

Sistemi Operativi I

Corso di Laurea in Informatica
2025-2026



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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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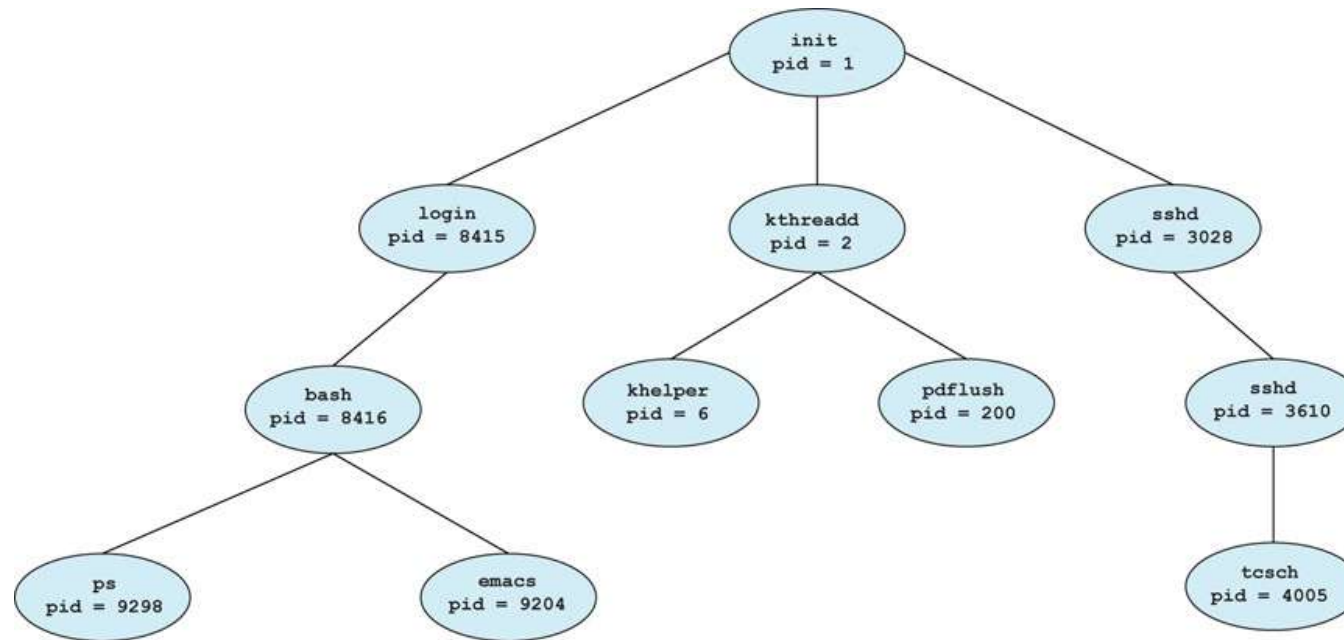
Process Creation

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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
- Each process is given an integer **identifier** (a.k.a. process identifier or PID) and a parent ID (PPID)

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



Process Creation: Parent vs. Child Resources

- Relatively to the parent, the address space of the child process can be:
 - **Duplicated** (UNIX/Linux `fork()`)
 - **Brand New** (Windows `spawn()`)

Process Creation: Parent vs. Child Resources

- When the child is an exact **duplicate of the parent**
 - It shares the same program and data segments in memory
 - Still, each process will have its own PCB, including program counter, registers, and PID

Process Creation: Parent vs. Child Resources

- When the child contains an **brand new program**
 - Its address space has new code and data segments
 - UNIX systems implement this as a second step, using the **exec** system call

Process Creation: Parent vs. Child Execution

- **2 options** for the parent after creating the child:

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Process Creation: Parent vs. Child Execution

- **2 options** for the parent after creating the child:
 1. Wait for the child to terminate before proceeding
 - The parent makes a `wait()` system call, for either a specific child or for any child
 - This causes the parent process to block until the `wait()` returns
 - Usual behavior of UNIX shell that normally waits for their children to complete before issuing a new prompt ">"

Process Creation: Parent vs. Child Execution

- **2 options** for the parent after creating the child:
 2. Run concurrently with the child, continuing to process without waiting (and blocking)
 - This is the operation seen when a UNIX shell runs a process as a background task "&"
 - The parent may also run for a while, and then wait for the child later, which might occur in a sort of a parallel processing operation

Process Creation: UNIX/Linux Code

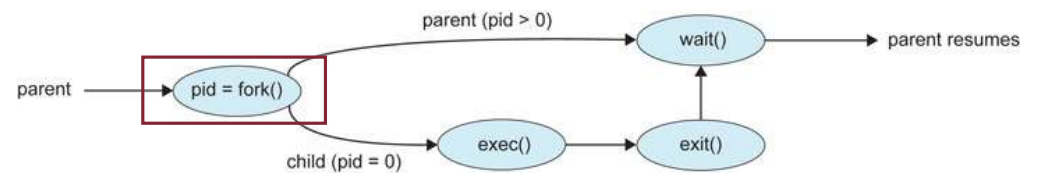
```
#include <sys/types.h>
#include <stdio.h>
#include <unistd.h>

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

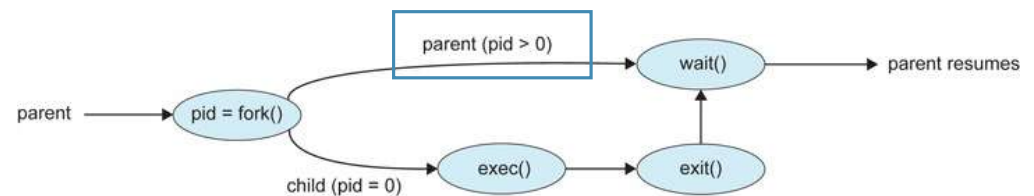
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        printf("Child Complete");
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    }
}
```

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

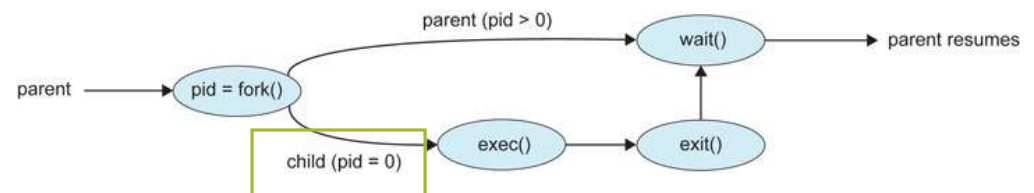
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#include <stdio.h>
#include <unistd.h>

int main()
{
    pid_t pid;

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

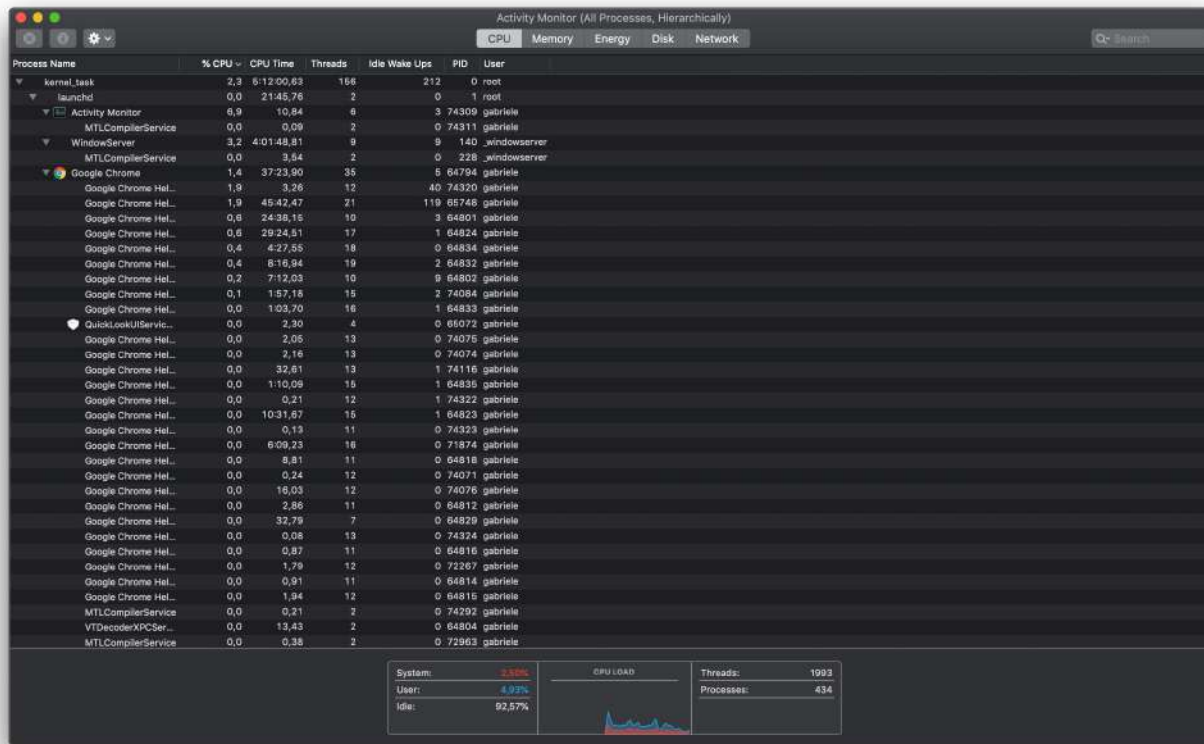
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Figure 3.10 C program forking a separate process.



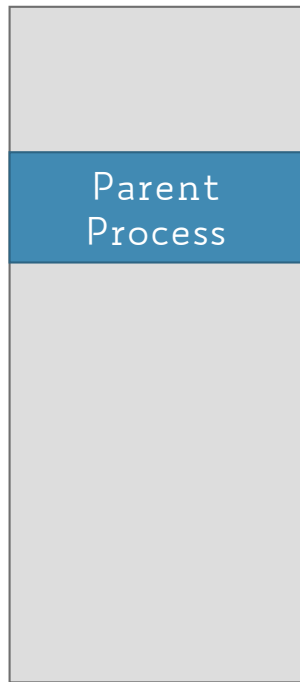
In the child process, it returns 0

Process Creation: Activity Monitor



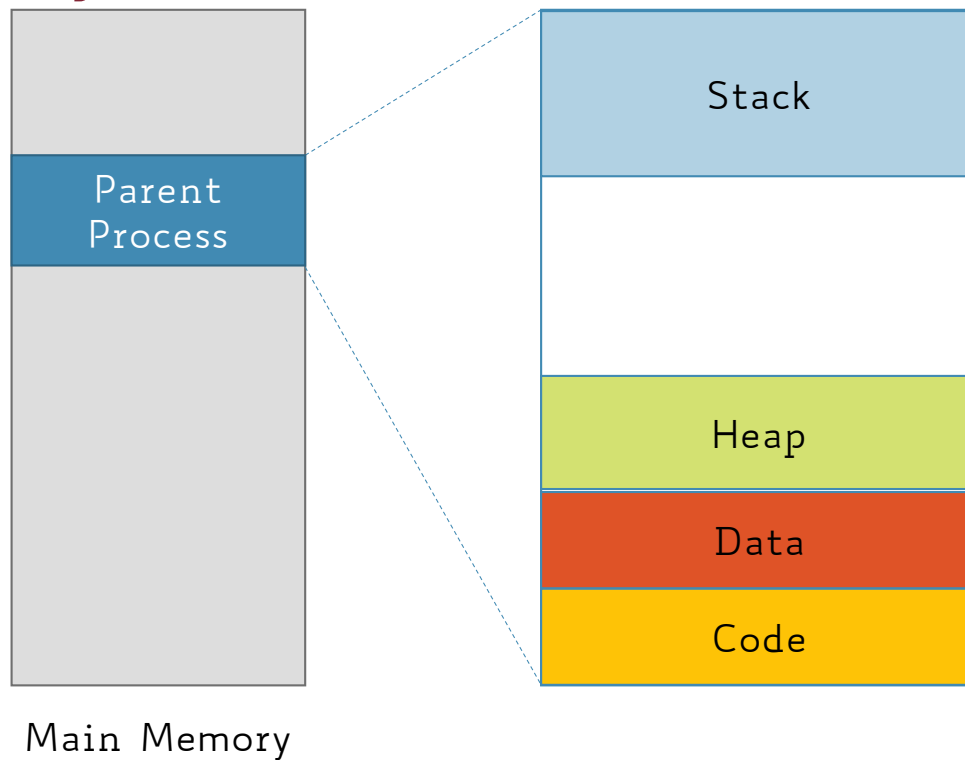
Hierarchy of
Processes
(i.e., process tree)

Process Creation: Parent vs. Child Layout

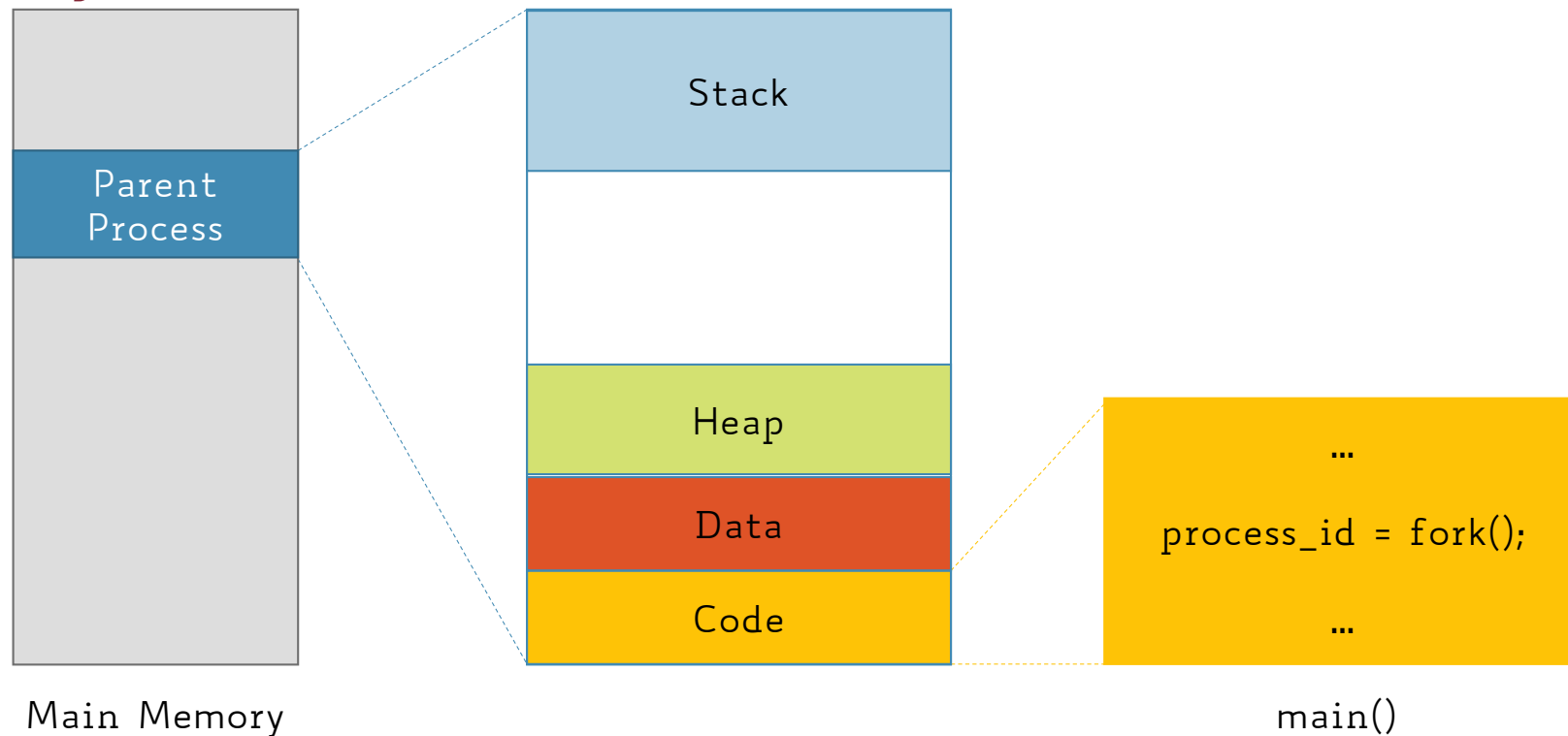


Main Memory

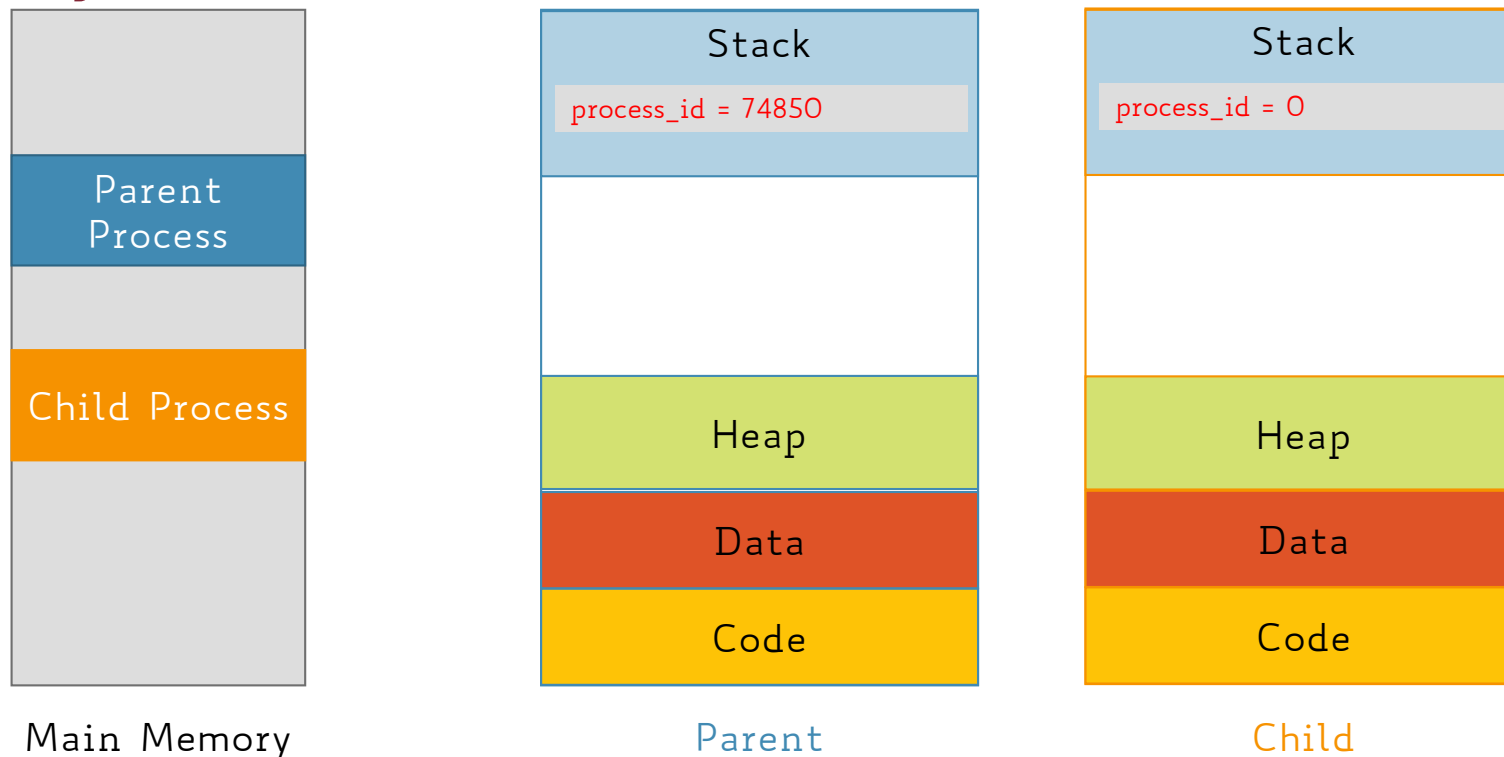
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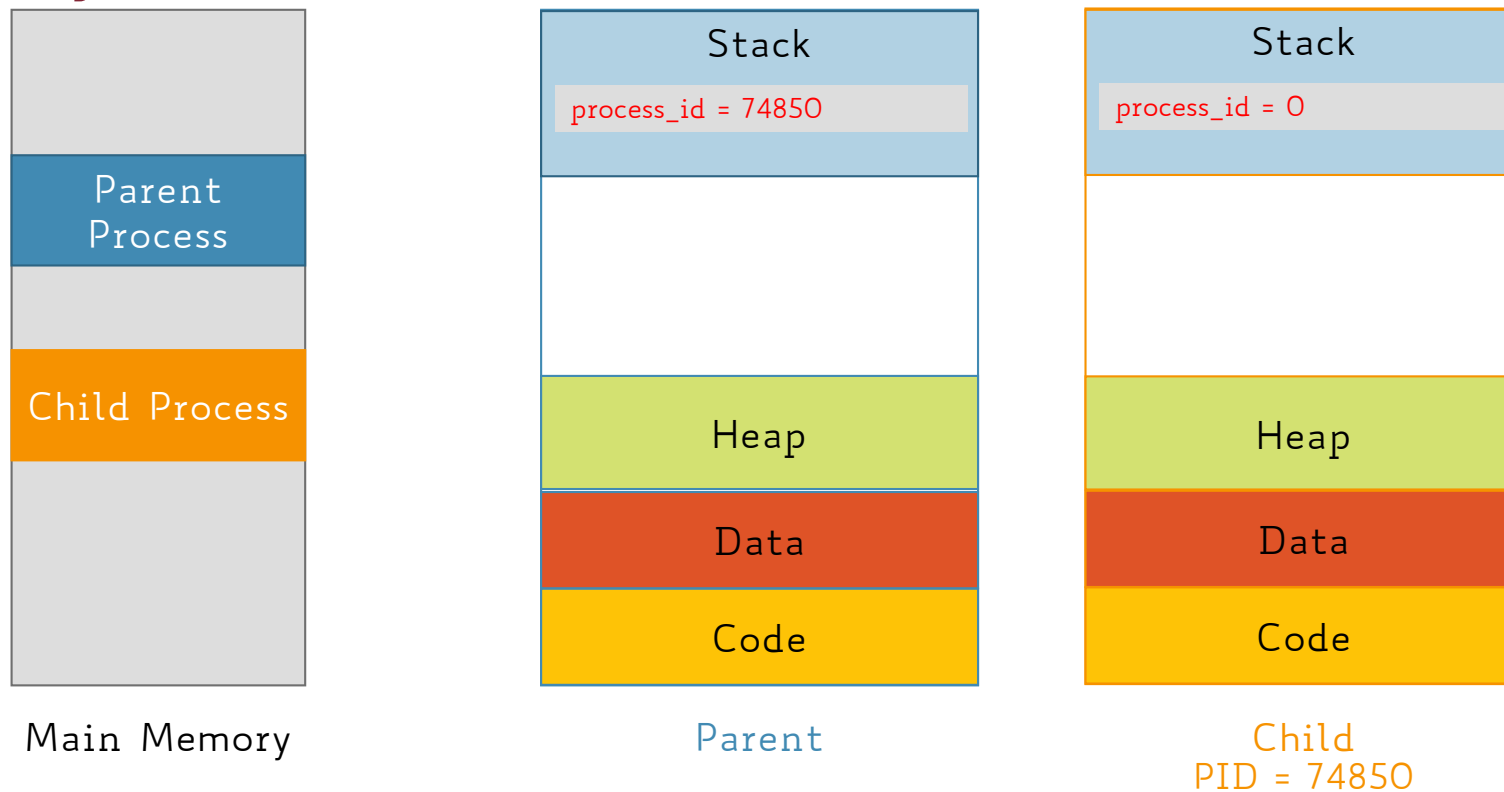
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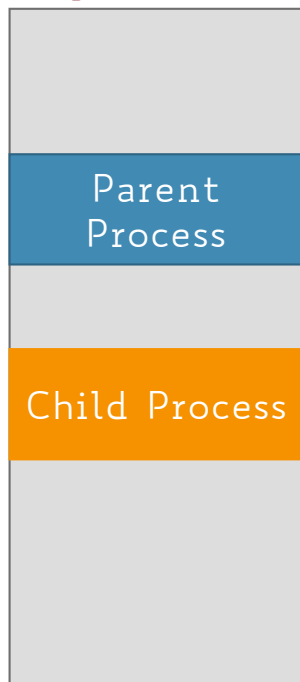
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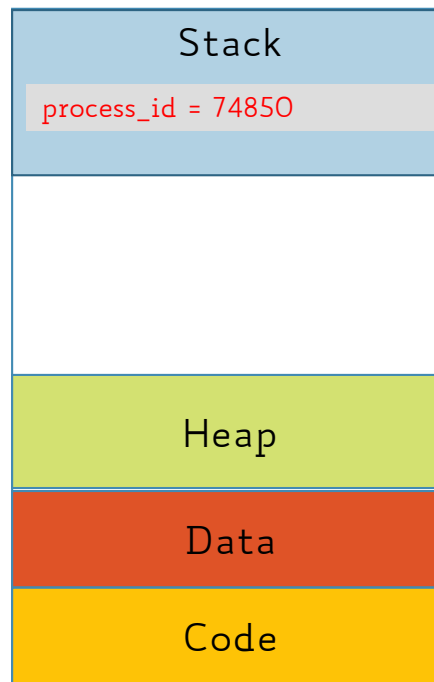


Process Creation: Parent vs. Child Layout



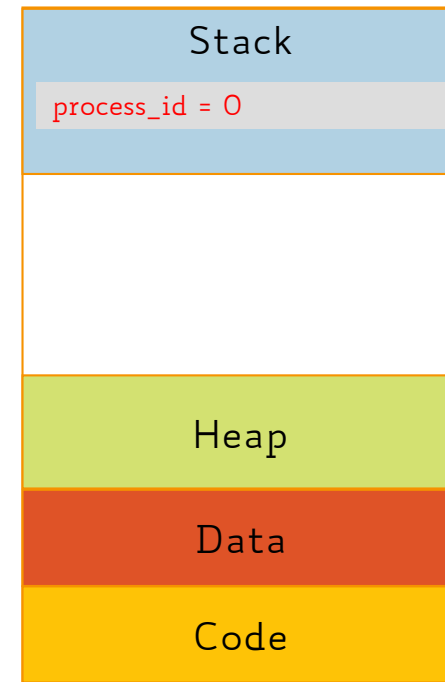
Main Memory

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Parent

PID = 74849



Child

PID = 74850

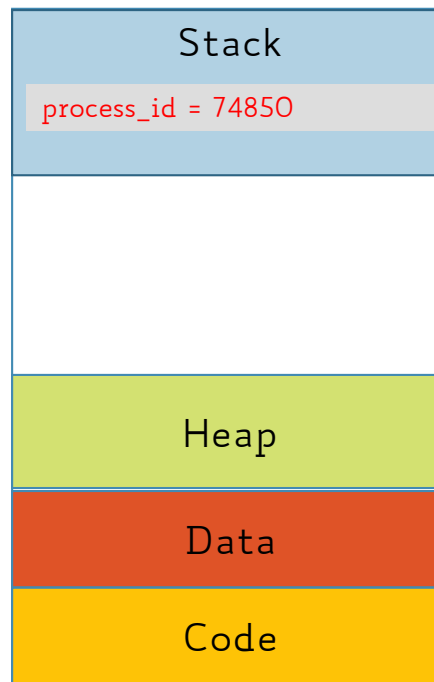
parentID = 74849

Process Creation: Parent vs. Child Layout



Main Memory

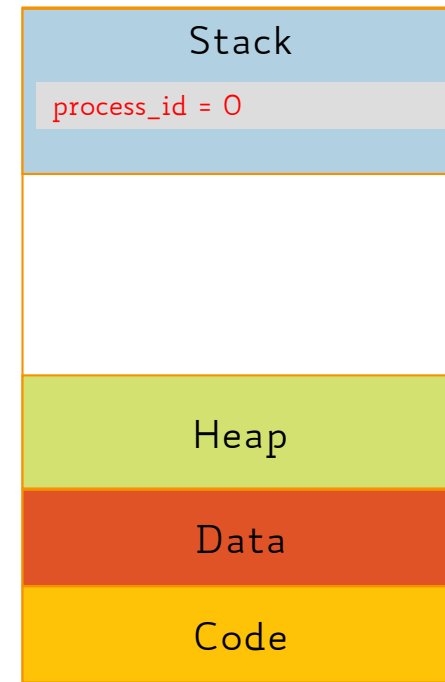
02/10/2025



Parent

PID = 74849

parentID = 65784



Child

PID = 74850

parentID = 74849

29

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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29     }
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!

Process Creation: The Example of UNIX Shell

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

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- When we log in to a UNIX machine a shell process is started
- Every command we type into the shell creates a new child process whose parent is the shell itself
- Implicitly, **2 system calls** take place: **fork** and **exec**
 - the former duplicates process, whilst the latter execute the new process
 - 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>
6
7 using namespace std;
8
9 int main() {
10
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
24         // following statement, as the child process will be replaced by prog!
25         printf("Can't load the program %s\n", prog);
26     }
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`execlp` loads the program
whose name is read from
`stdin`

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int execlp(const char *file, const char *arg, ...);
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path to executable

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argv[0]

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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`?



Process Creation and Execution: Exercise

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



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

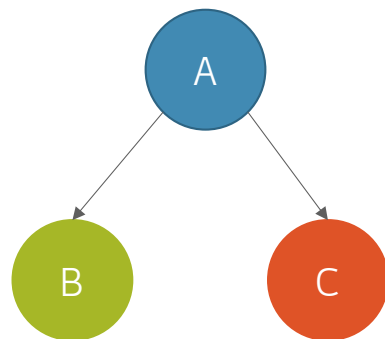
Process Creation and Execution: Exercise

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



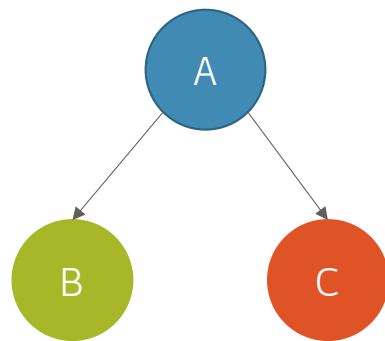
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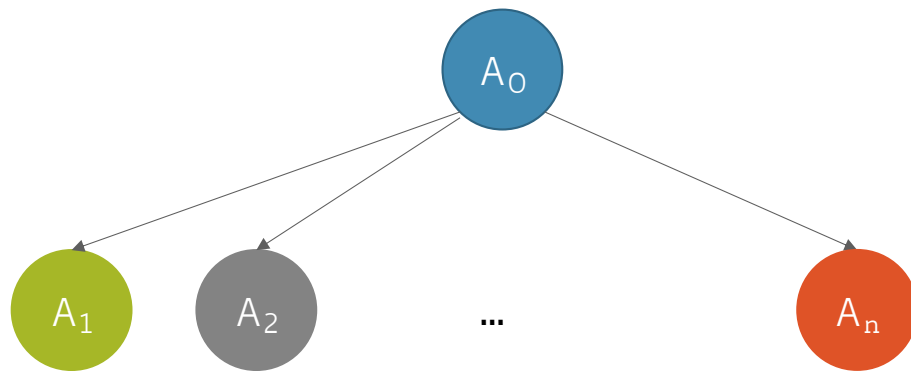


Left-to-Right (by convention)

```
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?

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

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

Recap of System Calls Seen So Far

- `fork` → spawn a new child process as an exact copy of the parent

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Recap of System Calls Seen So Far

- `fork` → spawn a new child process as an exact copy of the parent
- `execlp` → 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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- 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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- A parent may kill its children if the task assigned to them is no longer needed

Process Termination

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- 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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- 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**

Process Termination

- Processes which are trying to terminate but cannot because their parent is not waiting for them are called **zombies**

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- Eventually inherited by **init** as orphans and killed

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Process Scheduling

- **2 main goals** of the process scheduling system:
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 - i. keep the CPU busy at all times
 - ii. deliver "acceptable" response times for all programs, particularly for interactive ones

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- The process scheduler must meet these objectives by implementing suitable policies for swapping processes in and out of the CPU

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- 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

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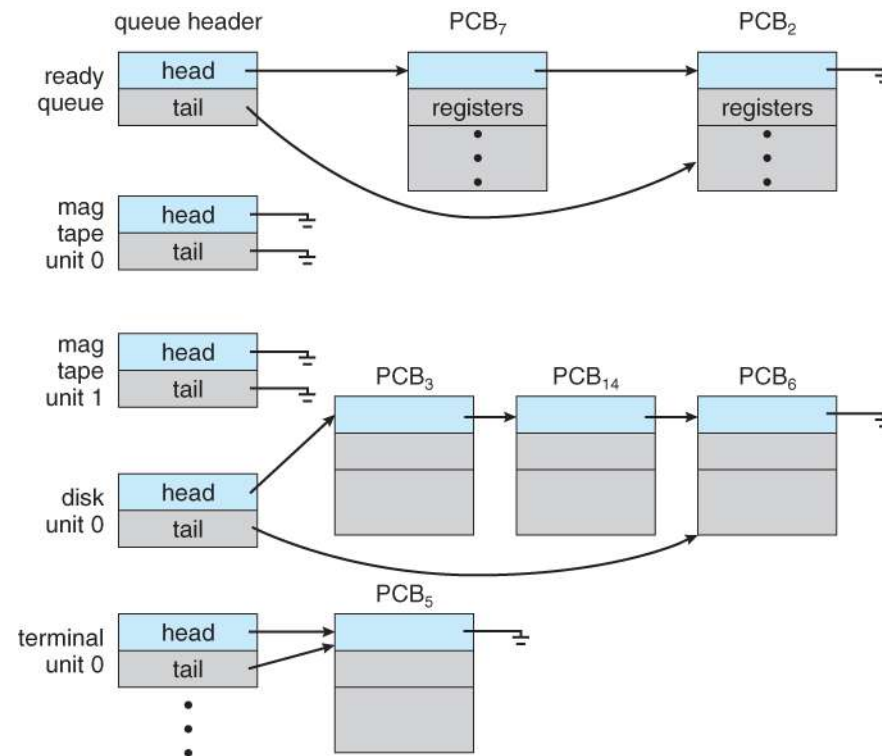
Process State Queues

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- There is typically one queue for each I/O device (where processes wait for sending/receiving data to/from a device)
- When the OS changes the status of a process (e.g., from ready to running) the PCB is unlinked from one queue and moved to appropriate one

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- 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 sending/receiving data to/from a device)
- When the OS changes the status of a process (e.g., from ready to running) the PCB is unlinked from one queue and moved to appropriate one
- The OS may use different policies to manage each state queue

Process State Queues: Example



Process State Queues: Considerations

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 - 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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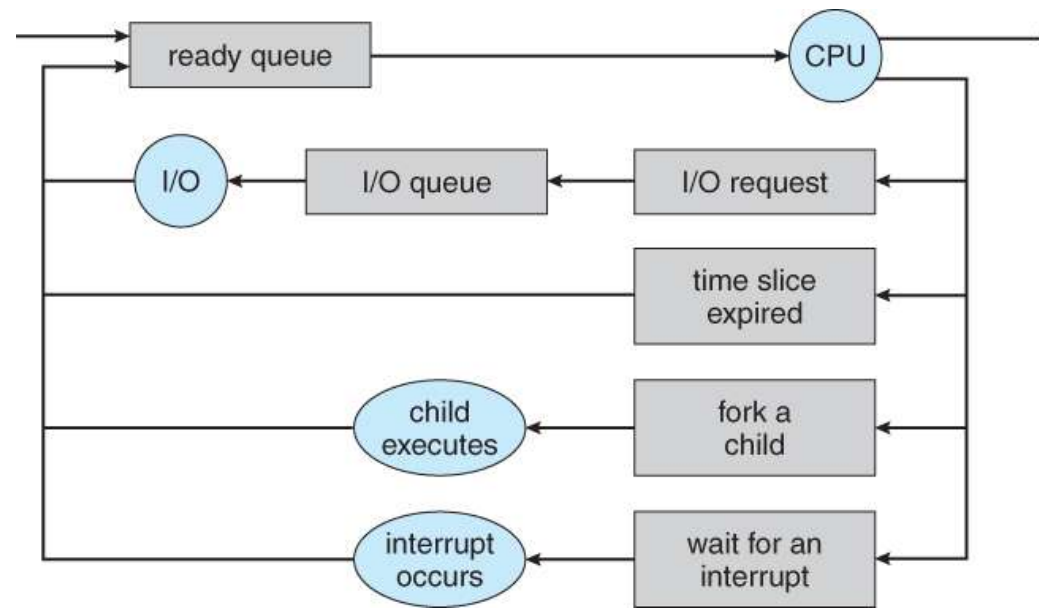
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- An efficient scheduling system will select a good mix of CPU-bound processes and I/O bound processes

Schedulers: Queuing Diagram



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- It is a highly costly operation because:
 - stopping the current process involves saving all of its internal state (PC, SP, other registers, etc.) to its PCB
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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

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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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- In practice, it can happen more frequently than that (e.g., due to I/O requests)

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- Can be easily implemented in HW through timer interrupt
- Mechanism used by modern time-sharing multi-tasking OSs to increase system responsiveness (**pseudo-parallelism**)

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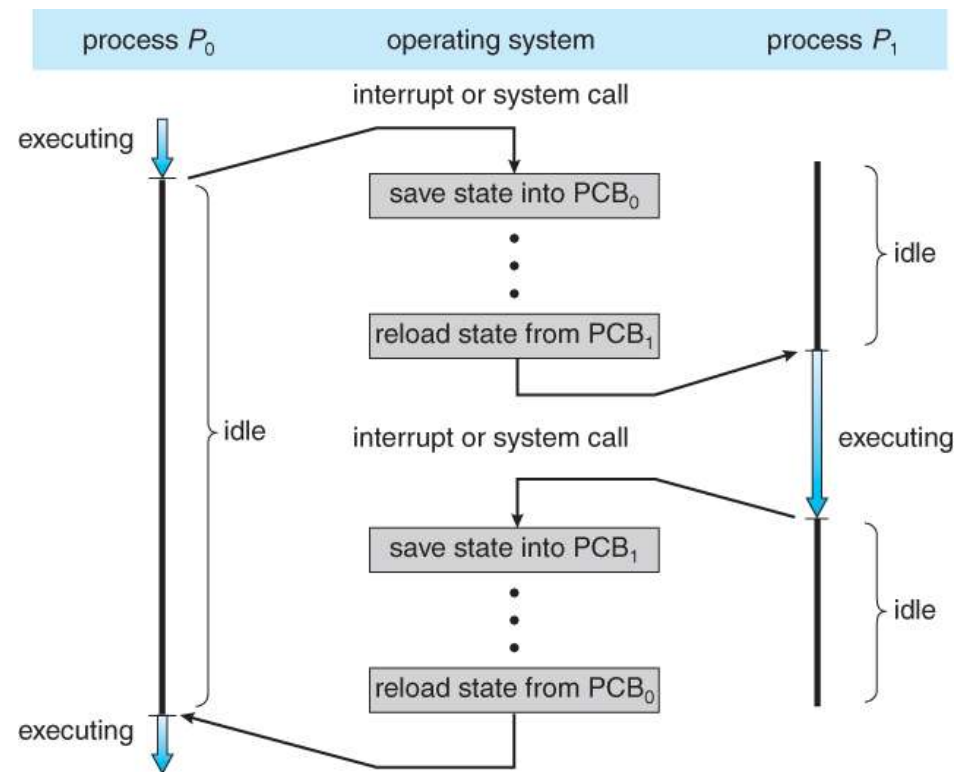
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Trade-off

Context Switch: A Few Numbers

- Typical values of time slice range between 10 and 100 ms
- Context switch takes around 10 μ s, so the overhead is small relative to time slice
- 10^{-2} to 10^{-1} vs. 10^{-8} seconds

Context Switch: Example



Outline

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

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- 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

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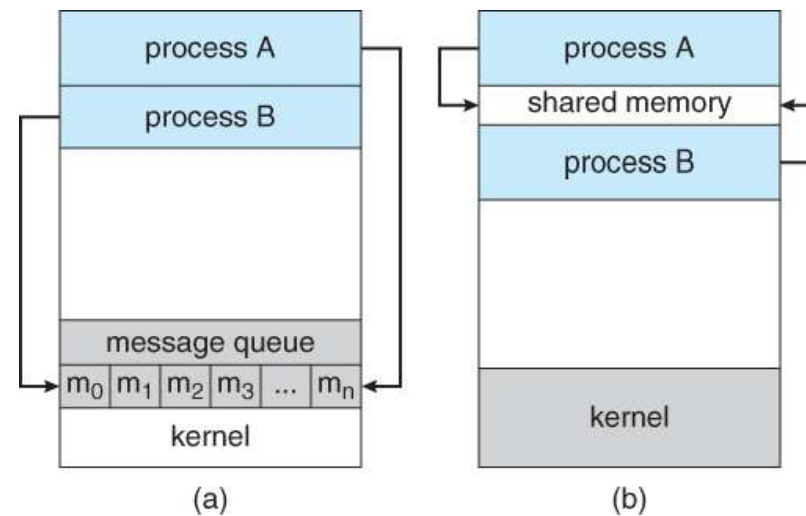
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- **Information sharing** → There may be several processes which need access to the same file (e.g., pipelines)
- **Computation speedup** → A problem can be solved faster if it can be broken down into sub-tasks to be solved simultaneously
- **Modularity** → 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

Shared Memory vs. Message Passing

- 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:
 - **Naming** → Does the sender talk directly to a process, or indirectly via mailbox/queue?
 - **Timing** → Do send/receive block (synchronous) or not (asynchronous)?
 - **Storage** → Who provides buffering (automatic/system vs. explicit/programmer), and how much? (zero, bounded, unbounded)

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- Scheduling policies to maximize CPU utilization for process execution
- **Context switch** to intertwine the execution of multiple processes
- Process communication either via **shared memory** or **message passing**