Processes

Operating Systems
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References:
- Chapter 2 of the Tanenbaum's book
- Chapter 4 of OSTEP book
- man pages in any UNIX/Linux system

Process

- A <u>process</u> is a program in execution.
  - A <u>program</u> is a set of instructions somewhere (like the disk).
  - These instructions are loaded into the process' memory "in the beginning" by the OS.

- <u>**Von Neumann model**</u> of computing : Once created, a process continuously does the following
  1. **Fetches** an instruction from memory.
  2. **Decodes** it.
     - i.e., figures out which instruction this is.
  3. **Executes** it.
     - i.e., it does the thing that it is supposed to do, like add two numbers together, access memory, check a condition, jump to a function, and so forth.

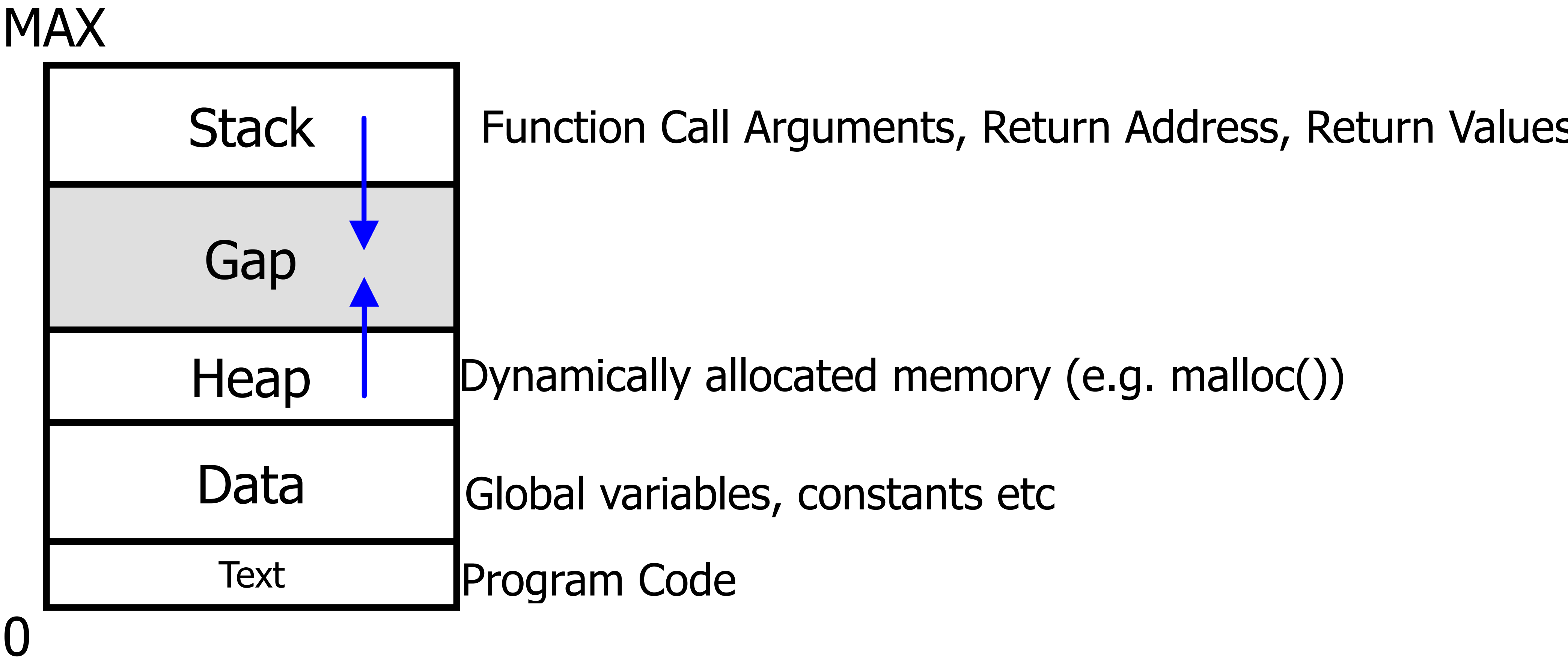
Process versus Program

- Program
  - Program is a passive entity stored in the disk
  - Static code and static data
- Process
  - Actively executing code and the associated static and dynamic data.
- Program is just one component of a process.
- There can be multiple process instances of the same program
  - Example: many users can run “ls” at the same time

So what constitutes a process?

- Memory space (static, dynamic)
- Procedure call stack
- Registers and counters :
    - Program counter, Stack pointer, General purpose registers
- Open files, connections
- And more.

Memory Layout of a typical process



- Stack and heap grow towards each other

System calls to control process lifetime

- fork()
  - Create a process

- exec()
  - Run a new program
  - More accurately: Replace the current process with a new program image

- wait() or waitpid()
  - wait for a child process to terminate

- exit()
  - Terminate the calling process

Process Creation

- Always using the fork() system call.
- When?
  - User runs a program at command line
  - OS creates a process to provide a service
    - Check the directory /etc/init.d/ on Linux for scripts that start off different services at boot time.
  - One process starts another process
    - For example in servers

Example : fork() and waitpid()

https://oscourse.github.io/examples/fork_ex.c

```
pid = fork();

if (pid < 0) {
        perror("fork failed:”);
        exit(1);
}

if (pid == 0) { // Child executes this block
        printf(“This is the child\n");
        exit(0);
}

if (pid > 0) { //Parent executes this block

      printf(“This is parent. The child is %d\n", pid);

      ret = waitpid(pid, &status, 0);
      if (ret < 0) {
            perror(“waitpid failed:”)
            exit(2);
      }

      printf(“Child exited with status %d\n”, &status);
      exit(0);
}
```

The strange behavior of fork()

- fork() is called once …

- But it returns twice!!
  - Once in the parent and
  - Once in the child

- The parent and the child are two different processes.

- Child is an exact “copy” of the parent.

- So how to make the child process do something different?
  - Return value of fork in child = 0
  - Return value of fork in parent = [process ID of the child]
  - By examining fork’s return value, the parent and the child can take different code paths.

Running a new program

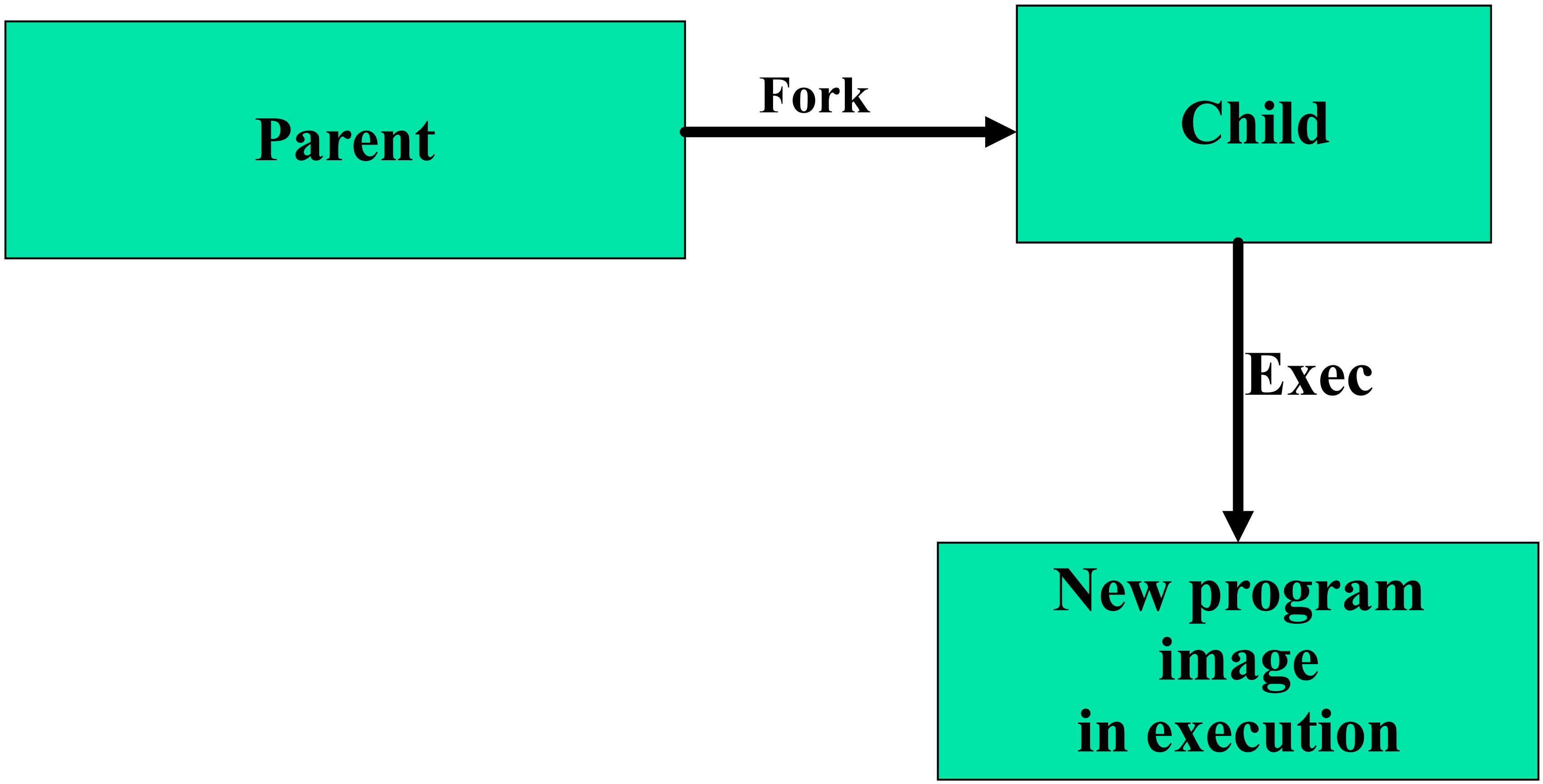
- Consider how a shell executes a command

$ pwd
/home/user

- How does that work?
  - Shell forked a child process
  - The child process executed /bin/pwd using the <u>exec() system call</u>

- Exec replaces the process' memory with a new program image.

exec() system call



exec() — Example code exec_ex.c

https://oscourse.github.io/examples/exec_ex.c

```
if ((pid = fork()) < 0) {
   fprintf(stderr, "fork failed\n");
   exit(1);
}

if (pid == 0) {
   if( execlp("echo",
              "echo",
              "Hello from the child",
              (char *) NULL) == -1)
       fprintf(stderr, "execl failed\n");

   exit(2);
}

printf("parent carries on\n");
```

The strange behavior of exec()

- Replaces current process image with new program image.
  - In the last example, parents’ image was replaced by the “echo” program image.

- All I/O descriptors open before exec stay open after exec.
  - I/O descriptors = file descriptors, socket descriptors, pipe descriptors etc.
  - This property is very useful for implementing filters.

Different Types of exec()

- `int execl(char * pathname, char * arg0, … , (char *)0);`
    - Full pathname + long listing of arguments

- `int execv(char * pathname, char * argv[]);`
    - Full pathname + arguments in an array

- `int execle(char * pathname, char * arg0, … , (char *)0, char envp[]);`
    - Full pathname + long listing of arguments + environment variables

- `int execve(char * pathname, char * argv[], char envp[]);`
    - Full pathname + arguments in an array + environment variables

- `int execlp(char * filename, char * arg0, … , (char *)0);`
    - Short pathname + long listing of arguments

- `int execvp(char * filename, char * argv[]);`
    - Short pathname + arguments in an array

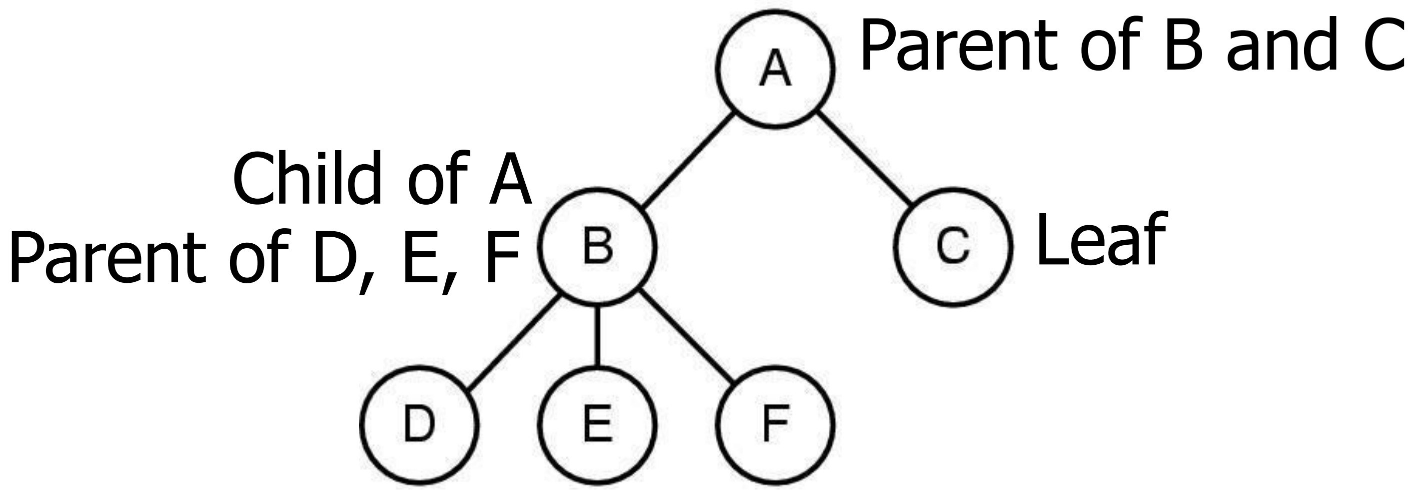
- More info: check “man 3 exec”

Terminating a process

- Return from the first function
  - Usually main()

- exit(status)
  - Exit the program.
  - Status is retrieved by the parent using wait().
  - 0 for normal status, non-zero for error

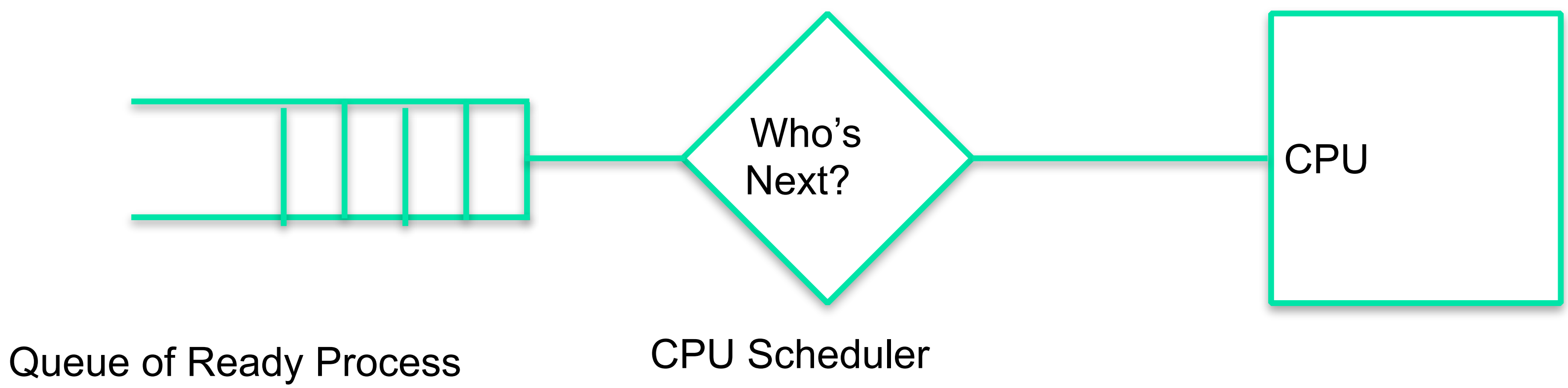
Process Hierarchy Tree



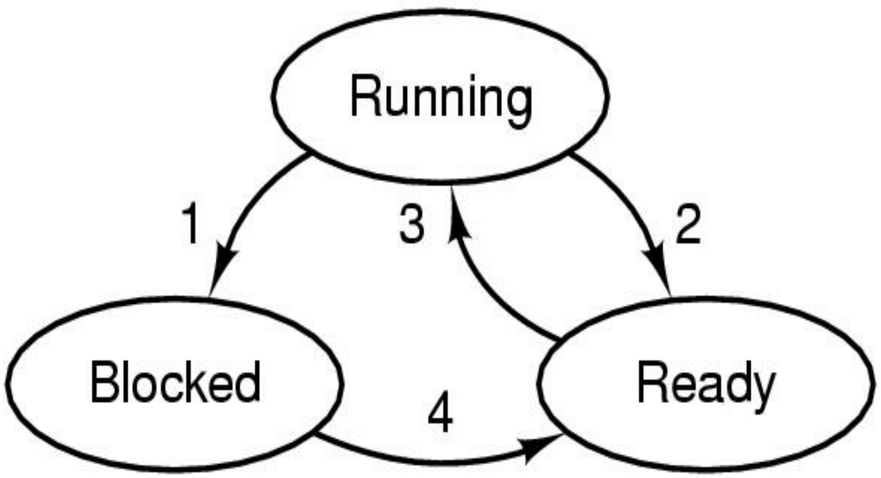
- A created two child processes, B and C
- B created three child processes, D, E, and F

CPU scheduler

- Time-shares many processes on one CPU



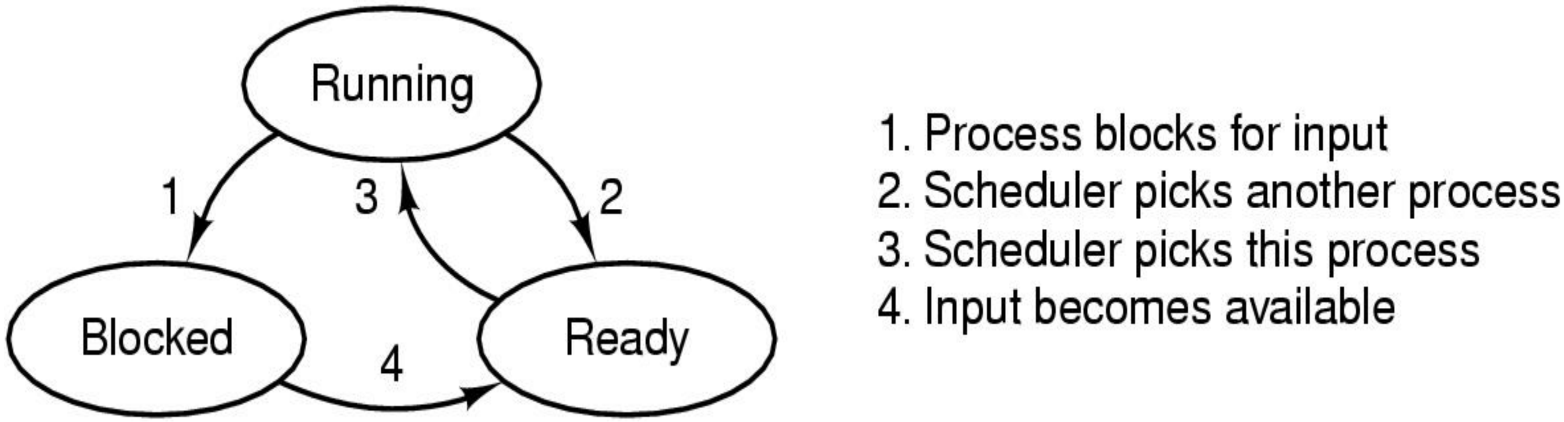
Process Lifecycle



1. Process blocks for input
2. Scheduler picks another process
3. Scheduler picks this process
4. Input becomes available

- Ready
  - Process is ready to execute, but not yet executing
  - Its waiting in the scheduling queue for the CPU scheduler to pick it up.
- Running
  - Process is executing on the CPU
- Blocked
  - Process is waiting (sleeping) for some event to occur.
  - Once the event occurs, process will be woken up, and placed on the scheduling queue.

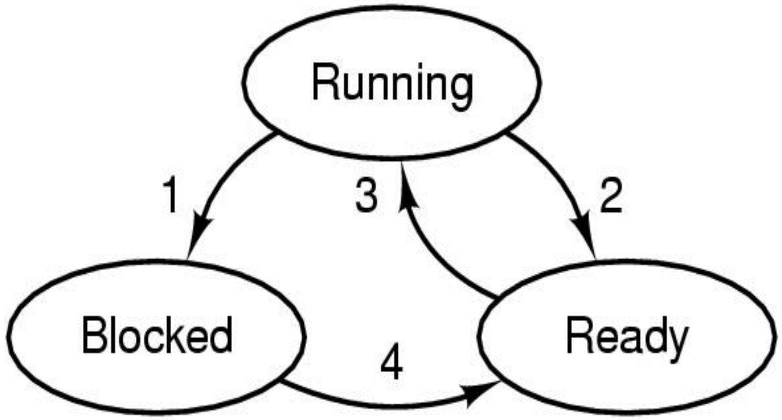
How do multiple processes share CPU?



Time	Process_0	Process_1	Notes
1	Running	Ready	
2	Running	Ready	
3	Running	Ready	
4	Running	Ready	Process_0 now done
5	–	Running	
6	–	Running	
7	–	Running	
8	–	Running	Process_1 now done

Figure 4.3: **Tracing Process State: CPU Only**

How do multiple processes share CPU?



1. Process blocks for input
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Time	$Process_0$	$Process_1$	Notes
1	Running	Ready	
2	Running	Ready	
3	Running	Ready	$Process_0$ initiates I/O
4	Blocked	Running	$Process_0$ is blocked,
5	Blocked	Running	so $Process_1$ runs
6	Blocked	Running	
7	Ready	Running	I/O done
8	Ready	Running	$Process_1$ now done
9	Running	–	
10	Running	–	$Process_0$ now done

Figure 4.4: **Tracing Process State: CPU and I/O**

Typical Kernel-level data structure for each process

Process management	Memory management	File management
Registers	Pointer to text segment	Root directory
Program counter	Pointer to data segment	Working directory
Program status word	Pointer to stack segment	File descriptors
Stack pointer		User ID
Process state		Group ID
Priority		
Scheduling parameters		
Process ID		
Parent process		
Process group		
Signals		
Time when process started		
CPU time used		
Children’s CPU time		
Time of next alarm		

- See task_struct in Linux source code

Examining Processes in Unix/Linux

- ps command
  - Standard process attributes
- /proc directory
  - More interesting information if you are the root.
- top command
  - Examining CPU and memory usage statistics.

Orphan process

- When a parent process dies, child process becomes an orphan process.
- The init process (pid = 1) becomes the parent of the orphan processes.
- Here's an example:
- http://www.cs.binghamton.edu/~kartik/cs350/examples/orphan.c
    - Do a 'ps –l' after running the above program and check parent's PID of the orphan process.
    - After you are done remember to kill the orphan process 'kill –9 <pid>'

Zombie Process

- When a child dies, a SIGCHLD signal is sent to the parent.
- If parent doesn’t wait()on the child, and child exit()s, it becomes a zombie (status “Z” seen with ps).
- Zombies hang around till parent calls wait() or waitpid().
- But they don’t take up any system resources.
  - Just an integer status is kept in the OS.
  - All other resources are freed up.

References

- Chapter 2 of the Tanenbaum’s book
- Chapter 4 of OSTEP book

- Man pages for different system calls
  - Try “man 2 <syscall_name>”
    - E.g. man 2 exec
  - Syscalls are normally listed in section 2 of the man page