Systems and Networking – Unit I

B.Sc. in Applied Computer Science and Artificial Intelligence

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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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Process Creation

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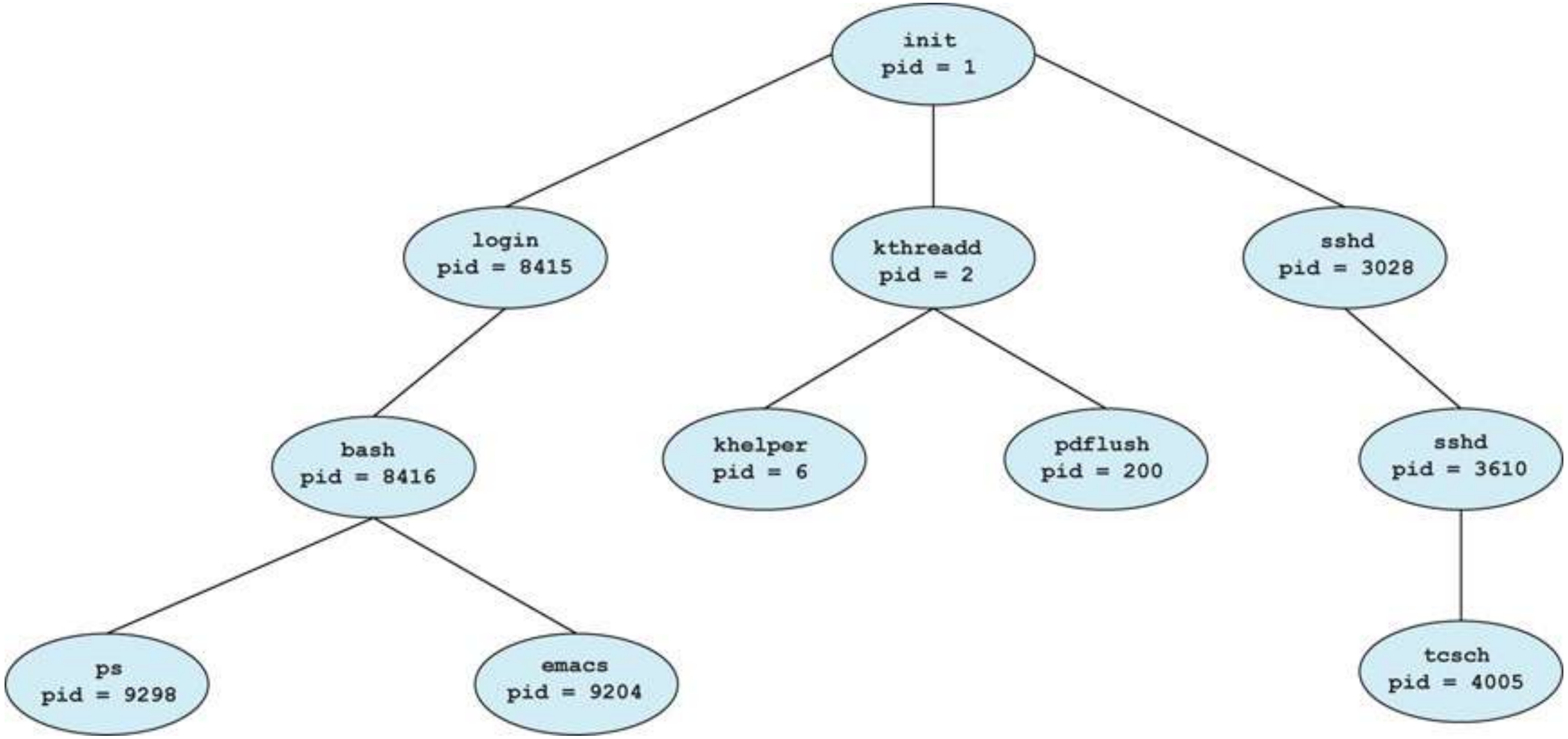
  - The parent shares resources and privileges to its children
  - A parent can either wait for a child to complete, or continue in parallel
- Each process is given an integer identifier (a.k.a. process identifier or PID)
- The parent PID (PPID) is also stored for each process

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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  - 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

```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");
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   }
   else if (pid == 0) {/* child process */
      execlp("/bin/ls","ls",NULL);
   }
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      wait(NULL);
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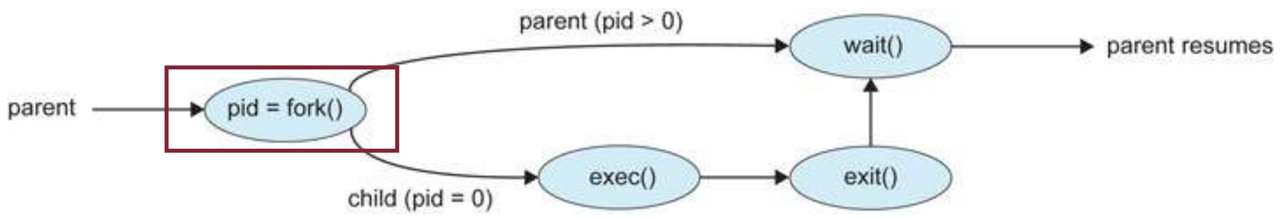
}
```

Figure 3.10 C program forking a separate process.



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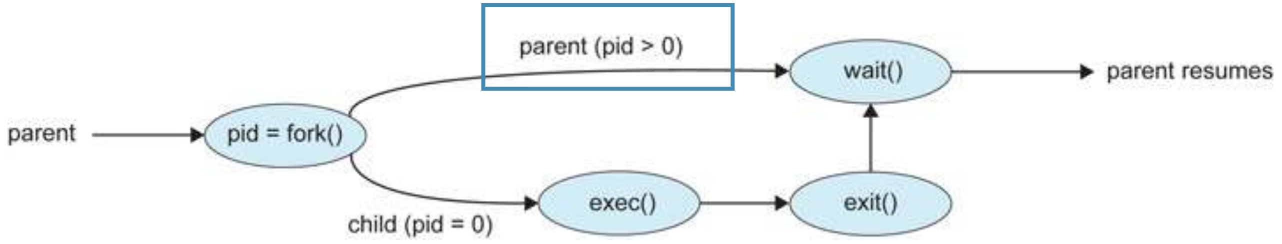

In the parent process, **`fork()`** returns the PID of the child

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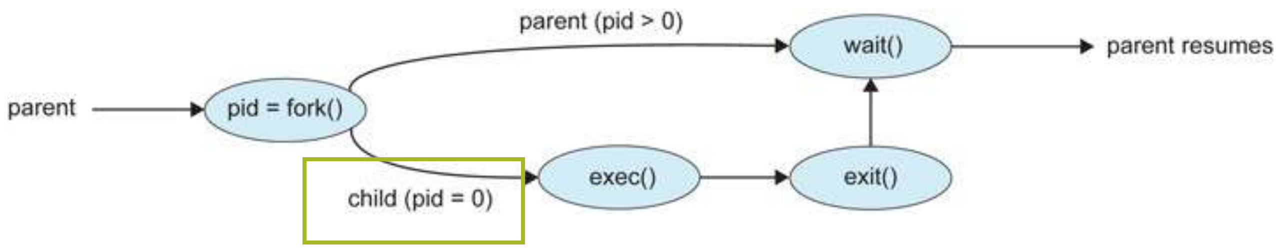
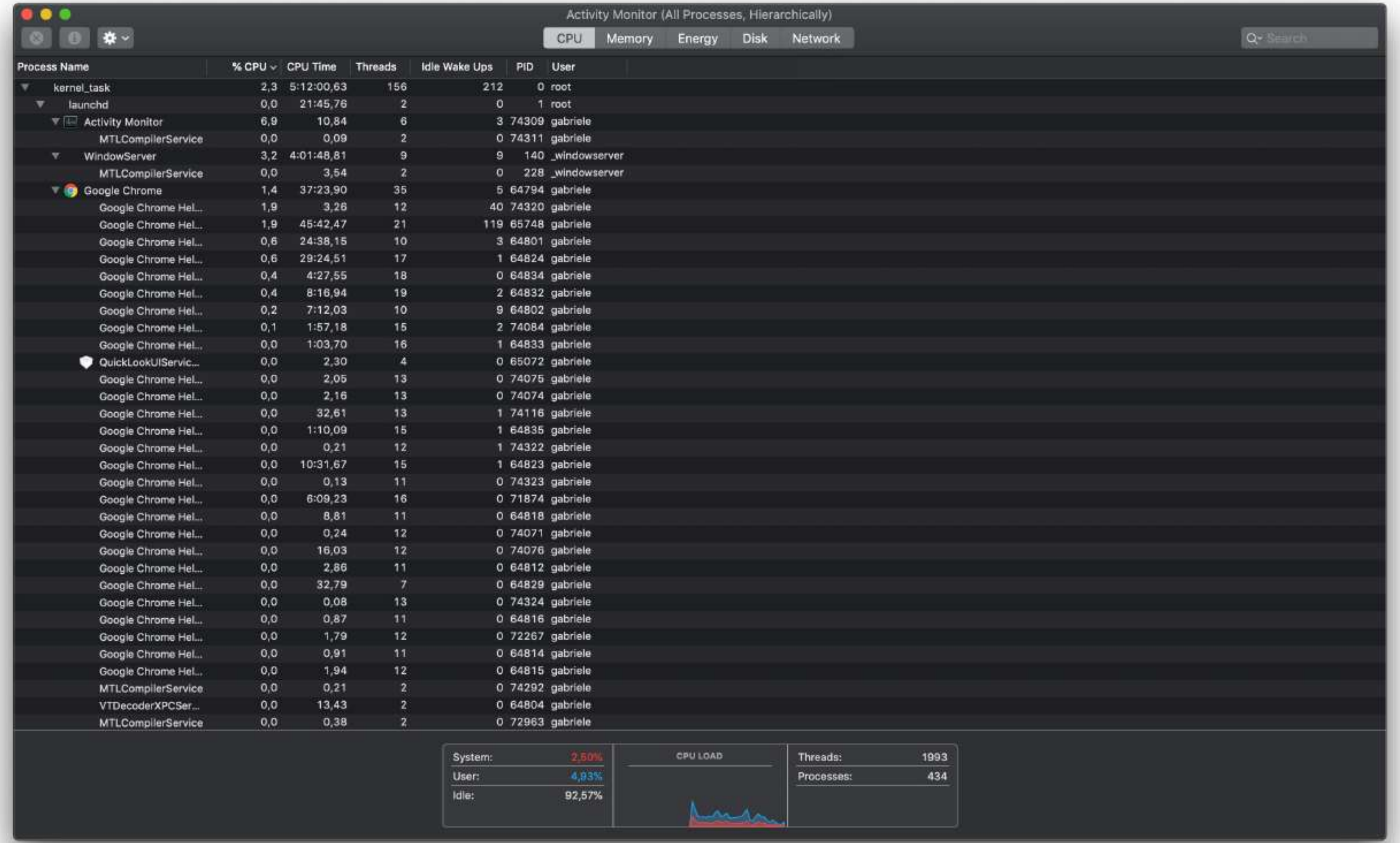


In the child process, it returns 0

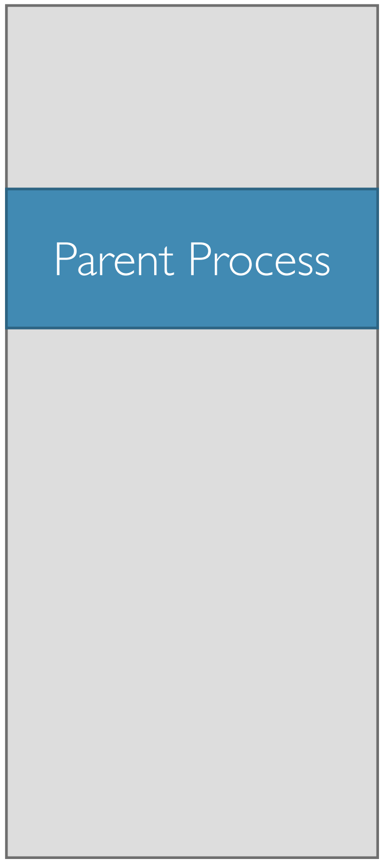
Process Creation: Activity Monitor



Process Name	% CPU	CPU Time	Threads	Idle Wake Ups	PID	User
kernel_task	2,3	5:12:00,63	156	212	0	root
launchd	0,0	21:45,76	2	0	1	root
Activity Monitor	6,9	10,84	6	3	74309	gabriele
MTLCompilerService	0,0	0,09	2	0	74311	gabriele
WindowServer	3,2	4:01:48,81	9	9	140	_windowserver
MTLCompilerService	0,0	3,54	2	0	228	_windowserver
Google Chrome	1,4	37:23,90	35	5	64794	gabriele
Google Chrome Hel...	1,9	3,26	12	40	74320	gabriele
Google Chrome Hel...	1,9	45:42,47	21	119	65748	gabriele
Google Chrome Hel...	0,6	24:38,15	10	3	64801	gabriele
Google Chrome Hel...	0,6	29:24,51	17	1	64824	gabriele
Google Chrome Hel...	0,4	4:27,55	18	0	64834	gabriele
Google Chrome Hel...	0,4	8:16,94	19	2	64832	gabriele
Google Chrome Hel...	0,2	7:12,03	10	9	64802	gabriele
Google Chrome Hel...	0,1	1:57,18	15	2	74084	gabriele
Google Chrome Hel...	0,0	1:03,70	16	1	64833	gabriele
QuickLookUIServic...	0,0	2,30	4	0	65072	gabriele
Google Chrome Hel...	0,0	2,05	13	0	74075	gabriele
Google Chrome Hel...	0,0	2,16	13	0	74074	gabriele
Google Chrome Hel...	0,0	32,61	13	1	74116	gabriele
Google Chrome Hel...	0,0	1:10,09	15	1	64835	gabriele
Google Chrome Hel...	0,0	0,21	12	1	74322	gabriele
Google Chrome Hel...	0,0	10:31,67	15	1	64823	gabriele
Google Chrome Hel...	0,0	0,13	11	0	74323	gabriele
Google Chrome Hel...	0,0	6:09,23	16	0	71874	gabriele
Google Chrome Hel...	0,0	8,81	11	0	64818	gabriele
Google Chrome Hel...	0,0	0,24	12	0	74071	gabriele
Google Chrome Hel...	0,0	16,03	12	0	74076	gabriele
Google Chrome Hel...	0,0	2,86	11	0	64812	gabriele
Google Chrome Hel...	0,0	32,79	7	0	64829	gabriele
Google Chrome Hel...	0,0	0,08	13	0	74324	gabriele
Google Chrome Hel...	0,0	0,87	11	0	64816	gabriele
Google Chrome Hel...	0,0	1,79	12	0	72267	gabriele
Google Chrome Hel...	0,0	0,91	11	0	64814	gabriele
Google Chrome Hel...	0,0	1,94	12	0	64815	gabriele
MTLCompilerService	0,0	0,21	2	0	74292	gabriele
VTDecoderXPCSer...	0,0	13,43	2	0	64804	gabriele
MTLCompilerService	0,0	0,38	2	0	72963	gabriele

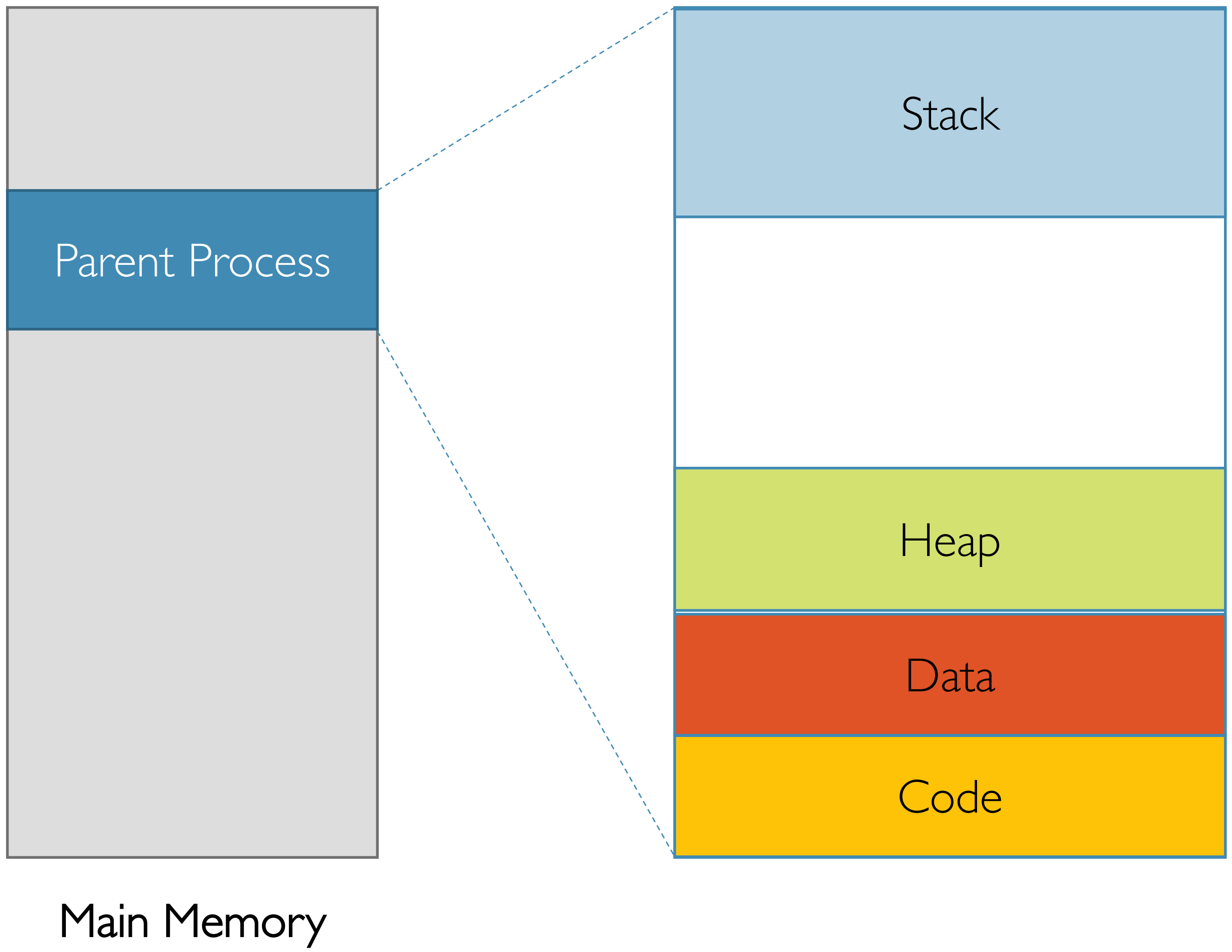
Hierarchy of Processes
(i.e., process tree)

Process Creation: Parent vs. Child Layout



Main Memory

Process Creation: Parent vs. Child Layout



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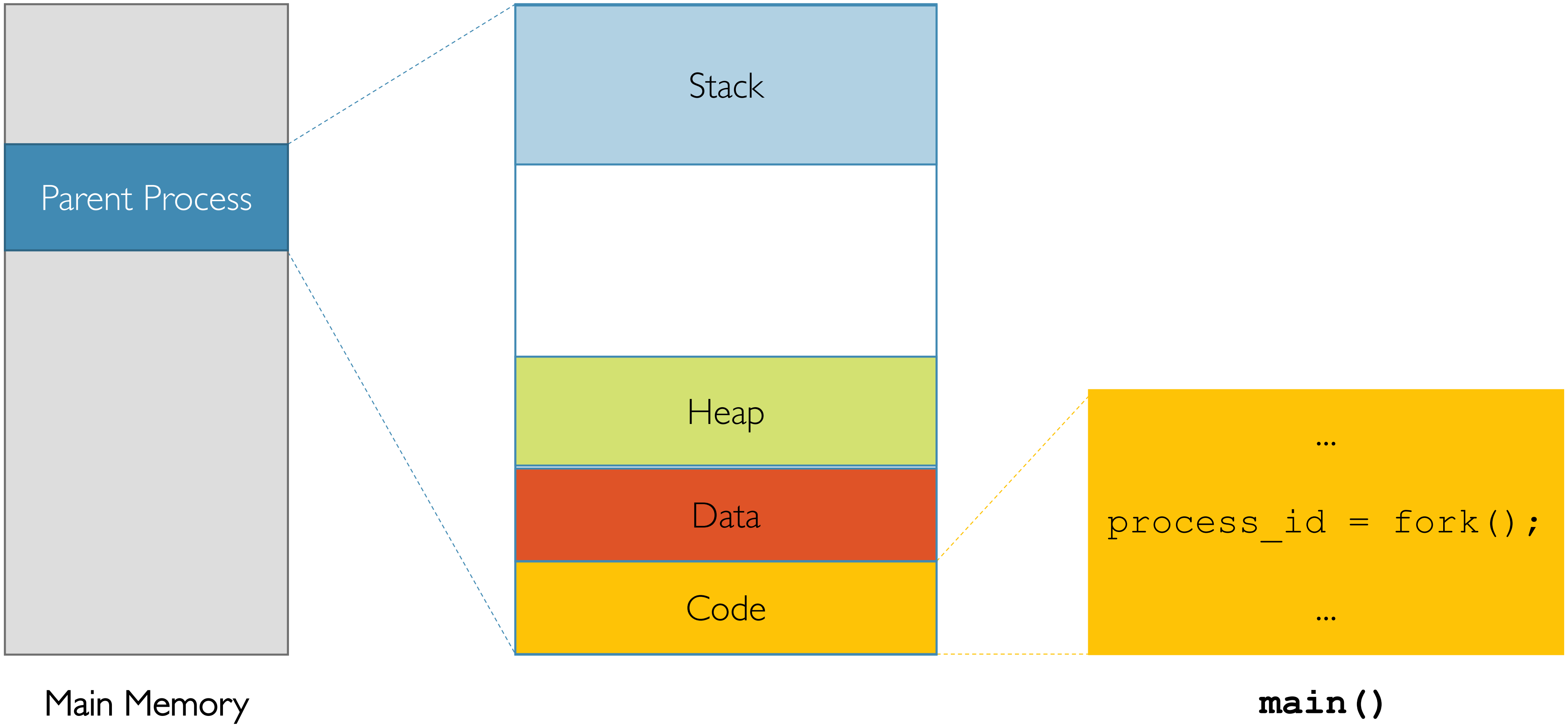

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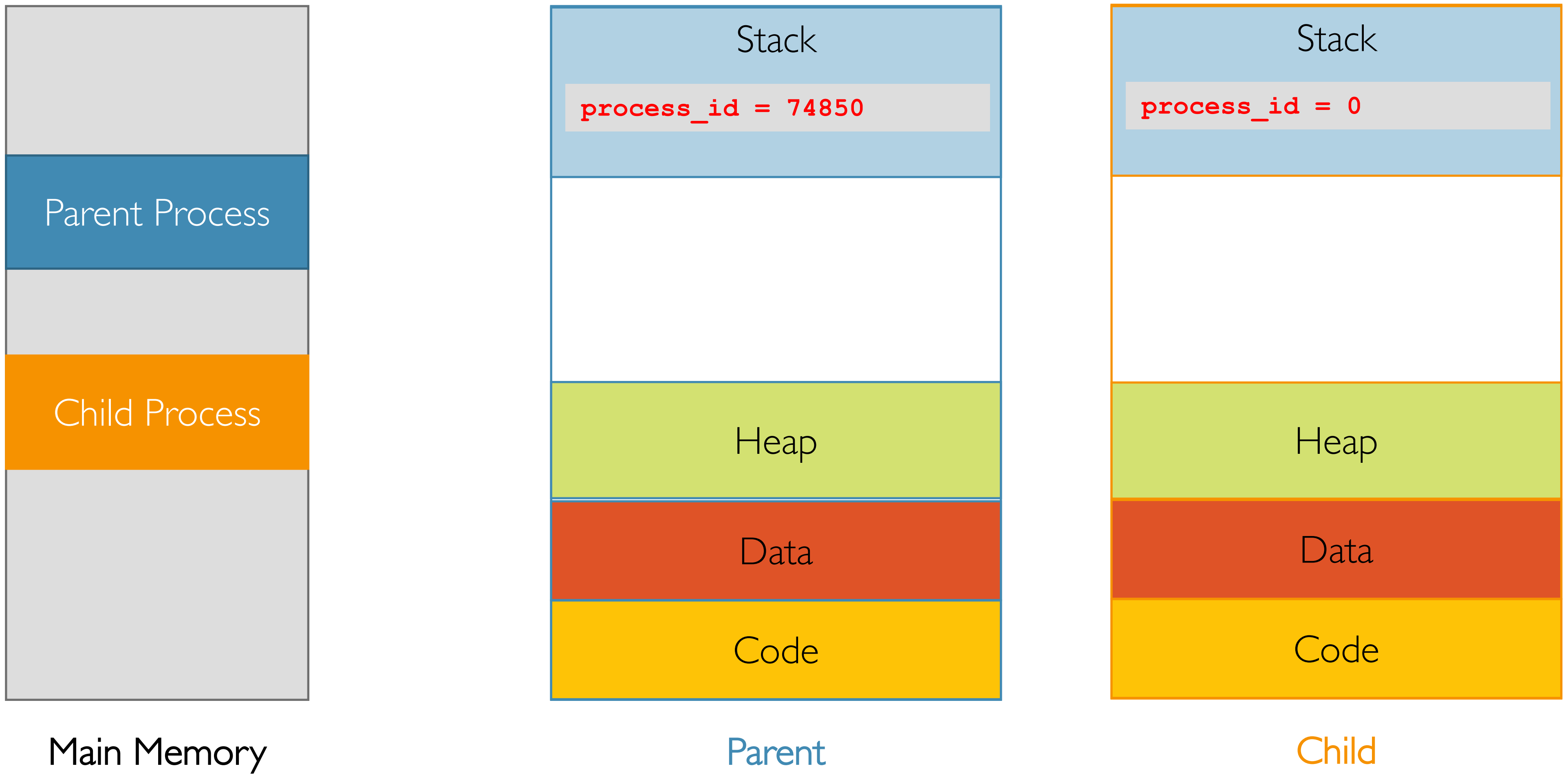

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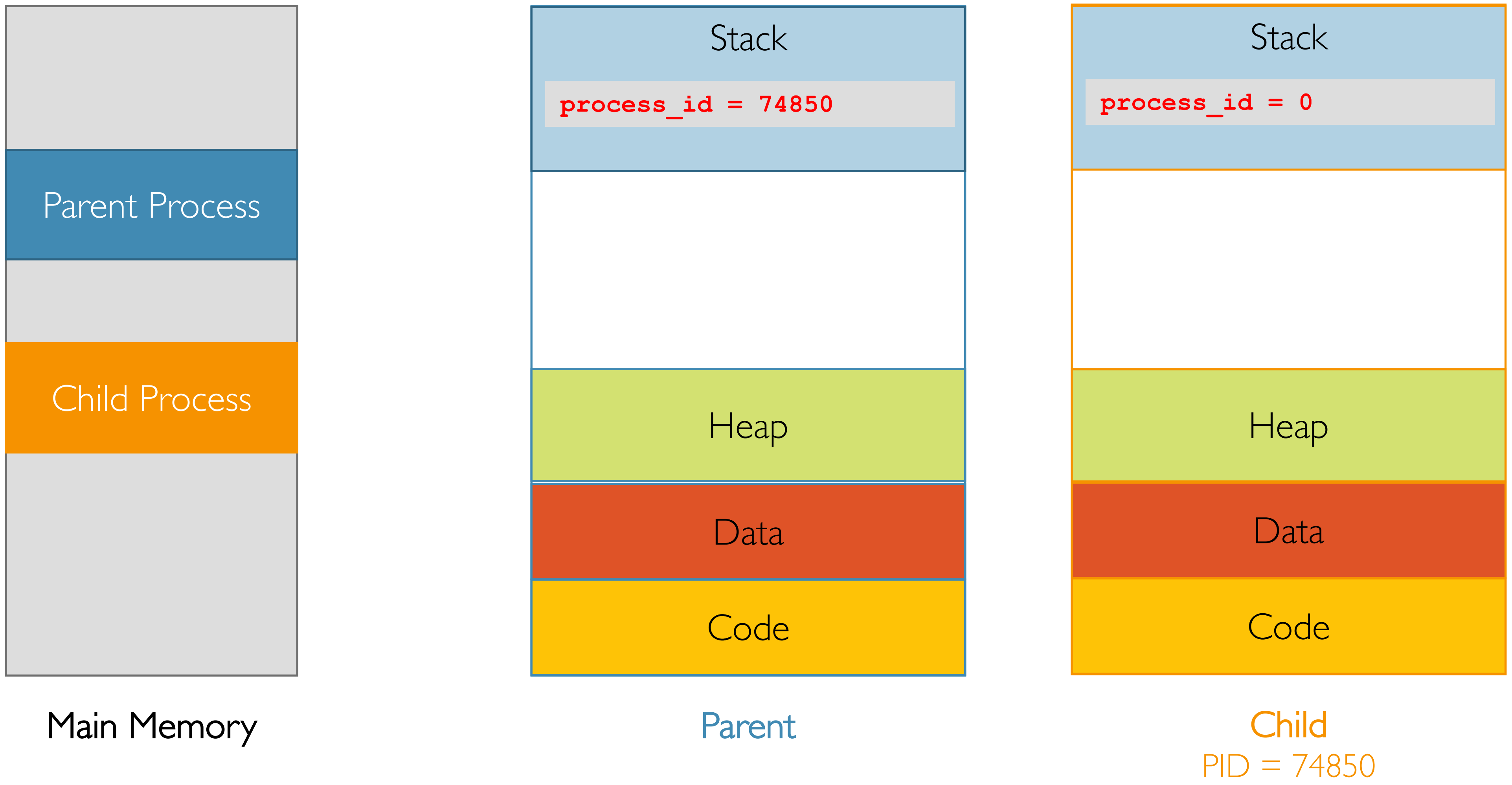

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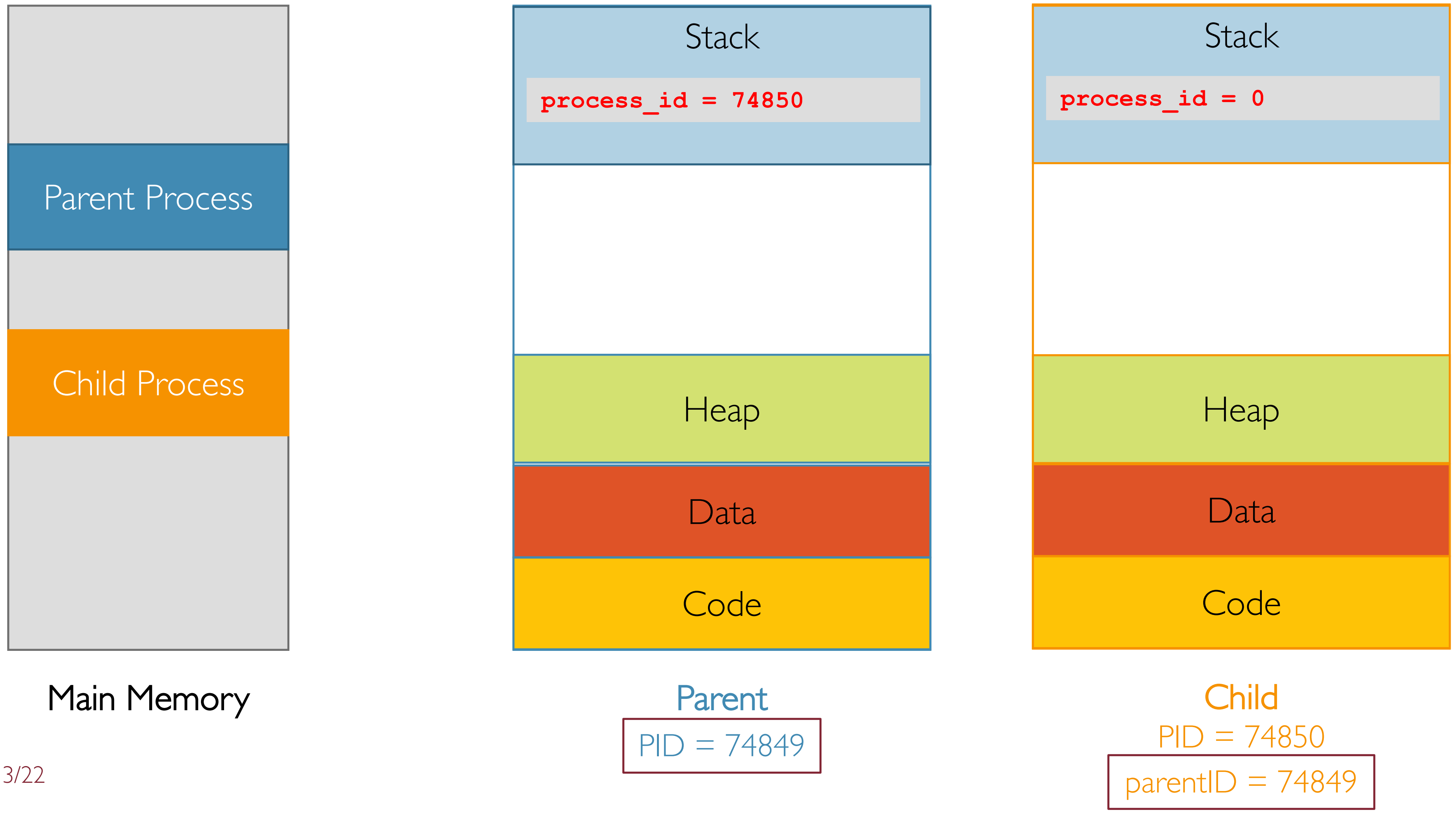

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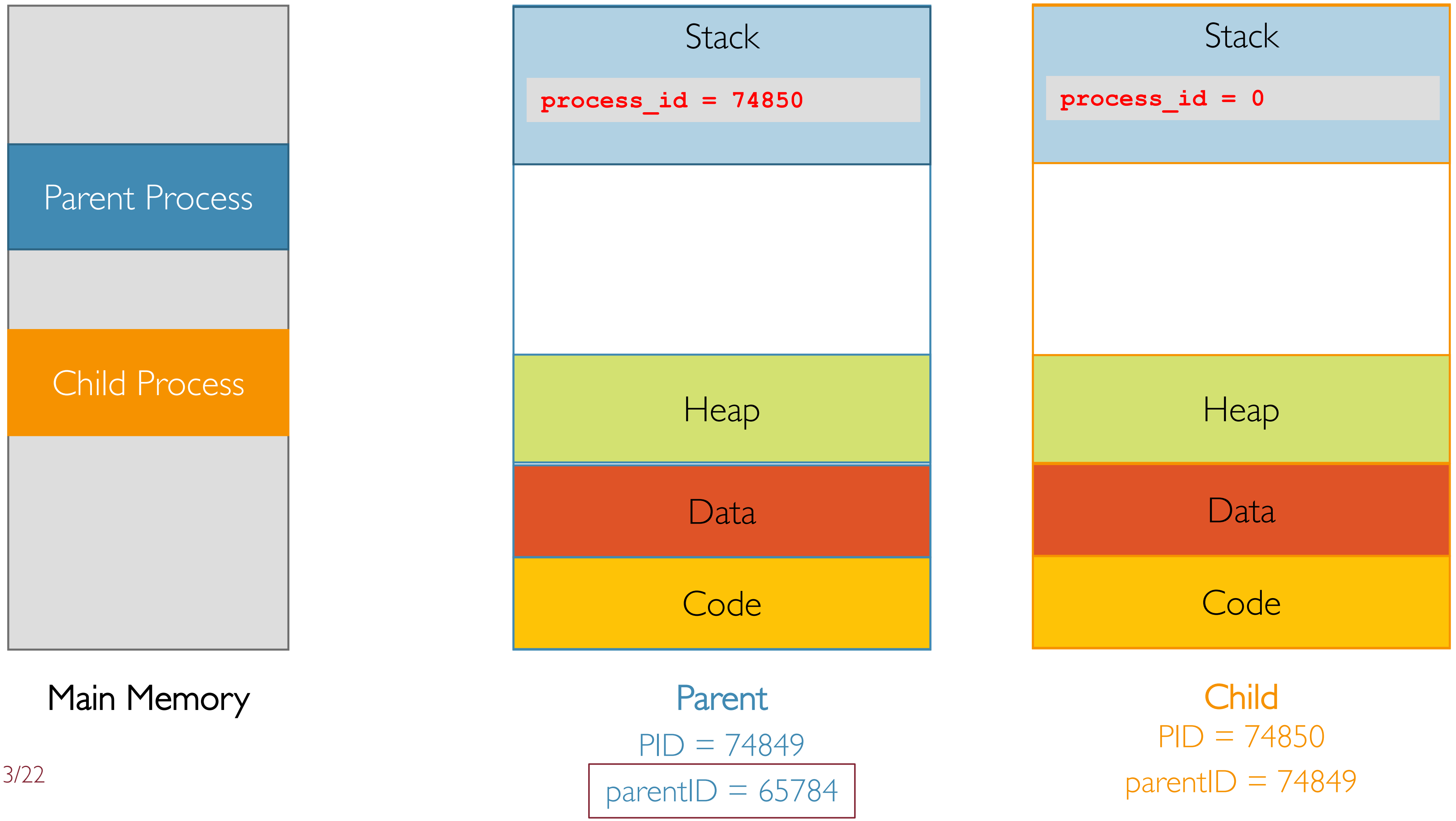

Process Creation: Code Example

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#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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```

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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- Implicitly, 2 system calls take place: **`fork`** and **`exec`**
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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

```
#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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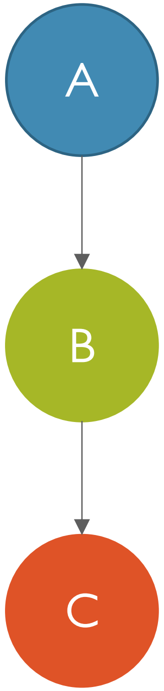
        printf("Program %s finished!\n", prog);
    }
    return 0;
}
```

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

```c
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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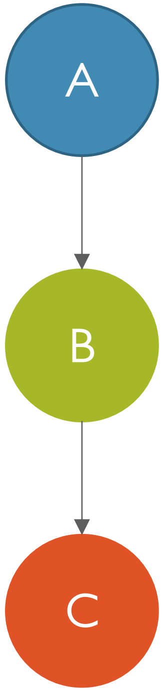
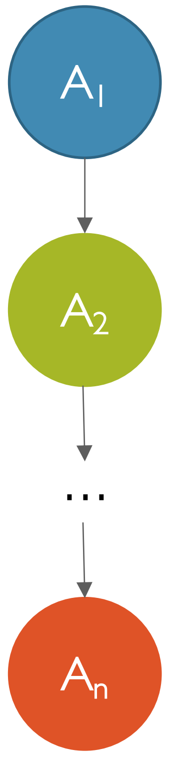



```
int pid = fork();

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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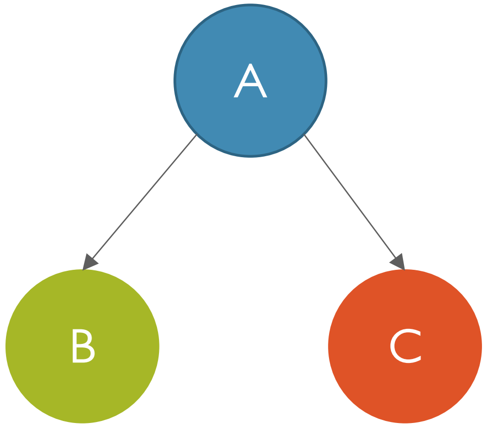

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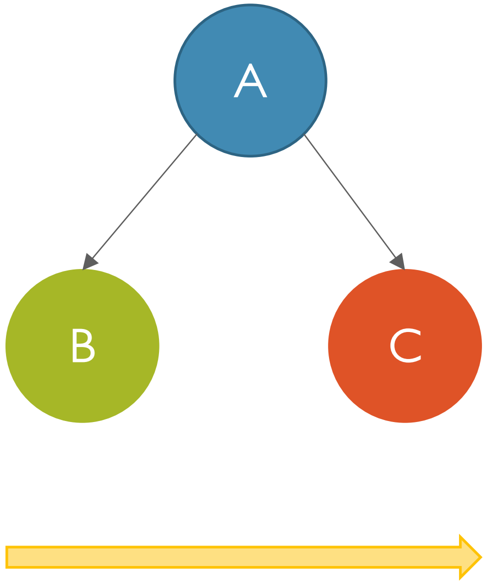
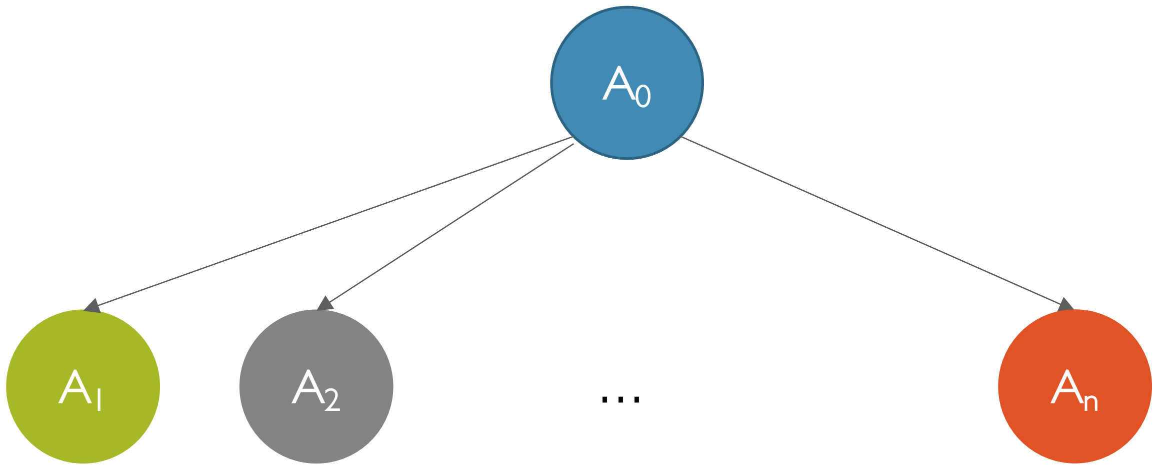


Left-to-Right (by convention)

```
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

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

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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

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
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- 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

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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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- 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

- Process creation
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- Process scheduling
- Process communication

Process Scheduling

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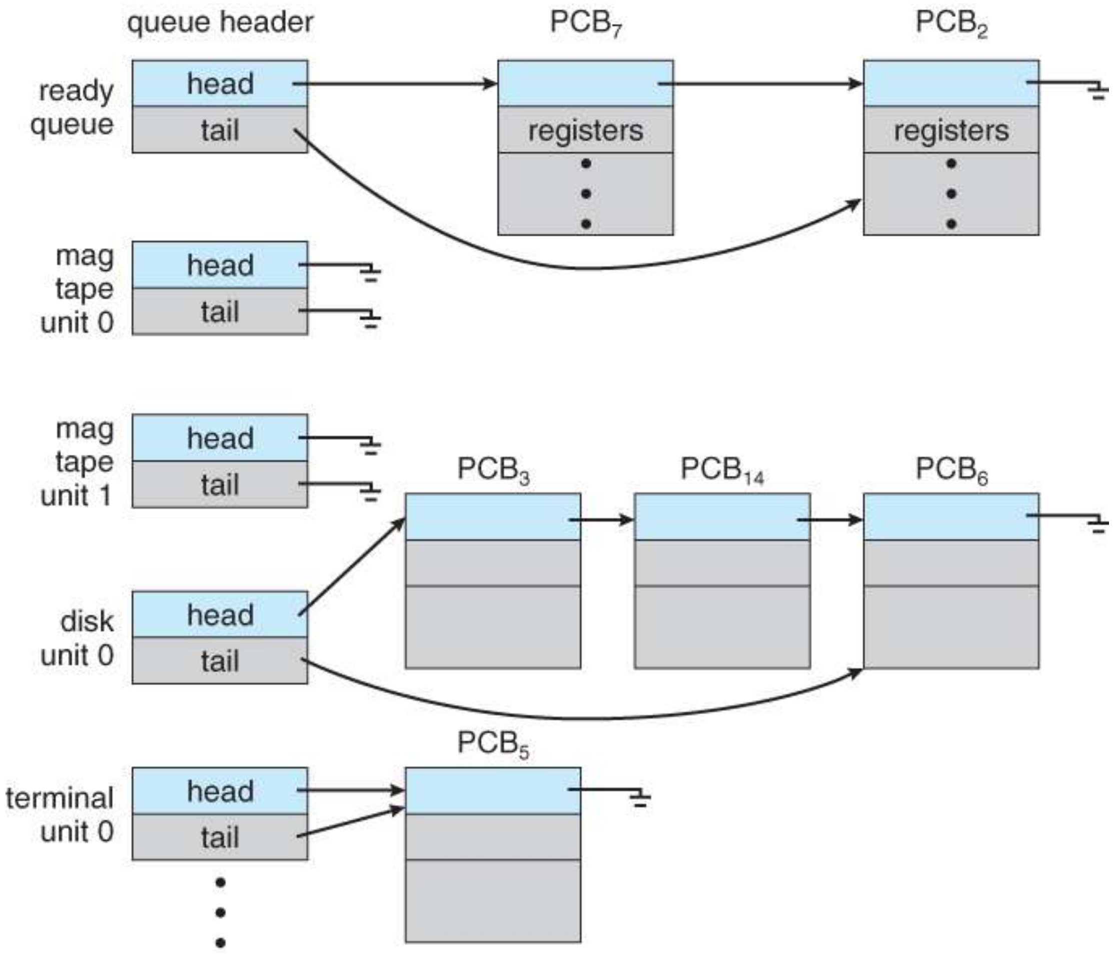
- The process scheduler must meet these objectives by implementing suitable policies for swapping processes in and out of the CPU
- Note that these objectives can be conflicting!
  - Every time the OS steps in to swap processes it takes up time on the CPU to do so, which is thereby "lost" from doing any useful productive work

Process State Queues

- 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



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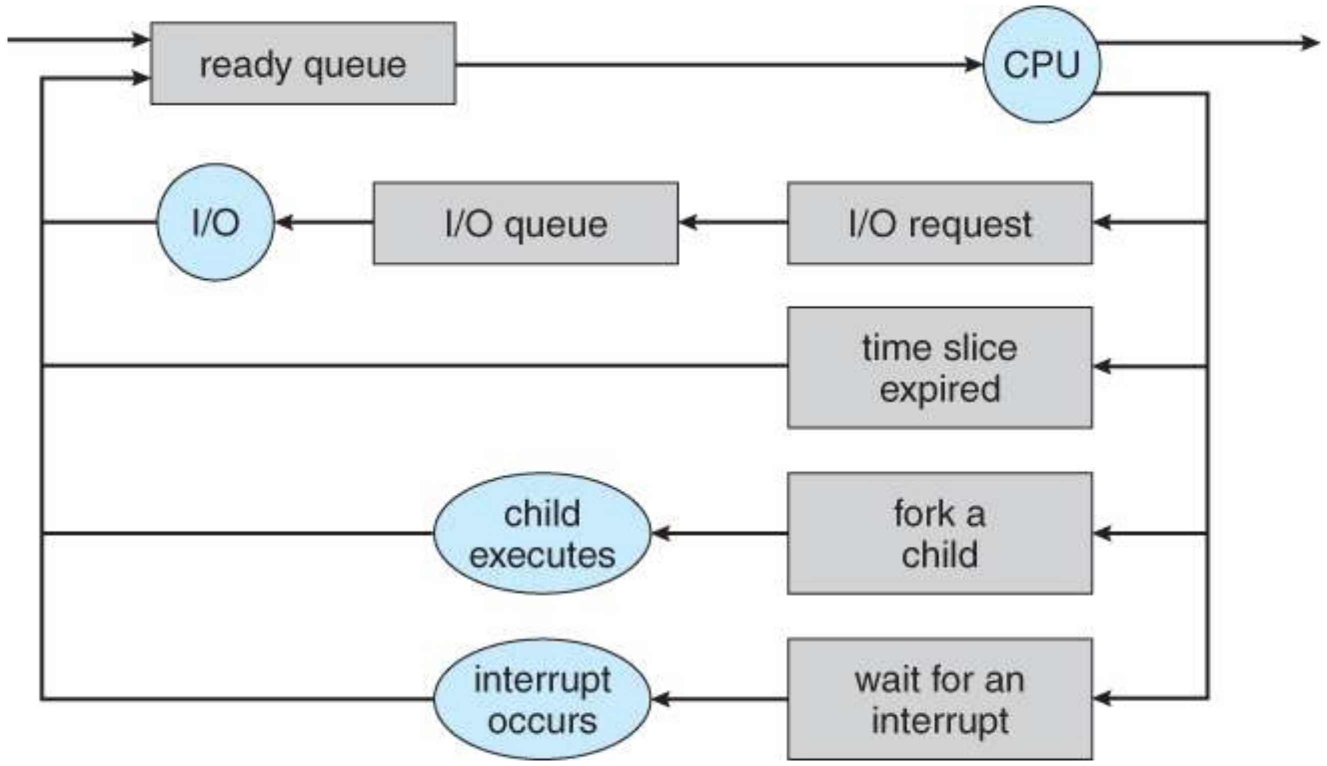
- Some systems also employ a medium-term scheduler: when system loads get high, this scheduler allows smaller faster jobs to finish up quickly and clear the system
- An efficient scheduling system will select a good mix of CPU-bound processes and I/O bound processes

Schedulers: Queuing Diagram



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Context Switch: What?

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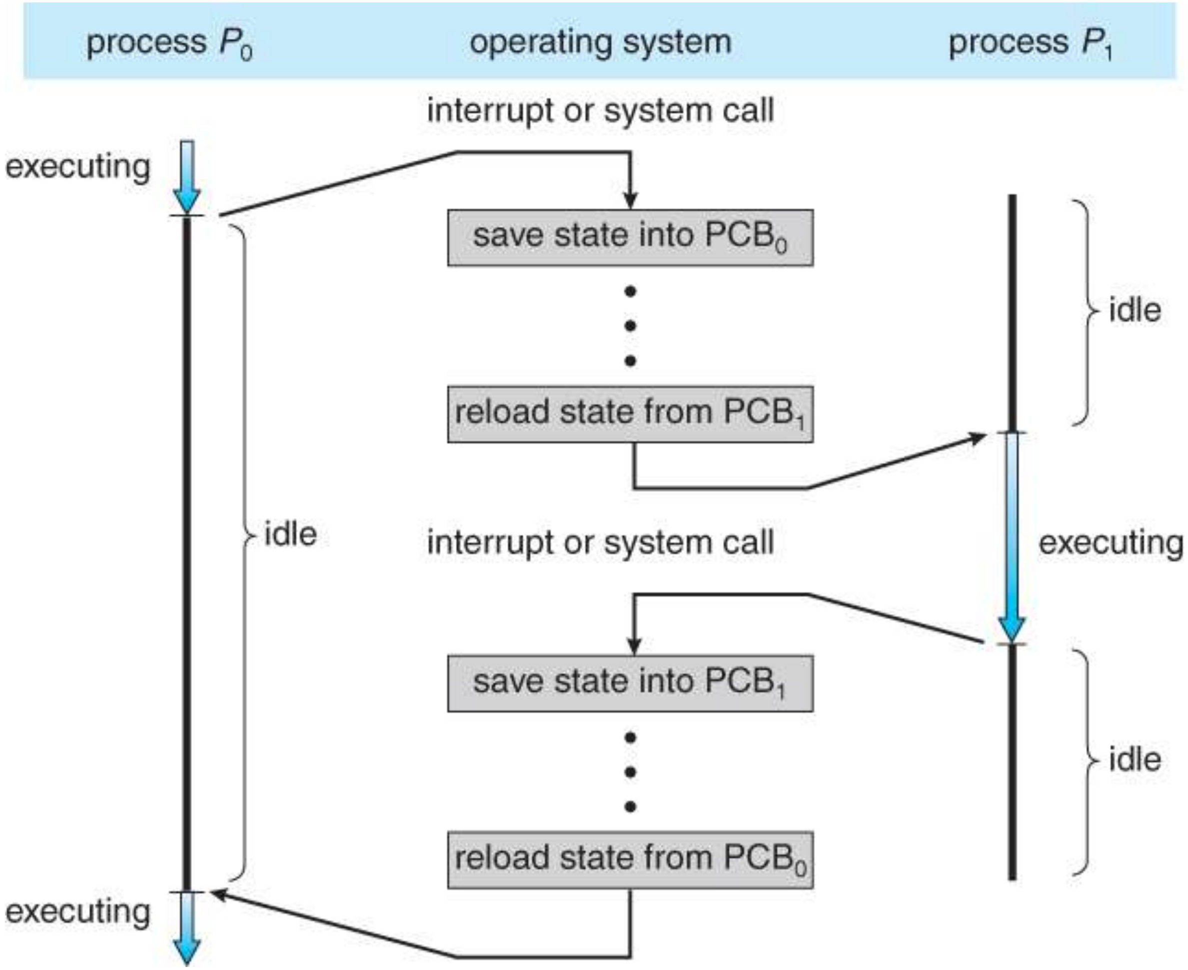
- Typical values of time slice are between 10 and 100 ms, and context switch takes around 10 μs, so the overhead is small relative to time slice

Context Switch: Example



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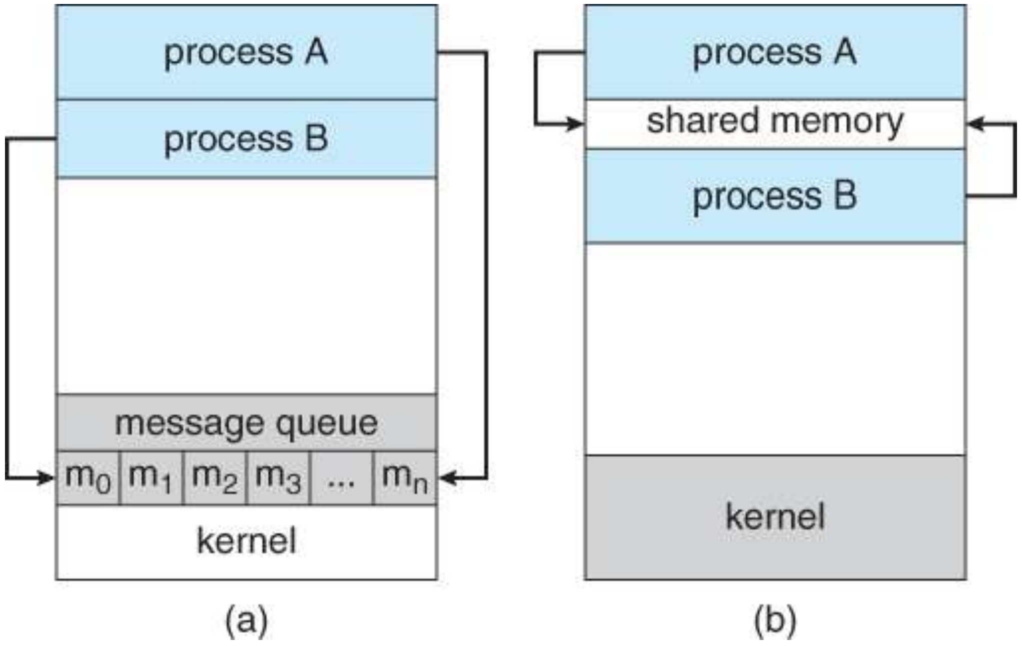
- Modularity → The most efficient architecture may be to break a system down into cooperating modules
- Convenience → Even a single user may be multi-tasking, such as editing, compiling, printing, and running the same code in different windows

Cooperating Processes: Communication

- 2 possible ways for cooperating processes to communicate:



Message Passing

Shared Memory

Shared Memory vs. Message Passing

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  - Faster once it is set up, as no system calls are needed
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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
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  - one-to-one link between every sender-receiver pair
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- 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