

Sistemi Operativi I

Corso di Laurea in Informatica
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OS Process Management So Far...

- How the OS abstracts processes from physical memory
 - Virtual Address Space (VAS)
- In which state a process can be while it is managed by the OS
- What data structure the OS uses to keep track of each process info
 - Process Control Block (PCB)

Outline

- Process creation
- Process termination
- Process scheduling
- Process communication

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Process Creation

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 - The creator process is called **parent** of the new process, which is called **child**
 - The parent shares resources and privileges to its children
 - A parent can either wait for a child to complete, or continue in parallel

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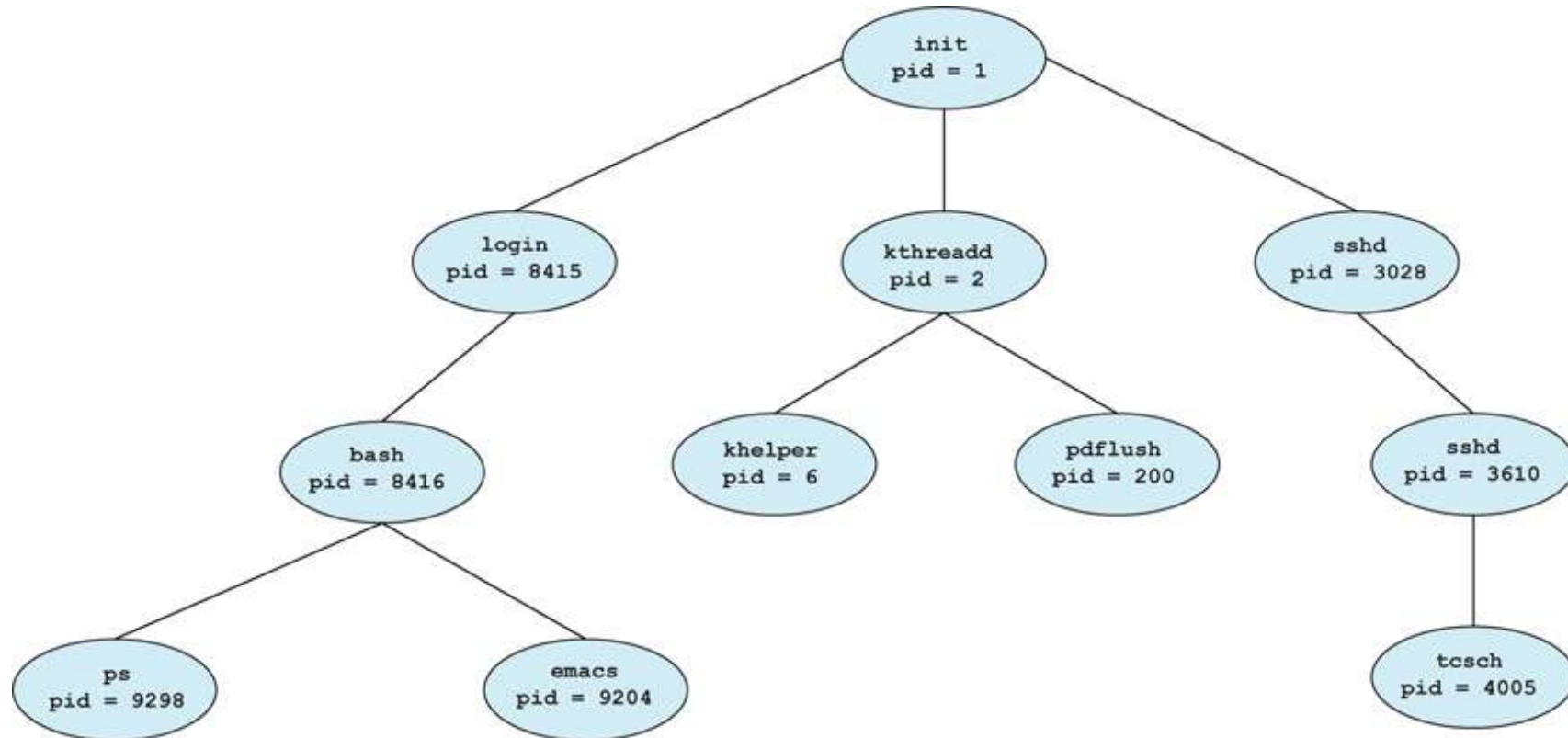
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 - The parent shares resources and privileges to its children
 - A parent can either wait for a child to complete, or continue in parallel
- Each process is given an integer **identifier** (a.k.a. process identifier or PID)
- The parent PID (PPID) is also stored for each process

Process Creation: UNIX/Linux

- On typical UNIX systems the process scheduler is named **sched**, and is given PID 0
- The first thing it does at system startup time is to launch **init**, which gives that process PID 1
- **init** then launches all system daemons and user logins, and becomes the ultimate parent of all other processes
- Processes are created through the **fork()** system call

Process Creation: UNIX/Linux



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 - Each will have their own PCB, including program counter, registers, and PID
 - This is the behavior of the **fork** system call in UNIX
 - The child process may have a **new program** loaded into its address space, with all new code and data segments
 - This is the behavior of the **spawn** system calls in Windows
 - UNIX systems implement this as a second step, using the **exec** system call

Process Creation: Parent vs. Child Execution

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- **2 options** for the parent process after creating the child:
 - Wait for the child process to terminate before proceeding by issuing a **wait** system call, for either a specific child or for any child
(usual behavior of UNIX shell)
 - Run concurrently with the child, continuing to process without being blocked
(when a UNIX shell runs a process as a background task using "&")

Process Creation: UNIX/Linux Code

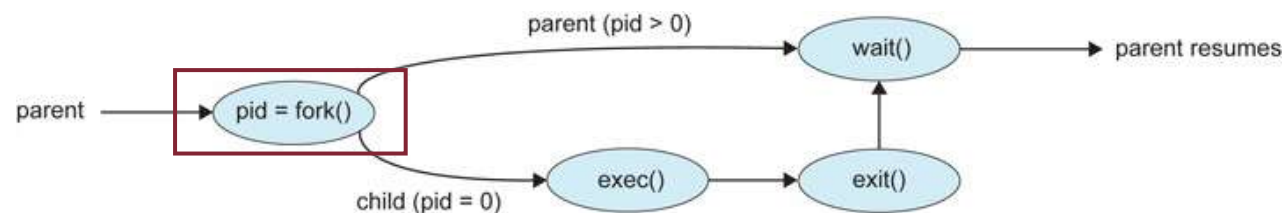
```
#include <sys/types.h>
#include <stdio.h>
#include <unistd.h>

int main()
{
    pid_t pid;

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

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

Figure 3.10 C program forking a separate process.



Process Creation: UNIX/Linux Code

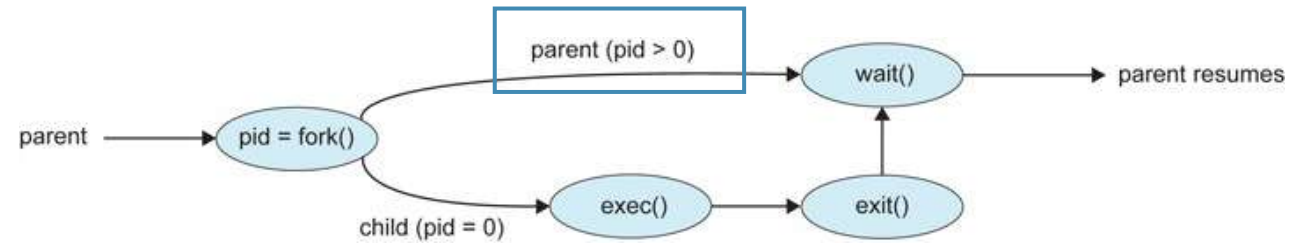
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        printf("Child Complete");
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    }
}
```

Figure 3.10 C program forking a separate process.



In the parent process, **fork()** returns the PID of the child

Process Creation: UNIX/Linux Code

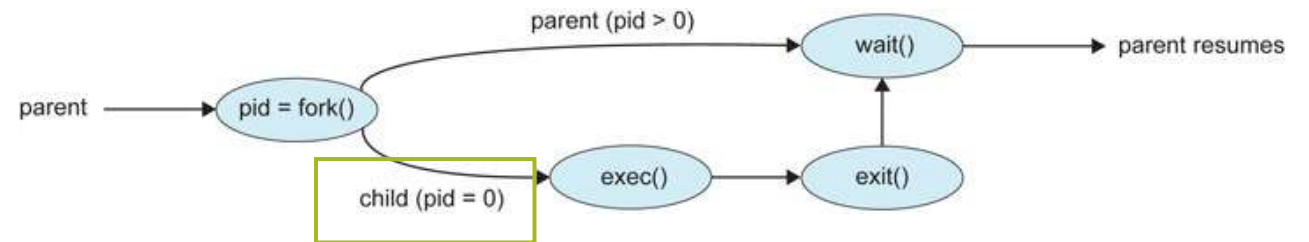
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#include <stdio.h>
#include <unistd.h>

int main()
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    pid_t pid;

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

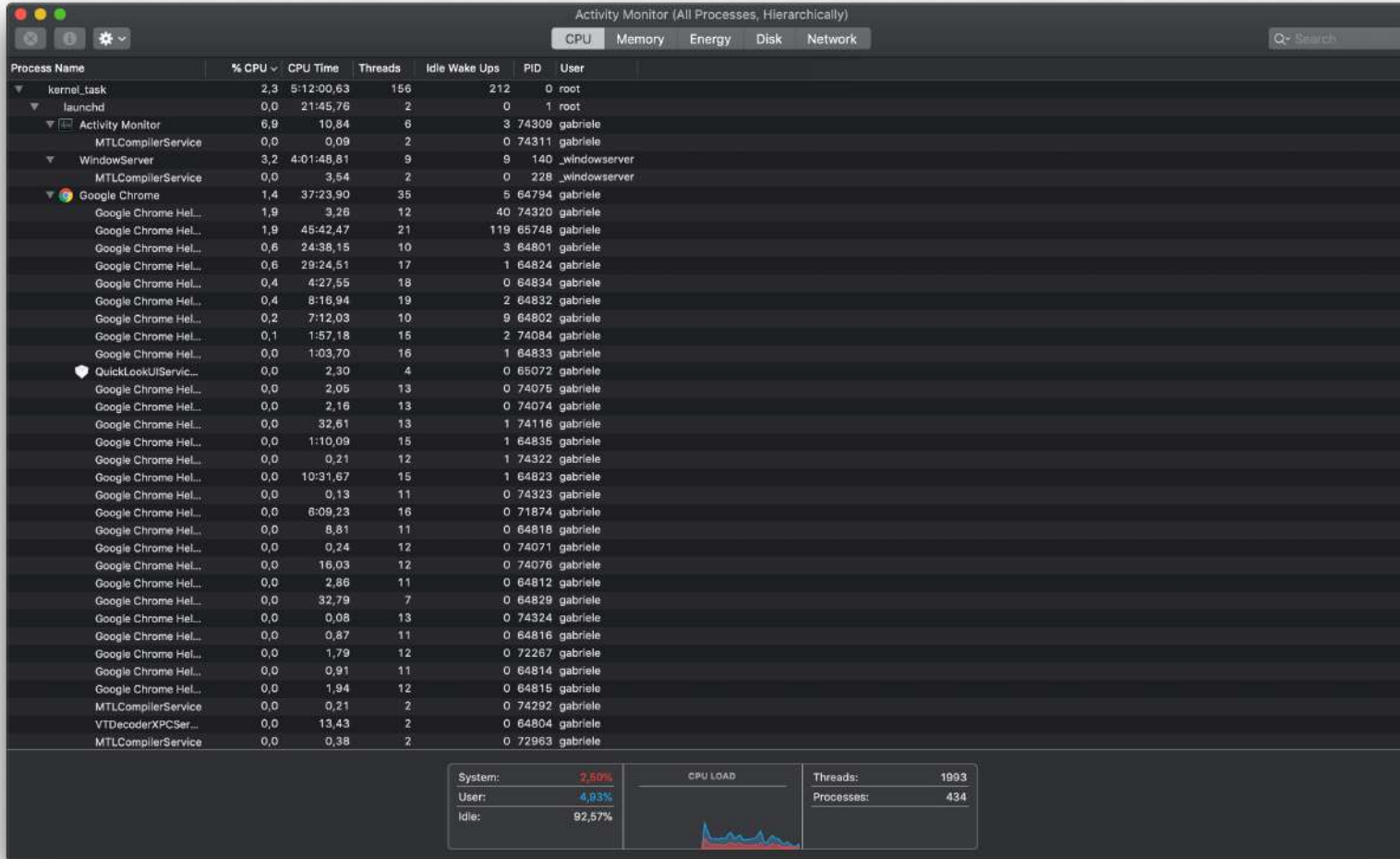
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        fprintf(stderr, "Fork Failed");
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    }
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Figure 3.10 C program forking a separate process.



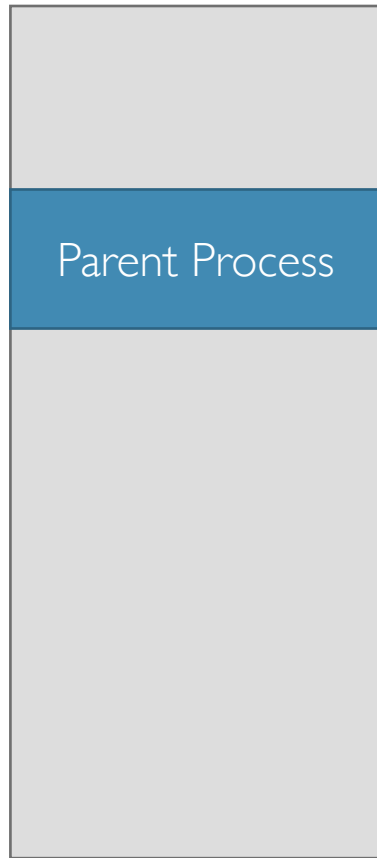
In the child process, it returns 0

Process Creation: Activity Monitor



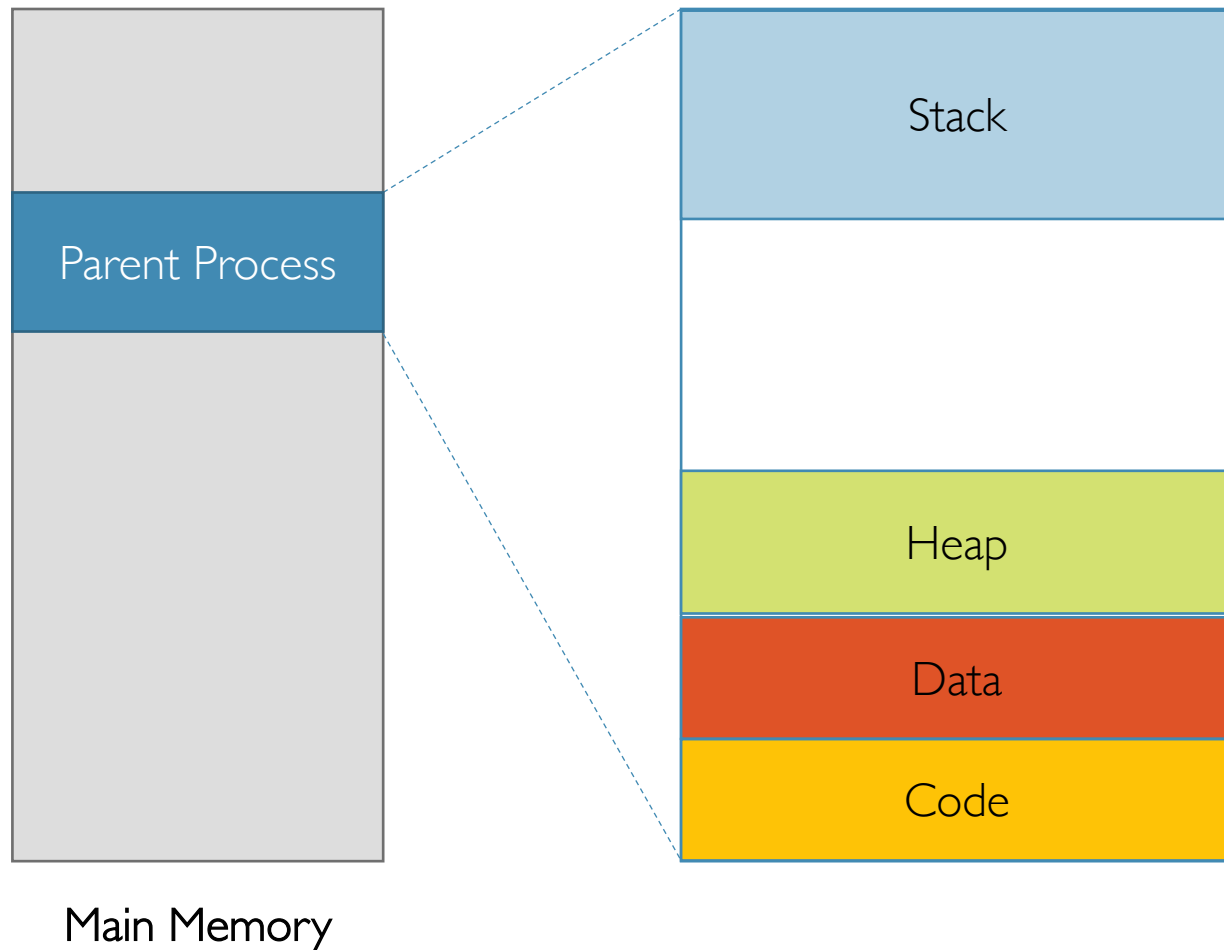
Hierarchy of Processes
(i.e., **process tree**)

Process Creation: Parent vs. Child Layout

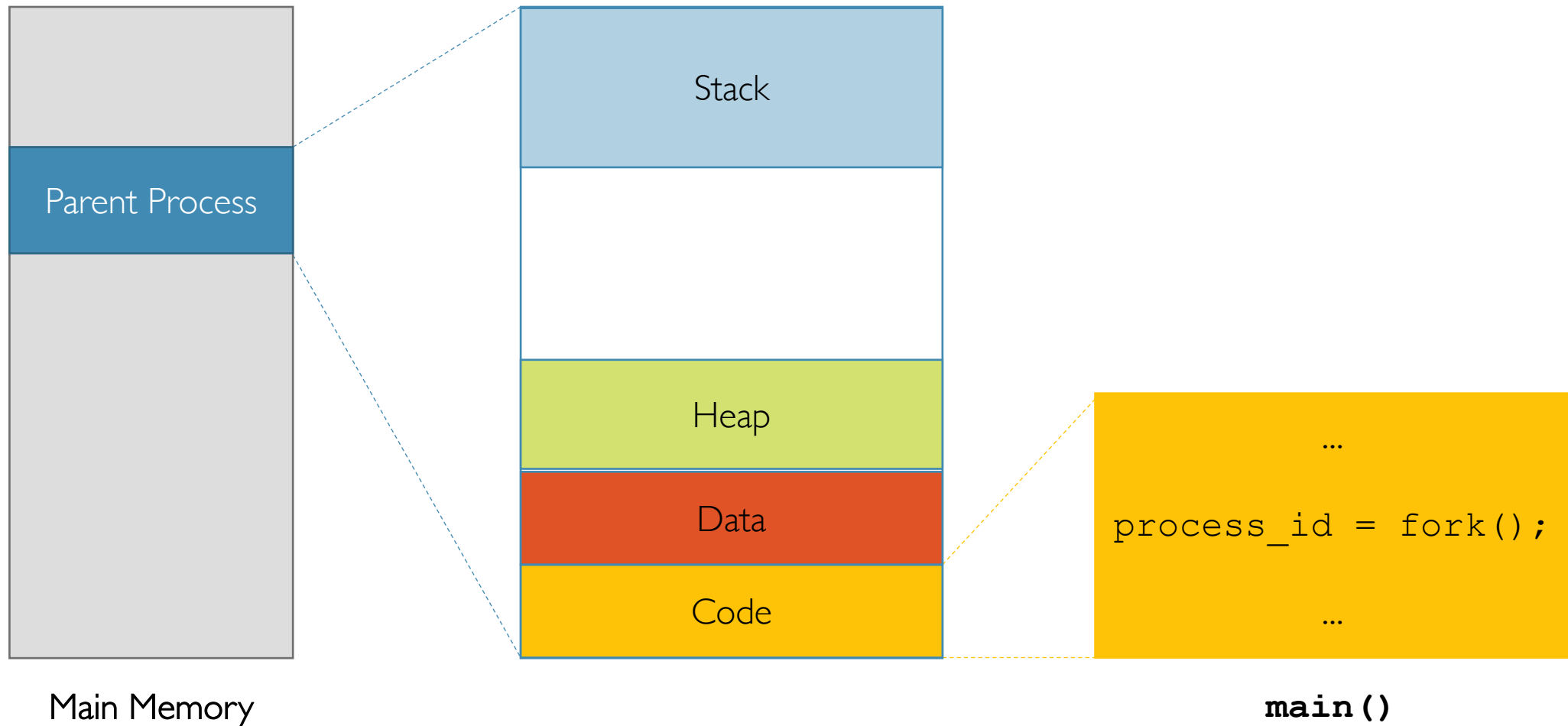


Main Memory

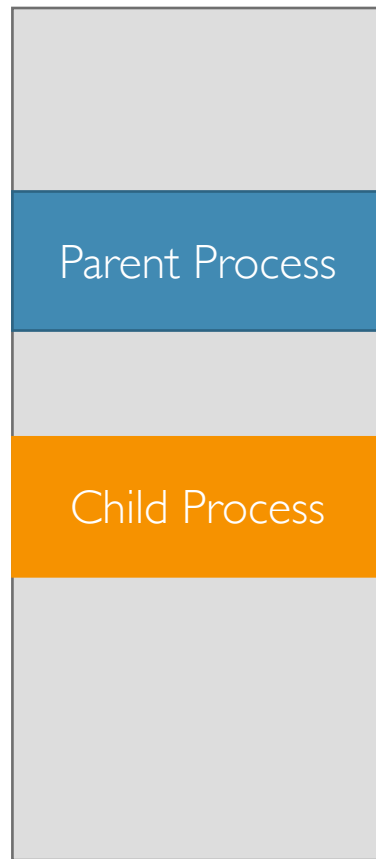
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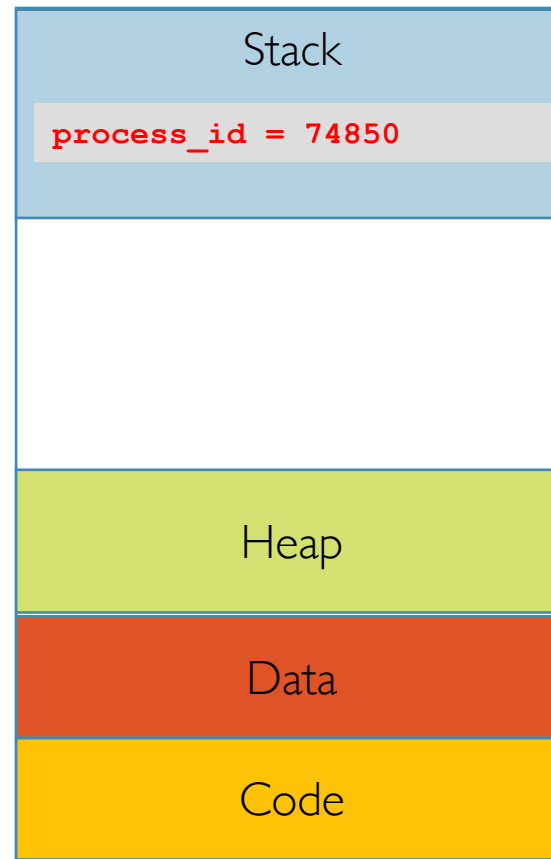
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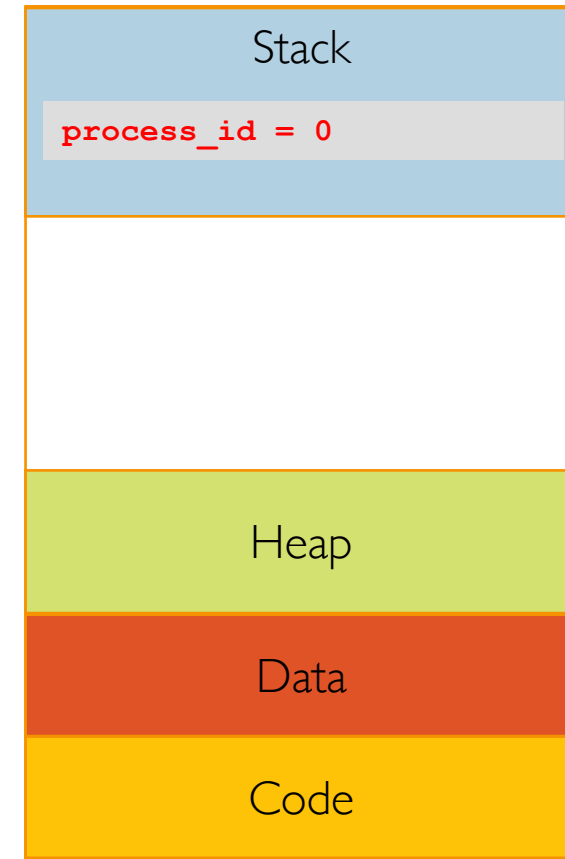
Process Creation: Parent vs. Child Layout



Main Memory



Parent

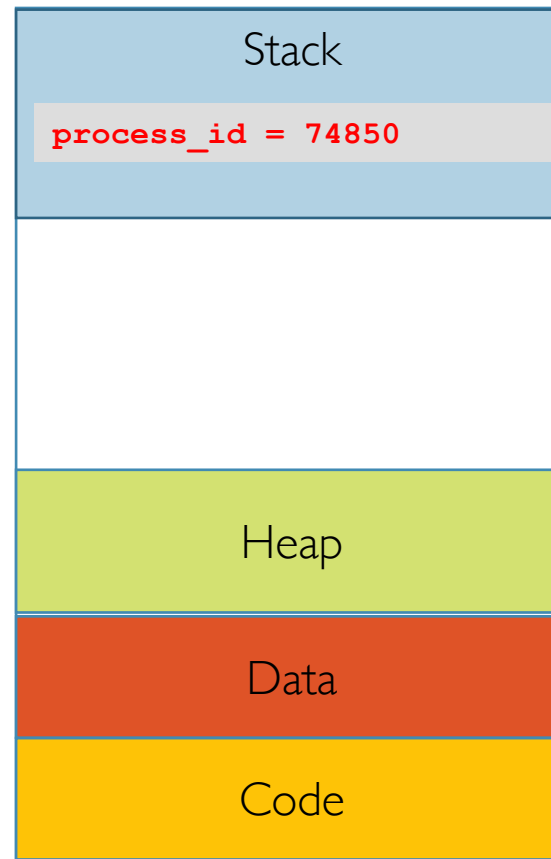


Child

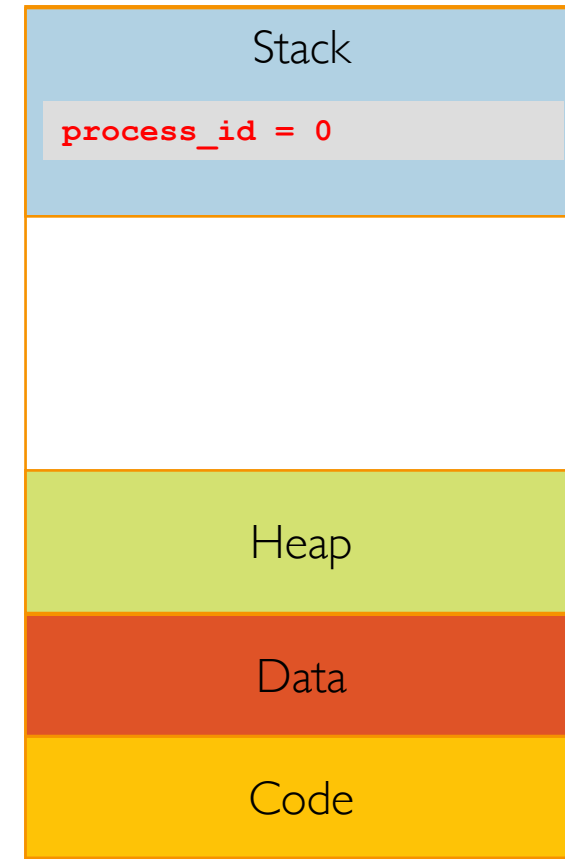
Process Creation: Parent vs. Child Layout



Main Memory



Parent

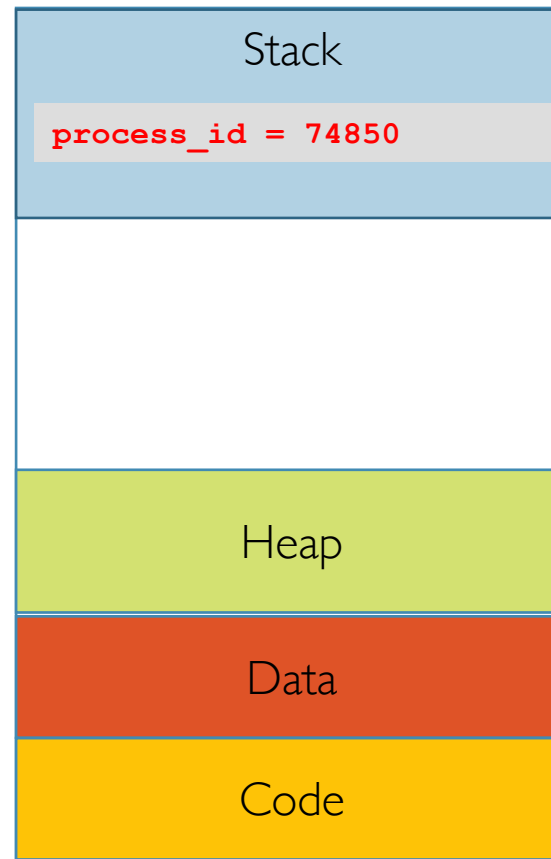


Child
PID = 74850

Process Creation: Parent vs. Child Layout

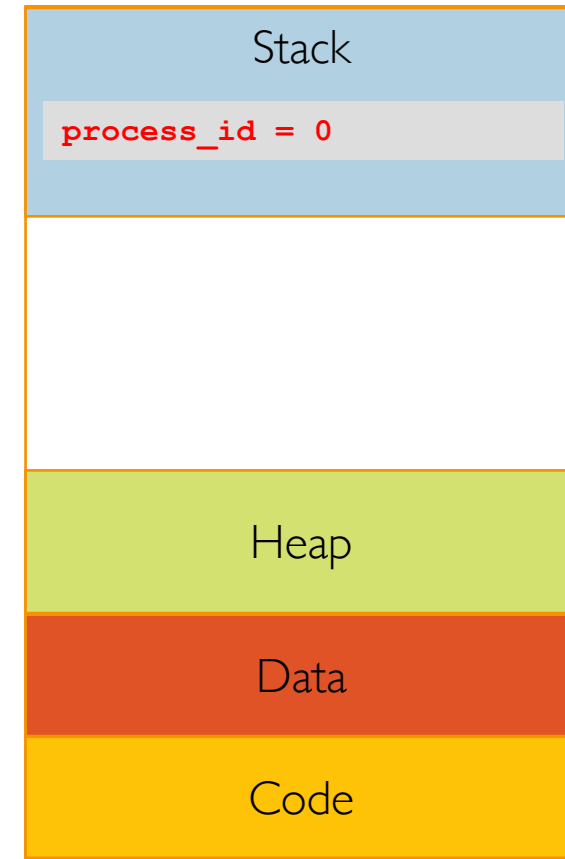


Main Memory



Parent

PID = 74849



Child

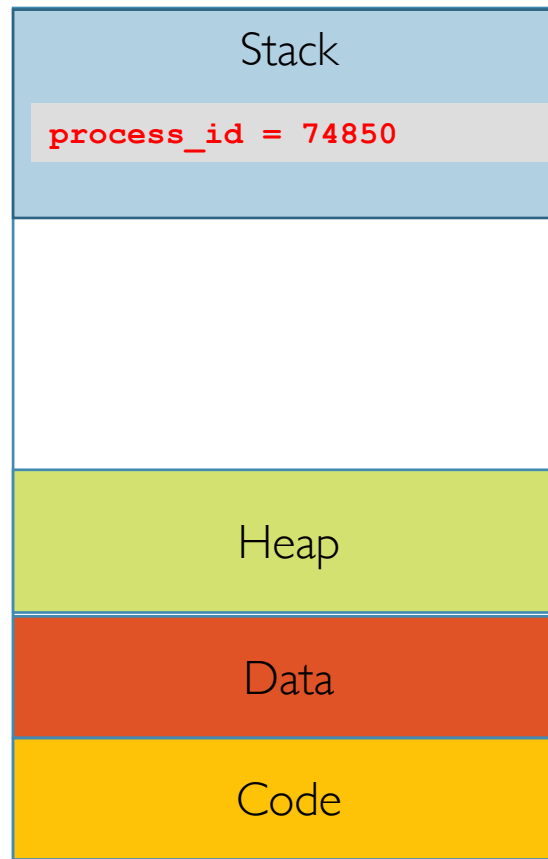
PID = 74850

parentID = 74849

Process Creation: Parent vs. Child Layout



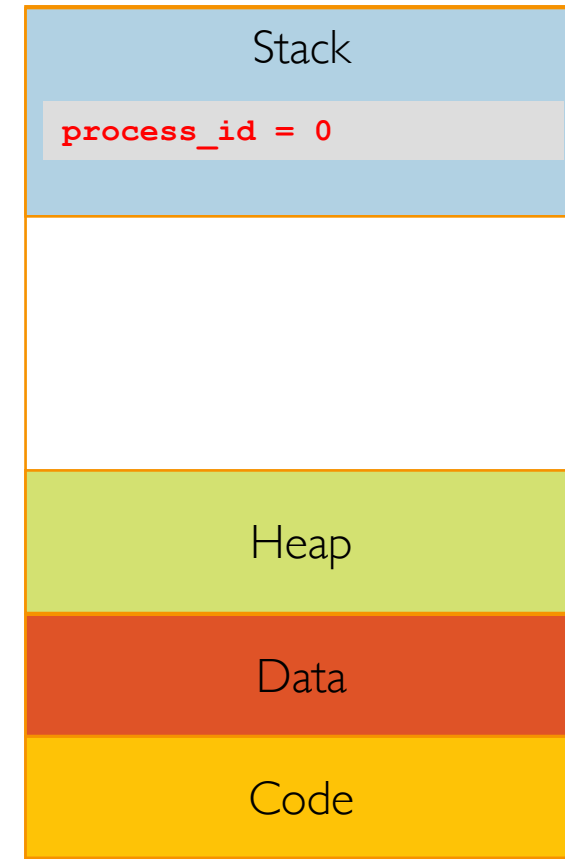
Main Memory



Parent

PID = 74849

parentID = 65784



Child

PID = 74850

parentID = 74849

Process Creation: Code Example

```
1  #include <iostream>
2  #include <unistd.h>
3
4  using namespace std;
5
6  int main() {
7
8      cout << "Current process ID is: " << getpid() << endl;
9      cout << "\nCurrent parent's process ID is: " << getppid() << endl;
10
11     int pid;
12     pid = fork();
13     // once the fork() system call returns,
14     // both the parent and the child processes will resume from this point onward
15
16     if (pid == 0) { // child
17         cout << "\nThis is the child process with process ID = "
18             << getpid() << endl;
19         cout << "\nThis is the child process with parent's process ID = "
20             << getppid() << endl;
21     }
22     else { // parent
23         sleep(1); // to ensure the child process finishes before the parent
24
25         cout << "\nThis is the parent process with process ID = "
26             << getpid() << endl;
27         cout << "\nThis is the parent process with parent's process ID = "
28             << getppid() << endl;
29     }
30
31     return 0;
32 }
```

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30
31     return 0;
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```

What happens if the child sleeps rather than the parent?

Process Creation: What's Next?

- So far, we have seen how **fork** system call is able to make a complete copy of an existing process
- However, this ability alone is not that useful, right?
- Our ultimate goal is to create new yet different processes, not just copies of a single one!

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 - the former creates a new process, whilst the latter execute the new process
 - e.g., try typing **emacs** on your shell

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 - e.g., try typing **emacs** on your shell
- **NOTE:** adding "&" at the end of the command will run the child process in parallel with the parent shell (background)

Process Creation and Execution: Example

```
1  #include <iostream>
2  #include <unistd.h>
3  #include <sys/wait.h>
4  #include <stdio.h>
5  #include <string.h>
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7  using namespace std;
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11     int current_pid = getpid();
12     cout << "Current process ID is: " << current_pid << endl;
13
14     string progStr;
15     // read the name of the program we want to start
16     getline(cin, progStr);
17     const char *prog = progStr.c_str();
18
19     int pid = fork();
20
21     if (pid == 0) { // child
22         execlp(prog, prog, 0); // load the program
23         // if prog can actually be started, we will never get to the
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25         printf("Can't load the program %s\n", prog);
26     }
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execlp loads the program
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argv[0]

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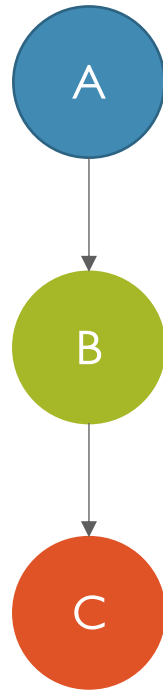
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waitpid allows the parent to wait for a child process to finish

```
pid_t waitpid(pid_t pid, int *status, int options);
```

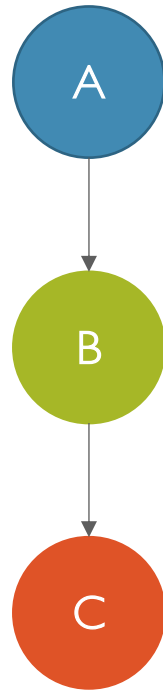
Process Creation and Execution: Exercise

How do we create the following process hierarchy using **fork** and possibly **exec**?



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```
int pid = fork();

if(pid == 0) { // A's child (B)

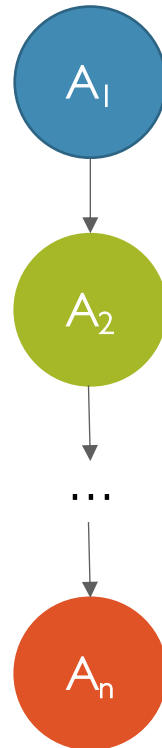
    pid = fork();

    if(pid == 0) { // B's child (C)

        ...
        execlp(...);
    }
    else { // B
        ...
    }
}
else { // A
    ...
}
```

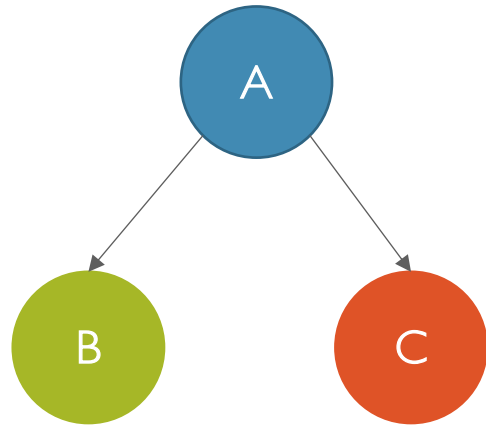
Process Creation and Execution: Exercise

More generally, we will need $n-1$ **fork** and **if-else**
if we want to create a sequence of n processes



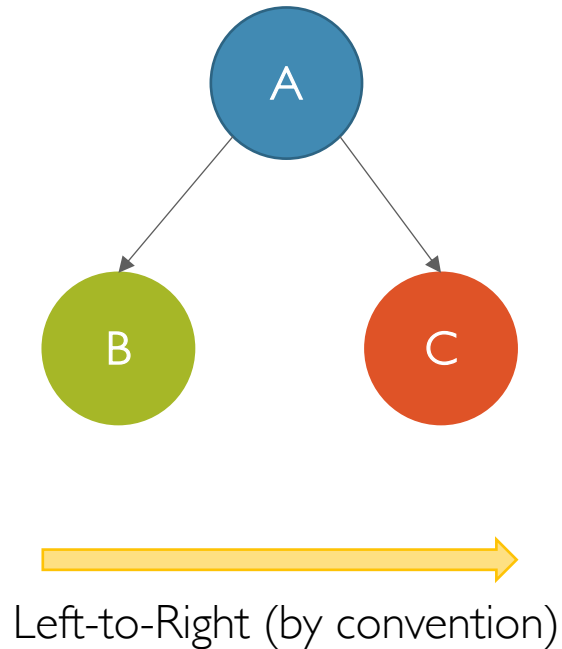
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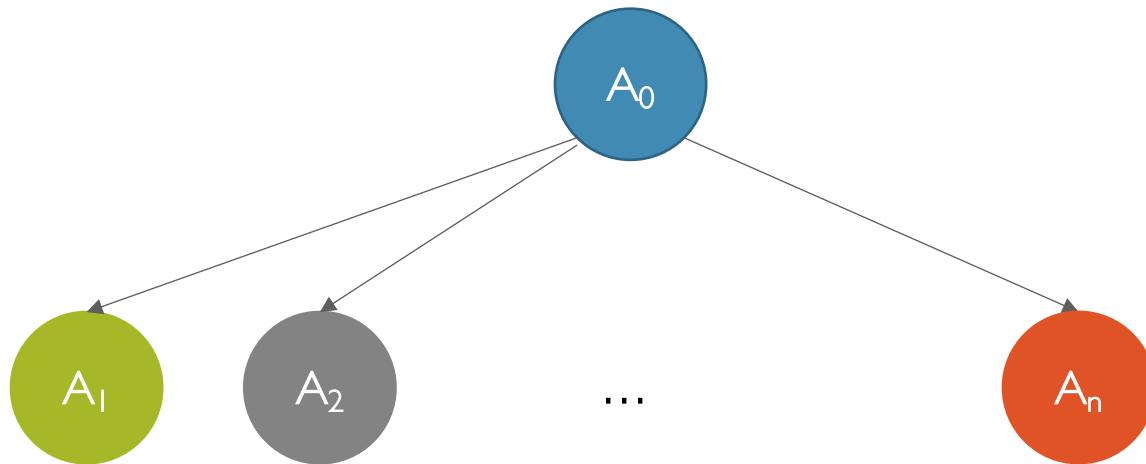
```
int pid = fork();

if(pid == 0) { // A's child (B)
    ...
    execlp(...);
}
else { // A
    pid = fork();

    if(pid == 0) { // A's child (C)
        ...
        execlp(...);
    }
}
```

Process Creation and Execution: Exercise

More generally, if we want to create n child processes all having the same parent



```
for(int i=0;i<n;i++) {  
    if(fork() == 0) { // A0's child  
        ...  
        execlp(...);  
    }  
    // else we are in the parent: keep forking  
}  
// back in the parent A0  
  
// wait for all children to terminate  
for(int i=0;i<n;i++) {  
    wait(NULL);  
}
```

Process Creation and Execution: Be Careful!

What will happen if we do the following?

```
while(1) {  
    fork();  
}
```

Process Creation and Execution: Be Careful!

What will happen if we do the following?

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```

Infinite number of child processes growing with an **exponential rate**

Recap of System Calls Seen So Far

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Recap of System Calls Seen So Far

- **fork** → spawn a new child process as an exact copy of the parent
- **exec1p** → replaces the program of the current process with the input named program
- **sleep** → suspends the execution for a certain amount of seconds
- **wait/waitpid** → wait for any/a specific process to finish execution

Outline

- Process creation
- **Process termination**
- Process scheduling
- Process communication

Process Termination

- Processes may request **their own** termination by making the **exit** system call, typically returning an int
- This int is passed along to the parent if it is doing a **wait**
- It is usually 0 on successful completion and some non-zero in the event of problems

Process Termination

- Processes may also be terminated by the system for a variety of reasons:
 - The inability of the system to deliver necessary system resources
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Process Termination

- Processes may also be terminated by the system for a variety of reasons:
 - The inability of the system to deliver necessary system resources
 - In response to a **kill** command, or other un handled process interrupt
- A parent may kill its children if the task assigned to them is no longer needed
- If the parent exits, the system may or may not allow the child to continue without a parent
 - On UNIX systems, **orphaned** processes are generally inherited by **init**, which then proceeds to kill them

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Process Termination

- When a process terminates, all of its system resources are freed up, open files flushed and closed, etc.
- The process termination status and execution times are returned to the parent if this is waiting for the child to terminate
 - Or eventually to **init** if the process becomes an **orphan**
- Processes which are trying to terminate but cannot because their parent is not waiting for them are called **zombies**
 - Eventually inherited by **init** as orphans and killed

Outline

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Process Scheduling

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- 2 main goals of the process scheduling system:
 - keep the CPU busy at all times
 - deliver "acceptable" response times for all programs, particularly for interactive ones
- The process scheduler must meet these objectives by implementing suitable policies for swapping processes in and out of the CPU

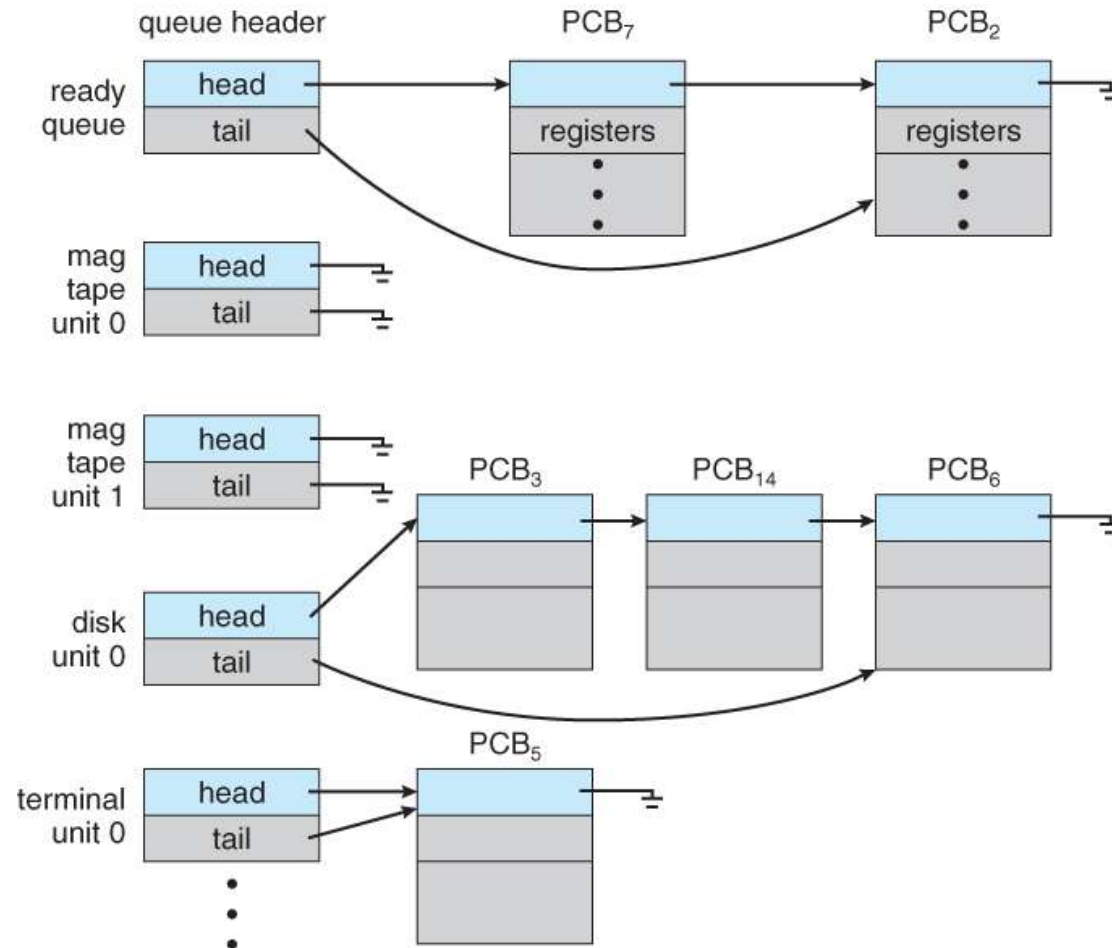
Process Scheduling

- 2 main goals of the process scheduling system:
 - keep the CPU busy at all times
 - deliver "acceptable" response times for all programs, particularly for interactive ones
- The process scheduler must meet these objectives by implementing suitable policies for swapping processes in and out of the CPU
- Note that these objectives can be conflicting!
 - Every time the OS steps in to swap processes it takes up time on the CPU to do so, which is thereby "lost" from doing any useful productive work

Process State Queues

- The OS maintains the PCBs of all the processes in state queues
- There is one queue for each of the 5 states a process can be in
- There is typically one queue for each I/O device (where processes wait for a device to become available or to deliver data)
- When the OS change the status of a process (e.g., from ready to running) the PCB is unlinked from the current queue and moved to the new one
- The OS may use different policies to manage each state queue

Process State Queues: Example



Process State Queues: Considerations

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- How many PCBs can be in the Running Queue?
 - The Running Queue is bound by the number of cores available on the system
 - At each time, only one process can be executed on a CPU
- What about the other queues?
 - They are basically unbounded as there is no theoretical limit on the number processes in new/ready/waiting/terminated states

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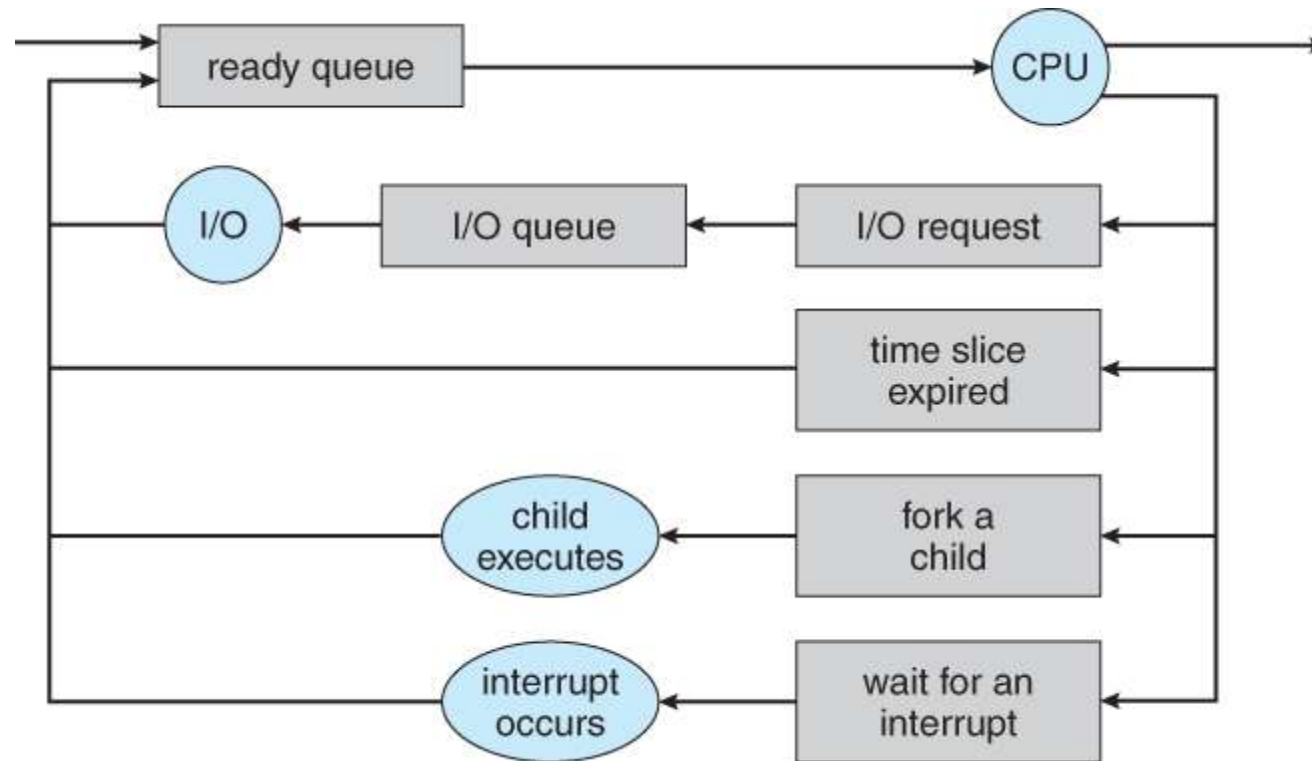
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- Some systems also employ a medium-term scheduler: when system loads get high, this scheduler allows smaller faster jobs to finish up quickly and clear the system
- An efficient scheduling system will select a good mix of CPU-bound processes and I/O bound processes

Schedulers: Queuing Diagram



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- A context switch occurs due to any incoming trap
 - system calls, exceptions, or HW interrupts
- Whenever a trap arrives, the CPU must:
 - perform a state-save of the currently running process
 - switch into kernel mode to handle the interrupt
 - perform a state-restore of the interrupted process

Context Switch: Fairness

- I/O-bound processes eventually get switched due to I/O requests
- CPU-bound processes, instead, could theoretically never issue any I/O requests
- To avoid CPU-bound processes hog the CPU, context switch is also triggered via HW timer interrupts (**time quantum** or **slice**)

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- Mechanism used by modern time-sharing multi-tasking OSs to increase system responsiveness (**pseudo-parallelism**)

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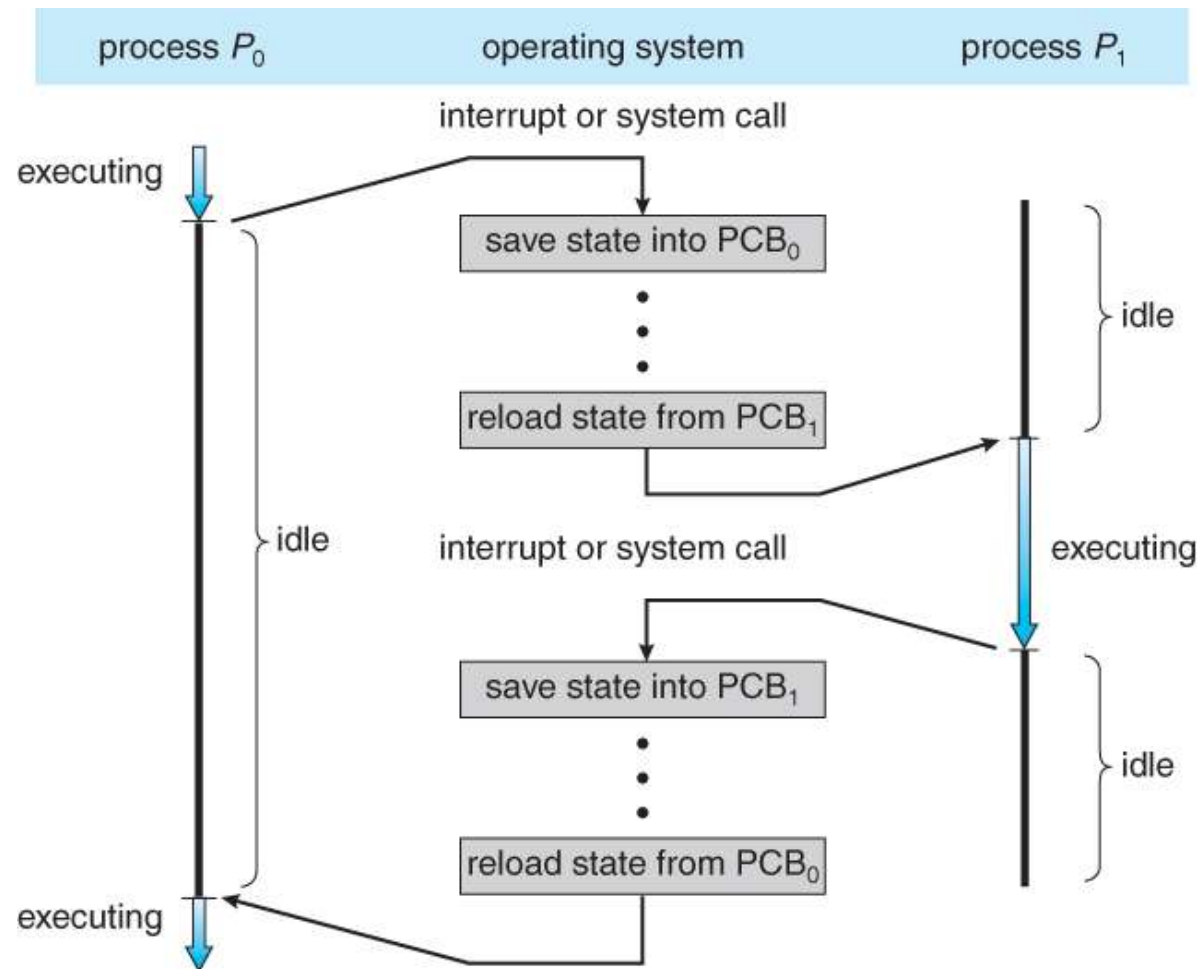
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- The time taken to complete a context switch is just wasted CPU time
- A smaller time slice results in more frequent context switches
 - maximizing responsiveness
- A larger time slice results in less frequent context switches
 - minimizing wasted CPU time, therefore maximizing CPU utilization
- Typical values of time slice are between 10 and 100 ms, and context switch takes around 10 μ s, so the overhead is small relative to time slice



Trade-off

Context Switch: Example



Outline

- Process creation
- Process termination
- Process scheduling
- **Process communication**

Interprocess Communication

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Interprocess Communication

- Processes can be either **independent** or **cooperating**
- **Independent processes** → operate concurrently on a system and can neither affect or be affected by other processes
- **Cooperating processes** → can affect or be affected by other processes in order to achieve a common task

Cooperating Processes: Why Do We Need Them?

- **Information sharing** → There may be several processes which need access to the same file (e.g., pipelines)

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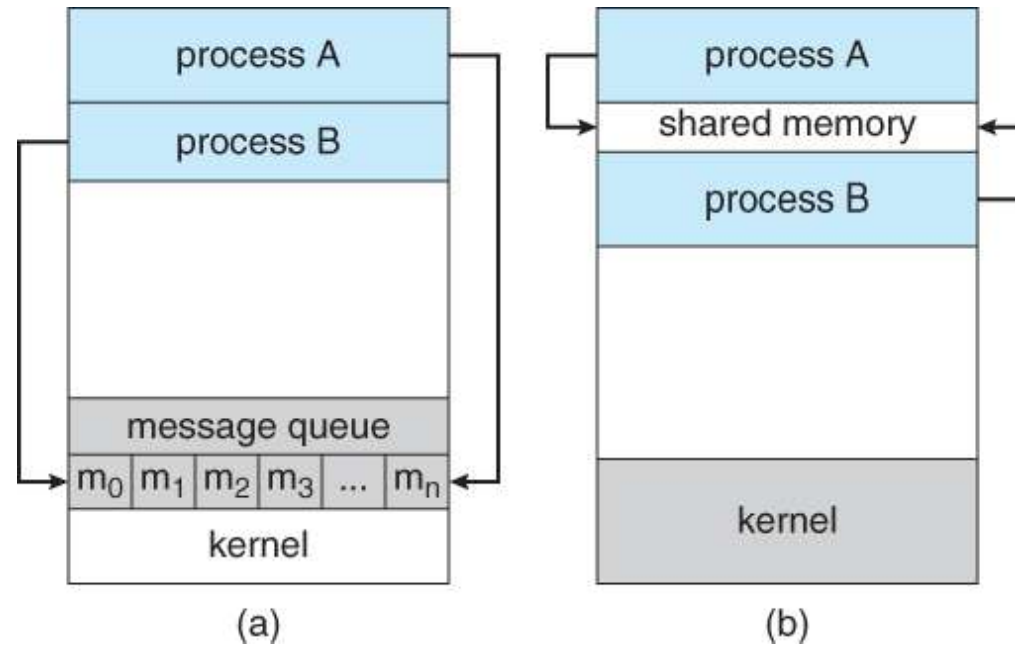
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- Modularity → The most efficient architecture may be to break a system down into cooperating modules
- **Convenience** → Even a single user may be multi-tasking, such as editing, compiling, printing, and running the same code in different windows

Cooperating Processes: Communication

- 2 possible ways for cooperating processes to communicate:



Message Passing

Shared Memory

Shared Memory vs. Message Passing

- Shared Memory

- Faster once it is set up, as no system calls are needed
- More complicated to set up, and doesn't work as well across multiple computers
- Preferable when (large amount of) information must be shared on the same computer

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- Message Passing

- Slower as it requires system calls for every message transfer
- Simpler to set up and works well across multiple computers
- Preferable when the amount and/or frequency of data transfers is small, or when multiple computers are involved

Shared Memory Systems

- The memory to be shared is initially within the address space of a particular process
- This needs to make system calls in order to make that memory publicly available to other processes
- Other processes must make their own system calls to attach the shared memory onto their address space

Message Passing Systems

- Must support at least system calls for sending and receiving messages
- A communication link must be established between the cooperating processes before messages can be sent
- **3 key issues** to be solved:
 - direct or indirect communication (i.e., naming)
 - synchronous or asynchronous communication
 - automatic or explicit buffering

Message Passing Systems: Naming

- **Direct communication** → the sender must know the name of the receiver to which it wishes to send a message
 - one-to-one link between every sender-receiver pair
 - for symmetric communication, the receiver must also know the name of the sender

Message Passing Systems: Naming

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 - one-to-one link between every sender-receiver pair
 - for symmetric communication, the receiver must also know the name of the sender
- **Indirect communication** → uses shared mailboxes or ports
 - multiple processes can share the same mailbox or port
 - only one process can read any given message in a mailbox
 - the OS must provide system calls to create and delete mailboxes, and to send and receive messages to/from mailboxes

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- **Unbounded capacity** → The queue has a theoretical infinite capacity, so senders are never forced to block

Summary

- Process are created programmatically via system calls (e.g., **fork/exec**)
- Scheduling policies to maximize CPU utilization for process execution
- **Context switch** to intertwine the execution of multiple processes
- Process communication either via **message passing** or **shared memory**