

CSE 421/521 - Operating Systems
Fall 2014

LECTURE - III
PROCESSES

Tevfik Koşar

University at Buffalo
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Roadmap

- Processes
 - Basic Concepts
 - Process Creation
 - Process Termination
 - Context Switching
 - Process Queues
 - Process Scheduling
 - Interprocess Communication



Process Concept

- a **Process** is a program in execution;

Pasta for six

- boil 1 quart salty water
- stir in the pasta
- cook on medium until "al dente"
- serve

Program

thread of execution



CPU

input data

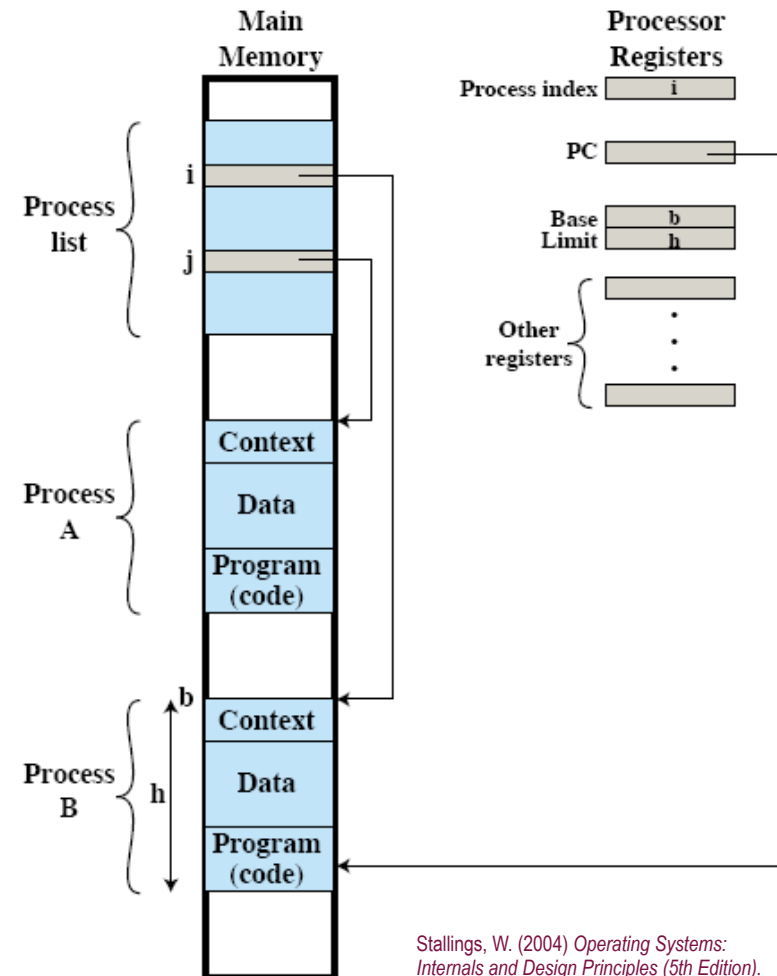
Process

Process Concept

- a **Process** is a program in execution;

➤ A process image consists of three components

- user address space
1. an executable program
 2. the associated data needed by the program
 3. the execution context of the process, which contains all information the O/S needs to manage the process (ID, state, CPU registers, stack, etc.)



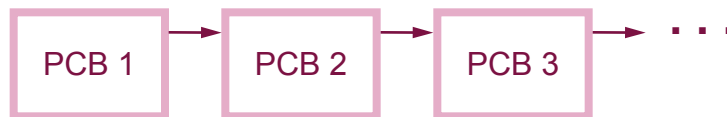
Stallings, W. (2004) *Operating Systems: Internals and Design Principles* (5th Edition).

Typical process image implementation

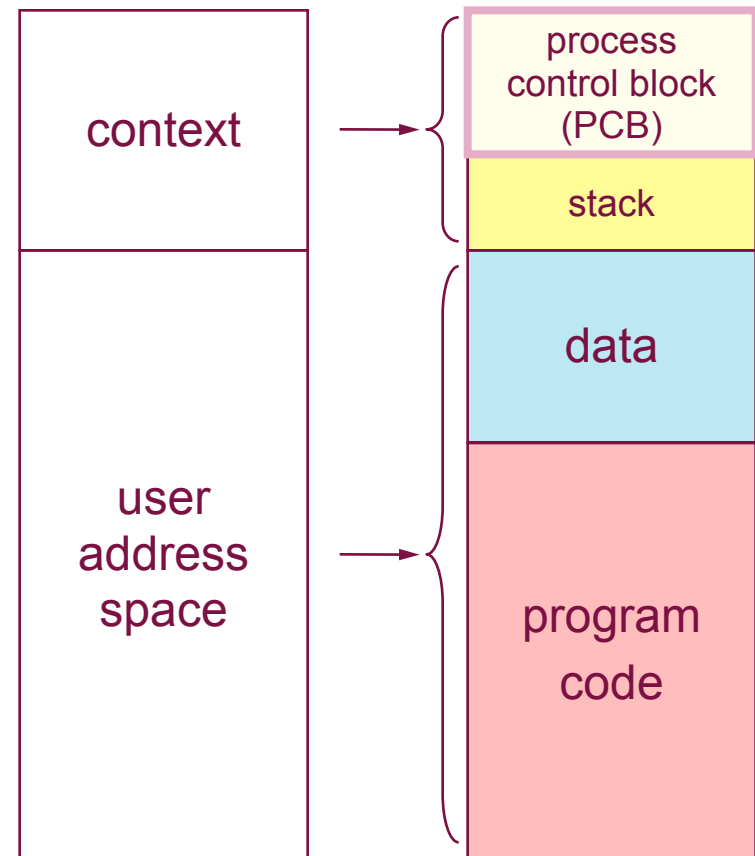
Process Control Block

➤ The Process Control Block (PCB)

- ✓ is included in the context, along with the stack
- ✓ is a “snapshot” that contains all necessary and sufficient data to restart a process where it left off (ID, state, CPU registers, etc.)
- ✓ is one entry in the operating system’s **process table** (array or linked list)

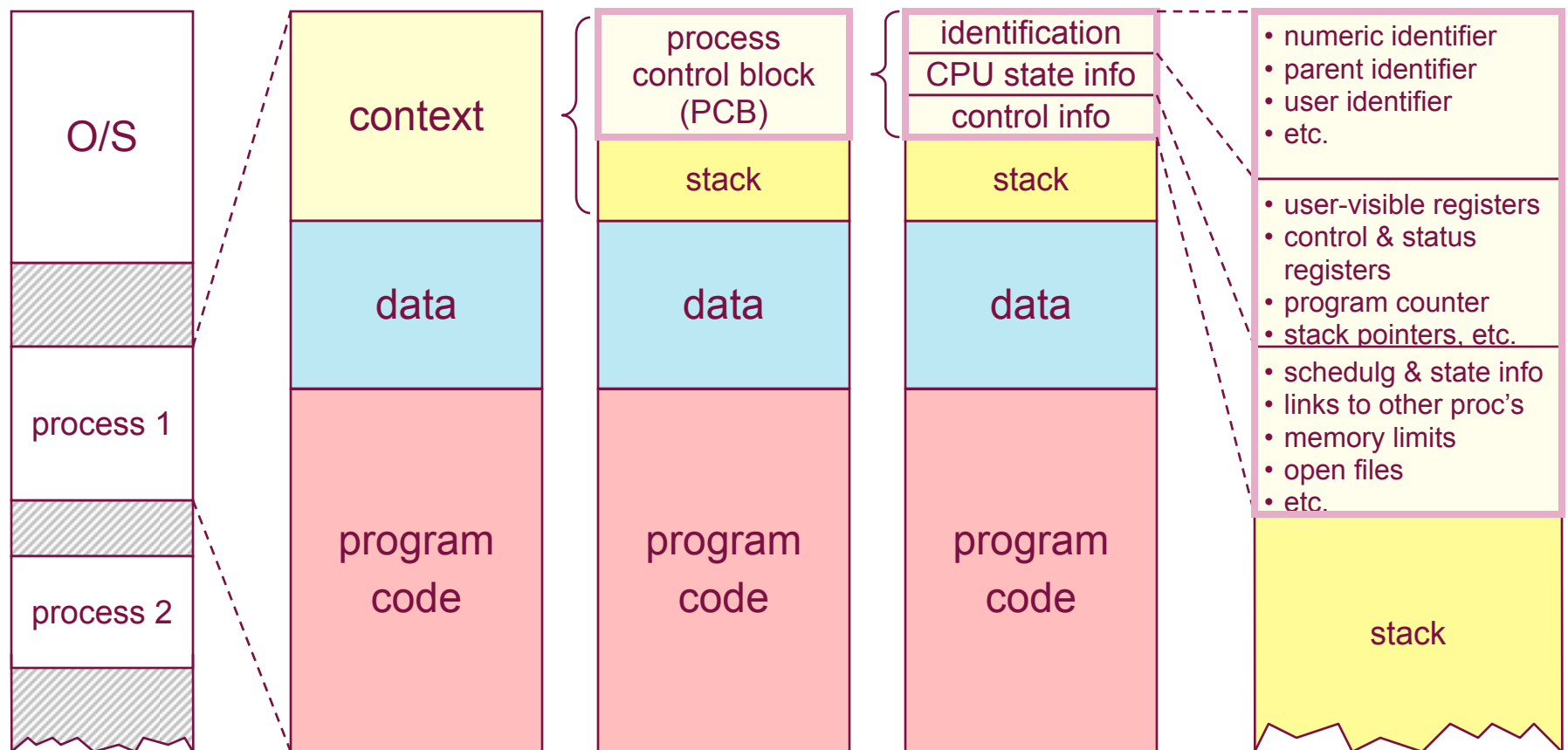


Typical process image implementation



Process Control Block

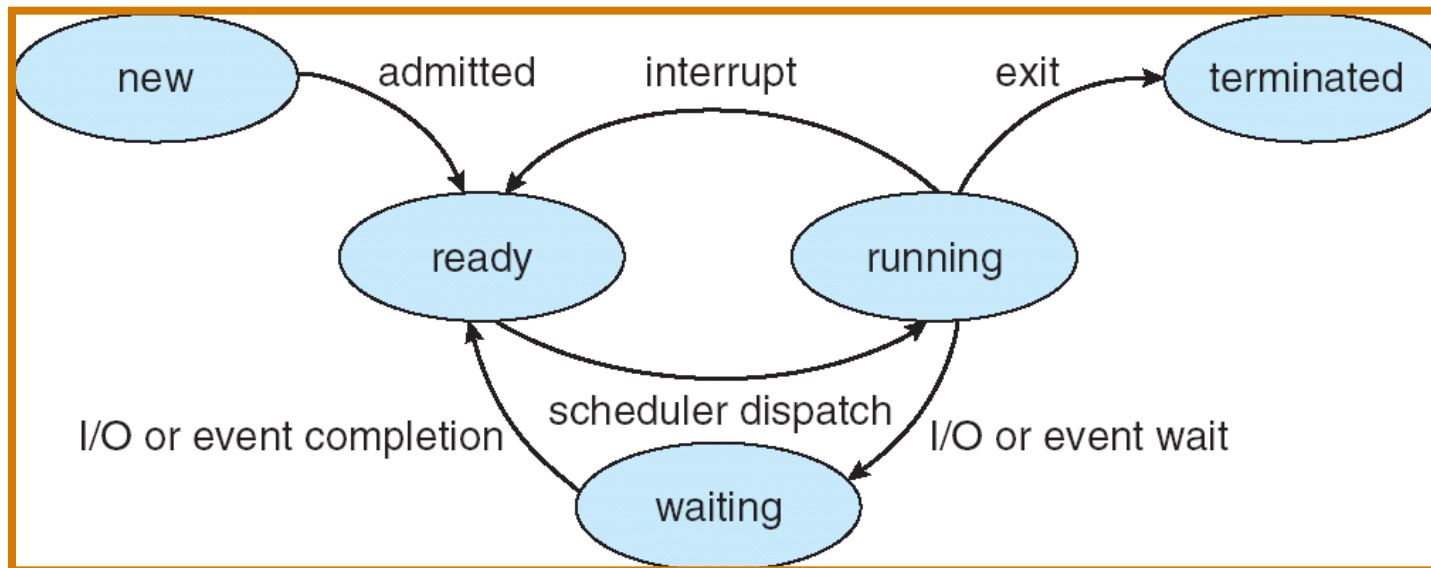
➤ Example of process and PCB location in memory



**Illustrative contents of a process image in
(virtual) memory**

Process State

- As a process executes, it changes *state*
 - **new**: The process is being created
 - **ready**: The process is waiting to be assigned to a processor
 - **running**: Instructions are being executed
 - **waiting**: The process is waiting for some event to occur
 - **terminated**: The process has finished execution



Process Creation

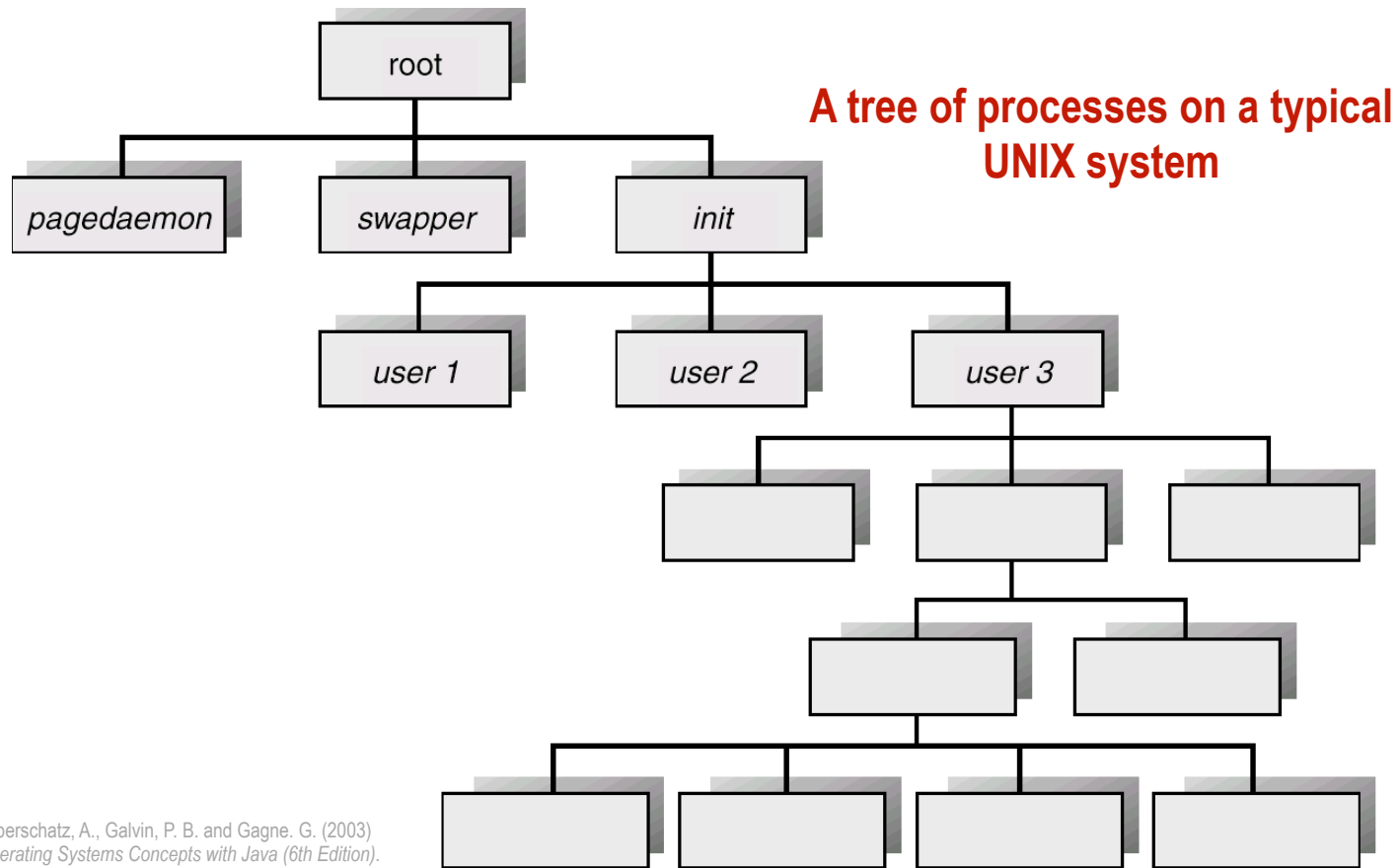
➤ Some events that lead to process creation (enter)

all cases of process spawning

- ✓ the system boots
 - when a system is initialized, several background processes or “daemons” are started (email, logon, etc.)
- ✓ a user requests to run an application
 - by typing a command in the CLI shell or double-clicking in the GUI shell, the user can launch a new process
- ✓ an existing process spawns a child process
 - for example, a server process (i.e. web server, file server) may create a new process for each request it handles
 - the *init* daemon waits for user login and spawns a shell
- ✓ a batch system takes on the next job in line

Process Creation

➤ Process creation by spawning



Silberschatz, A., Galvin, P. B. and Gagne, G. (2003)
Operating Systems Concepts with Java (6th Edition).

Process Creation

```
...
int main(...)
{
    ...
    if ((pid = fork()) == 0)                // create a process
    {
        fprintf(stdout, "Child pid: %i\n", getpid());
        err = execvp(command, arguments);   // execute child
                                              // process
        fprintf(stderr, "Child error: %i\n", errno);
        exit(err);
    }
    else if (pid > 0)                       // we are in the
    {                                       // parent process
        fprintf(stdout, "Parent pid: %i\n", getpid());
        pid2 = waitpid(pid, &status, 0);    // wait for child
        ...                                // process
    }
    ...

    return 0;
}
```

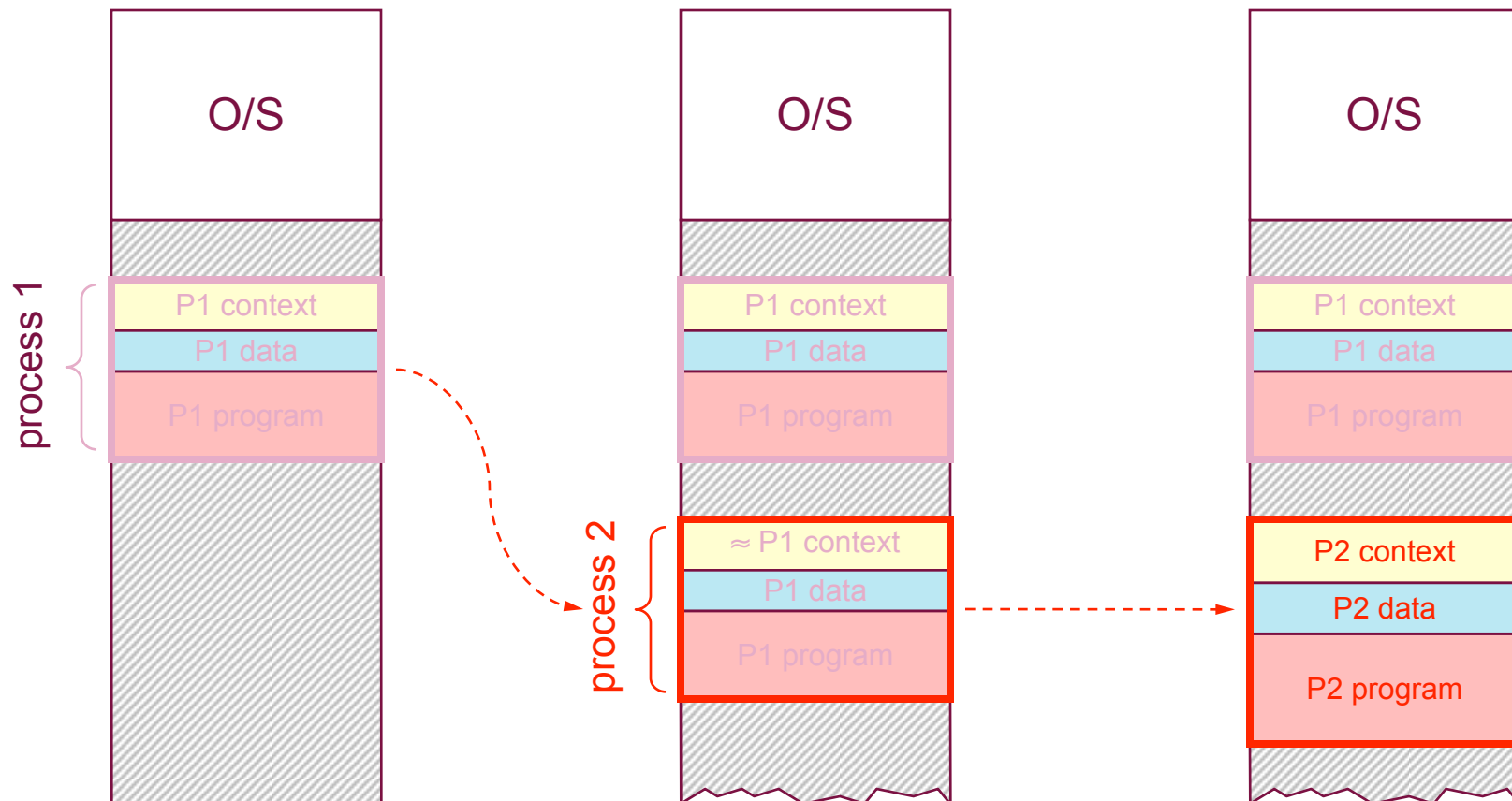
Process Creation

1. Clone child process

✓ `pid = fork()`

2. Replace child's image

✓ `execve(name, ...)`



Fork Example 1

```
#include <stdio.h>

main()
{
    int ret_from_fork, mypid;

    mypid = getpid();           /* who am i? */
    printf("Before: my pid is %d\n", mypid); /* tell pid */

    ret_from_fork = fork();

    sleep(1);
    printf("After: my fork returns pid : %d, said %d\n",
           ret_from_fork, getpid());
}
```

Fork Example 2

```
#include <stdio.h>

main()
{
    fork();
    fork();
    fork();
    printf("my pid is %d\n", getpid() );
}
```

How many lines of output will this produce?

Process Termination

- Some events that lead to process termination (exit)
 - ✓ regular completion, with or without error code
 - the process voluntarily executes an **exit(err)** system call to indicate to the O/S that it has finished
 - ✓ fatal error (uncatchable or uncaught)
 - service errors: no memory left for allocation, I/O error, etc.
 - total time limit exceeded
 - arithmetic error, out-of-bounds memory access, etc.
 - ✓ killed by another process via the kernel
 - the process receives a **SIGKILL** signal
 - in some systems the parent takes down its children with it

Process Pause/Dispatch

➤ Some events that lead to process pause / dispatch

✓ I/O wait

O/S-triggered
(following system
call)

- a process invokes an I/O system call that blocks waiting for the I/O device: the O/S puts the process in “Waiting” mode and dispatches another process to the CPU

✓ preemptive timeout

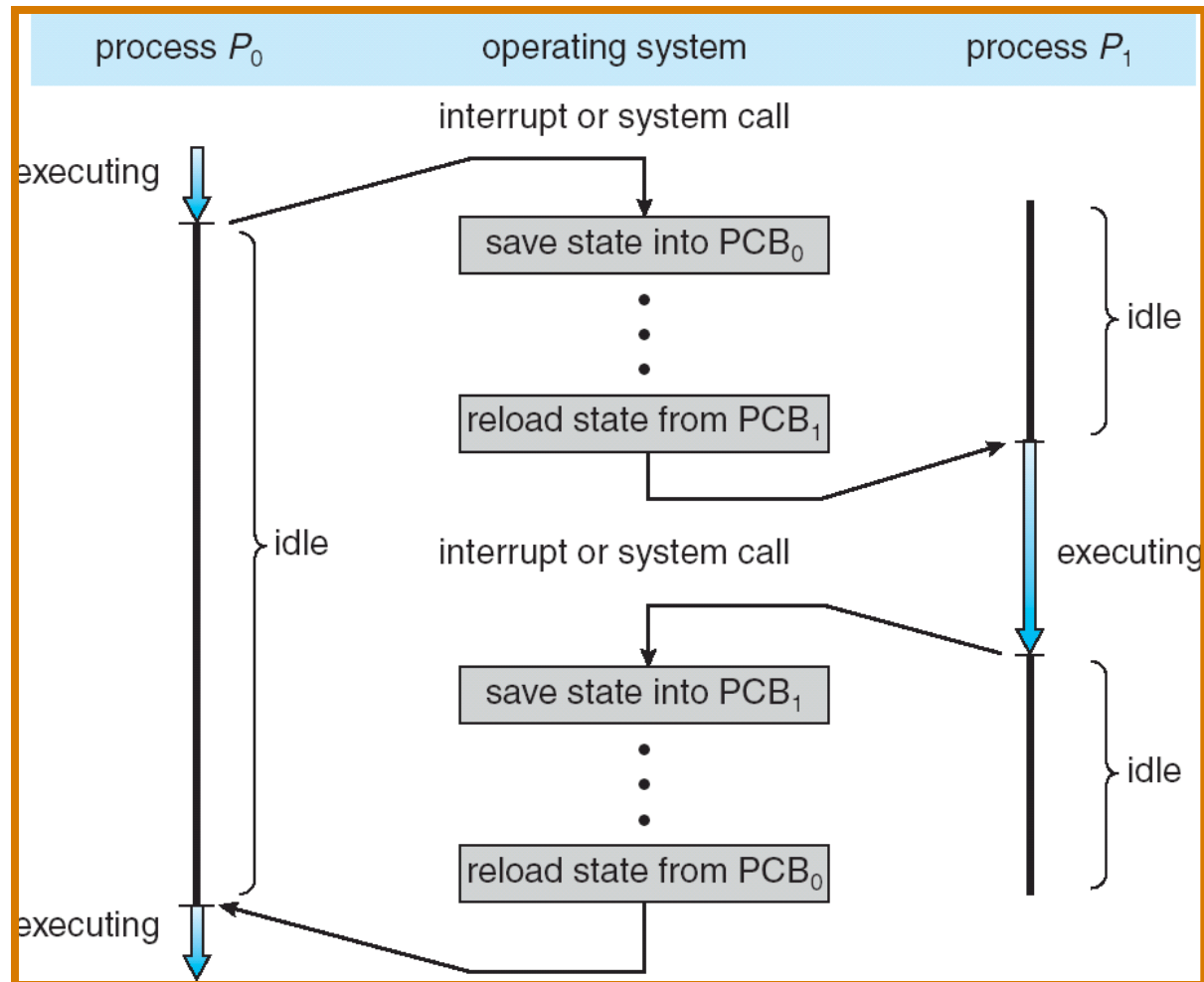
hardware
interrupt-
triggered (timer)

- the process receives a timer interrupt and relinquishes control back to the O/S dispatcher: the O/S puts the process in “Ready” mode and dispatches another process to the CPU
- not to be confused with “total time limit exceeded”, which leads to process termination

Process “Context” Switching

- When CPU switches to another process, the system must save the state of the old process and load the saved state for the new process
- Context-switch time is overhead; the system does no useful work while switching
- Switching time is dependent on hardware support

CPU Switch From Process to Process



Process “Context” Switching

- How does a full process switch happen, step by step?
1. save CPU context, including PC and registers (*the only step needed in a simple mode switch*)
 2. update process state (to “Ready”, “Blocked”, etc.) and other related fields of the PCB
 3. move the PCB to the appropriate queue
 4. select another process for execution: this decision is made by the CPU scheduling algorithm of the O/S
 5. update the PCB of the selected process (state = “Running”)
 6. update memory management structures
 7. restore CPU context to the values contained in the new PCB

Process “Context” Switching

➤ What events trigger the O/S to switch processes?

✓ **interrupts** — external, asynchronous events, independent of the currently executed process instructions

- clock interrupt → O/S checks time and may block process
- I/O interrupt → data has come, O/S may unblock process
- memory fault → O/S may block process that must wait for a missing page in memory to be swapped in

traps { ✓ **exceptions** — internal, synchronous (but involuntary) events caused by instructions → O/S may terminate or recover process

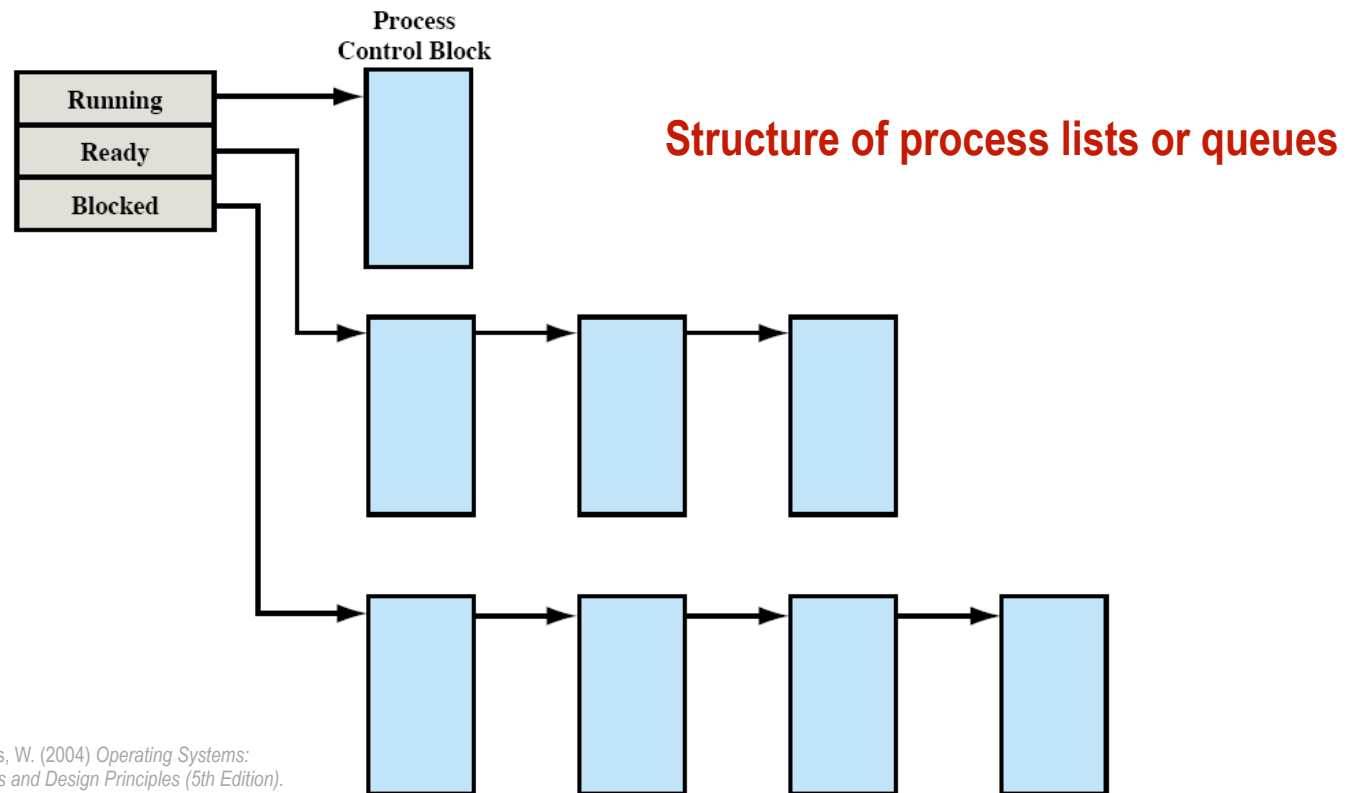
✓ **system calls** — voluntary synchronous events calling a specific O/S service → after service completed, O/S may either resume or block the calling process, depending on I/O, priorities, etc.

Process Scheduling Queues

- **Job queue** - set of all jobs in the system
- **Ready queue** - set of all processes residing in main memory, ready and waiting to execute
- **Device queues** - set of processes waiting for an I/O device
- Processes migrate among the various queues

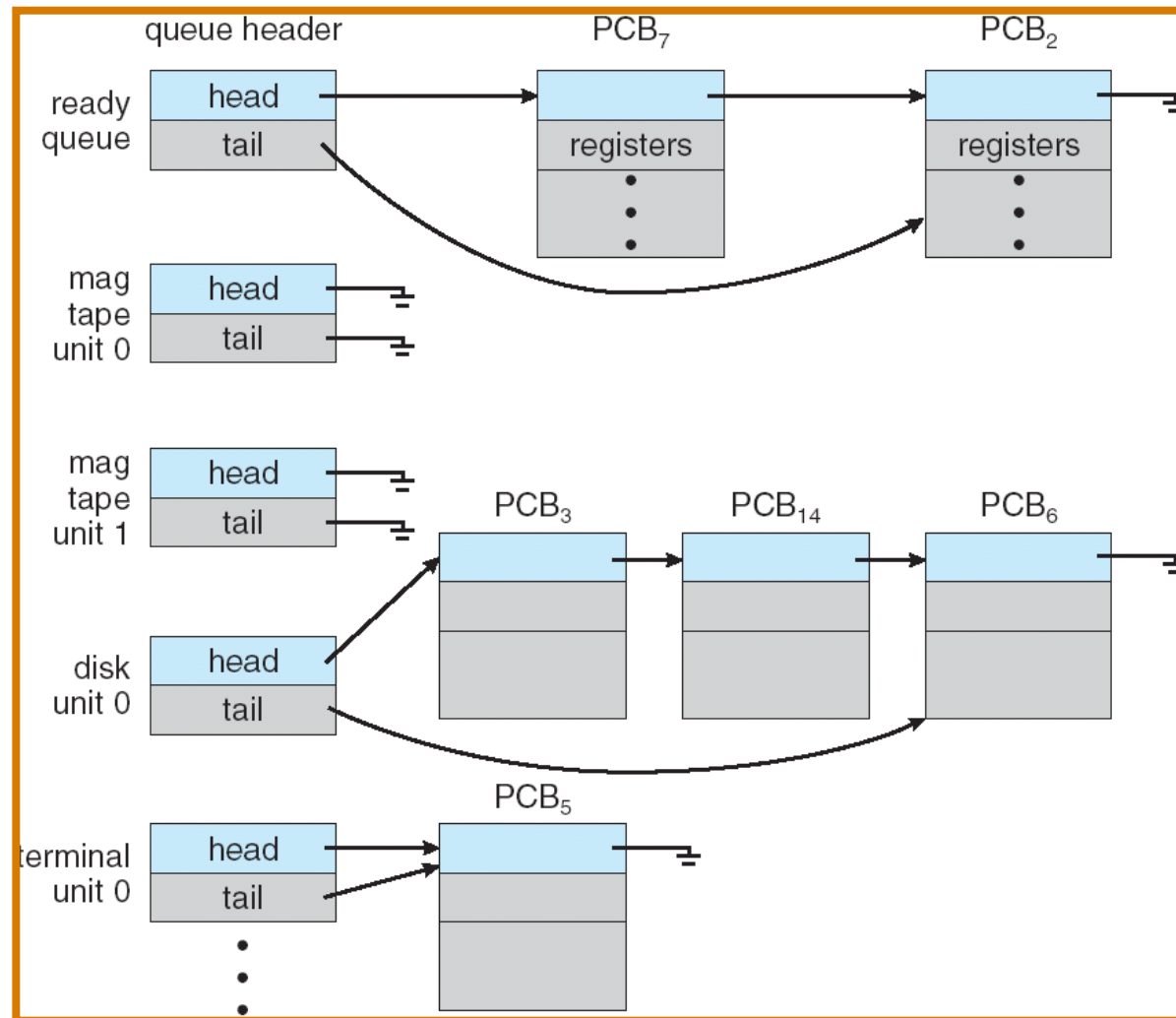
Process Queues

- The process table can be split into per-state queues
 - ✓ PCBs can be linked together if they contain a pointer field

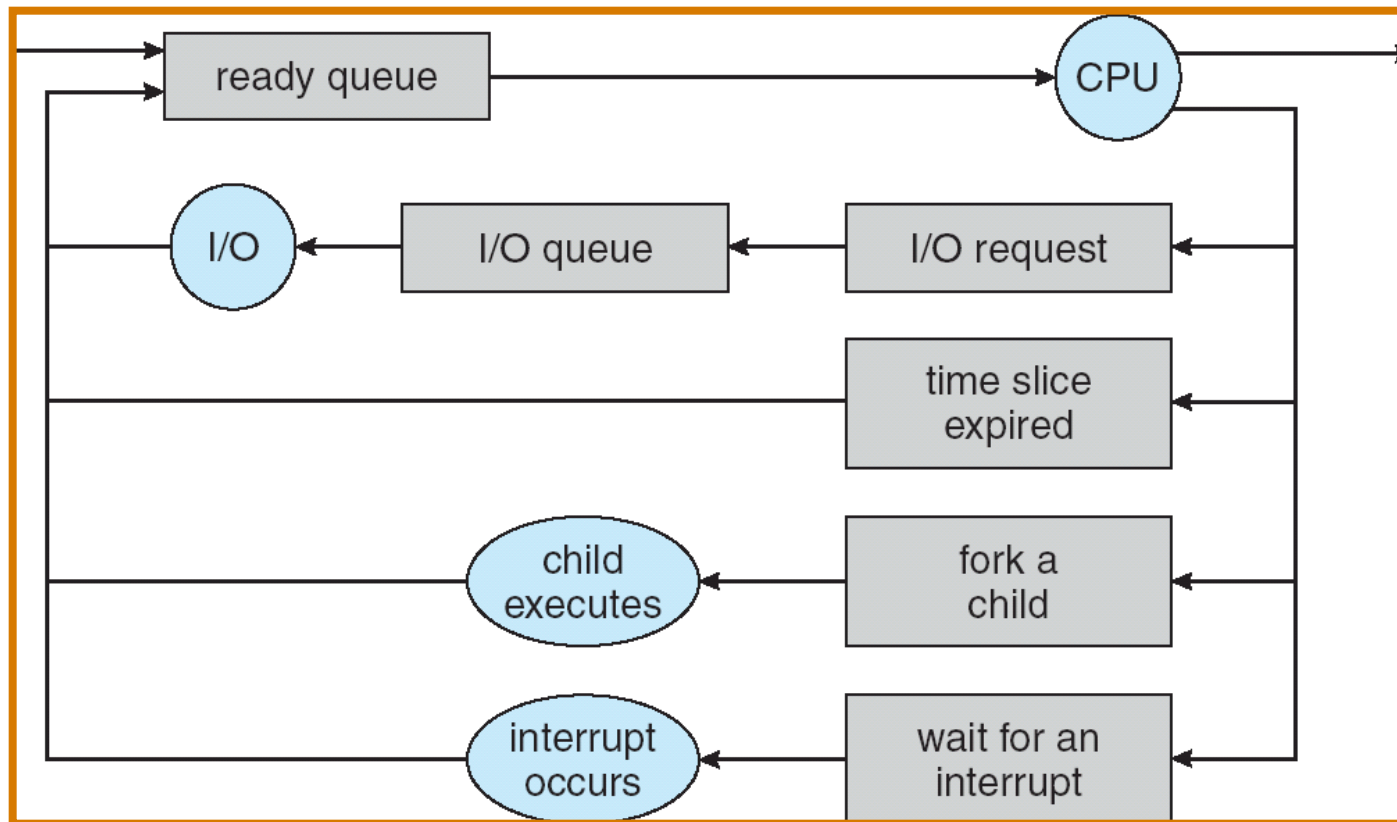


Stallings, W. (2004) *Operating Systems: Internals and Design Principles (5th Edition)*.

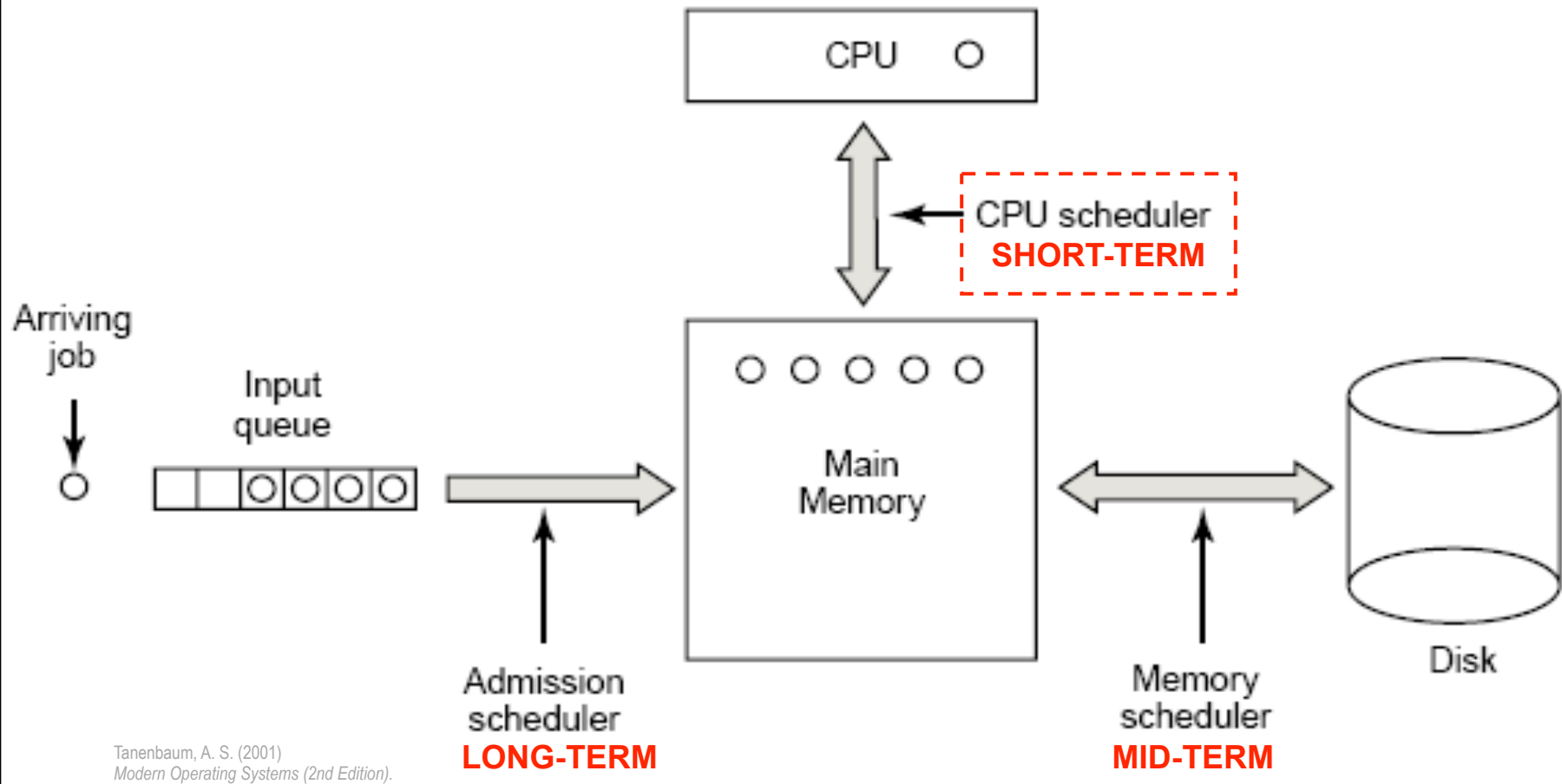
Ready Queue And Various I/O Device Queues



Representation of Process Scheduling



Three Level CPU Scheduling



OS Scheduling

➤ Long-term scheduling

- ✓ the decision to add a program to the pool of processes to be executed (job scheduling)

➤ Medium-term scheduling

- ✓ the decision to add to the number of processes that are partially or fully in main memory ("swapping")

➤ Short-term scheduling = CPU scheduling

- ✓ the decision as to which available processes in memory are to be executed by the processor ("dispatching")

➤ I/O scheduling

- ✓ the decision to handle a process's pending I/O request



fine- to coarse-grain level

frequency of intervention

Schedulers

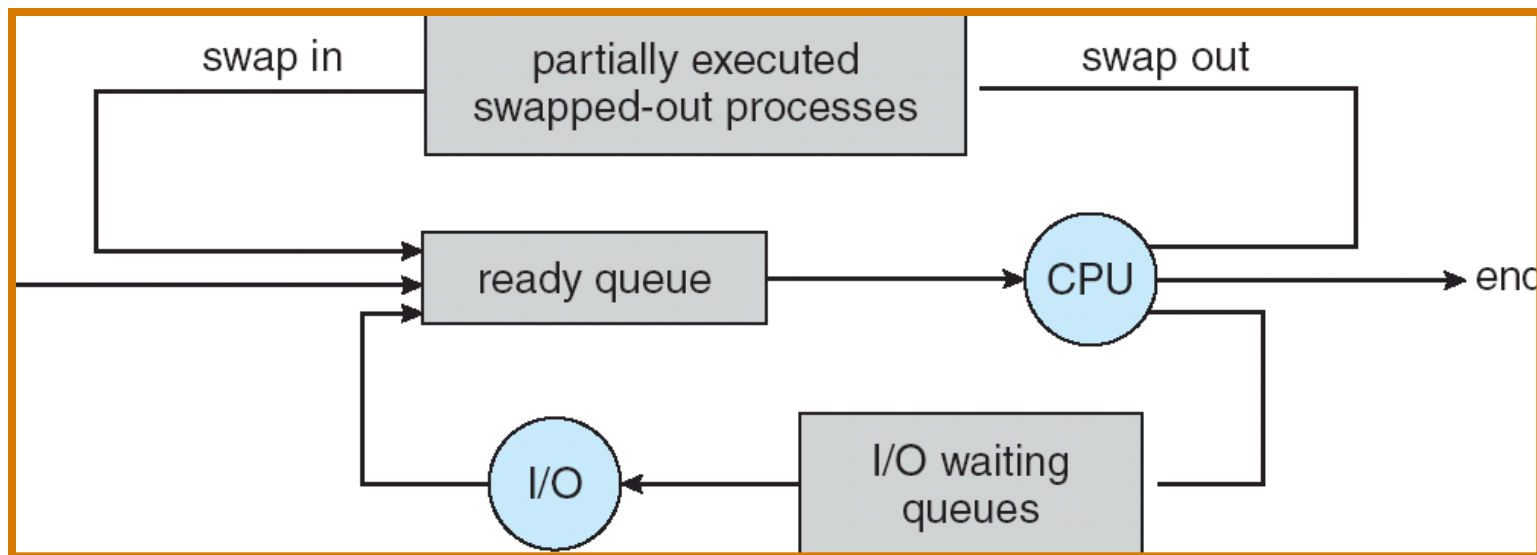
- **Long-term scheduler** (or job scheduler) - selects which processes should be brought into the ready queue
- **Short-term scheduler** (or CPU scheduler) - selects which process should be executed next and allocates CPU

Schedulers (Cont.)

- Short-term scheduler is invoked very frequently (milliseconds) \Rightarrow (must be fast)
 - Long-term scheduler is invoked very infrequently (seconds, minutes) \Rightarrow (may be slow)
 - The long-term scheduler controls the *degree of multiprogramming*
 - Processes can be described as either:
 - **I/O-bound process** - spends more time doing I/O than computations, many short CPU bursts
 - **CPU-bound process** - spends more time doing computations; few very long CPU bursts
- ➔ long-term schedulers need to make careful decision

Addition of Medium Term Scheduling

- In time-sharing systems: remove processes from memory “temporarily” to reduce degree of multiprogramming.
- Later, these processes are resumed → **Swapping**



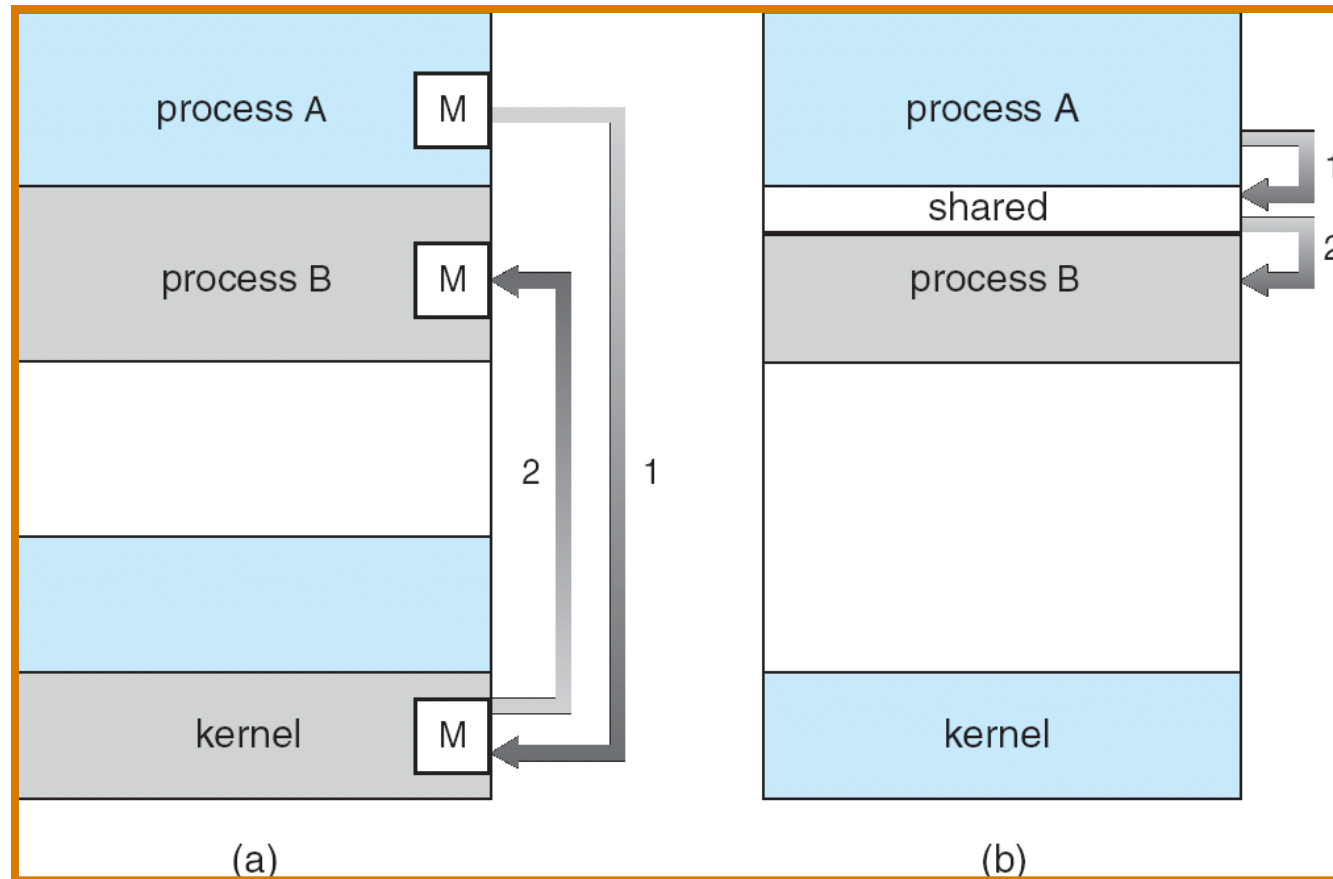
Cooperating Processes

- **Independent** process cannot affect or be affected by the execution of another process
- **Cooperating** process can affect or be affected by the execution of another process
- Advantages of process cooperation
 - Information sharing
 - Computation speed-up
 - Modularity
 - Convenience
- Disadvantage
 - Synchronization issues and race conditions

Interprocess Communication (IPC)

- Mechanism for processes to communicate and to synchronize their actions
- **Shared Memory:** by using the same address space and shared variables
- **Message Passing:** processes communicate with each other without resorting to shared variables

Communications Models



a) Message Passing

b) Shared Memory

Message Passing

- Message Passing facility provides two operations:
 - `send(message)` - message size fixed or variable
 - `receive(message)`
- If P and Q wish to communicate, they need to:
 - establish a *communication link* between them
 - exchange messages via send/receive
- Two types of Message Passing
 - direct communication
 - indirect communication

Message Passing - direct communication

- Processes must name each other explicitly:
 - `send (P, message)` - send a message to process P
 - `receive(Q, message)` - receive a message from process Q
- Properties of communication link
 - Links are established automatically
 - A link is associated with exactly one pair of communicating processes
 - Between each pair there exists exactly one link
 - The link may be unidirectional, but is usually bi-directional
- Symmetrical vs Asymmetrical direct communication
 - `send (P, message)` - send a message to process P
 - `receive(id, message)` - receive a message from any process
- Disadvantage of both: limited modularity, hardcoded

Message Passing - indirect communication

- Messages are directed and received from mailboxes (also referred to as ports)
 - Each mailbox has a unique id
 - Processes can communicate only if they share a mailbox
- Primitives are defined as:
 - send**(*A, message*) - send a message to mailbox A
 - receive**(*A, message*) - receive a message from mailbox A

Indirect Communication (*cont.*)

- Operations
 - create a new mailbox
 - send and receive messages through mailbox
 - destroy a mailbox
- Properties of communication link
 - Link established only if processes share a common mailbox
 - A link may be associated with many processes
 - Each pair of processes may share several communication links
 - Link may be unidirectional or bi-directional

Indirect Communication (*cont.*)

- Mailbox sharing
 - P_1 , P_2 , and P_3 share mailbox A
 - P_1 , sends; P_2 and P_3 receive
 - Who gets the message?
- Solutions
 - Allow a link to be associated with at most two processes
 - Allow only one process at a time to execute a receive operation
 - Allow the system to select arbitrarily the receiver. Sender is notified who the receiver was.

Synchronization

- Message passing may be either blocking or non-blocking
- **Blocking** is considered **synchronous**
 - **Blocking send** has the sender block until the message is received
 - **Blocking receive** has the receiver block until a message is available
- **Non-blocking** is considered **asynchronous**
 - **Non-blocking send** has the sender send the message and continue
 - **Non-blocking receive** has the receiver receive a valid message or null

Buffering

- Queue of messages attached to the link; implemented in one of three ways
 1. Zero capacity - 0 messages
Sender must wait for receiver (rendezvous)
 2. Bounded capacity - finite length of n messages
Sender must wait if link full
 3. Unbounded capacity - infinite length
Sender never waits

Exercise

In the code below, assume that *(i)* all `fork` and `execvp` statements execute successfully, *(ii)* the program arguments of `execvp` do not spawn more processes or print out more characters, and *(iii)* all `pid` variables are initialized to 0.

- a. What is the total number of processes that will be created by the execution of this code?
- b. How many of each character 'A' to 'G' will be printed out?

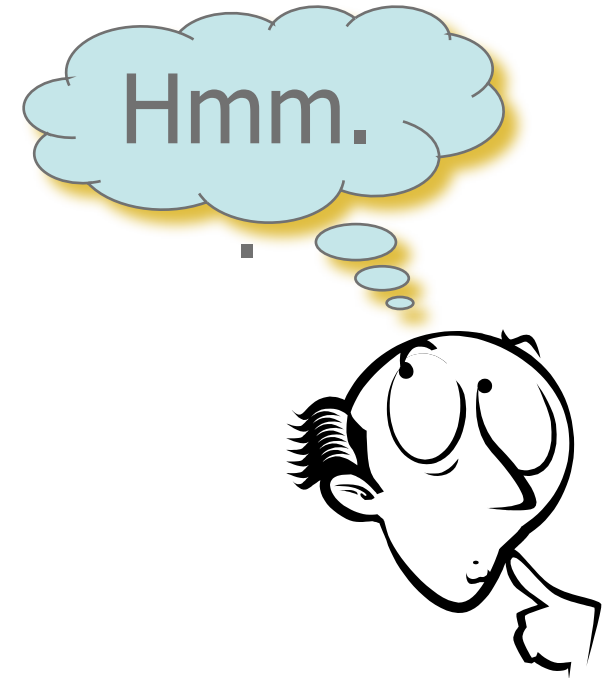
```

void main()
{
    ...
    pid1 = fork();
    pid2 = fork();
    if (pid1 != 0) {
        pid3 = fork();
        printf("A\n");
    } else {
        printf("B\n");
        execvp(...);
    }
    if (pid2 == 0 && pid3 != 0) {
        execvp(...);
        printf("C\n");
    }
    pid4 = fork();
    printf("D\n");
    if (pid3 != 0) {
        printf("E\n");
        pid5 = fork();
        execvp(...);
    }
    printf("F\n");
    execvp(...);
    pid6 = fork();
    printf("G\n");
    if (pid6 == 0)
        pid7 = fork();
}

```


Summary

- Processes
 - Basic Concepts
 - Process Creation
 - Process Termination
 - Context Switching
 - Process Queues
 - Process Scheduling
 - Interprocess Communication



- Next Lecture: Threads
- Reading Assignment: Chapter 4 from Silberschatz.
- HW 1 will be out on Thursday

Acknowledgements

- “Operating Systems Concepts” book and supplementary material by A. Silberschatz, P. Galvin and G. Gagne
- “Operating Systems: Internals and Design Principles” book and supplementary material by W. Stallings
- “Modern Operating Systems” book and supplementary material by A. Tanenbaum
- R. Doursat and M. Yuksel from UNR