KOÇ UNIVERSITY

# Process Creation and Inter-process Communication

Didem Unat

Lecture 4

COMP304 - Operating Systems (OS)

# Outline

- Last Lecture: Process Management
  - Process State
  - Context Switch
  - Process Creation and Termination
- Today: Inter-Process Communication (IPC)
  - Cooperating Processes
  - Direct Communication
  - Indirect Communication
  - IPC on Unix, Mac and Windows
  - Pipes

# Quiz Question

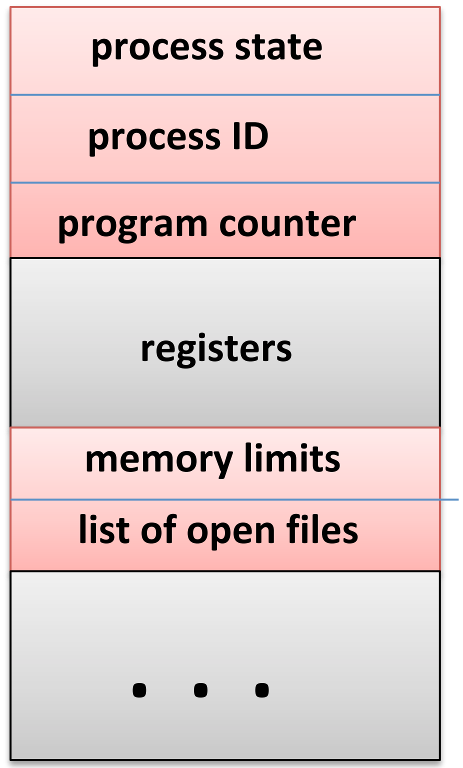
- Each process has its own process control block
  - True or False?
- From waiting state, a process can only enter into __________.
  - A) running state
  - B) ready state
  - C) new state
  - D) terminated state

# Process Control Block

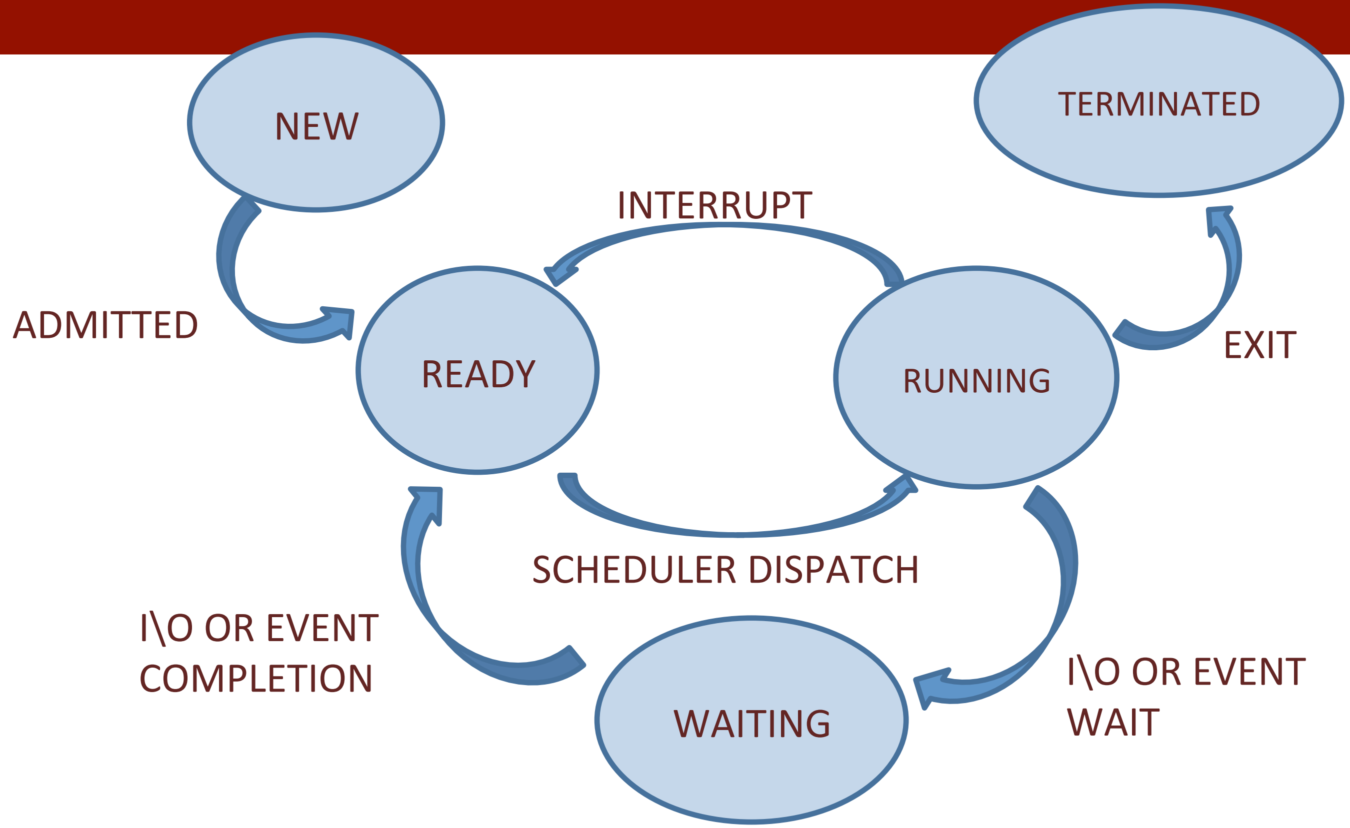
## Keeps the process context

- **Process state** – running, waiting, etc
- **Program counter** – location of instruction to next execute
- **CPU registers** – contents of all process registers
- **CPU scheduling information**- priorities, scheduling queue pointers
- **Memory-management information** – memory allocated to the process
- **Accounting information** – CPU used, clock time elapsed since start, time limits
- **I/O status information** – I/O devices allocated to process, list of open files

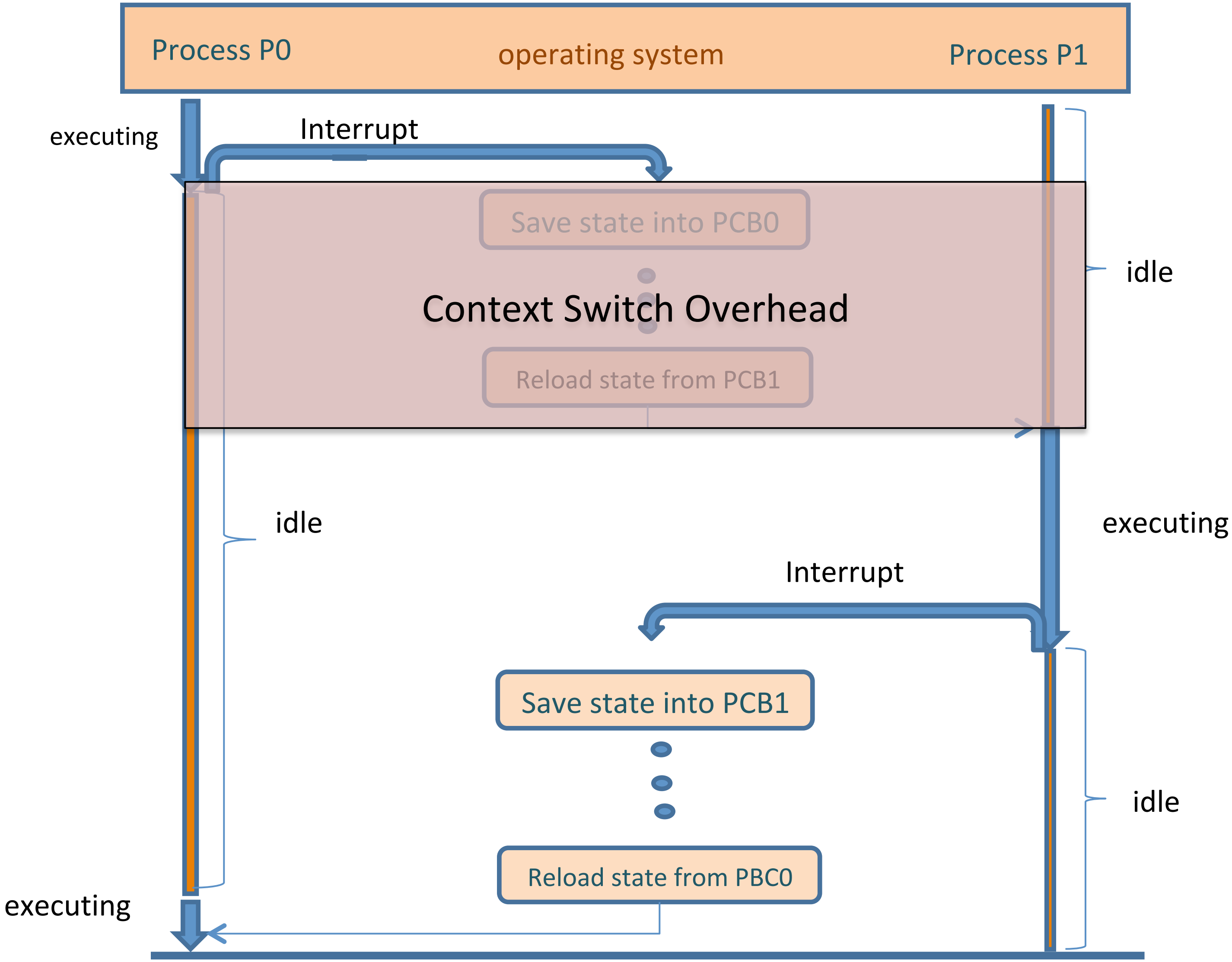
Metadata about a process



# Transition between Process States




- Process transitions from one state to another
- An animation for process states
  - http://williamstallings.com/OS/Animation/Queensland/PROCESS.SWF

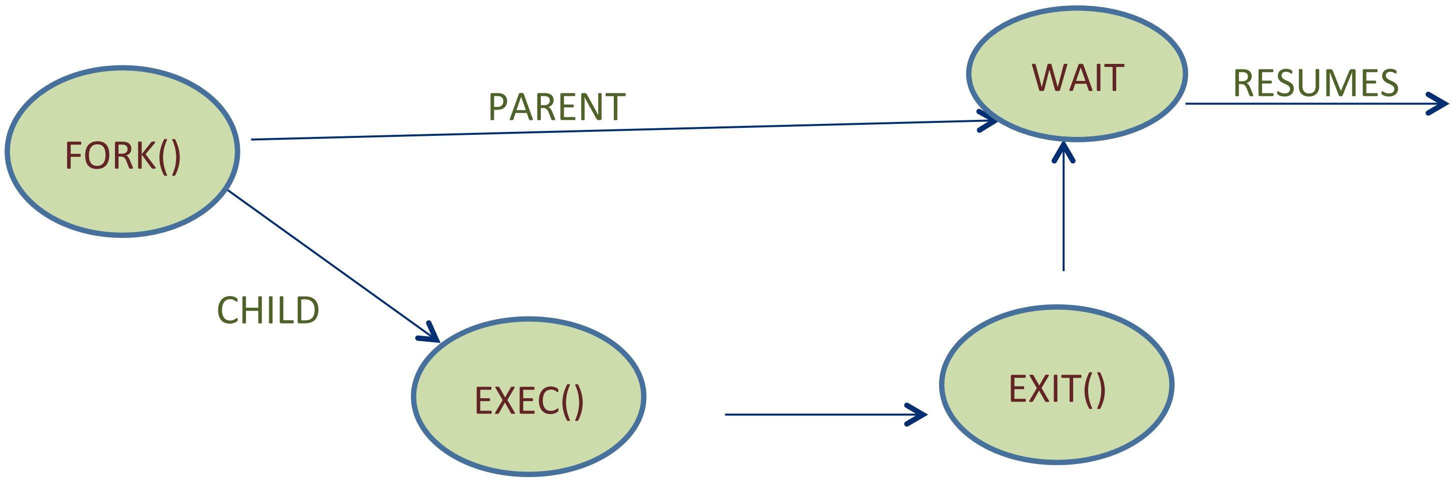



- Switching between threads of a single process can be faster than between two separate processes

# Process Creation

- Address space
  - Child duplicate of parent
  - Child has a program loaded into it

- UNIX examples
  - **fork()** system call creates a new process
  - **exec()** system call is used after a **fork()** to replace the process' memory space with a new program



# Process Termination

- Process executes last statement and asks the operating system to delete it (**exit()**)
  - Output data from child to parent (via **wait()**)
  - Terminated process' resources are deallocated by operating system

- Parent may terminate execution of children processes
  - Via **kill()** system call

- A terminated process is a **zombie,** until its parent calls wait()
  - Still has an entry in the process table

- What happens if the parent dies before the child?

# Process Termination

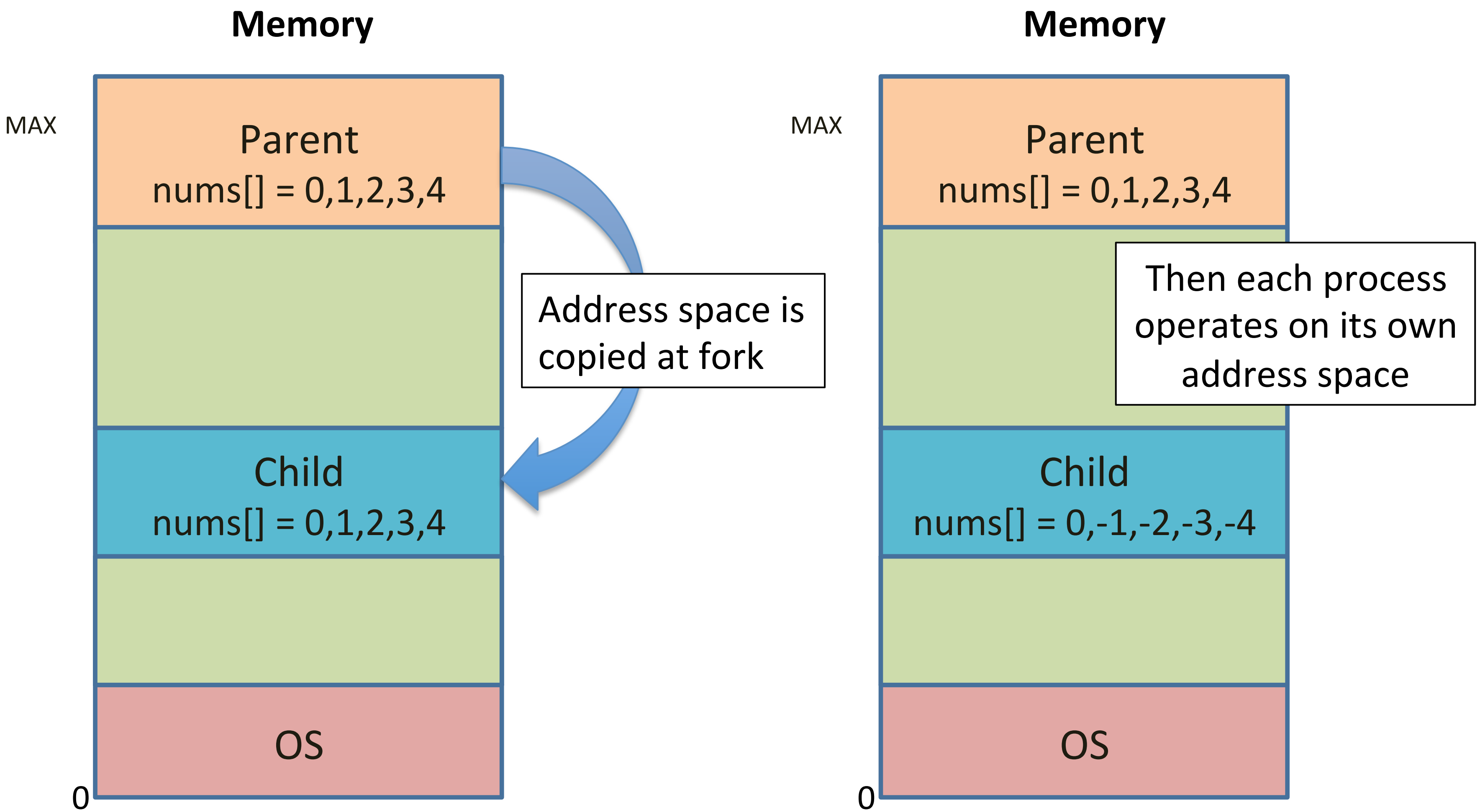
- Some operating systems do not allow child to continue without its parent
  - All children terminated - **cascading termination**

- If parent terminates, still executing children processes are called **orphans**
  - Those are adopted by init process
- **Init** periodically calls wait to terminate orphans and zombies

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

What output will be at Line X and Line Y?

# Address Spaces



# Question

```c
#include <stdio.h>

int main()
{
        printf("%d\n",getpid());

        fork();
        printf("%d\n",getpid());


        fork();
        printf("%d\n",getpid());

        fork();
        printf("%d\n",getpid());

        return 0;
}
```

How many processes are there?

How many prints are called?

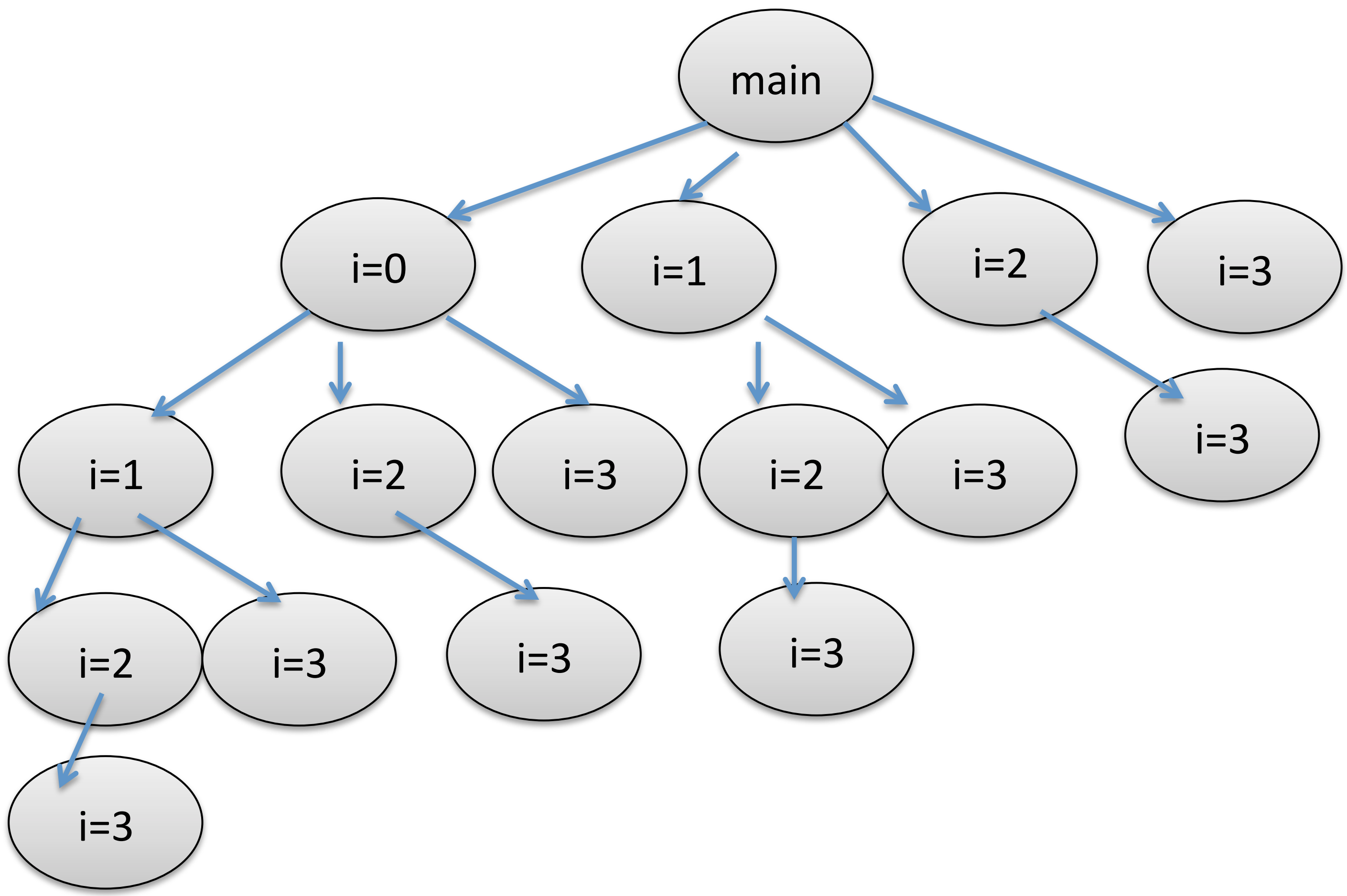
# Quiz

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

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

    printf("PID %d\n", getpid());
    return 0;
}
```

Including the initial parent process, How many processes are created?

Draw a process tree starting from the initial parent process as the root!

# Process Tree for Quiz Question

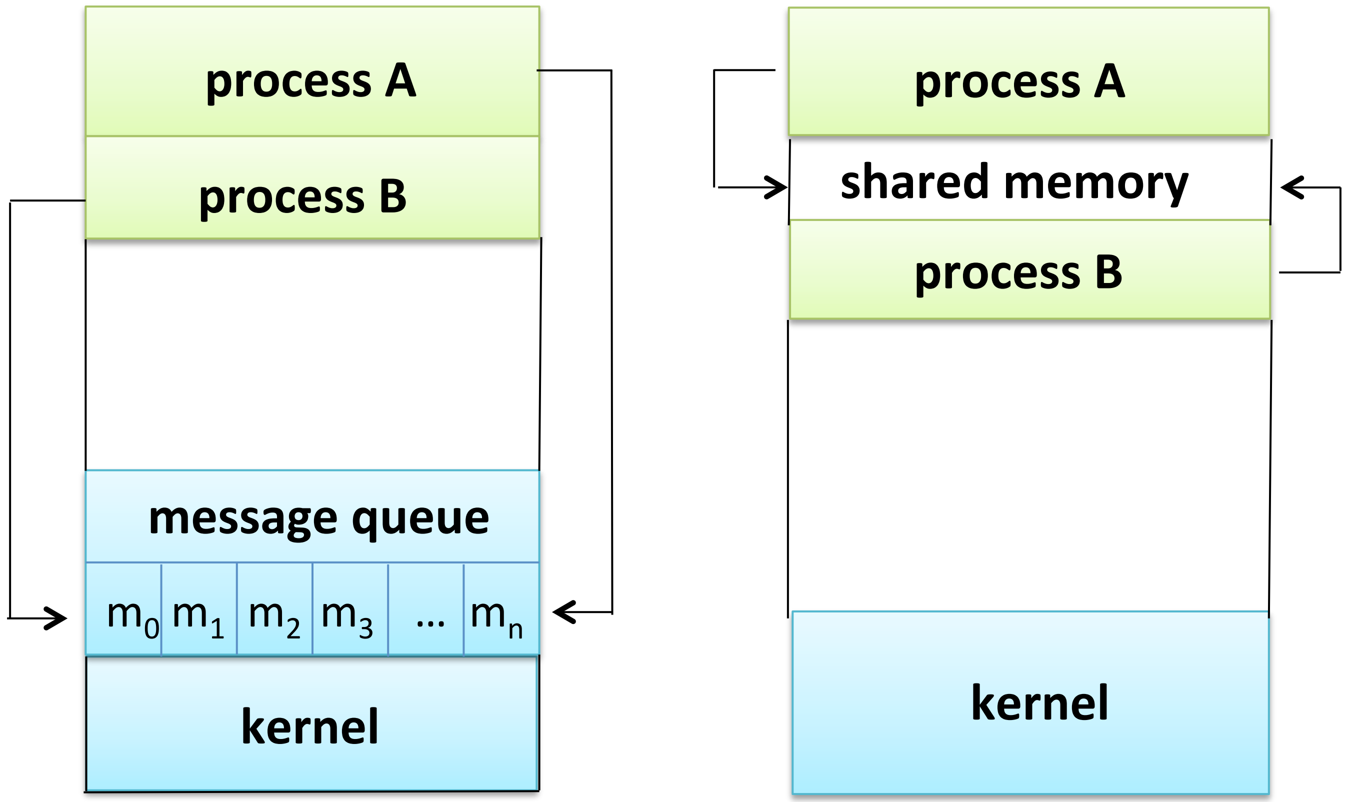


# Inter-process Communication (IPC)

- *An independent* process cannot affect or be affected by the execution of another process.
- *Cooperating* processes can affect or be affected by the execution of another processes
- Cooperating processes need **inter-process communication**
- Two models of IPC
  - **Shared memory**
  - **Message passing**

# Two Models of Communication

Message Passing vs Shared Memory




- Message passing requires the message of A to be copied to a buffer and copied to process B's memory – thus it is slower but safer

# Why support IPC?

There are several reasons for supporting IPC

- Sharing information
  - for example, web servers use IPC to share web documents and media with users through a web browser
- Distributing work across systems
  - for example, Wikipedia uses multiple servers that communicate with one another using IPC to process user requests
- Separating privilege
  - for example, network systems are separated into layers based on privileges to minimize the risk of attacks. These layers communicate with one another using encrypted IPC
- Processes within the same computer or across computers use similar techniques for communications

# Message Passing

- 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
  - Direct or indirect,
  - Synchronous or asynchronous,
  - Automatic or explicit buffering

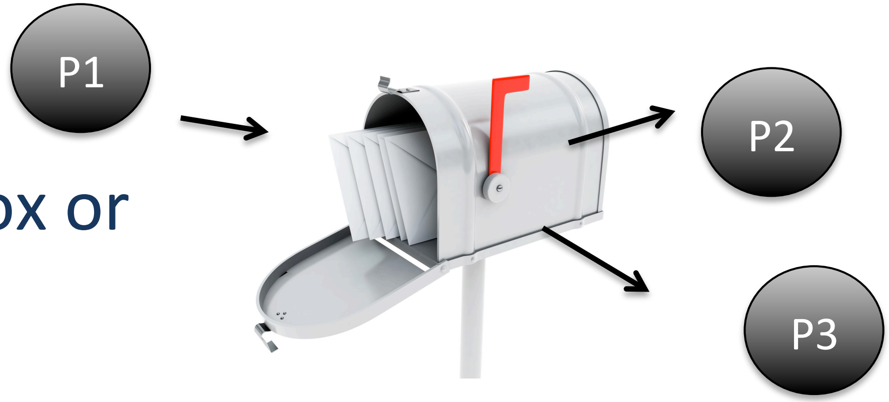
# Direct Communication

- 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




- A process may own a mailbox or
- OS provides operations to
  - 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

# Blocking or Nonblocking ?

- 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

Blocking or non-blocking?

Blocking or non-blocking?

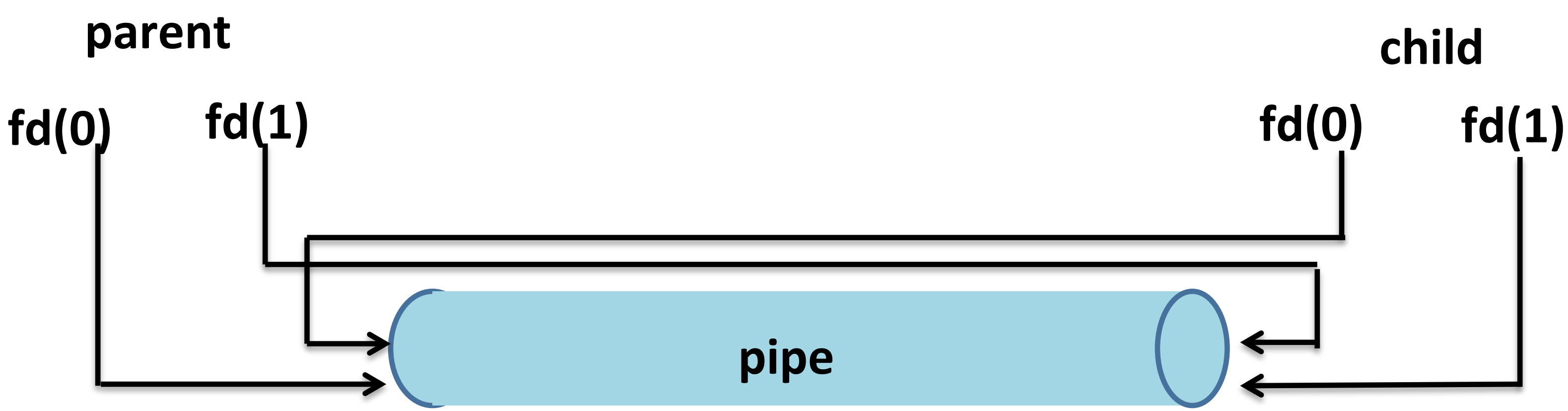
# Pipes

- Acts as a conduit allowing two processes to communicate
  - Ordinary Pipes
  - Named Pipes

- **Issues**
  - Is communication unidirectional or bidirectional?
  - Must there exist a relationship (i.e. ***parent-child***) between the communicating processes?
  - Can the pipes be used over a network?

# Ordinary Pipes

- Ordinary Pipes allow communication in standard producer-consumer style
- Producer writes to one end (the **write-end** of the pipe)
- Consumer reads from the other end (the **read-end** of the pipe)
- Ordinary pipes are therefore **unidirectional**
- Require parent-child relationship between communicating processes



# An Example of Ordinary Pipes

- Powerful command for I/O redirection
- Connects multiple commands together
- With pipes, the standard output of one command is fed into the standard input of another.

```
bash$> ls -l | less

bash$> history | less
```

# Examples of IPC Systems - POSIX

- POSIX Shared Memory
  - Process first creates shared memory segment
    ```
    shm_fd = shm_open(name, O_CREAT | O_RDRW, 0666);
    ```
  - Also used to open an existing segment to share it
  - Set the size of the object
    ```
    ftruncate(shm_fd, SIZE);
    ```
  - Memory-mapped the file

    ptr = mmap (start, length, PROT_WRITE, MAP_SHARED, shm_fd, offset);
  - Now the process could write to the shared memory
    ```
    sprintf(ptr, "Writing to shared memory");
    ```

http://linux.about.com/library/cmd/blcmdl2_mmap.htm

# IPC POSIX Producer

```c
#include <stdio.h>
#include <stlib.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_RDRW, 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;
}
```

Create a shared memory segment

Memory-mapped file

Writing into the shared memory object

# IPC POSIX Consumer

```
#include <stdio.h>
#include <stlib.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";
/* shared memory file descriptor */
int shm_fd;
/* pointer to shared memory obect */
void *ptr;

   /* open the shared memory object */
   shm_fd = shm_open(name, O_RDONLY, 0666);

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

   /* read from the shared memory object */
   printf("%s",(char *)ptr);

   /* remove the shared memory object */
   shm_unlink(name);

   return 0;
}
```

Create a shared memory segment for readonly

Memory-mapped file for reading

Read from the shared memory object

# 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 communication, created via

    **port_allocate()**
  - Send and receive are flexible, for example four options if mailbox full:
    - Wait indefinitely
    - Wait at most n milliseconds
    - Return immediately
    - Temporarily cache a message

# Examples of IPC Systems – Windows

- Message-passing centric via **advanced 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.

# Reading

- Read Chapter 3.4-3.7
  - Excluding client-server communication

- Acknowledgments
  - These slides are adapted from
    - Öznur Özkasap (Koç University)
    - Operating System and Concepts (9th edition) Wiley