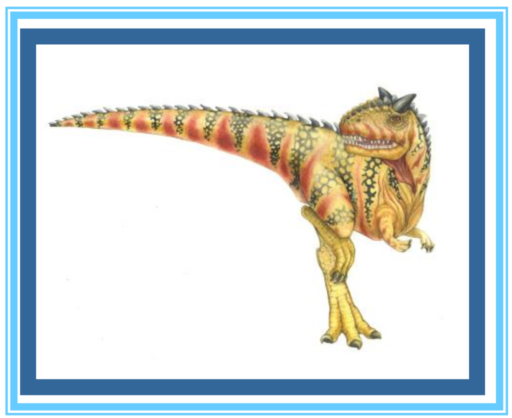
# Chapter 3:  Process Concept



# Chapter 3: Process-Concept

- Process Concept
- Process Scheduling
- Operations on Processes
- Interprocess Communication
- Examples of IPC Systems
- Communication in Client-Server Systems

# Objectives

- To introduce the notion of a process -- a program in execution, which forms the basis of all computation
- To describe the various features of processes, including scheduling, creation and termination, and communication
- To describe 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
- Process – a program in execution; process execution must progress in sequential fashion
- A process includes:
  - program counter
  - stack
  - data section

# Process in Memory

```
#include "stdafx.h"

int x;
int y = 1;


int _tmain(int argc, _TCHAR* argv[])
{
    int z;
    int *h = new int[100];

    printf("main => %p\n", _tmain);
    printf("x => %p\n", &x);
    printf("y => %p\n", &y);
    printf("z => %p\n", &z);
    printf("h is %p\n", h);

    getchar();

    return 0;
}
```

# Process in Memory

```
    3:
    4: #include "stdafx.h"
    5:
    6: int x;
    7: int y = 1;
    8:
    9:
   10: int _tmain(int argc, _TCHAR* argv[])
   11: {
000007F7FB402E50 48 89 54 24 10       mov         qword ptr [rsp+10h],rdx
000007F7FB402E55 89 4C 24 08          mov         dword ptr [rsp+8],ecx
000007F7FB402E59 57                   push        rdi
000007F7FB402E5A 48 83 EC 50          sub         rsp,50h
000007F7FB402E5E 48 8B FC             mov         rdi,rsp
000007F7FB402E61 B9 14 00 00 00       mov         ecx,14h
000007F7FB402E66 B8 CC CC CC CC       mov         eax,0CCCCCCCCh
000007F7FB402E6B F3 AB                rep stos    dword ptr [rdi]
000007F7FB402E6D 8B 4C 24 60          mov         ecx,dword ptr [rsp+60h]
   12:     int z;
   13:     int *h = new int[100];
000007F7FB402E71 B9 90 01 00 00       mov         ecx,190h
000007F7FB402E76 E8 DB E2 FF FF       call        operator new (7F7FB401156h)
000007F7FB402E7B 48 89 44 24 40       mov         qword ptr [rsp+40h],rax
000007F7FB402E80 48 8B 44 24 40       mov         rax,qword ptr [rsp+40h]
000007F7FB402E85 48 89 44 24 38       mov         qword ptr [h],rax
   14:
   15:     printf("main => %p\n", _tmain);
000007F7FB402E8A 48 8D 15 74 E1 FF FF lea         rdx,[@ILT+0(wmain) (7F7FB401005h)]
000007F7FB402E91 48 8D 0D F8 38 00 00 lea         rcx,[__xi_z+130h (7F7FB406790h)]
000007F7FB402E98 FF 15 72 86 00 00    call        qword ptr [__imp_printf (7F7FB40B510h)]
   16:     printf("x => %p\n", &x);
000007F7FB402E9E 48 8D 15 AB 62 00 00 lea         rdx,[x (7F7FB409150h)]
000007F7FB402EA5 48 8D 0D F4 38 00 00 lea         rcx,[__xi_z+140h (7F7FB4067A0h)]
000007F7FB402EAC FF 15 5E 86 00 00    call        qword ptr [__imp_printf (7F7FB40B510h)]
   17:     printf("y => %p\n", &y);
000007F7FB402EB2 48 8D 15 47 61 00 00 lea         rdx,[y (7F7FB409000h)]
000007F7FB402EB9 48 8D 0D F0 38 00 00 lea         rcx,[__xi_z+150h (7F7FB4067B0h)]
000007F7FB402EC0 FF 15 4A 86 00 00    call        qword ptr [__imp_printf (7F7FB40B510h)]
```

# Process in Memory

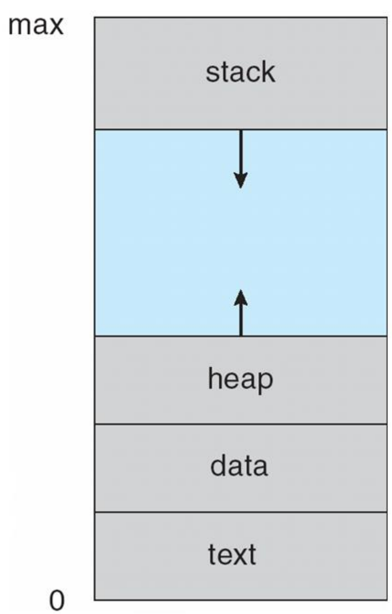
```
    18:      printf("z => %p\n", &z);
000007F7FB402EC6 48 8D 54 24 24       lea         rdx,[z]
000007F7FB402ECB 48 8D 0D EE 38 00 00 lea         rcx,[__xi_z+160h (7F7FB4067C0h)]
000007F7FB402ED2 FF 15 38 86 00 00    call        qword ptr [__imp_printf (7F7FB40B510h)]
    19:      printf("h is %p\n", h);
000007F7FB402ED8 48 8B 54 24 38       mov         rdx,qword ptr [h]
000007F7FB402EDD 48 8D 0D EC 38 00 00 lea         rcx,[__xi_z+170h (7F7FB4067D0h)]
000007F7FB402EE4 FF 15 26 86 00 00    call        qword ptr [__imp_printf (7F7FB40B510h)]
    20:
    21:      getchar();
000007F7FB402EEA FF 15 28 86 00 00    call        qword ptr [__imp_getchar (7F7FB40B518h)]
    22:
    23:      return 0;
000007F7FB402EF0 33 C0                xor         eax,eax
    24: }
000007F7FB402EF2 8B F8                mov         edi,eax
000007F7FB402EF4 48 8B CC             mov         rcx,rsp
000007F7FB402EF7 48 8D 15 22 39 00 00 lea         rdx,[__xi_z+1C0h (7F7FB406820h)]
000007F7FB402EFE E8 CD E1 FF FF       call        _RTC_CheckStackVars (7F7FB4010D0h)
000007F7FB402F03 8B C7                mov         eax,edi
000007F7FB402F05 48 83 C4 50          add         rsp,50h
000007F7FB402F09 5F                   pop         rdi
000007F7FB402F0A C3                   ret
```

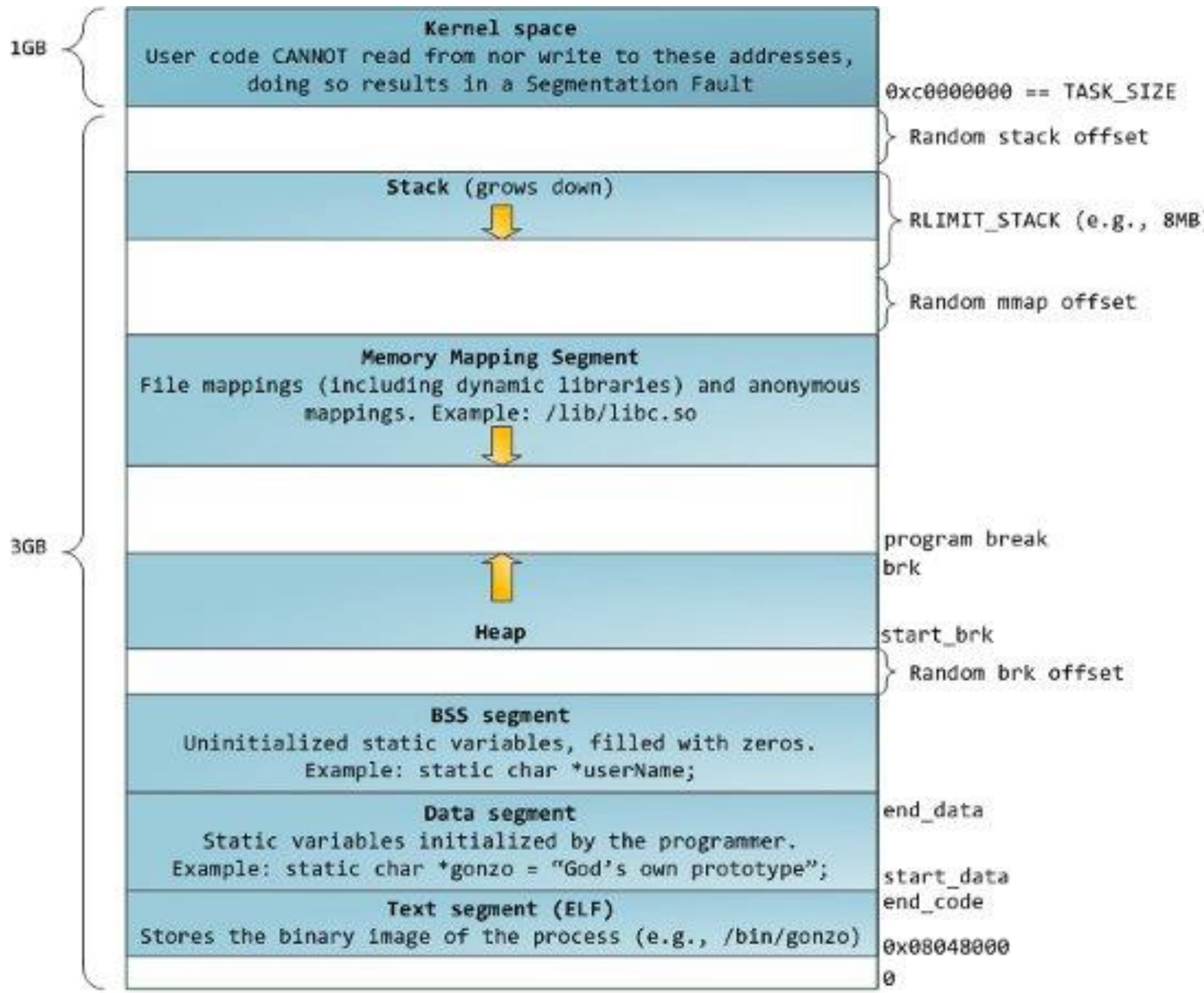
c:\users\hank\documents\visual studio 2010\Projects\test_process1\x64\...

```
main => 000007F7FB401005
x => 000007F7FB409150
y => 000007F7FB409000
z => 0000000000097FAD4
h is 00000000000AD83A0
```

| Address | Type | Size | Protection | Details |
|---|---|---|---|---|
| + 0000000000850000 | Heap (Shareable) | 64 K | Read/Write | Heap ID: 2 [COMPATABILITY] |
| + 0000000000860000 | Mapped File | 4 K | Read | C:\Windows\Globalization\zh-TW.nlx |
| + 0000000000870000 | Shareable | 36 K | Read | |
| − 0000000000880000 | Thread Stack | 1,024 K | Read/Write/Guard | Thread ID: 1340 |
| 0000000000880000 | Thread Stack | 992 K | Reserved | |
| 0000000000978000 | Thread Stack | 12 K | Read/Write/Guard | |
| 000000000097B000 | Thread Stack | 20 K | Read/Write | |
| + 0000000000980000 | Shareable | 16 K | Read | |
| + 0000000000990000 | Shareable | 4 K | Read | |
| + 00000000009A0000 | Private Data | 8 K | Read/Write | |
| + 00000000009B0000 | Mapped File | 468 K | Read | C:\Windows\System32\locale.nls |
| − 0000000000AD0000 | Heap (Private Data) | 64 K | Read/Write | Heap ID: 3 [COMPATABILITY] |
| 0000000000AD0000 | Heap (Private Data) | 36 K | Read/Write | Heap ID: 3 [COMPATABILITY] |
| 0000000000AD9000 | Heap (Private Data) | 28 K | Reserved | Heap ID: 3 [COMPATABILITY] |
| + 0000000000B50000 | Heap (Private Data) | 1,024 K | Read/Write | Heap ID: 1 [COMPATABILITY] |
| + 000000005B3E0000 | Image (ASLR) | 1,856 K | Execute/Read | C:\Windows\System32\msvcr100d.dll |
| + 000000007FFE0000 | Private Data | 64 K | Read | |
| + 000007F7FB0F0000 | Shareable | 1,024 K | Read | |
| + 000007F7FB1F0000 | Shareable | 204 K | Read | |
| + 000007F7FB223000 | Private Data | 4 K | Read/Write | Process Environment Block |
| + 000007F7FB22E000 | Private Data | 8 K | Read/Write | Thread Environment Block ID: 1340 |
| − 000007F7FB400000 | Image (ASLR) | 56 K | Execute/Read | C:\Users\Hank\Documents\Visual Studio 2010\Projects\test_pr |
| 000007F7FB400000 | Image (ASLR) | 4 K | Read | Header |
| 000007F7FB401000 | Image (ASLR) | 20 K | Execute/Read | .text |
| 000007F7FB406000 | Image (ASLR) | 12 K | Read | .rdata |
| 000007F7FB409000 | Image (ASLR) | 4 K | Read/Write | .data |
| 000007F7FB40A000 | Image (ASLR) | 4 K | Read | .pdata |
| 000007F7FB40B000 | Image (ASLR) | 4 K | Read/Write | .idata |
| 000007F7FB40C000 | Image (ASLR) | 4 K | Read | .rsrc |
| 000007F7FB40D000 | Image (ASLR) | 4 K | Read | .reloc |
| + 000007FDCCDA0000 | Image (ASLR) | 972 K | Execute/Read | C:\Windows\System32\KernelBase.dll |

# Process in Memory



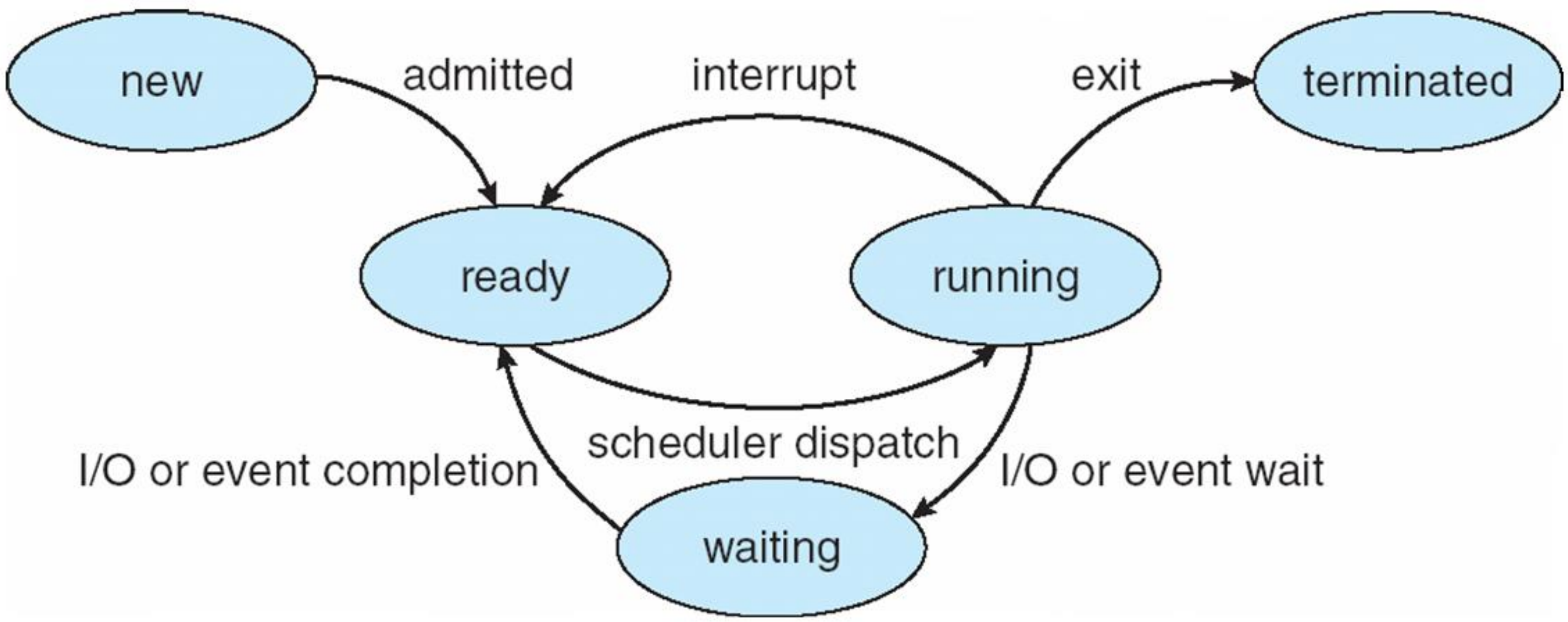
# Process State

- 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

```
hank@Maestro:/home/hank
File  Edit  View  Search  Terminal  Help
top - 23:19:48 up 3 min,  2 users,  load average: 0.56, 0.52, 0.25
Tasks: 144 total,   2 running, 142 sleeping,   0 stopped,   0 zombie
Cpu(s): 10.3%us,  7.4%sy,  0.0%ni, 81.9%id,  0.2%wa,  0.0%hi,  0.2%si,  0.0%st
Mem:   1019704k total,   878904k used,   140800k free,    34432k buffers
Swap:  2064380k total,        0k used,  2064380k free,   318172k cached

  PID USER      PR  NI  VIRT  RES  SHR S %CPU %MEM    TIME+  COMMAND
 2669 hank      20   0  721m 100m  31m S 19.3 10.0   0:15.16 firefox
 1936 root      20   0  303m  93m  14m S 12.0  9.4   0:07.24 Xorg
 2268 hank      20   0 1836m  94m  43m S 10.6  9.5   0:08.35 gnome-shell
 2477 hank      20   0  572m  15m 9884 S  0.3  1.5   0:00.55 gnome-terminal
 2668 root      20   0 15256 1212  900 R  0.3  0.1   0:00.21 top
    1 root      20   0 66744  24m 2080 S  0.0  2.5   0:01.20 systemd
    2 root      20   0     0    0    0 S  0.0  0.0   0:00.00 kthreadd
    3 root      20   0     0    0    0 S  0.0  0.0   0:00.01 ksoftirqd/0
    4 root      20   0     0    0    0 S  0.0  0.0   0:00.00 kworker/0:0
    5 root      20   0     0    0    0 S  0.0  0.0   0:00.00 kworker/u:0
    6 root      RT   0     0    0    0 S  0.0  0.0   0:00.00 migration/0
    7 root      RT   0     0    0    0 S  0.0  0.0   0:00.00 watchdog/0
    8 root      RT   0     0    0    0 S  0.0  0.0   0:00.00 migration/1
    9 root      20   0     0    0    0 S  0.0  0.0   0:00.00 kworker/1:0
   10 root      20   0     0    0    0 S  0.0  0.0   0:00.04 ksoftirqd/1
   11 root      RT   0     0    0    0 S  0.0  0.0   0:00.00 watchdog/1
   12 root       0 -20     0    0    0 S  0.0  0.0   0:00.00 cpuset
   13 root       0 -20     0    0    0 S  0.0  0.0   0:00.00 khelper
```

# Diagram of Process State



# Process State

hank@Maestro:/home/ha

File Edit View Search Terminal Help

```
[root@Maestro hank]# ps axfj | more
 PPID   PID  PGID   SID TTY      TPGID STAT   UID   TIME COMMAND
    0     2     0     0 ?           -1 S        0   0:00 [kthreadd]
    2     3     0     0 ?           -1 S        0   0:00  \_ [ksoftirqd/0]
    2     5     0     0 ?           -1 S        0   0:00  \_ [kworker/u:0]
    2     6     0     0 ?           -1 S        0   0:00  \_ [migration/0]
    2     7     0     0 ?           -1 S        0   0:00  \_ [watchdog/0]
    2     8     0     0 ?           -1 S        0   0:00  \_ [migration/1]
    2    10     0     0 ?           -1 S        0   0:00  \_ [ksoftirqd/1]
    2    11     0     0 ?           -1 S        0   0:00  \_ [watchdog/1]
    2    12     0     0 ?           -1 S<       0   0:00  \_ [cpuset]
    2    13     0     0 ?           -1 S<       0   0:00  \_ [khelper]
    2    14     0     0 ?           -1 S        0   0:00  \_ [kdevtmpfs]
    2    15     0     0 ?           -1 S<       0   0:00  \_ [netns]
    2    16     0     0 ?           -1 S        0   0:00  \_ [sync_supers]
    2    17     0     0 ?           -1 S        0   0:00  \_ [bdi-default]
    2    18     0     0 ?           -1 S<       0   0:00  \_ [kintegrityd]
    2    19     0     0 ?           -1 S<       0   0:00  \_ [kblockd]
    2    20     0     0 ?           -1 S<       0   0:00  \_ [ata_sff]
    2    21     0     0 ?           -1 S        0   0:00  \_ [khubd]
    2    22     0     0 ?           -1 S<       0   0:00  \_ [md]
    2    23     0     0 ?           -1 S        0   0:00  \_ [kworker/1:1]
    2    25     0     0 ?           -1 S        0   0:00  \_ [kswapd0]
    2    26     0     0 ?           -1 SN       0   0:00  \_ [ksmd]
    2    27     0     0 ?           -1 SN       0   0:00  \_ [khugepaged]
    2    28     0     0 ?           -1 S        0   0:00  \_ [fsnotify_mark]
    2    29     0     0 ?           -1 S<       0   0:00  \_ [crypto]
    2    35     0     0 ?           -1 S<       0   0:00  \_ [kthrotld]
    2    38     0     0 ?           -1 S        0   0:00  \_ [scsi_eh_0]
    2    39     0     0 ?           -1 S        0   0:00  \_ [scsi_eh_1]
    2    40     0     0 ?           -1 S        0   0:00  \_ [scsi_eh_2]
    2    41     0     0 ?           -1 S        0   0:00  \_ [kworker/u:2]
    2    43     0     0 ?           -1 S<       0   0:00  \_ [kpsmoused]
    2    44     0     0 ?           -1 S<       0   0:00  \_ [deferwq]
    2    46     0     0 ?           -1 S        0   0:00  \_ [kworker/0:2]
    2   238     0     0 ?           -1 S        0   0:00  \_ [kworker/1:2]
    2   290     0     0 ?           -1 S<       0   0:00  \_ [kdmflush]
    2   291     0     0 ?           -1 S<       0   0:00  \_ [kdmflush]
    2   338     0     0 ?           -1 S        0   0:00  \_ [jbd2/dm-1-8]
    2   339     0     0 ?           -1 S<       0   0:00  \_ [ext4-dio-unwrit]
    2   375     0     0 ?           -1 S        0   0:00  \_ [kauditd]
```

## UNIX-LIKE FOR LIFE

Friday, July 31, 2009

### Linux process state codes

Here are the different values that the s, stat and state output specifiers (header "STAT" or "S") will display to describe the state of a process.

D Uninterruptible sleep (usually IO)
R Running or runnable (on run queue)
S Interruptible sleep (waiting for an event to complete)
T Stopped, either by a job control signal or because it is being traced.
W paging (not valid since the 2.6.xx kernel)
X dead (should never be seen)
Z Defunct ("zombie") process, terminated but not reaped by its parent.

For BSD formats and when the stat keyword is used, additional characters may be displayed:
< high-priority (not nice to other users)
N low-priority (nice to other users)
L has pages locked into memory (for real-time and custom IO)
s is a session leader
l is multi-threaded (using CLONE_THREAD, like NPTL pthreads do)
+ is in the foreground process group

Posted by M.Burak Alkan at 12:01 AM

Labels linux

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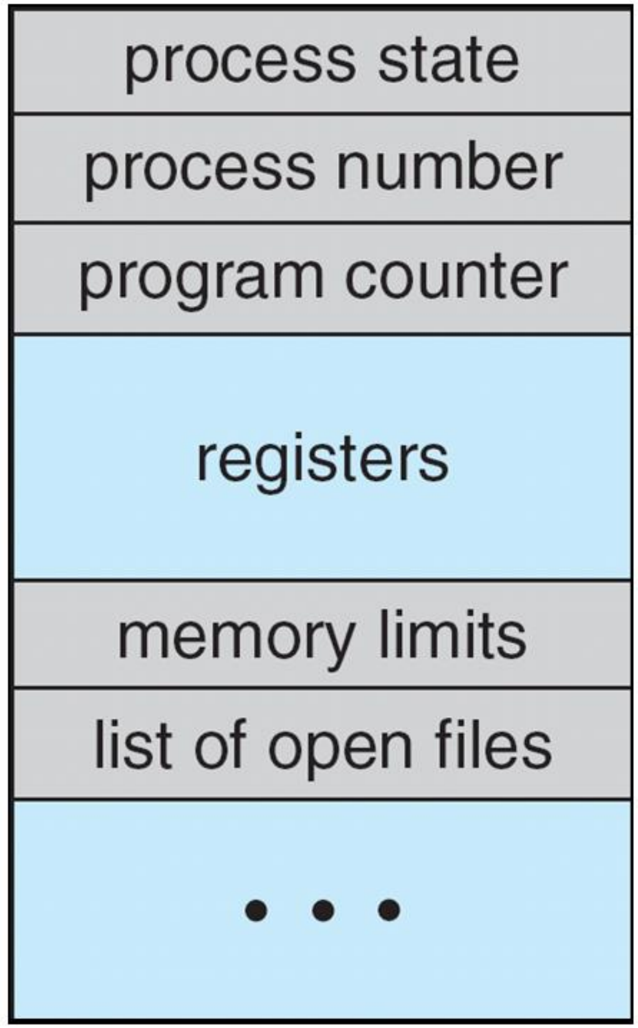
# Process Control Block (PCB)

Information associated with each process

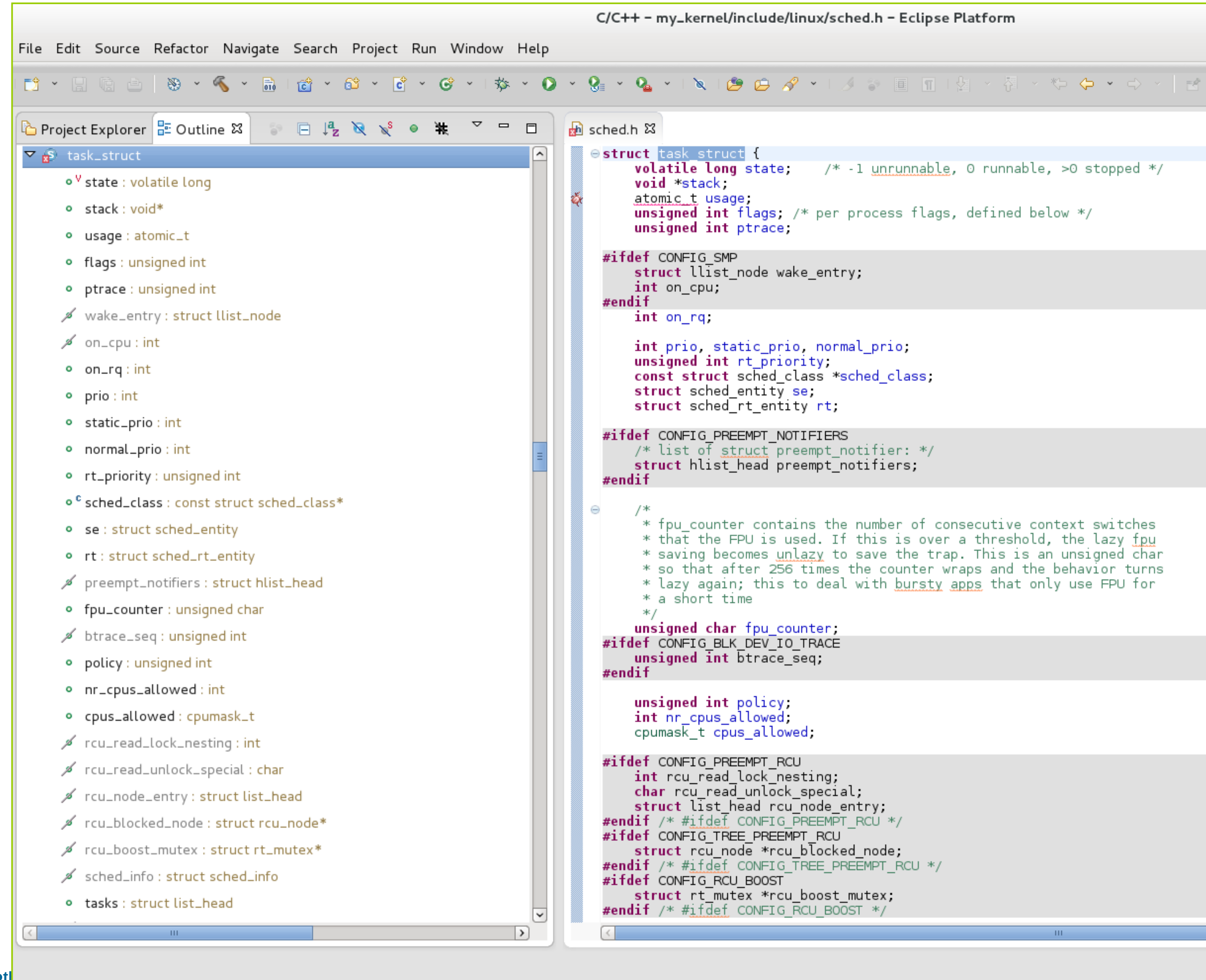
- Process state
- Program counter
- CPU registers
- CPU scheduling information
- Memory-management information
- Accounting information
- I/O status information

# Process Control Block (PCB)



# Process Control Block (PCB)

include/linux/sched.h

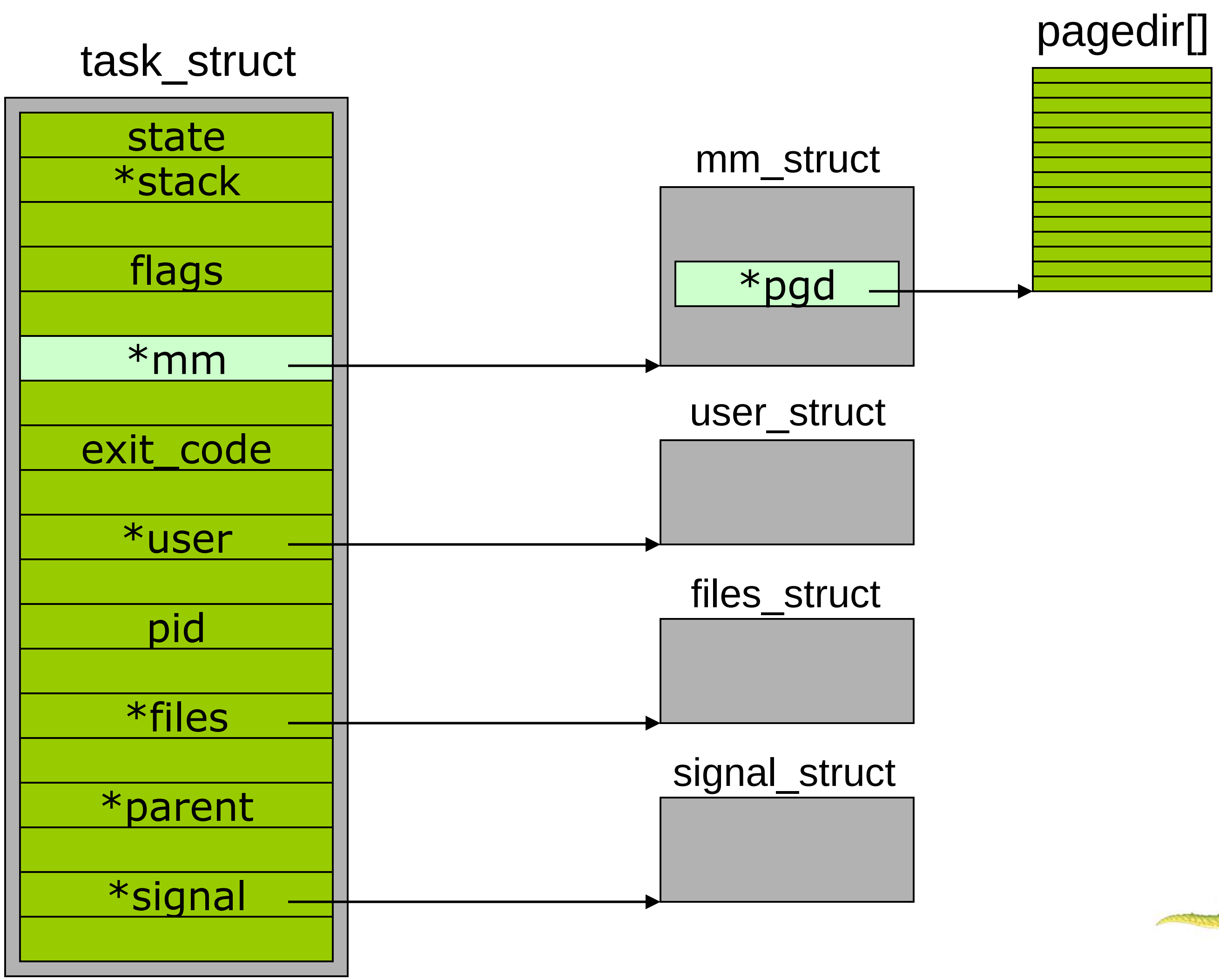


# The Linux process descriptor

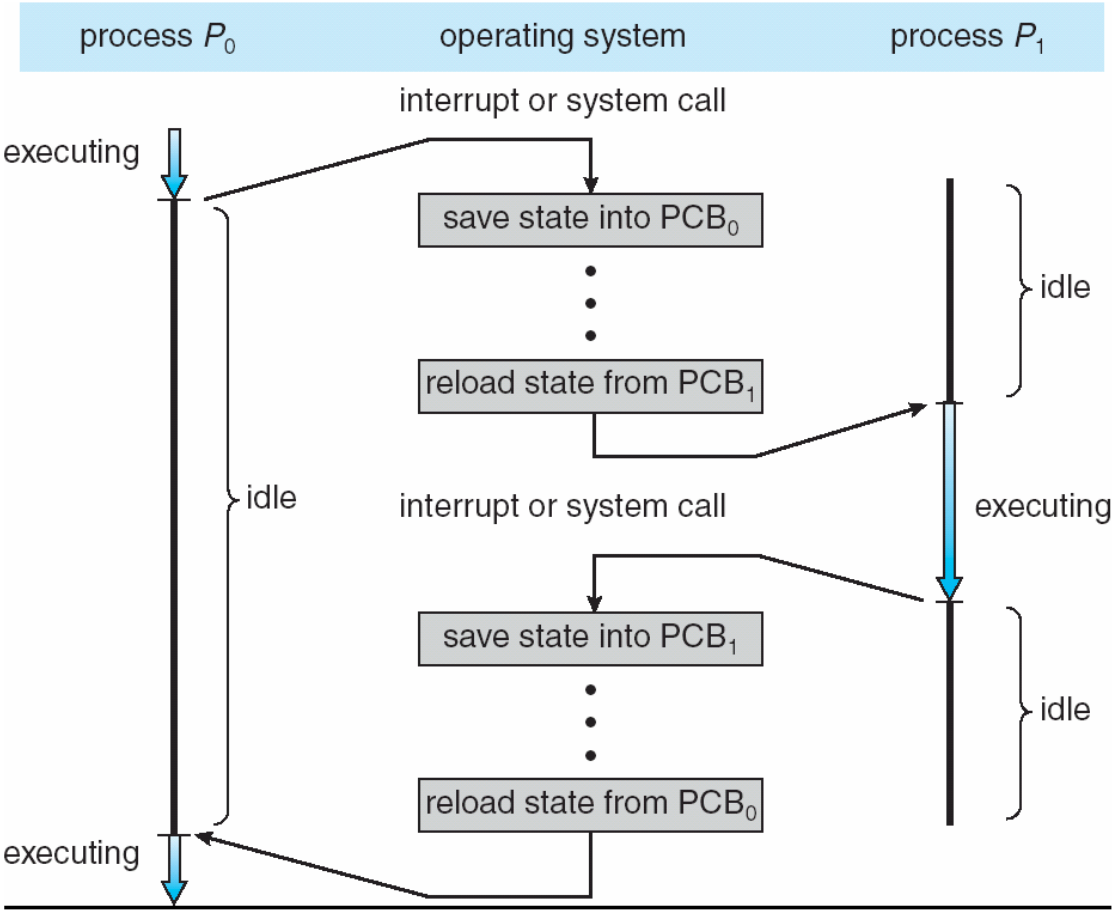
Each process descriptor contains many fields

and some are pointers to other kernel structures

which may themselves include fields that point to structures



# CPU Switch From Process to Process

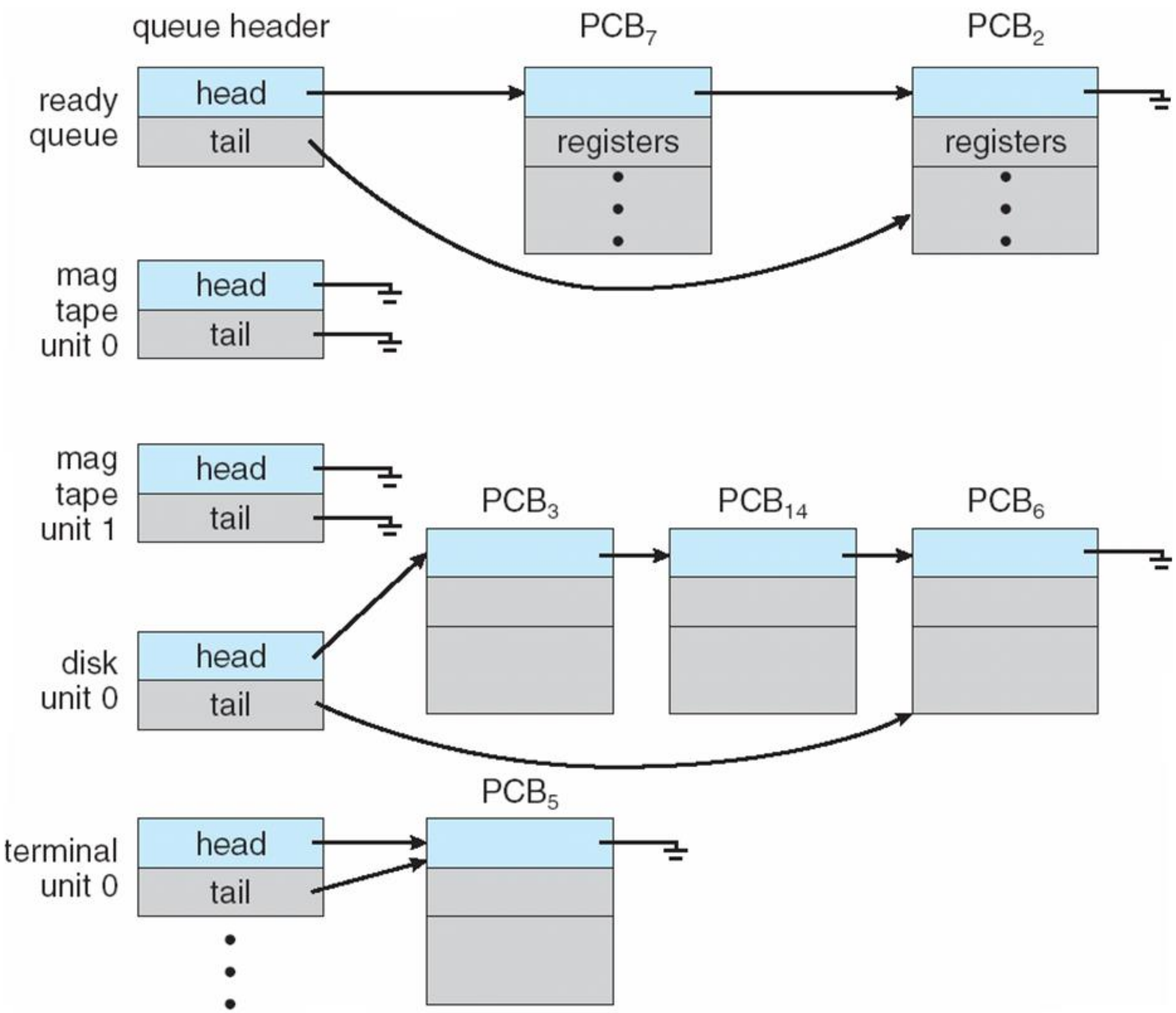


# Process Scheduling Queues

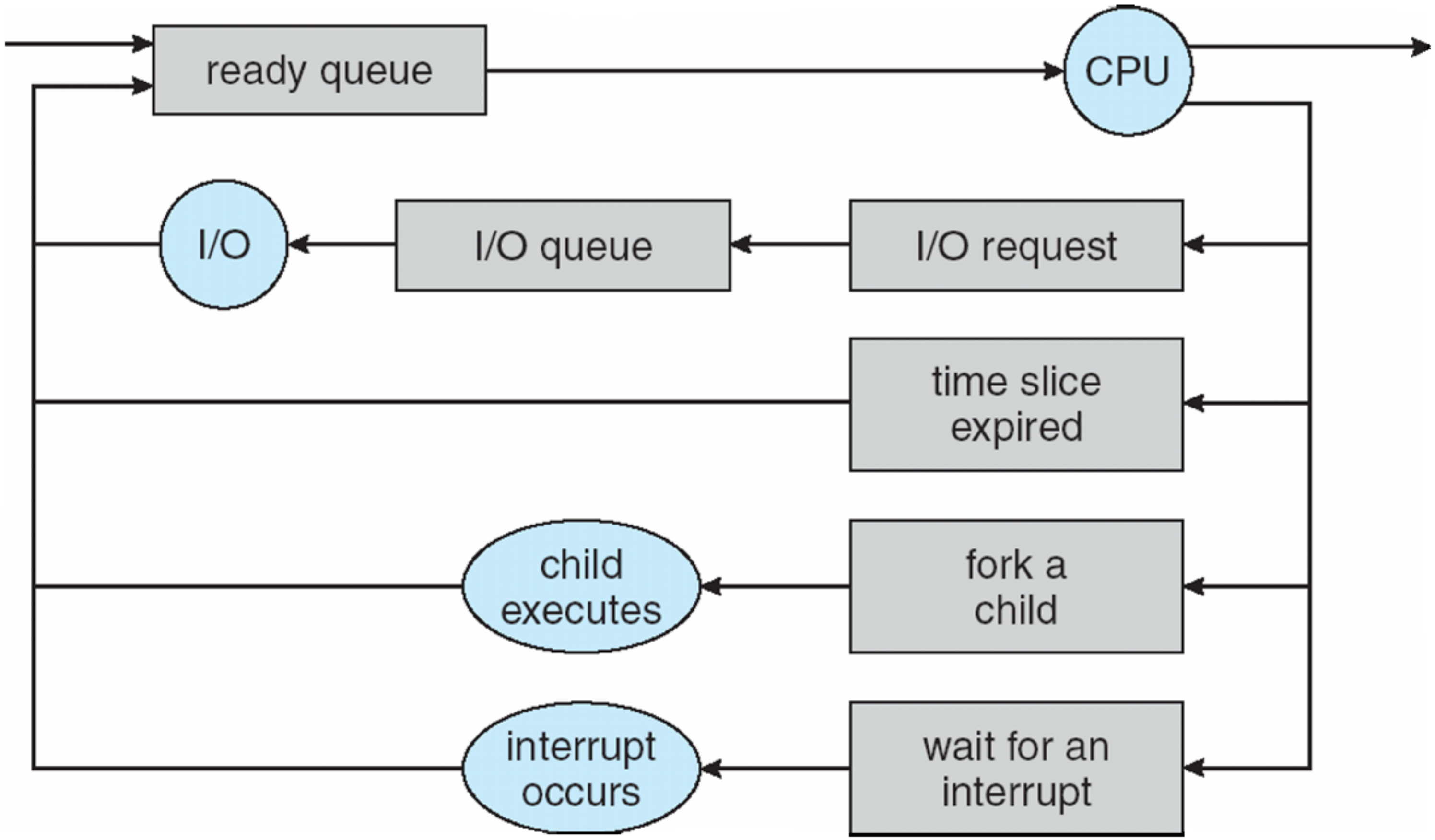
- **Job queue** – set of all processes in the system
- **Ready queue** – set of all processes residing in main memory, ready and waiting to execute
- **Device queues** – set of processes waiting for an I/O device
- Processes migrate among the various queues


Silberschatz, Galvin and Gagne ©2009

# Ready Queue And Various I/O Device Queues

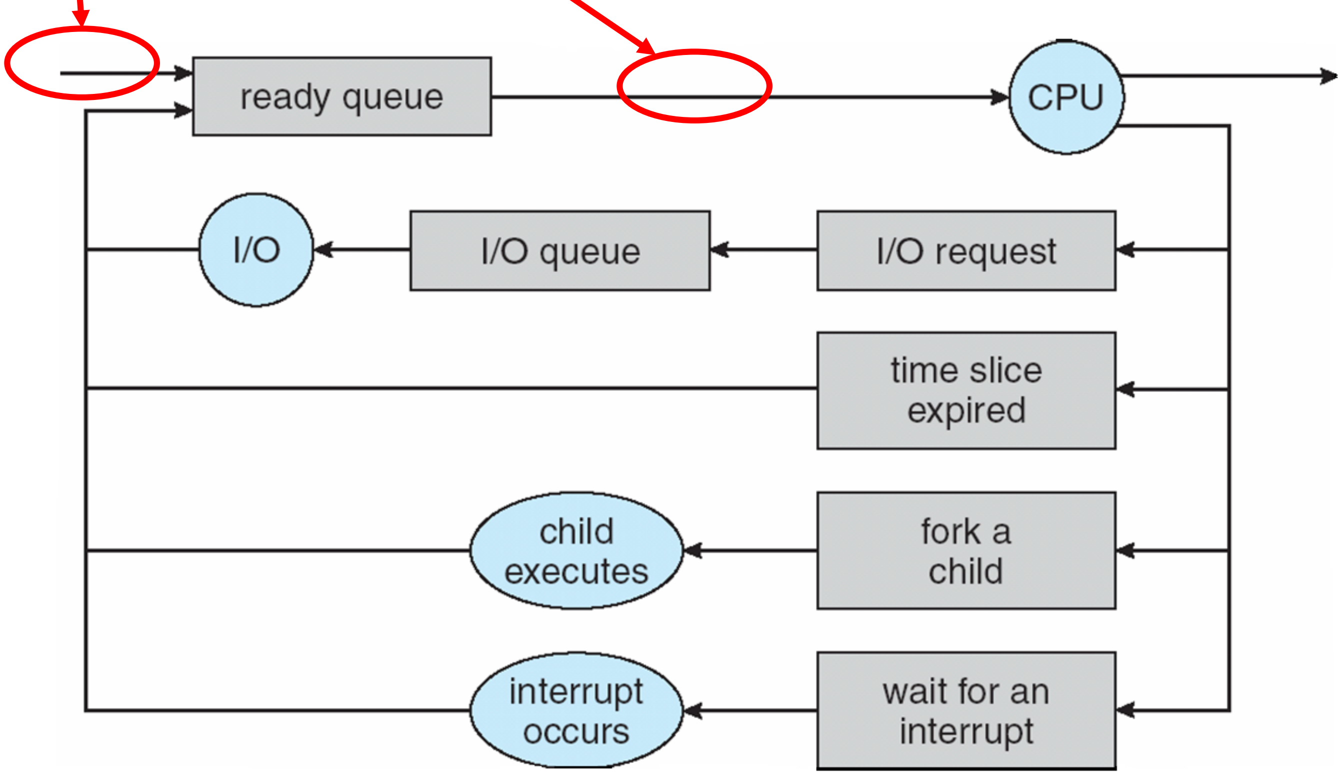


# Representation of Process Scheduling

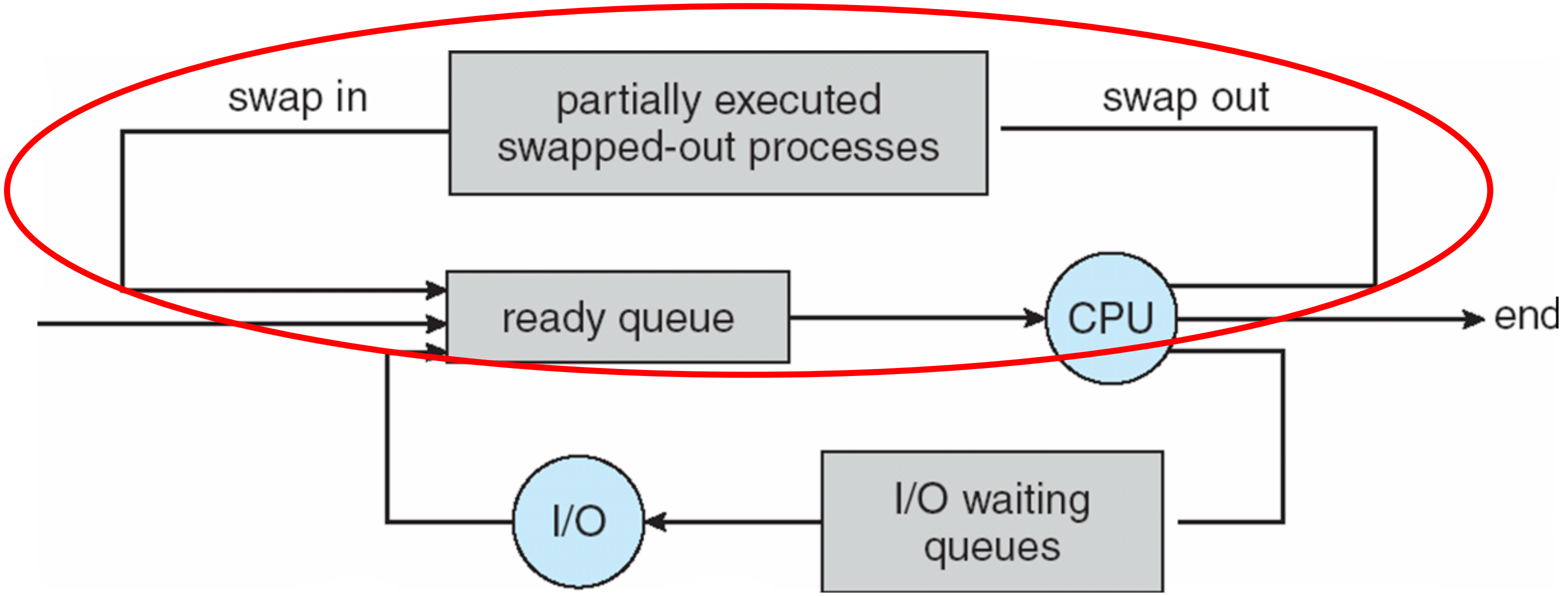


# Schedulers

- **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



# Addition of Medium Term Scheduling



# 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

# Context Switch

- 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 via a context switch
- Context of a process represented in the PCB
- Context-switch time is overhead; the system does no useful work while switching
- Time dependent on hardware support

# Process Creation

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

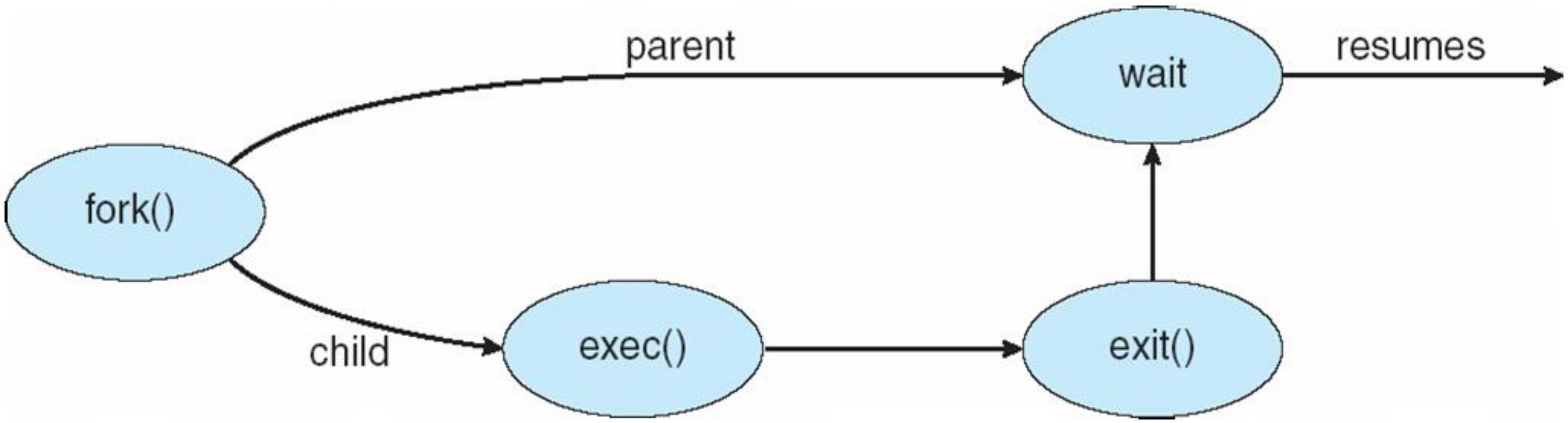
```
[hank@Maestro linux-3.5.0-2.fc17.x86_64]$ pstree
systemd─┬─NetworkManager─┬─dhclient
        │                └─3*[{NetworkManager}]
        ├─3*[VBoxClient───{VBoxClient}]
        ├─VBoxService───7*[{VBoxService}]
        ├─abrt-watch-log
        ├─abrtd
        ├─accounts-daemon───{accounts-daemon}
        ├─atd
        ├─auditd─┬─audispd─┬─sedispatch
        │        │         └─{audispd}
        │        └─{auditd}
        ├─avahi-daemon───avahi-daemon
        ├─bluetoothd
        ├─chronyd
        ├─colord───{colord}
        ├─colord-sane───{colord-sane}
        ├─crond
        ├─cupsd
        ├─2*[dbus-daemon───{dbus-daemon}]
        ├─dbus-launch
        ├─dconf-service───2*[{dconf-service}]
        ├─gconfd-2
        ├─gdm-binary─┬─gdm-simple-slav─┬─Xorg───8*[{Xorg}]
        │            │                 ├─gdm-session-wor─┬─gnome-session─┬─abrt-applet
        │            │                 │                 │               ├─deja-dup-monito───2*[{deja-dup-monito+
        │            │                 │                 │               ├─evolution-alarm───2*[{evolution-alarm+
        │            │                 │                 │               ├─gnome-screensav───2*[{gnome-screensav+
        │            │                 │                 │               ├─gnome-settings-───2*[{gnome-settings-+
        │            │                 │                 │               ├─gnome-shell─┬─eclipse───java───23*[{j+
        │            │                 │                 │               │             ├─gnome-system-mo───2*[{g+
        │            │                 │                 │               │             ├─gnome-terminal─┬─bash───+
++
        │            │                 │                 │               │             │                ├─bash───+
++
        │            │                 │                 │               │             │                ├─gnome-+
        │            │                 │                 │               │             │                └─3*[{gn+
        │            │                 │                 │               │             └─15*[{gnome-shell}]
        │            │                 │                 │               ├─nm-applet───{nm-applet}
        │            │                 │                 │               ├─seapplet
        │            │                 │                 │               ├─tracker-miner-f───2*[{tracker-miner-f+
        │            │                 │                 │               ├─zeitgeist-datah───{zeitgeist-datah}
        │            │                 │                 │               └─3*[{gnome-session}]
        │            │                 │                 └─2*[{gdm-session-wor}]
        │            │                 └─{gdm-simple-slav}
        │            └─{gdm-binary}
        ├─gnome-keyring-d───6*[{gnome-keyring-d}]
```

- Generally, process identified and managed via **a process identifier** (**pid**)
- 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

# 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

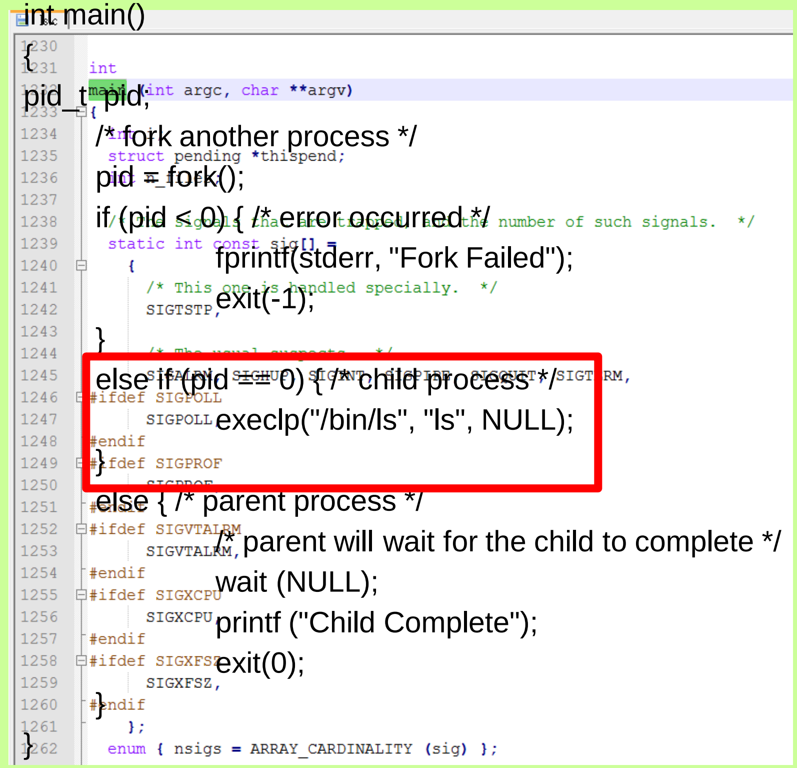


# C Program Forking Separate Process

```
int main()
{
pid_t  pid;
	/* fork another process */
	pid = fork();
	if (pid < 0) { /* error occurred */
		fprintf(stderr, "Fork Failed");
		exit(-1);
	}
	else if (pid == 0) { /* child process */
		execlp("/bin/ls", "ls", NULL);
	}
	else { /* parent process */
		/* parent will wait for the child to complete */
		wait (NULL);
		printf ("Child Complete");
		exit(0);
	}
}
```

```
int main()
{
pid_t  pid;
        /* fork another process */
        pid = fork();
        if (pid < 0) { /* error occurred */
                fprintf(stderr, "Fork Failed");
                exit(-1);
        }
        else if (pid == 0) { /* child process */
                execlp("/bin/ls", "ls", NULL);
        }
        else { /* parent process */
                /* parent will wait for the child to complete */
                wait (NULL);
                printf ("Child Complete");
                exit(0);
        }
}
```

parent process memory

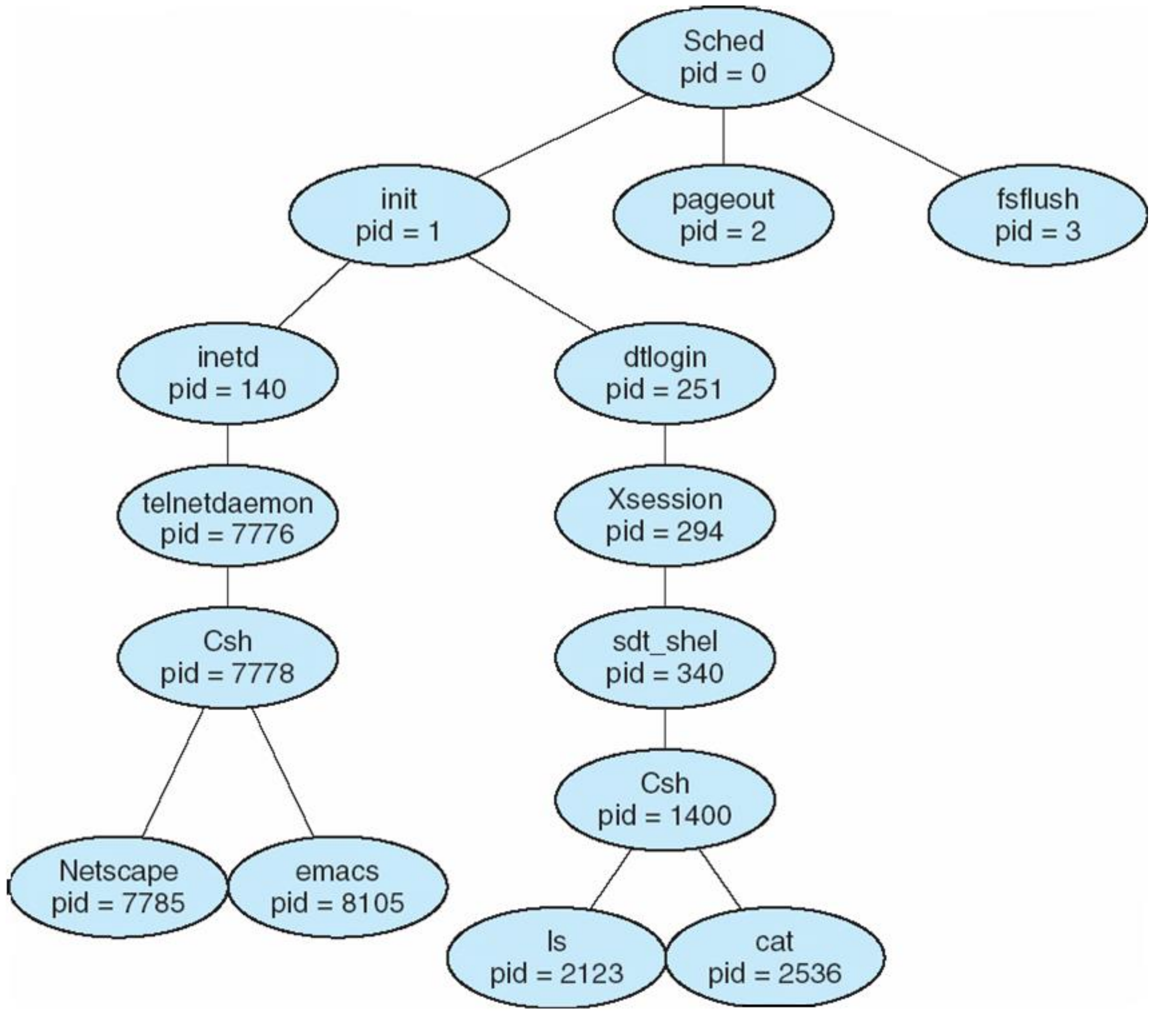




```
int main()
{
pid_t  pid;
        /* fork another process */
        pid = fork();
        if (pid < 0) { /* error occurred */
                fprintf(stderr, "Fork Failed");
                exit(-1);
        }
        else if (pid == 0) { /* child process */
                execlp("/bin/ls", "ls", NULL);
        }
        else { /* parent process */
                /* parent will wait for the child to complete */
                wait (NULL);
                printf ("Child Complete");
                exit(0);
        }
}
```


child process memory

# A tree of processes on a typical Solaris



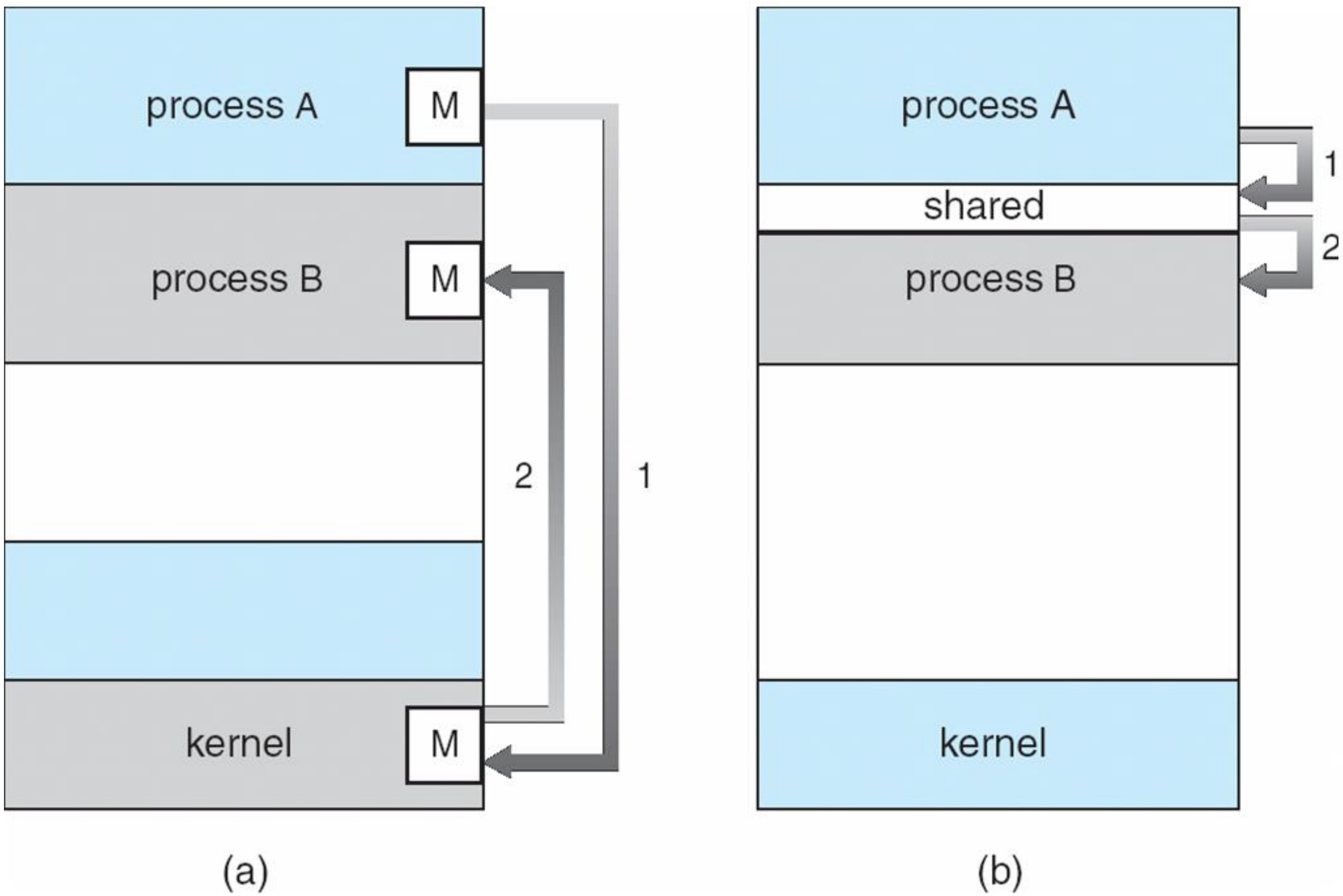
# Process Termination

- 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 operating system
- Parent may terminate execution of children processes (**abort**)
  - Child has exceeded allocated resources
  - Task assigned to child is no longer required
  - If parent is exiting
    - Some operating system do not allow child to continue if its parent terminates
      - All children terminated - **cascading termination**

# Interprocess Communication

- Processes within a system may be **independent** or **cooperating**
- Cooperating process can affect or be affected by other processes, including sharing data
- Reasons for cooperating processes:
  - Information sharing
  - Computation speedup
  - Modularity
  - Convenience
- Cooperating processes need **interprocess communication** (**IPC**)
- Two models of IPC
  - Shared memory
  - Message passing

# Communications Models



# 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

# 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 – Shared-Memory Solution

- Shared data

```
#define BUFFER_SIZE 10
typedef struct {
   . . .
} item;

item buffer[BUFFER_SIZE];
int in = 0;
int out = 0;
```

- Solution is correct, but can only use BUFFER_SIZE-1 elements

# Bounded-Buffer – Producer

```
while (true) {
   /* Produce an item */
   while (( (in + 1) % BUFFER_SIZE)  == out)   ;   /* do nothing -- no
free buffers */
    buffer[in] = item;
    in = (in + 1) % BUFFER_SIZE;
}
```

# Bounded Buffer – Consumer

```
while (true) {
     while (in == out)
          ; // do nothing -- nothing to consume

     // remove an item from the buffer
     item = buffer[out];
     out = (out + 1) % BUFFER_SIZE;
     return item;
}
```

# Interprocess Communication – Message Passing

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

# Examples of IPC Systems - POSIX

- POSIX Shared Memory
  - Process first creates shared memory segment

```
segment id = shmget(IPC_PRIVATE, size, S_IRUSR |
  S_IWUSR);
```

  - Process wanting access to that shared memory must attach to it

```
shared memory = (char *) shmat(id, NULL, 0);
```

  - Now the process could write to the shared memory

```
sprintf(shared memory, "Writing to shared memory");
```

  - When done a process can detach the shared memory from its address space

```
shmdt(shared memory);
```

# Examples of IPC Systems - Mach

- Mach communication is message based
  - Even system calls are messages
  - Each task gets two mailboxes at creation- Kernel and Notify
  - Only three system calls needed for message transfer

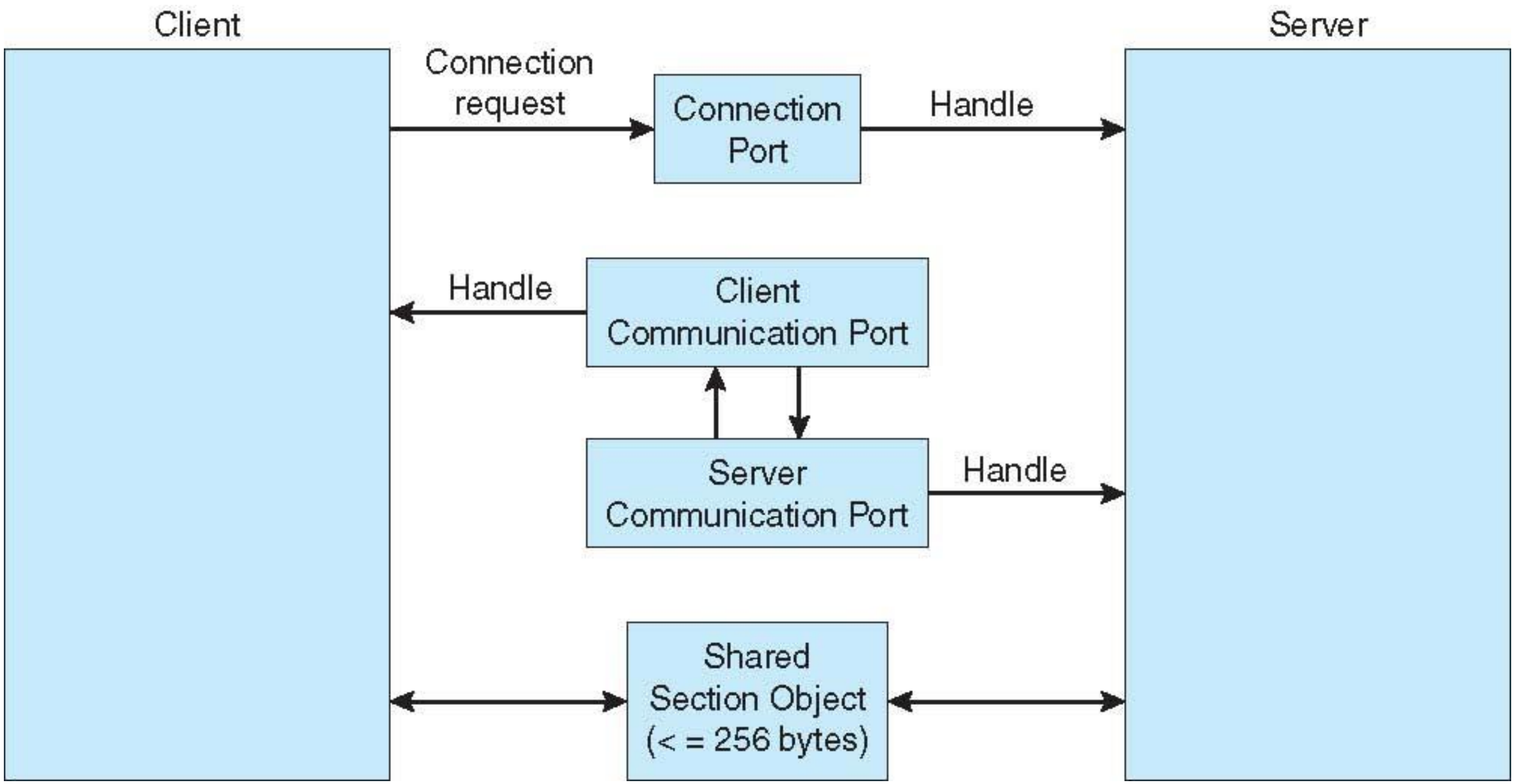
    `msg_send(), msg_receive(), msg_rpc()`
  - Mailboxes needed for commuication, created via

    `port_allocate()`

# Examples of IPC Systems – Windows XP

- Message-passing centric via local procedure call (LPC) facility
  - Only works between processes on the same system
  - Uses ports (like mailboxes) to establish and maintain communication channels
  - Communication works as follows:
    - The client opens a handle to the subsystem’s connection port object
    - The client sends a connection request
    - The server creates two private communication ports and returns the handle to one of them to the client
    - The client and server use the corresponding port handle to send messages or callbacks and to listen for replies

# Local Procedure Calls in Windows XP



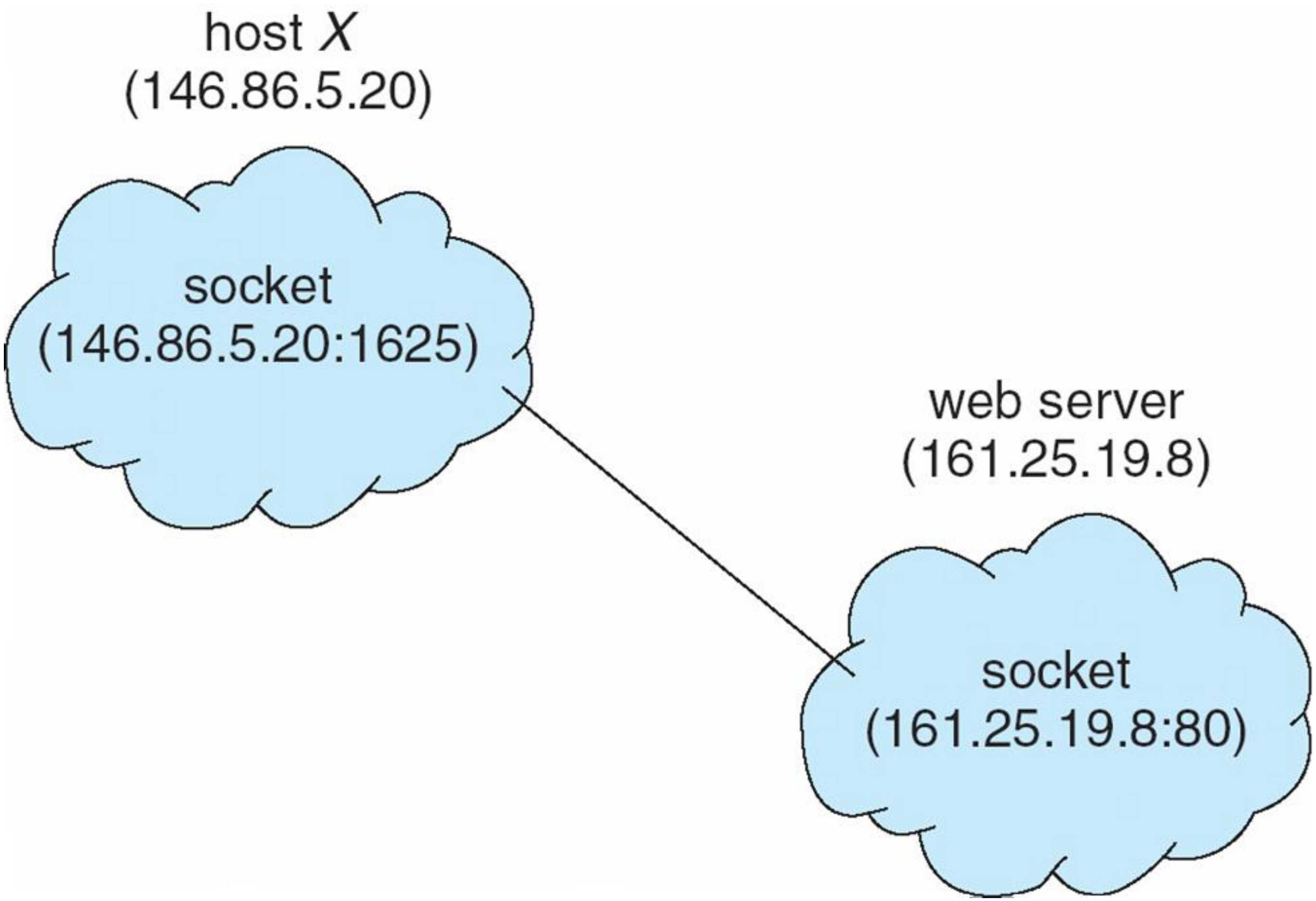
# Communications in Client-Server Systems

- 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

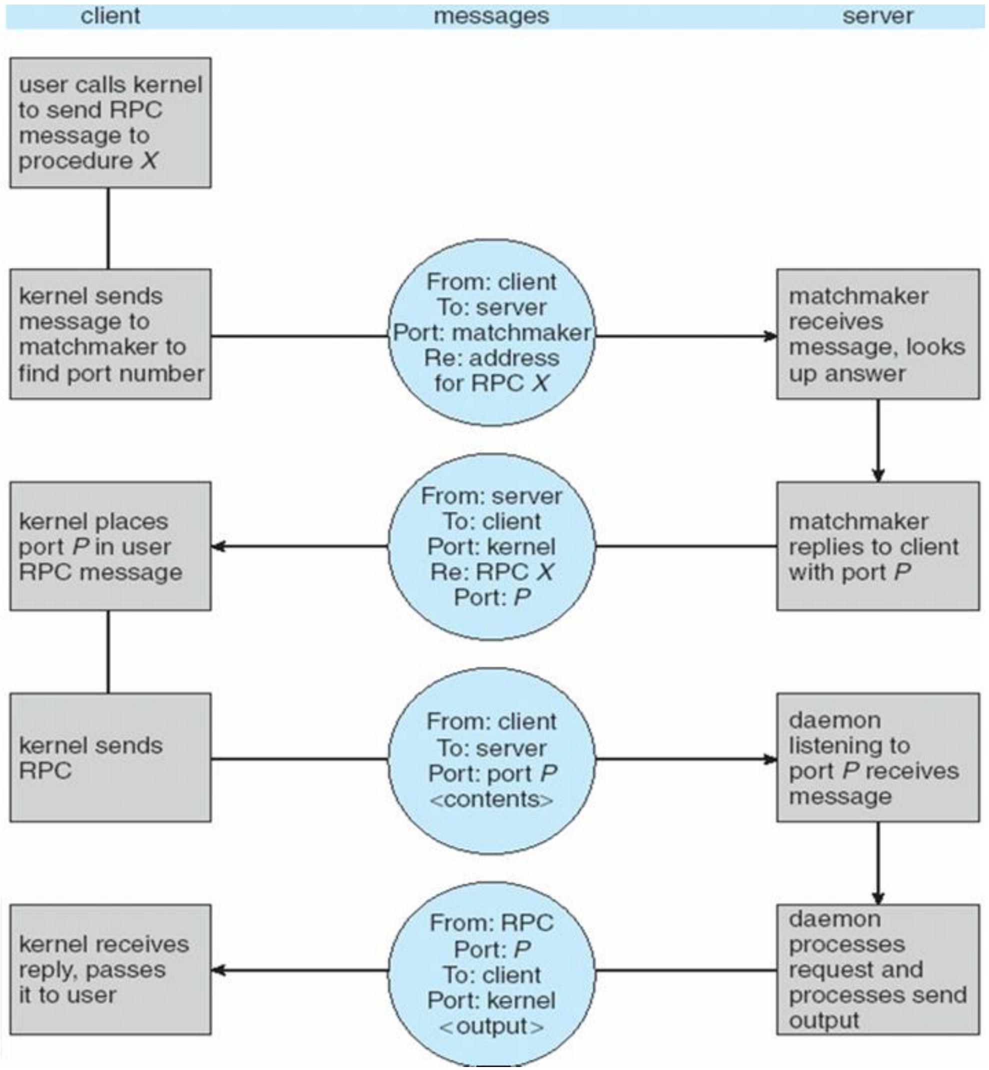
# Socket Communication



# Remote Procedure Calls

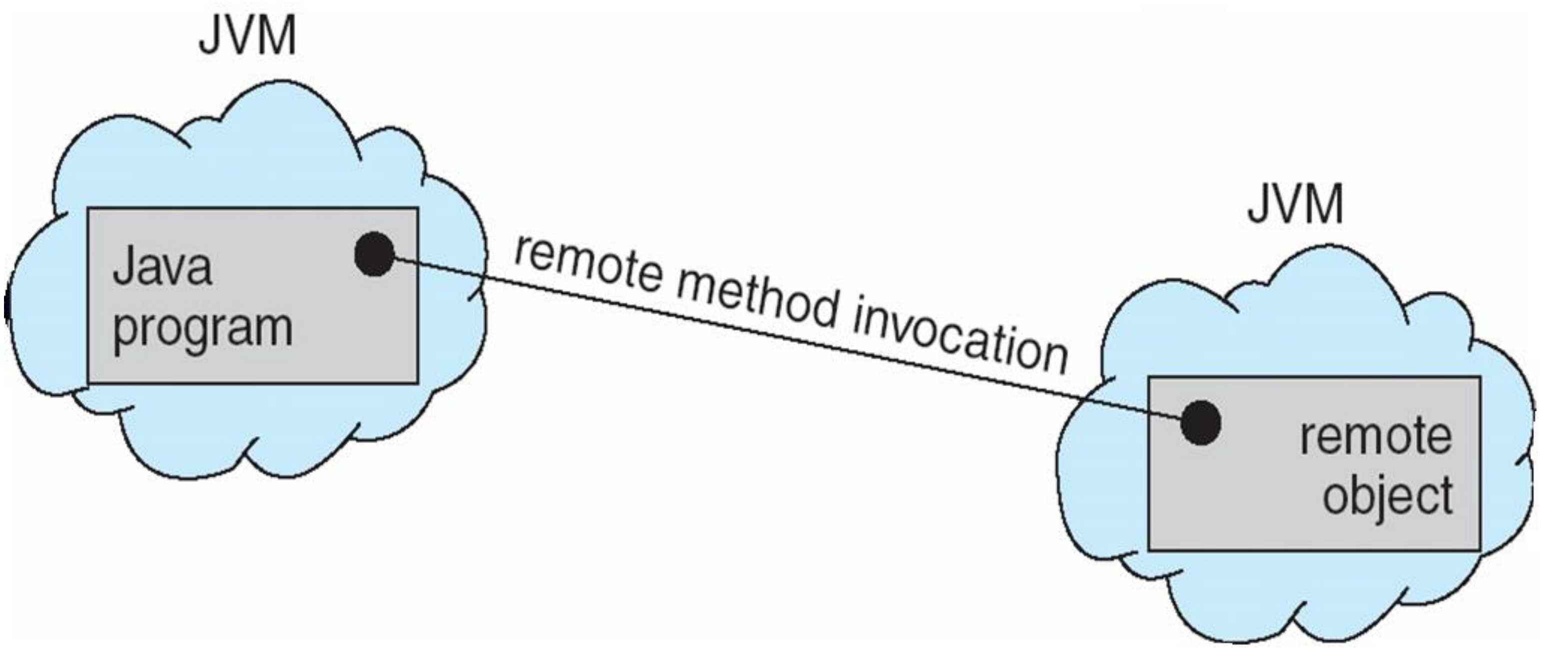
- Remote procedure call (RPC) abstracts procedure calls between processes on networked systems
- **Stubs** – client-side proxy for the actual procedure on the server
- The client-side stub locates the server and *marshalls* the parameters
- The server-side stub receives this message, unpacks the marshalled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

# Execution of RPC

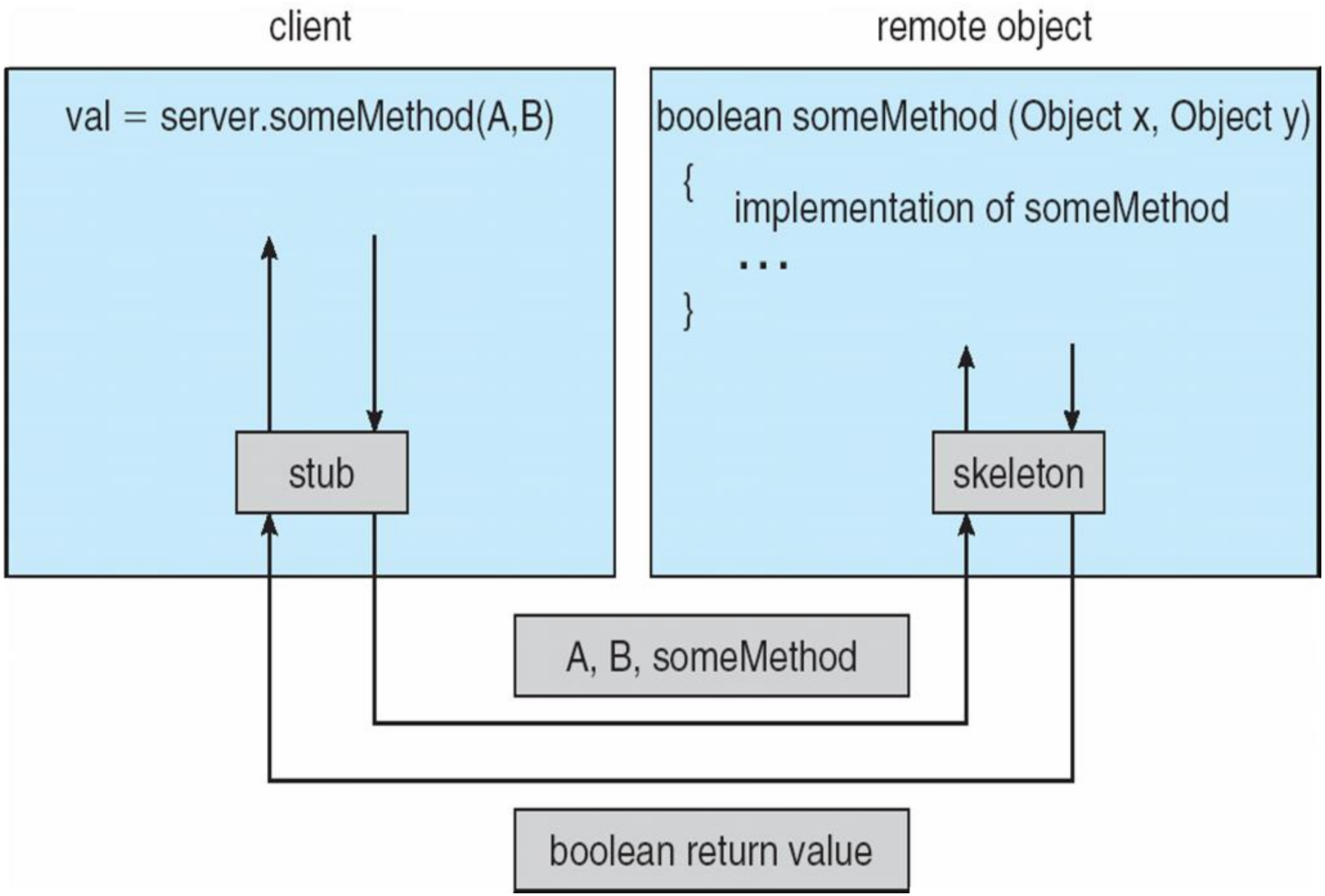


# Remote Method Invocation

- 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



# Reflection

- Emulate shared memory with message passing
- Emulate message passing with shared memory

- How to implement RPC ?
- Advantage / Disadvantage of RPC

# End of Chapter 3