Sistemi Operativi I

Corso di Laurea in Informatica

2024-2025

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SAPIENZA
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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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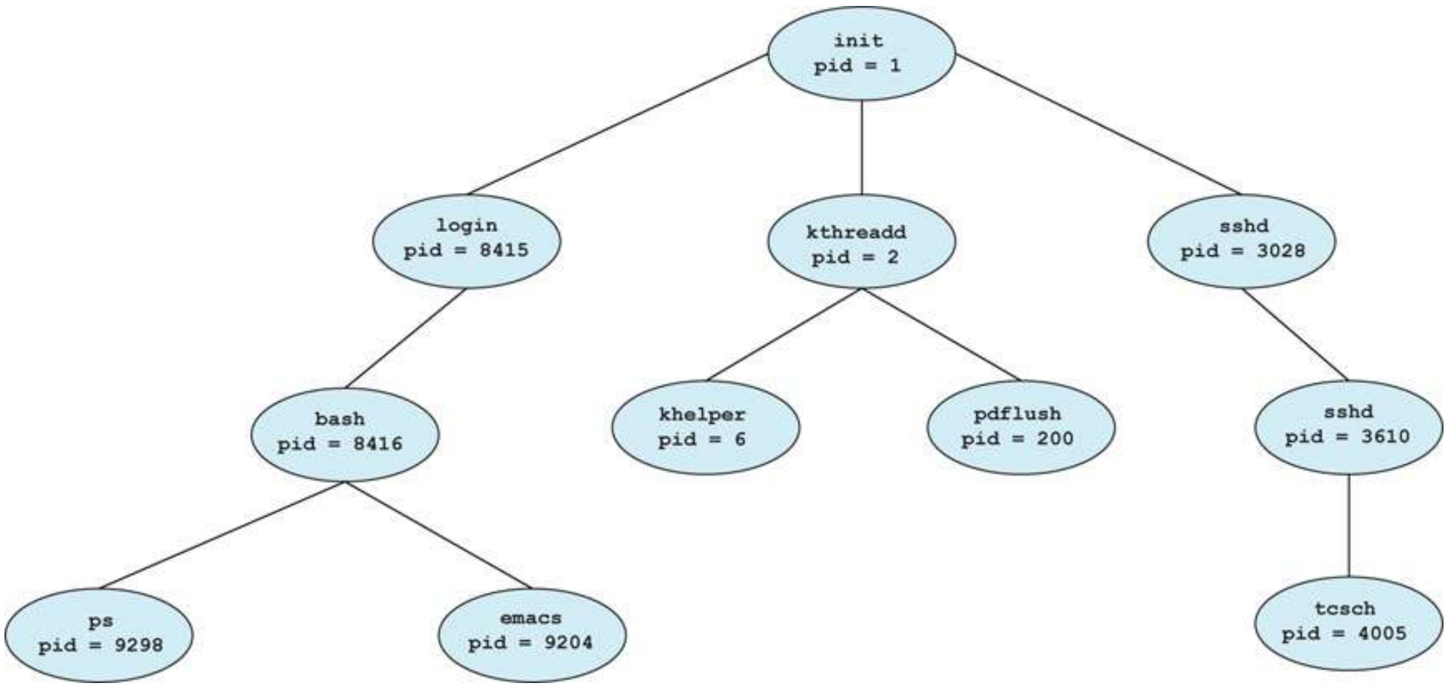
  - The creator process is called **parent** of the new process, which is called **child**
  - The parent shares resources and privileges to its children
  - A parent can either wait for a child to complete, or continue in parallel
- Each process is given an integer **identifier** (a.k.a. process identifier 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

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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

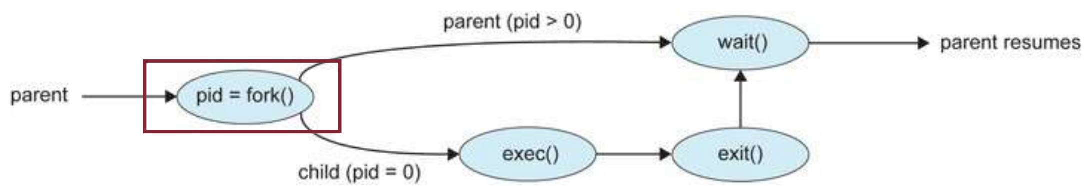
```c
#include <sys/types.h>
#include <stdio.h>
#include <unistd.h>

int main()
{
pid_t pid;

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

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



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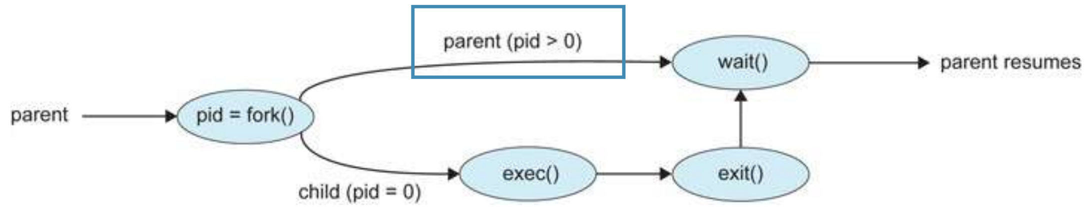

In the parent process, fork() returns the PID of the child

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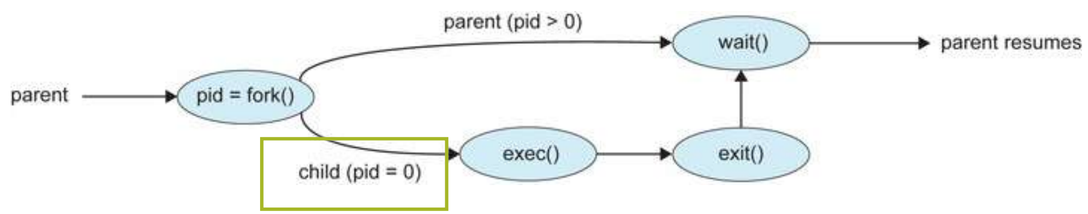
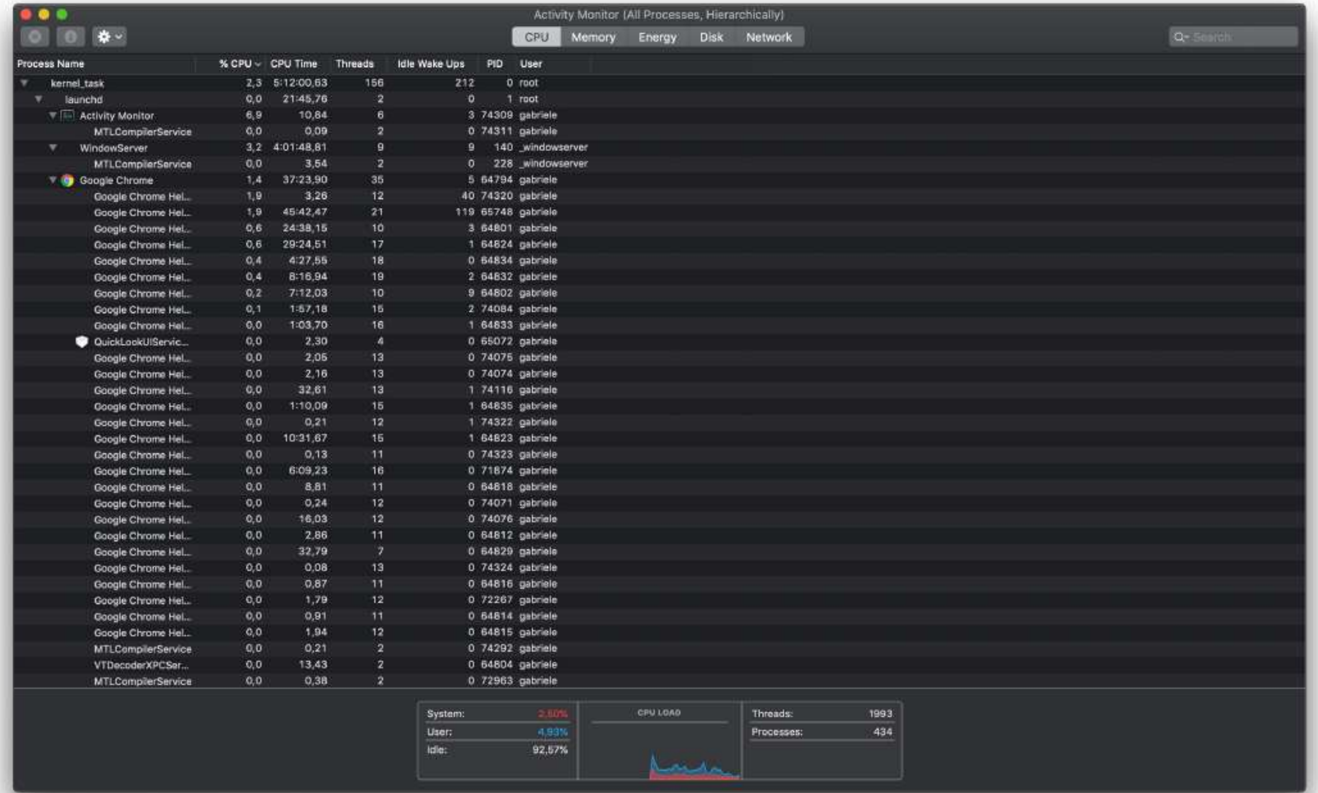


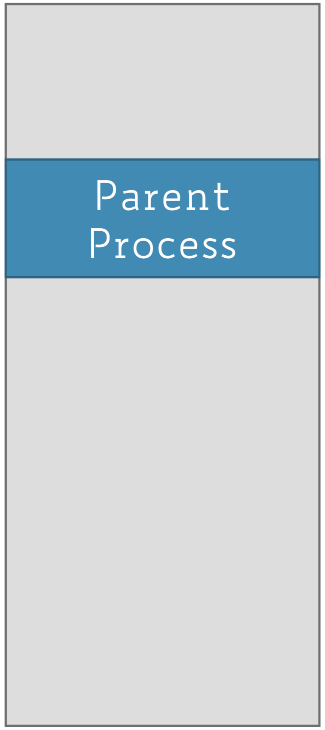
In the child process, it returns 0

Process Creation: Activity Monitor



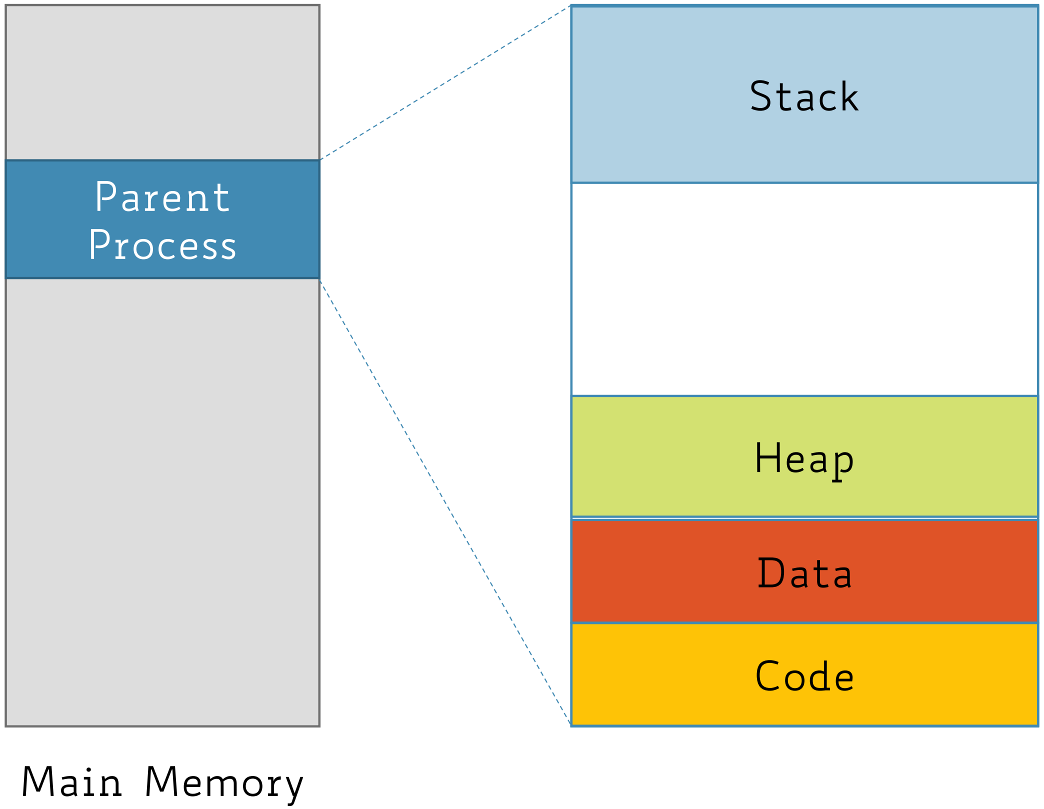
Hierarchy of Processes (i.e., process tree)

Process Creation: Parent vs. Child Layout



Main Memory

Process Creation: Parent vs. Child Layout



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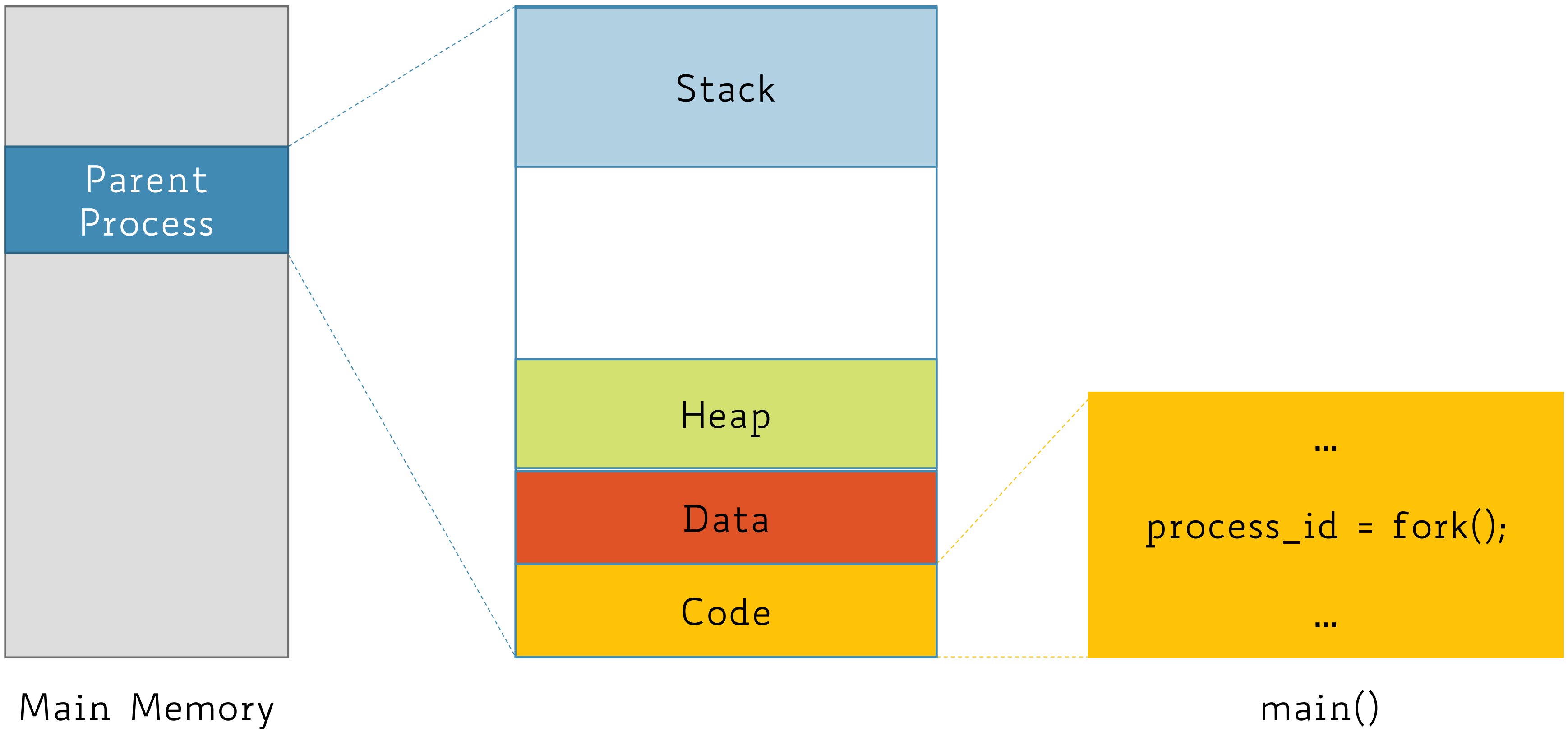

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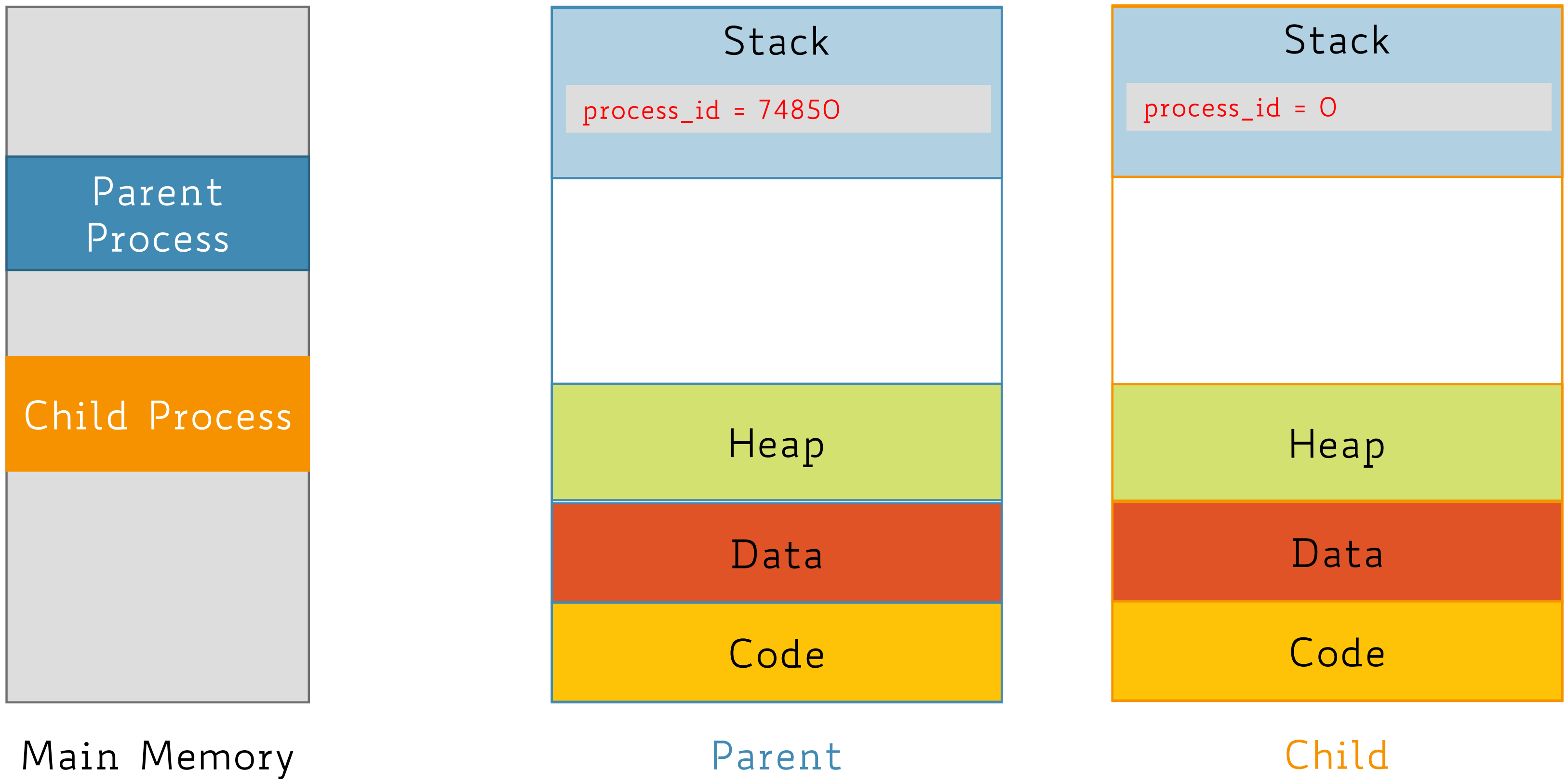

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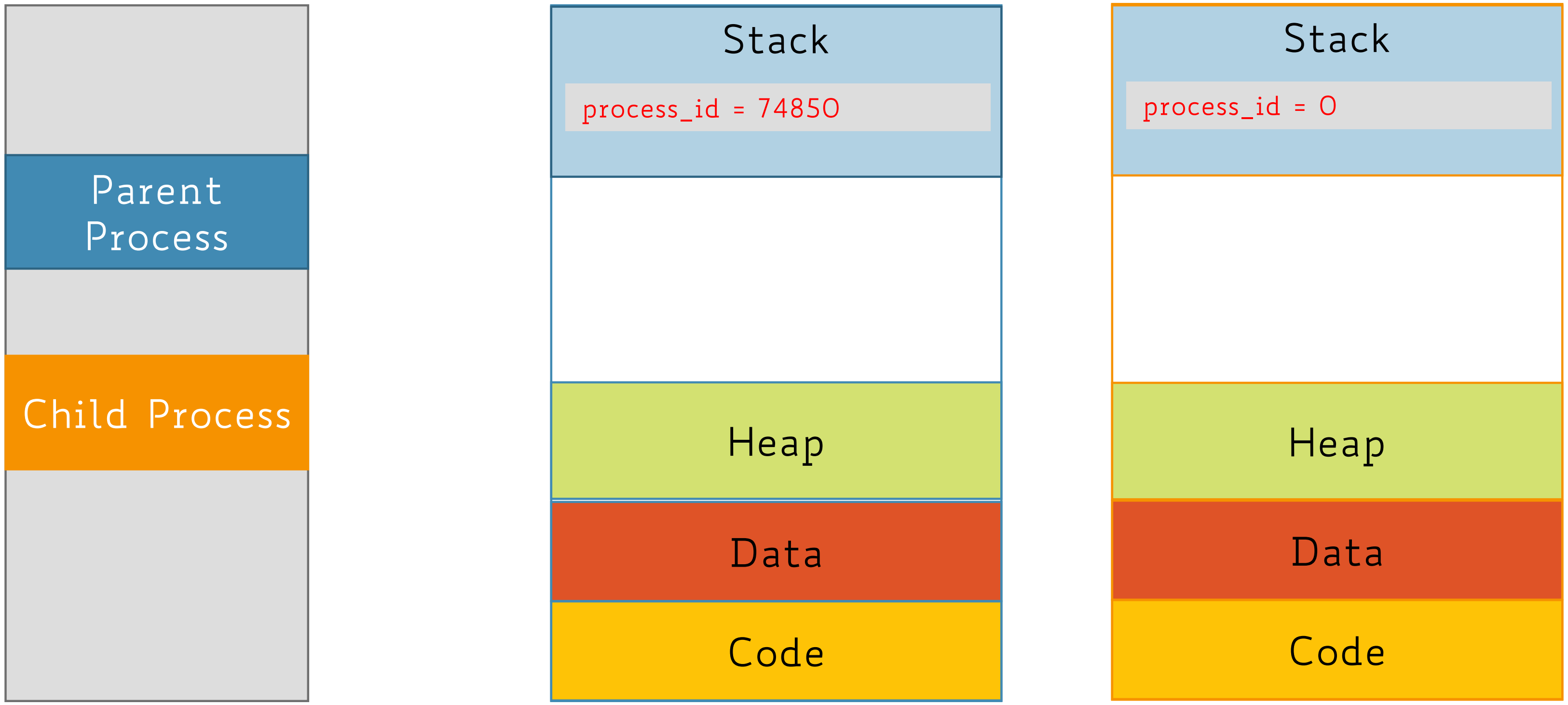
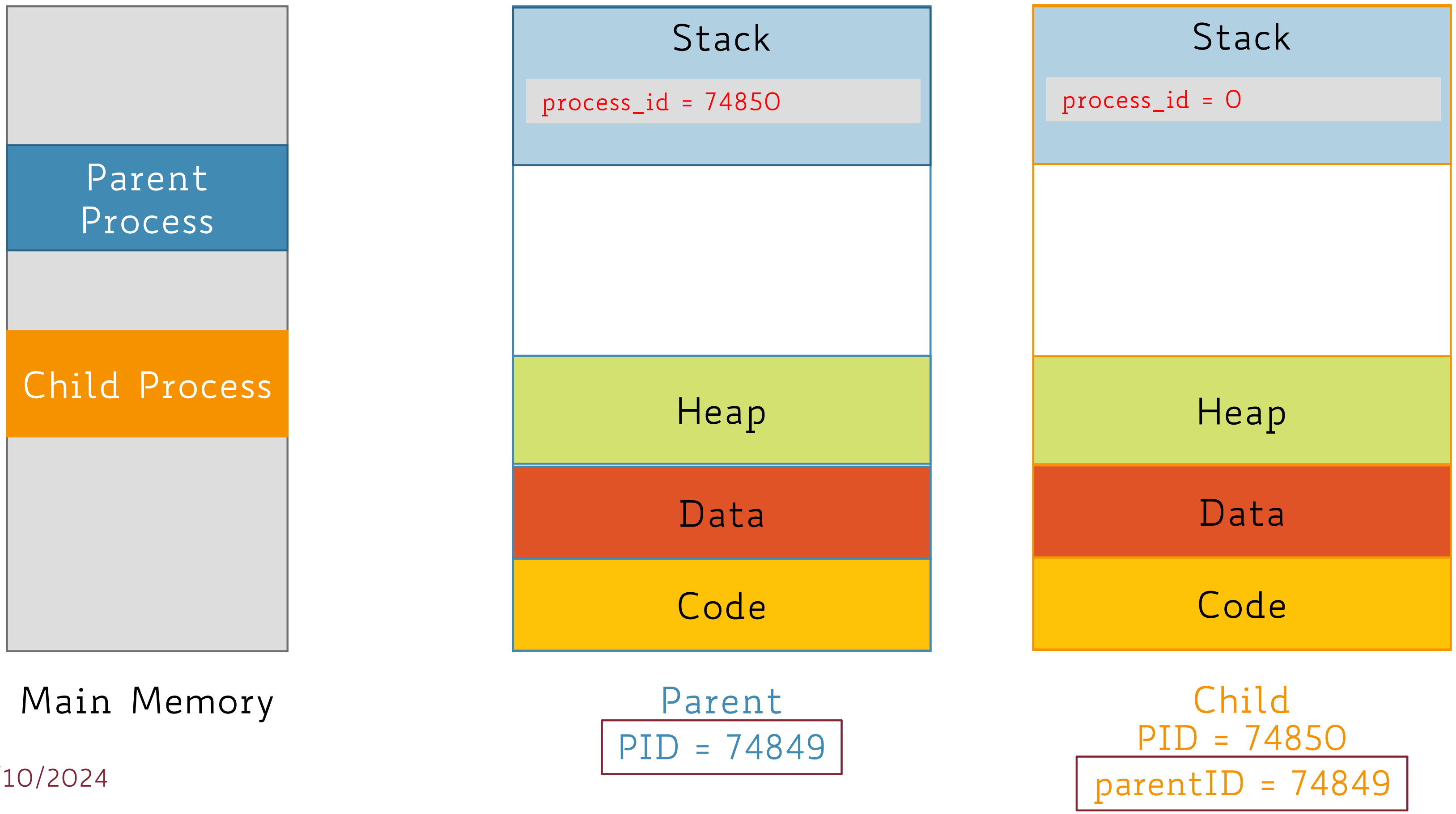


Main Memory

Parent

Child
PID = 74850

Process Creation: Parent vs. Child Layout



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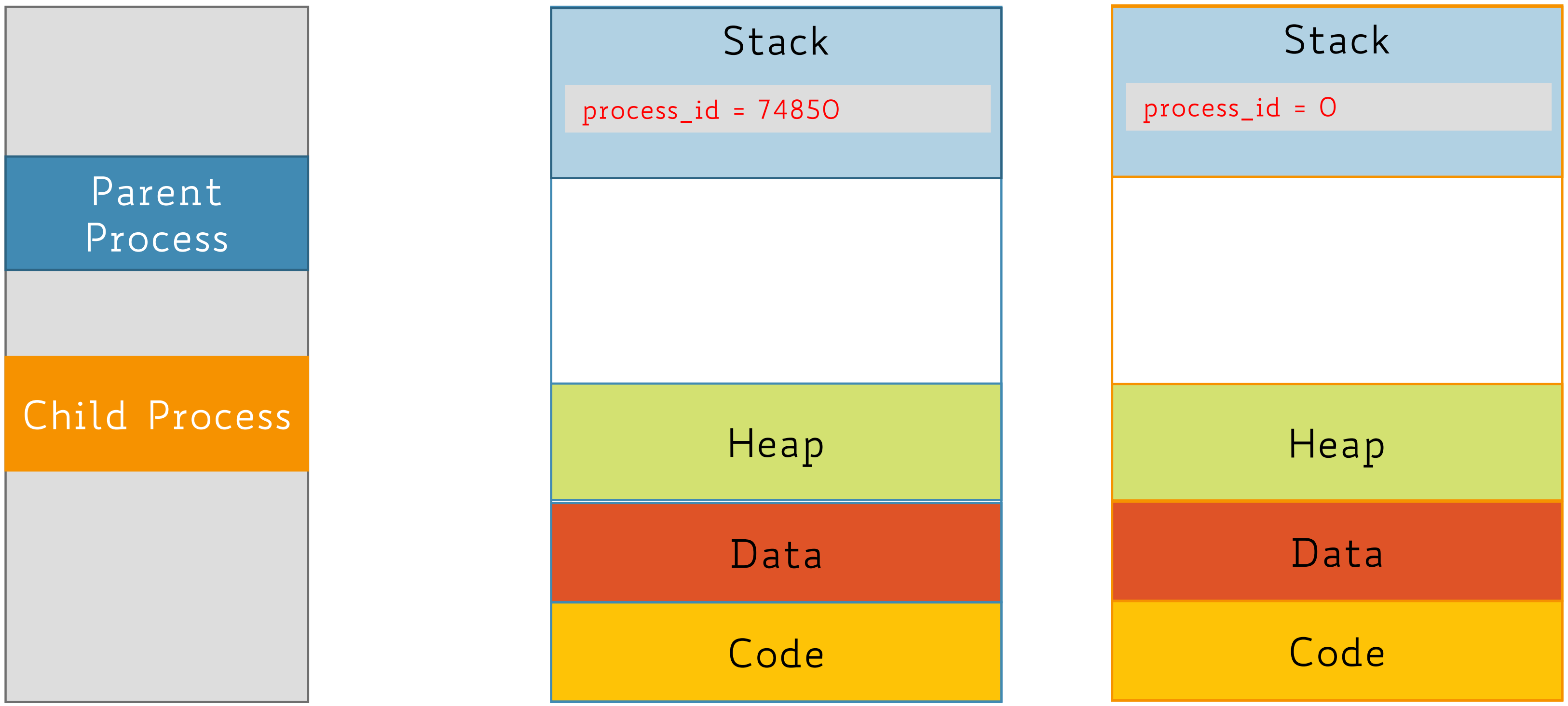

Main Memory

Parent
PID = 74849
parentID = 65784

Child
PID = 74850
parentID = 74849

Process Creation: Code Example

```cpp
#include <iostream>
#include <unistd.h>

using namespace std;

int main() {

    cout << "Current process ID is: " << getpid() << endl;
    cout << "\nCurrent parent's process ID is: " << getppid() << endl;

    int pid;
    pid = fork();
    // once the fork() system call returns,
    // both the parent and the child processes will resume from this point onward

    if (pid == 0) { // child
        cout << "\nThis is the child process with process ID = "
             << getpid() << endl;
        cout << "\nThis is the child process with parent's process ID = "
             << getppid() << endl;
    }
    else { // parent
        sleep(1); // to ensure the child process finishes before the parent

        cout << "\nThis is the parent process with process ID = "
             << getpid() << endl;
        cout << "\nThis is the parent process with parent's process ID = "
             << getppid() << endl;

    }
    return 0;
}
```

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             << getpid() << endl;
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             << getppid() << endl;

    }
    return 0;
}
```

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
- **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

```
#include <iostream>
#include <unistd.h>
#include <sys/wait.h>
#include <stdio.h>
#include <string.h>

using namespace std;

int main() {

    int current_pid = getpid();
    cout << "Current process ID is: " << current_pid << endl;

    string progStr;
    // read the name of the program we want to start
    getline(cin, progStr);
    const char *prog = progStr.c_str();

    int pid = fork();

    if (pid == 0) { // child
        execlp(prog, prog, 0); // load the program
        // if prog can actually be started, we will never get to the
        // following statement, as the child process will be replaced by prog!
        printf("Can't load the program %s\n", prog);
    }
    else { // parent
        sleep(1); // give some time to the child process to starting up
        waitpid(pid, 0, 0); // wait for child process to terminate
        printf("Program %s finished!\n", prog);
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execlp loads the program whose name is read from stdin

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path to executable

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argv[0]

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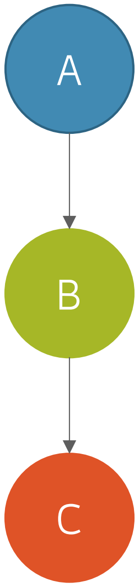
    }
    return 0;
}
```

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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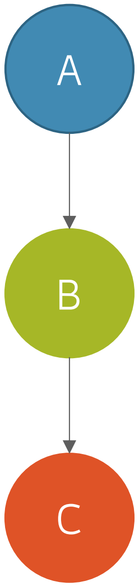



```
int pid = fork();

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

    pid = fork();

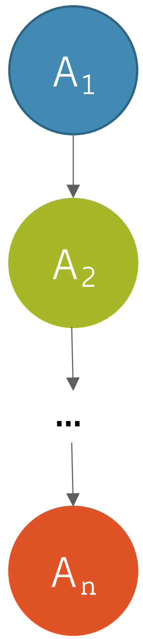
    if(pid == 0) { // B's child (C)

        …
        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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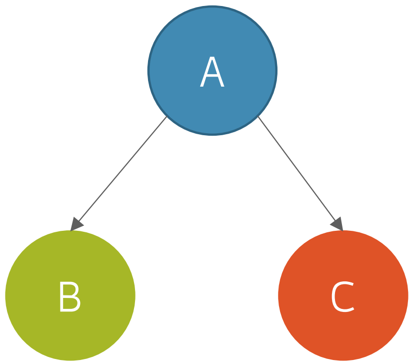

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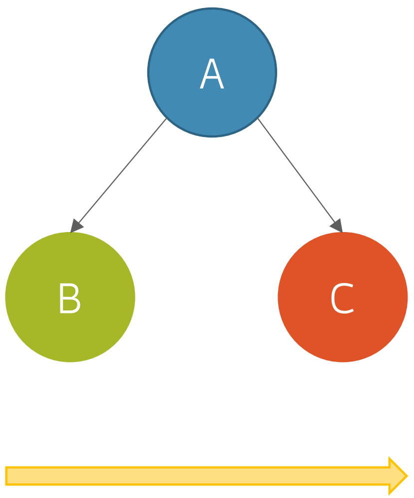

Left-to-Right (by convention)

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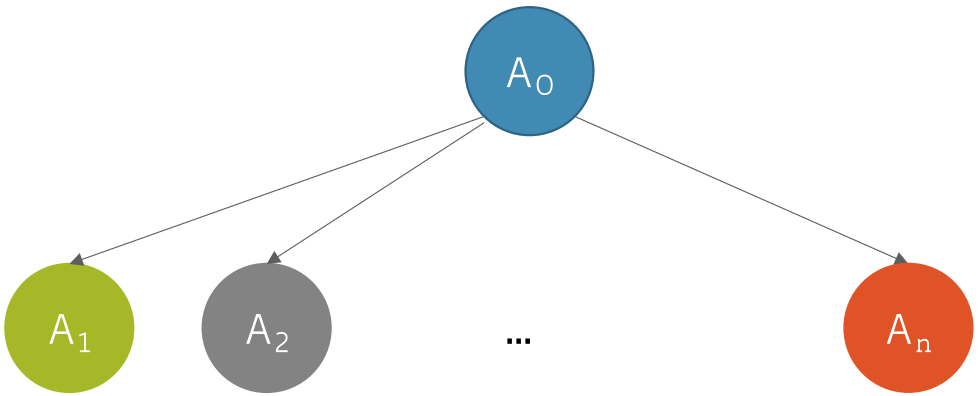
        ...
        execlp(...);
}
else { // A

    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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- 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

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- **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
  - 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

Process Termination

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Process Termination

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- 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

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  1. keep the CPU busy at all times
  2. 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
- 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

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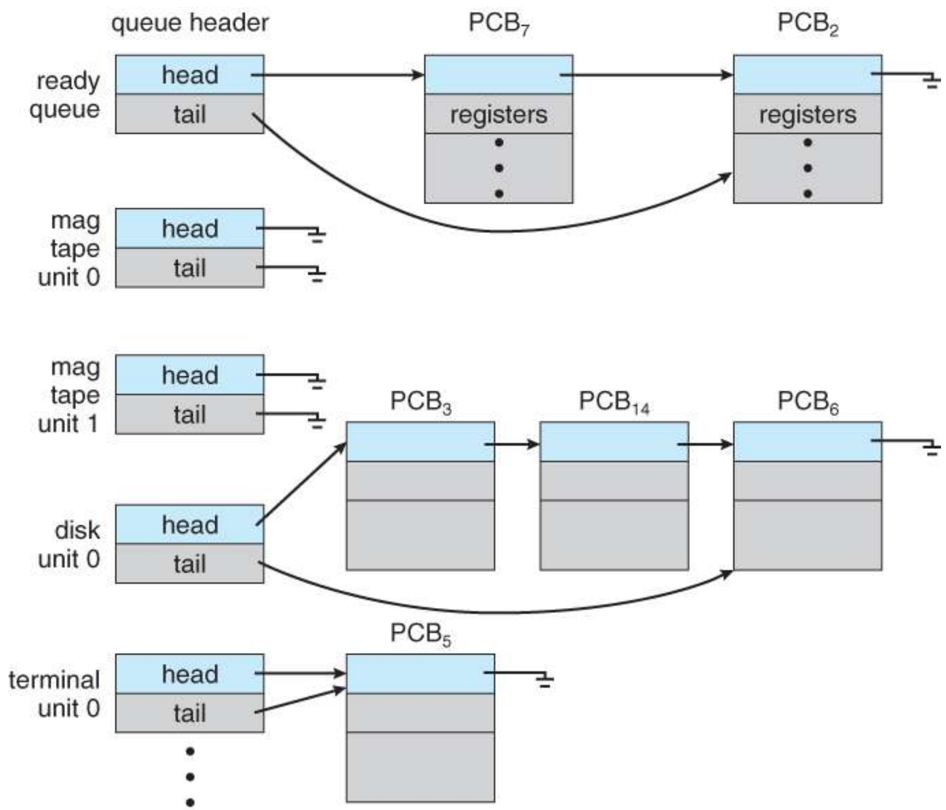
- When the OS changes the status of a process (e.g., from ready to running) the PCB is unlinked from one queue and moved to appropriate one
- The OS may use different policies to manage each state queue

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

Schedulers

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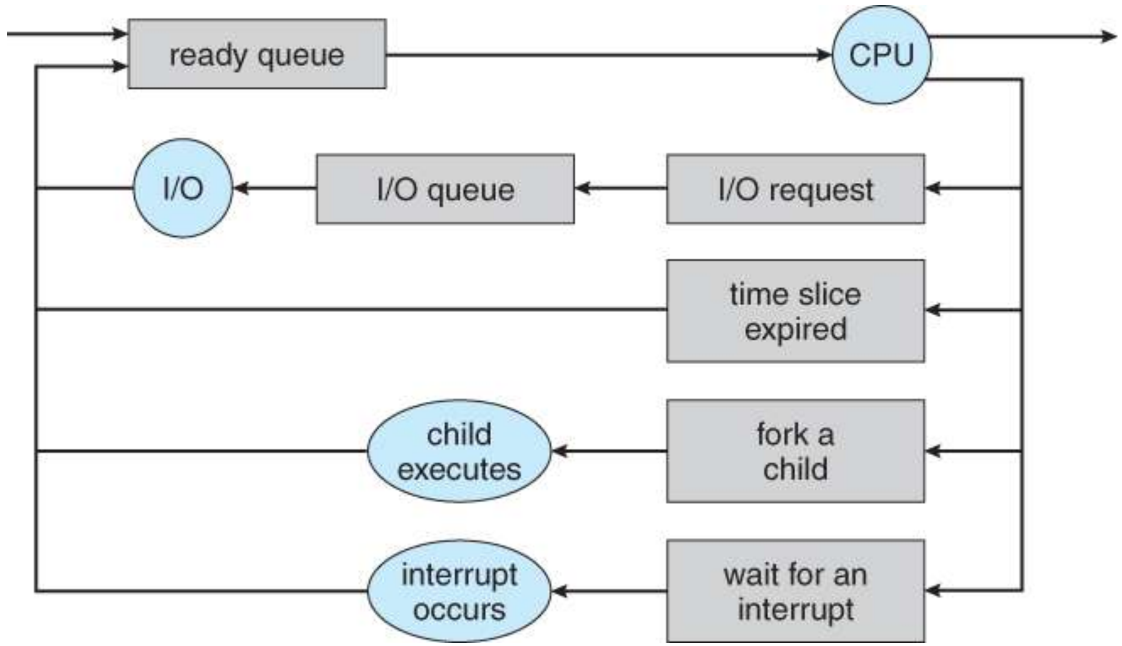
- When system loads get high, a medium-term scheduler allows smaller faster jobs to finish up quickly and clear the system
- An efficient scheduling system will select a good mix of CPU-bound processes and I/O bound processes

Schedulers: Queuing Diagram



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- It is a highly costly operation because:
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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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- 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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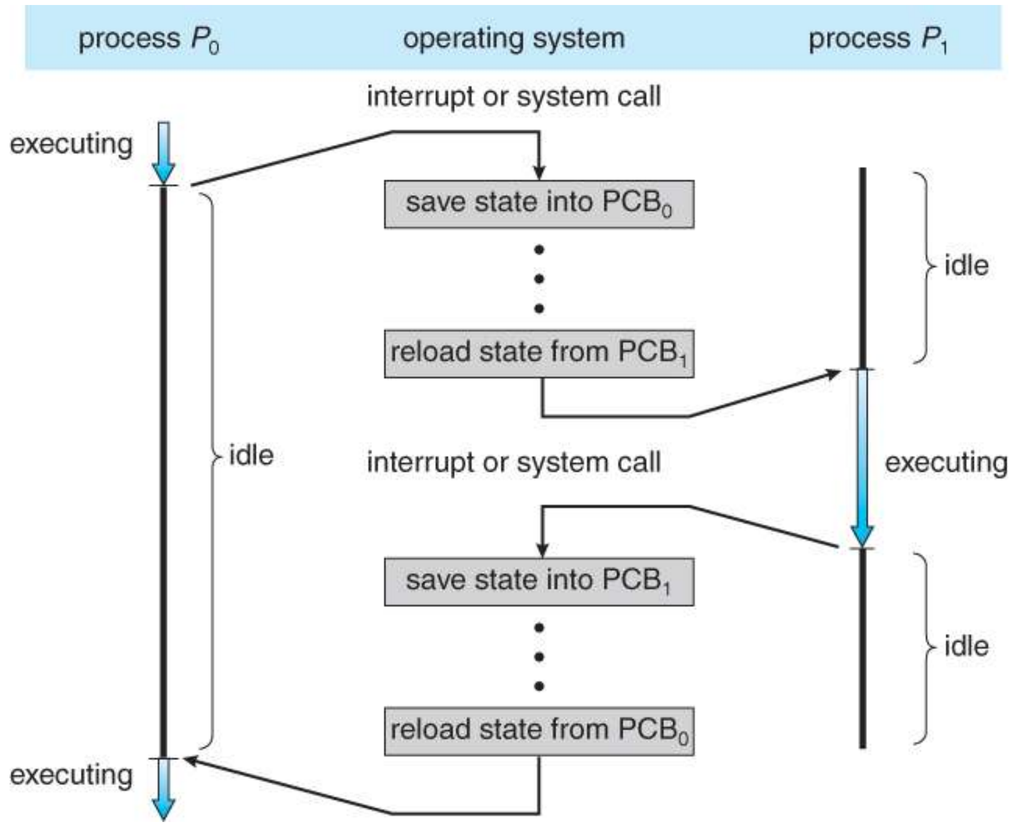
Trade-off

- 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**

Context Switch: A Few Numbers

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

Context Switch: Example



Outline

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

Interprocess Communication

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

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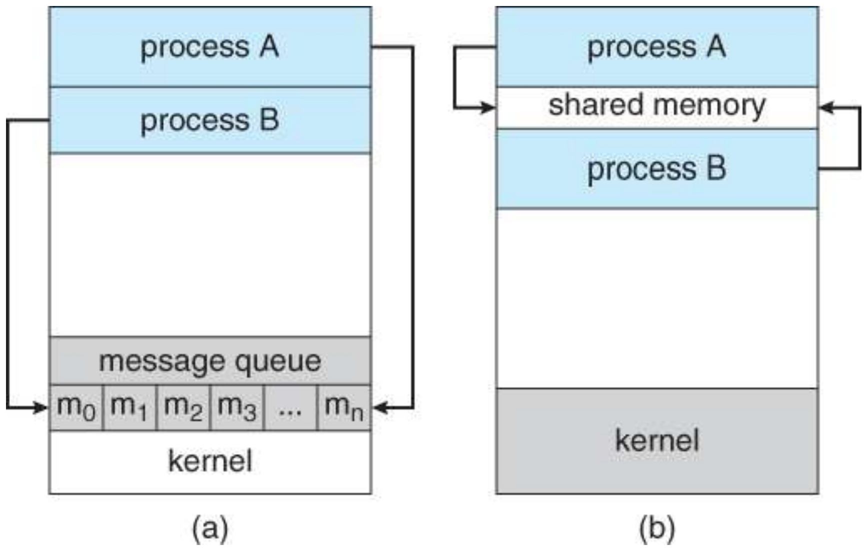
- **Computation speedup** → A problem can be solved faster if it can be broken down into sub-tasks to be solved simultaneously
- **Modularity** → The most efficient architecture may be to break a system down into cooperating modules
- **Convenience** → Even a single user may be multi-tasking, such as 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:
  - 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

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- **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
- **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

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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**