Operating System: Chap3 Processes Concept

National Tsing-Hua University

2022, Fall Semester

Outline

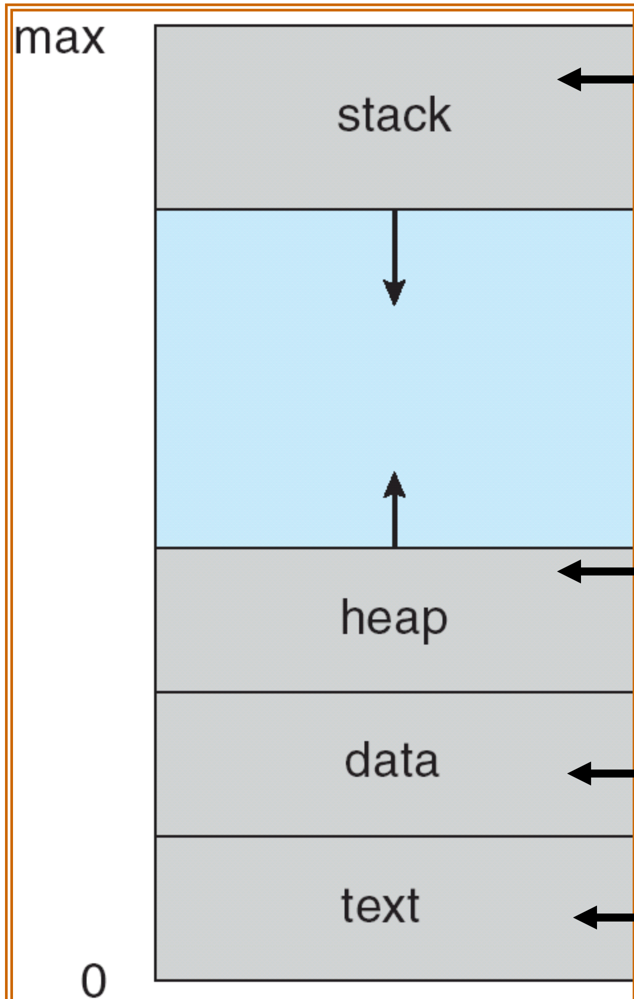
- Process Concept
- Process Scheduling
- Operations on Processes
- Interprocess Communication

Process Concept

Process Concept

- An operating system concurrently executes a variety of programs (e.g Web browser, text editor, etc)
  - Program — passive entity: binary stored in disk
  - Process — active entity: a program in execution in memory
- A process includes:
  - **Code** segment (text section)
  - **Data section**— global variables
  - **Stack** —temporary local variables and functions
  - **Heap** —dynamic allocated variables or classes
  - Current activity (**program counter**, register contents)
  - A set of associated **resources** (e.g. open file handlers)

Process in Memory



temporary data (e.g. function parameters, return addresses, local variables)

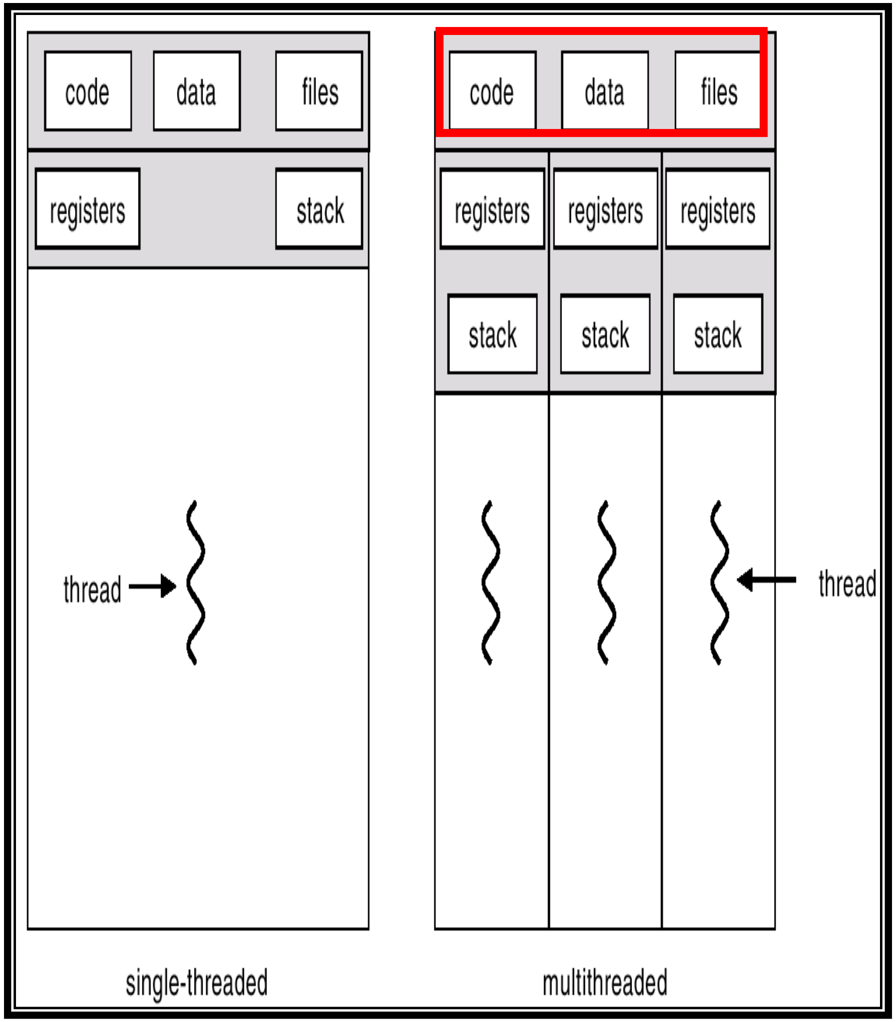
dynamic allocation (e.g. class object, pointer object)

global variables

code

Threads

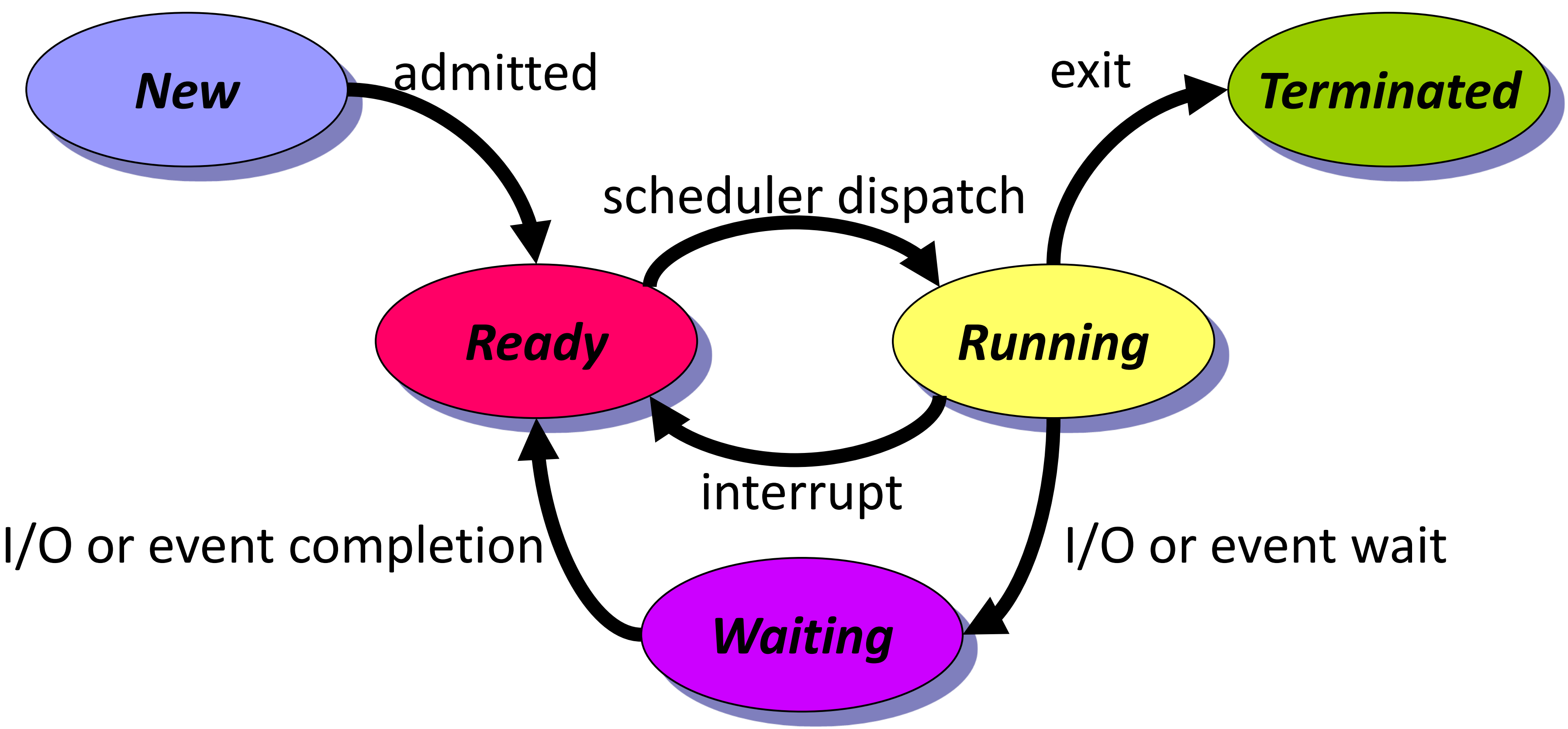
- A.k.a lightweight process: basic unit of CPU utilization
- All threads belonging to the same process share
  - code section, data section, and OS resources (e.g. open files and signals)
- But each thread has its own
  - thread ID, program counter, register set, and a stack



Process State

- States
  - New: the process is being created
  - Ready: the process is in the memory waiting to be assigned to a processor
  - Running: instructions are being executed by CPU
  - Waiting: the process is waiting for events to occur
  - Terminated: the process has finished execution

Diagram of Process State

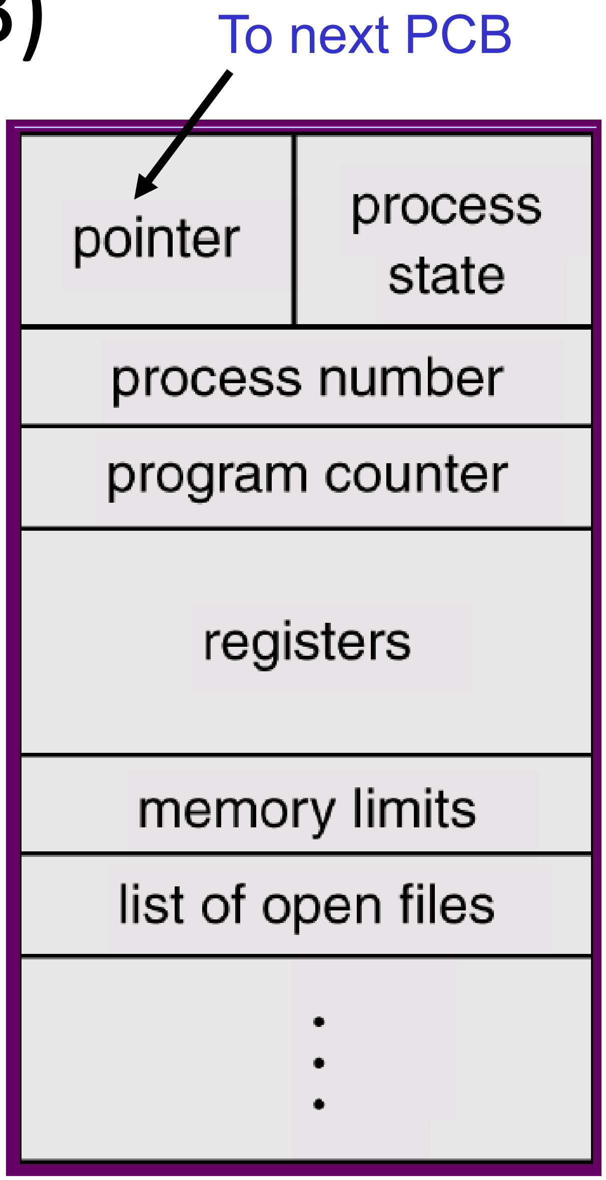


- Only one process is running on any processor at any instant
- However, many processes may be ready or waiting

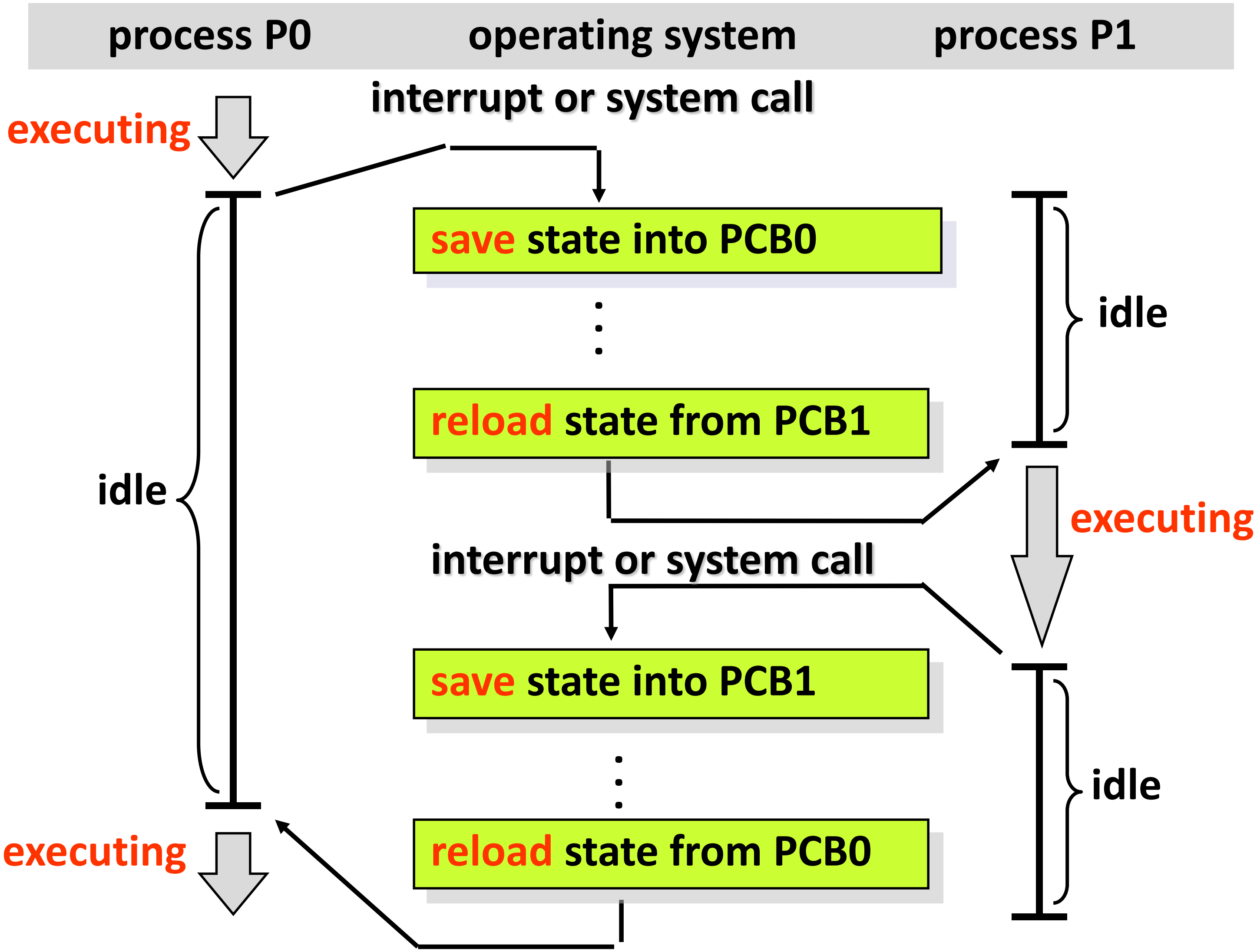
Process Control Block (PCB)

Info. associated with each process

- Process state
- Program counter
- CPU registers
- CPU scheduling information (e.g. priority)
- Memory-management information (e.g. base/limit register)
- I/O status information
- Accounting information



Context Switch



Context Switch

- **Context Switch**: Kernel saves the state of the old process and loads the saved state for the new process
- Context-switch time is purely **overhead**
- Switch time (about 1~1000 ms) depends on
  - memory speed
  - number of registers
  - existence of special instructions
    - a single instruction to save/load all registers
  - hardware support
    - multiple sets of registers (Sun UltraSPARC – a context switch means changing register file pointer)

Review Slides (1)

- What’s the definition of a process?
- What’s the difference between process and thread?
- What’s PCB? its contents?
  - Process state
  - Program counter
  - CPU registers
- The kinds of process state?
  - New, Ready, Running, Waiting, Terminated
- What’s context switch?

Process Scheduling

Process Scheduling

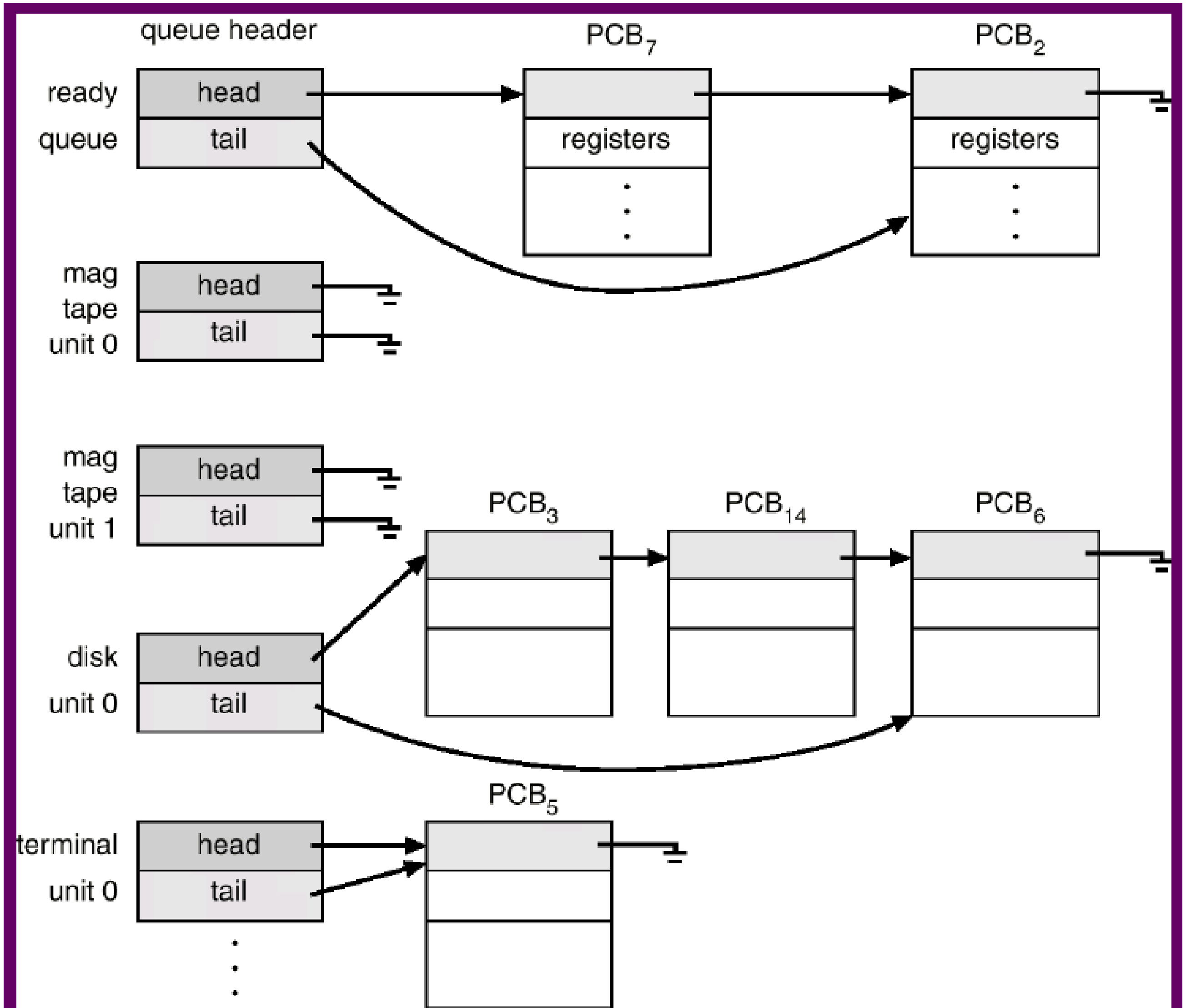
- Multiprogramming: CPU runs process at all times to maximize CPU utilization
- Time sharing: switch CPU frequently such that users can interact with each program while it is running
- Processes will have to wait until the CPU is free and can be re-scheduled

Process Scheduling Queues

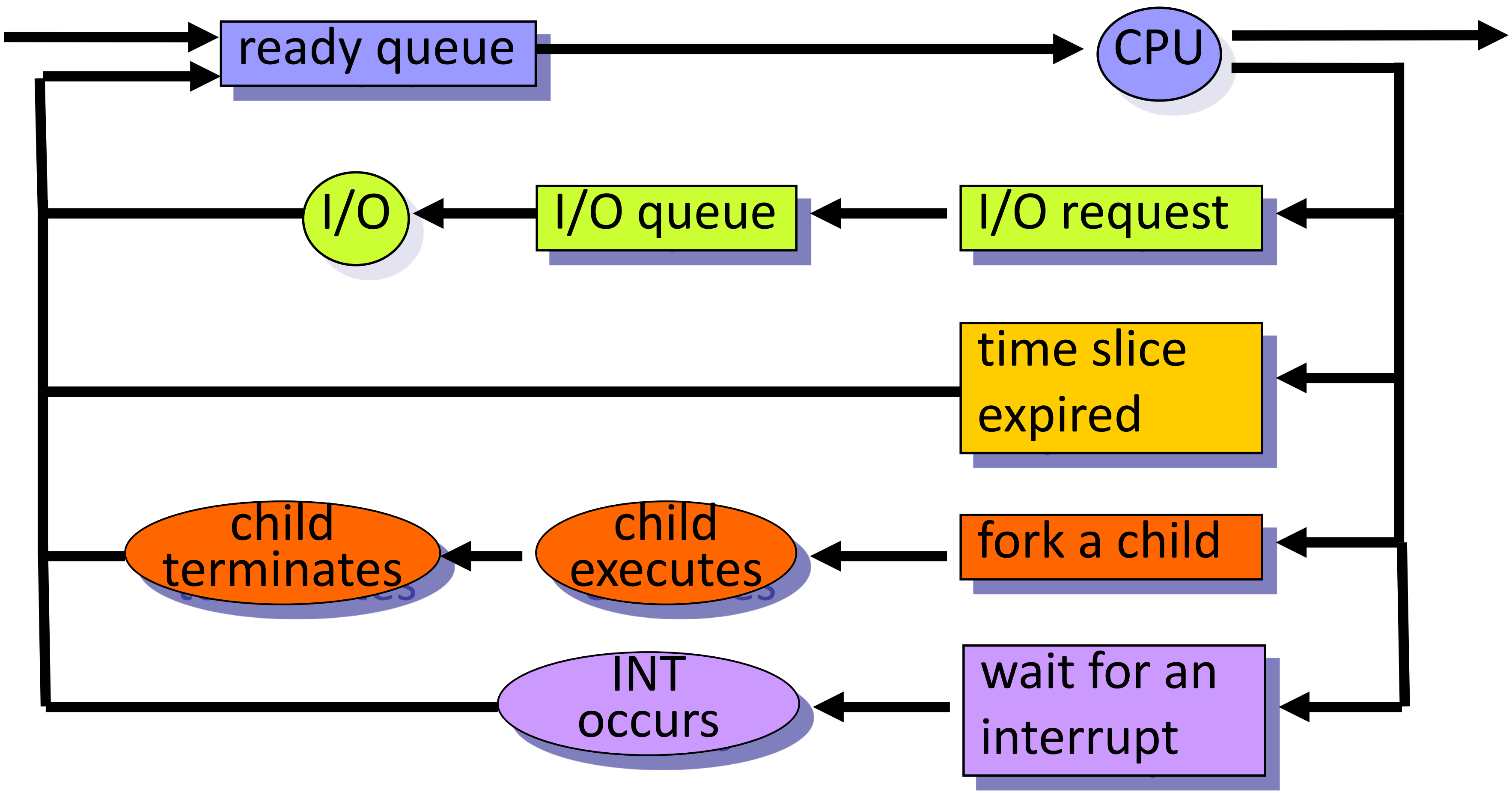
- Processes migrate between the various queues (i.e. switch among states)
- Job queue (New State) – set of all processes in the system
- Ready queue (Ready State) – set of all processes residing in main memory, ready and waiting to execute
- Device queue (Wait State)– set of processes waiting for an I/O device

Process Scheduling Queues

I/O queue

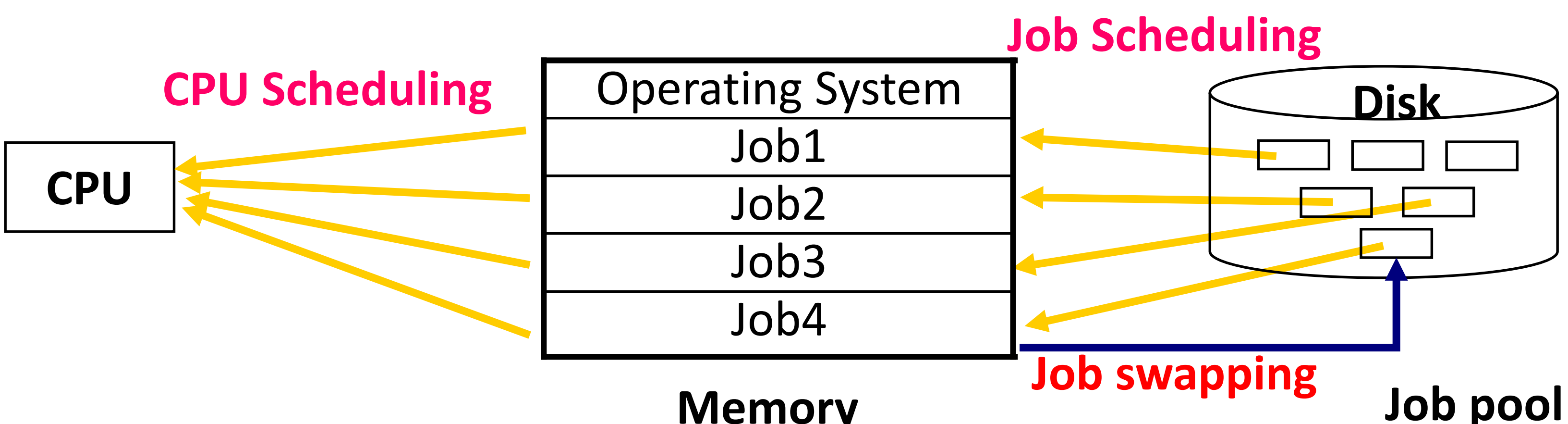


Process Scheduling Diagram



Schedulers

- Short-term scheduler (CPU scheduler)– selects which process should be executed and allocated CPU (Ready state ➔ Run state)
- Long-term scheduler (job scheduler) – selects which processes should be loaded into memory and brought into the ready queue (New state ➔ Ready state)
- Medium-term scheduler – selects which processes should be swapped in/out memory (Ready state ➔ Wait state)

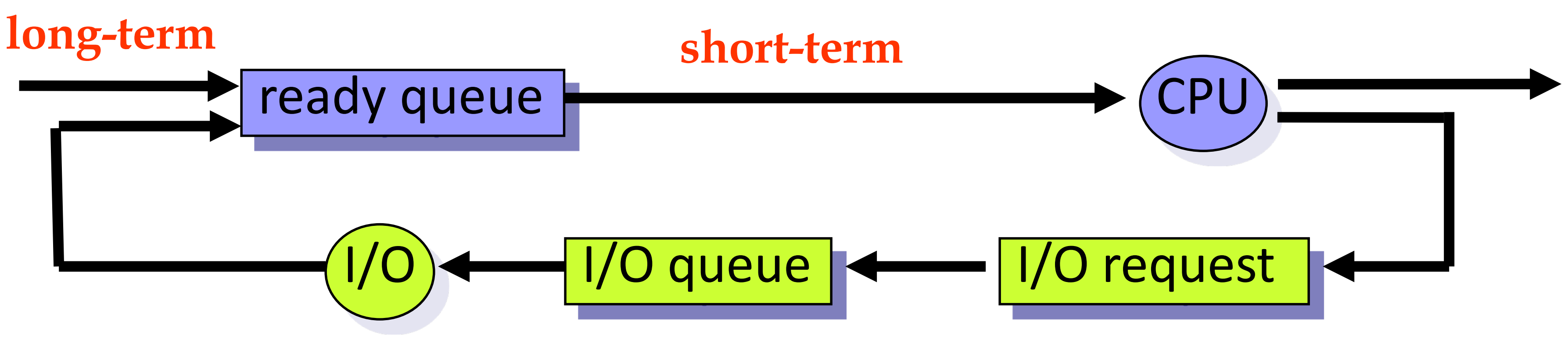


Long-Term Scheduler

- Control **degree of multiprogramming**
- Execute less frequently (e.g. invoked only when a process leaves the system or once several minutes)
- Select a good mix of CPU-bound & I/O-bound processes to increase system overall performance
- UNIX/NT: no long-term scheduler
  - Created process placed in memory for short-term scheduler
  - Multiprogramming degree is bounded by hardware limitation (e.g., # of terminals) or on the self-adjusting nature of users

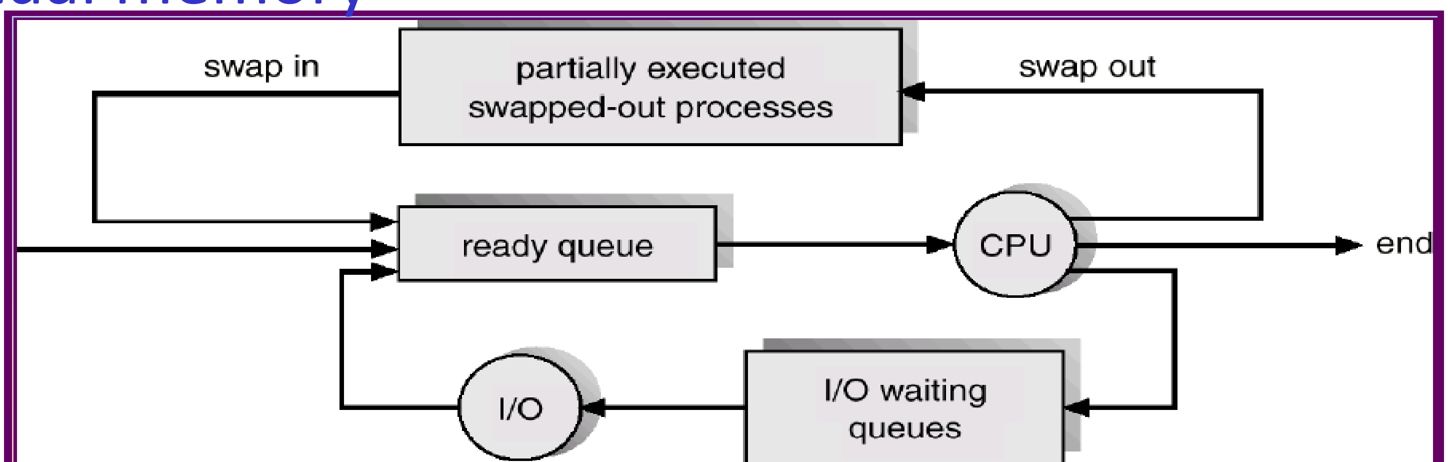
Short-Term Scheduler

- Execute quite frequently (e.g. once per 100ms)
- Must be efficient:
  - if 10 ms for picking a job, 100 ms for such a pick,
    → overhead = 10 / 110 = 9%



Medium-Term Scheduler

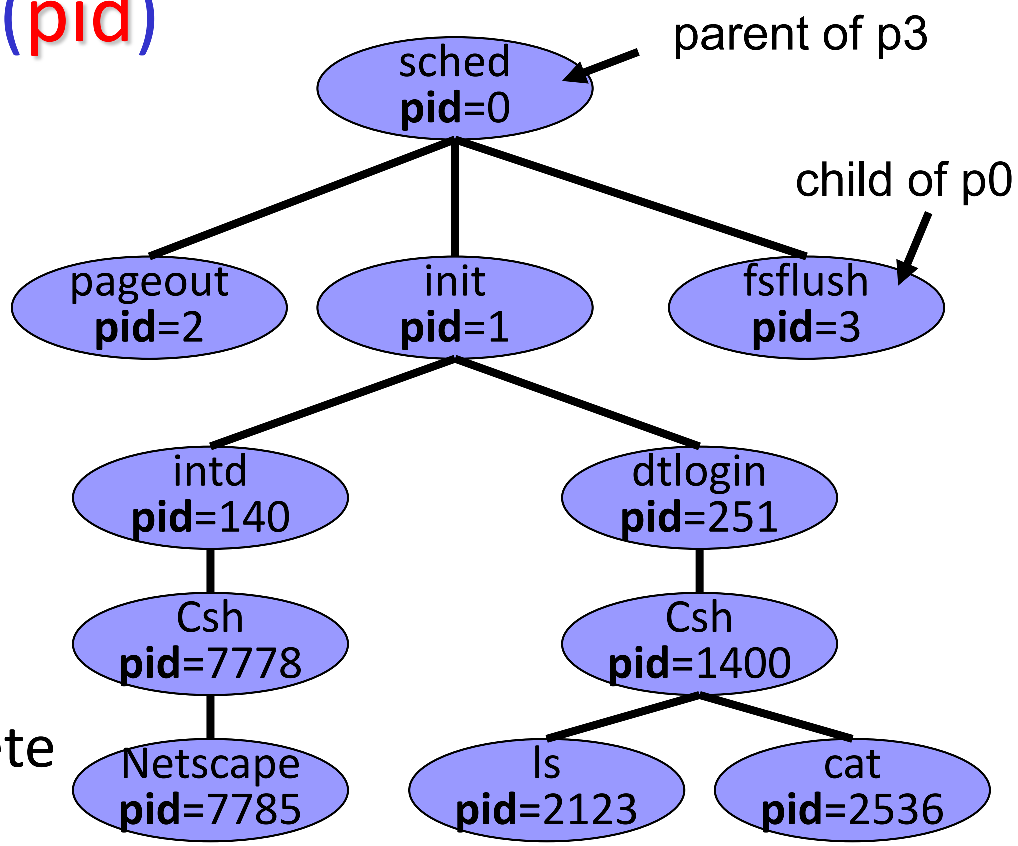
- **swap out**: removing processes from memory to reduce the degree of multiprogramming
- **swap in**: reintroducing swap-out processes into memory
- Purpose: <u>improve process mix , free up memory</u>
- Most modern OS doesn't have medium-term scheduler because having sufficient physical memory or using virtual memory



Operations on Processes

Tree of Processes

- Each process is identified by a unique processor identifier (pid)



UNIX: "**ps -ael**" will list complete info of all active processes

Process Creation

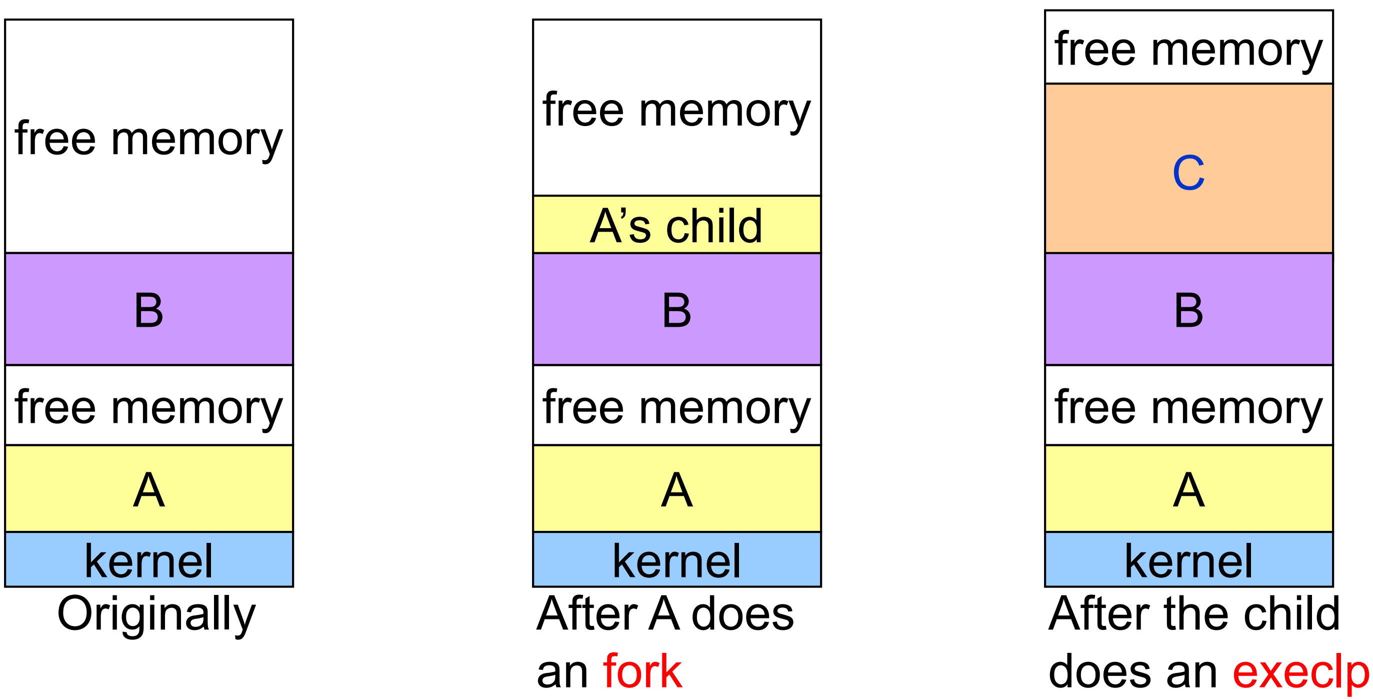
- Resource sharing
  - Parent and child processes share all resources
  - Child process shares subset of parent's resources
  - Parent and child share no resources
- Two possibilities of execution
  - Parent and children execute concurrently
  - Parent waits until children terminate
- Two possibilities of address space
  - Child duplicate of parent, communication via sharing variables
  - Child has a program loaded into it, communication via message passing

UNIX/Linux Process Creation

- fork system call
  - Create a new (child) process
  - The new process **duplicates** the address space of its parent
  - Child & Parent execute **concurrently** after fork
  - Child: return value of fork is 0
  - Parent: return value of fork is PID of the child process
- execlp system call
  - Load a new binary file into memory – destroying the old code
- wait system call
  - The parent waits for **one of its child processes** to complete

UNIX/Linux Process Creation

- Memory space of fork():
  - Old implementation: A's child is an exact copy of parent
  - Current implementation: use copy-on-write technique to store differences in A's child address space



UNIX/Linux Example

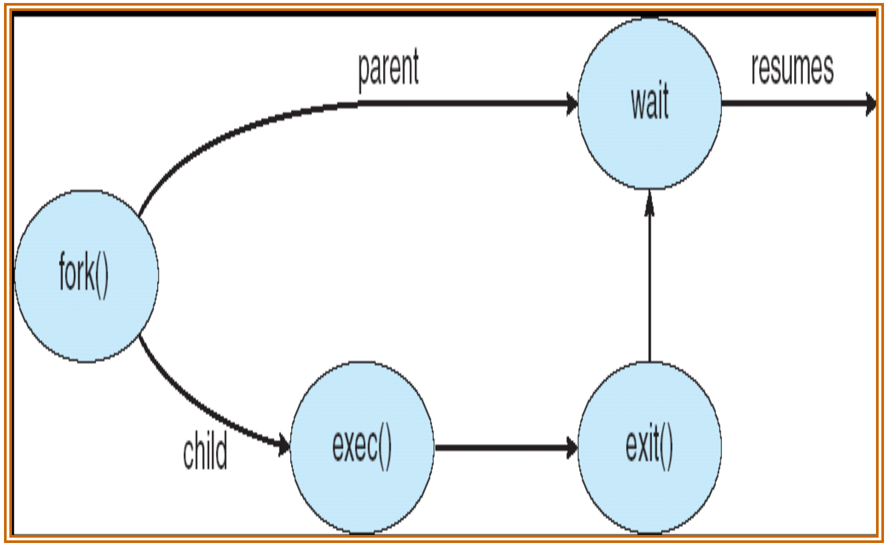
```
#include <stdio.h>
void main( )
{
    int A;
    /* fork another process */
    A = fork( );

    if (A == 0) { /* child process */
      printf("this is from child process\n");
      execlp("/bin/ls", "ls", NULL);

    } else {  /* parent process */
      printf("this is from parent process\n");
      int pid = wait(&status);
      printf("Child %d completes", pid);
    }
    printf("process ends  %d\n", A);
}
```

Output:

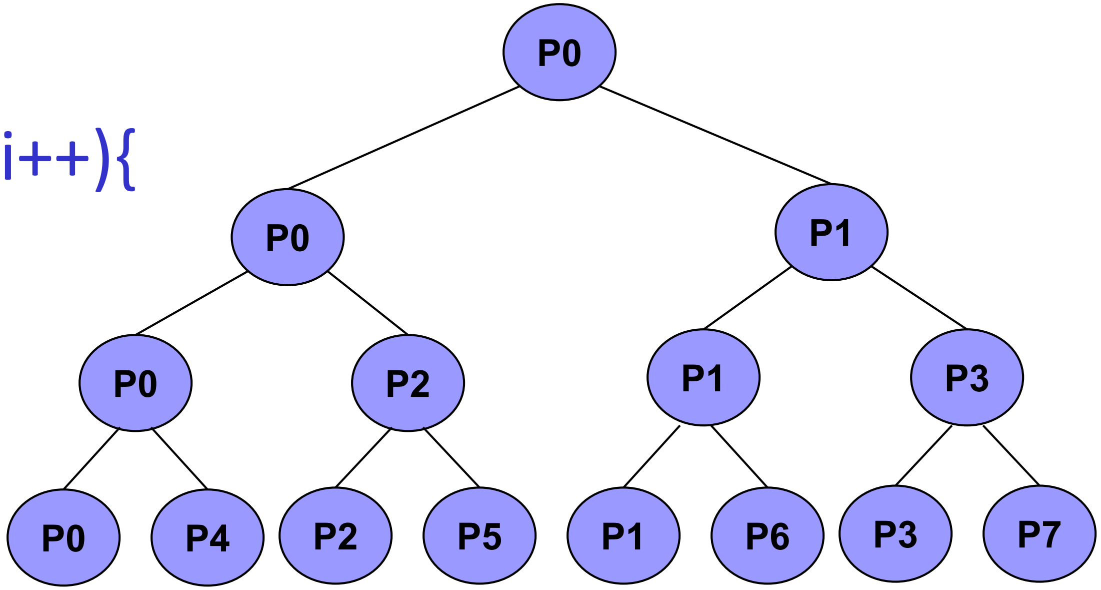
this is from child process
this is from parent process
a.out hello.c readme.txt
Child 32185 completes
process ends 32185



Example Quiz:

- How many processes are created?

```
#include <stdio.h>
#include <unistd.h>
int main() {
        for (int i=0; i<3; i++){
                fork();
        }
        return 0;
}
```



Process Termination

- Terminate when the last statement is executed or exit() is called
  - All resources of the process, including physical & virtual memory, open files, I/O buffers, are deallocated by the OS
- Parent may terminate execution of children processes by specifying its PID (**abort**)
  - Child has exceeded allocated resources
  - Task assigned to child is no longer required
- Cascading termination:
  - killing (exiting) parent → killing (exiting) all its children

Review Slides (2)

- What’s long-term scheduler? features?
- What’s short-term scheduler? features?
- What’s medium-term scheduler? features?
- What’s the different between duplicate address space and load program? Their commands?

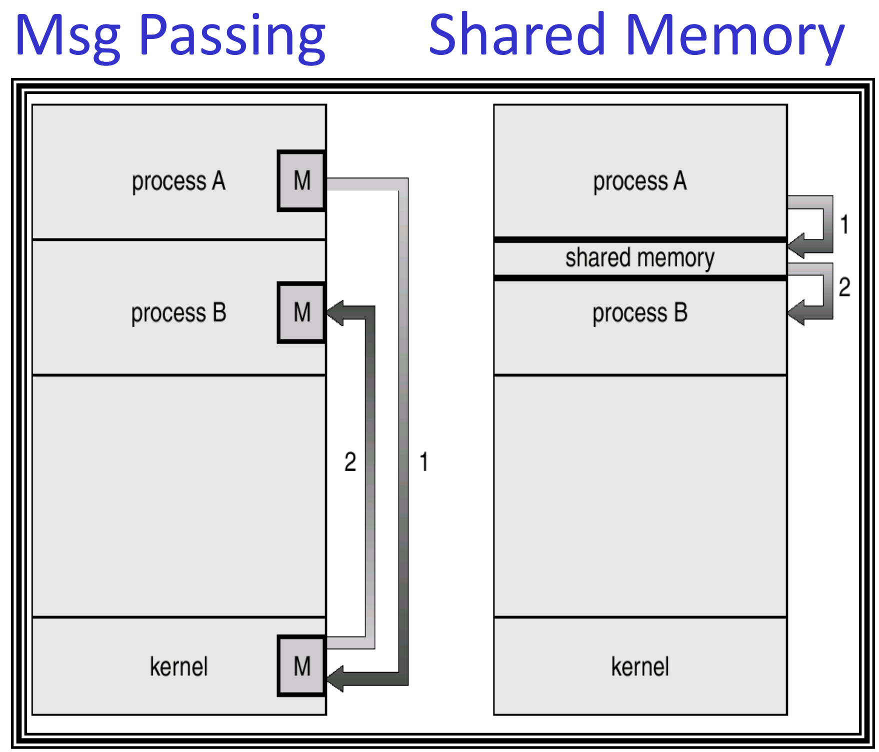
Interprocess Communication (IPC)

Interprocess Communication

- IPC: a set of methods for the exchange of data among multiple threads in one or more processes
- Independent process: cannot affect or be affected by other processes
- Cooperating process: otherwise
- Purposes
  - information sharing
  - computation speedup (not always true…)
  - convenience (performs several tasks at one time)
  - modularity

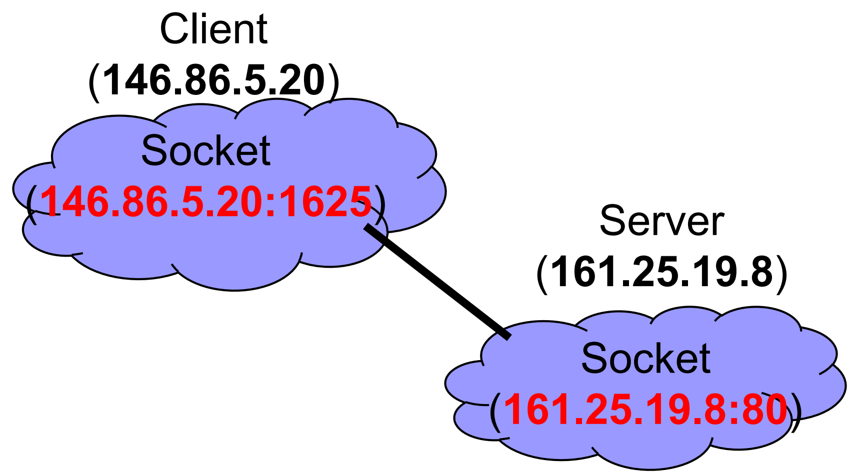
Communication Methods

- Shared memory:
  - Require more careful user synchronization
  - Implemented by memory access: faster speed
  - Use memory address to access data
- Message passing:
  - No conflict: more efficient for small data
  - Use send/recv message
  - Implemented by system call: slower speed

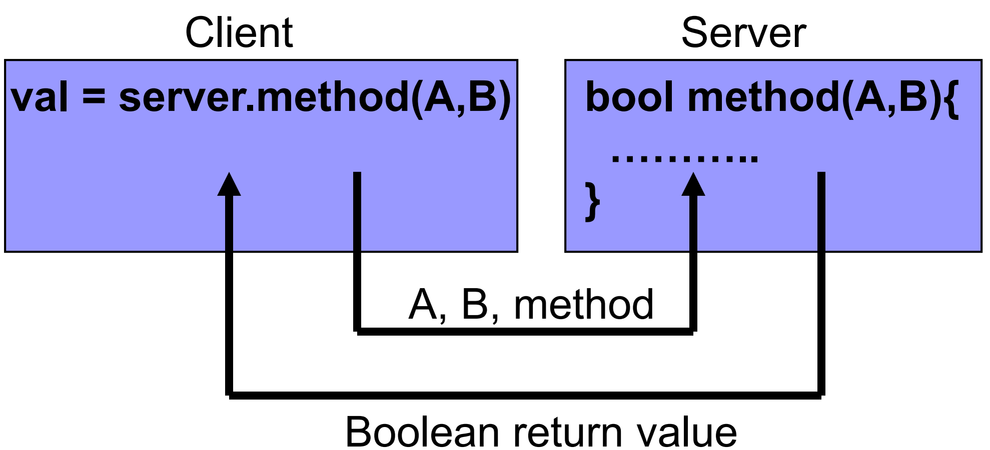


Communication Methods

- Sockets:
  - A network connection identified by IP & port
  - Exchange unstructured stream of bytes



- Remote Procedure Calls:
  - Cause a procedure to execute in another address space
  - Parameters and return values are passed by message



Interprocess Communication

- Shared Memory
- Message Passing
- Socket
- Remote Procedure Calls

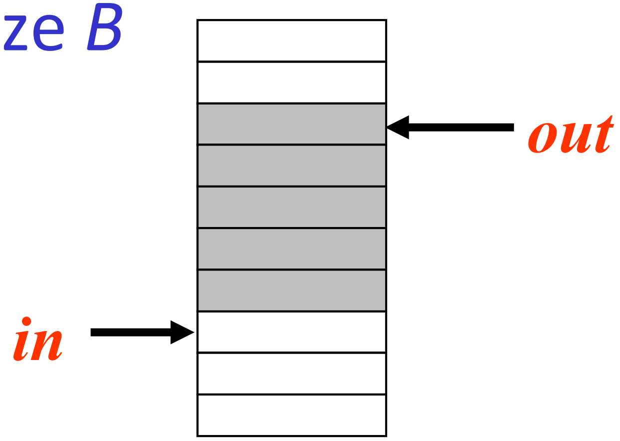
Shared Memory

- Processes are responsible for…
  - Establishing a region of shared memory
    - Typically, a shared-memory region resides in the address space of the process creating the shared-memory segment
    - Participating processes must agree to remove memory access constraint from OS
  - Determining the form of the data and the location
  - Ensuring data are not written simultaneously by processes

Consumer & Producer Problem

- **Producer** process produces information that is consumed by a **Consumer** process

- Buffer as a circular array with size *B*
  - next free: in
  - first available: out
  - empty: $in = out$
  - full: $(in+1)\ \%\ B = out$

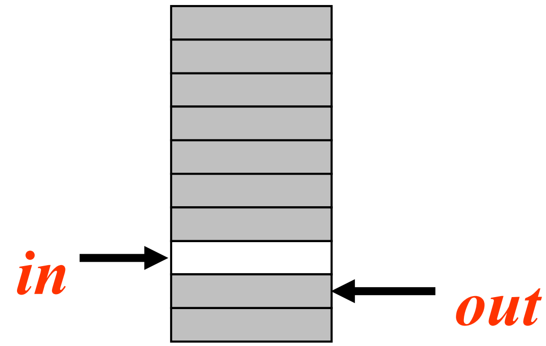


- The solution allows at most (B-1) item in the buffer
  - Otherwise, cannot tell the buffer is fall or empty

Shared-Memory Solution

```
/*producer*/
while (1) {
    while (((in + 1) % BUFFER_SIZE) == out)
        ; //wait if buffer is full
    buffer[in] = nextProduced;
    in = (in + 1) % BUFFER_SIZE;
}
```

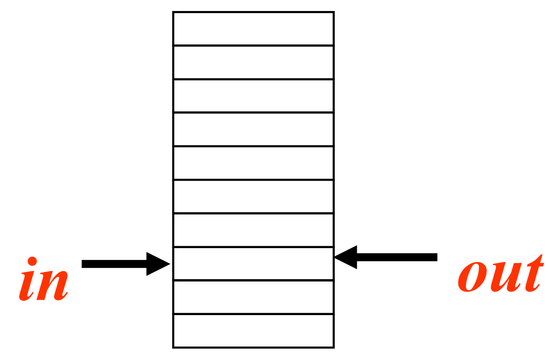
“in” only modified by producer




```
/* global data structure */
#define BUFSIZE  10
item buffer[BUFSIZE];
int  in = out = 0;
```

```
/*consumer*/
while (1) {
    while (in == out); //wait if buffer is empty
    nextConsumed = buffer[out];
    out = (out + 1) % BUFFER_SIZE;
}
```

“out” only modified by consumer



Interprocess Communication

- Shared Memory
- Message Passing
- Socket
- Remote Procedure Calls

Message-Passing System

- Mechanism for processes to communicate and **synchronize** their actions
- IPC facility provides two operations:
  - *Send(message)* – message size fixed or variable
  - *Receive(message)*
- Message system – processes communicate without resorting to shared variables
- To communicate, processes need to
  - Establish a communication link
  - Exchange a message via send/receive

Message-Passing System

- Implementation of communication link
  - physical (e.g., shared memory, HW bus, or network)
  - logical (e.g., logical properties)
    - Direct or indirect communication
    - Symmetric or asymmetric communication
    - Blocking or non-blocking
    - Automatic or explicit buffering
    - Send by copy or send by reference
    - Fixed-sized or variable-sized messages

Direct communication

- Processes must name each other explicitly:
  - *Send (P, message)* – send a message to proc P
  - *Receive (Q, message)* – receive a message from process Q
- Properties of communication link
  - Links are established automatically
  - One-to-One relationship between links and processes
  - The link may be unidirectional, but is usually bi-directional

Direct communication

- Solution for producer-consumer problem:

```
/*producer*/
while (1) {
        send (consumer, nextProduced);
}
/*consumer*/
while (1) {
        receive (producer, nextConsumed);
}
```

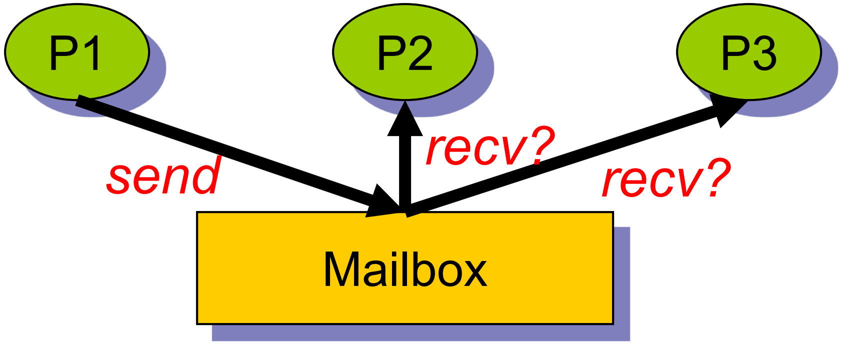
- limited modularity: if the name of a process is changed, all old names should be found

Indirect communication

- Messages are directed and received from mailboxes (also referred to as ports)
  - Each mailbox has a unique ID
  - Processes can communicate if they share a mailbox
  - *Send (A, message)* – send a message to mailbox A
  - *Receive (A, message)* – receive a message from mailbox A
- Properties of communication link
  - Link established only if processes share a common mailbox
  - Many-to-Many relationship between links and processes
  - Link may be unidirectional or bi-directional
  - Mailbox can be owned either by OS or processes

Indirect Communication

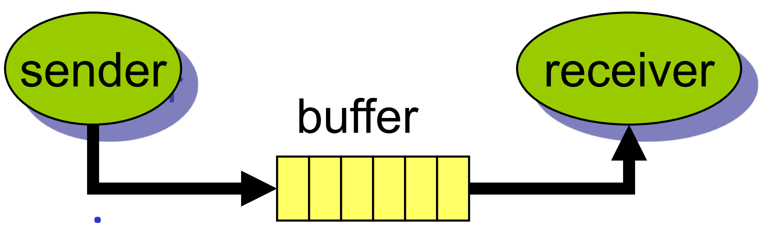
- Mailbox sharing



- 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 a single receiver. Sender is notified who the receiver was

Synchronization

- Message passing may be either **blocking** (synchronous) or **non-blocking** (asynchronous)
  - Blocking send: sender is blocked until the message is received by receiver or by the mailbox
  - Nonblocking send: sender sends the message and resumes operation
  - Blocking receive: receiver is blocked until the message is available
  - Nonblocking receive: receiver receives a valid message or a null



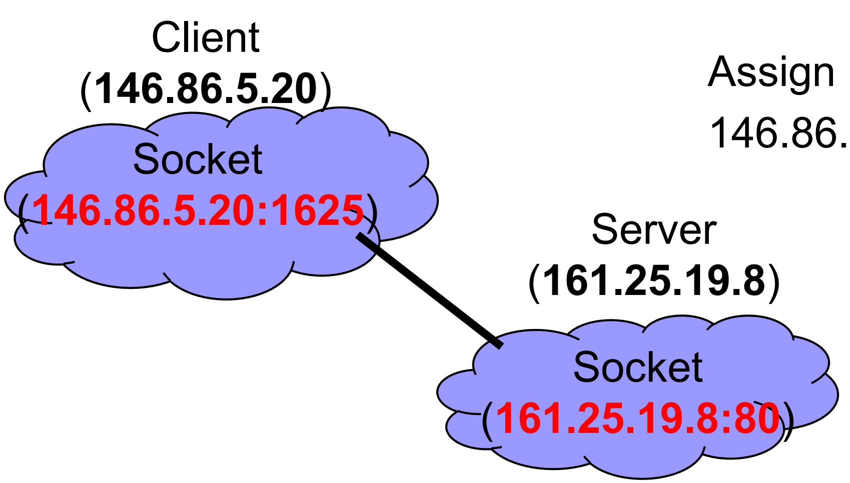
- Buffer implementation
  - Zero capacity: blocking send/receive
  - Bounded capacity: if full, sender will be blocked
  - Unbounded capacity: sender never blocks

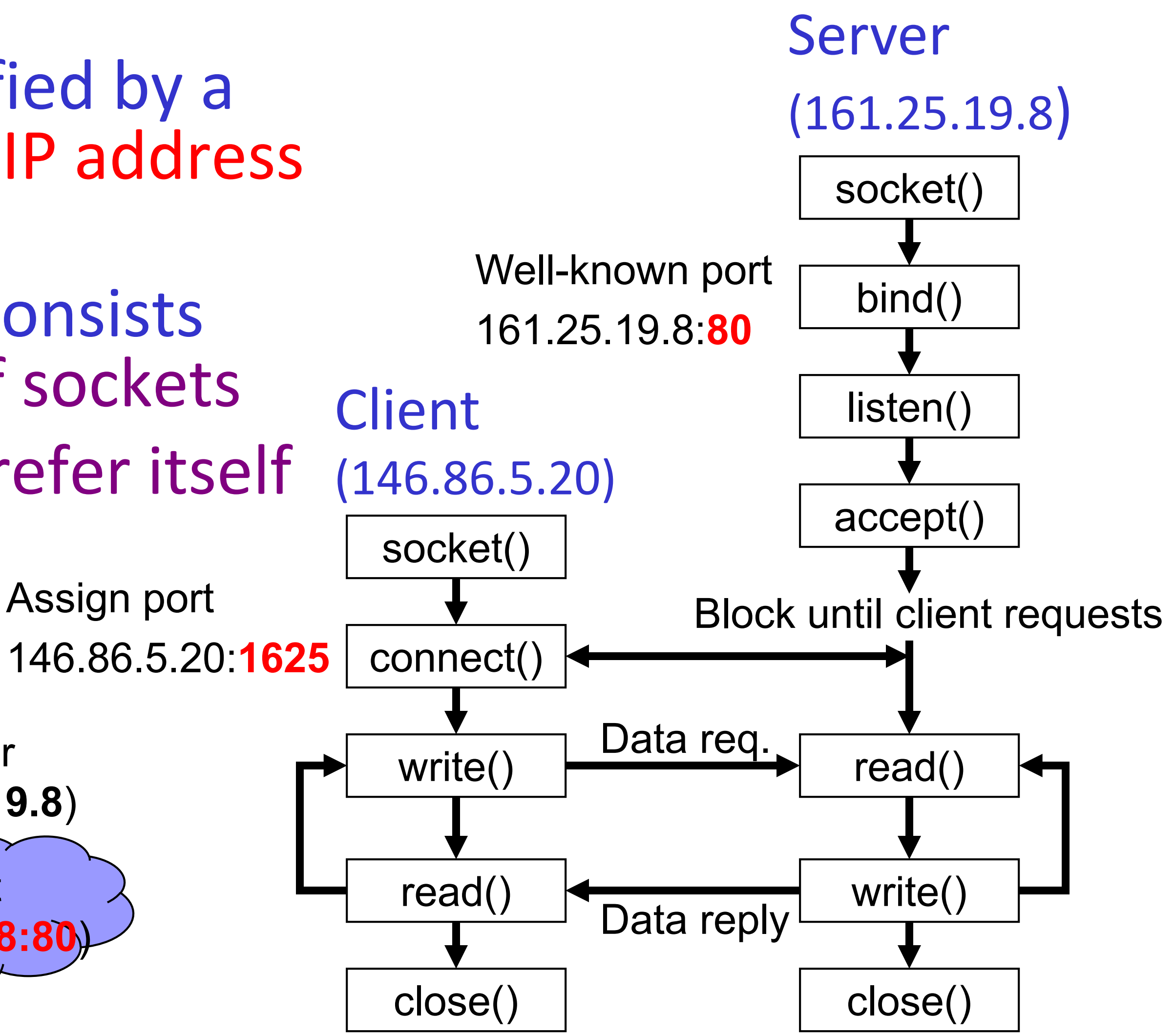
Interprocess Communication

- Shared Memory
- Message Passing
- Socket
- Remote Procedure Calls

Sockets

- A socket is identified by a concatenation of IP address and port number
- Communication consists between a pair of sockets
- Use 127.0.0.1 to refer itself

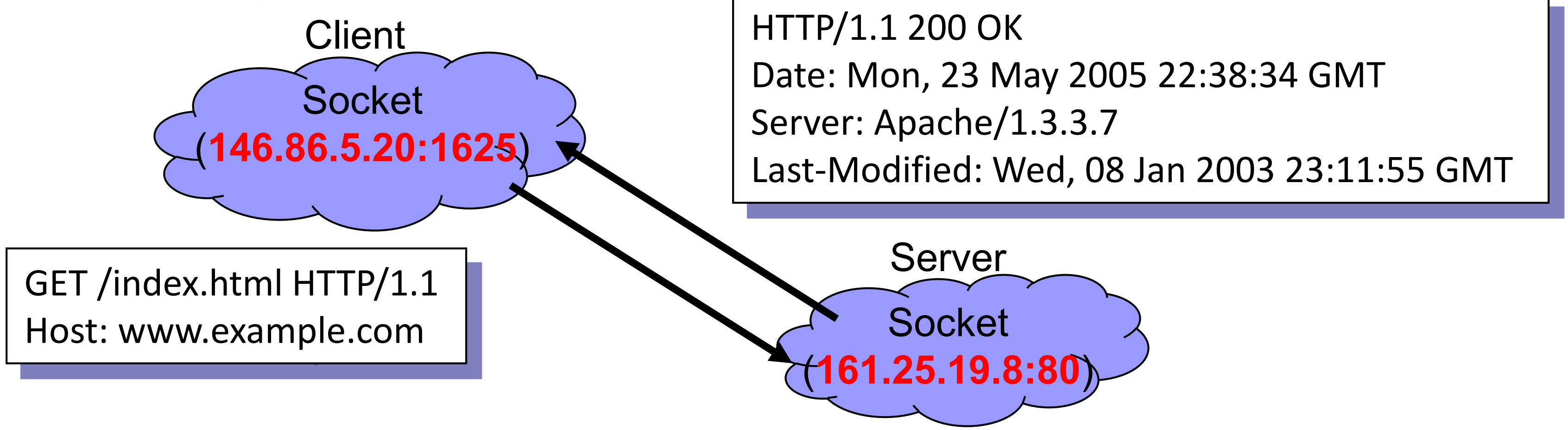




Sockets

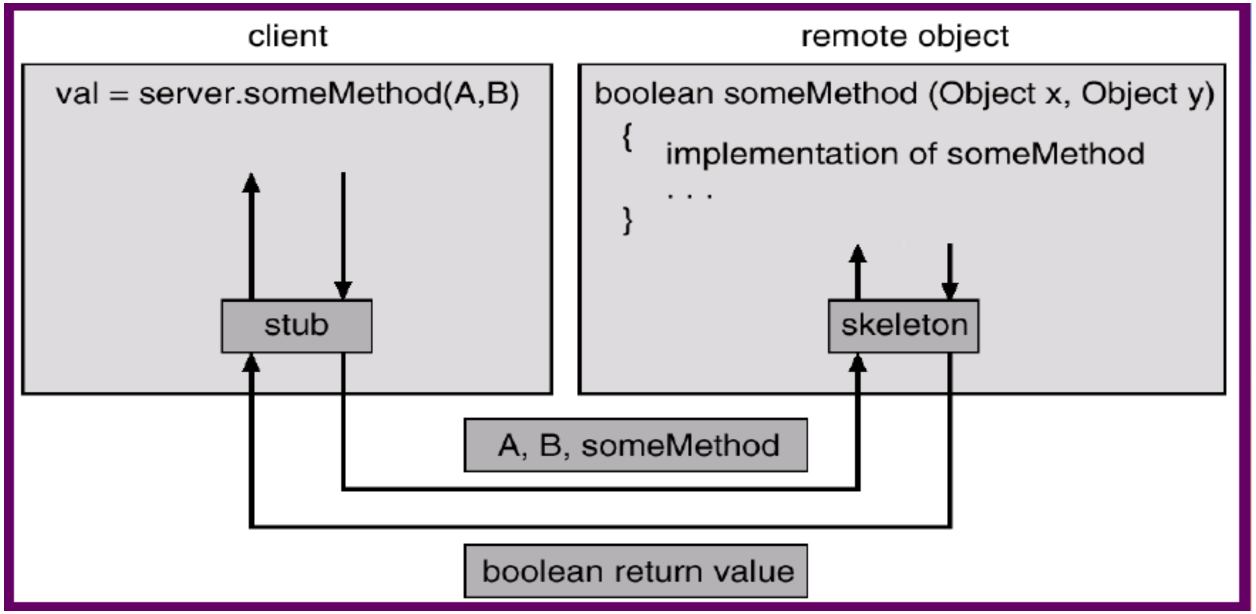
- Considered as a low-level form of communication unstructured stream of bytes to be exchanged
- Data parsing responsibility falls upon the server and the client applications

HTTP example:



Remote Procedure Calls: RPC

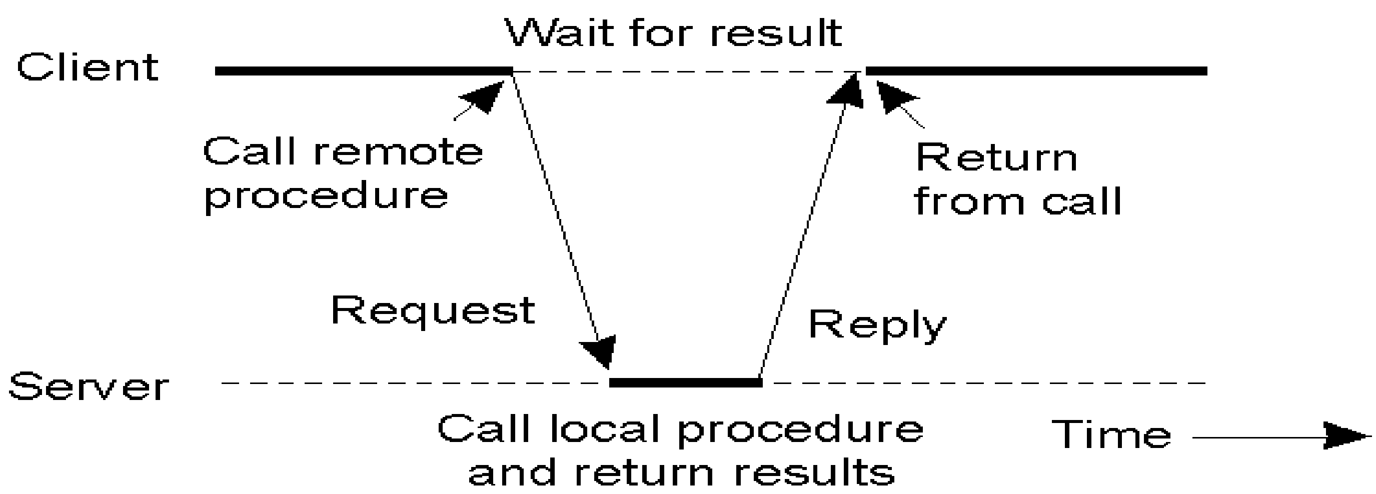
- Remote procedure call (RPC) abstracts procedure calls between processes on networked systems
  - allows programs to call procedures located on other machines (and other processes)
- Stubs – client-side proxy for the actual procedure on the server



Client and Server Stubs

Client stub:

- Packs parameters into a message (i.e. parameter marshaling)
- Calls OS to send directly to the server
- Waits for result-return from the server



Server stub:

- Receives a call from a client
- Unpacks the parameters
- Calls the corresponding procedure
- Returns results to the caller

Review Slides (3)

- Shared memory vs. Message-passing system?
- Direct vs. Indirect message-passing system?
- Blocking vs. Non-Blocking?
- Socket vs. RPC?

Reading Material & HW

```
#include<stdio.h>
#include<unistd.h>

int main()
{
	int i;
	for(i=0;i<4;i++)
		fork();
	return 0;
}
```

Fig1

- Chap 3
- HW (Problem set)
  - 3.2: Describe the actions taken by the kernel to context-switch between two processes.
  - 3.5: Include the initial parent process, how many processes created by the program shown in Fig. 1?
  - 3.10: Using the program shown in Figure 2, explain what the output will be at lines X and Y.

Reading Material & HW

```c
#include <sys/types.h>
#include <stdio.h>
#include <unistd.h>

#define SIZE 5

int nums[SIZE] = {0,1,2,3,4};

int main()
{
int i;
pid_t pid;

    pid = fork();

    if (pid == 0) {
        for (i = 0; i < SIZE; i++) {
            nums[i] *= -i;
            printf("CHILD: %d ",nums[i]); /* LINE X */
        }
    }
    else if (pid > 0) {
        wait(NULL);
        for (i = 0; i < SIZE; i++)
            printf("PARENT: %d ",nums[i]); /* LINE Y */
    }

    return 0;
}
```

Fig2

Backup

Example: POSIX Shared Memory

```
{
    /* allocate a R/W shared memory segment */
```

size R/W mode

```
    char* segment_id = shmget(IPC_PRIVATE, 4096, S_IRUSR | S_IWUSR);
    /* attach the shared memory segment */
```

mem. location R/W mode

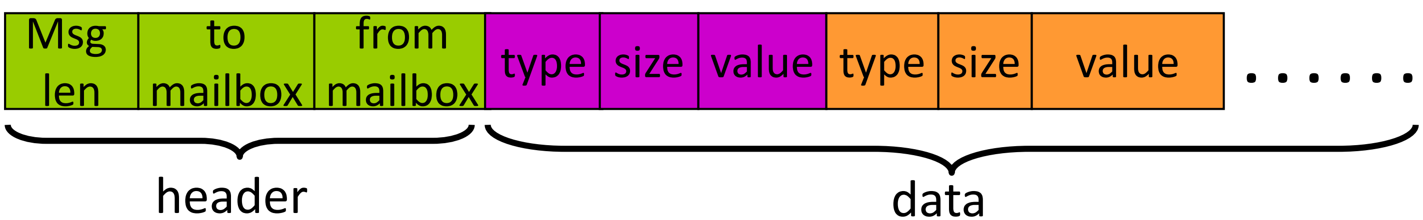
```
    char* shared_memory = (char*) shmat(segment_id, NULL, 0);
    /* write a message to the shared memory segment */
    sprintf(shared_memory, "Write to shared memory");
    /* print out the string from the shared memory segment */
    printf("%s\n", shared_memory);
    /* detach the shared memory segment */
    shmdt(shared_memory);
    /* remove the shared memory segment */
    shmctl(shared_memory, IPC_RMID, NULL);
}
```

Example: Mach Message Passing

- Mach operating system
  - developed at CMU
  - microkernel design
  - most communications are carried out by messages and mailboxes (aka ports)
  - Problem: performance (data coping)
- When each task (process) is created
  - kernel & notify mailboxes also created
  - kernel mailbox: channel between OS & task
  - notify mailbox: OS sends event notification to

Mach Mailbox

- port-allocate: system call to create a mailbox
  - default buffer size: 8 messages
  - FIFO queueing
  - a message: one fixed-size header + variable-length data portion
  - implementing both blocking- & non-blocking send/receive



RPC Problems

- Data representations → integer, floating?
- Different address spaces → pointer?
- Communication error →duplicate or missing calls

RPC Problems: Data Representation Issue

- Problem
  - IBM mainframes use EBCDIC char code and IBM PC uses ASCII code
  - Integer: one's complement and 2's complement
  - Floating-point numbers
  - Little endian and big endian
- *Solution*
  - ***External data representation (XDR)***

RPC Problems: Address Space Issue

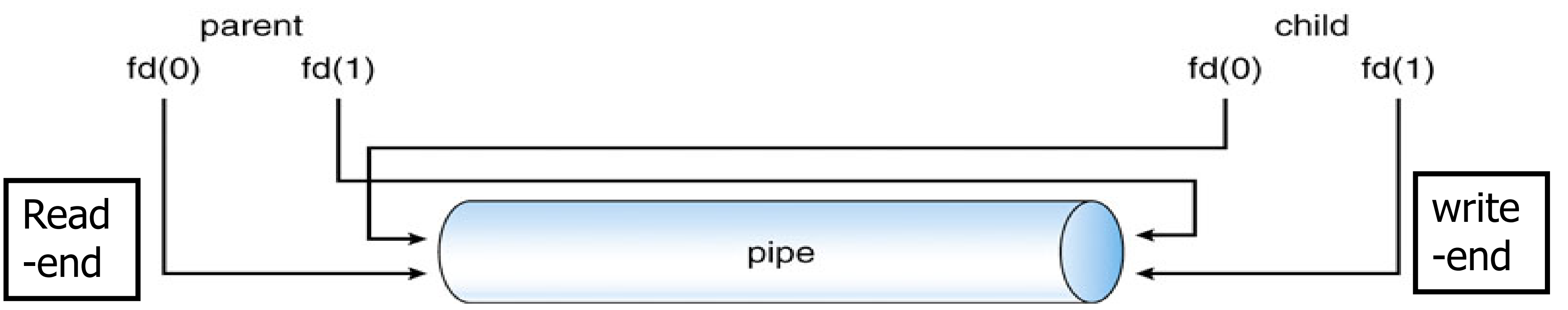
- A pointer is only meaningful in its address space
- Solutions
  - No pointer usage in RPC calls
  - Copy the entire pointed area (such as arrays or strings)
    - Only suitable for bounded and known areas

RPC Problems: Communication Issue

- RPCs may fail, or be duplicated and execute more than once, as a result of common network errors
- *at most once*: prevent duplicate calls
  - Implemented by attaching a **timestamp** to each message
  - The server must keep a history large enough to ensure that repeated messages are detected
- *exact once*: prevent missing calls
  - The server must acknowledge to the client that the RPC call was received and executed
  - The client must resend each RPC call periodically until the server receives the ACK

Pipes

- One of the 1st IPC mechanism in early UNIX systems
- Pipe is a special type of file
- Issues in implementing
  - uni- or bi-directional?
  - half or full duplex? (travel in both directions simultaneously)
  - Must a relationship (parent – child) exist?
  - Over a network, or reside on the same machine?



Ordinary Pipes

- Also called anonymous pipes in Windows
- Requires a parent-child relationship between the communicating processes
  - Implemented as a special file on Unix (via fork(), a child process inherits open files from its parent)
  - Can only be used between processes on the same machine
- Unidirectional: two pipes must be used for two–way communication

UNIX:
```
int fd[2];
pipe(fd);
```

Windows:
```
CreatePipe(&ReadHandle, &WriteHandle, &sa, 0)
```

Named Pipes

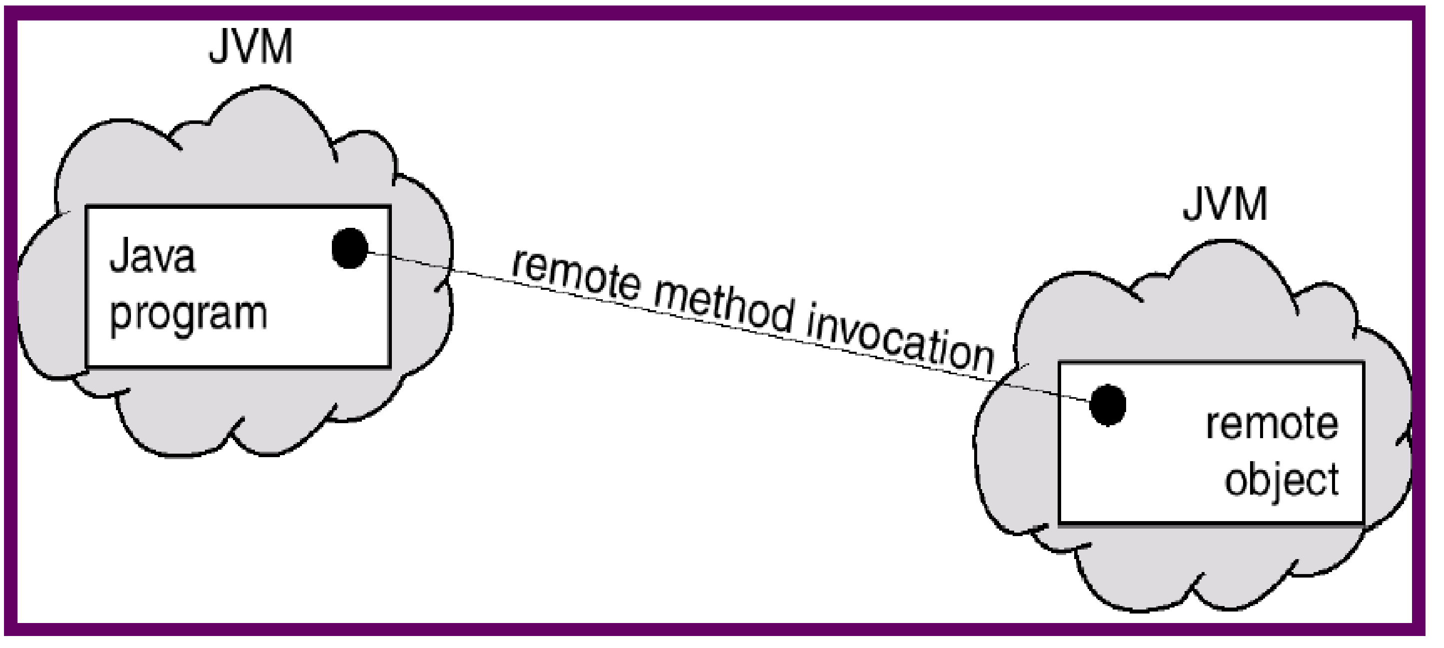
- No parent-child relationship is required
- Several processes can use it for communications
  - It may have several writers
- Continue to exist after communicating processes exit
- In Unix:
  - Also called FIFO
  - Communicating processes have to be on the same machine
- In Windows:
  - bi-directional
  - Communicating processes can be on different machine

UNIX/Linux: Fork

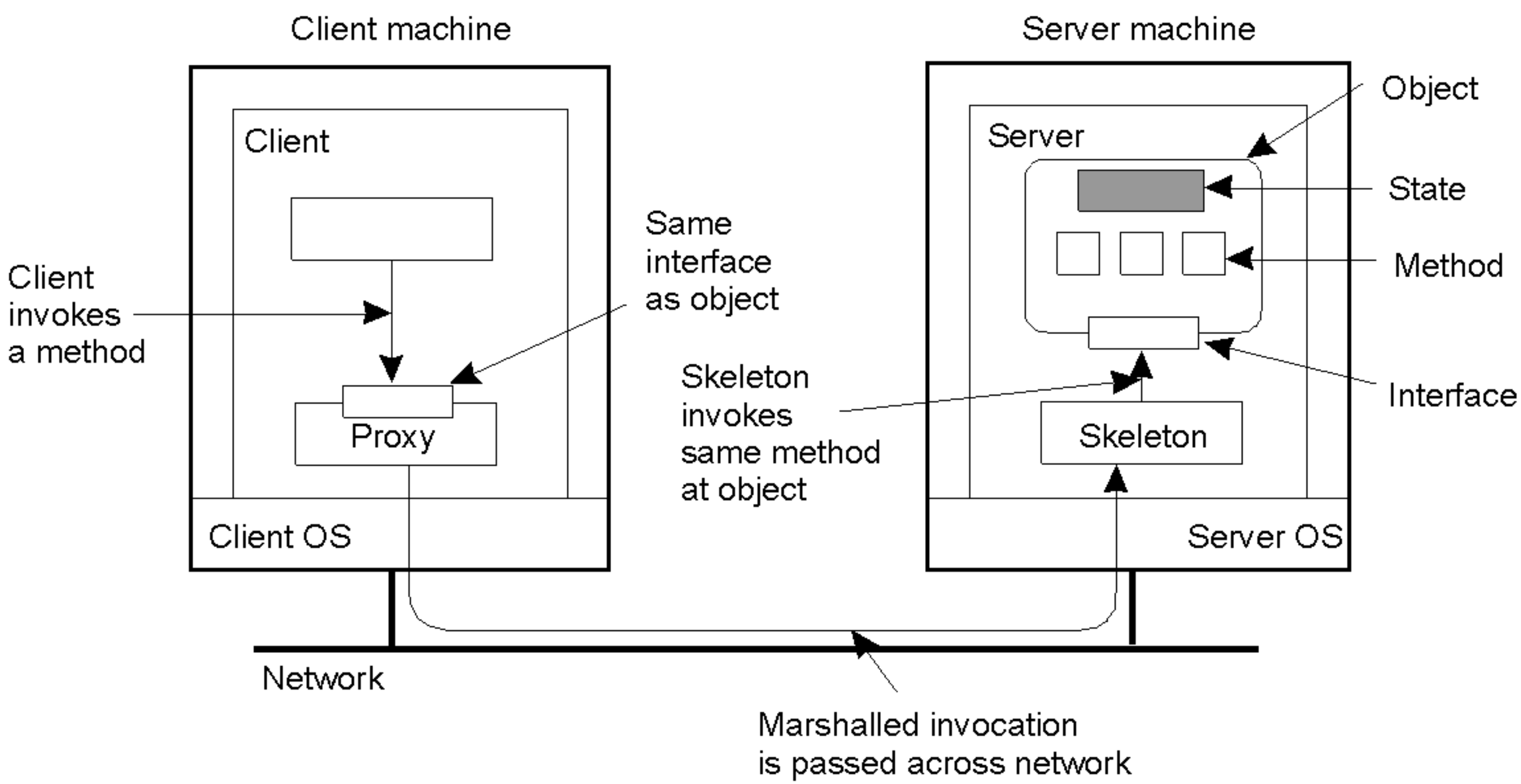
- Inherited from the parent:
  - process credentials
  - environment
  - stack
  - memory
  - open file descriptors
  - signal handling settings
  - scheduler class
  - process group ID
  - session ID
  - current working directory
  - root directory
  - file mode creation mask (umask)
  - resource limits
  - controlling terminal
- Unique to the child:
  - process ID
  - different parent process ID
  - Own copy of file descriptors and directory streams.
  - process, text, data and other memory locks are NOT inherited.
  - process times, in the tms struct
  - resource utilizations are set to 0
  - pending signals initialized to the empty set
  - timers created by timer_create not inherited
  - asynchronous input or output operations not inherited

Remote Method Invocation

- RMI is a Java mechanism similar to RPC
- RMI allows a Java program on one machine to invoke a method on a remote object instead of a function



Distributed Objects



A remote object with client-side proxy

Static & Dynamic RMI

- RMI = Remote Method Invocation
  - Invoke an object's method through proxy
- Static invocation
  - objectname.methodname(para)
  - If interfaces change, apps must be recompiled
- Dynamic invocation
  - invoke(object, method, inpars, outpars)