# Chapter 3: Processes

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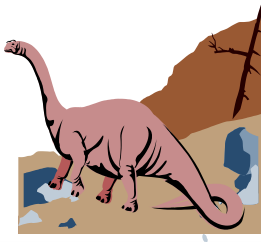
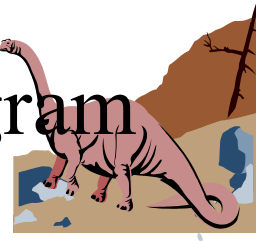
# Chapter 3: Processes

- Process Concept
- Operations and APIs on Processes
- Process Scheduling
- Cooperating Processes
- Interprocess Communication
- Communication in Client-Server Systems

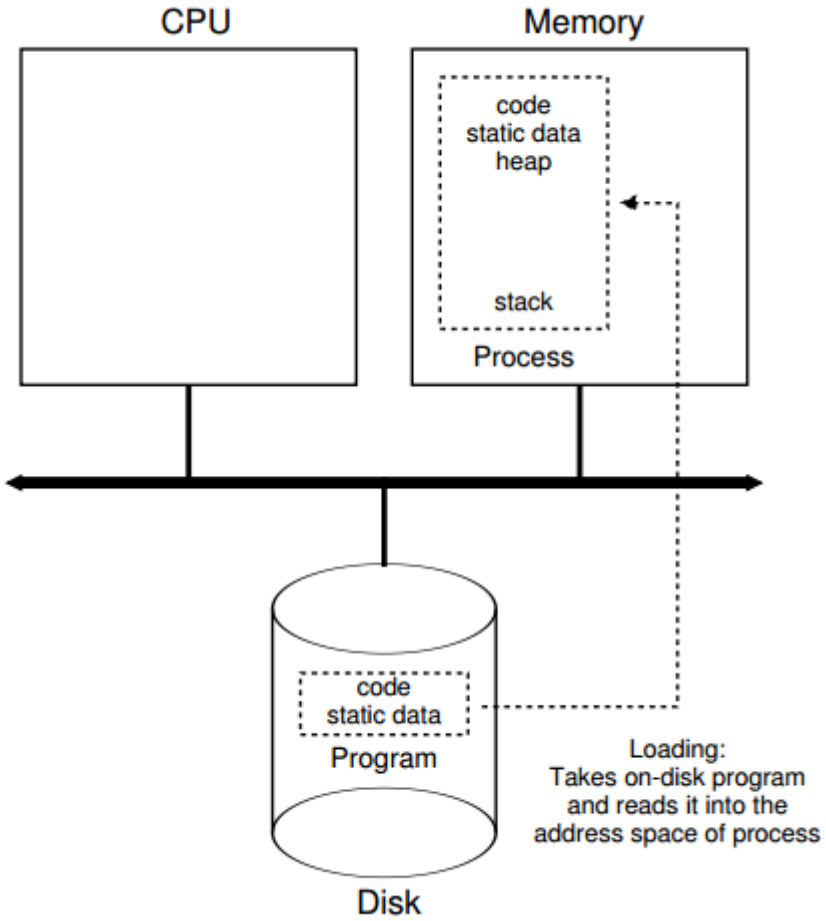


# Process Concept

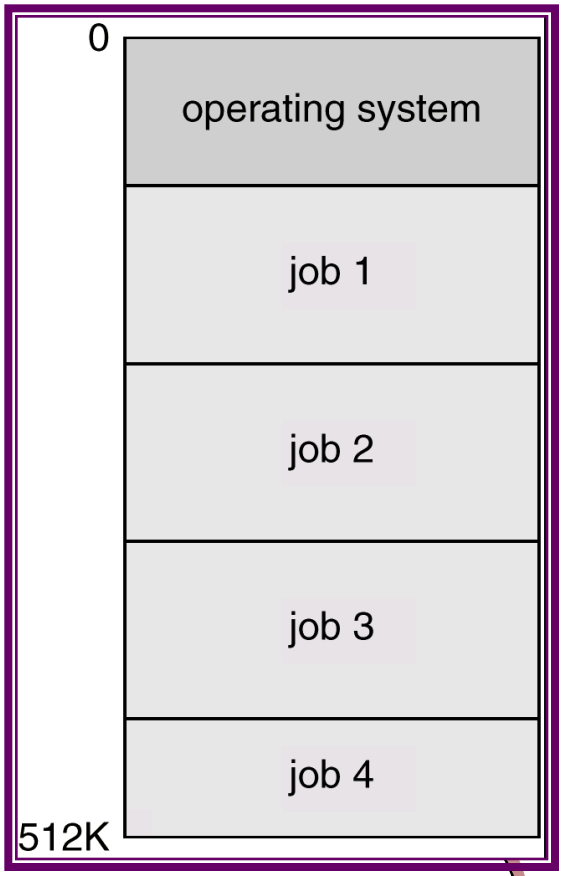
- An operating system executes a variety of programs:
  - Batch system – jobs
  - Time-shared systems – user programs or tasks
- Textbook uses the terms *job* and *process* almost interchangeably.
- Q: Why process, not program? What is a program?
- Process: running program
  - A program is lifeless, the OS makes it running (as a process).
  - A process can be viewed as a running program with machine states.

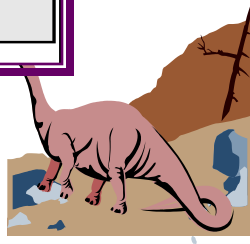


# Loading into Memory: From Program To Process




## Virtualizing the Memory



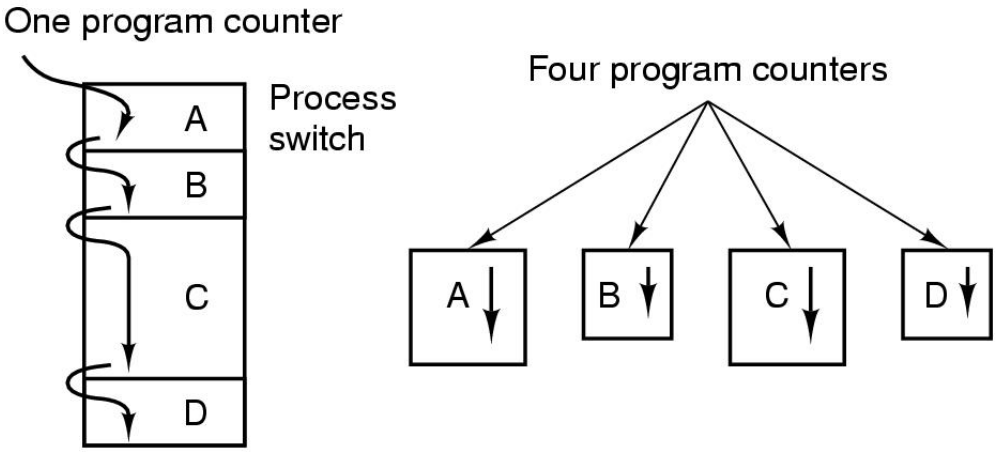



# Processes

## The Process Model

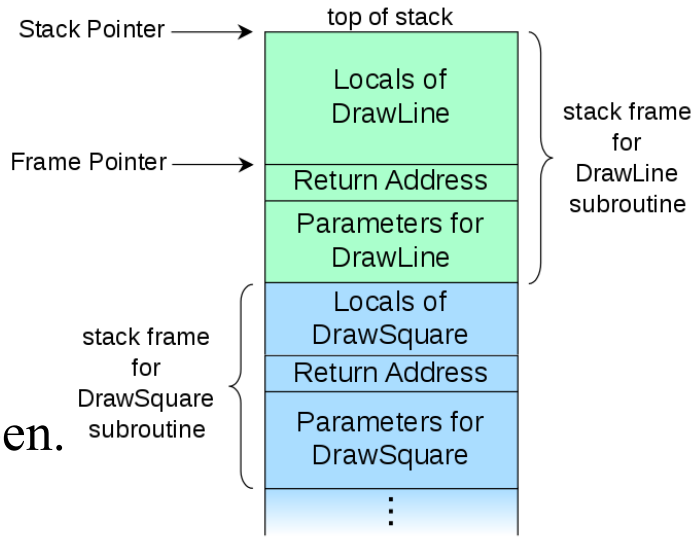
- Virtualizing the CPU:
  - By running one process, then stopping it and running another, and so forth.

- An Example: Multiprogramming of four programs
  - Conceptual model of 4 independent, sequential processes
  - Only one program active at any instant



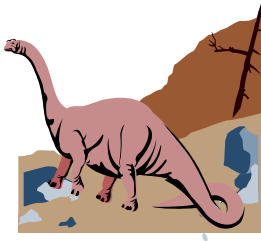

# Process Concept (Cont.)

- Process – a program in execution; process execution must progress in sequential fashion.
- The running state of a process includes:
  - Memory
    - ✓ Address space: Instructions and data.
  - Registers
    - ✓ Program counter (PC) / instruction pointer (IP): current instruction.
    - ✓ Stack pointer, frame pointer: management of stack for parameters, local variables, and return addresses.
    - ✓ Contents of the processor's other registers
  - I/O information
    - ✓ A list of the files the process currently has open.

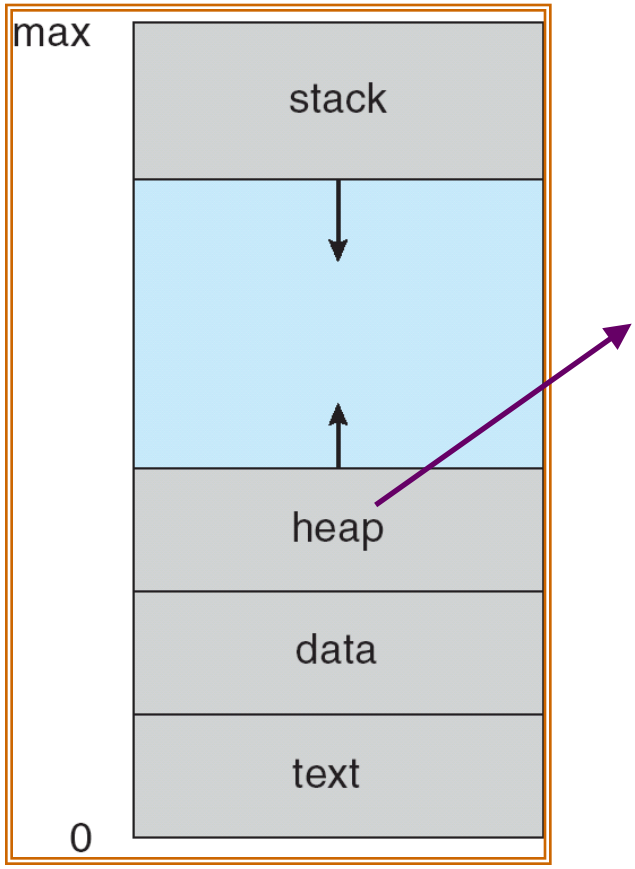


# Process in Memory

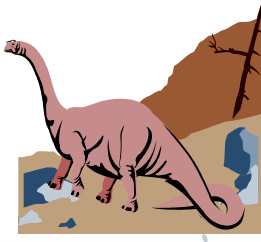
```
//main.cpp
int a = 0;          ←—— 数据段
char *p1;           ←—— 数据段
main()
{   int b;          ←—— 栈
    char s[] = "abc";   ←—— 栈
    char *p2;       ←—— 栈
    char *p3 = "123456";   ←—— 栈
    p1 = (char *)malloc(10);   ←—— 堆
    p2 = (char *)malloc(20);   ←—— 堆
}
```



# Process in Memory

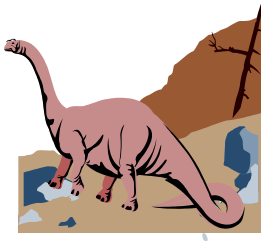



Heap is memory that is dynamically allocated during process run time.

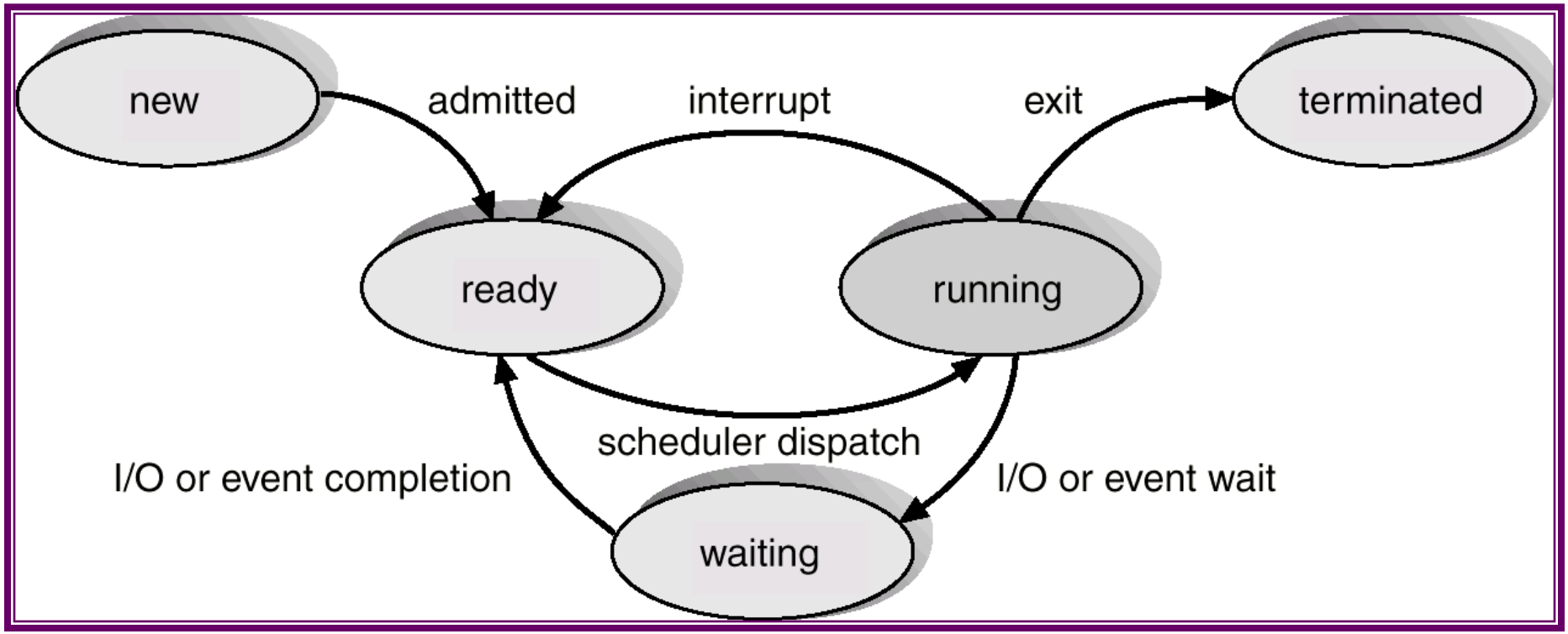


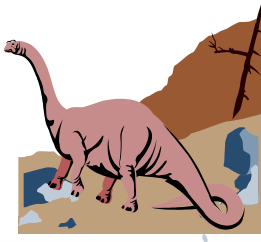
# Process State

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



# Diagram of Process State

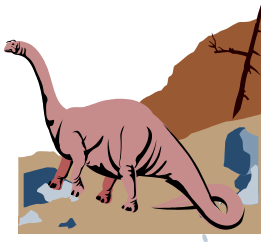


# Tracing Process State

| Time | $Process_0$ | $Process_1$ | Notes |
|---|---|---|---|
| 1 | Running | Ready | |
| 2 | Running | Ready | |
| 3 | Running | Ready | $Process_0$ initiates I/O |
| 4 | Blocked | Running | $Process_0$ is blocked, |
| 5 | Blocked | Running | so $Process_1$ runs |
| 6 | Blocked | Running | |
| 7 | Ready | Running | I/O done |
| 8 | Ready | Running | $Process_1$ now done |
| 9 | Running | – | |
| 10 | Running | – | $Process_0$ now done |

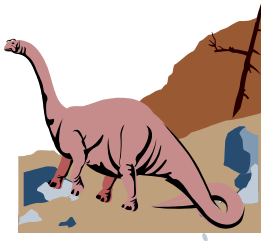
Figure 4.4: **Tracing Process State: CPU and I/O**



# Discussion

- Q1: Draw on the blackboard the Diagram of Process State

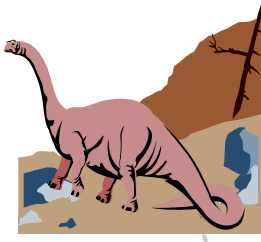
- Q2: 下列哪一种情况不会引起进程之间的切换？
  - A.进程调用本程序中定义的函数进行计算
  - B.进程处理I/O请求
  - C.进程创建子进程并等待子进程结束
  - D.产生中断



# Data Structure

- OS is a program, so it has some key data structures that track the state of each process.
  - Process lists for all ready / running / waiting processes

- An example: xv6 kernel
  - types of information an OS needs to track processes



```
// the registers xv6 will save and restore
// to stop and subsequently restart a process
struct context {
  int eip;
  int esp;
  int ebx;
  int ecx;
  int edx;
  int esi;
  int edi;
  int ebp;
};

// the different states a process can be in
enum proc_state { UNUSED, EMBRYO, SLEEPING,
                  RUNNABLE, RUNNING, ZOMBIE };

// the information xv6 tracks about each process
// including its register context and state
struct proc {
  char *mem;                  // Start of process memory
  uint sz;                    // Size of process memory
  char *kstack;               // Bottom of kernel stack
                              // for this process
  enum proc_state state;      // Process state
  int pid;                    // Process ID
  struct proc *parent;        // Parent process
  void *chan;                 // If non-zero, sleeping on chan
  int killed;                 // If non-zero, have been killed
  struct file *ofile[NOFILE]; // Open files
  struct inode *cwd;          // Current directory
  struct context context;     // Switch here to run process
  struct trapframe *tf;       // Trap frame for the
                              // current interrupt
};
```

All registers

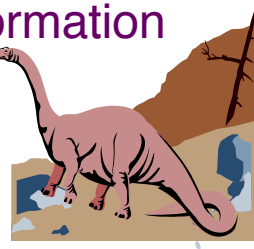
Memory: address space

Stack

Process state

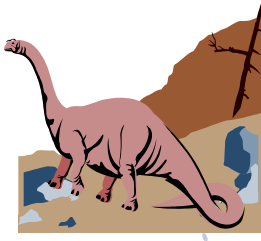
Process ID

I/O information

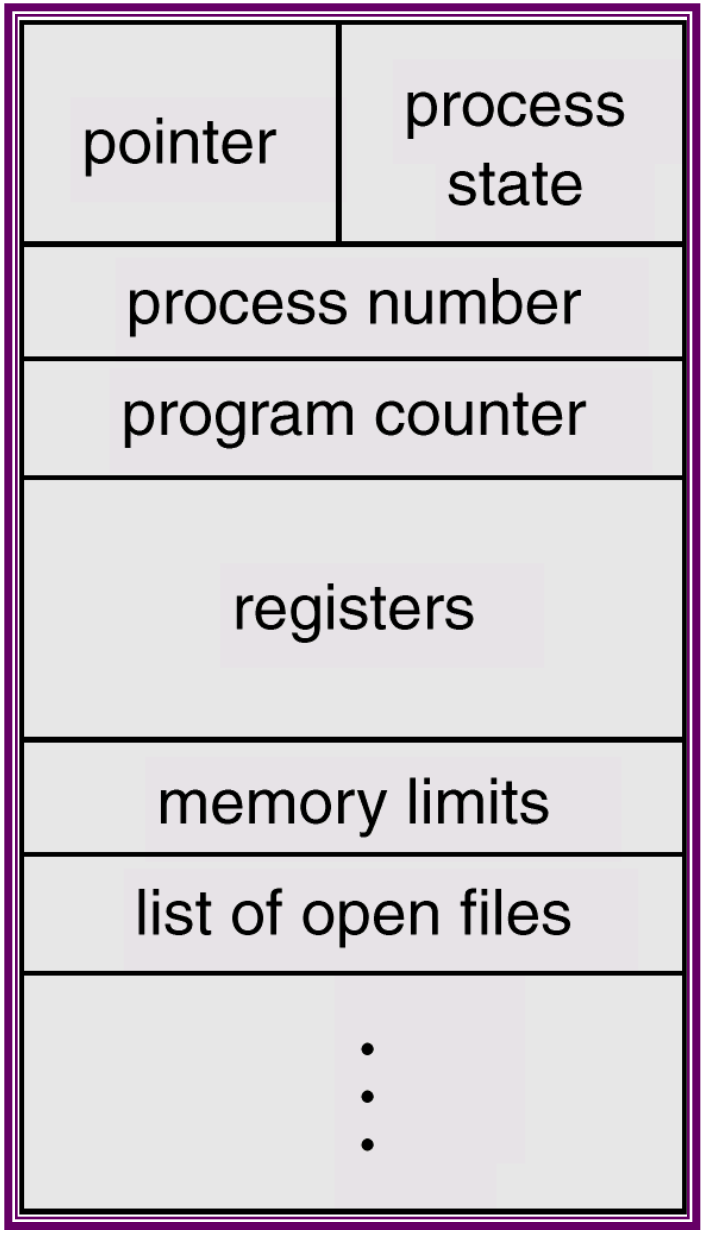


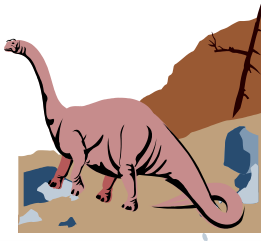
# Process Control Block (PCB)

- Information associated with each process.
  - Process state
  - Program counter
  - CPU registers
  - CPU scheduling information
  - Memory-management information
  - Accounting information
  - File usage and I/O status information



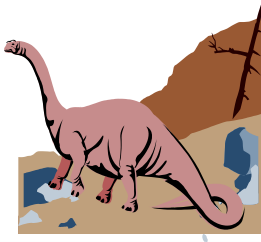
# Process Control Block (PCB)



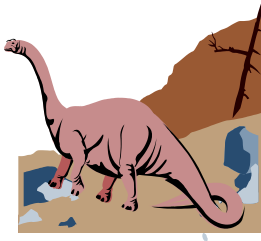
# Context Switch

- What is a process context?
  - The *context* of a process includes the values of CPU registers, the process state, the program counter, and other memory/file management information.

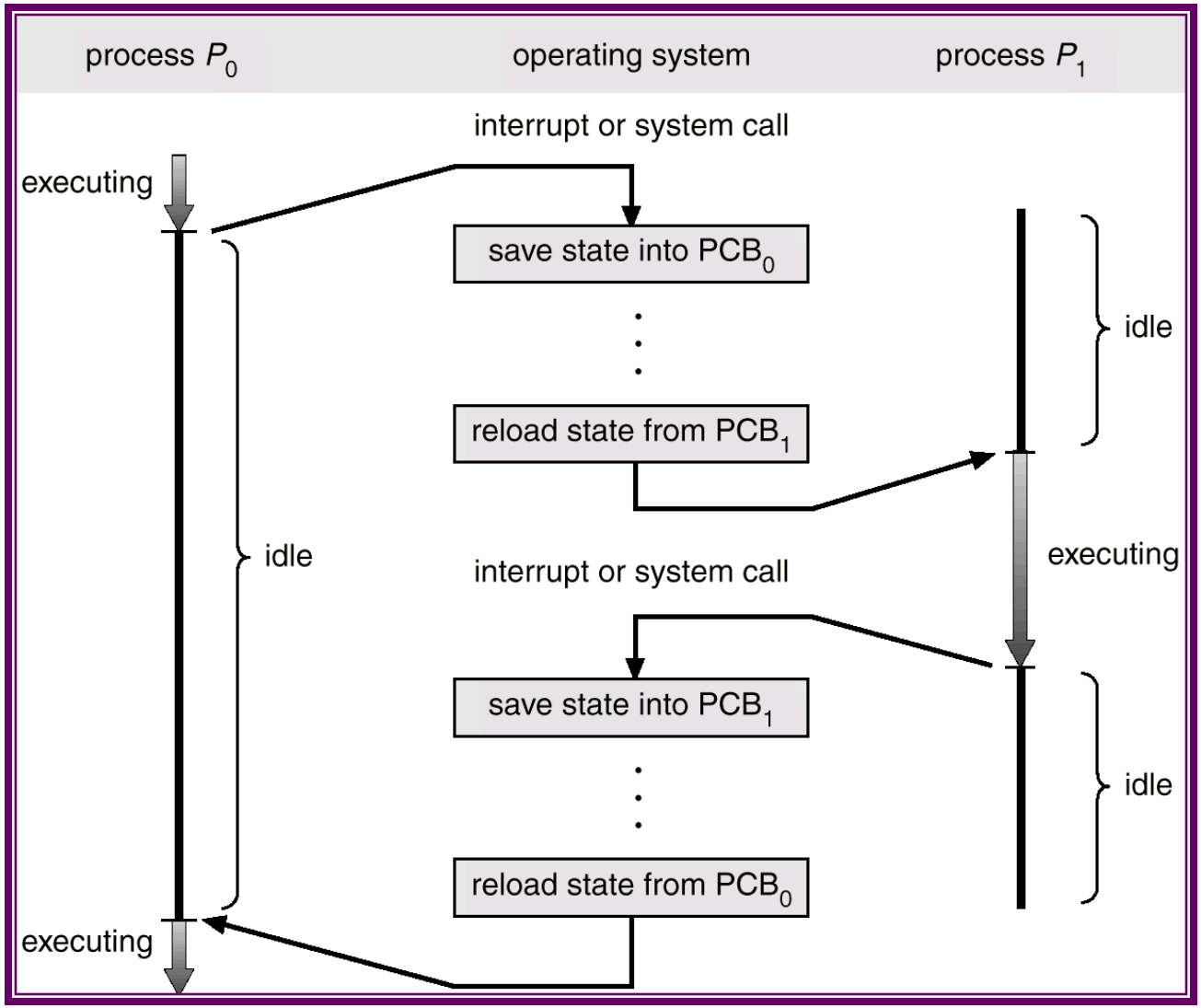


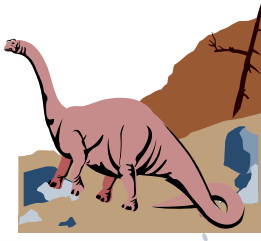
# Context Switch (cont.)

- **What is a context switch?**
  - After the CPU scheduler selects a process (from the *ready queue*) and before allocates CPU to it, the CPU scheduler must
    - ✓ save the *context* of the currently running process,
    - ✓ put it into a queue,
    - ✓ load the *context* of the selected process, and
    - ✓ let it run.



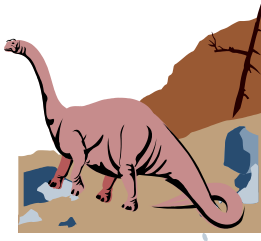
# CPU Switch From Process to Process



# Context Switch (Cont.)

- 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.
- Time dependent on hardware support.



# Chapter 3: Processes

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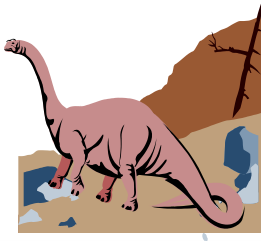
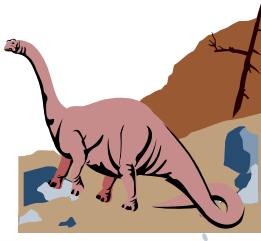
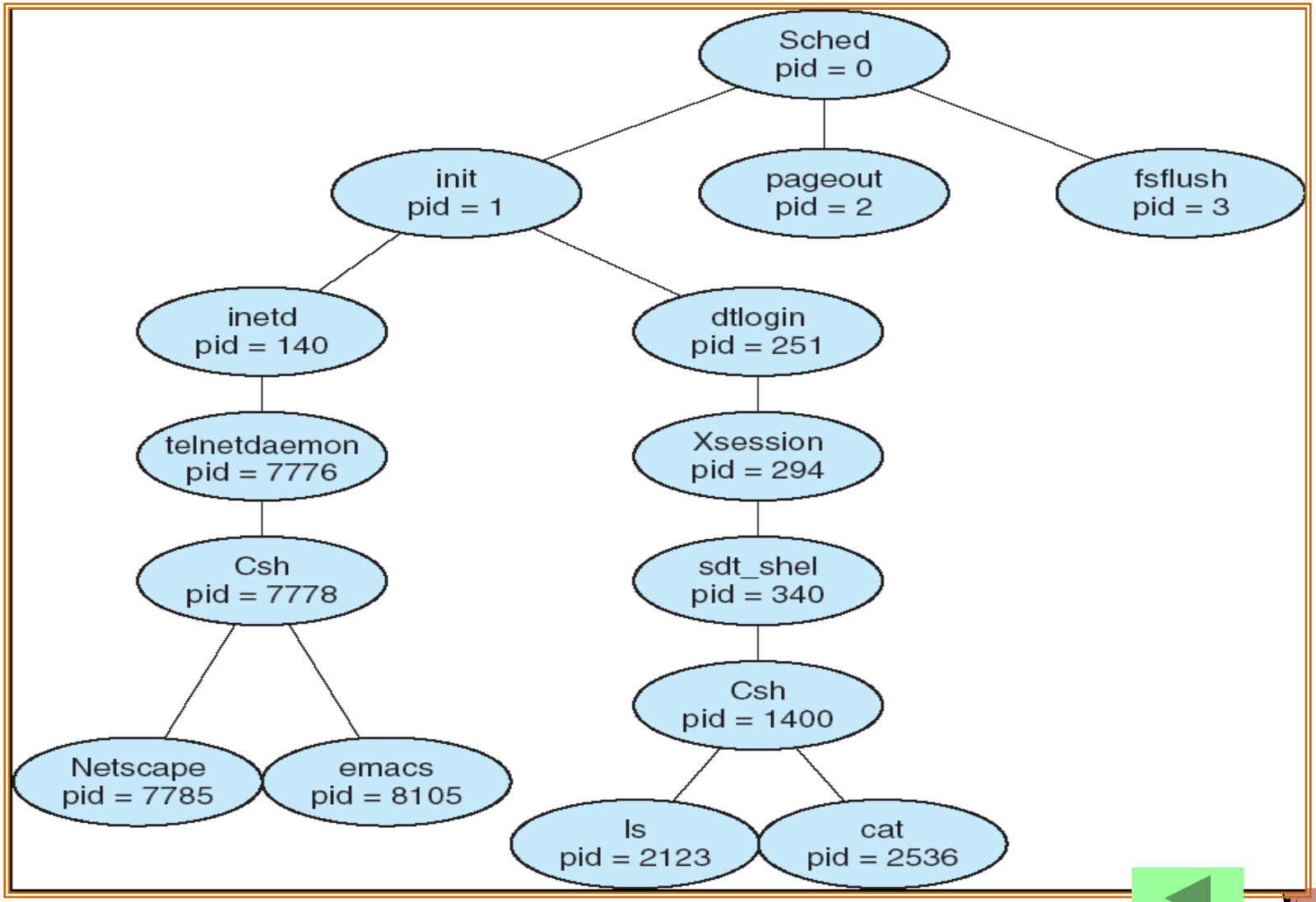


# Process Creation

- Parent process create children processes, which, in turn create other processes, forming a tree of processes.
- Resource sharing
  - Parent and children share all resources.
  - Children share subset of parent's resources.
  - Parent and child share no resources.
- Execution
  - Parent and children execute concurrently.
  - Parent waits until children terminate.

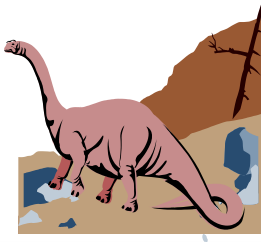


# Processes Tree on Solaris

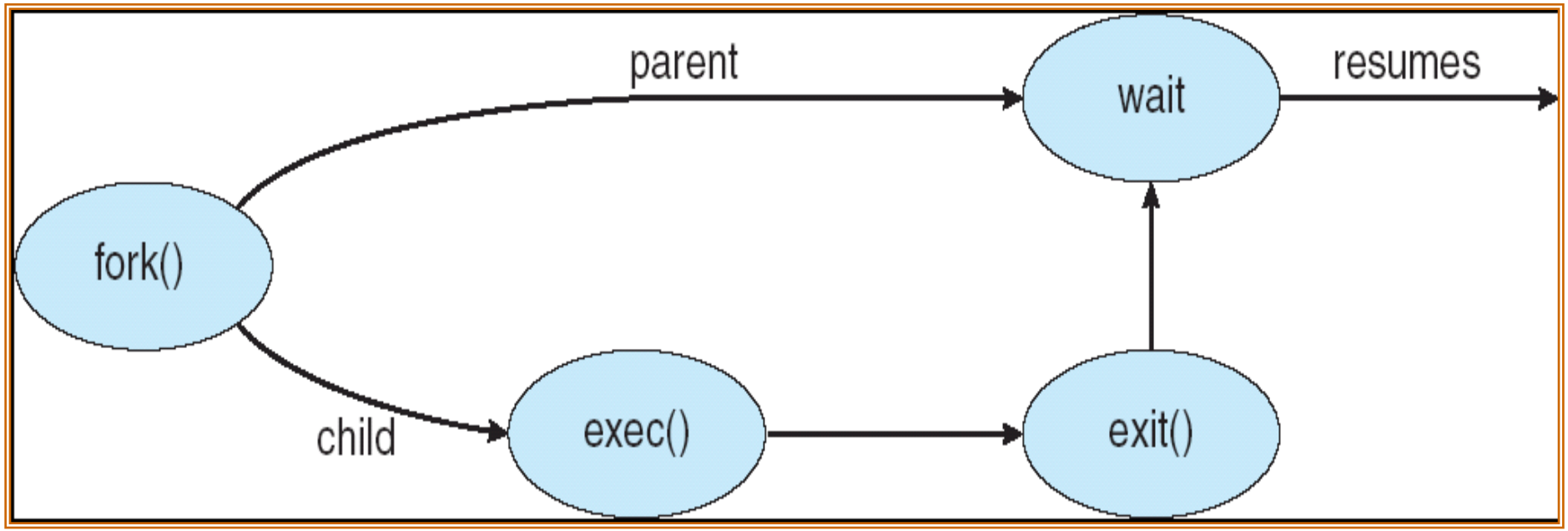


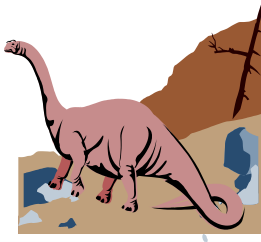
# Process Creation (Cont.)

- Address space
  - Child duplicate of parent.
  - Child has a program loaded into it.
- UNIX examples
  - **fork** system call creates new process
  - **exec** system call used after a **fork** to replace the process' memory space with a new program.



# Process Creation (UNIX)



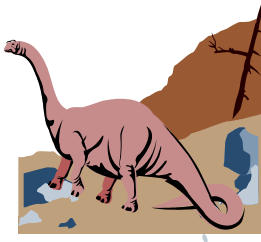



# The fork() System Call

```
1   #include <stdio.h>
2   #include <stdlib.h>
3   #include <unistd.h>
4
5   int
6   main(int argc, char *argv[])
7   {
8       printf("hello world (pid:%d)\n", (int) getpid());
9       int rc = fork();
10      if (rc < 0) {          // fork failed; exit
11          fprintf(stderr, "fork failed\n");
12          exit(1);
13      } else if (rc == 0) { // child (new process)
14          printf("hello, I am child (pid:%d)\n", (int) getpid());
15      } else {               // parent goes down this path (main)
16          printf("hello, I am parent of %d (pid:%d)\n",
17                  rc, (int) getpid());
18      }
19      return 0;
20  }
```

```
prompt> ./p1
hello world (pid:29146)
hello, I am parent of 29147 (pid:29146)
hello, I am child (pid:29147)
prompt>
```

ODD?



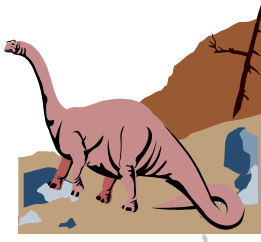
# The fork() System Call

- The process that is created by using the fork() system call is an (almost) exact **copy** of the calling process.

- Discussion:

what is the output?

```
int rc = fork();
if (rc < 0) {
    printf("A");
    exit(1);
} else if (rc == 0) {
    printf("B");
} else {
    printf("C");
}
return 0;
```



# The fork() System Call

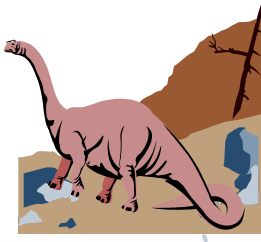
- Discussion: What is the output if we add a loop command before the screen print command?

```
int
main(int argc, char *argv[])
{
    printf("hello world (pid:%d)\n", (int) getpid());
    int rc = fork();
    if (rc < 0) {
        // fork failed; exit
        fprintf(stderr, "fork failed\n");
        exit(1);
    } else if (rc == 0) {
        // child (new process)
        int sum = 0;
        for (int i = 0; i < 100000000; i ++)
            sum += i;
        printf("hello, I am child (pid:%d)\n", (int) getpid());
    } else {
        // parent goes down this path (original process)
        int sum = 0;
        for (int i = 0; i < 100000000; i ++)
            sum += i;
        printf("hello, I am parent of %d (pid:%d)\n",
               rc, (int) getpid());
    }
    return 0;
}
```

# The fork() System Call

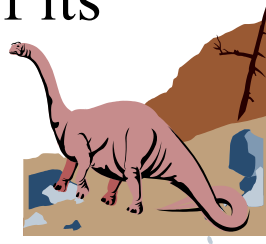
```
Qingjuns-MacBook-Pro:OSC3_code_cpu-api csqjxiao$ ./p1-2
hello world (pid:43349)
hello, I am parent of 43350 (pid:43349)
hello, I am child (pid:43350)
Qingjuns-MacBook-Pro:OSC3_code_cpu-api csqjxiao$ ./p1-2
hello world (pid:43352)
hello, I am child (pid:43353)
hello, I am parent of 43353 (pid:43352)
Qingjuns-MacBook-Pro:OSC3_code_cpu-api csqjxiao$
```

- Discussion: why not deterministic?



# Process Termination

- Process executes last statement and asks the operating system to delete it (**exit**).
  - Output data from child to parent (via **wait**).
  - Process' resources are deallocated by OS.
- Parent may terminate execution of children processes (**abort**).
  - Child has exceeded allocated resources.
  - Task assigned to child is no longer required.
  - Parent is exiting.
    - ✓Operating system does not allow child to continue if its parent terminates.
    - ✓Cascading termination.



# The wait() System Call

```
1   #include <stdio.h>
2   #include <stdlib.h>
3   #include <unistd.h>
4   #include <sys/wait.h>
5
6   int
7   main(int argc, char *argv[])
8   {
9       printf("hello world (pid:%d)\n", (int) getpid());
10      int rc = fork();
11      if (rc < 0) {          // fork failed; exit
12          fprintf(stderr, "fork failed\n");
13          exit(1);
14      } else if (rc == 0) { // child (new process)
15          printf("hello, I am child (pid:%d)\n", (int) getpid());
16      } else {               // parent goes down this path (main)
17          int wc = wait(NULL);
18          printf("hello, I am parent of %d (wc:%d) (pid:%d)\n",
19                 rc, wc, (int) getpid());
20      }
21      return 0;
22  }
```

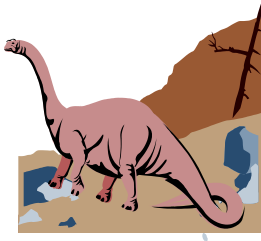
parent waits for child process to finish

```
prompt> ./p2
hello world (pid:29266)
hello, I am child (pid:29267)
hello, I am parent of 29267 (wc:29267) (pid:29266)
prompt>
```

# The exec() System Call

- The process that is created by using the exec() system call can be a different program.

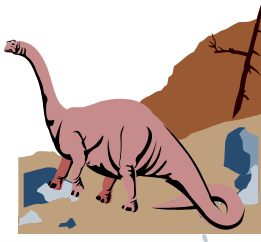
- Some details in exec()
  - It does not create a new process; rather, it transforms the currently running program into a different running program.



# The exec() System Call

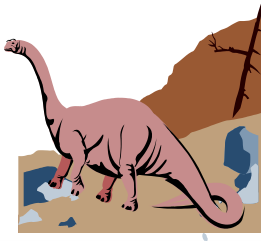
```
1   #include <stdio.h>
2   #include <stdlib.h>
3   #include <unistd.h>
4   #include <string.h>
5   #include <sys/wait.h>
6
7   int
8   main(int argc, char *argv[])
9   {
10      printf("hello world (pid:%d)\n", (int) getpid());
11      int rc = fork();
12      if (rc < 0) {          // fork failed; exit
13          fprintf(stderr, "fork failed\n");
14          exit(1);
15      } else if (rc == 0) { // child (new process)
16          printf("hello, I am child (pid:%d)\n", (int) getpid());
17          char *myargs[3];
18          myargs[0] = strdup("wc");   // program: "wc" (word count)
19          myargs[1] = strdup("p3.c"); // argument: file to count
20          myargs[2] = NULL;           // marks end of array
21          execvp(myargs[0], myargs);  // runs word count
22          printf("this shouldn't print out");
23      } else {                // parent goes down this path (main)
24          int wc = wait(NULL);
25          printf("hello, I am parent of %d (wc:%d) (pid:%d)\n",
26                 rc, wc, (int) getpid());
27      }
28      return 0;
29  }
```

```
prompt> ./p3
hello world (pid:29383)
hello, I am child (pid:29384)
      29     107    1030 p3.c
hello, I am parent of 29384 (wc:29384) (pid:29383)
```



# Review

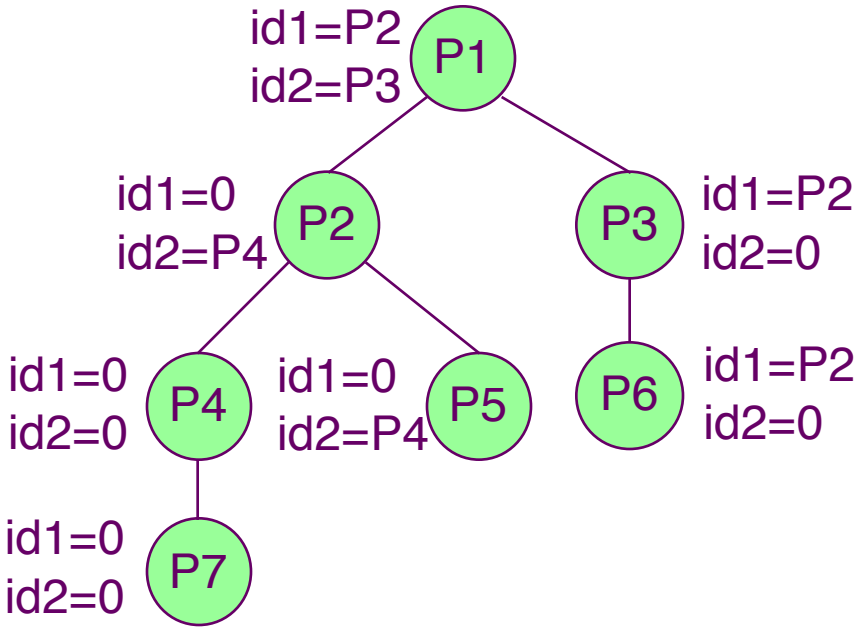
- Process creation APIs
  - fork()
  - wait()
  - exec()
  - What are the differences?



# Quiz

- Consider the following C program. Guess how many lines of output will be printed.

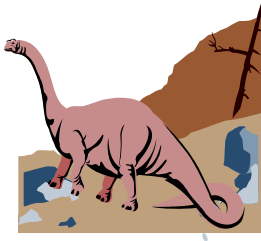
```
int main(int argc, char * argv[])
{
   int i, id1, id2;
   for (i = 1; i < 2; i++) {
      id1 = fork();
      id2 = fork();
      if (id1 == 0 || id2 == 0) fork();
   }
   printf("I am %d\n", getpid());
}
```




- What if we change the initial value i=1 to i=0?

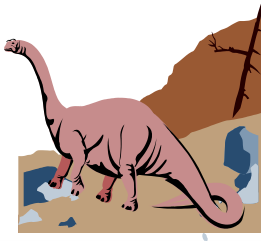
# Chapter 3: Processes

- Process Concept
- Operations and APIs on Processes
- Process Scheduling
- Cooperating Processes
- Interprocess Communication
- Communication in Client-Server Systems

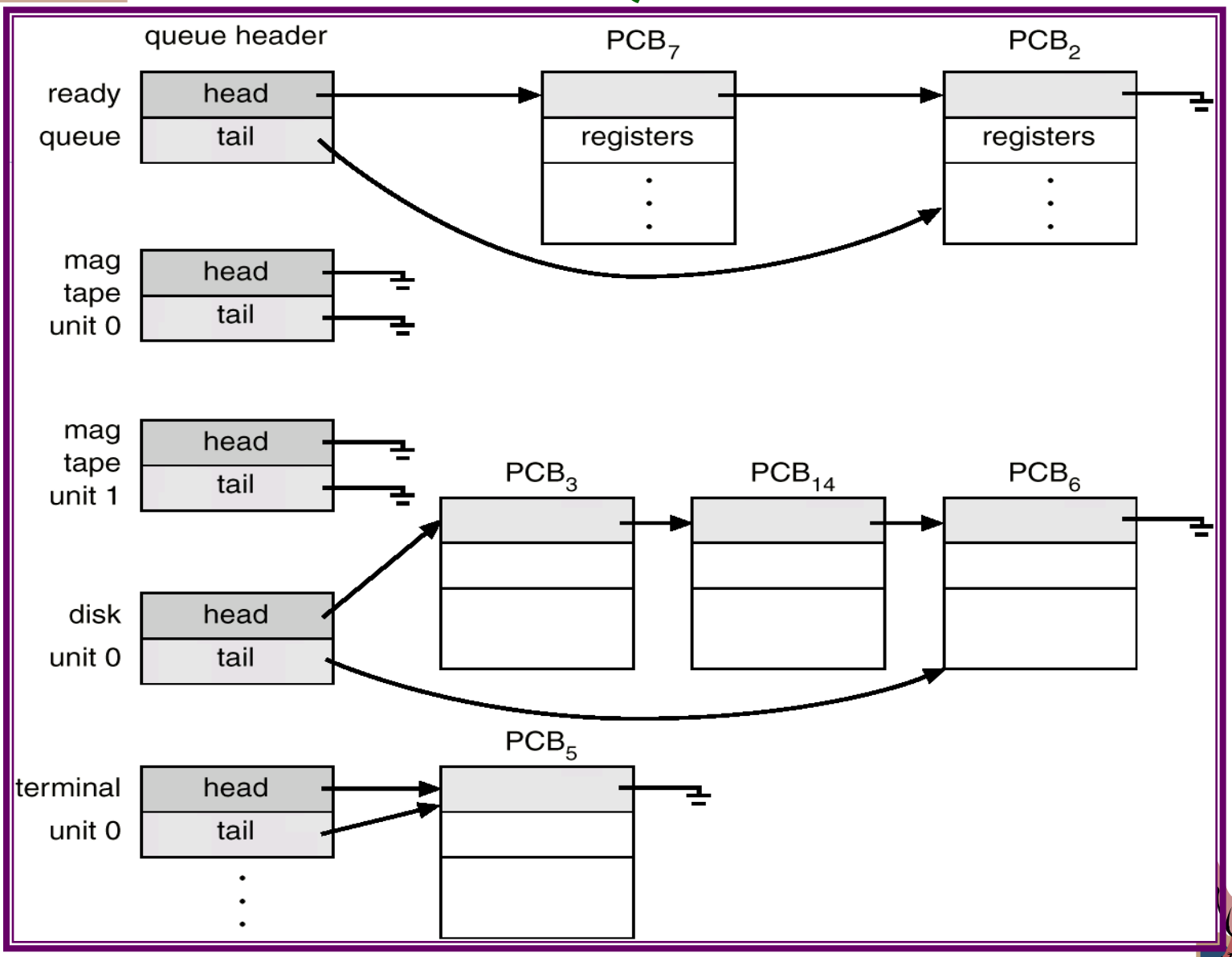


# Process Scheduling Queues

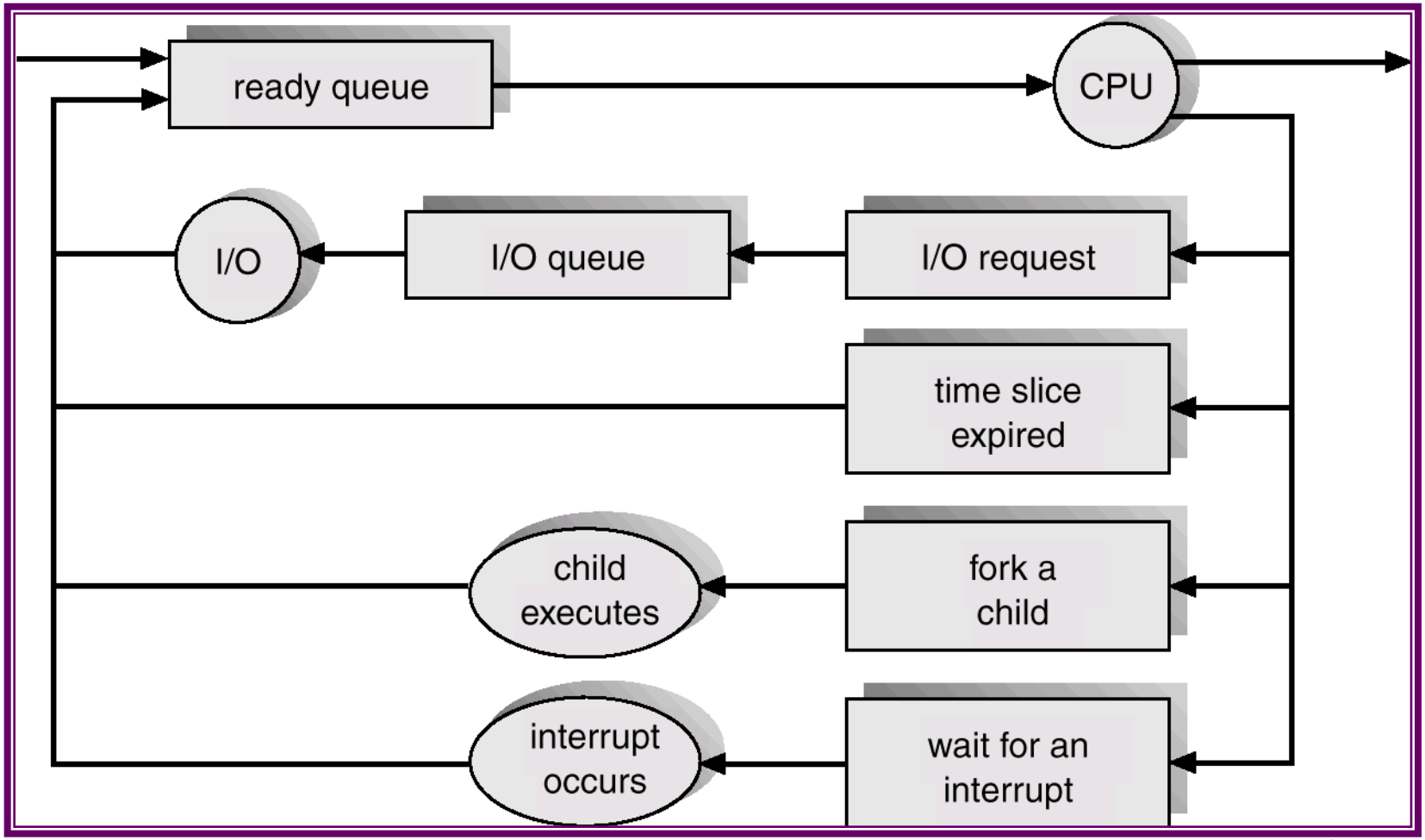
- Job queue – set of all processes in the system.
- Ready queue – set of all processes residing in main memory, ready and waiting to execute.
- Device queues – set of processes waiting for an I/O device.
- Process migration between the various queues.



# Ready Queue And Various I/O Device Queues

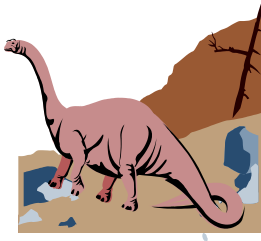


# Representation of Process Scheduling



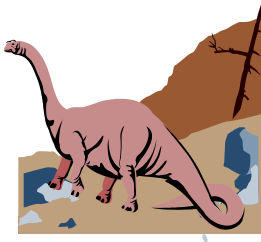
# Schedulers

- Long-term scheduler (or job scheduler) – selects which processes should be loaded into memory for execution.
- Short-term scheduler (or CPU scheduler) – selects which process should be executed next and allocates CPU.



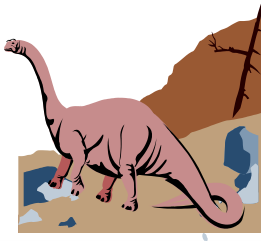
# Schedulers (Cont.)

- Short-term scheduler is invoked very frequently (milliseconds) ⇒ (must be fast).
- Long-term scheduler is invoked very infrequently (seconds, minutes) ⇒ (may be slow).
- The _____ scheduler controls the *degree of multiprogramming*.
  - long-term
  - short-term



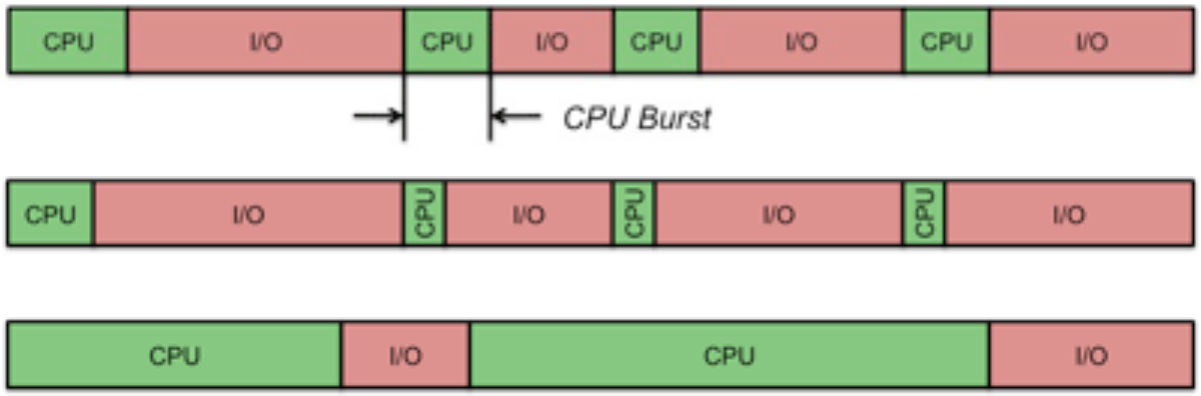
# Schedulers (Cont.)

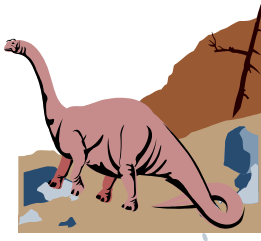
- The long-term scheduler controls the *degree of multiprogramming*.
- Long-term scheduling performs a **gatekeeping function**. It decides whether there's enough memory, or room, to allow new programs into the system.
- Short-term scheduling affects processes
  - running;
  - ready;
  - blocked;
- Long-term scheduling affects processes
  - new;
  - exited;



# Schedulers (Cont.)

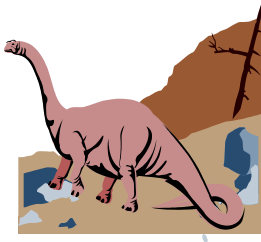
- Processes can be described as either:
  - I/O-*bound process* – spends more time doing I/O than computations, many short CPU bursts.
  - *CPU-bound process* – spends more time doing computations; few very long CPU bursts.
- The period of computation between I/O requests is called the **CPU burst**.



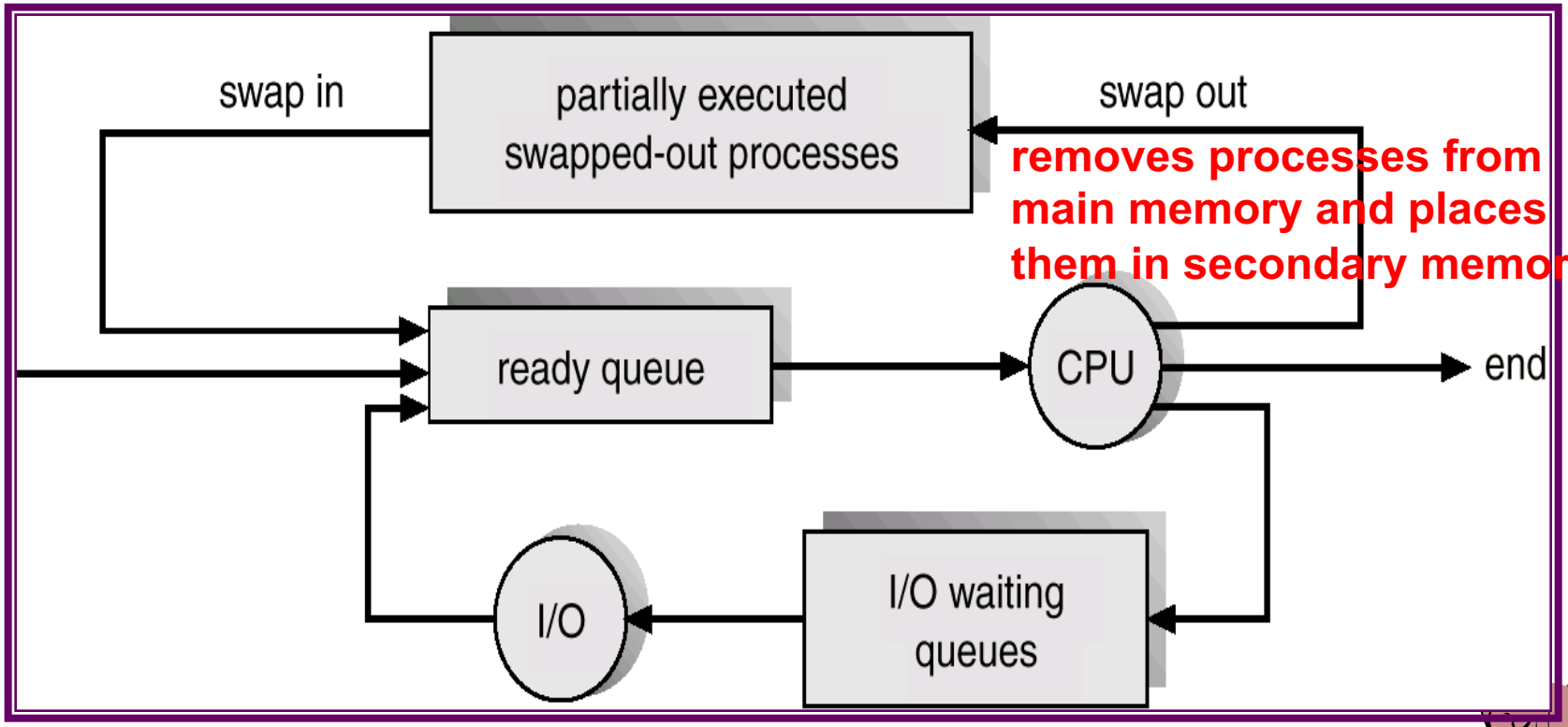
# Schedulers (Cont.)

- Discussion: If you design a CPU scheduler, which type of processes will you give a higher priority of granting CPU resource? I/O-bound processes, or CPU-bound processes?



# Addition of Medium-Term Scheduling

- The resource needs of a process may vary during its runtime. When the system resources become insufficient, some processes may need to swap out




http://en.wikipedia.org/wiki/Scheduling_(computing)#Medium-term_scheduling

# Chapter 3: Processes

- Process Concept
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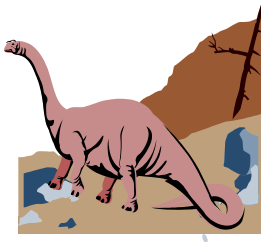
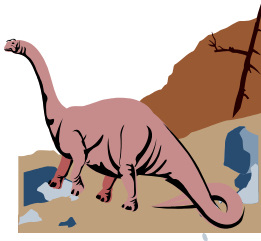
- Interprocess Communication
- Communication in Client-Server Systems



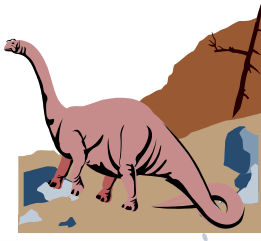
# Cooperating Processes

- *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



# A Common Cooperating Pattern: Producer-Consumer Problem

- Paradigm for cooperating processes, *producer* process produces information that is consumed by a *consumer* process.
  - *unbounded-buffer* places no practical limit on the size of the buffer.
  - *bounded-buffer* assumes that there is a fixed buffer size.

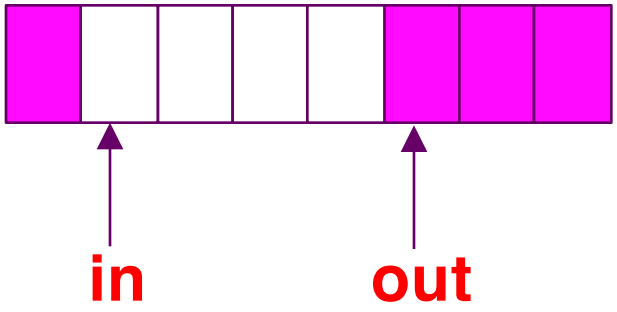


# Bounded-Buffer – Share-memory Solution

```
#define BUF_LEN 10
Typedef struct {
    . . .
} item;
item buffer[BUF_LEN];
int in = 0, out = 0;
```

**Shared Data**

**Circular queue**



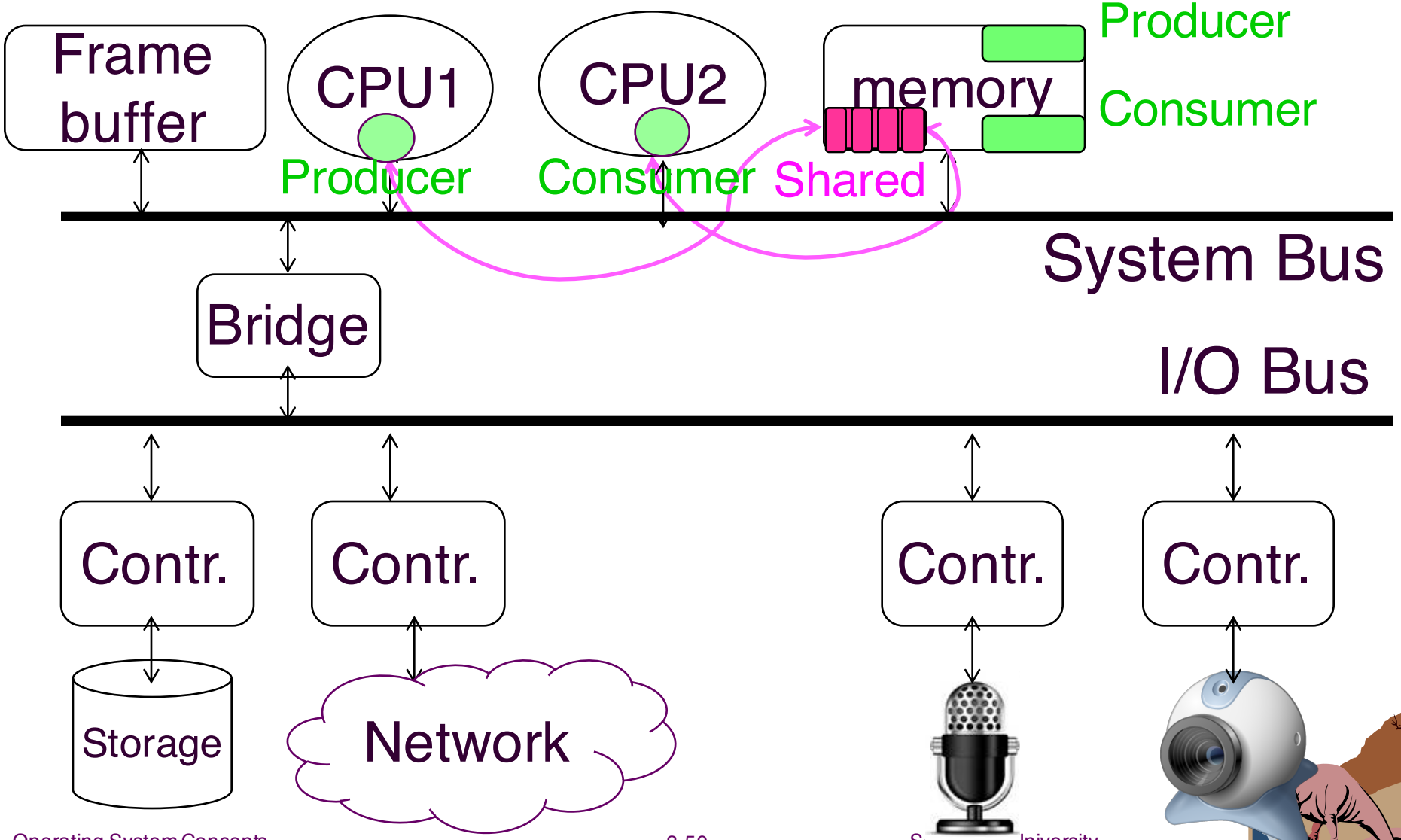

## Producer Process

```
item nextProduced;
while (1) {
  while (((in+1)%BUF_LEN) == out)
    ; /* do nothing */
  buffer[in] = nextProduced;
  in = (in + 1) % BUF_LEN;
}
```

## Consumer Process

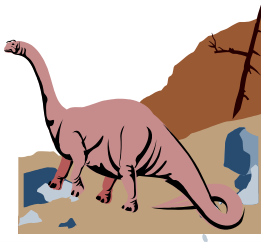
```
item nextConsumed;
while (1) {
  while (in == out)
    ; /* do nothing */
  nextConsumed = buffer[out];
  out = (out + 1) % BUF_LEN;
}
```

# Implementation of Communication Link by Shared Memory



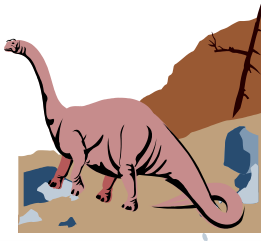
# Interprocess Communication (IPC)

- Mechanism for processes to communicate and to synchronize their actions.
- Message-passing system – processes communicate with each other without resorting to shared variables.



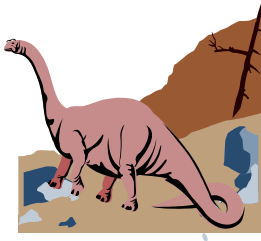
# Interprocess Communication (Cont.)

- IPC 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
- Implementation of communication link
  - physical (e.g., shared memory, hardware bus)
  - logical (e.g., logical properties)



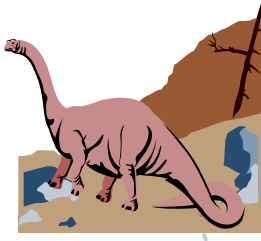
# Implementation Questions

- How are links established?
- Can a link be associated with more than two processes?
- How many links can there be between every pair of communicating processes?
- What is the capacity of a link?
- Is the size of a message that the link can accommodate fixed or variable?
- Is a link unidirectional or bi-directional?



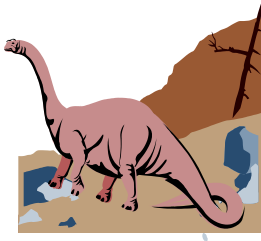
# Direct Communication

- 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.



# Indirect Communication

- Messages are directed and received from mailboxes (also referred to as ports).
  - Each mailbox has a unique id.
  - can communicate only if they share 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.



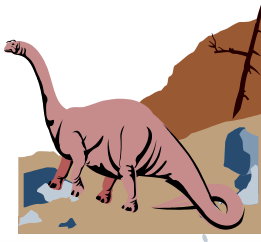
# Indirect Communication

- Operations
  - create a new mailbox
  - send and receive messages through mailbox
  - destroy a mailbox

- Primitives are defined as:

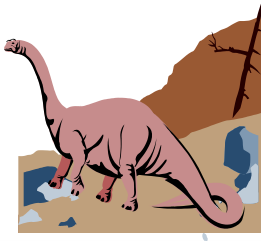
  **send**(*A, message*) – send a message to mailbox A

  **receive**(*A, message*) – receive a message from mailbox A



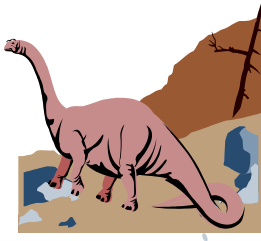
# Indirect Communication

- 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.



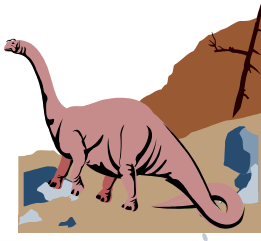
# Synchronization

- Message passing may be either blocking or non-blocking.
- **Blocking** is considered **synchronous**
- **Non-blocking** is considered **asynchronous**
- **send** and **receive** primitives may be either blocking or non-blocking.



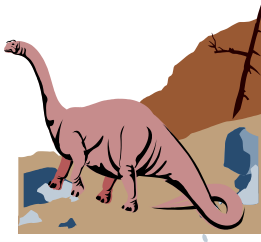
# Buffering

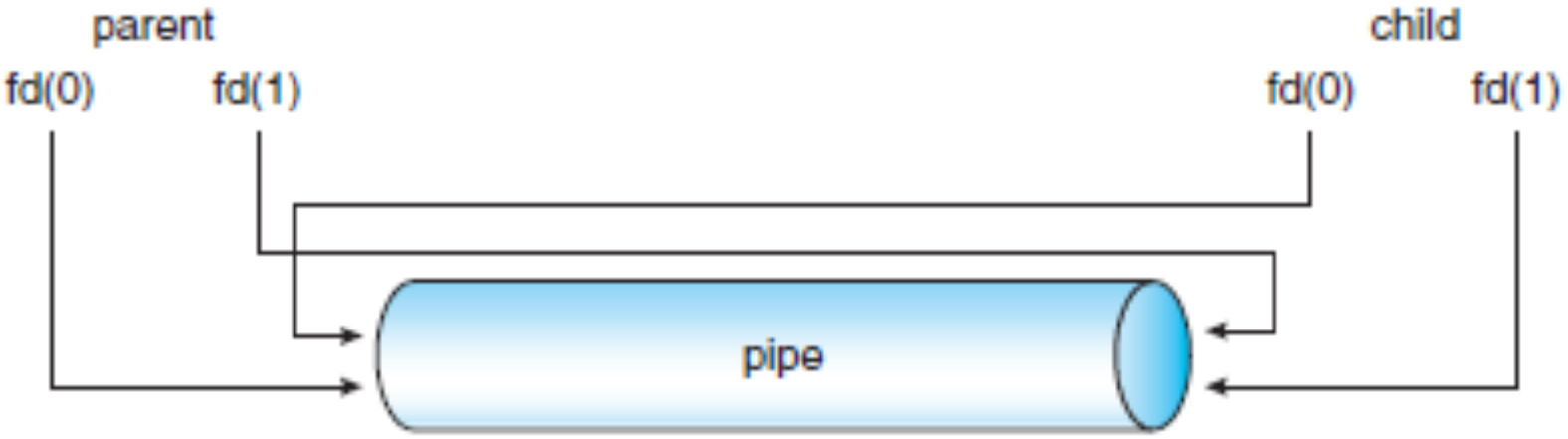
- Queue of messages attached to the link; implemented in one of three ways.
  1. Zero capacity – 0 messages
     Sender must wait for receiver (rendezvous).
  2. Bounded capacity – finite length of *n* messages
     Sender must wait if link full.
  3. Unbounded capacity – infinite length
     Sender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



# Pipes in Unix

- UNIX pipes are implemented in a similar way, but with the **pipe**() system call.
  - The output of one process is connected to an in-kernel pipe.
  - The input of another process is connected to that same pipe.
  - E.g.,
    - ✓ ls | wc

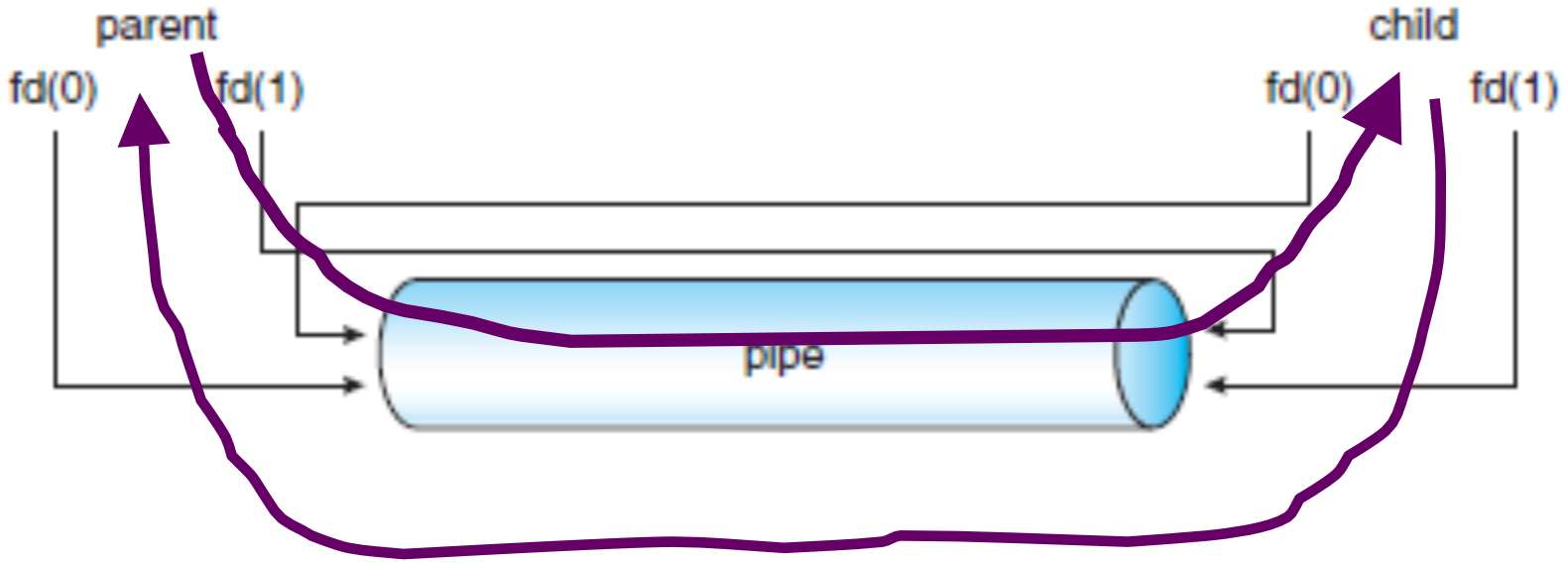





```
if (pid > 0) { /* parent process */
   /* close the unused end of the pipe */
   close(fd[READ_END]);

   /* write to the pipe */
   write(fd[WRITE_END], write_msg, strlen(write_msg)+1);

   /* close the write end of the pipe */
   close(fd[WRITE_END]);
}
else { /* child process */
   /* close the unused end of the pipe */
   close(fd[WRITE_END]);

   /* read from the pipe */
   read(fd[READ_END], read_msg, BUFFER_SIZE);
   printf("read %s",read_msg);

   /* close the write end of the pipe */
   close(fd[READ_END]);
}
```

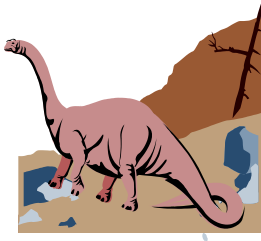
# Discussion

- What if the parent wants to write something to child, while child also wants to write something to parent?



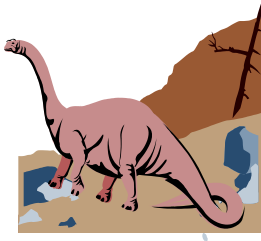

**HOW?**

- Hints, ordinary pipes are unidirectional



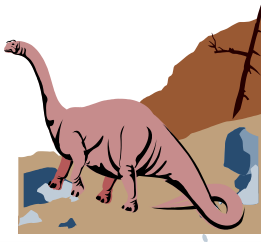
# Chapter 3: Processes

- Process Concept
- Operations and APIs on Processes
- Process Scheduling
- Cooperating Processes
- Interprocess Communication
- Communication in Client-Server Systems



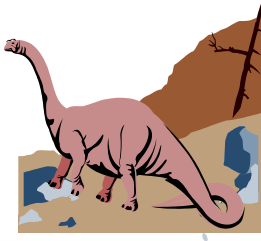
# Client-Server Communication

- Sockets
- Remote Procedure Calls
- Remote Method Invocation (Java)

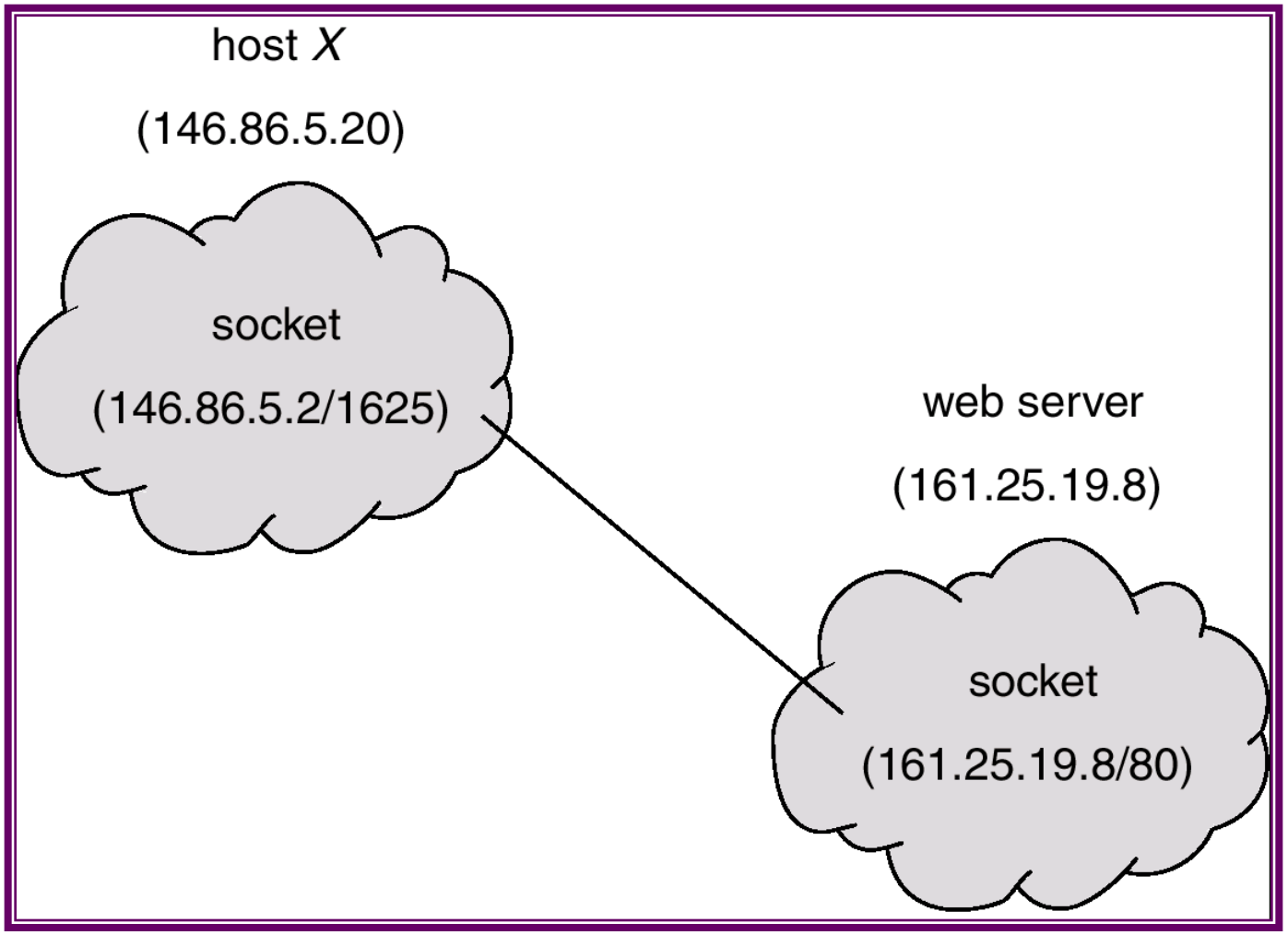


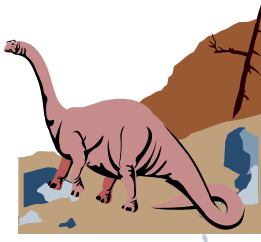
# Sockets

- A socket is defined as an *endpoint for communication*.
- Concatenation of IP address and port
- The socket **161.25.19.8:1625** refers to port **1625** on host **161.25.19.8**
- Communication consists between a pair of sockets.



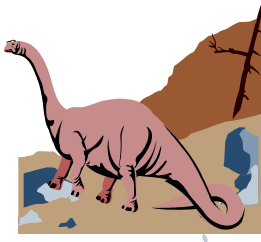
# Socket Communication



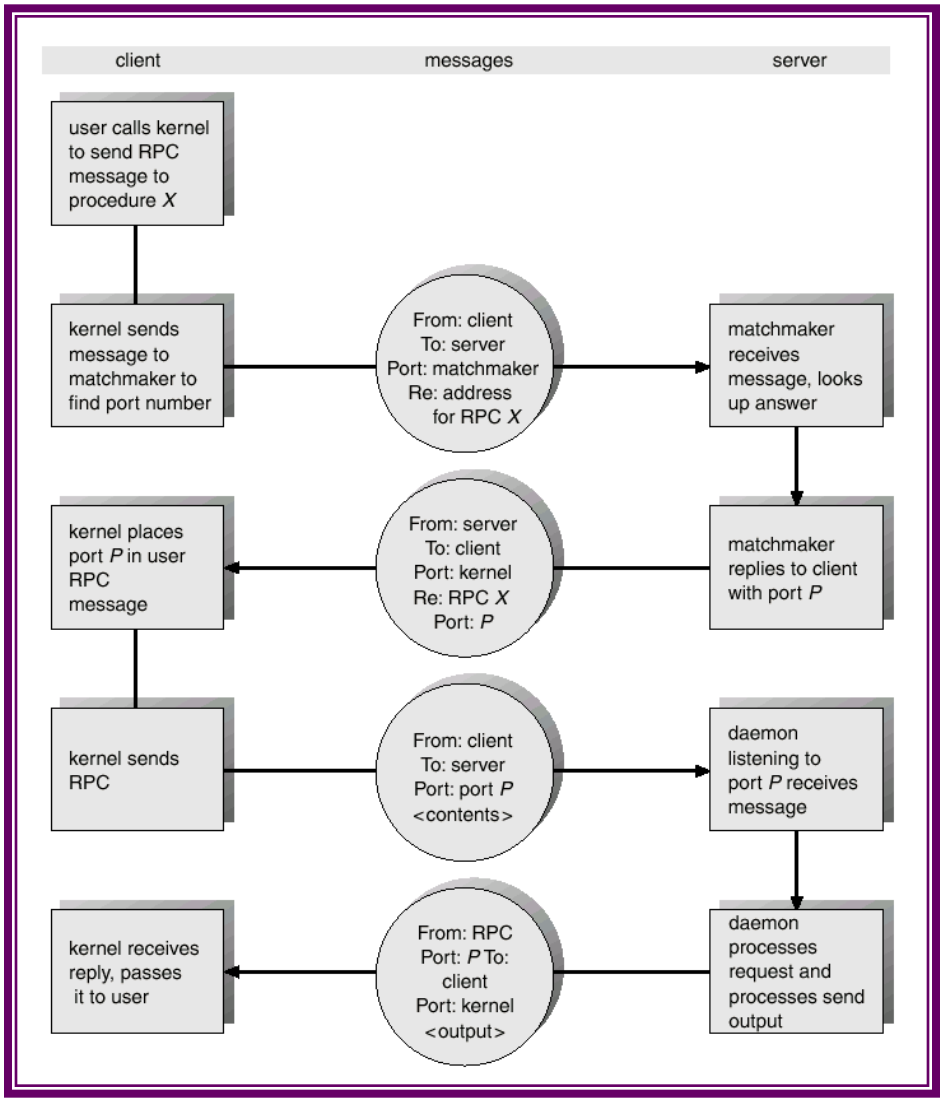



# Remote Procedure Calls

- Remote procedure call (RPC) abstracts procedure calls between processes on networked systems.
- **Stubs** – client-side proxy for the actual procedure on the server.
- The client-side stub locates the server and *marshalls* the parameters.
- The server-side stub receives this message, unpacks the marshalled parameters, and peforms the procedure on the server.

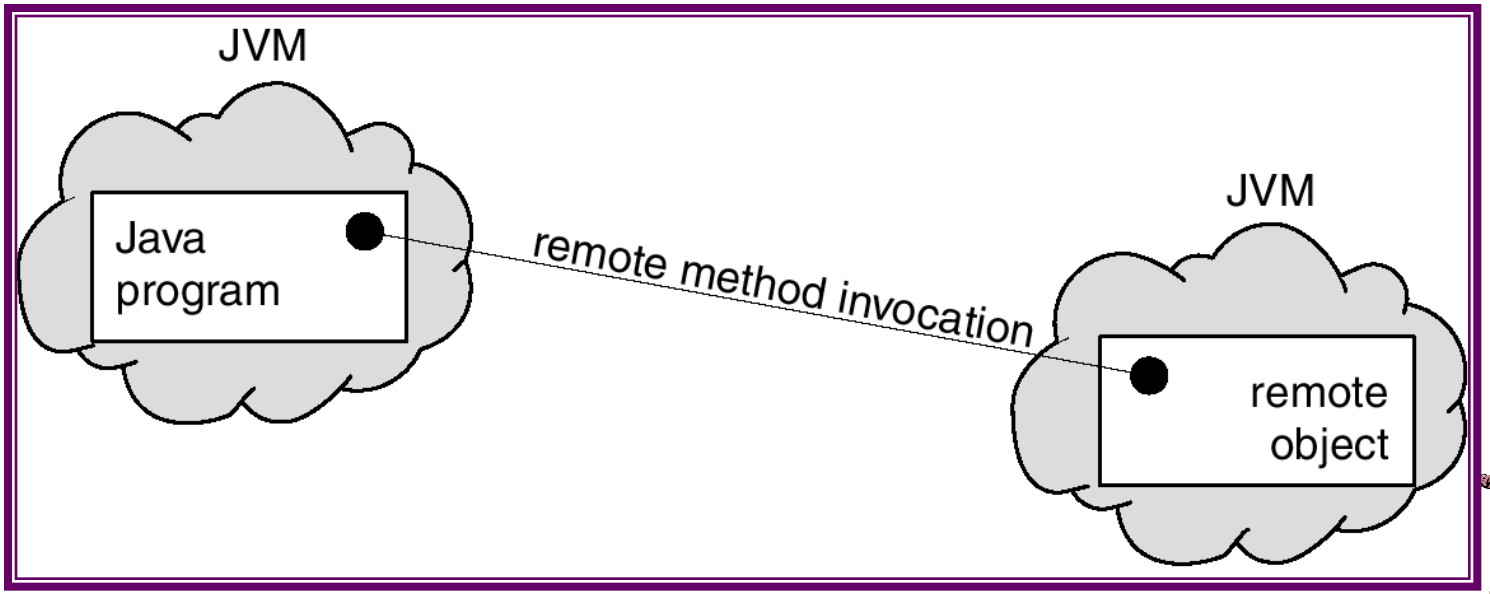


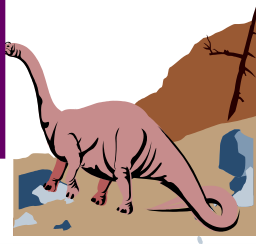
# Execution of RPC



# Remote Method Invocation

- Remote Method Invocation (RMI) is a Java mechanism similar to RPCs.
- RMI allows a Java program on one machine to invoke a method on a remote object.



# Marshalling Parameters