CSC 112: Computer Operating Systems
Lecture 2

Processes

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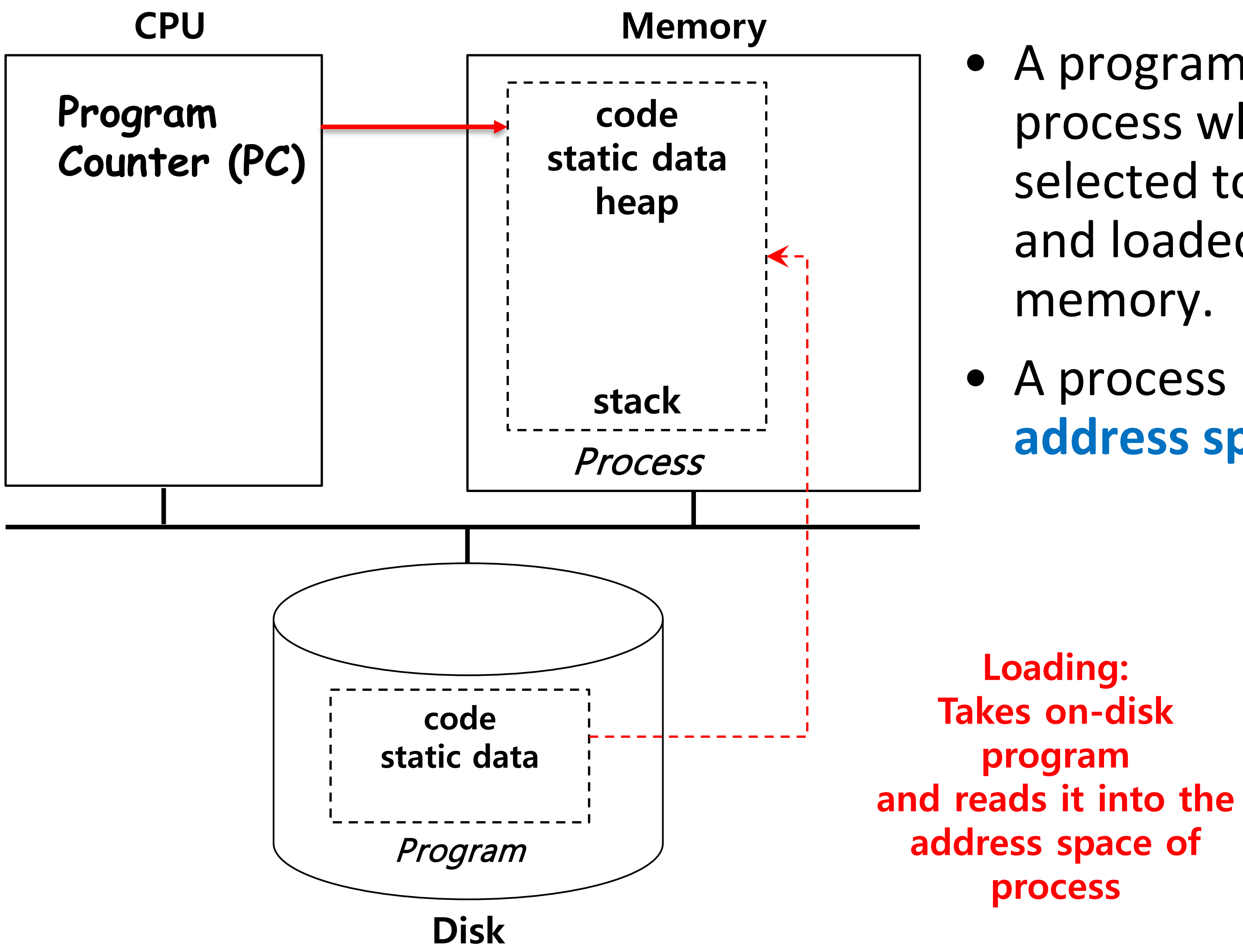
Overview

- Process concept
- Process state
- Process API (creation, wait)
- Process tree

Process

- Program is a ***static*** entity stored on disk (**executable file**), process is ***active***
  - Program becomes process when executable file loaded into memory
  - Process is an abstraction of CPU
- Execution of program started via Graphic User Interface (GUI) mouse clicks, command line entry of its name, etc
- A physical CPU is shared by many processes
  - Time sharing: run one process for a little while, then run another one, and so forth.
  - Processes believe they are using CPU alone

Process

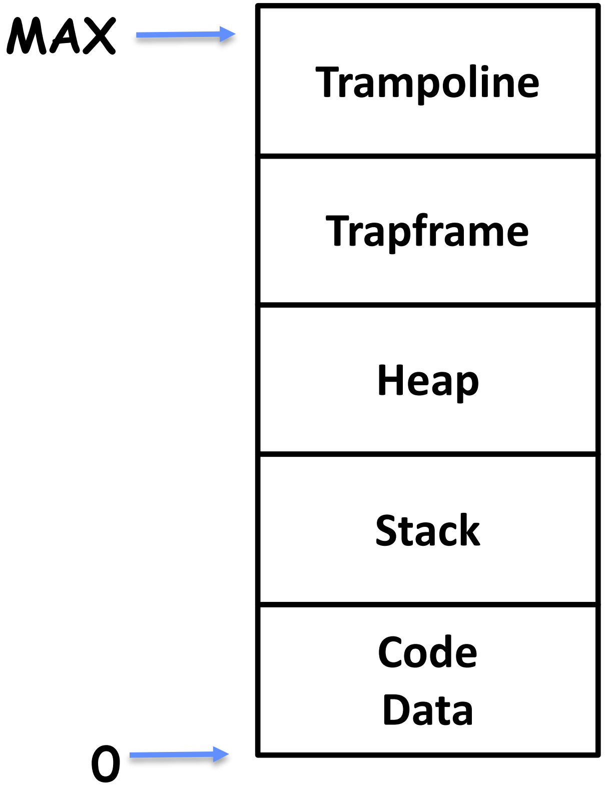


- A program becomes a process when it is selected to execute and loaded into memory.
- A process has an **address space**

Process

Process: a running program

- **Consists of:**
  - Code: Instructions
  - Stack: Temporary data, e.g., function parameters, returned addresses, local variables
  - Registers: Program counter (PC), general purpose, stack pointer
  - Data: Global variables
  - Heap: Dynamically allocated



XV6 Address Space

Process

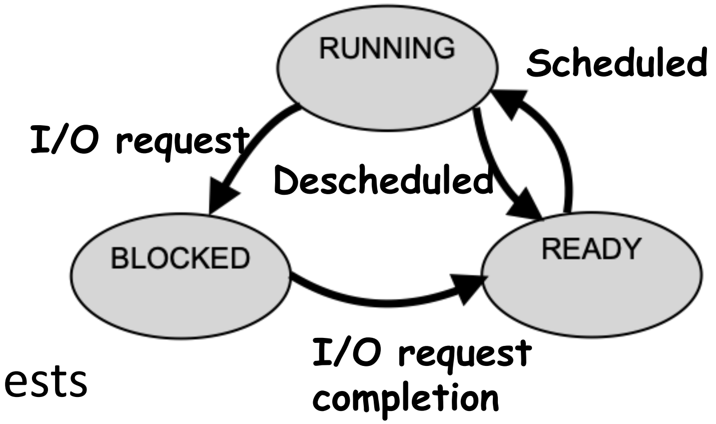
```
struct proc {
        struct spinlock lock; // p->lock must be held when using these:
        enum procstate state; // Process state
        void *chan; // If non-zero, sleeping on chan
        int killed; // If non-zero, have been killed
        int xstate; // Exit status to be returned to parent's wait
        int pid; // Process ID
        // wait_lock must be held when using this:
        struct proc *parent; // Parent process
        // these are private to the process, so p->lock need not be
held.
        uint64 kstack; // Virtual address of kernel stack
        uint64 sz; // Size of process memory (bytes)
        pagetable_t pagetable; // User page table
        struct trapframe *trapframe; // data page for trampoline.S
        struct context context; // swtch() here to run process
        struct file *ofile[NOFILE]; // Open files
        struct inode *cwd; // Current directory
        char name[16]; // Process name (debugging)
};
```

XV6 (proc.h)

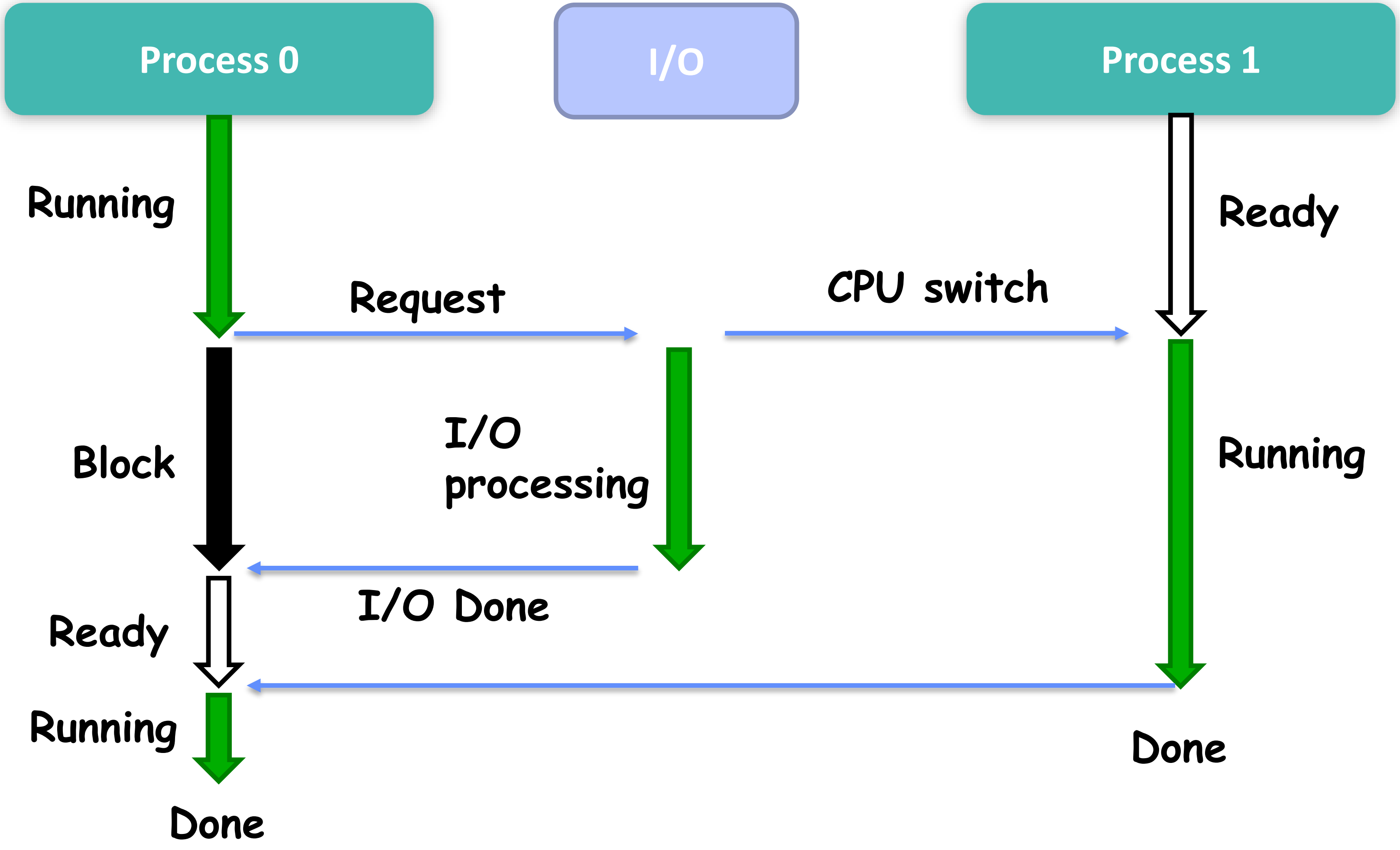
- A process is represented by a **process control block (PCB)**
  - Process ID (PID, unique)
  - State
  - Parent process
  - Opened files
  - etc.

Process State

- Process has different states
  - **READY**
    - » Ready to run and pending for running
  - **RUNNING**
    - » Being executed by OS
  - **BLOCKED**
    - » Suspended due to some other events, e.g., I/O requests



Process State



Process API

- Process API to manipulate processes
  - **CREATE**
    - » Create a new process, e.g., double click, a command in terminal
  - **WAIT**
    - » Wait for a process to stop
    - » Like I/O request
  - **DESTROY**
    - » Kill the processes
  - **STATUS**
    - » Obtain the information of a process
  - **OTHERS**
    - » Suspend or resume a process

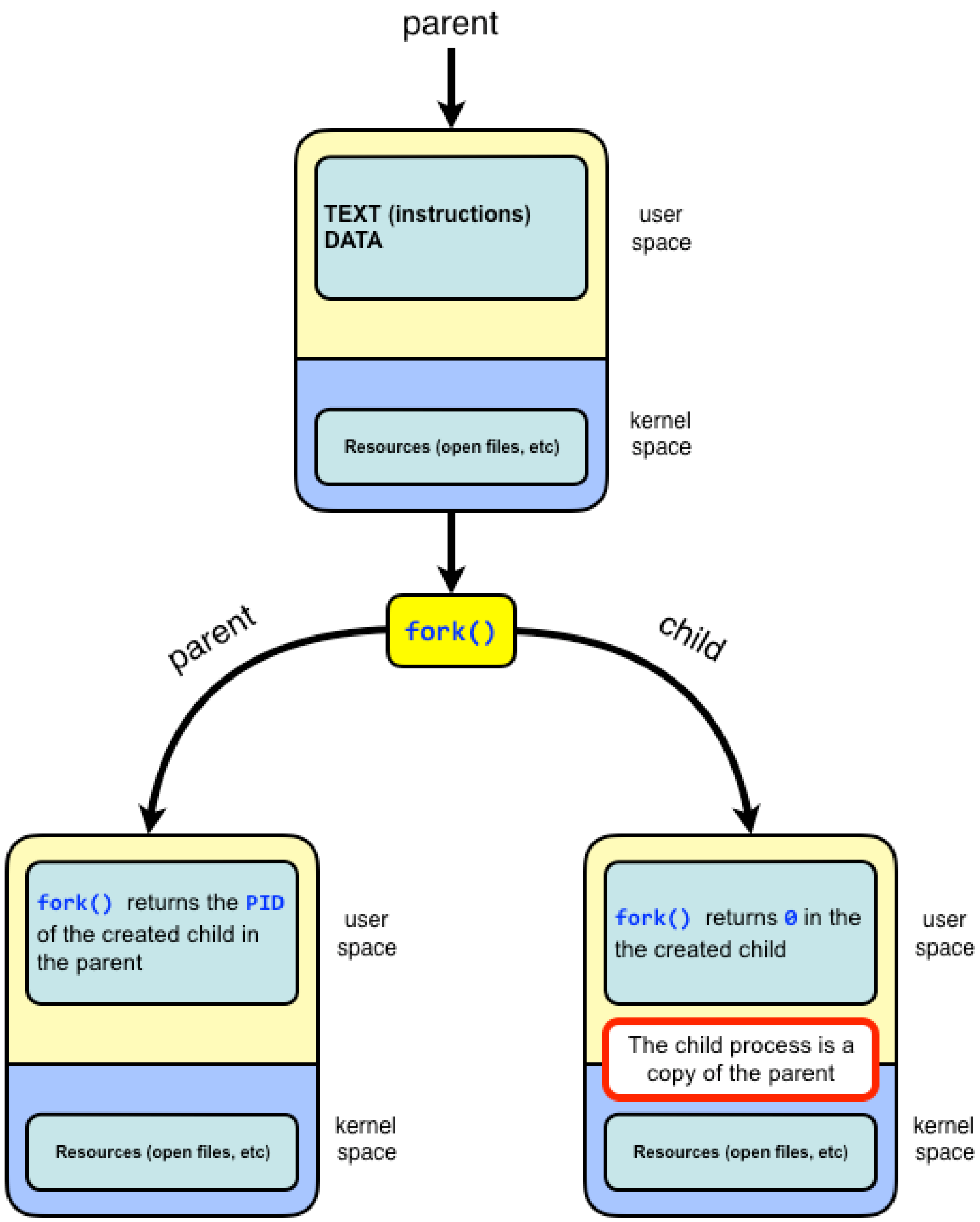
Process Creation

- A process is created by another process, **parent process** or **calling process**

- Process creation relies on two system calls
  - **fork()**
    - » Create a new process and clone its parent process
  - **exec()**
    - » Overwrite the created process with a new program

fork()

- A function without any arguments
  - **pid = fork()**
- Both **parent process** and **child process** continue to execute **the instruction following the fork()**
- The return value indicates which process it is (**parent** or **child**)
  - **Non-0 pid (**pid of child process**)** : return value of the parent process,
  - **0** : return value of the new child process
  - **-1** : an error or failure occurs when creating new process
- Child process is a duplicate of its parent process and has same
  - **instructions, data, stack**
- Child and parents have different
  - **PIDs, memory spaces**



fork()

```
int main(int argc, char *argv[])
{
    printf("hello world (pid:%d)\n", (int) getpid());
    int rc = fork();
    if (rc < 0) {
            // fork failed; exit
            fprintf(stderr, "fork failed\n"); exit(1);
    } else if (rc == 0) {
            // child (new process)
            printf("hello, I am child (pid:%d)\n", (int) getpid());
    } else {
            // parent goes down this path (original process)
            printf("hello, I am parent of %d (pid:%d)\n", rc, (int) getpid());
    }
    return 0;
}
```

Output

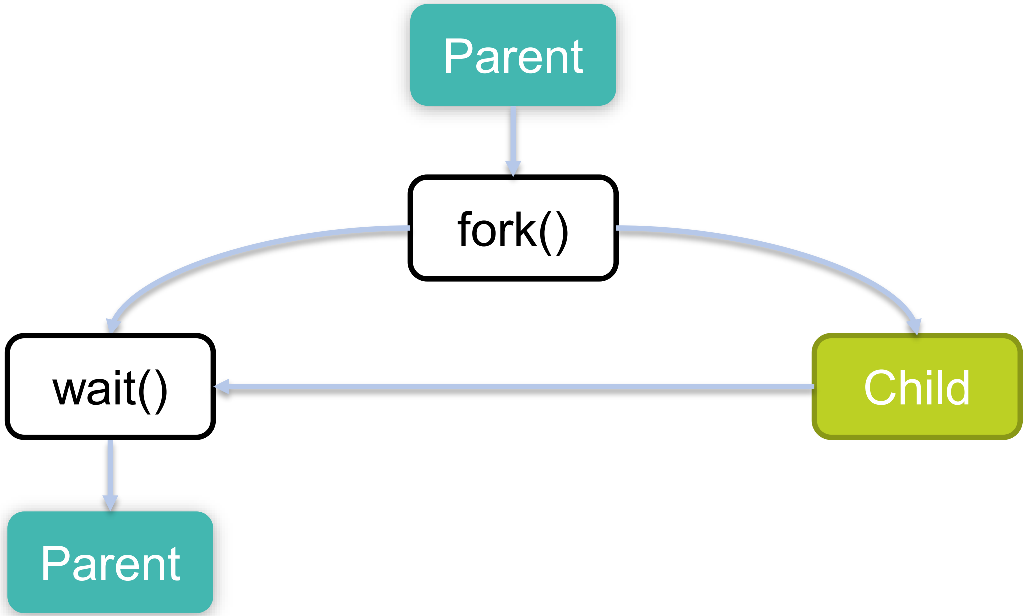
```
hello world (pid:96744)
hello, I am parent of 96745 (pid:96744)
hello, I am child (pid:96745)
```

Child Process

Parent Process

wait()

- Let the parent process wait for the completion of the child process
  - **pid = wait()**
- **wait()** suspends the execution of the calling process until one of its child processes terminates. It does not allow the parent to specify which child process to wait for. It will reap any terminated child arbitrarily.
- **waitpid(pid)** is an advanced version of wait. It allows the parent process to specify which child process (or group of processes) it wants to wait for.



wait()

```
int main(int argc, char *argv[])
{
        printf("hello world (pid:%d)\n", (int) getpid());
        int rc = fork();
        if (rc < 0) {
                // fork failed; exit
                fprintf(stderr, "fork failed\n");
                exit(1);
        } else if (rc == 0) {
                // child (new process)
                printf("hello, I am child (pid:%d)\n", (int) getpid());
                sleep(1);
        } else {
                // parent goes down this path (original process). wc stores pid of the child process that is waited for
                int wc = wait(NULL);
                printf("hello, I am parent of %d (wc:%d) (pid:%d)\n", rc, wc, (int) getpid());
        }
        return 0;
}
```

Child process sleeps for 1 second
Parent process waits for the child process to finish sleeping

Child Process

Parent Process

wait()

- **Without wait():** it is nondeterministic which process (parent or child) runs first

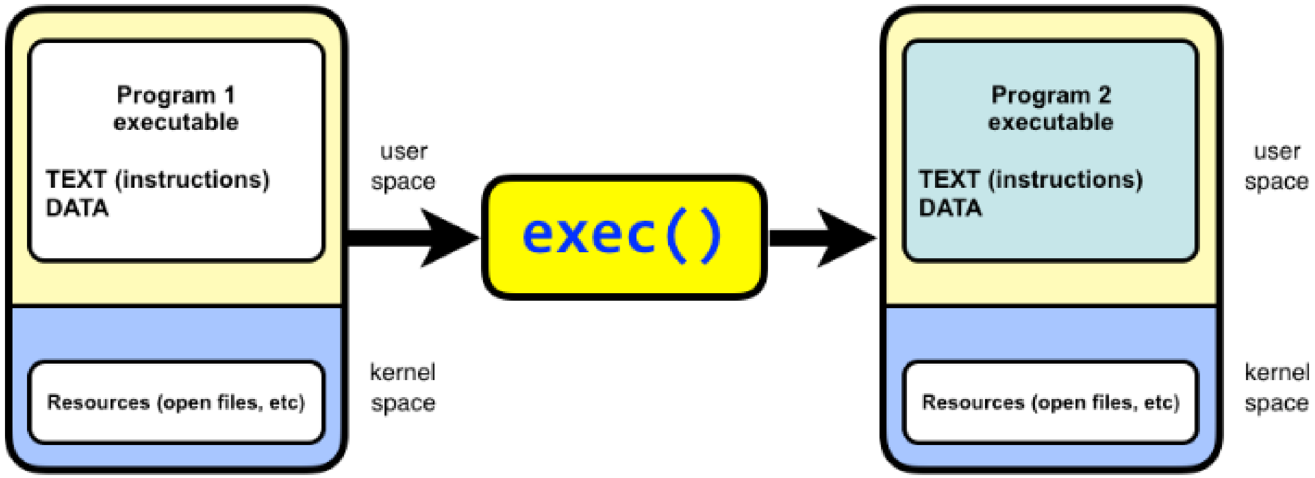
```
hello world (pid:96744)
hello, I am parent of 96745 (pid:96744)
hello, I am child (pid:96745)
```

- **With wait():** child runs first, and parents waits for child to finish

```
hello world (pid:96848)
hello, I am child (pid:96849)
hello, I am parent of 96849 (wc:96849) (pid:96848)
```

exec()

- **exec(cmd, argv)** replaces the current process image with a new process image specified by the path to an executable file.
  - It does not return. It starts to execute the new program.
- There is a family of **exec(),** e.g., **execl(), execvp()**
  - **execl()** takes a variable number of arguments that represent the program name and its arguments.
    - » int execl(const char *path, const char *arg, ..., NULL);
  - **execvp()** takes an array of arguments instead of a variable-length argument list
    - » int execvp(const char *file, char *const argv[]);

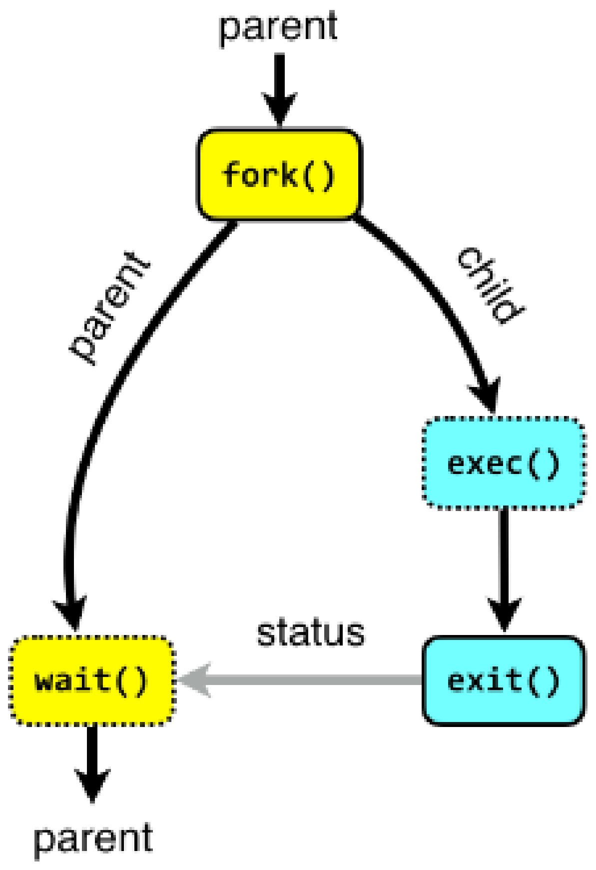


exec() Example

```
int main(int argc, char *argv[])
{
    printf("hello world (pid:%d)\n", (int) getpid());
    int rc = fork();
    if (rc < 0) {
            // fork failed; exit
            fprintf(stderr, "fork failed\n"); exit(1);
    } else if (rc == 0) { // child (new process)
            printf("hello, I am child (pid:%d)\n", (int) getpid());
            char *myargs[3];
            myargs[0] = strdup("wc"); // program: "wc" (word count)
            myargs[1] = strdup("p3.c"); // argument: file to count
            myargs[2] = NULL; // marks end of array
            execvp(myargs[0], myargs); // run word count
            printf("this will be replaced, so not printed out");
    } else { // parent
            int rc_wait = wait(NULL);
            printf("hello, I am parent of %d (rc_wait:%d) (pid:%d)\n", rc, rc_wait, (int) getpid());}
    return 0;
}
```

wc: counts Lines, Words, and Bytes in a File:
Output format: [lines] [words] [bytes] [filename]

```
hello world (pid:97511)
hello, I am child (pid:97512)
      32      123      966 p3.c
hello, I am parent of 97512 (wc:97512) (pid:97511)
```



IO redirection and pipe

- By separating **`fork()`** and **`exec()`**, we can manipulate various settings just before executing a new program and **make the IO redirection and pipe possible**.
  - IO redirection

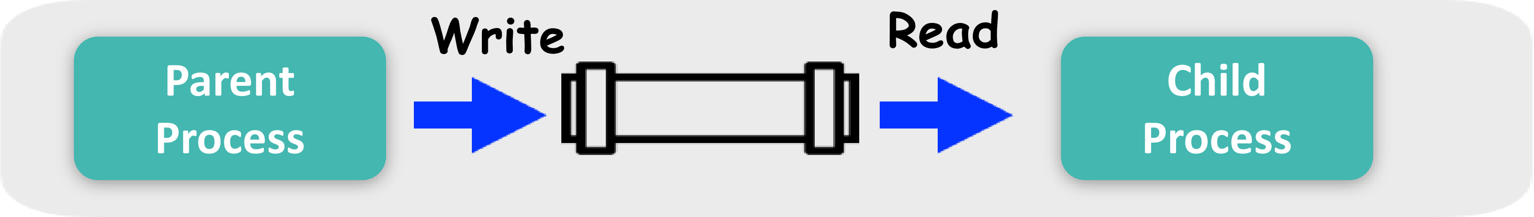
```
% cat w3.c > newfile.txt
```

  - pipe

```
% echo hello world | wc
```

pipe

- A communication method between two processes

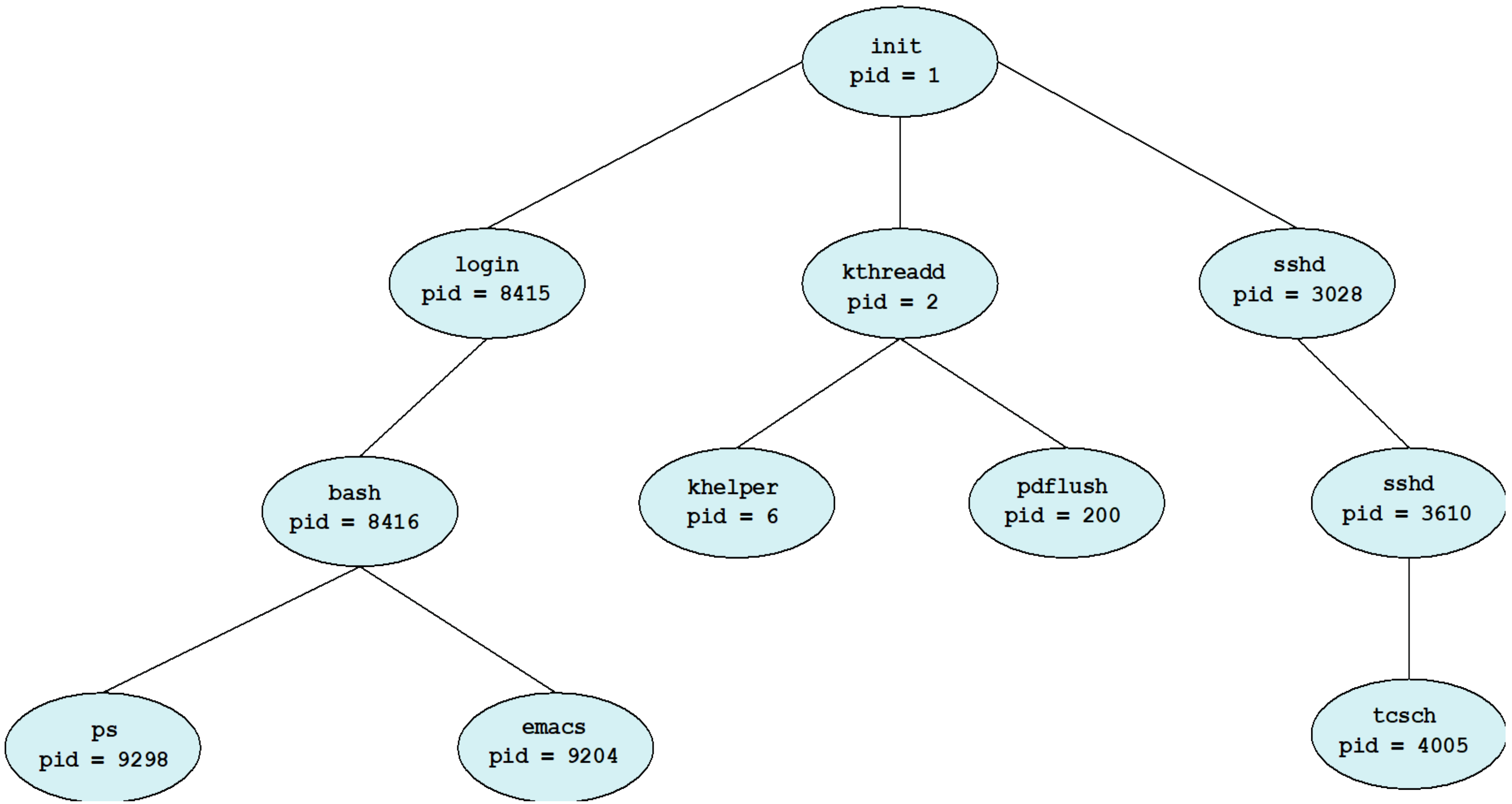



```
(base) dliu@dhcp-10-24-18-121 my_code % cat hello.c
#include <stdio.h>

int main()
{
    printf("Hello World!\n");
    return 0;
}
```

```
(base) dliu@dhcp-10-24-18-121 my_code % cat hello.c |grep printf
    printf("Hello World!\n");
(base) dliu@dhcp-10-24-18-121 my_code %
```

Process Tree



Process Tree

- % pstree (to show the process tree)

```
(base) dliu@dhcp-10-24-17-236 ~ % pstree
-+= 00001 root /sbin/launchd
 |--= 00322 root /usr/libexec/logd
 |--= 00323 root /usr/libexec/smd
 |--= 00324 root /usr/libexec/UserEventAgent (System)
```

- % ps (to show all processes)

```
PID   TT  STAT      TIME COMMAND
  1   ??  Ss    17:57.36 /sbin/launchd
322   ??  Rs     6:29.86 /usr/libexec/logd
323   ??  Ss     0:00.19 /usr/libexec/smd
324   ??  Ss     0:19.58 /usr/libexec/UserEventAgent (System)
```

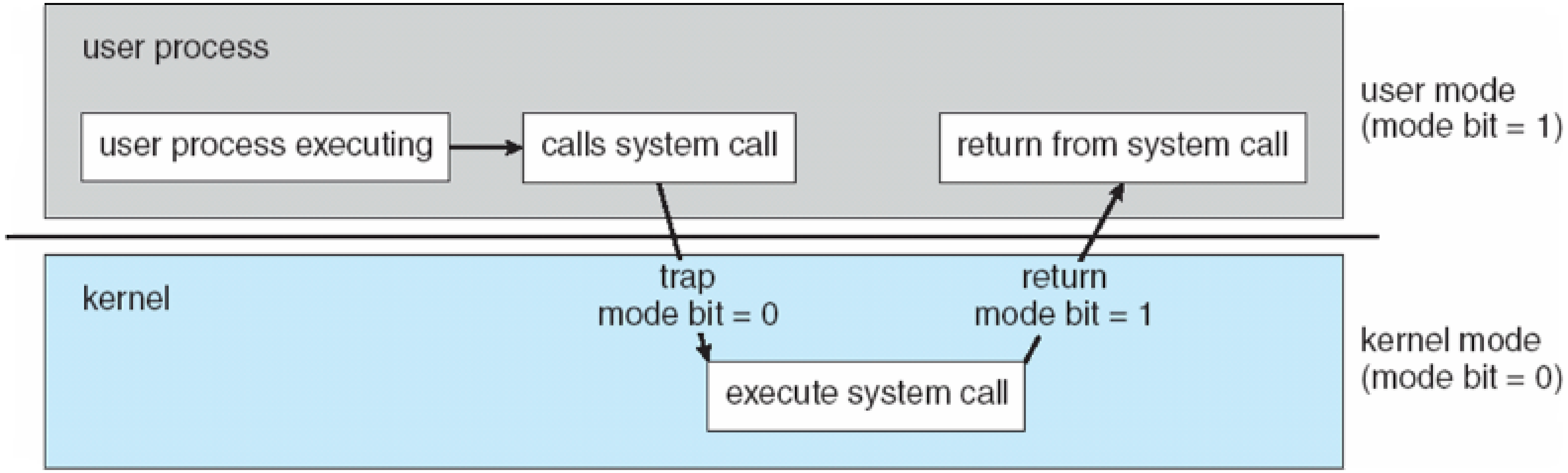
User/Kernel Mode Separation

- **User mode**: restricted, limited operations
  - Processes start in user mode
- **Kernel mode**: privileged, not restricted
  - OS starts in kernel mode

- What if a process wants to perform some restricted operations?
  - **System calls:** Allow the kernel services to provide some functionalities to user programs

User/Kernel Mode Separation

- A process starts in **user mode**
- If it needs to perform a restricted operation, it calls a system call by executing a **trap instruction**.
- The state and registers of the calling process are stored, the system enters **kernel mode**, OS completes the syscall work.
- **Return from syscall**, restore the states and registers of the process, and resume the execution of the process



Process Scheduling

- **Switching Between Processes**
  - **Cooperative approach**
  - **Non-cooperative approach**

- **Cooperative approach**
  - **Trust process to relinquish CPU to OS through traps**
    - » **System calls**
    - » **Illegal operations, e.g., divided by zero**
  - **Issue: if no system call**

- **Non-cooperative approach**
  - **The OS takes control**
  - **OS obtains control periodically, e.g., timer interrupter**

Summary

- In OS, process is a running program and has an address space
- We use process API to create and manage processes
- Fork() to duplicate a process, exec() to replace the command
- Process scheduling