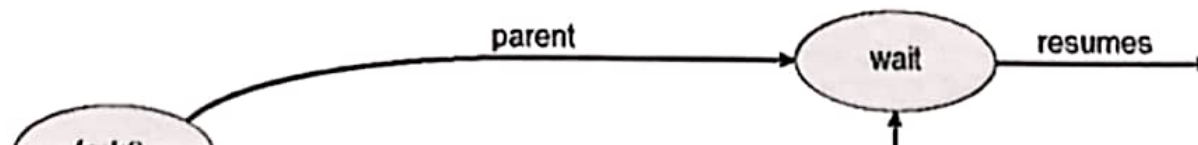# Process Creation (Cont.)

- 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

Interprocess Communication – Shared Memory

- An area of memory shared among the processes that wish to communicate

- The communication is under the control of the users processes not the operating system.

- Major issues is to provide mechanism that will allow the user processes to synchronize their actions when they access shared memory.

- Synchronization is discussed in great details in Chapter 5.

Indirect Communication

- Operations
  - create a new mailbox (port)
  - 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

Examples of IPC Systems - POSIX

POSIX Shared Memory
- Process first creates shared memory segment
  ```
  shm_fd = shm_open(name, O_CREAT | O_RDWR, 0666);
  ```
- Also used to open an existing segment to share it
- Set the size of the object
  ```
  ftruncate(shm_fd, 4096);
  ```
- Now the process could write to the shared memory
  ```
  sprintf(shared memory, "Writing to shared memory");
  ```

IPC POSIX Producer

```c
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <fcntl.h>
#include <sys/shm.h>
#include <sys/stat.h>

int main()
{
/* the size (in bytes) of shared memory object */
const int SIZE = 4096;
/* name of the shared memory object */
const char *name = "OS";
/* strings written to shared memory */
const char *message_0 = "Hello";
const char *message_1 = "World!";

/* shared memory file descriptor */
int shm_fd;
/* pointer to shared memory obect */
void *ptr;

    /* create the shared memory object */
    shm_fd = shm_open(name, O_CREAT | O_RDWR, 0666);

    /* configure the size of the shared memory object */
    ftruncate(shm_fd, SIZE);

    /* memory map the shared memory object */
    ptr = mmap(0, SIZE, PROT_WRITE, MAP_SHARED, shm_fd, 0);

    /* write to the shared memory object */
    sprintf(ptr,"%s",message_0);
    ptr += strlen(message_0);
    sprintf(ptr,"%s",message_1);
    ptr += strlen(message_1);

    return 0;
}
```

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** -- the sender is blocked until the message is received
    - **Blocking receive** -- the receiver is blocked until a message is available
- **Non-blocking** is considered **asynchronous**
    - **Non-blocking send** -- the sender sends the message and continue
    - **Non-blocking receive** -- the receiver receives:
        - A valid message, or
        - Null message

    - Different combinations possible
        - If both send and receive are blocking, we have a **rendezvous**

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

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

Message Passing (Cont.)

- Implementation of communication link
  - Physical:
    - Shared memory
    - Hardware bus
    - Network
  - Logical:
    - Direct or indirect
    - Synchronous or asynchronous
    - Automatic or explicit buffering

Message Passing (Cont.)

- If processes *P* and *Q* wish to communicate, they need to:
  - Establish a **communication link** between them
  - Exchange messages via send/receive

- Implementation issues:
  - 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?

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*)
  - **receive**(*message*)

- The *message* size is either fixed or variable

Bounded Buffer – Consumer

```
item next_consumed;

while (true) {
        while (in == out)
                ; /* do nothing */
        next_consumed = buffer[out];

        out = (out + 1) % BUFFER_SIZE;


        /* consume the item in next consumed */

}
```

Bounded-Buffer – Producer

```
item next_produced;
while (true) {
        /* produce an item in next produced */
        while (((in + 1) % BUFFER_SIZE) == out)
                ; /* do nothing */
        buffer[in] = next_produced;
        in = (in + 1) % 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
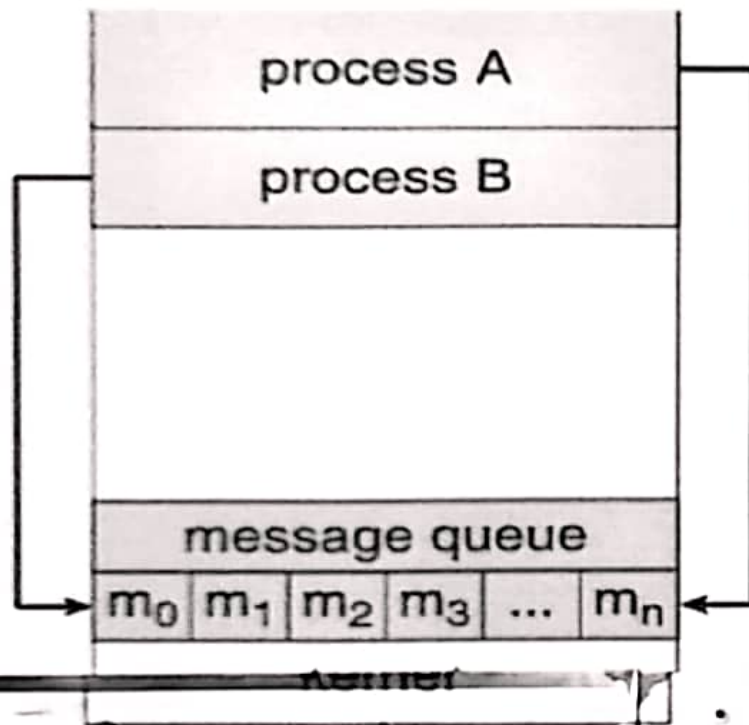
Producer-Consumer Problem

- 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

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
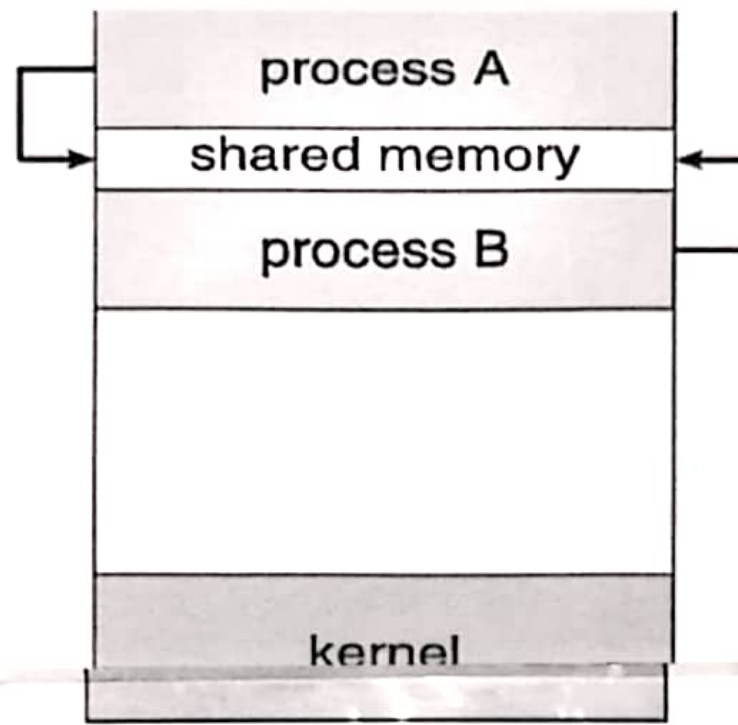 - Computation speed-up
  - Modularity
  - Convenience

Communications Models

(b) shared memory.

process A
process B

message queue

m_0	m_1	m_2	m_3	...	m_n

kernel

(a)

process A
shared memory
process B

kernel

(b)

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

Addition of Medium Term Scheduling

❑ **Medium-term scheduler** can be added if degree of multiple programming needs to decrease

    ❑ Remove process from memory, store on disk, bring back in from disk to continue execution: **swapping**
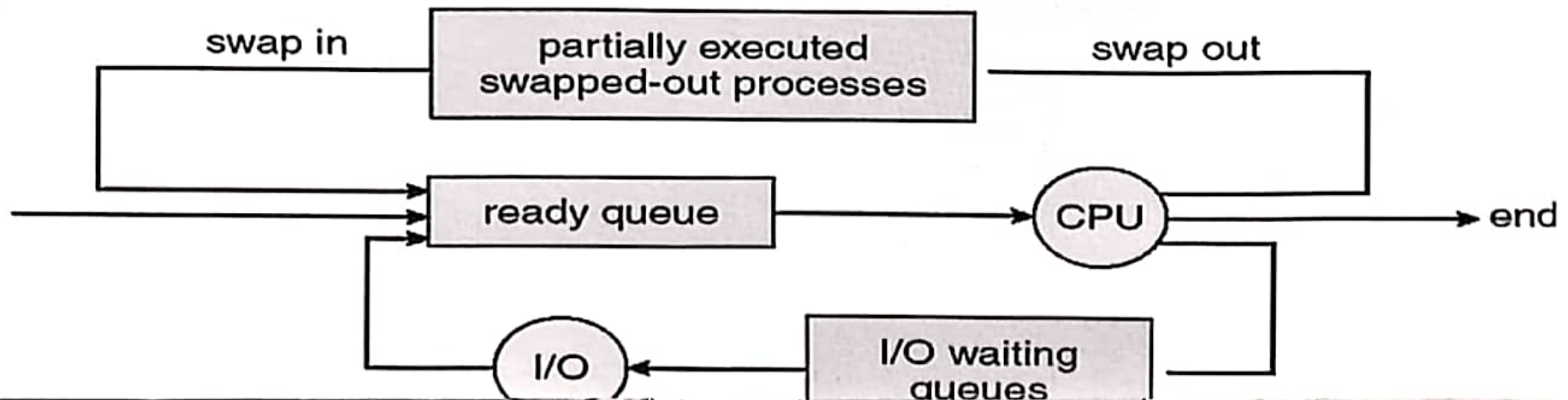
Schedulers

- **Short-term scheduler** (or **CPU scheduler**) – selects which process should be executed next and allocates CPU
  - Sometimes the only scheduler in a system
  - Short-term scheduler is invoked frequently (milliseconds) $\Rightarrow$ (must be fast)
- **Long-term scheduler** (or **job scheduler**) – selects which processes should be brought into the ready queue
  - Long-term scheduler is invoked infrequently (seconds, minutes) $\Rightarrow$ (may be slow)
  - The long-term scheduler controls the **degree of multiprogramming**
- Processes can be described as either:
  - **I/O-bound process** – spends more time doing I/O than computations, many short CPU bursts
  - **CPU-bound process** – spends more time doing computations; few very long CPU bursts
- Long-term scheduler strives for good *process mix*

Process Scheduling

- Maximize CPU use, quickly switch processes onto CPU for time sharing

- **Process scheduler** selects among available processes for next execution on CPU

- Maintains **scheduling queues** of processes
    - **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

C Program Forking Separate Process

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

int main()
{
pid_t pid;

    /* fork a child process */
    pid = fork();

    if (pid < 0) { /* error occurred */
       fprintf(stderr, "Fork Failed");
       return 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");
    }

    return 0;
}
```