Recap

OS Goal: to run programs easily, efficiently, securely, …

Approaches:

- Virtualize CPU and Memory for each running program (process)
- Manage concurrency
- Provide data persistence
- Support networking, security, …

OS interface for programs: system calls

L2: Process Abstraction & API

(Based on Chapters 4 & 5)

Spring 2023

Slides borrowed from
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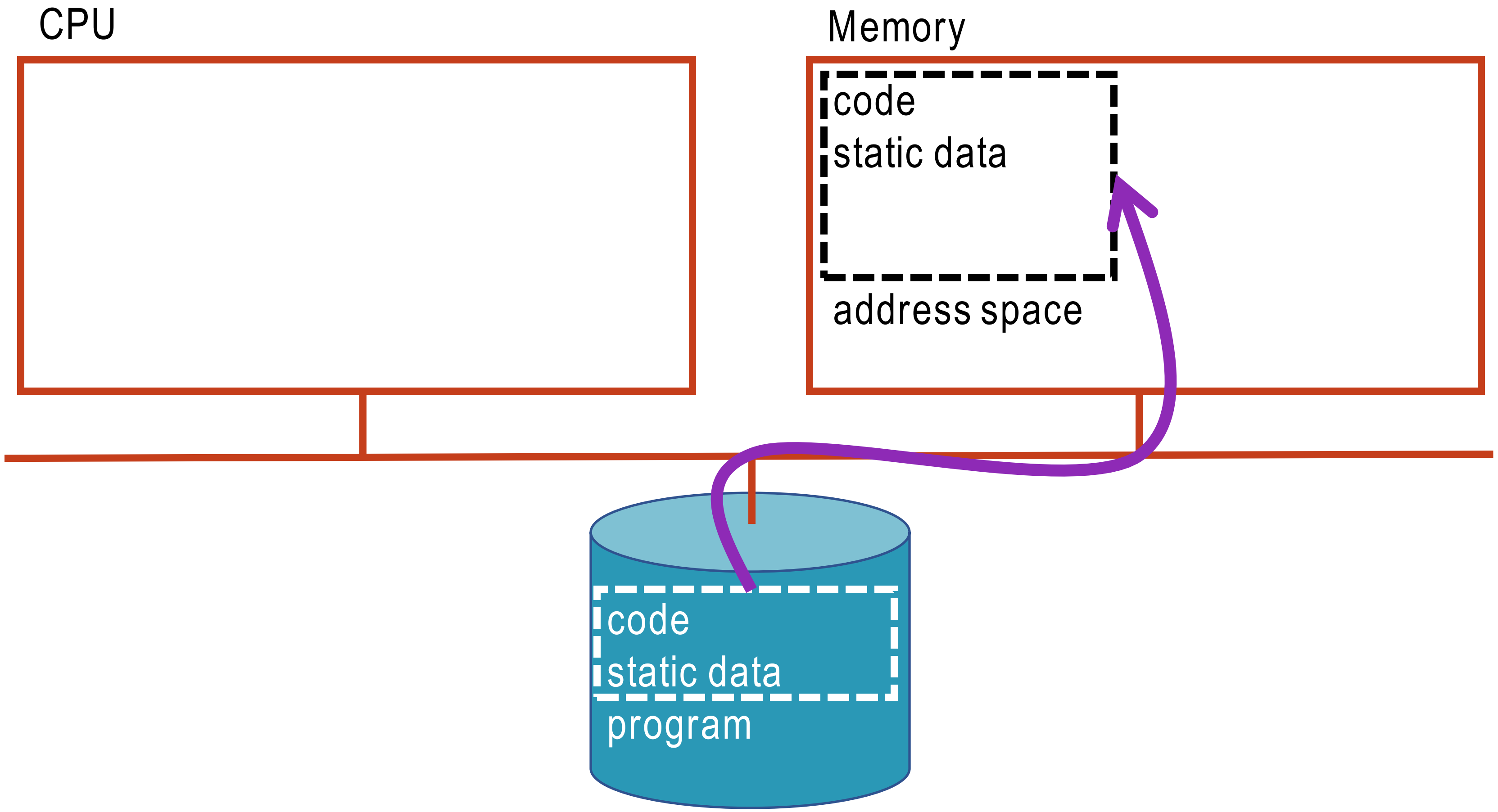
Iowa State University

Program vs Process

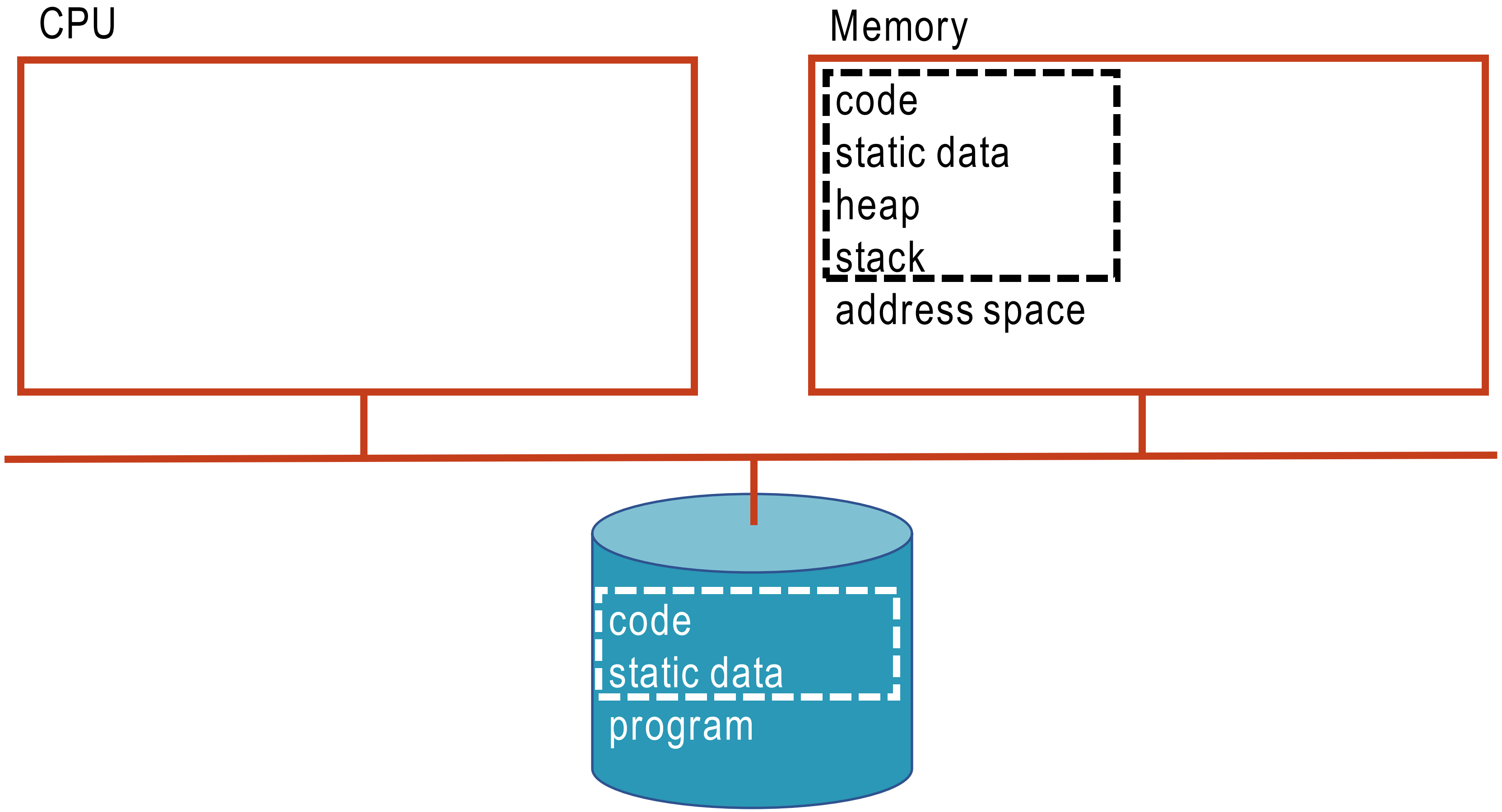
A *program* is instructions (including static data) stored on disk – an executable file

A *process* is a running program

Process Creation



Address Space



The *address space* is where the program's data resides.

Process Information

A process is more than a list of instructions, execution requires knowing…

- Which instruction to execute next? *program counter*
- What is the immediate data on which instructions operate? *registers*
- Where are the instructions and data stored in memory? *address space*
- How to find parameters of current function? *stack and frame pointer*
- And more that we will cover later in this class (e.g., open files, threads…)

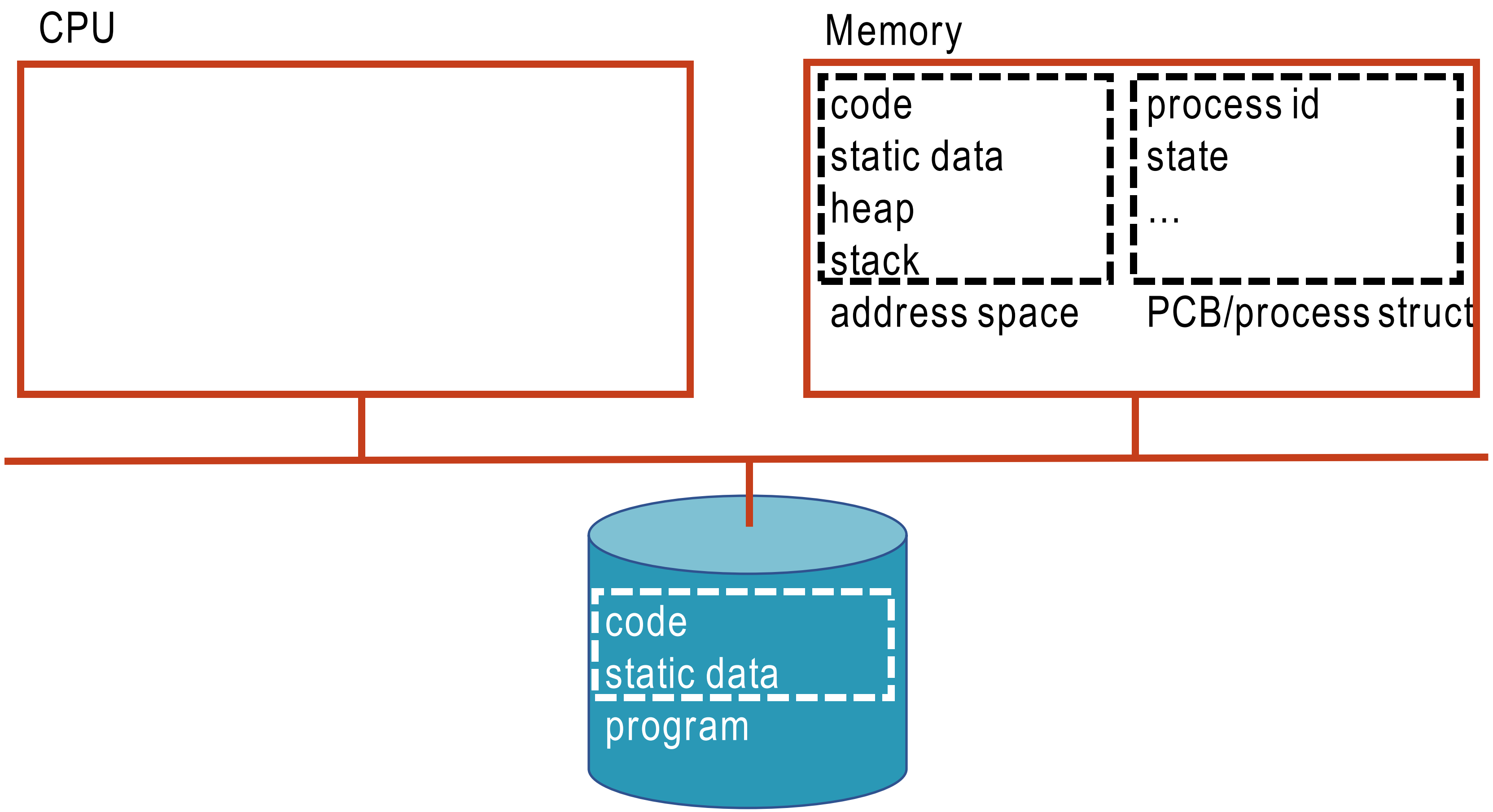
Process Control Block (struct proc) in xv6

proc.h

```
// Saved registers for kernel context switches.
struct context {
  uint64 ra;
  uint64 sp;

  // callee-saved
  uint64 s0;
  uint64 s1;
  uint64 s2;
  uint64 s3;
  uint64 s4;
  uint64 s5;
  uint64 s6;
  uint64 s7;
  uint64 s8;
  uint64 s9;
  uint64 s10;
  uint64 s11;
};

enum procstate { UNUSED, USED, SLEEPING,
RUNNABLE, RUNNING, ZOMBIE };
```

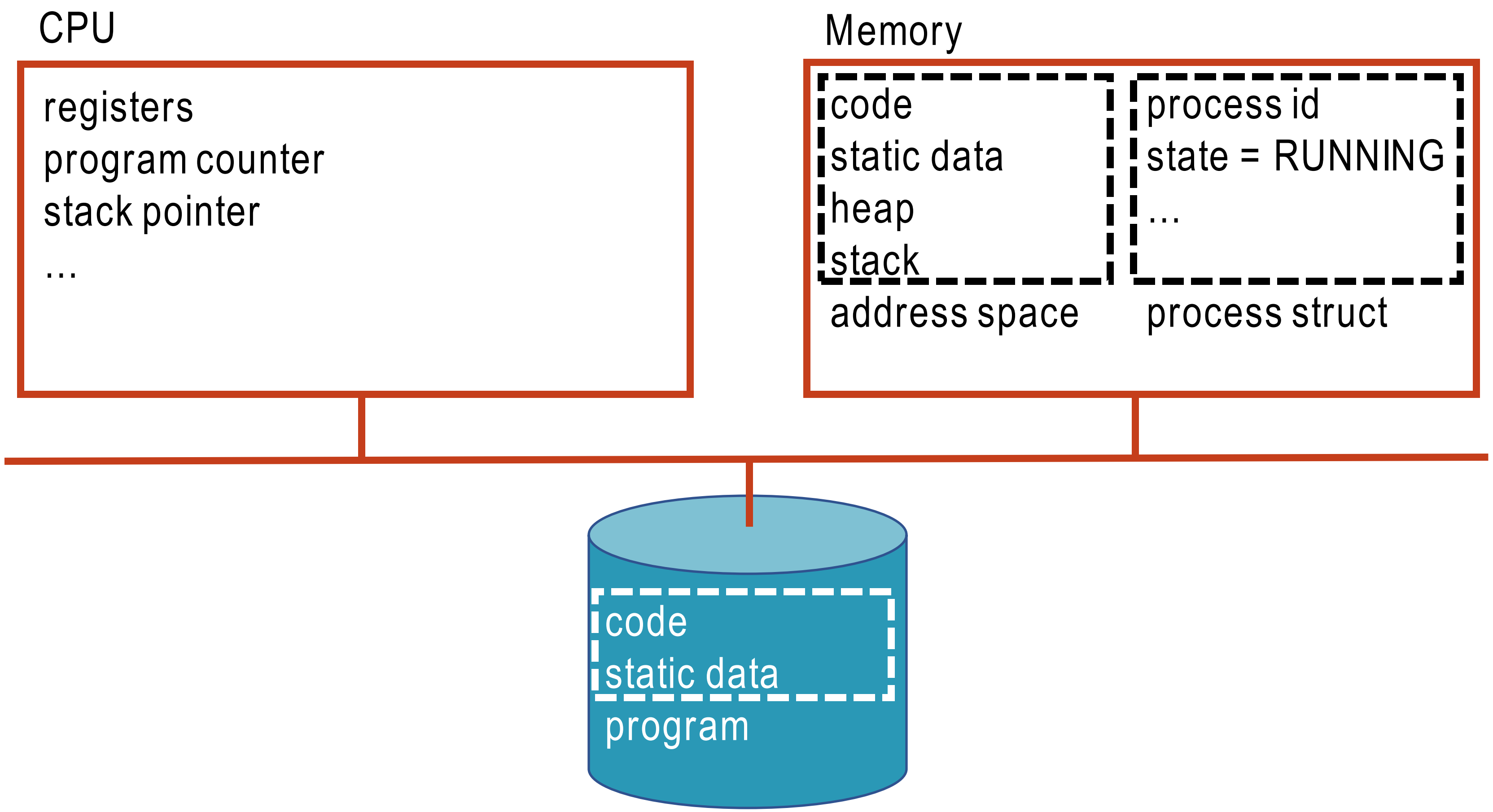
```
// Per-process state
struct proc {
  struct spinlock lock;

  // p->lock must be held when using these:
  enum procstate state;        // Process state
  void *chan;                  // If non-zero, sleeping on channel
  int killed;                  // If non-zero, have been killed
  int xstate;                  // Exit status to be returned to parent's wait
  int pid;                     // Process ID

  // proc_tree_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)
};
```

Process Control Block



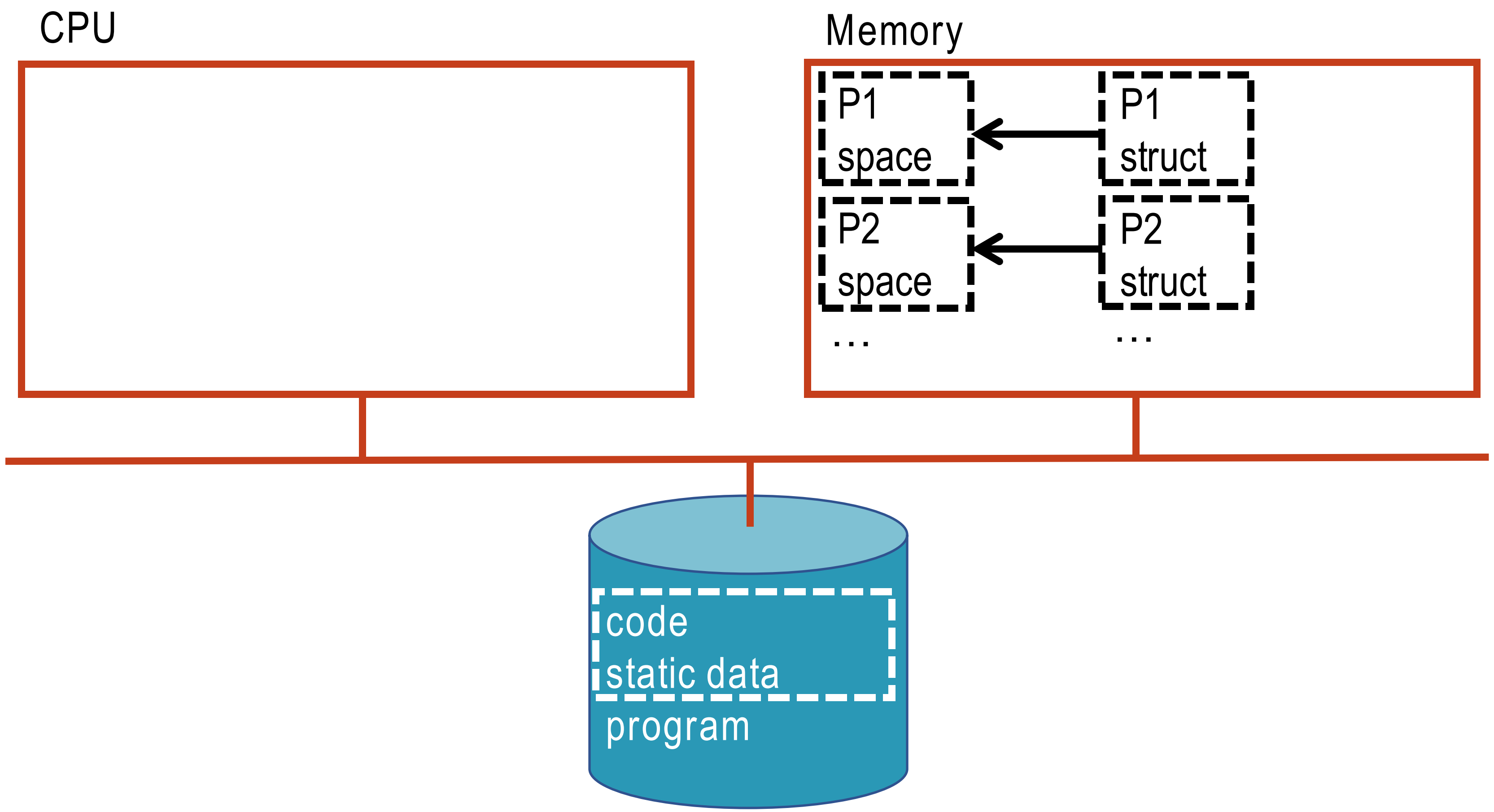
The *Process Control Block (PCB)* is a structure the OS uses to keep track of the process information.

Process In Execution



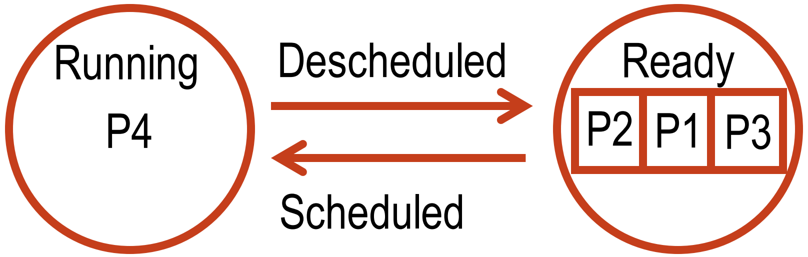
During execution, the state of the CPU is dedicated to the process.

Multiple Processes



We don't want to be limited to one process, but a CPU can only execute one process at a time… Which process should be running?

Scheduler: Running and Ready



The scheduler is part of the OS, it manages the process' *states*
Only one process *running* at a time (if there is single CPU core)
Other processes that are ready to execute go in a *ready queue*

When there are multiple processes, should we run them one by one sequentially?

Not a good idea!

Multiprogramming

Processes need to perform I/O, e.g., disk read/write

Consider a process that makes a random read from disk

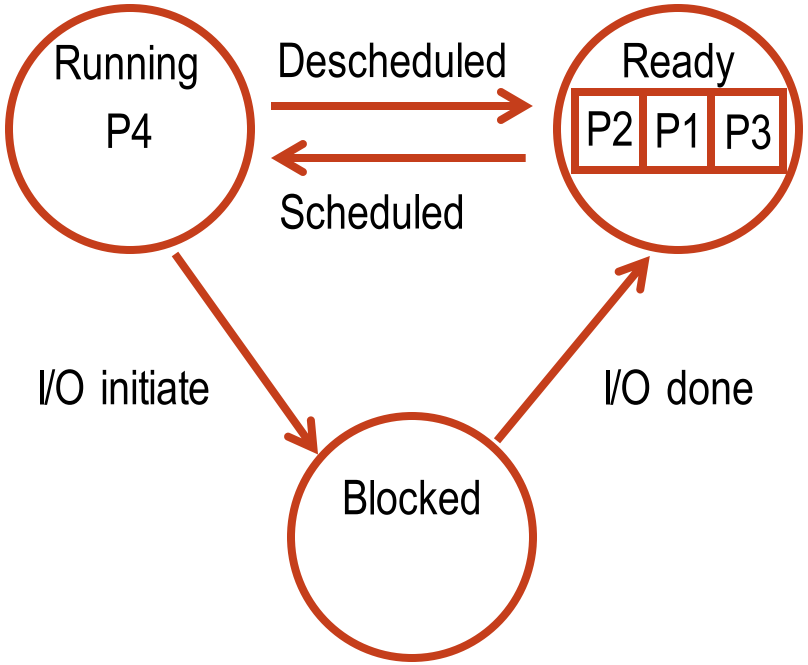
- Hard drive latency 10ms and SSD latency 1ms
- CPU clock 0.3ns cycle and 1 instructions per cycle
- **10 million instructions wasted waiting for SSD and 100 million for hard drive!**

Clearly not good use of the CPU

Multiprogramming is letting the user run multiple processes together

When one process needs to wait for I/O another can be scheduled on the CPU

Scheduler with Blocked State

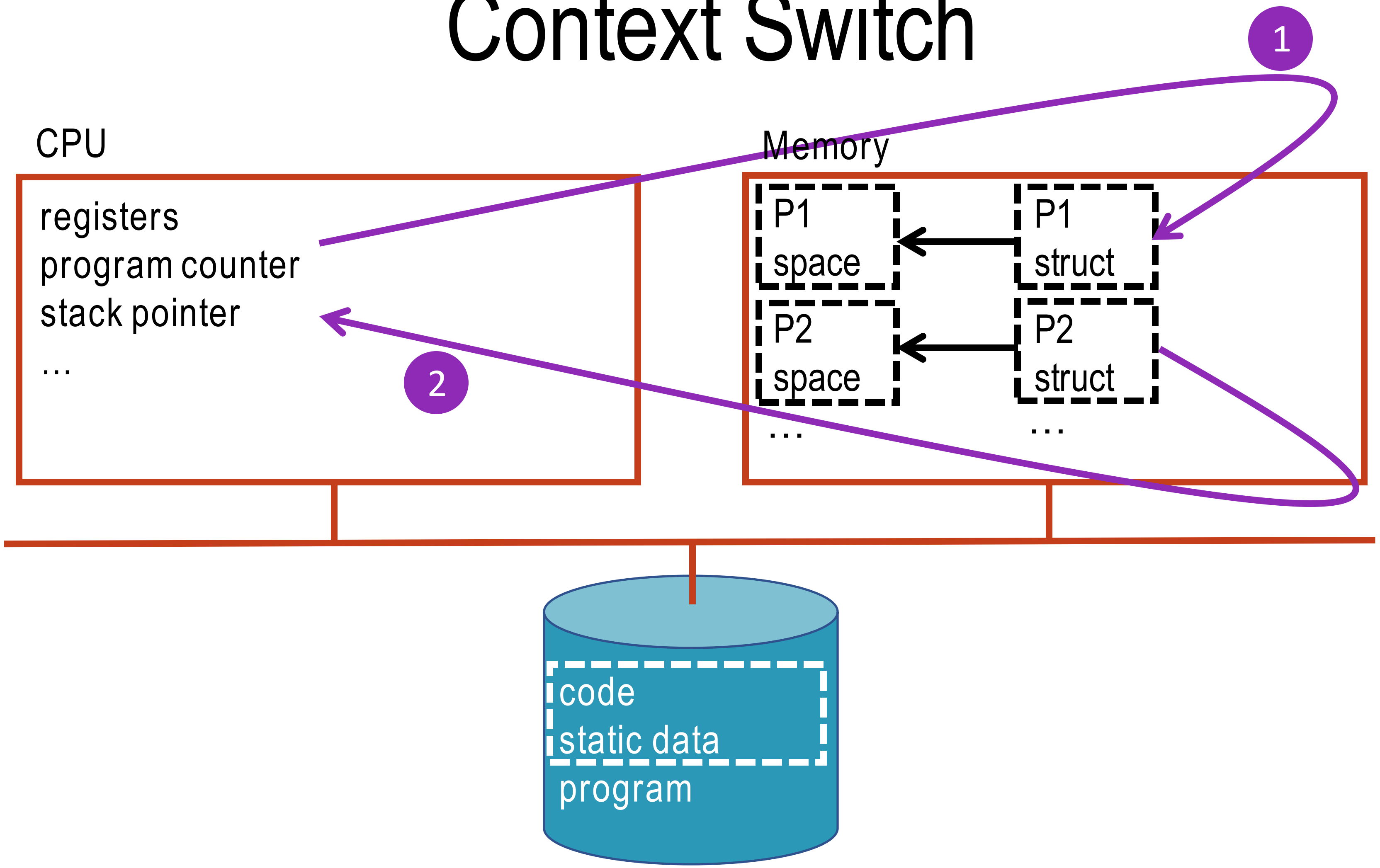


When a process is waiting for I/O it is placed in the *blocked* queue (in blocked state)

Next process in ready queue is set to running

When a blocked process finishes I/O, it returns to ready state

Context Switch



Save CPU context of descheduled process (so the process can resume from this point later …)

Load CPU context of scheduled process

Example

Time	Process0	Process1	Notes
1	Running	Ready	
2	Running	Ready	
3	Running	Ready	Process0 initiates I/O
4	Blocked	Running	Process0 is blocked, so Process1 runs
5	Blocked	Running	
6	Ready	Running	I/O done
7	Ready	Running	Process1 now done
8	Running		
9	Running		

Process API

Process Tree

Every process is created by another process (except to root process)

Every process must have a *parent*, by default the parent is the process that created it (the *child* process)

When a process is created it starts in an *initial state* and when it terminates it goes to a *final (zombie) state*

- The final state is required because we can't delete the PCB immediately, the parent may want information such as the exit code

If a parent terminates before the child, the child becomes an *orphan* process and the root process becomes its parent

Process System Calls

POSIX (Portable Operating System Interface)

Standard programming interface provided by UNIX like systems

fork()	Create another process (child) that is a copy of the current process (parent)
exec()	Change the program of the currently executing process
wait()	Do nothing until a child process has terminated

fork( ) // Process Creation

```
pid_t fork(void);
```

Creates a new process by duplicating the calling process

Child process has a copy of parent's address space

On success:

- Both parent and child continue execution at the point of return from fork()
- Returns pid of the child process to the parent process; returns 0 to child process

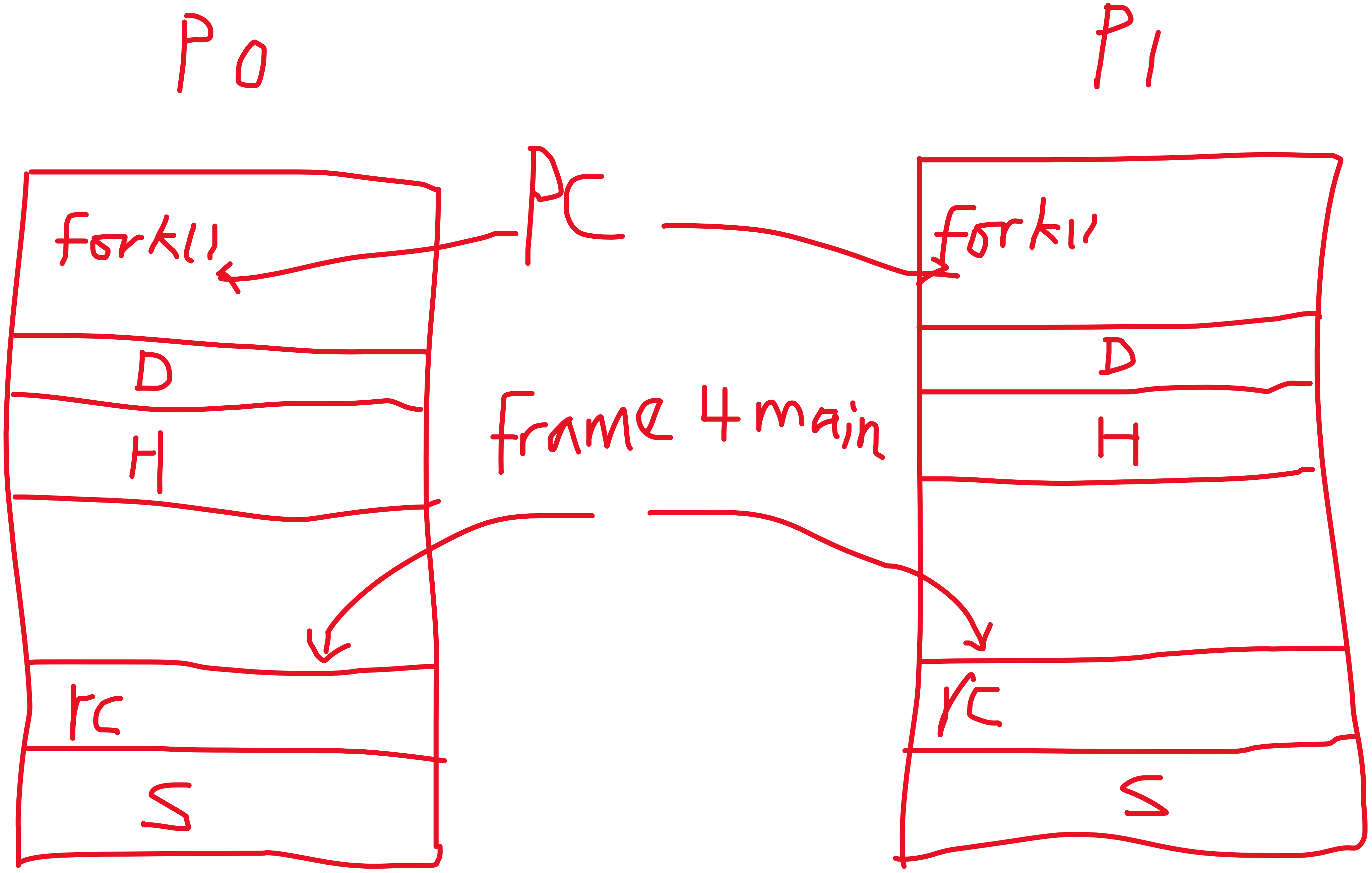
On failure:

- Child is not created; returns –1 to parent fork.c

```c
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>

int main(int args, 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
        printf("hello, I am parent of %d (pid:%d)\n", rc, (int) getpid());
    }
    return 0;
}
```

console

```
hello world (pid:19979)
hello, I am parent of 19980 (pid:19979)
hello, I am child (pid:19980)
```



P0
P1
PC
fork()
fork()
frame 4 main
D
H
rc
S
D
H
rc
S

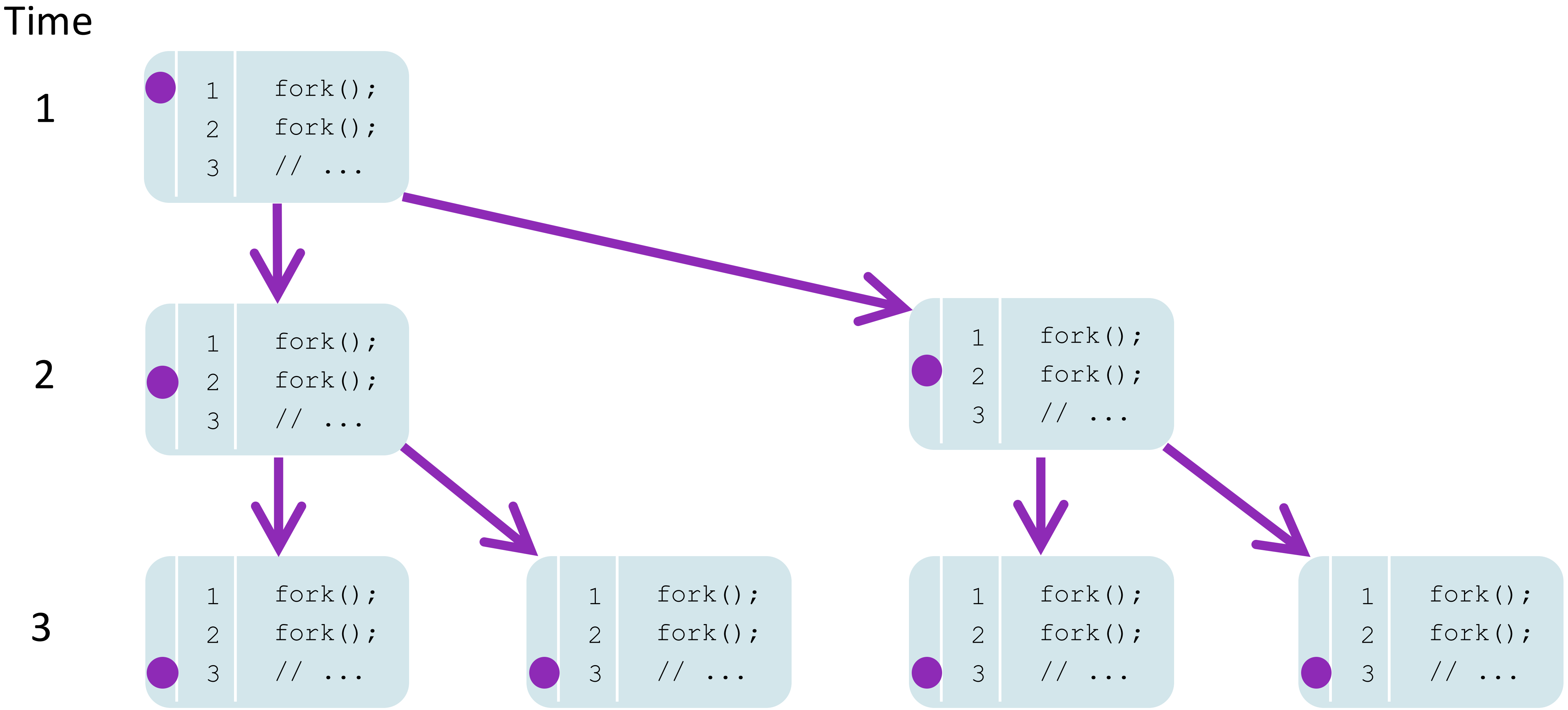
parent

```
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
    printf("hello, I am parent of %d (pid:%d)\n", rc, (int) getpid());
}
return 0;
}
```

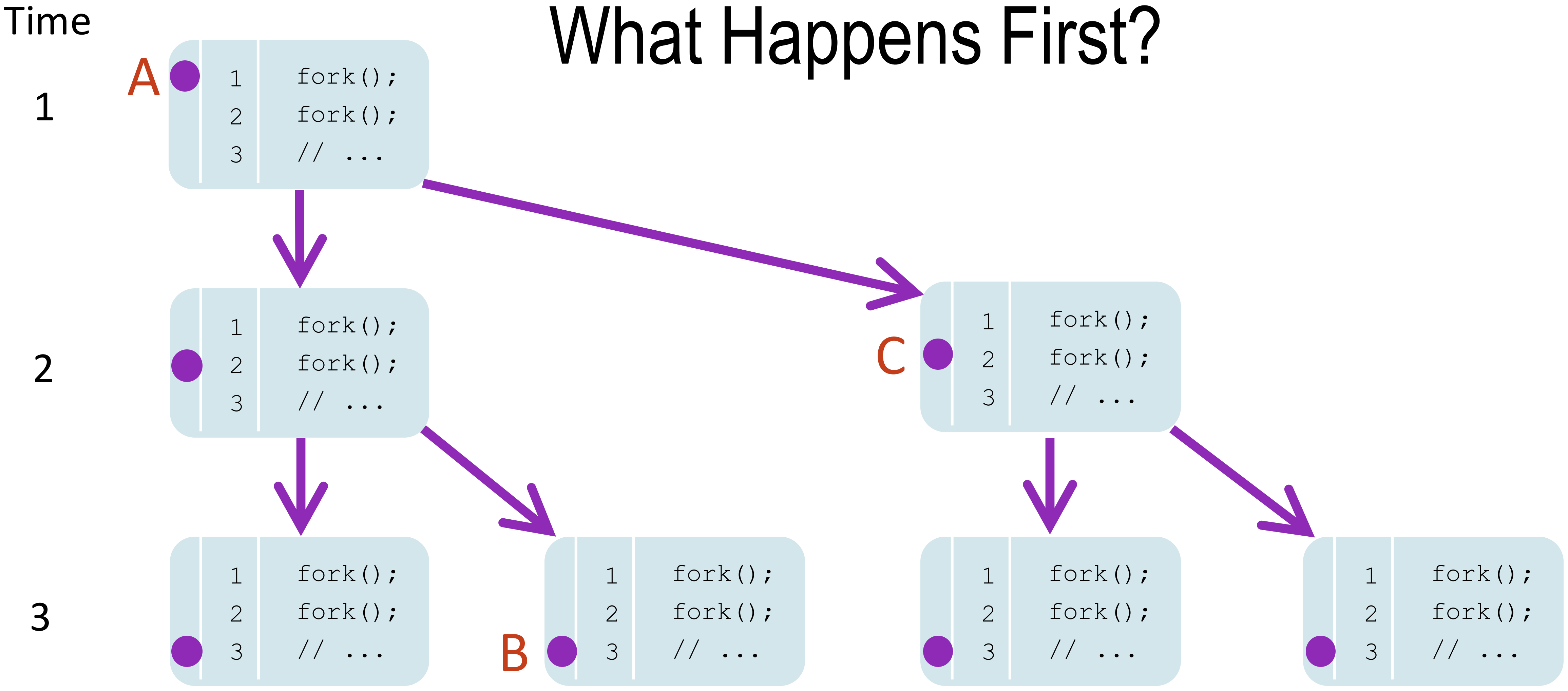
child

```
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
    printf("hello, I am parent of %d (pid:%d)\n", rc, (int) getpid());
}
```

Process Tree



What Happens First?



Question: What is the order for A, B and C?

wait( ) // Wait for Child

```
pid_t wait(int *wstatus);
```

Suspend execution of the parent until one of its children terminates

On success:

- Returns pid of the child process that terminated
- wstatus is populated with information about the way the child process terminated

If a process has terminated, but parent has not yet called wait(), the process becomes a *zombie*

If the parent terminated without calling wait(), the child process becomes an *orphan*, and a system process (systemd in Linux) becomes the parent

exec( ) // Change the Program

```
int exec(const char *pathname, char *const argv[]);
```

Replaces the current program with a new one

Command line arguments are passed in argv

On success:

- The process is running a new program
- The function does not return (**no where** to return – the caller is gone)

On failure:

- The function returns -1

Frist argument is always the name of the executable

Example usage:

```
char *args[]={"wc","README",0};
execvp("wc", args);
```

View Processes on Command Line

```
$ ps aux
USER         PID %CPU %MEM    VSZ   RSS TTY      STAT START   TIME COMMAND
root           1  0.0  0.1 186896 15884 ?        Ss    2020  13:22 /usr/lib/systemd/systemd --system --deserialize 39
root     2758580  0.1  0.1  41896  9916 ?        SNs  00:45   0:00 sshd: wzhang [priv]
wzhang   2758586  0.0  0.0  41772  5904 ?        RN   00:45   0:00 sshd: wzhang@pts/1
root     2758587  0.0  0.0      0     0 ?        I    00:45   0:00 [kworker/3:2]
wzhang   2758588  0.5  0.0  17352  5444 pts/1    SNs  00:45   0:00 -bash
root     2758598  0.0  0.0      0     0 ?        I    00:45   0:00 [kworker/4:2]
Wzhang   2758634  0.0  0.0  17932  3616 pts/1    RN+  00:45   0:00 ps aux
```

Systemd (syst manager), Linux parent, PID=1
SSH processes managing my connection
bash shell process I am interacting with
ps command (it saw itself)

Exploring Process Tree on Command Line

```
$ pstree
systemd─┬─NetworkManager───2*[{NetworkManager}]
├─sshd─┬─sshd───sshd───bash───pstree
│      └─sshd───sshd───bash
...
```

pstree command

bash shell

SSH child to manage connection A

SSH child to manage connection B

SSH server

systemd is Linux parent process

Question: How did bash create a child process that executes pstree?

Interprocess Communication

A pipe is a unidirectional data channel that can be used to communicate from one process to another

- Sender puts data to one end (the write-end of the pipe)
- Receiver gets data from the other end (the read-end of the pipe)

Common example is the shell, it creates two children and pipes standard out (e.g., printf) of one into standard in (e.g., read) of other

pipe( ) // Connect two processes

```
int pipe(int p[2]);
```

Creates communication channel

Typical usage is right before calling fork, each process must close the ends of the pipe it is not using

On success:

- p[0] is file descriptor of read side of pipe, p[1] is write side of pipe
- Returns 0

On failure:

- Returns –1

Example Usage:

- See sh.c

Pipe Creation

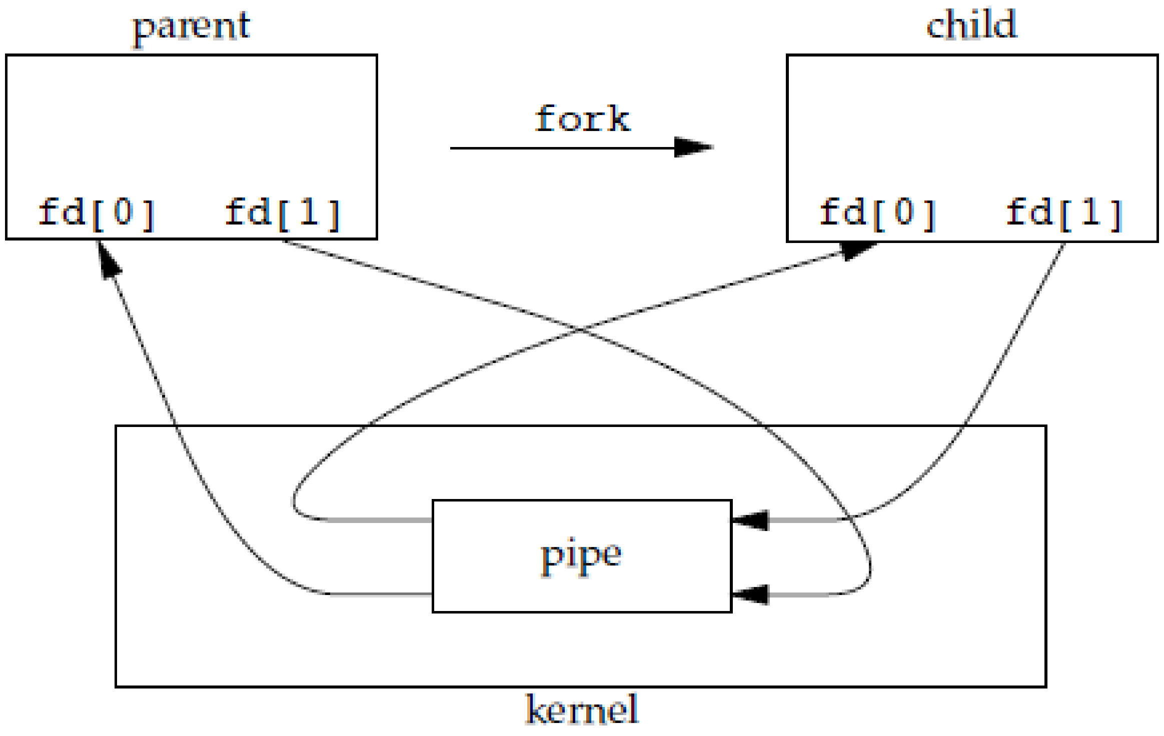


Figure 15.3 Half-duplex pipe after a `fork`

https://github.com/ethanny2/linux-kernel-pipe

dup( ) // Duplicate file descriptor

```
int dup(int fd);
```

Returns new file descriptor that is the lowest numbered available descriptor

New file descriptor refers to the same source as fd did previously

For example, closing standard out (1) and then calling dup(fd) will cause all calls to printf to be directed to what fd pointed to

On success:

- New file descriptor points to source of provided file descriptor
- Returns new file descriptor

On failure:

- Returns –1

Example Usage:

- See sh.c