CSE 421/521 - Operating Systems
Spring 2018

Lecture - III
Processes

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Roadmap

- Processes
  - Process Representation in OS
  - 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*

thread of execution

Program

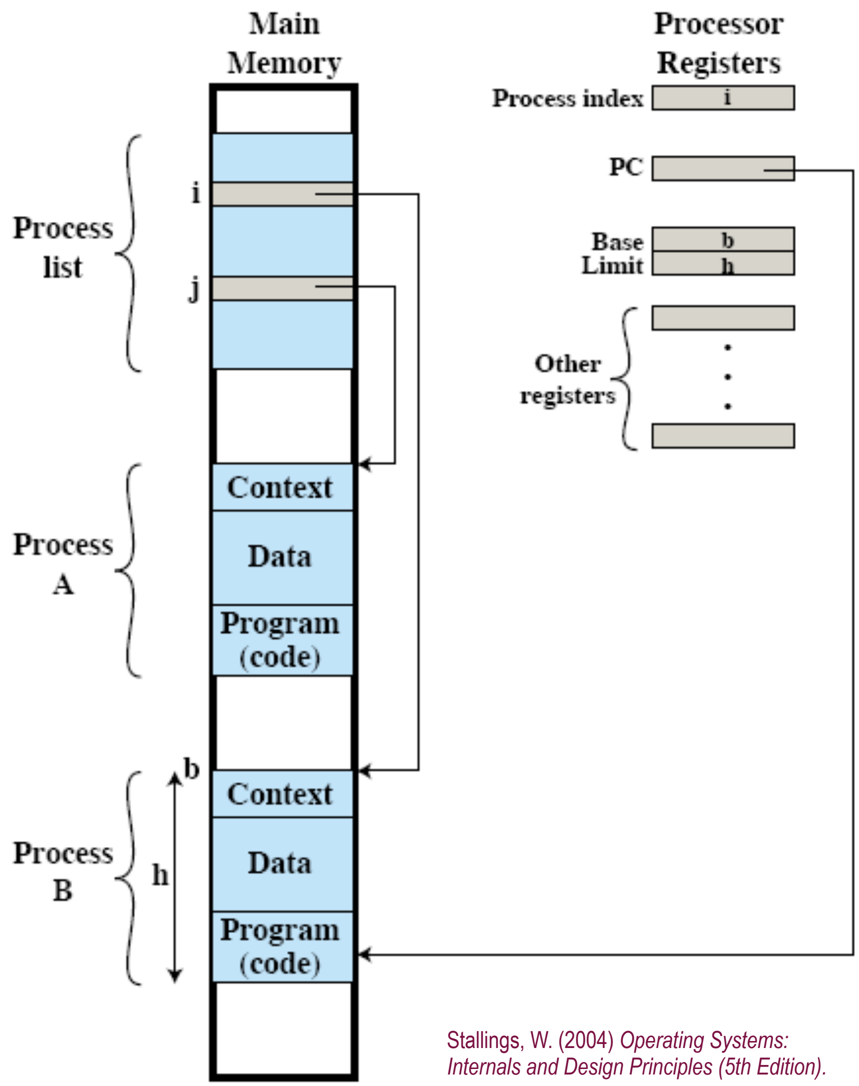
Process

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.)

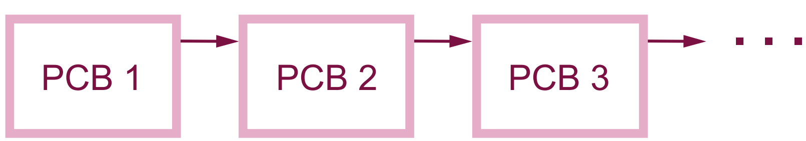


Stallings, W. (2004) *Operating Systems: Internals and Design Principles (5th Edition).*

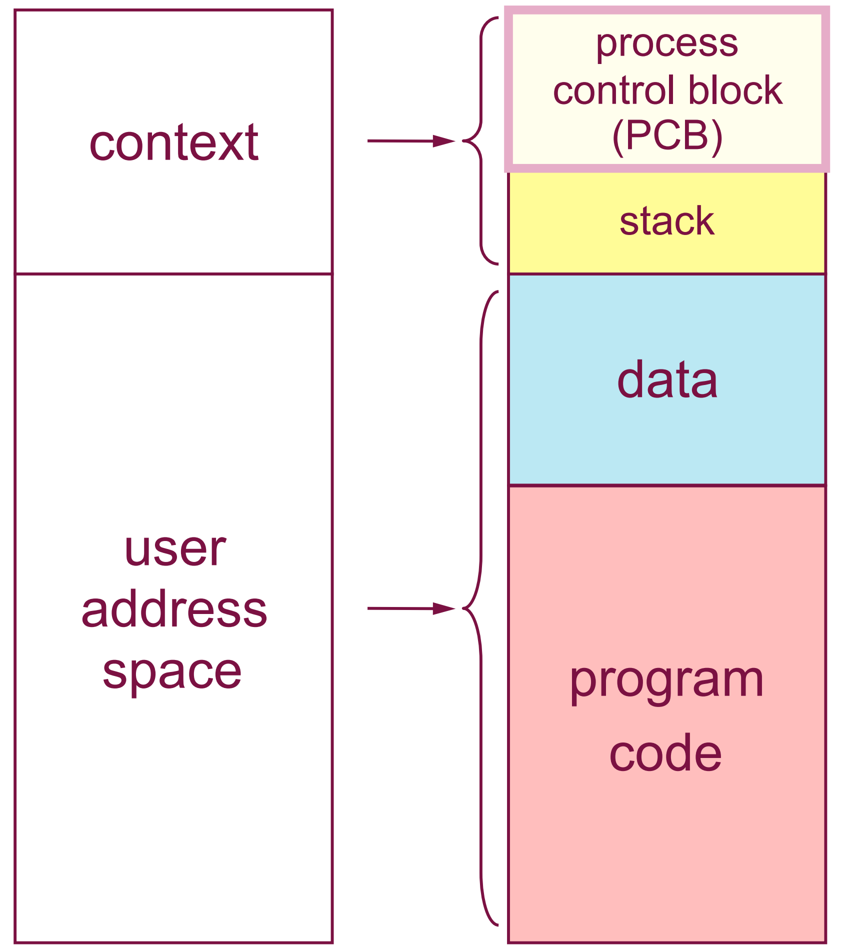
Typical process image implementation

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)

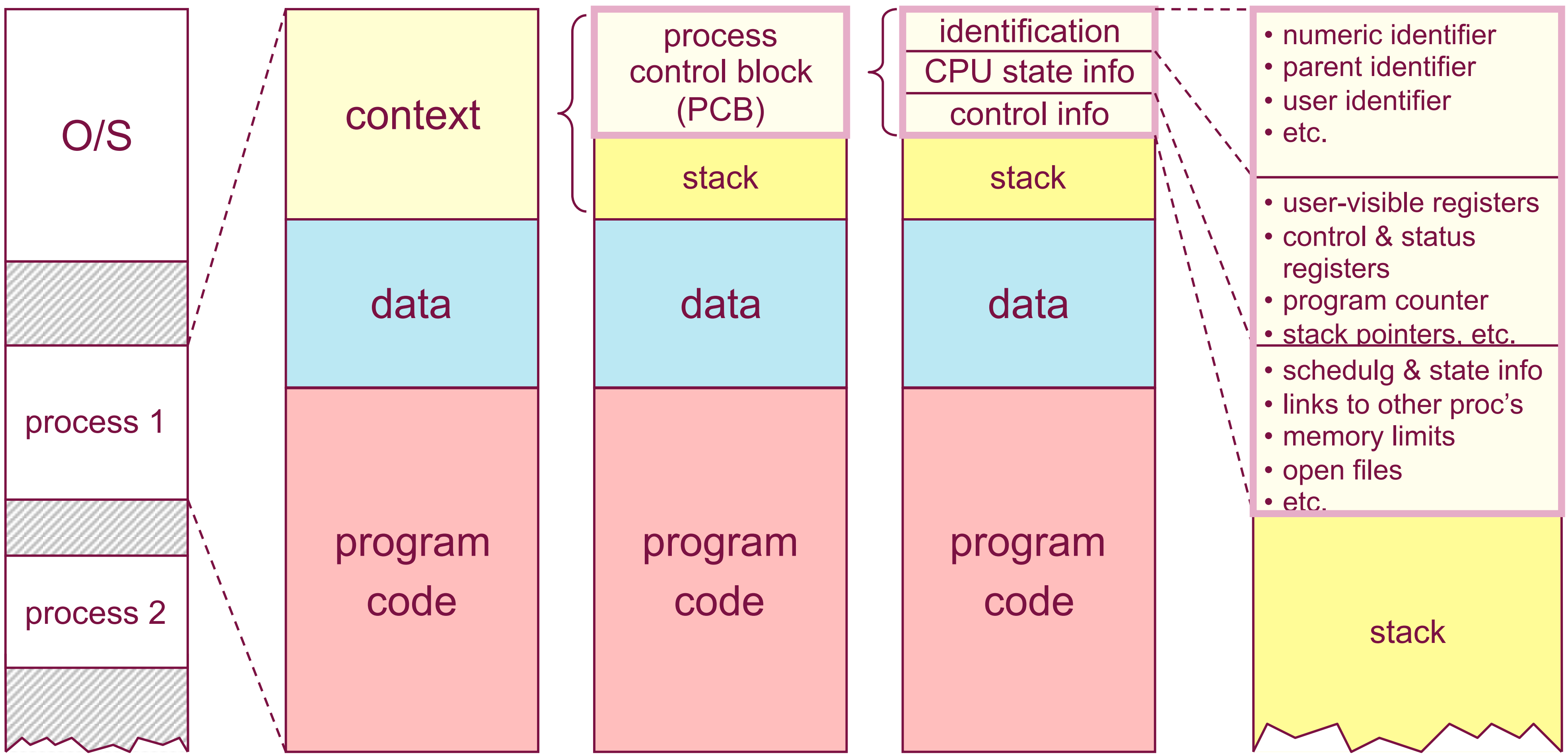


Typical process image implementation



Process Control Block

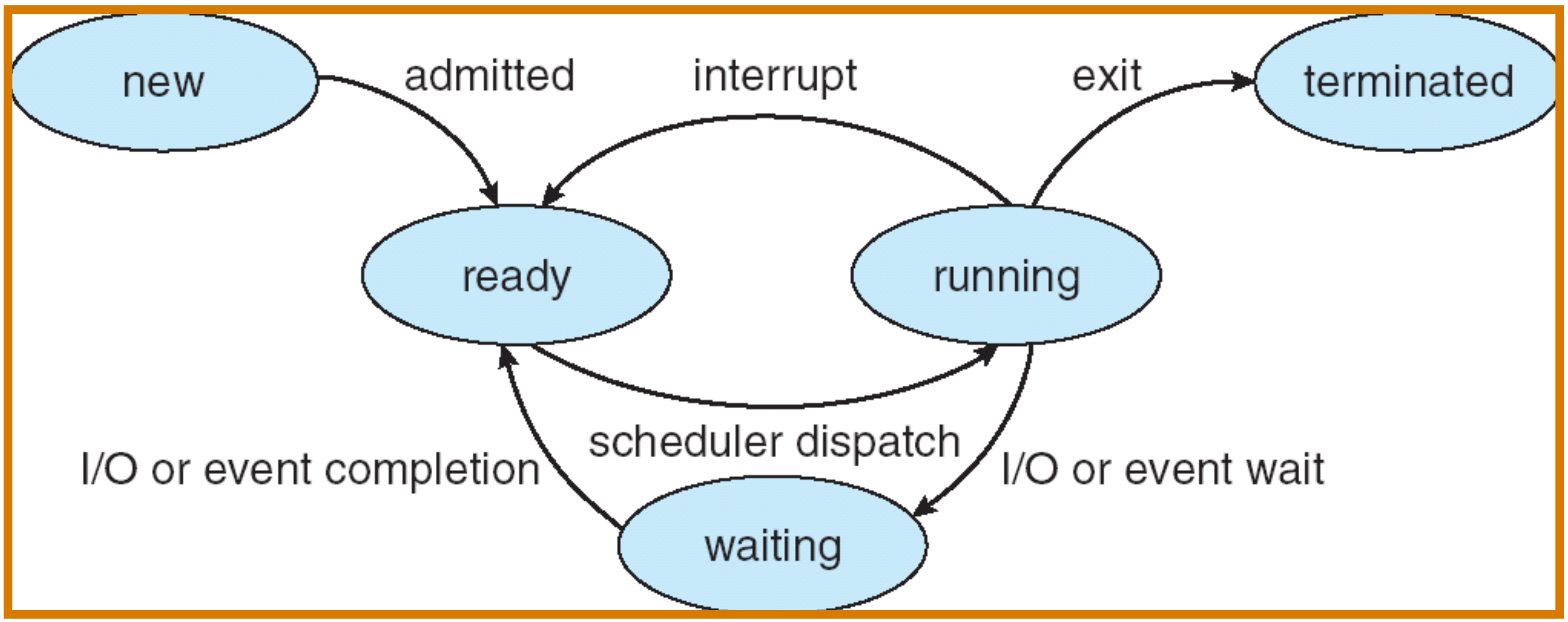
- Example of process and PCB location in memory



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



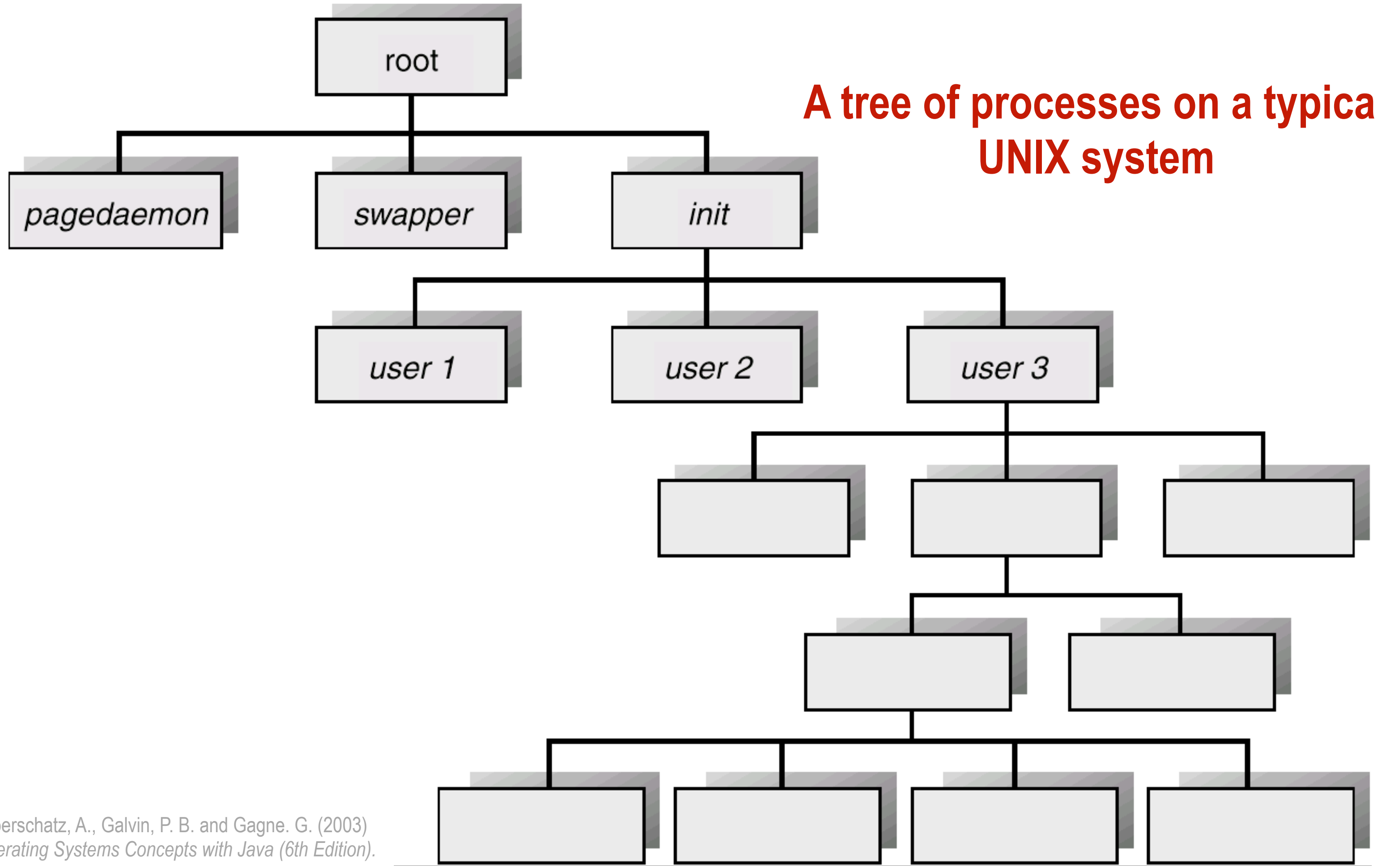
Process Creation

- Some events that lead to process creation (enter)
  - ✓ 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

all cases of process spawning

Process Creation

- <u>Process creation by spawning</u>



A tree of processes on a typical UNIX system

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

Process Creation

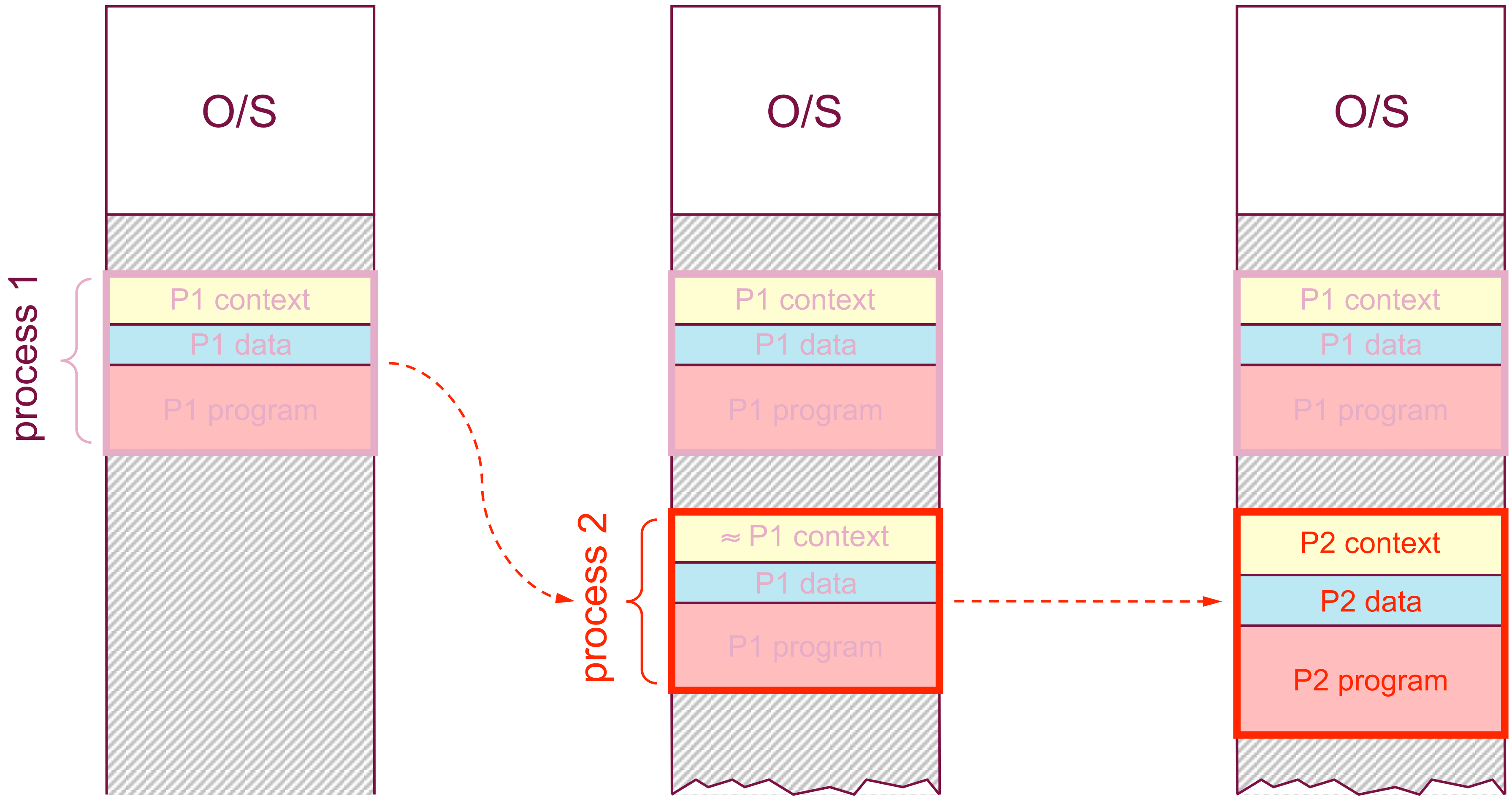
```
...
int main(...)
{
    ...
    if ((pid = fork()) == 0)                        // create a process
    {
        fprintf(stdout, "Child pid: %i\n", getpid());
       err = execvp(command, arguments);            // execute child
                                                    //   process
        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

- <u>Some events that lead to process pause / dispatch</u>
  - ✓ I/O wait
    - 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
    - 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

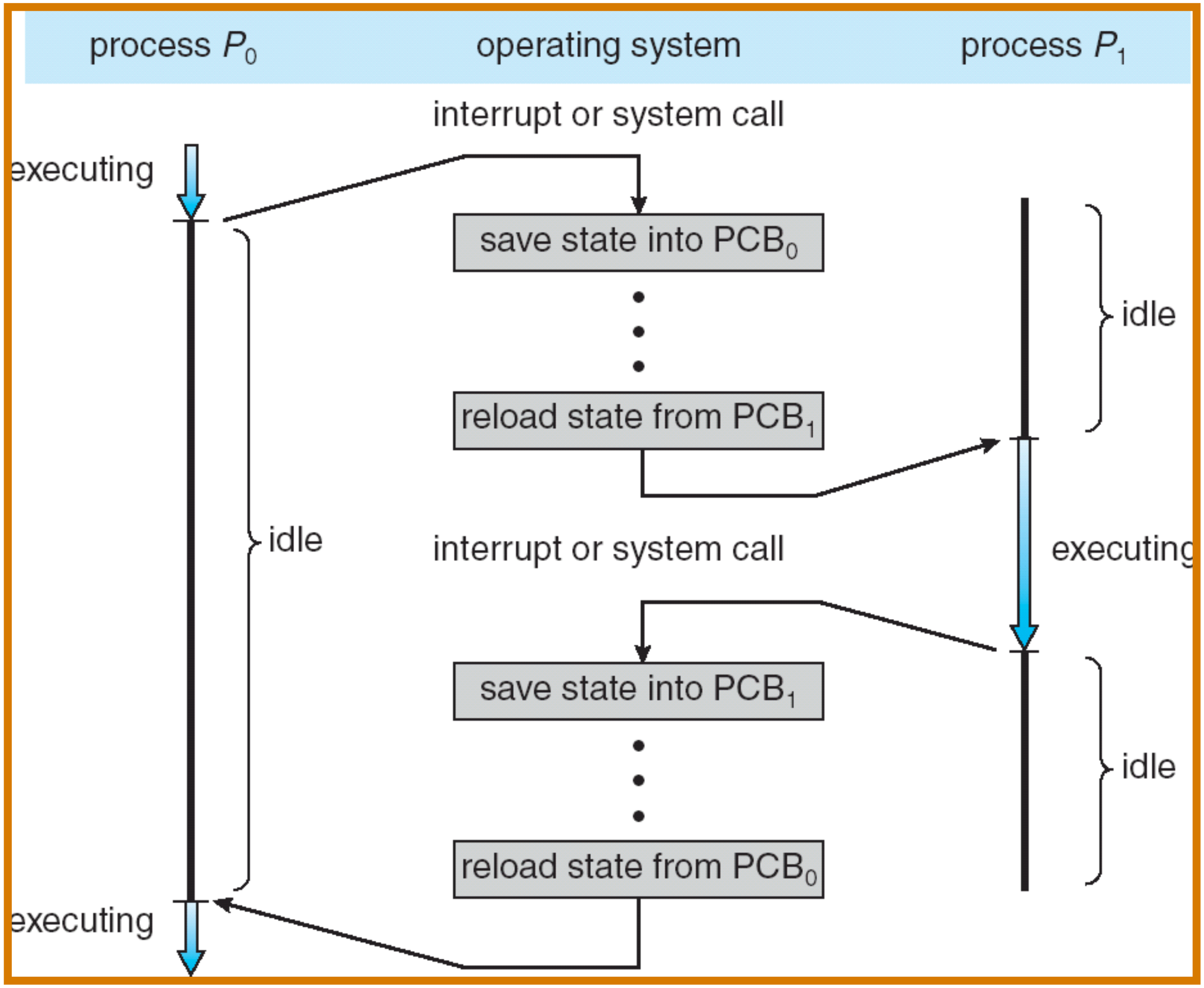
O/S-triggered (following system call)

hardware interrupt-triggered (timer)

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

- <u>How does a full process switch happen, step by step?</u>
  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
  - **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.

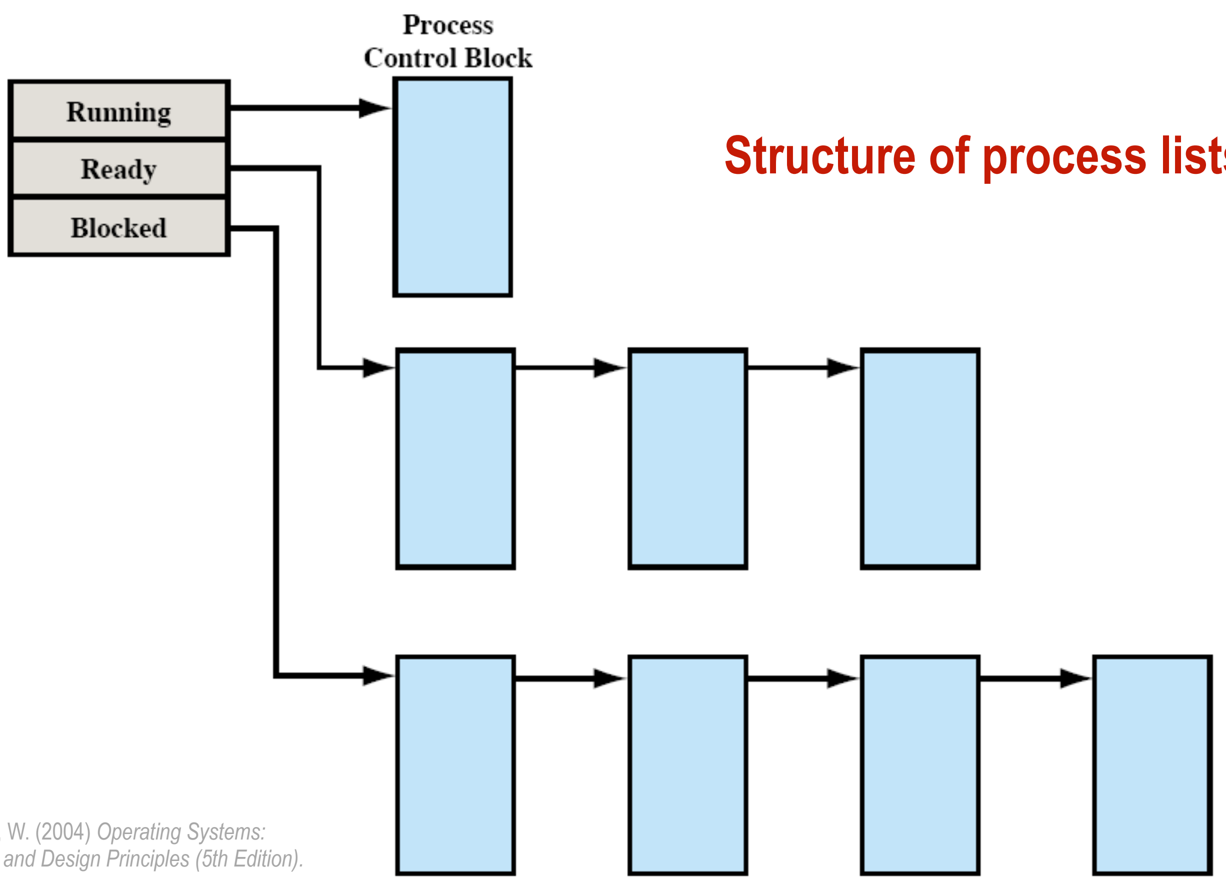
traps

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

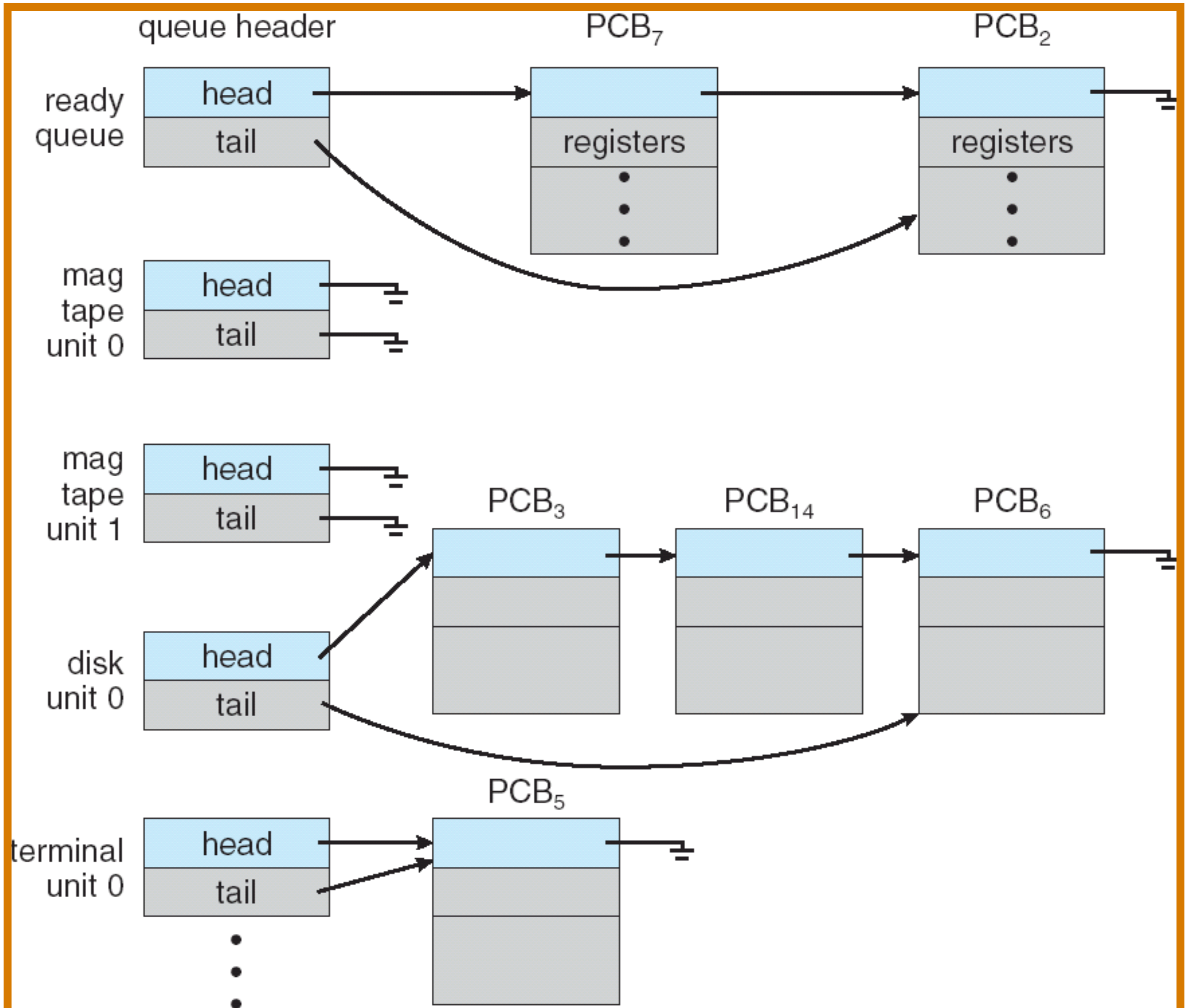
- **The process table can be split into per-state queues**
  - ✓ PCBs can be linked together if they contain a pointer field



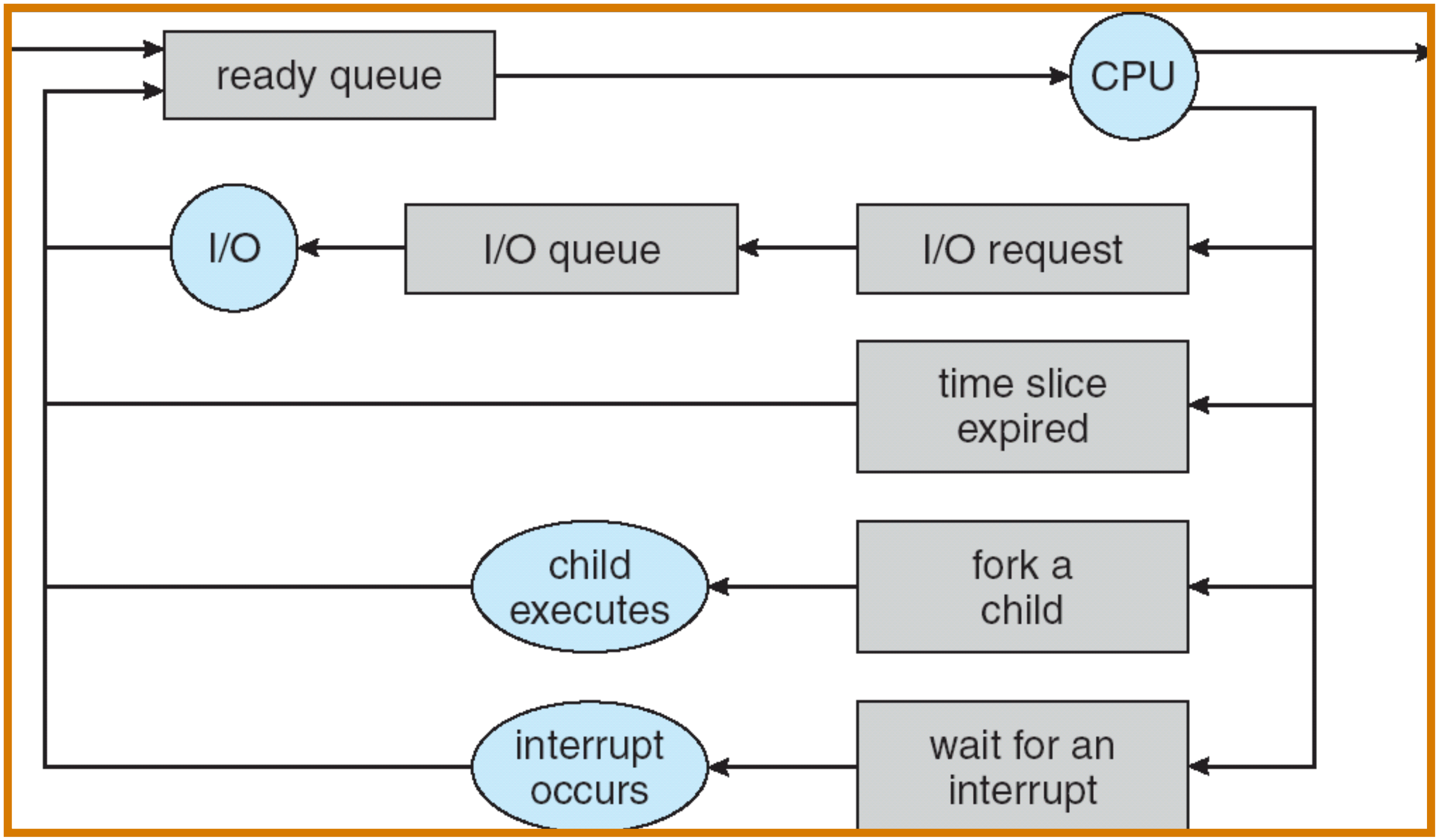
Structure of process lists or queues

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

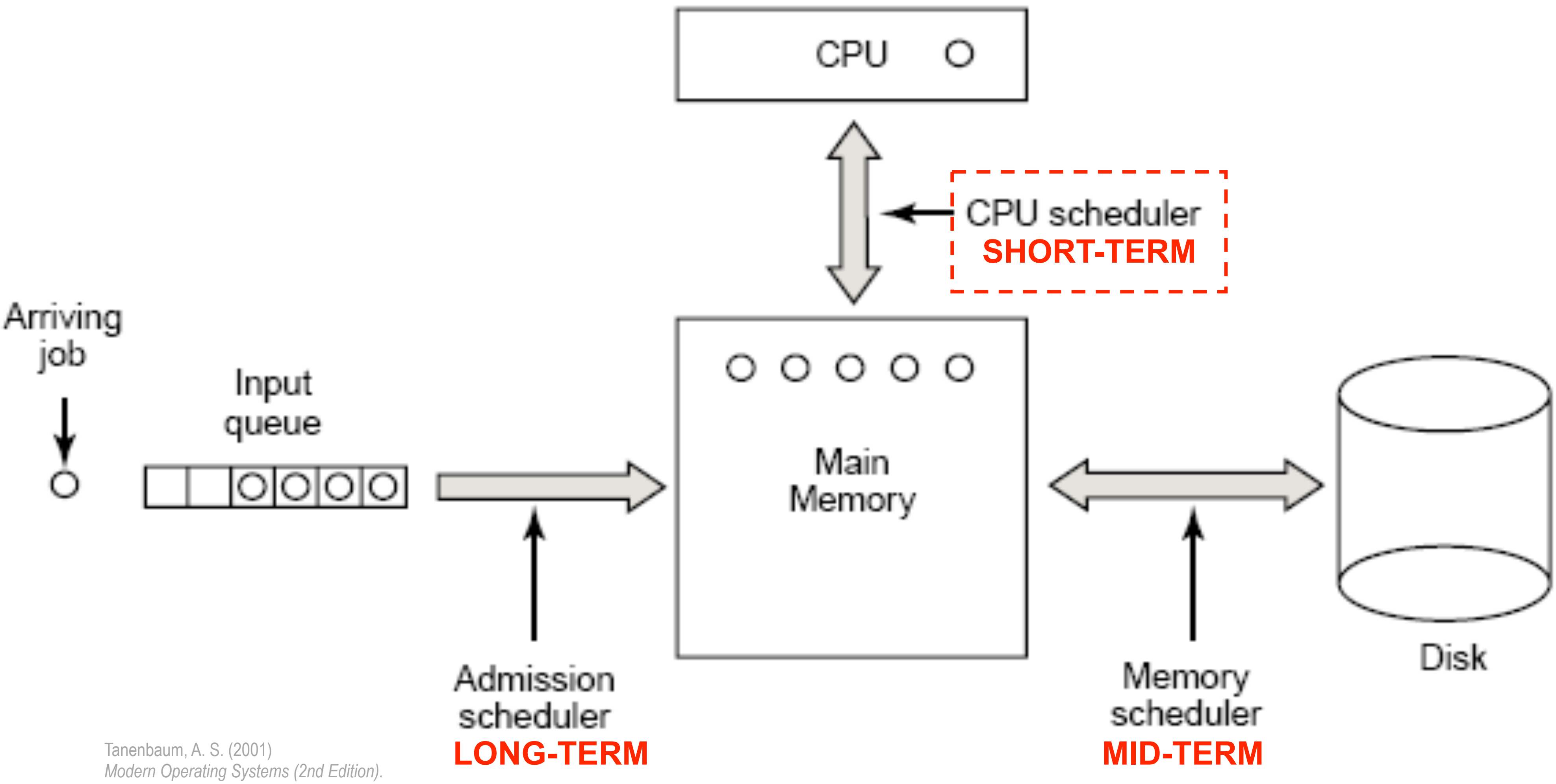
Ready Queue And Various I/O Device Queues



Representation of Process Scheduling



Three Level Process Scheduling



Three-level 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

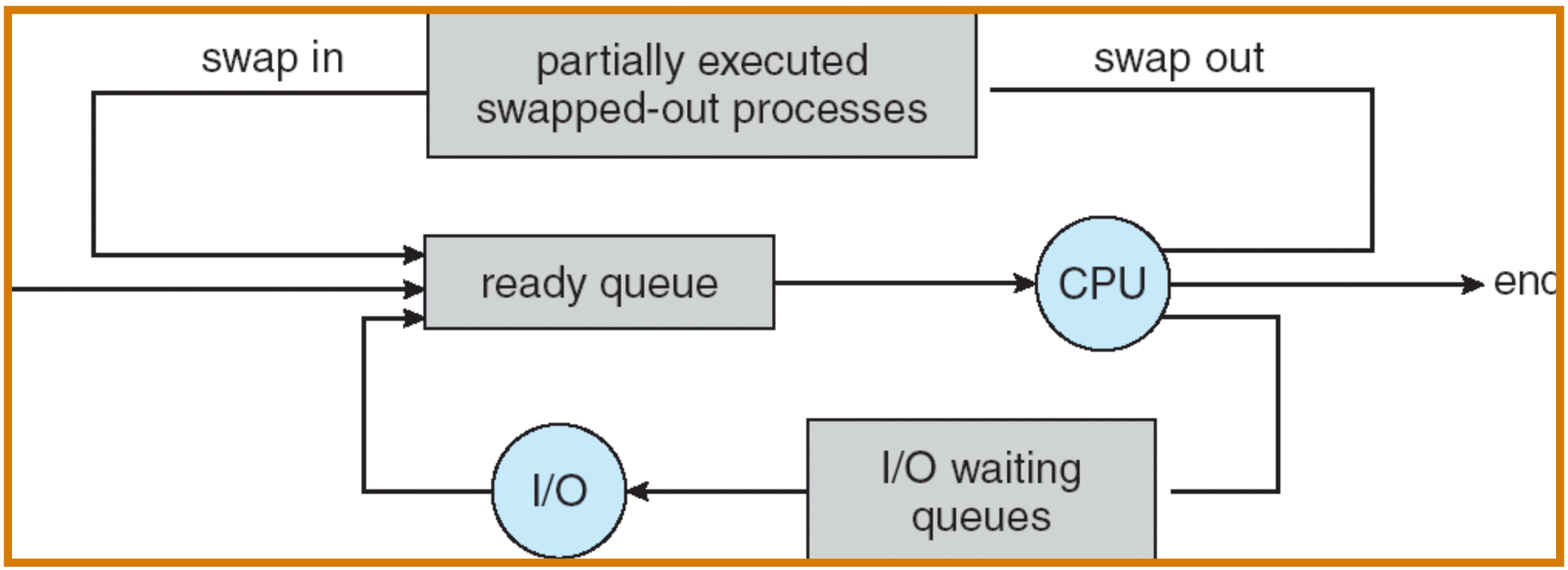
Schedulers

- 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



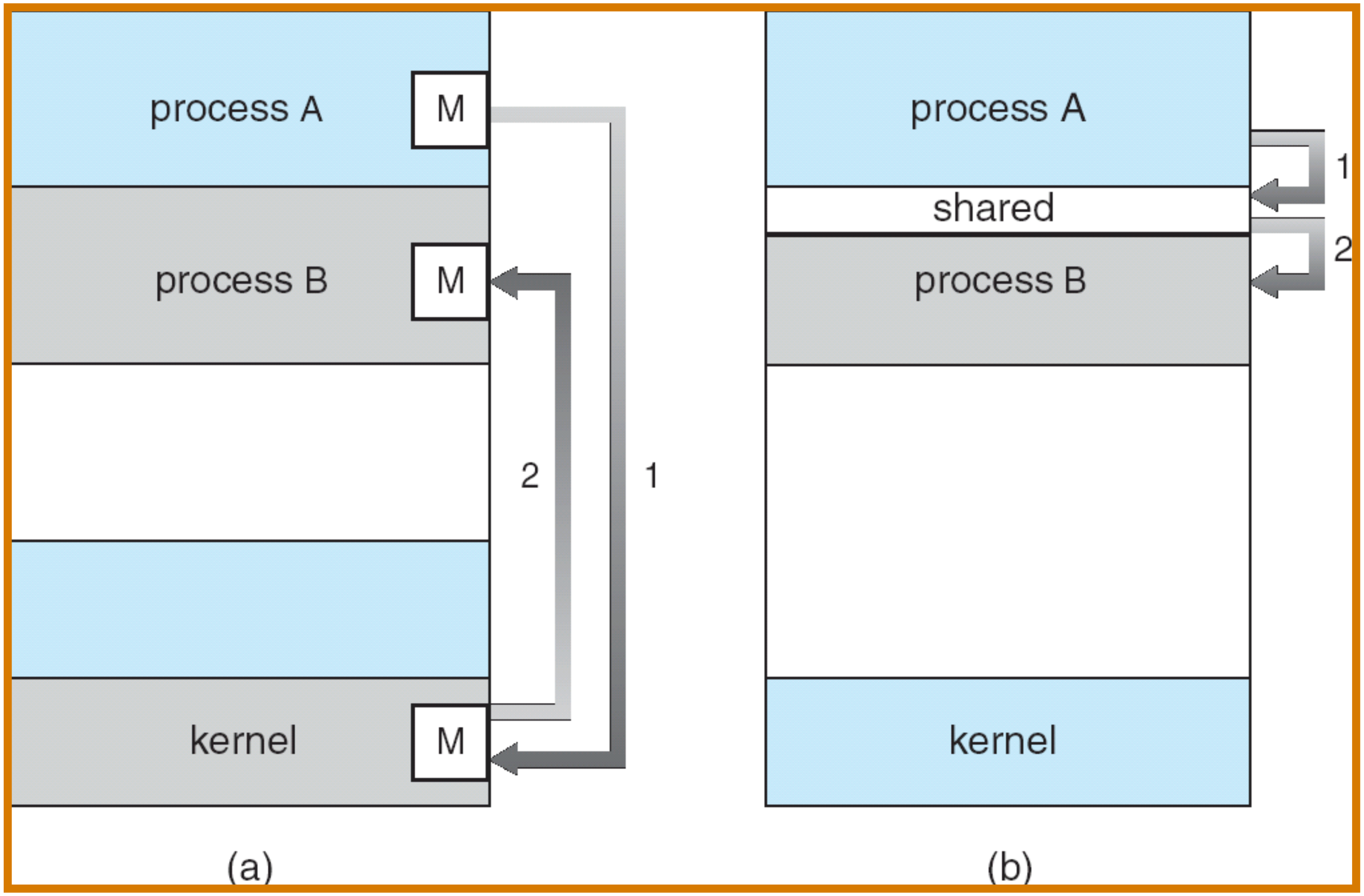
Cooperating Processes

- **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

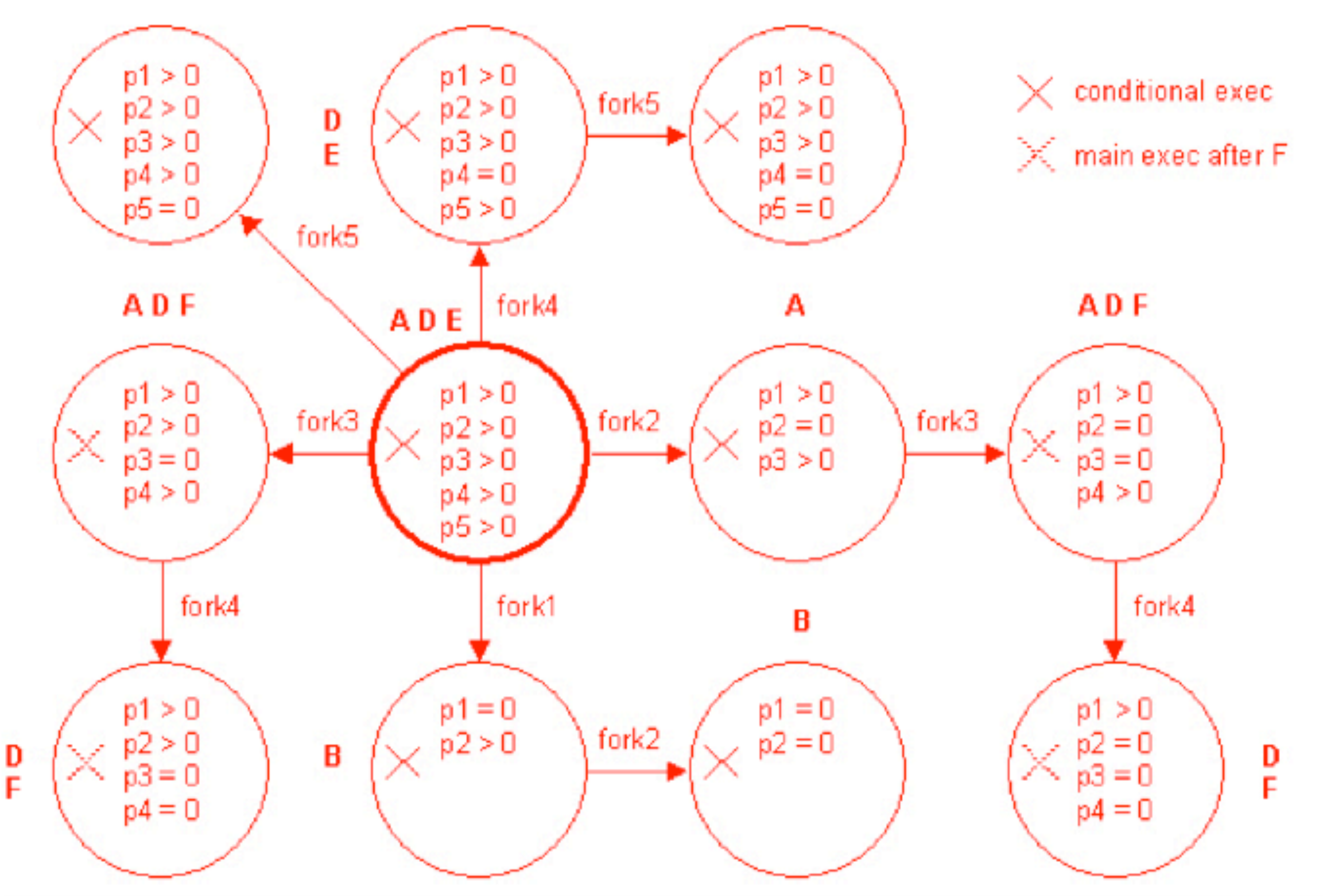
In the code below, assume that *(i)* all `fork` and `execvp` statements execute successfully, *(ii)* the program arguments of `execvp` do not spawn more processes or print out more characters, and *(iii)* all `pid` variables are initialized to `0`.

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();
}
```

```
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();
}
```

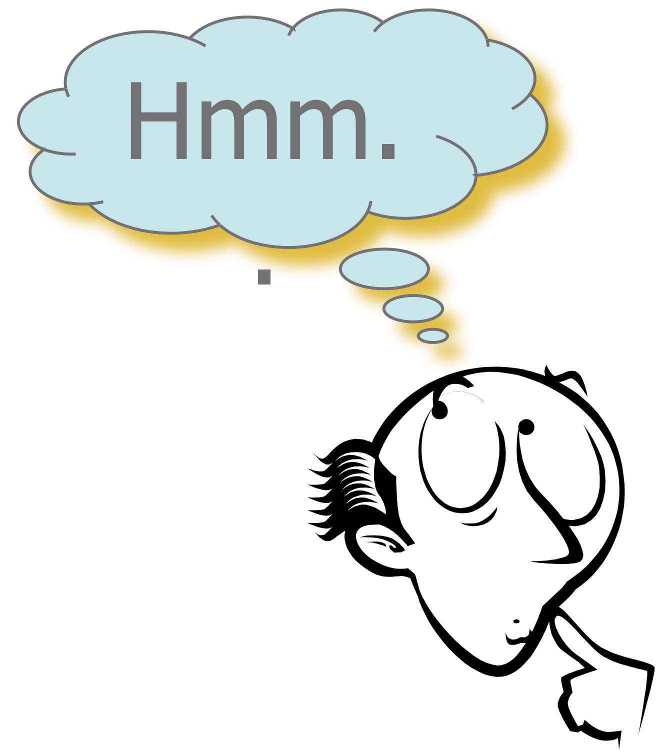
Solution



conditional exec
main exec after F
p1 > 0
p2 > 0
p3 > 0
p4 > 0
p5 = 0
D
E
p1 > 0
p2 > 0
p3 > 0
p4 = 0
p5 > 0
fork5
p1 > 0
p2 > 0
p3 > 0
p4 = 0
p5 = 0
fork5
fork4
A D F
A D E
A
A D F
p1 > 0
p2 > 0
p3 = 0
p4 > 0
fork3
p1 > 0
p2 > 0
p3 > 0
p4 > 0
p5 > 0
fork2
p1 > 0
p2 = 0
p3 > 0
fork3
p1 > 0
p2 = 0
p3 = 0
p4 > 0
fork4
fork1
B
fork4
D
F
p1 > 0
p2 > 0
p3 = 0
p4 = 0
B
p1 = 0
p2 > 0
fork2
p1 = 0
p2 = 0
p1 > 0
p2 = 0
p3 = 0
p4 = 0
D
F

Summary

- Processes
  - Process Representation in OS
  - 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