# Systems and Networking – Unit I

## B.Sc. in Applied Computer Science and Artificial Intelligence

## 2021-2022


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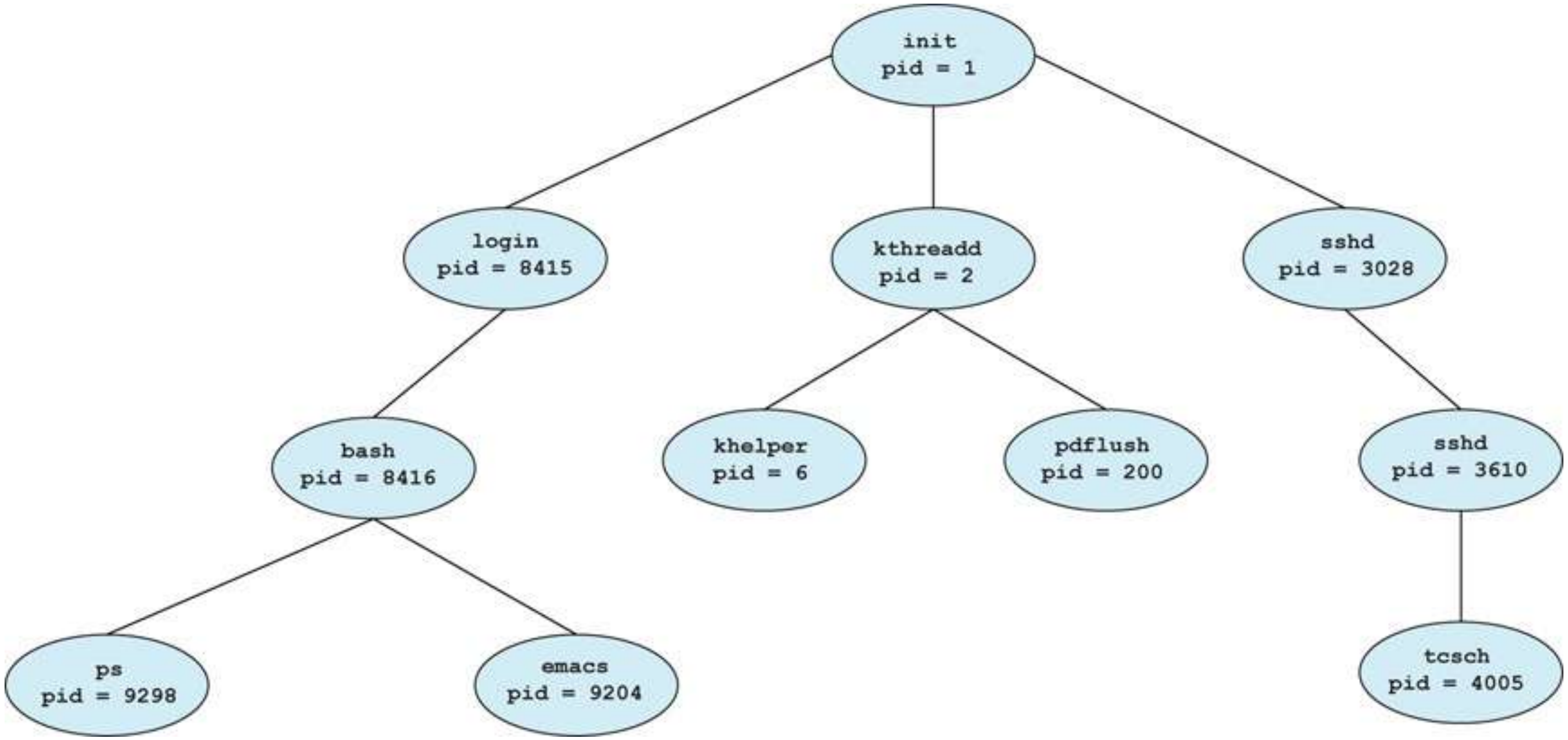
  - The parent shares resources and privileges to its children
  - A parent can either wait for a child to complete, or continue in parallel
- Each process is given an integer identifier (a.k.a. process identifier or PID)
- The parent PID (PPID) is also stored for each process

# 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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    - 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

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    (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);
   }
}
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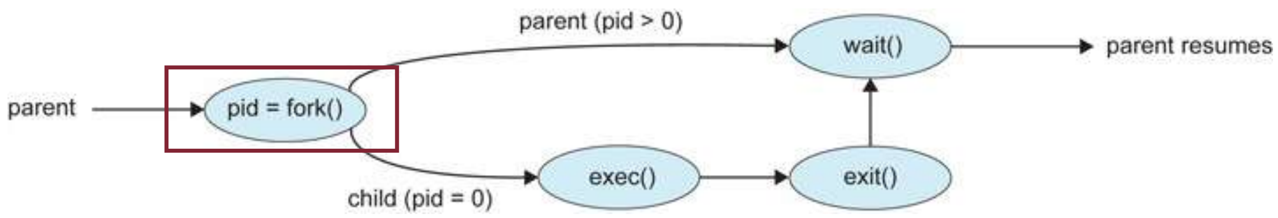
**Figure 3.10** C program forking a separate process.



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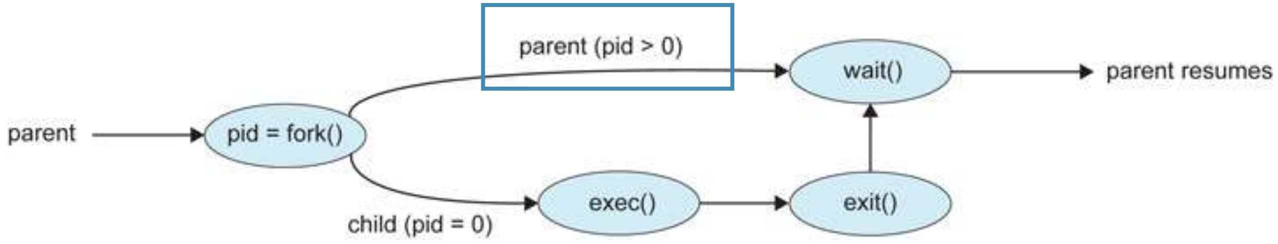


In the parent process, **`fork()`** returns the PID of the child

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int main()
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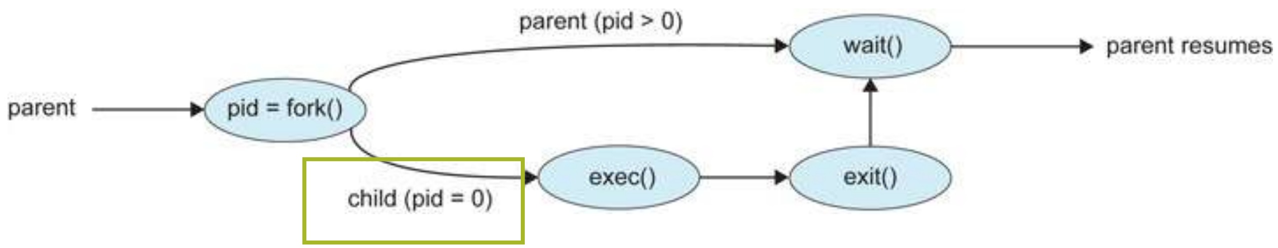
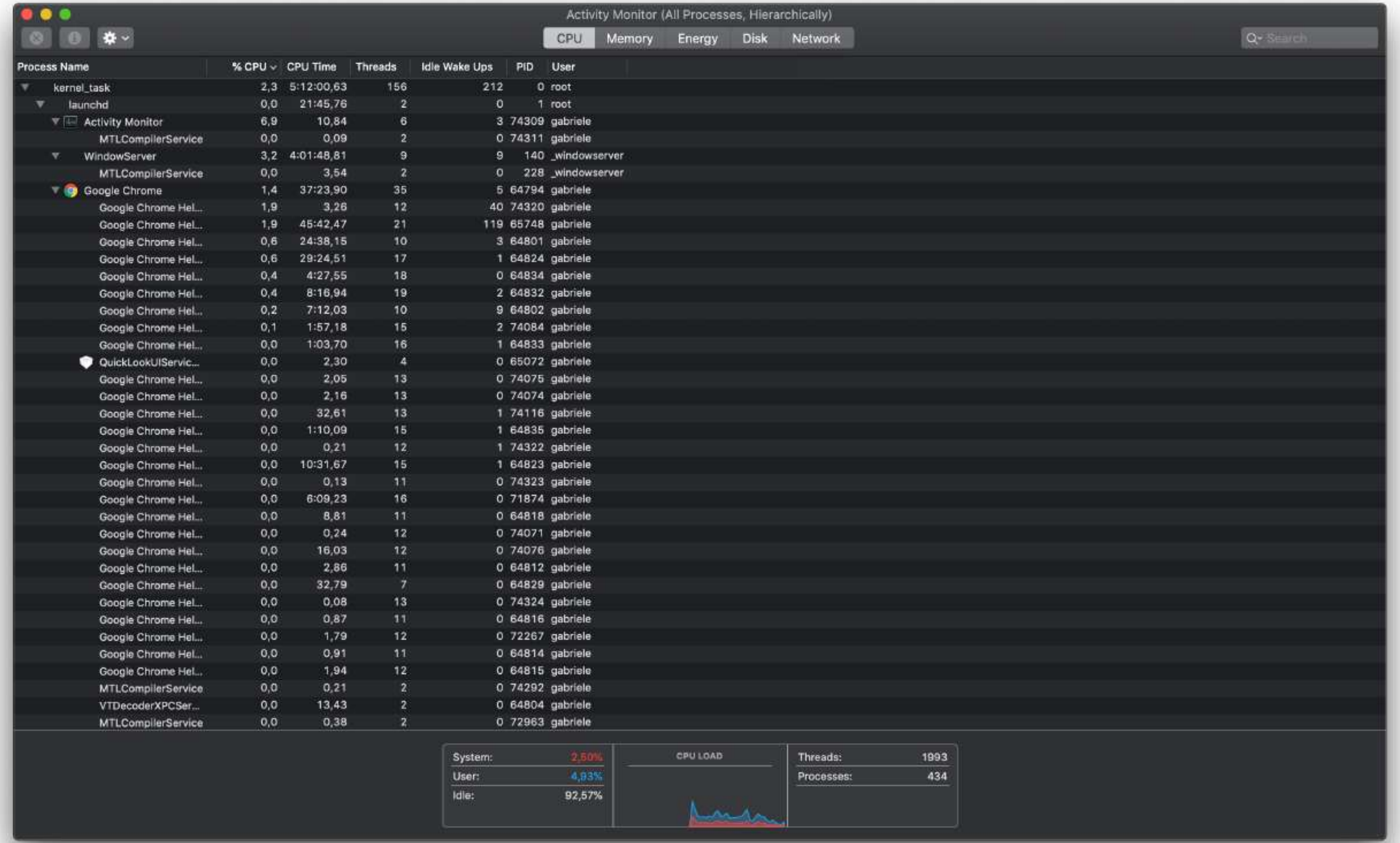


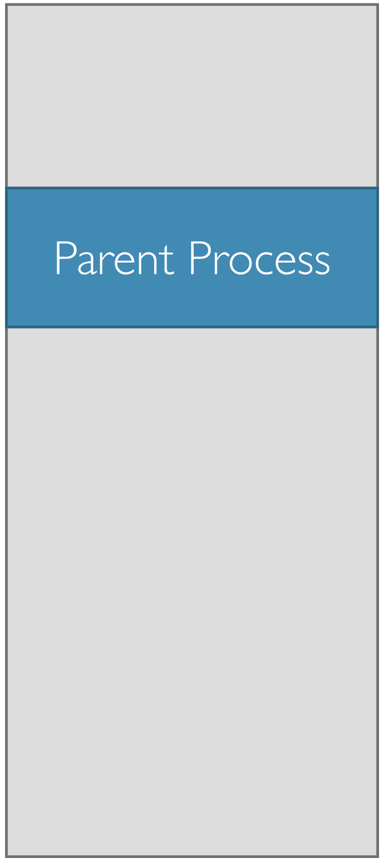

In the child process, it returns 0

# Process Creation: Activity Monitor




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

# Process Creation: Parent vs. Child Layout




Main Memory

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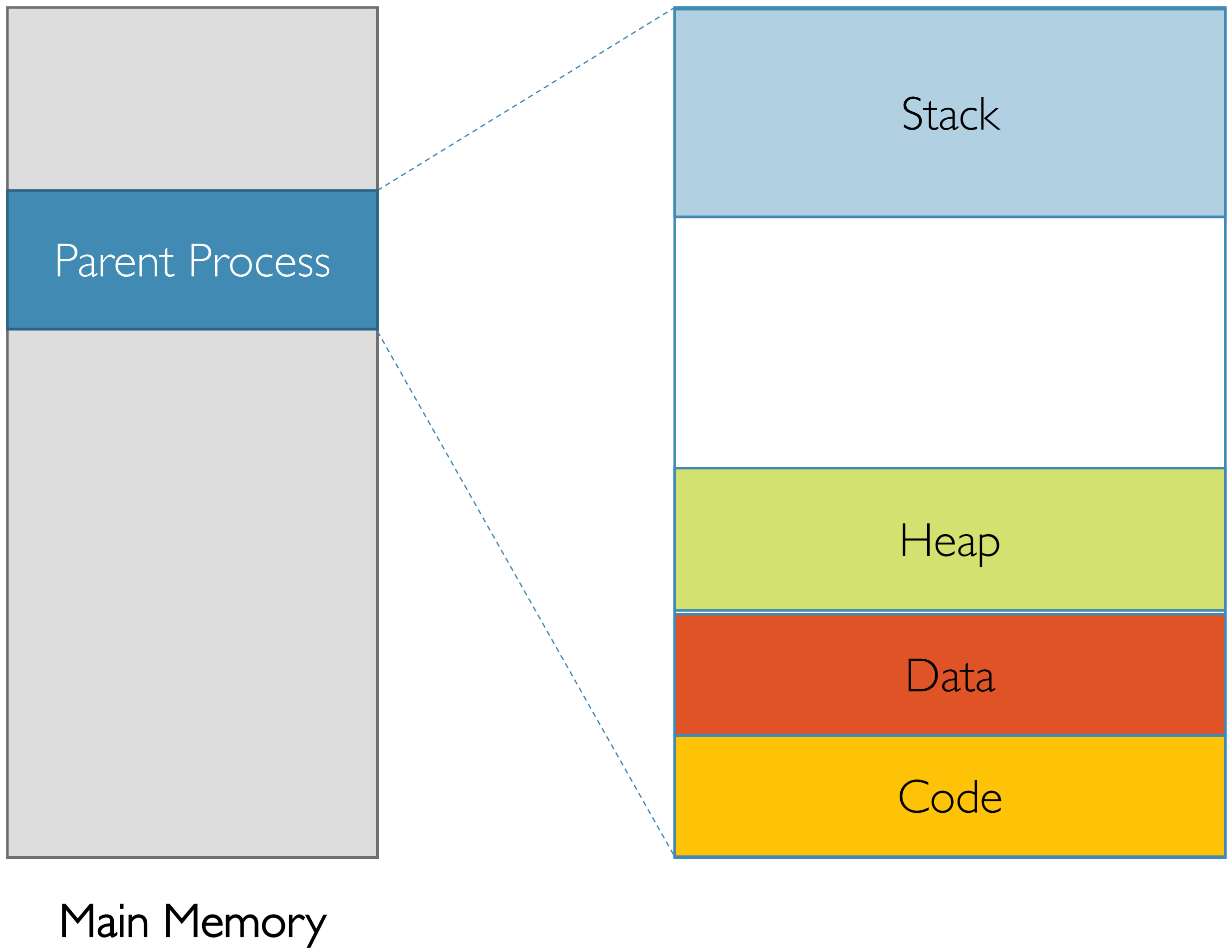

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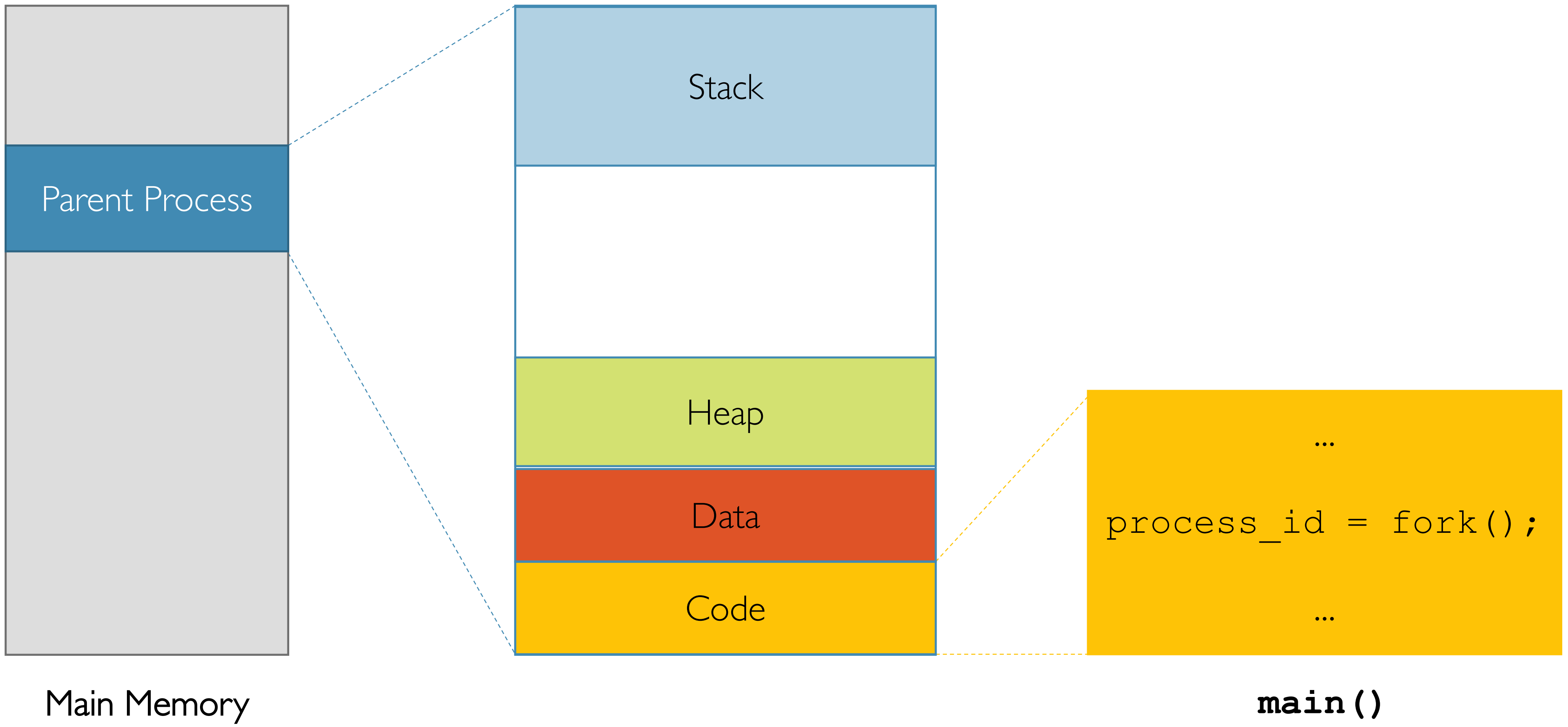

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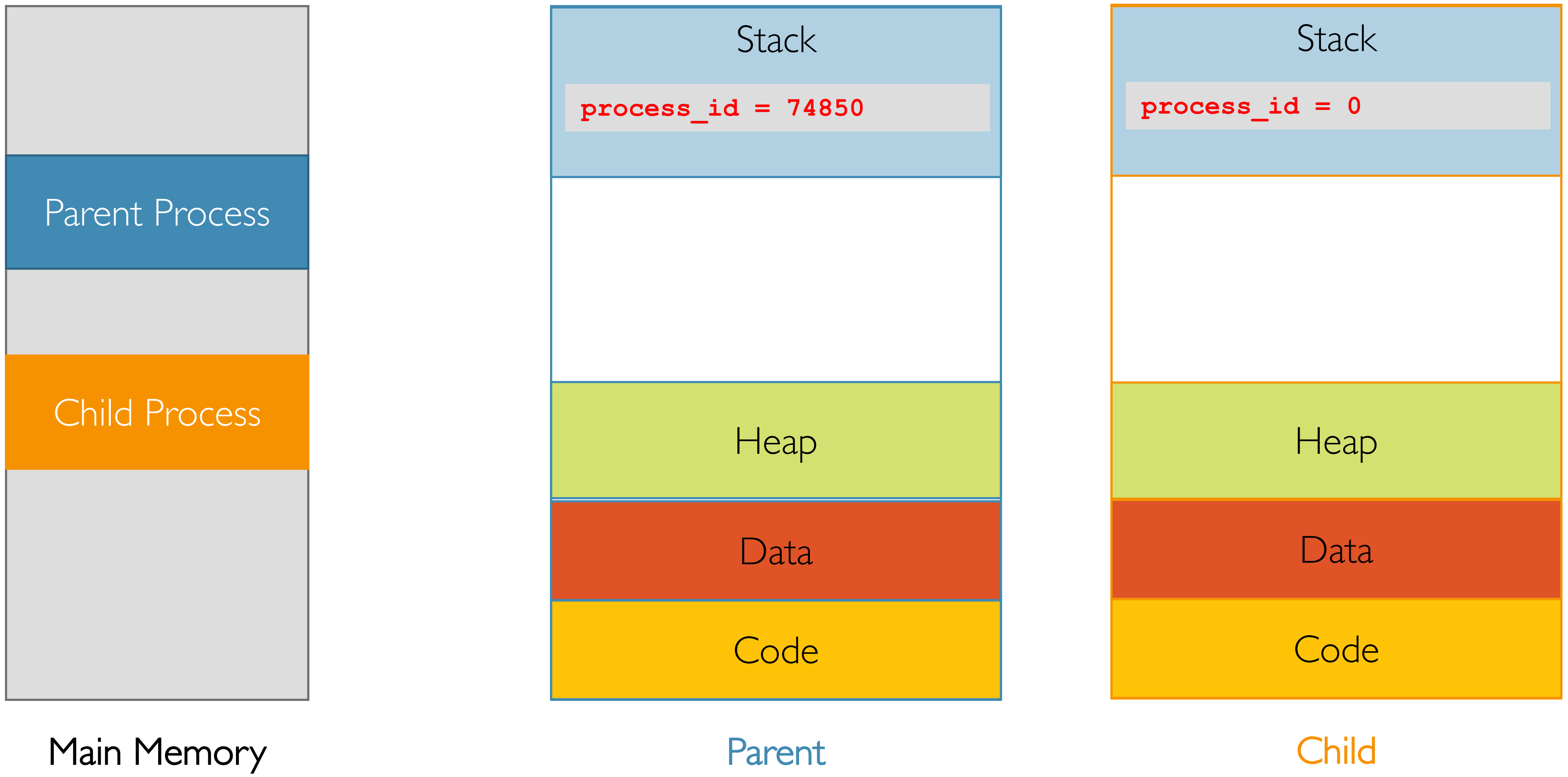

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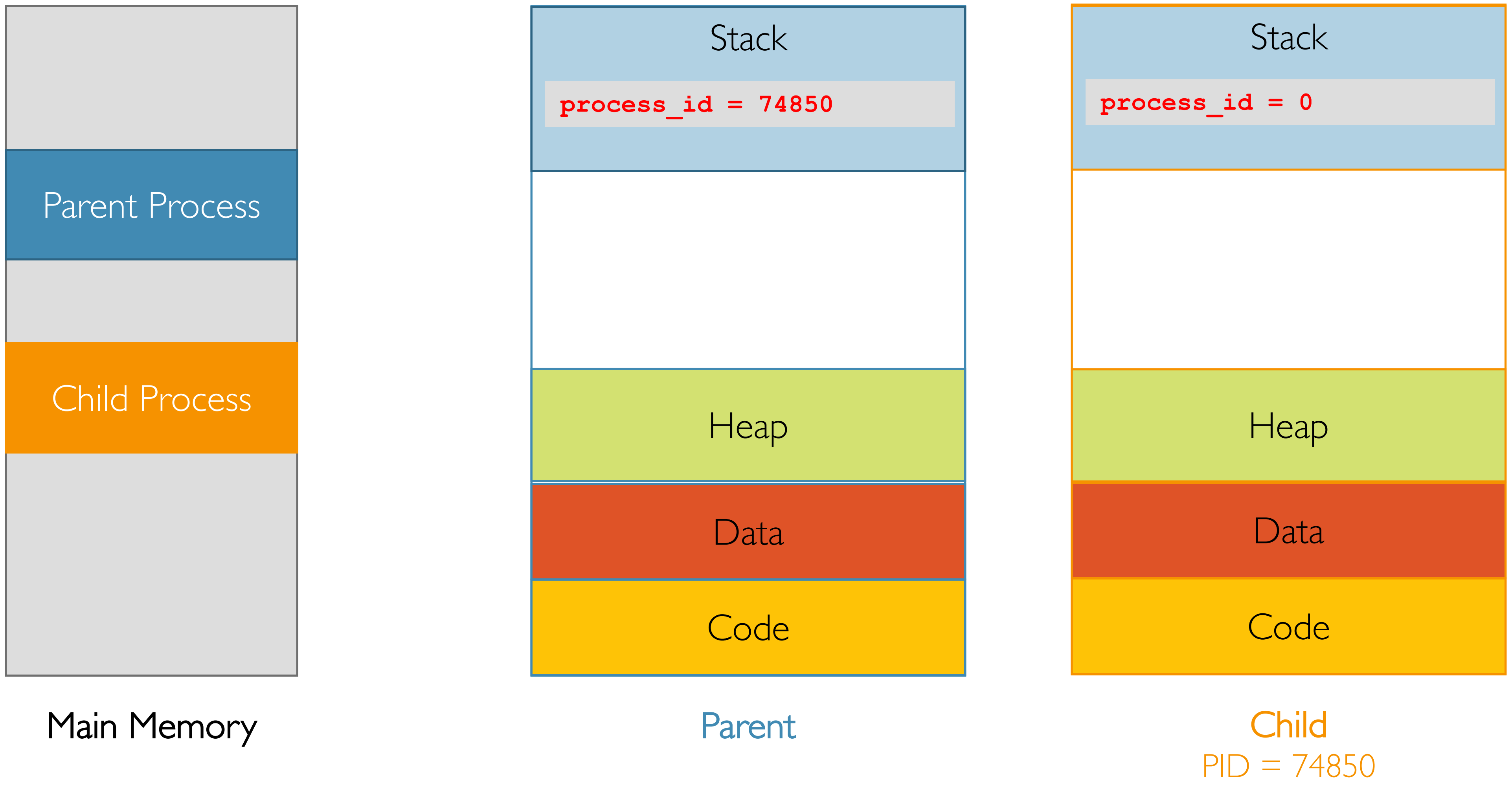

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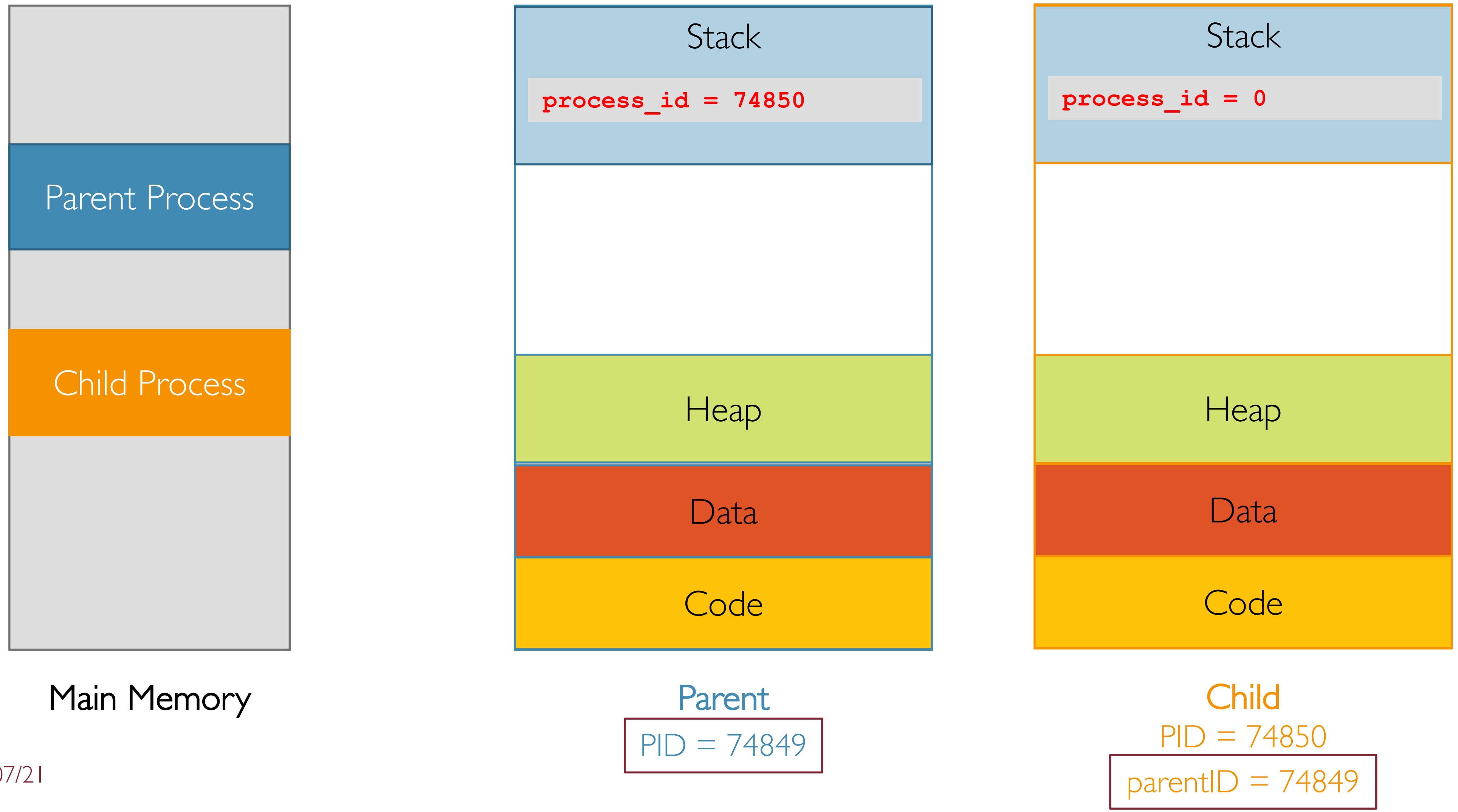

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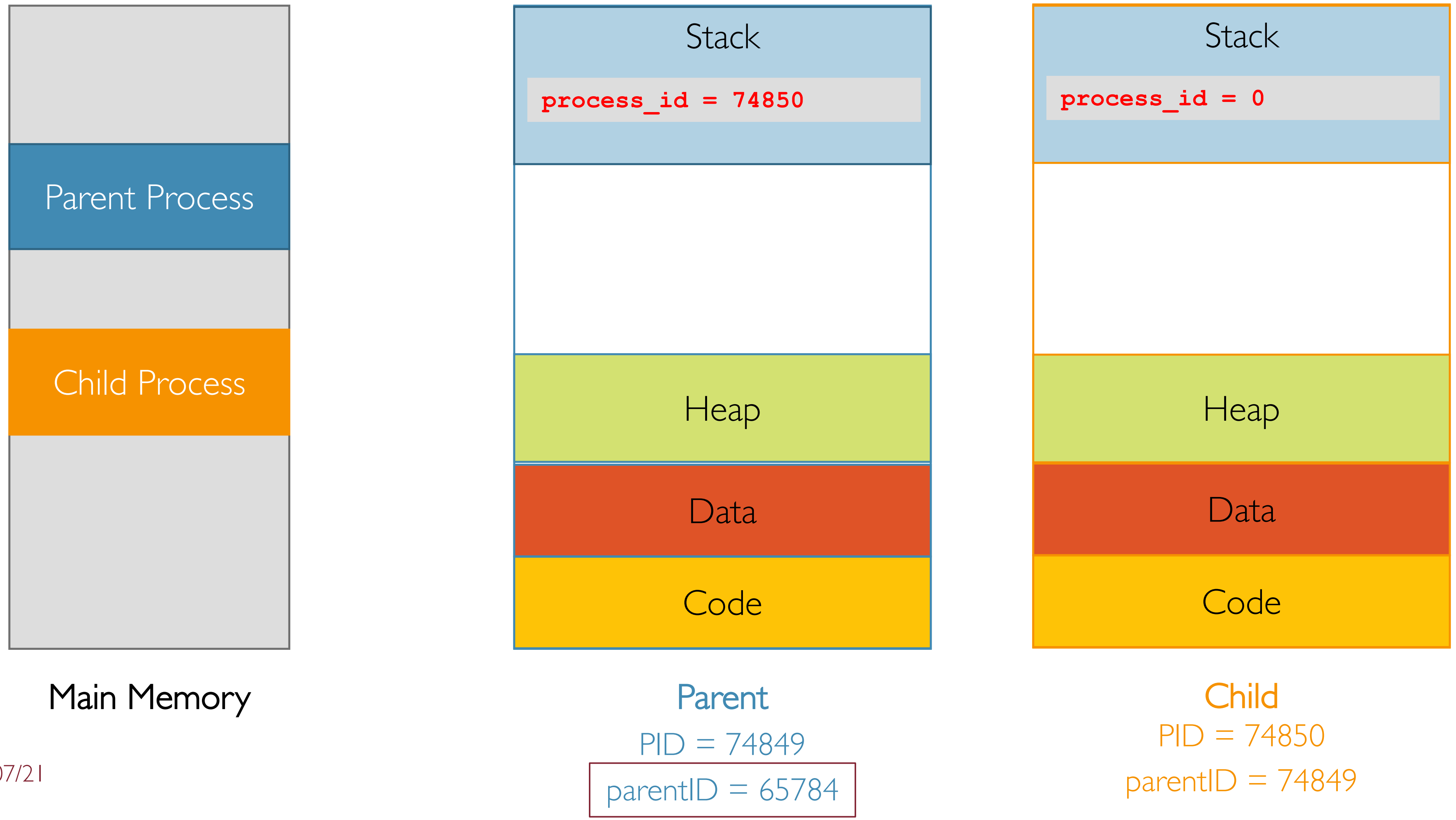

# Process Creation: Code Example

```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 = "
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    }
    return 0;
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    }
    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!

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  - e.g., try typing **`emacs`** on your shell

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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
- 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
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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;
}
```
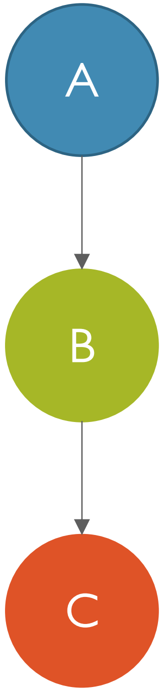

**`waitpid`** allows the parent to wait for a child process to finish

```
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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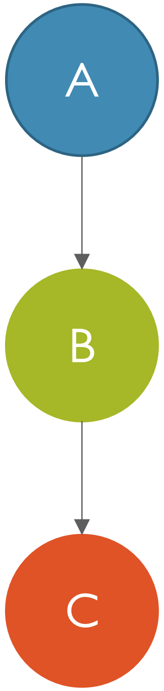
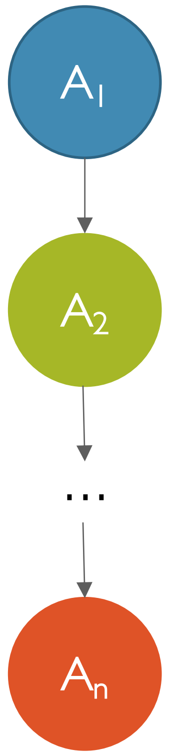



```
int pid = fork();

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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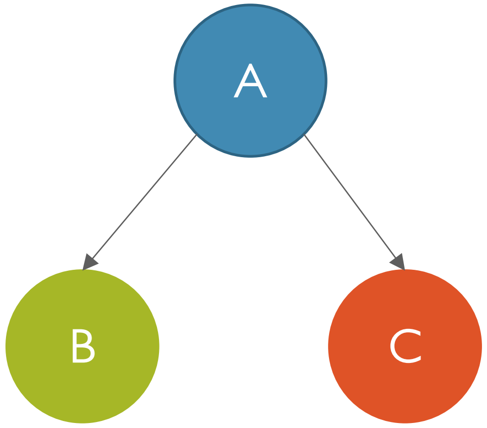

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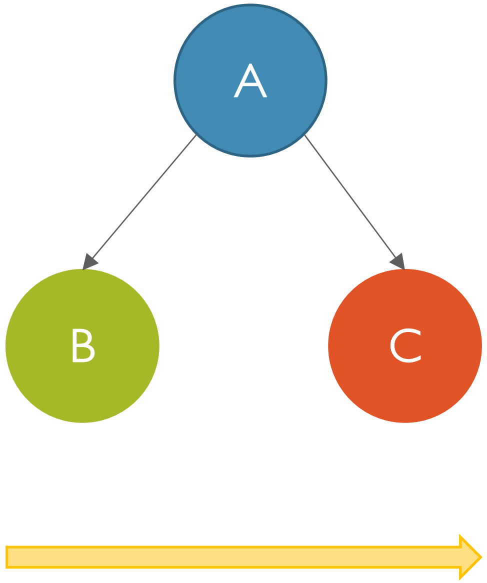


Left-to-Right (by convention)

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

    pid = fork();

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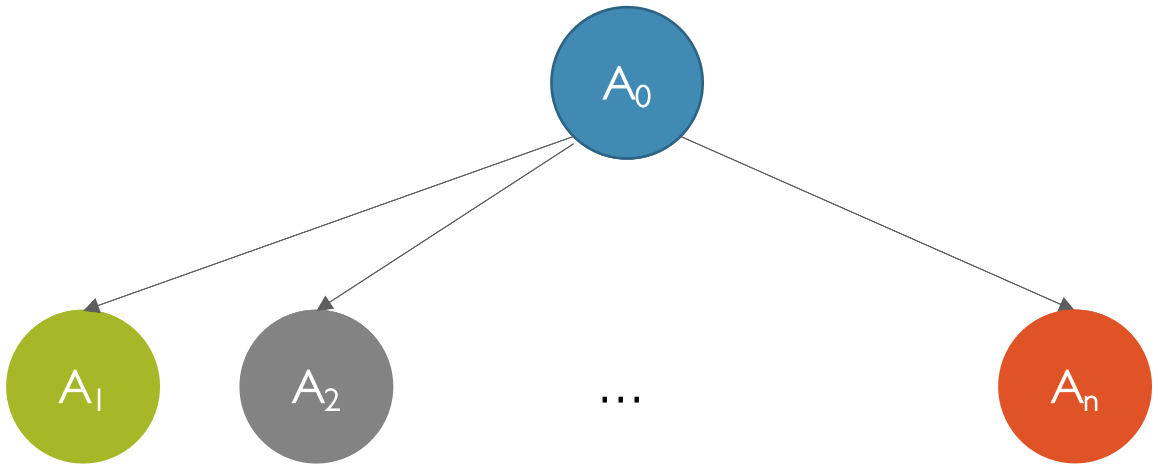

# Process Creation and Execution: Exercise

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();
}
```

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Infinite number of child processes growing with an exponential rate

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# Recap of System Calls Seen So Far

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- **`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

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# 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

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- Processes may also be terminated by the system for a variety of reasons:
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  - 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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- 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

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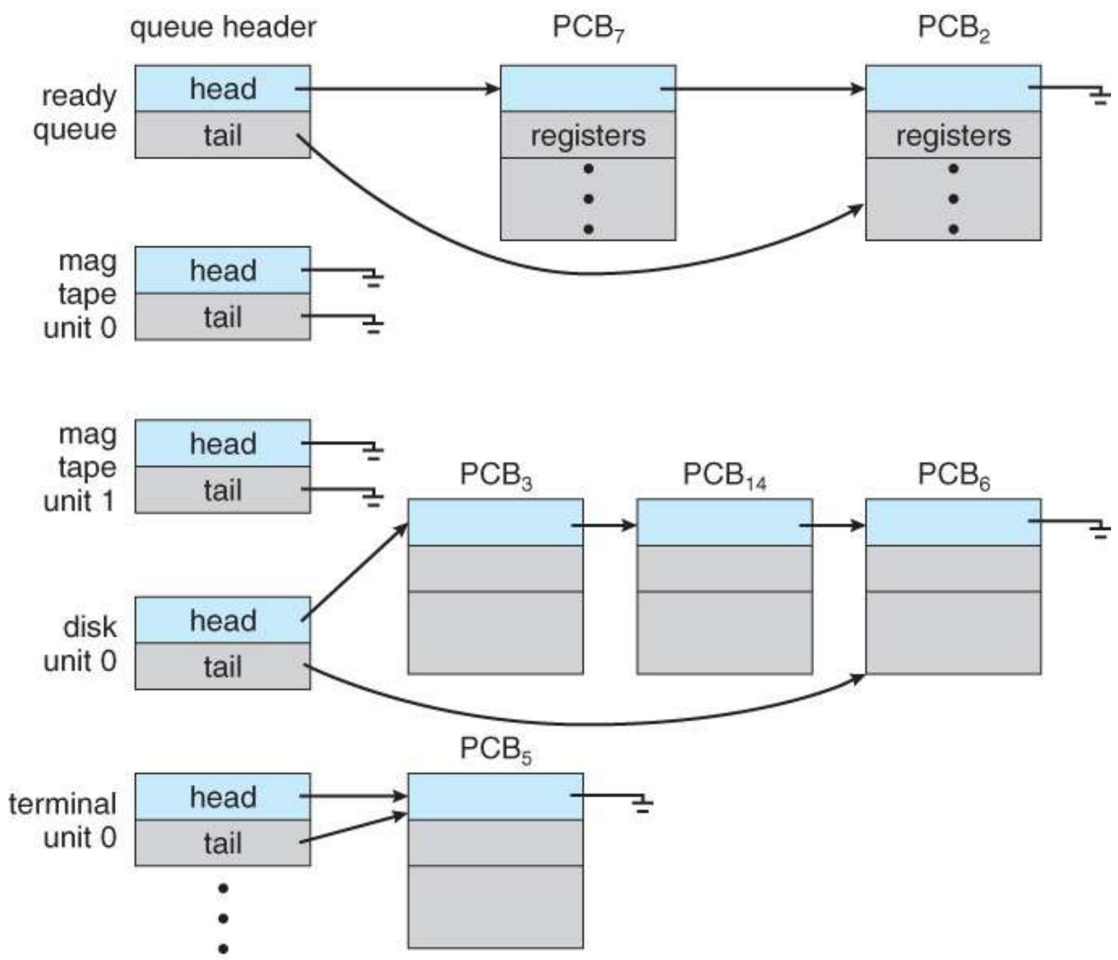
  - keep the CPU busy at all times
  - deliver "acceptable" response times for all programs, particularly for interactive ones
- The process scheduler must meet these objectives by implementing suitable policies for swapping processes in and out of the CPU
- Note that these objectives can be conflicting!
  - 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 mantains 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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  - The Running Queue is bound by the number of cores available on the system
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- 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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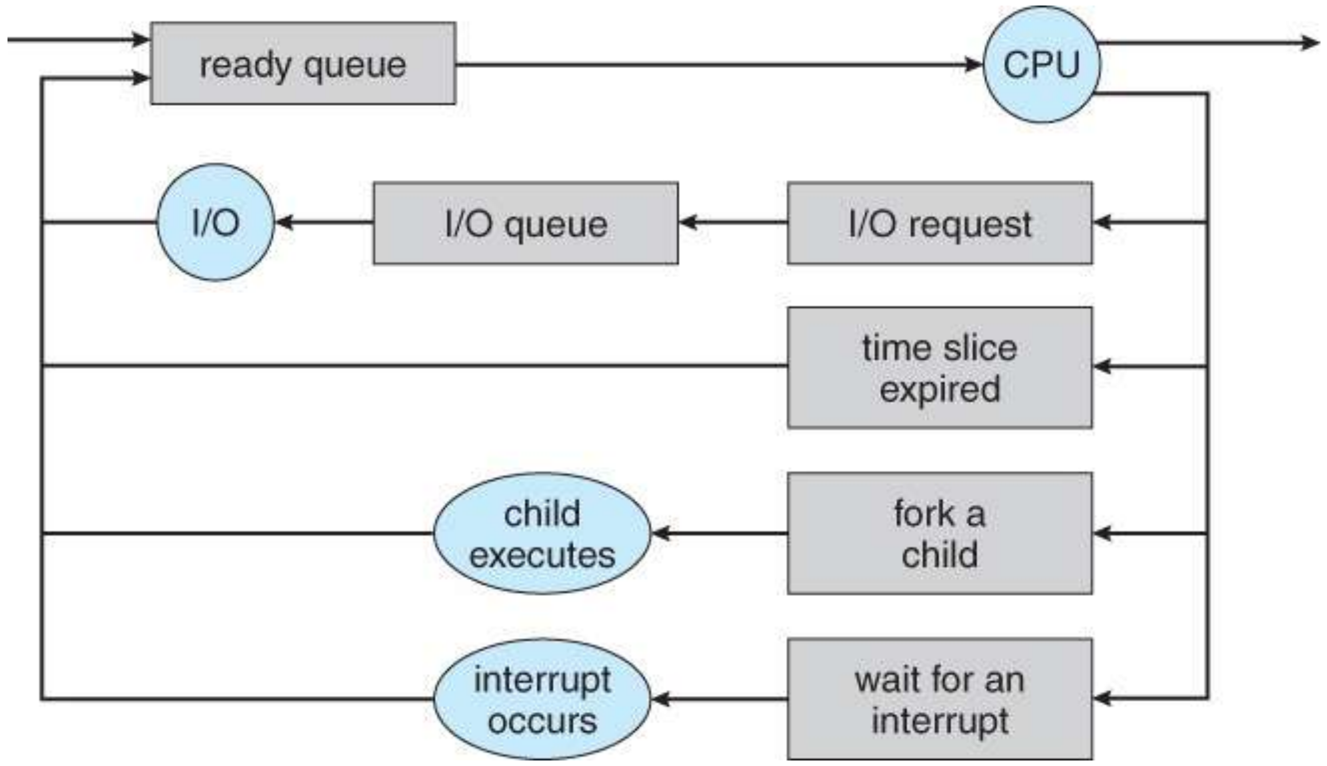
- Some systems also employ a medium-term scheduler: when system loads get high, this scheduler allows smaller faster jobs to finish up quickly and clear the system
- An efficient scheduling system will select a good mix of CPU-bound processes and I/O bound processes

# Schedulers: Queuing Diagram



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  - 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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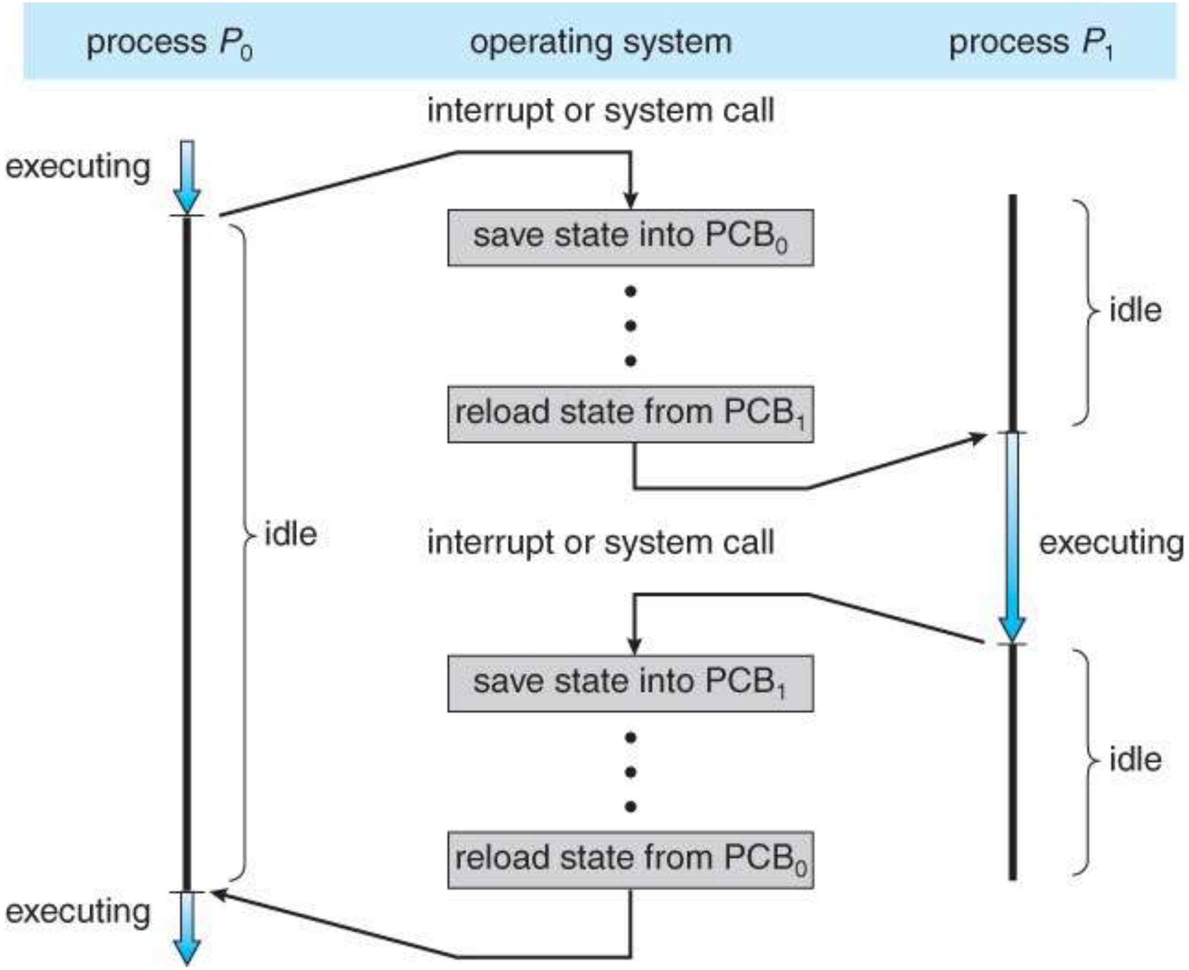
- Typical values of time slice are between 10 and 100 ms, and context switch takes around 10 μs, so the overhead is small relative to time slice

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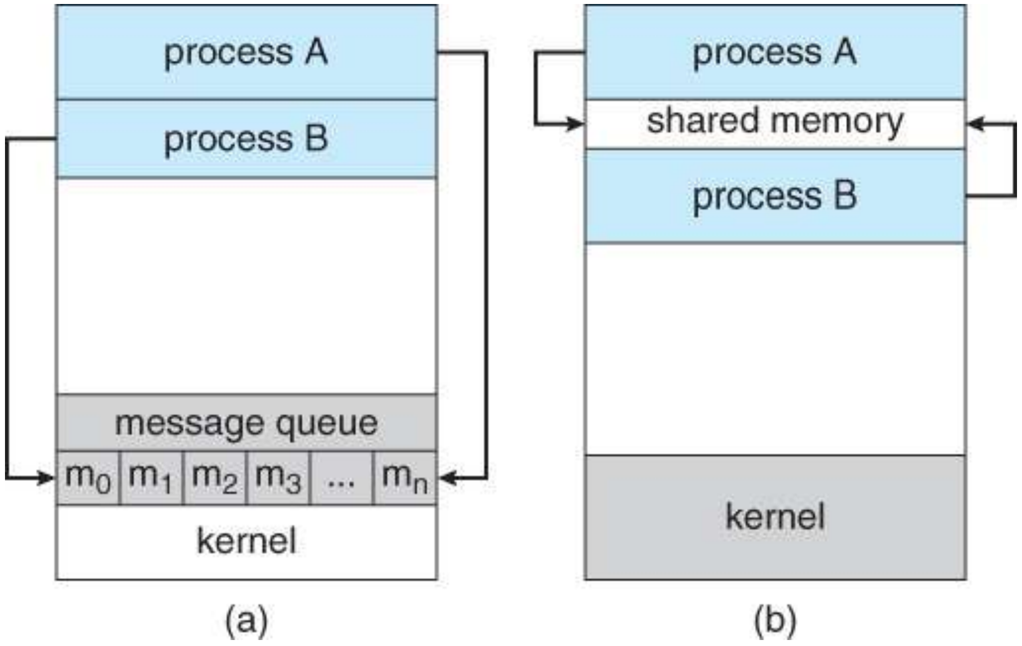
- Modularity → The most efficient architecture may be to break a system down into cooperating modules
- Convenience → Even a single user may be multi-tasking, such as editing, compiling, printing, and running the same code in different windows

# Cooperating Processes: Communication

- 2 possible ways for cooperating processes to communicate:




Message Passing — Shared Memory

# Shared Memory vs. Message Passing

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  - Preferable when (large amount of) information must be shared on the same computer
- 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
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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

# 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