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Processes

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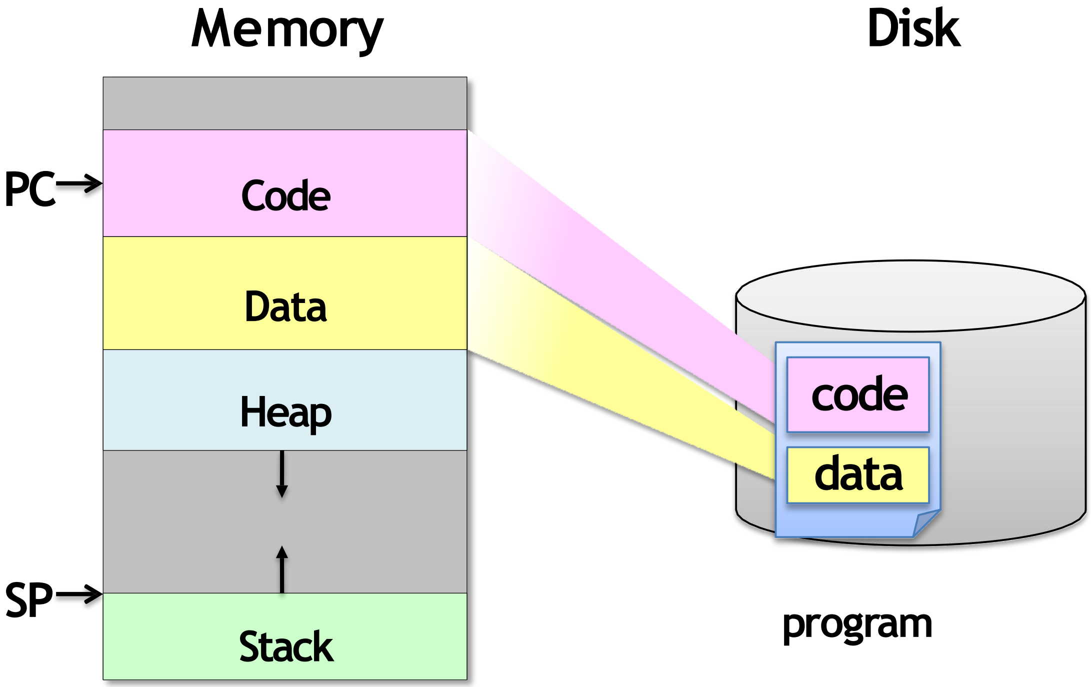
Processes (1)

- **It is not same as “program” or “processor”**

- **What’s the difference?**
  - Program
  - **Process**
  - Processor

Processes (2)

- **Process**
  - **An instance of a program in execution**
  - One of the most profound ideas in computer science



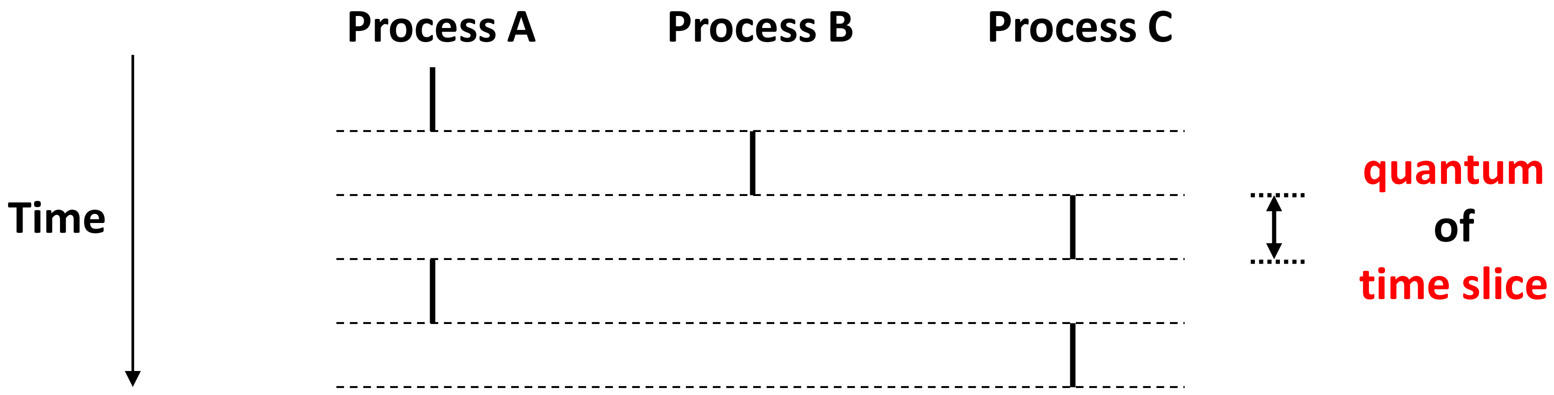
Processes (3)

- **Process provides each program with two key abstractions:**
  - Logical control flow
    - Each program seems to have exclusive use of the CPU
  - Private address space
    - Each program seems to have exclusive use of main memory

- **How are these illusions maintained?**
  - Process executions interleaved (multitasking).
  - Address space managed by virtual memory system.

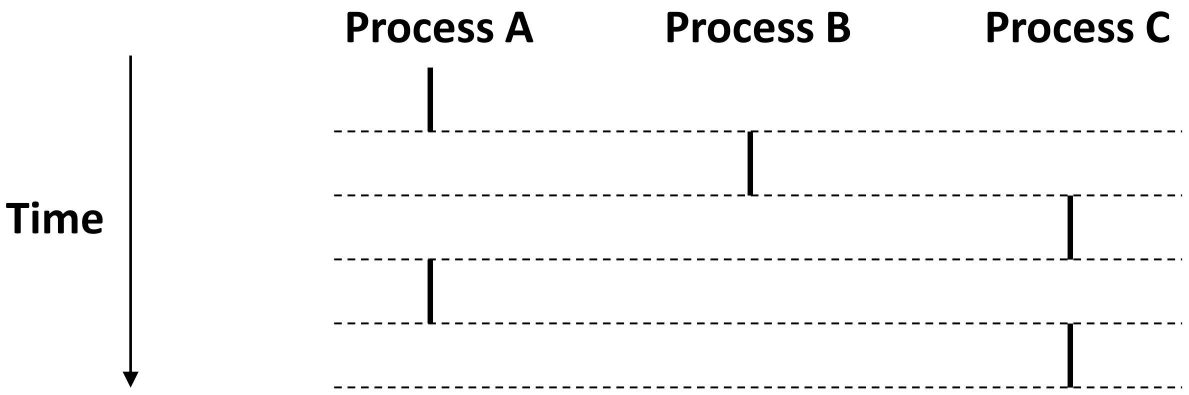
Logical Control Flows

- Each process has its own logical control flow

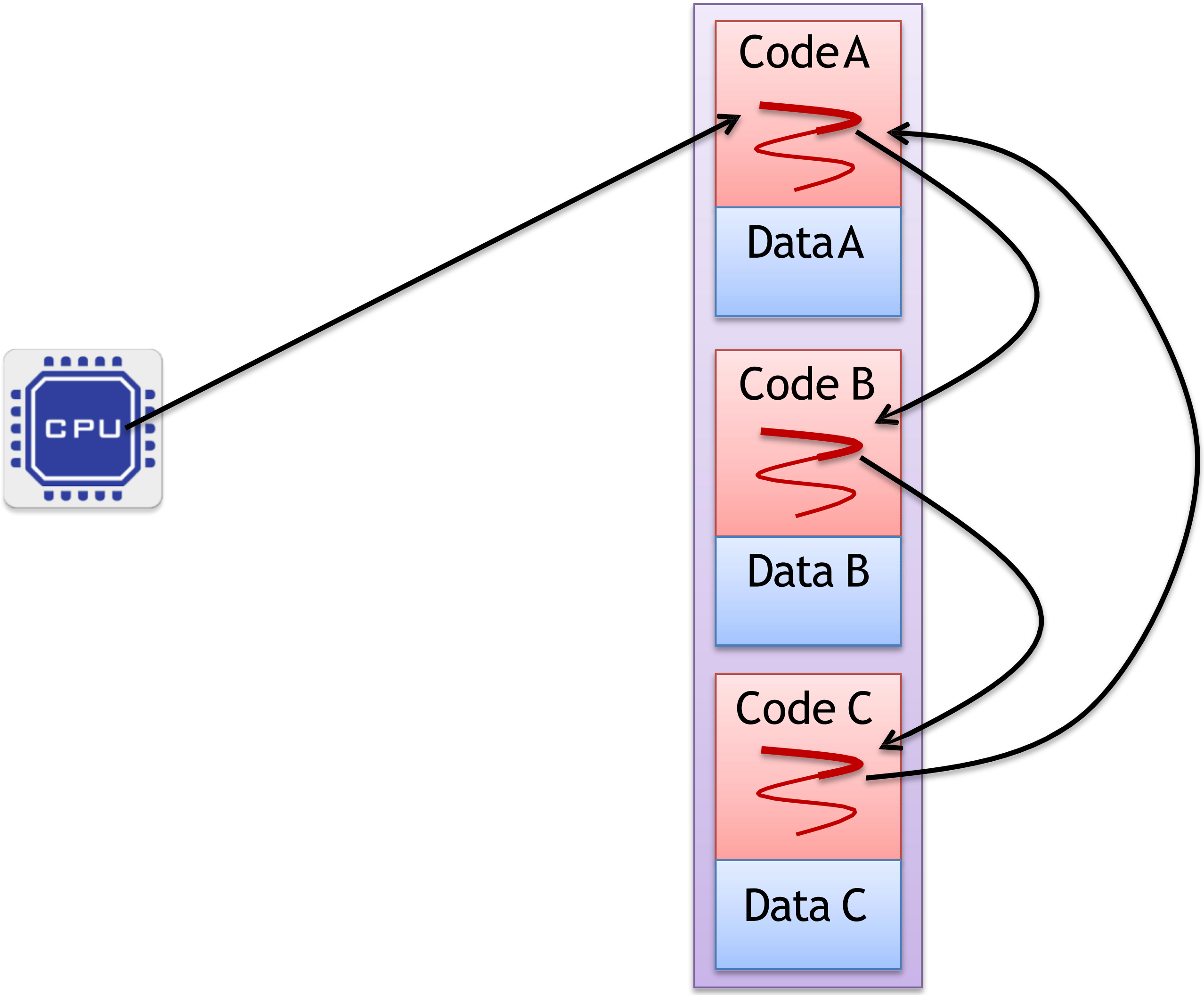


Concurrent Processes (1)

- **Definition**
  - Two processes run concurrently (are concurrent) if their flows overlap in time.
  - Otherwise, they are sequential.
  - Examples (running on single core):
    - Concurrent: A & B, A & C
    - Sequential: B & C

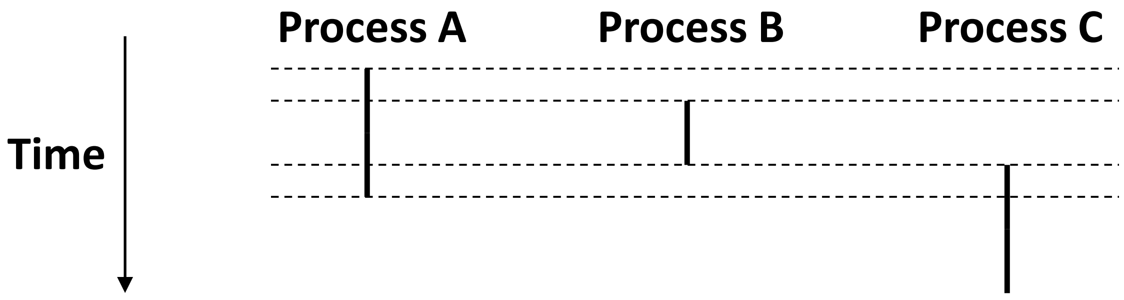


Concurrent Processes (2)



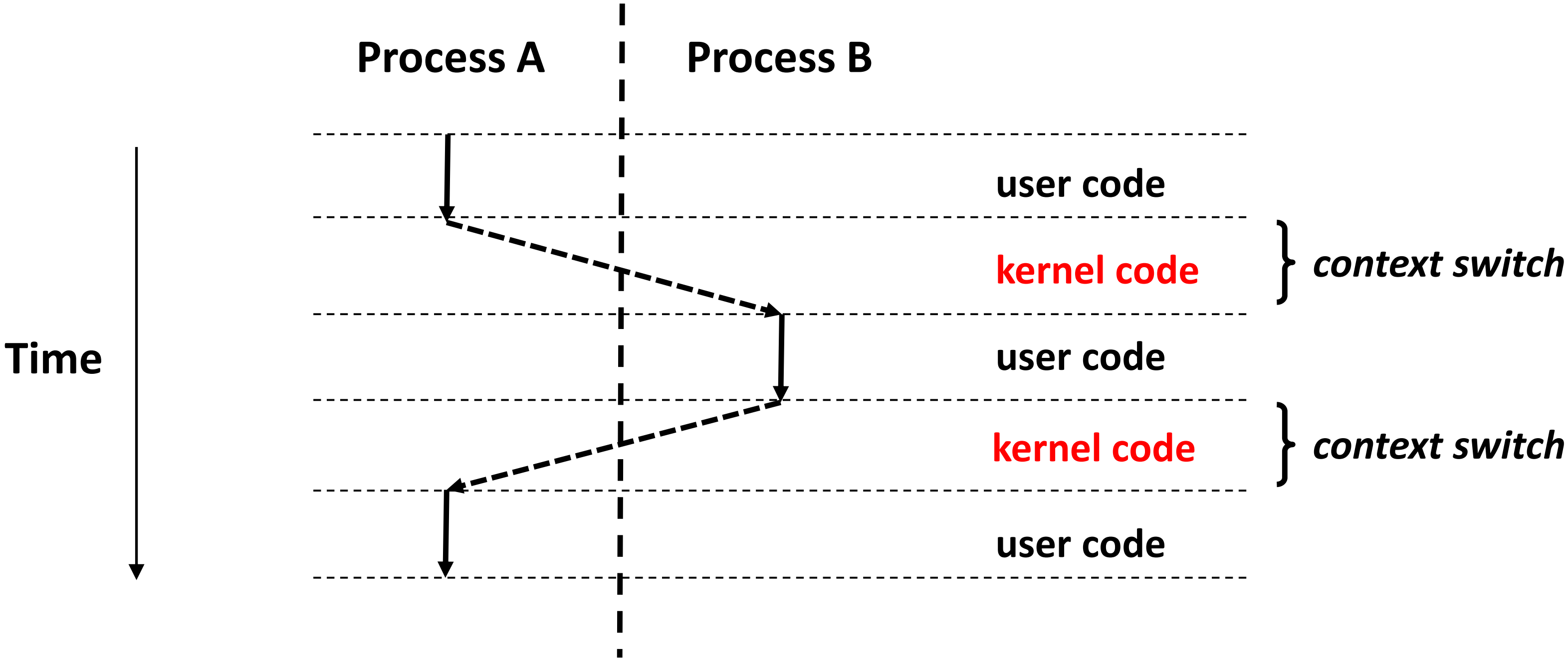
Concurrent Processes (3)

- **User View of Concurrent Processes**
  - Control flows for concurrent processes are physically disjoint in time
  - However, we can think of concurrent processes are running in parallel with each other



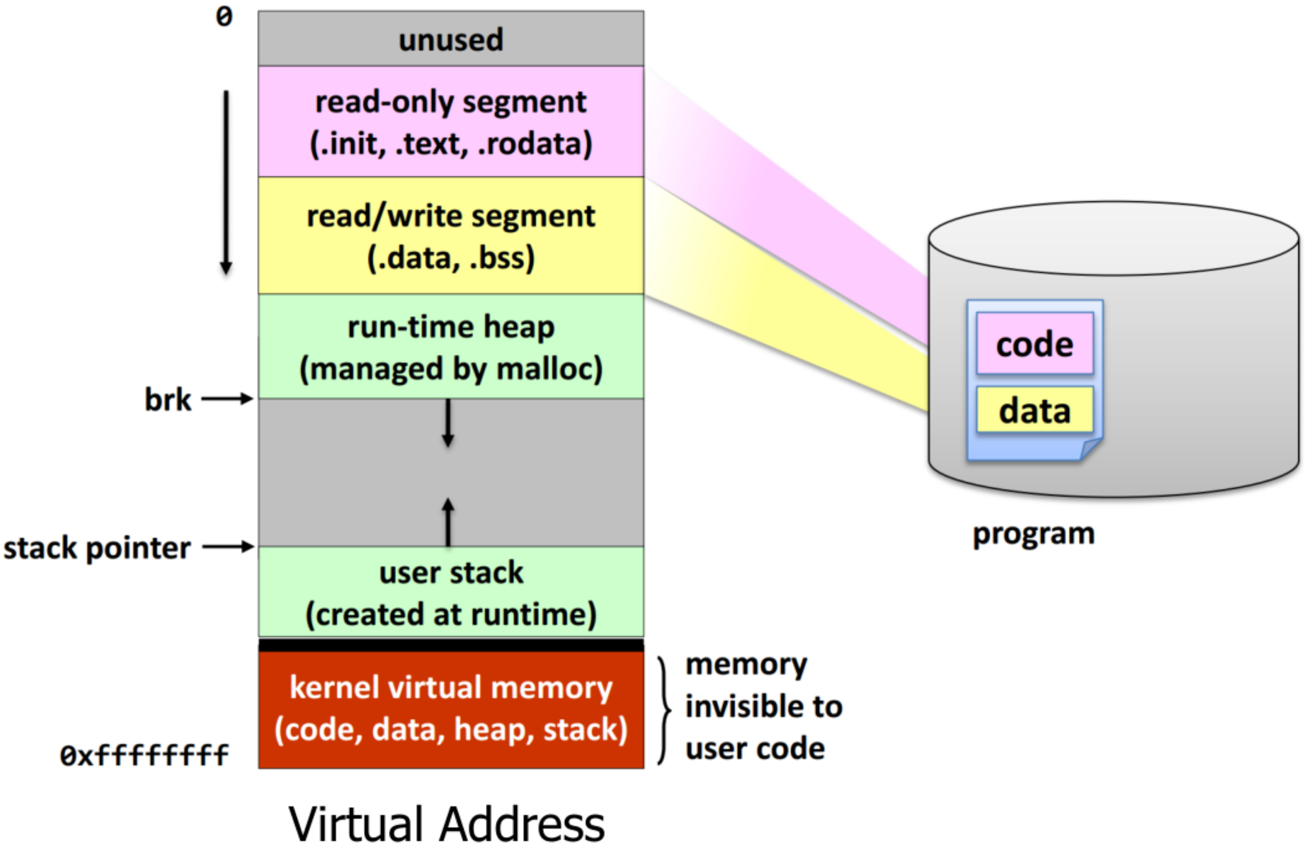
Context Switching

- Control flow passes from one process to another via a context switch



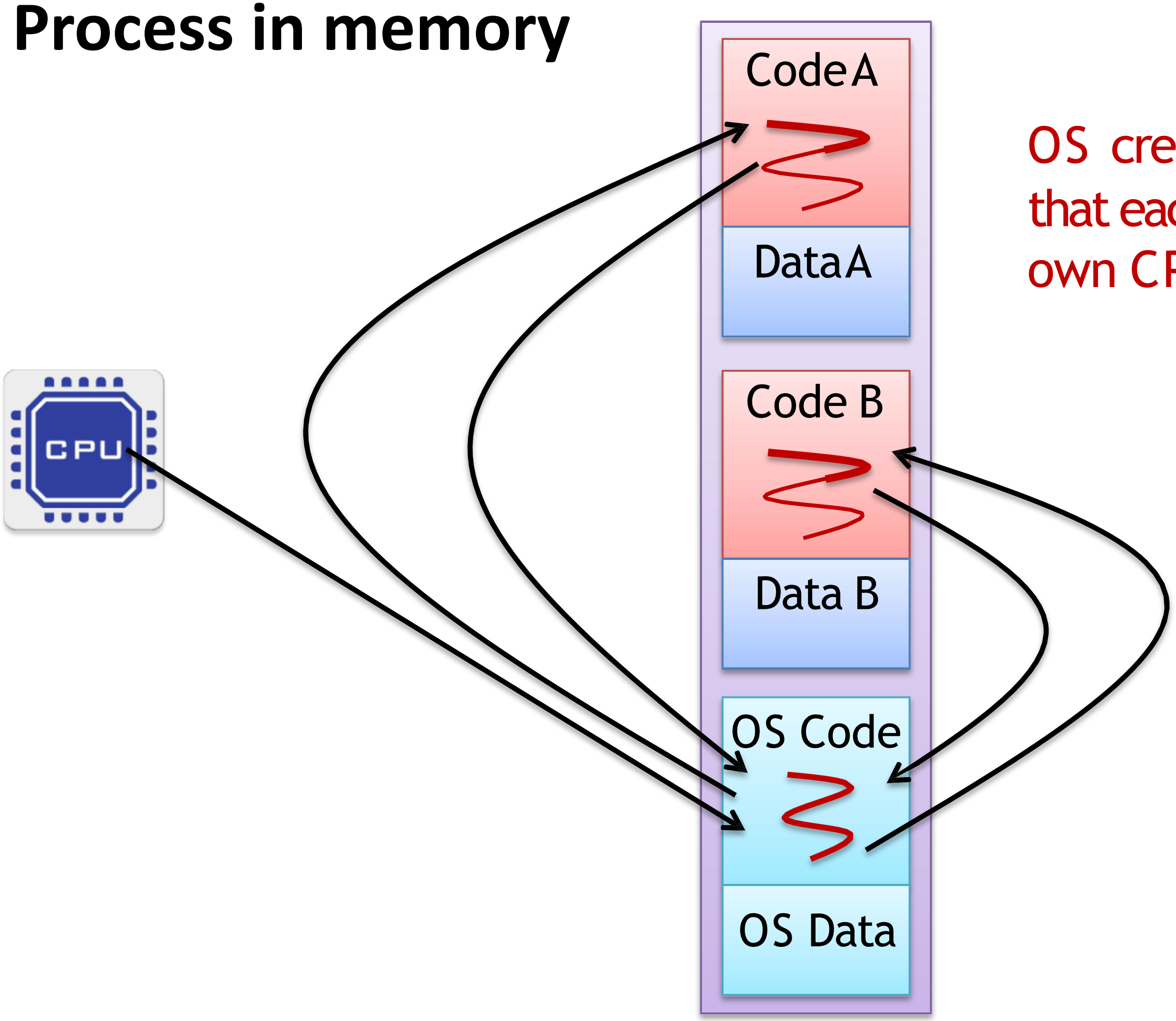
Private Address Space

- Process in memory



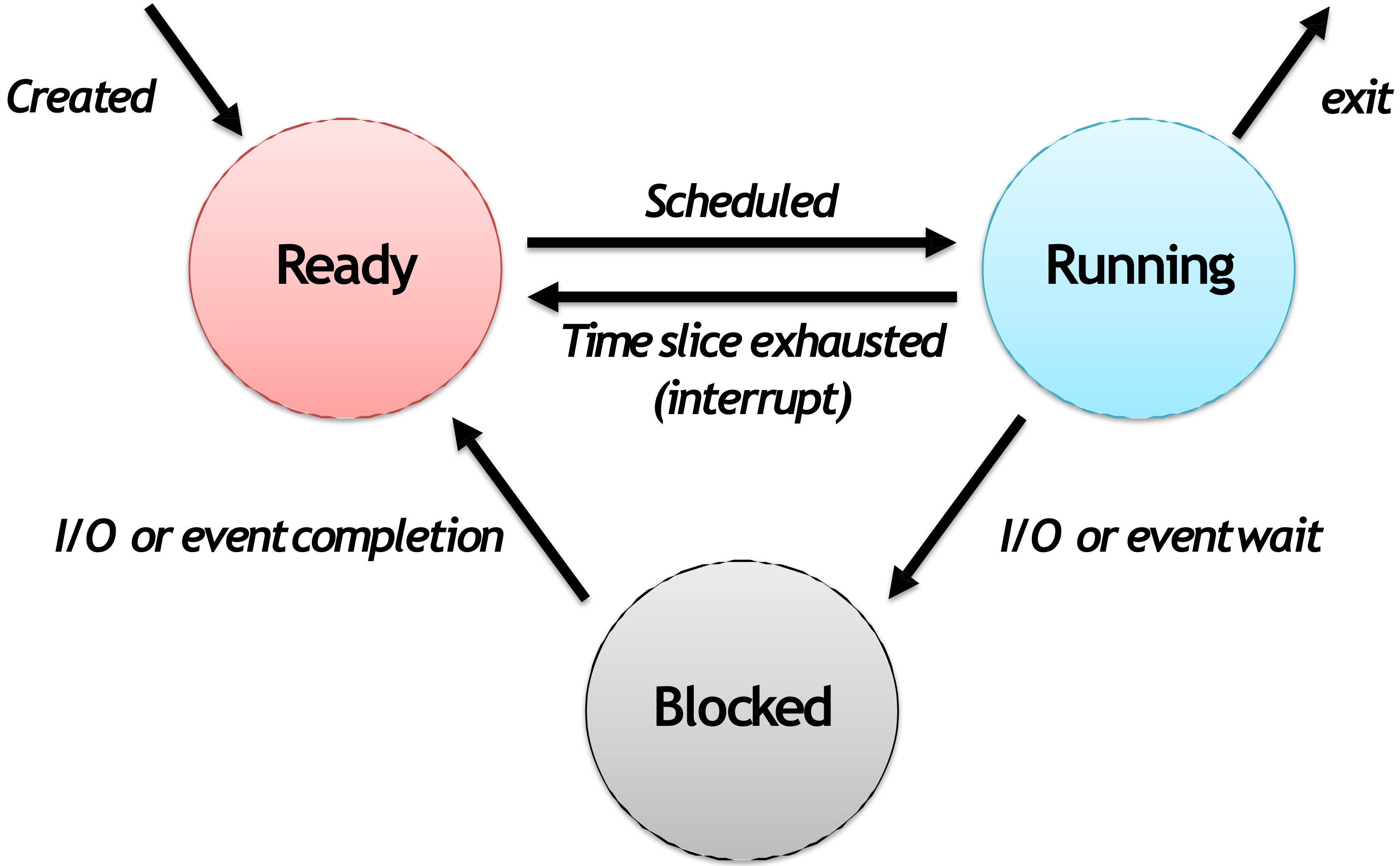
Private Address Space

- **Process in memory**



OS creates the illusion that each process has its own CPU (and memory)

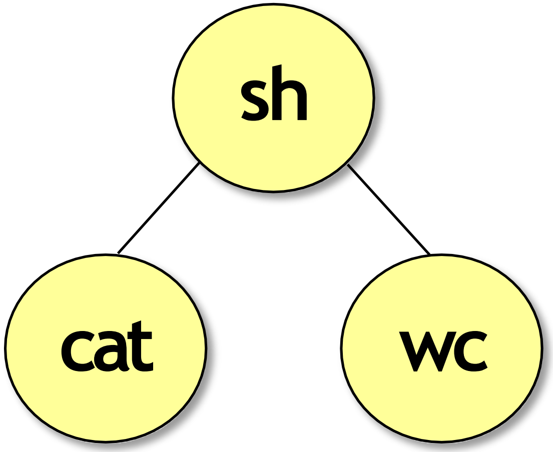
Process State Transition



Process Hierarchy

- **Parent-child relationship**
  - One process can create another process
  - Unix calls the hierarchy a “process group”
  - Windows has no concept of process hierarchy

```
$ cat file1 | wc
```



- **Browsing a list of processes:**
  - ps in Unix
  - Task Manager (taskmgr) in Windows

Creating a New Process

- pid_t fork(void)
  - Creates a new process (child process) that is identical to the calling process (parent process)
  - Returns 0 to the child process
  - Returns child’s **pid** to the parent process

```
if (fork() == 0) {
   printf("hello from child\n");
} else {
   printf("hello from parent\n");
}
```

Fork is interesting (and often confusing) because it is called *once* but returns *twice*

Fork Example (1)

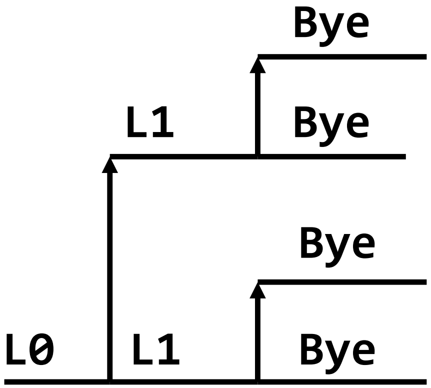
- **Key points**
  - – Parent and child both run **same code**
    - Distinguish parent from child by **return value** from **fork()**
  - – Start with same state, but each has private copy.
    - Share file descriptors, since child inherits all open files.

```
void fork1() {
    int x = 1;
    pid_t pid = fork();
    if (pid == 0) {
        printf("Child has x = %d\n", ++x);
    } else {
        printf("Parent has x = %d\n", --x);
    }
    printf("Bye from process %d with x = %d\n", getpid(), x);
}
```

Fork Example (2)

- **Key points**
  - Both parent and child can continue forking.

```
void fork2()
{
    printf("L0\n");
    fork();
    printf("L1\n");
    fork();
    printf("Bye\n");
}
```



Fork Example (3)

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

int main()
{
    int pid;

    if ((pid = fork()) == 0)
        /* child */
        printf (“Child of %d is %d\n”, getppid(), getpid());
    else
        /* parent */
        printf (“I am %d. My child is %d\n”, getpid(), pid);
}
```

```
% ./a.out
I am 31098. My child is 31099
Child of 31098 is 31099.

% ./a.out
Child of 31100 is 31101.
I am 31100. My child is 31101
```

Process Termination

- **Normal exit (voluntary)**
- **Error exit (voluntary)**
- **Fatal error (involuntary)**
  - Segmentation fault – illegal memory access
  - Protection fault
  - Exceed allocated resources, etc.
- **Killed by another process (involuntary)**
  - By receiving a signal

- **Zombie process: terminated, but not removed**

Destroying a Process

- **void exit (int status)**
  - Exits a process.
    - Normally returns with status 0
  - **atexit()** registers functions to be executed upon exit.

```
void cleanup(void) {
   printf("cleaning up\n");
}

void fork6() {
   atexit(cleanup);
   fork();
   exit(0);
}
```

Synchronizing with Children

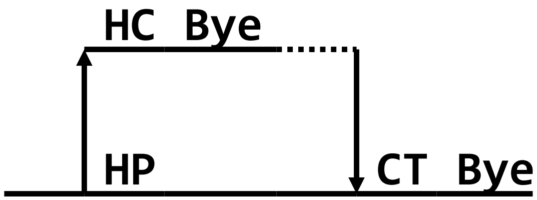
- **pid_t wait (int *status)**
  - suspends current process until one of its children terminates.
  - return value is the **pid** of the child process that terminated.
  - if **status != NULL**, then the object it points to will be set to a status indicating why the child process terminated.

- **pid_t waitpid (pid_t pid, int *status, int options)**
  - Can wait for specific process
  - Various options

Wait Example (1)

```
void fork9() {
   int child_status;

   if (fork() == 0) {
      printf("HC: hello from child\n");
   }
   else {
      printf("HP: hello from parent\n");
      wait(&child_status);
      printf("CT: child has terminated\n");
   }
   printf("Bye\n");
   exit();
}
```



Wait Example (2)

- **If multiple children completed,**
  - will take in arbitrary order.
  - Can use macros **WIFEXITED** and **WEXITSTATUS** to get information about exit status.

```
void fork10() {
    pid_t pid[N];
    int i, child_status;
    for (i = 0; i < N; i++)
        if ((pid[i] = fork()) == 0)
            exit(100+i); /* Child */
    for (i = 0; i < N; i++) {
        pid_t wpid = wait(&child_status);
        if (WIFEXITED(child_status))
            printf("Child %d terminated with exit status %d\n",
                   wpid, WEXITSTATUS(child_status));
        else
            printf("Child %d terminated abnormally\n", wpid);
    }
}
```

Waitpid Example

```
void fork11()
{
    pid_t pid[N];
    int i;
    int child_status;
    for (i = 0; i < N; i++)
        if ((pid[i] = fork()) == 0)
            exit(100+i); /* Child */
    for (i = 0; i < N; i++) {
        pid_t wpid = waitpid(pid[i], &child_status, 0);
        if (WIFEXITED(child_status))
            printf("Child %d terminated with exit status %d\n",
                  wpid, WEXITSTATUS(child_status));
        else
            printf("Child %d terminated abnormally\n", wpid);
    }
```

Zombies (1)

- **Idea**
  - When a process terminates, still consumes system resources.
    - Various tables maintained by OS
  - Called a “zombie”
    - Living corpse, half alive and half dead
- **Reaping**
  - Performed by parent on terminated child.
  - Parent is given exit status information.
  - Kernel discards the terminated process.
- **What if parent doesn’t reap?**
  - If any parent terminates without reaping a child, then child will be reaped by init process.
  - Only need explicit reaping for long-running processes.
    - e.g. shells and servers

Zombies (2)

```
void fork7()
{
  if (fork() == 0) {
    /* Child */
    printf("Terminating Child, PID = %d\n",
            getpid());
    exit(0);
  } else {
    printf("Running Parent, PID = %d\n",
            getpid());
    while (1); /* Infinite loop */
  }
}
```

```
linux> ./forks 7 &
[1] 6639
Running Parent, PID = 6639
Terminating Child, PID = 6640
linux> ps
  PID TTY          TIME CMD
 6585 ttyp9    00:00:00 tcsh
 6639 ttyp9    00:00:03 forks
 6640 ttyp9    00:00:00 forks <defunct>
 6641 ttyp9    00:00:00 ps
linux> kill 6639
[1]    Terminated
linux> ps
  PID TTY          TIME CMD
 6585 ttyp9    00:00:00 tcsh
 6642 ttyp9    00:00:00 ps
```

- **ps shows child processes as “defunct”**
- **Killing parent allows child to be reaped**

Running New Programs (1)

- **int execl (char *path, char *arg0, …, NULL)**
  - loads and runs executable at **path** with arguments **arg0**, **arg1**, …
    - **path** is the complete path of an executable
    - **arg0** becomes the name of the process
      - Typically **arg0** is either identical to **path**, or else it contains only the executable filename from path.
    - “real” arguments to the executable start with **arg1**, etc.
    - list of args is terminated by a **(char *)** 0 argument.
  - returns –1 if error, otherwise doesn’t return!
- **int execv (char *path, char *argv[])**
  - argv : null terminated pointer arrays

Running New Programs (2)

- Example: running /bin/ls

```
main() {
   if (fork() == 0) {
      execl("/bin/ls", "ls", "/", NULL);
   }
   wait(NULL);
   printf("completed\n");
   exit();
}
```

```
main() {
   char *args[] = {"ls", "/", NULL};
   if (fork() == 0) {
      execv("/bin/ls", args);
   }
   wait(NULL);
}
```

Summary

- **Process abstraction**
  - Logical control flow
  - Private address space

- **Process-related system calls**
  - `fork()`
  - `exit(), atexit()`
  - `wait(), waitpid()`
  - `execl(), execle(), execv(), execve(), …`

Exercise

Exercise

- Make “xcp” using “cat”
  - Call “cat *<src>*” after change fd 1 to *<dest>*
  - $ xcp <src> <dest>
    - fork()
    - if child
      - close() / open()
      - exec(cat, *<src>*)
      - return *<last 2 numbers of your student id>*
    - if parent
      - wait(&status)
      - printf(“pid: *<pid>*”);
      - printf(“status: *<status>*”);

Using dup2 function

You should include <fcntl.h>, <unistd.h>, <sys/wait.h>, <sys/types.h>
You can also use <stdio.h>