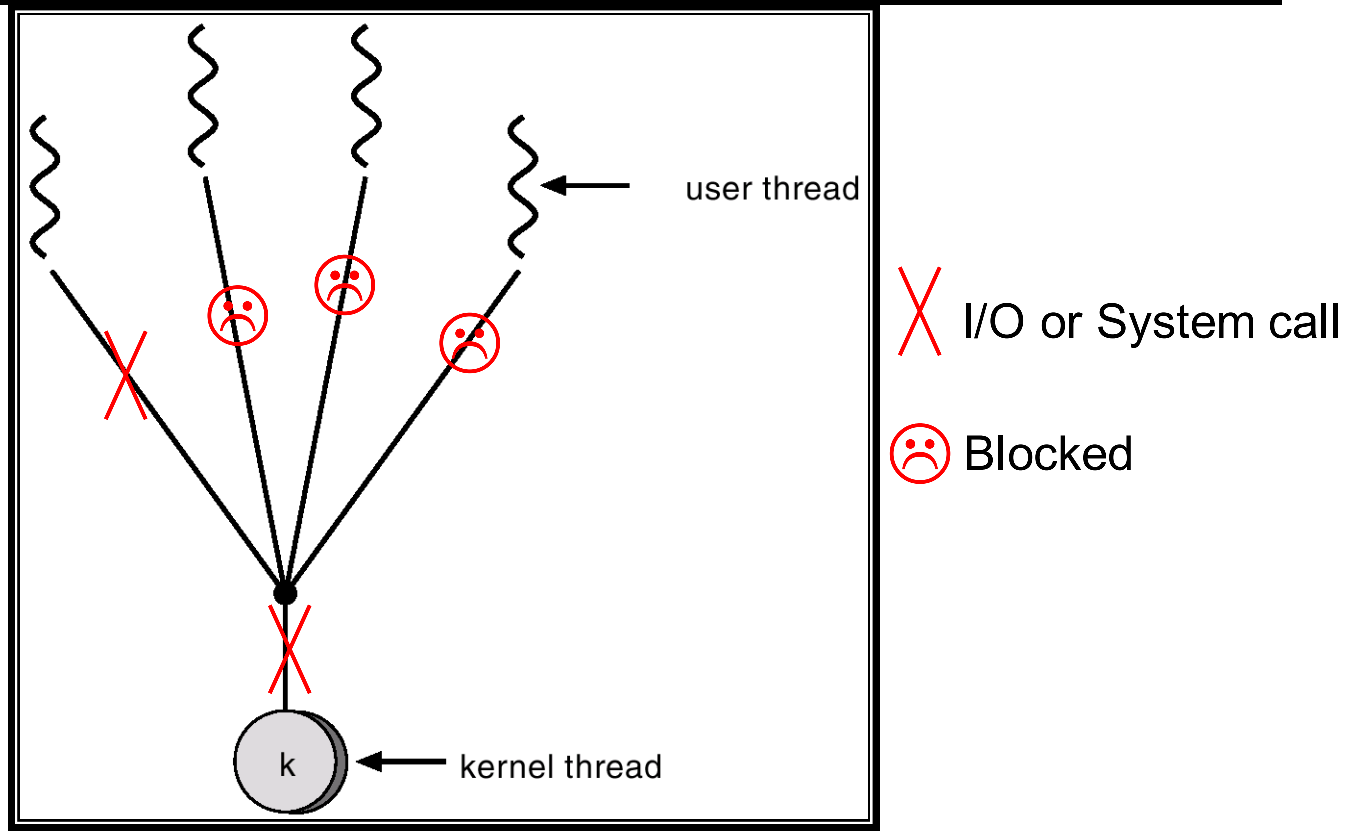
- Paradox
  - Allow users to implement an arbitrary number of threads, BUT
  - OS kernel can support a limited number of threads due to resource constraints

- Solution: Two layers of abstraction
  - User threads (logical): Created in user space
    - Allows users to create as many threads as they want
  - Kernel threads (physical): Created in kernel space
    - Slower to create and manage than user threads
    - Resources are eventually allocated in kernel threads
  - OS maintains the mapping from user to kernel threads

Multithreading Models

- Model that defines the mapping between user threads and kernel threads
  - Many-to-One
  - One-to-One
  - Many-to-Many
- Why is there no One-to-Many mapping?
  - Wastage of OS resources to map a single user thread to many kernel threads

Many-to-One Mapping



Disadvantage: A blocked user thread, will also block other user threads mapped to the same kernel thread

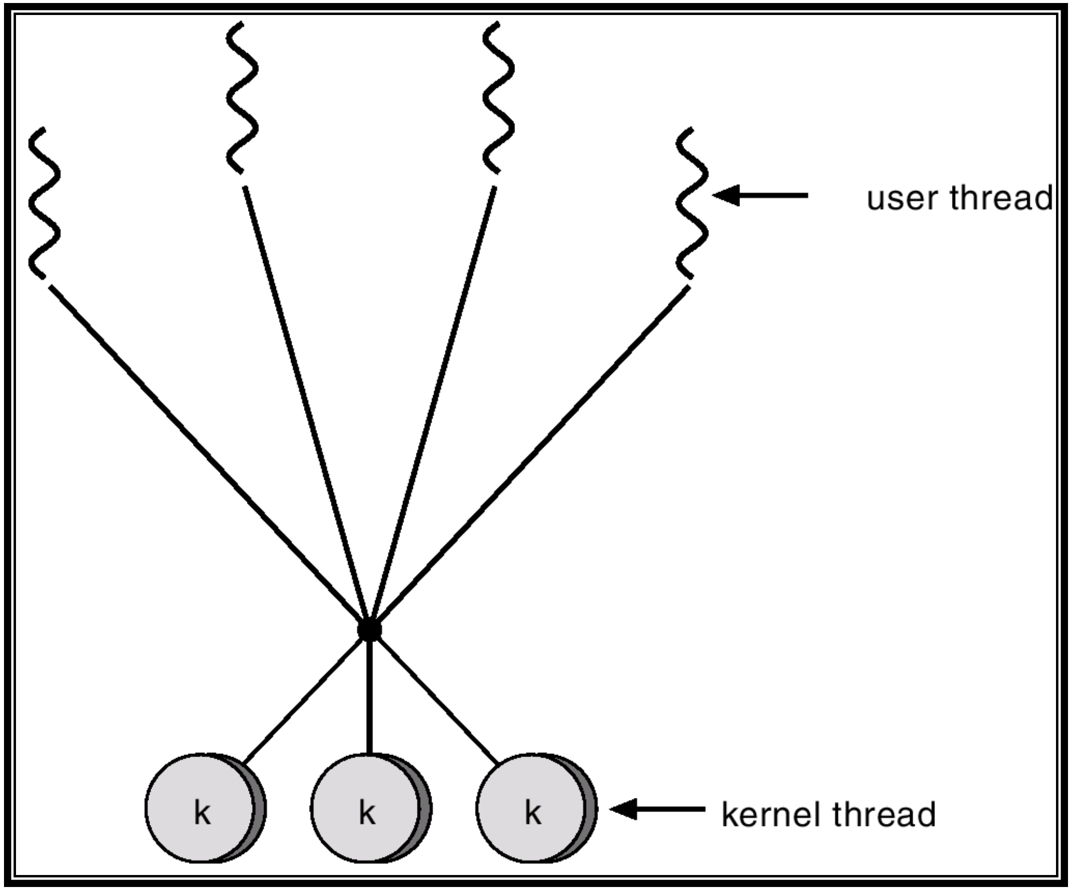
One-to-One Mapping

- Each user-level thread maps to a unique kernel thread
  - Examples: Windows 95/98/NT/2000, OS/2, Linux
- Provides more concurrency than many-to-one model
- Disadvantages:
  - Creating a user thread requires creating the corresponding kernel thread
  - May create too many kernel threads which is a burden on the system

Many-to-Many Mapping

- Allows many user level threads to be mapped to many kernel threads (see next slide)
  - Examples: Solaris 2, Windows NT/2000
- Allows the operating system to create a sufficient number of kernel threads
- Does not have the disadvantages of one-to-one and many-to-one models
- Disadvantage: Not easy to decide the mapping

Many-to-Many Mapping



Advanced Readings

- Beej's Guide to Unix Interprocess Communication
  - http://beej.us/guide/bgipc/
  - Very good introduction on the IPC implementation inside Unix
- Tutorials on how to use thread libraries:
  - POSIX pthreads, http://randu.org/tutorials/threads/
  - Windows Process and Thread Functions http://msdn.microsoft.com/en-us/library/windows/desktop/ms684847(v=vs.85).aspx