CSCI 350
Ch. 3 Programmer's Interface

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Getting on the Same Page

- What is a thread?
- What is a process?
- What is user mode vs. kernel mode?

Getting on the Same Page

- What is a thread?
  - Independently scheduled task
  - PC + state (i.e. registers, stack, etc.)
- What is a process?
  - Instance of an executable program
  - Threads + independent address space
- What is user mode vs. kernel mode?
  - User mode = non-priviledged execution environment
  - Kernel mode = privileged execution environment where the OS executes

Chapter 3 of "Operating Systems…", Anderson and Dahlin

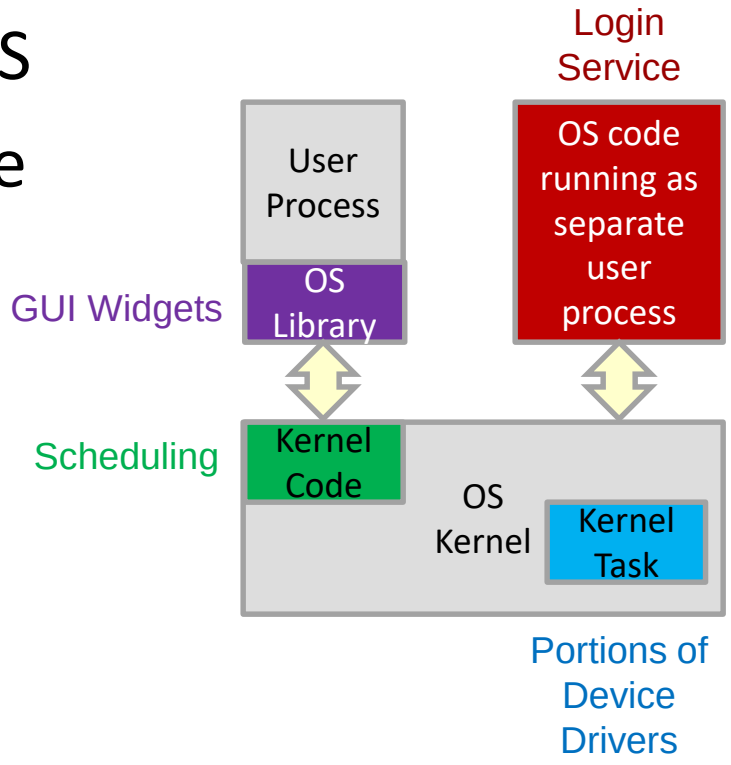
PROGRAMMING INTERFACE

Overview

- OS must provide services to a user application
  - Process and thread management
  - Input/output (file systems, network, etc.)
  - Memory management
  - Authentication and security
  - Graphics and window management

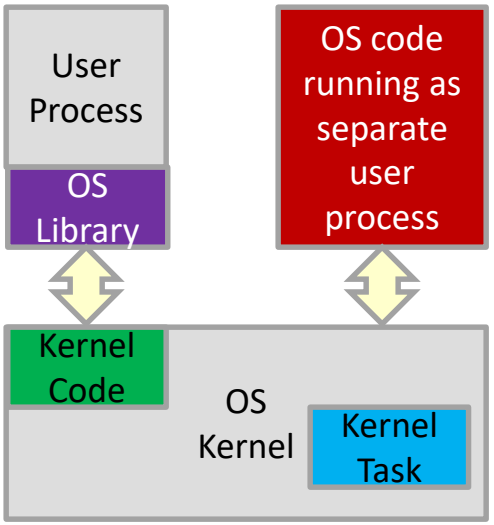
Where Services Might Execute

- Many services must be provided to user level processes by the OS
- Options exist for where to locate those services
  - Directly in the user process by linking in a user-level OS library
  - Separate user level processes
  - Part of the kernel executed in the control flow of the calling process
  - Part of the kernel running as a separate kernel task



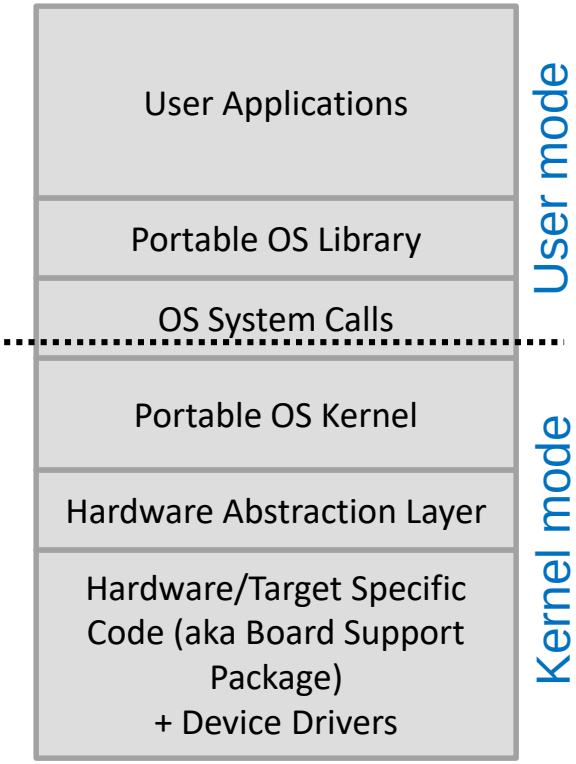
Considerations

- Evaluate where services should be located based on:
  - **Safety**, **Flexibility**, **Performance**
- Pros of locating services in a user-level process
  - Safety/Isolation from other kernel structures (i.e. a bug cannot bring down the rest of the kernel)
  - Flexibility: Easier to update and provide new versions of functionality (no recompilation of kernel needed)
- Cons of location services in a user-level process
  - Performance: Overhead of moving data and switching contexts



Common OS Layers/Architecture

- System calls are the "interface" between user applications and the kernel
  - OS may provide libraries that provide some services and abstraction above the system call level
  - Changing the interface of system calls has a major impact on software
    - Likely requires recompile/update of software applications



Meet the syscalls

- Process management
  - fork() : new_pid
  - exec(char* exec, char** args)
  - wait(pid)
  - exit()
- I/O
  - open(name) : fd
  - read(fd, buffer, size) : int
  - write(fd, buffer, size) : int
  - close(fd)
  - pipe(fd[2])
  - select(fd_array[], fd_array_size) : fd
  - dup2(fromFd, toFd)

Some definitions

- **Address space** = Protected (hardware checked) memory ranges accessible only to a single process (and possibly the kernel)
- **pid** = Process ID (unique identifier of a process)
- **fd** = File descriptor (identifier to lookup data structure holding the state of I/O access to a file, network socket, "pipe", etc.)
  - Often just an integer (index) into some table of descriptors in the kernel

fork, exec, wait, exit

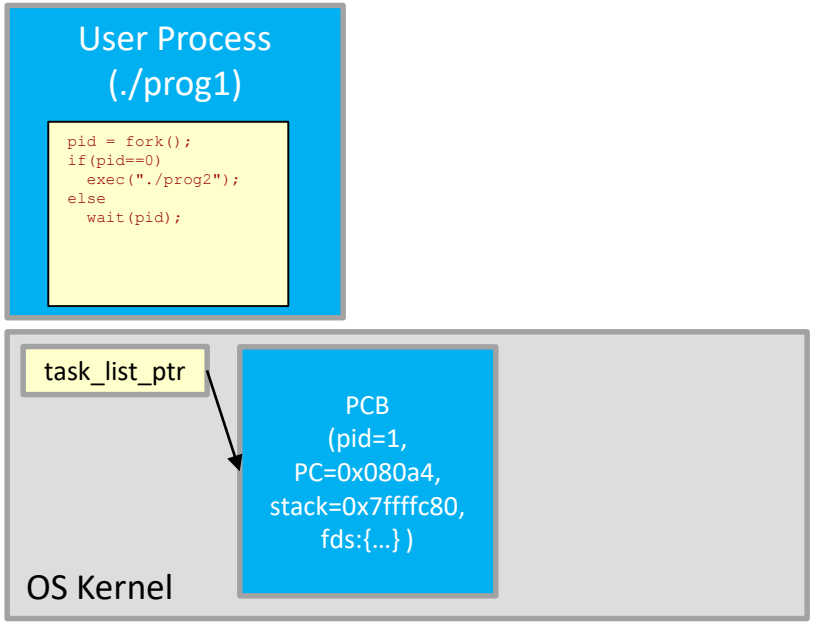
SYSCALLS FOR PROCESS MANAGEMENT

Process Management

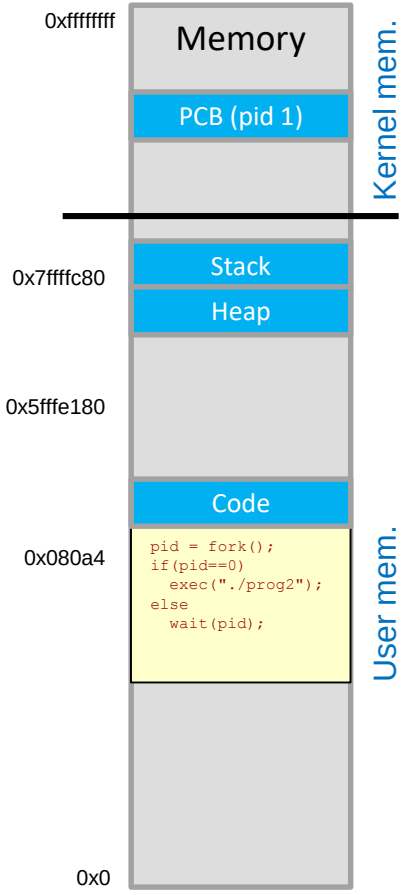
- Most OSs allow one user process to create another through various system calls
  - Rather than the kernel initiating all process creations
- Windows approach
  - Perform process creation, environment setup, and program startup through a **single** system call
    - Single `createProcess(…)` system call
- Unix approach
  - Separate process creation, environment setup, and program startup with **separate** system calls
    - Create process with `fork()` system call
    - Setup environment with possible calls to `open()`, `close()`, `dup2()`
    - Load program image and start execution with `exec(…)` system call

Unix Process Syscalls

- Suppose a process (pid=1) is running and wants to start another



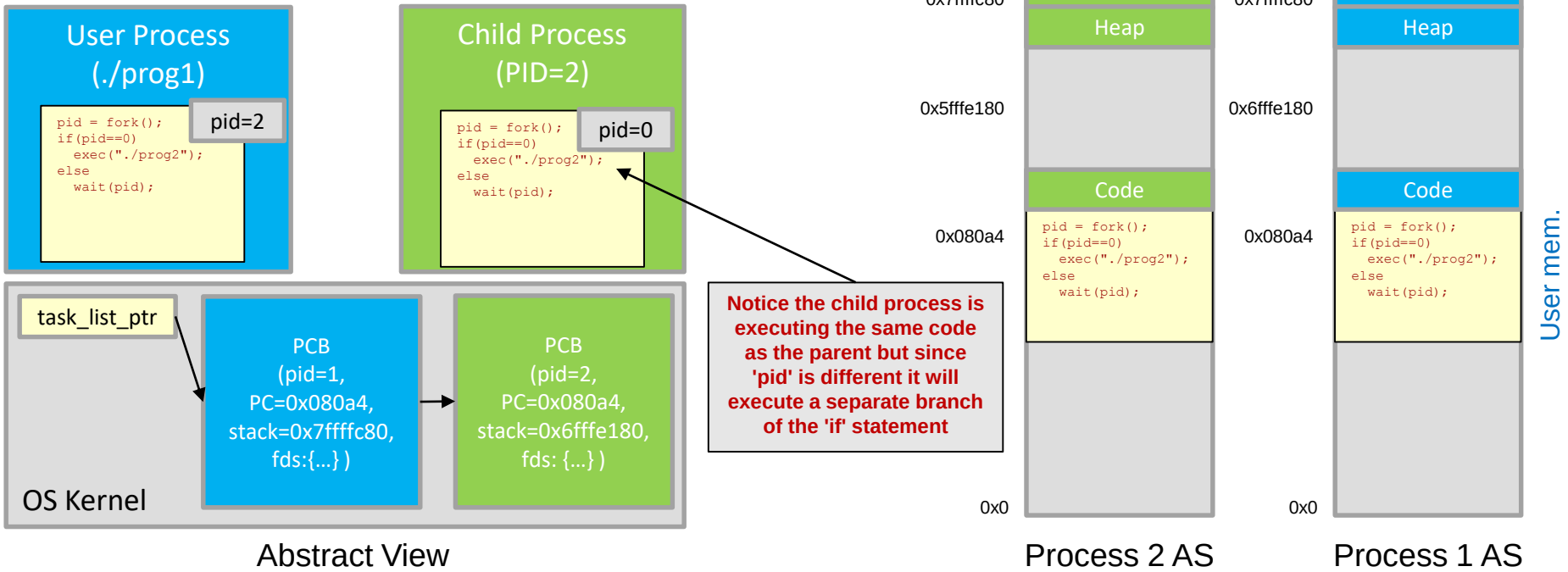
Abstract View



Process 1 AS

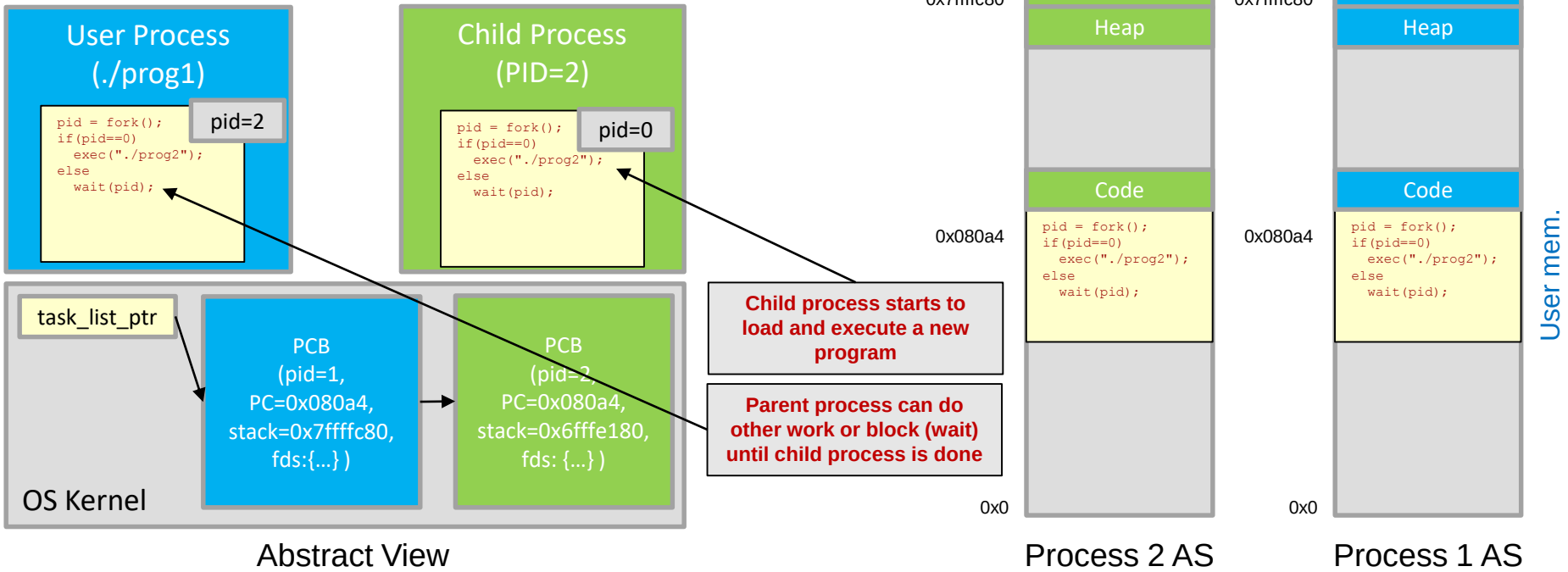
Fork

- A call to **fork** copies the state (exact replica) of the current (**parent**) process to a new **child** process
  - Returns new pid (e.g. 2) to the parent
  - Returns 0 to the child process (it can retrieve its own pid with another system call if it needs that info)



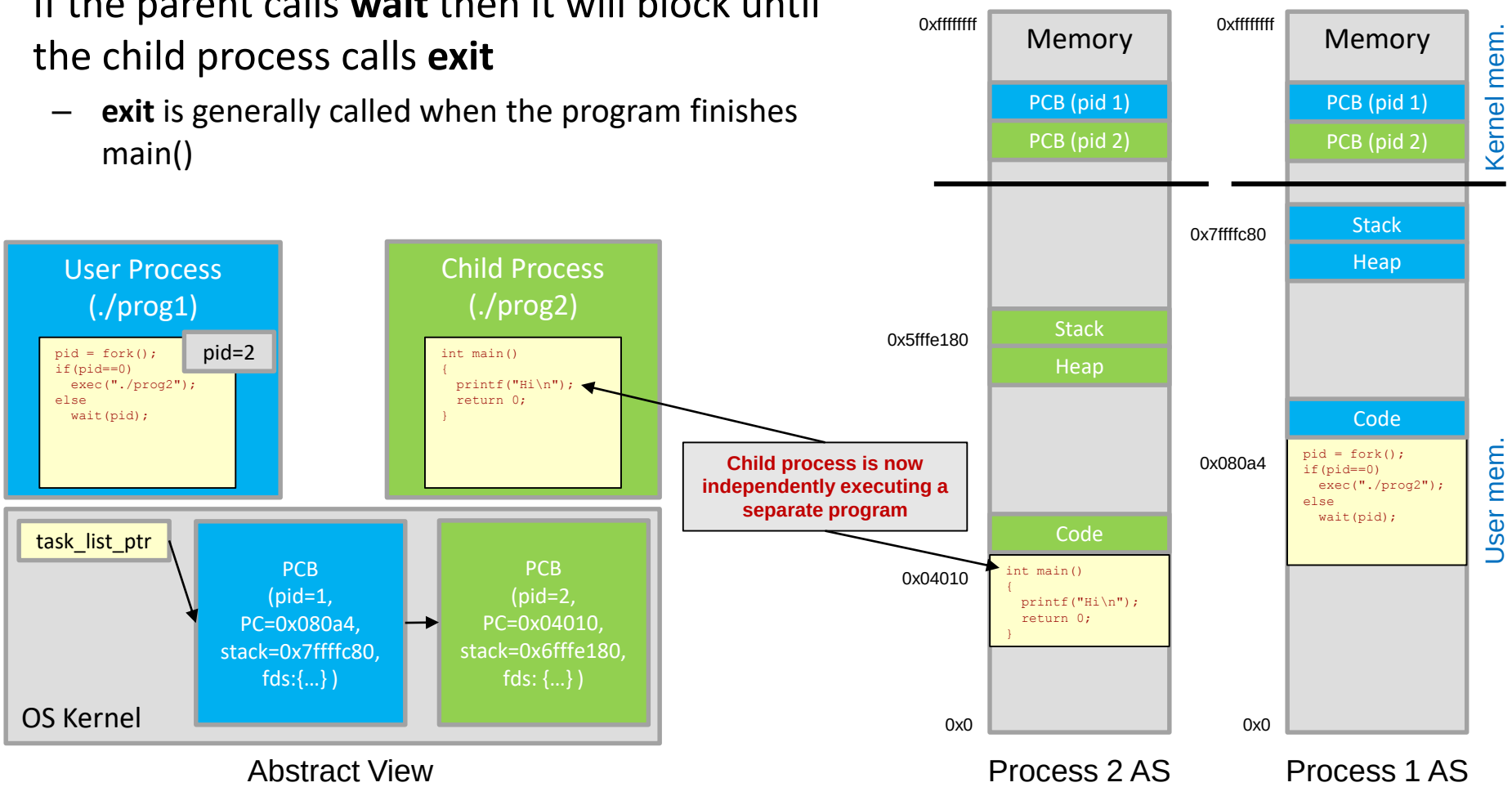
Exec 1

- A call to **exec** now loads a new program (e.g. ./prog2) with its own code, sets up its global data, stack, heap, etc.
  - **exec** returns only if an error occurs
- Parent can continue execution or block until the child process finishes by calling **wait**



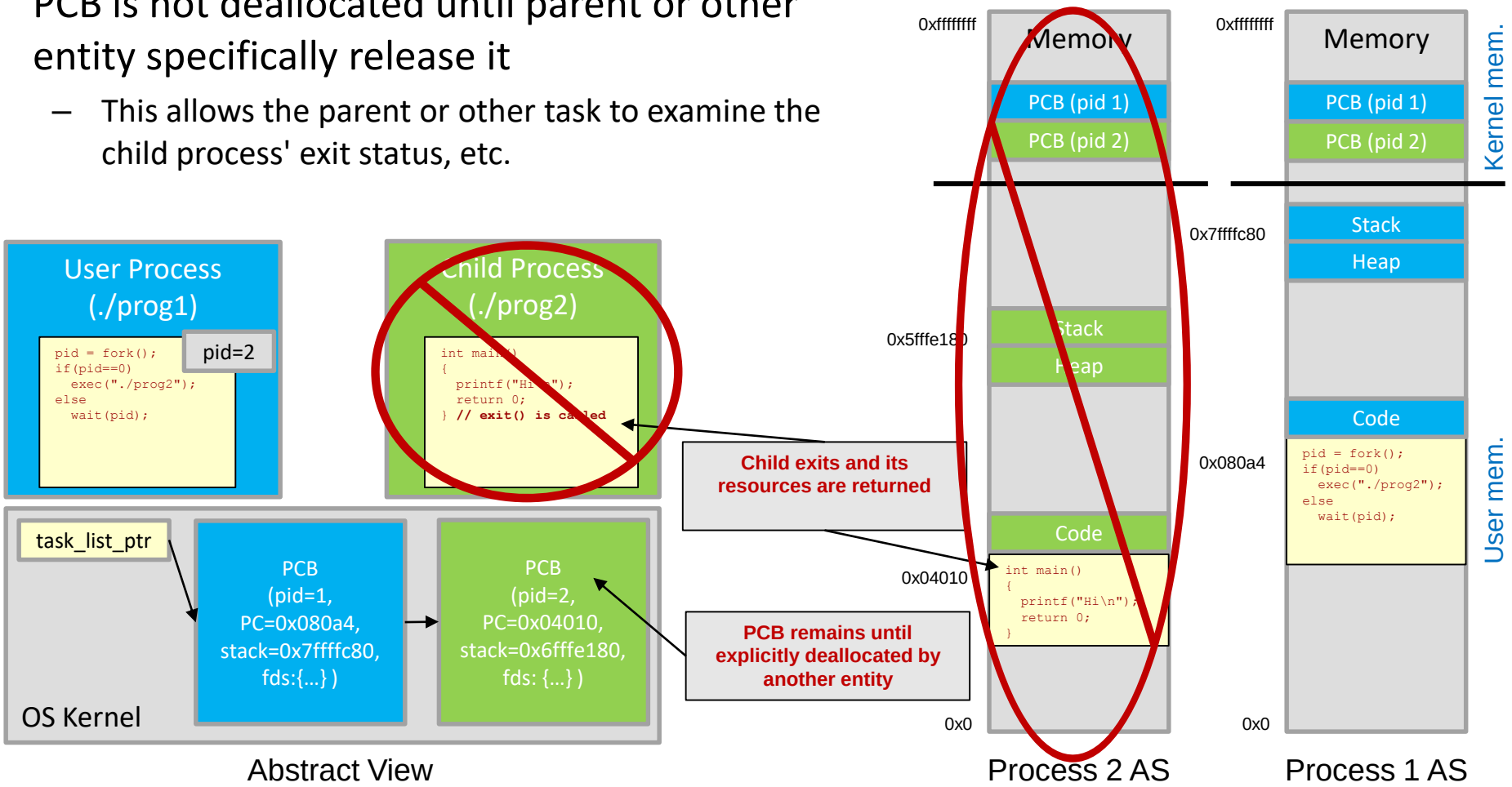
Exec, Wait, and Exit

- The effect of a call to **exec** is a separate program image is loaded and begins execution
- If the parent calls **wait** then it will block until the child process calls **exit**
  - **exit** is generally called when the program finishes main()



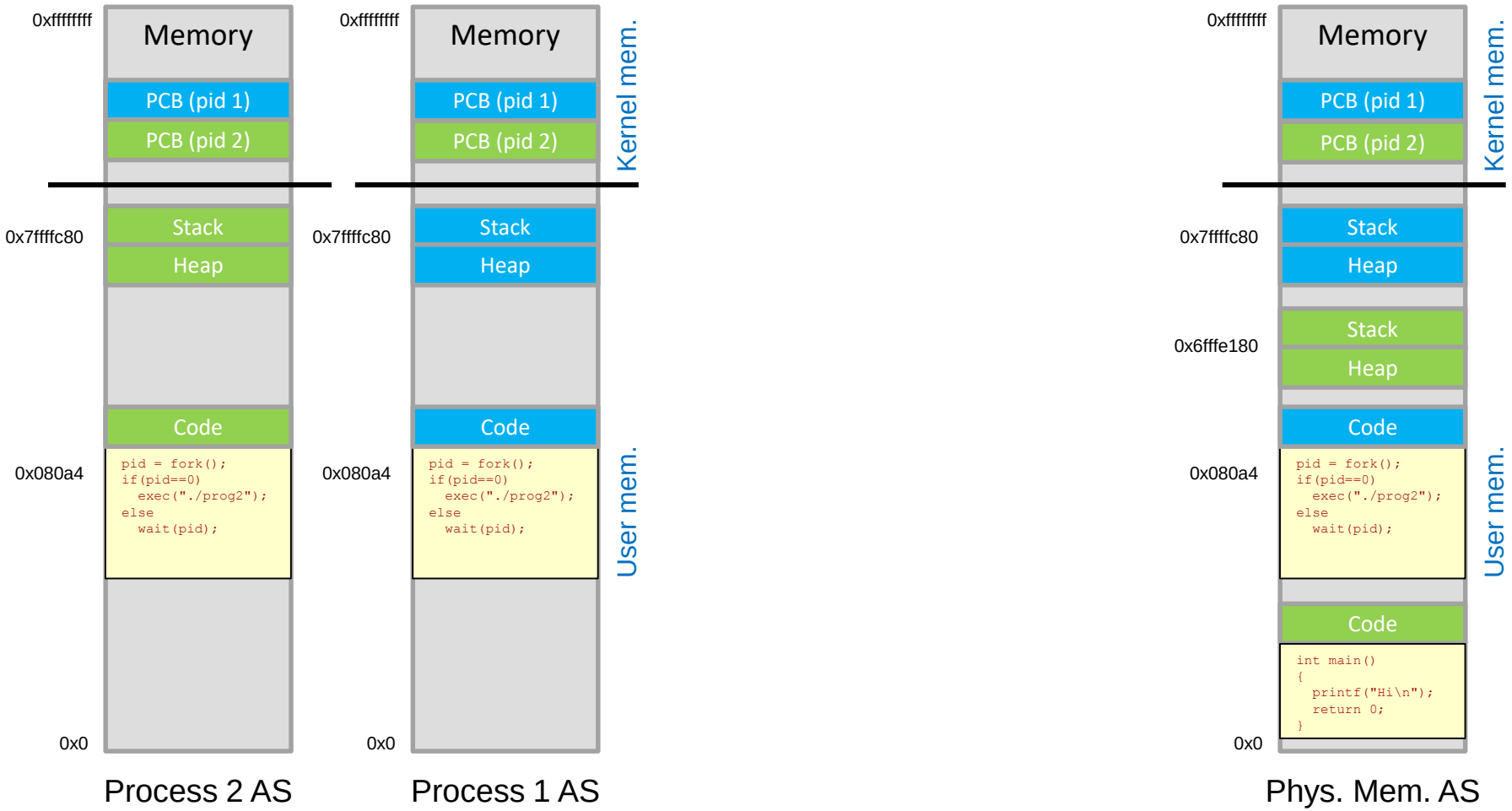
Exit

- **exit** deletes the current process and its resources (i.e. address space, etc.)
- PCB is not deallocated until parent or other entity specifically release it
  - This allows the parent or other task to examine the child process' exit status, etc.



Virtual Memory (Backup)

- Virtual Memory allows multiple "virtual" address spaces to be mapped to a single physical address space



Summary

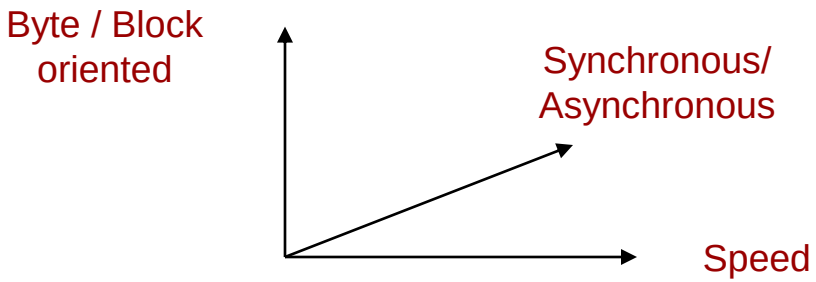
- **Fork** causes the kernel to
  - Create an initialize the PCB entry for a new process
  - Create a new address space
  - Initialize the new address space with a complete copy of the parent's address space
  - Inherit the execution context of the parent (open files, etc.)
  - Inform the scheduler that the new process is ready to run
- **Exec** causes the kernel to
  - Load a new program image into the current address space
  - Copy arguments into the address space
  - Initialize the hardware context (PC + stack) to the "start" entry point of the program image

open, close, read, write, select, dup2

SYSCALLS FOR INPUT/OUTPUT

Problem with I/O

- There are a vast number of input/output devices that may be connected to a computer and many possible interfaces
  - A magnetic disk may want a group of values (think struct) that indicate the location (sector, cylinder, etc.) and amount of data to read synchronously
  - A keyboard device may asynchronously supply a byte of data at a time
- Is there a single API that can generally fit for all these different devices?



Common I/O Syscall Characteristics

- Unix and many other OSs try to interact with all I/O devices with a common set of syscalls
- Most OSs I/O syscall characteristics
  - Accessed via **file descriptors**
    - Files, network sockets, pipes (more in a moment), etc. are all identified with a file descriptor and a common set of syscalls
    - **file descriptor** is a handle or index (usually just an int) to the internal bookkeeping information and state of the I/O connection
  - **Byte oriented**: Whether you need to pass a single byte, an array of bytes, or a struct the API is just a pointer to the start byte and total size
  - **Open/close**: Open/close allows kernel to setup internal bookkeeping (file position, etc.) and access control to a device before read/writes are allowed
    - Open returns a **file descriptor**

```
struct DiskOp
{
  uint8_t flags;
  uint8_t padding[3];
  uint32_t sector;
  uint32_t cylinder;
};

struct DiskOp myop;
```

Login Service

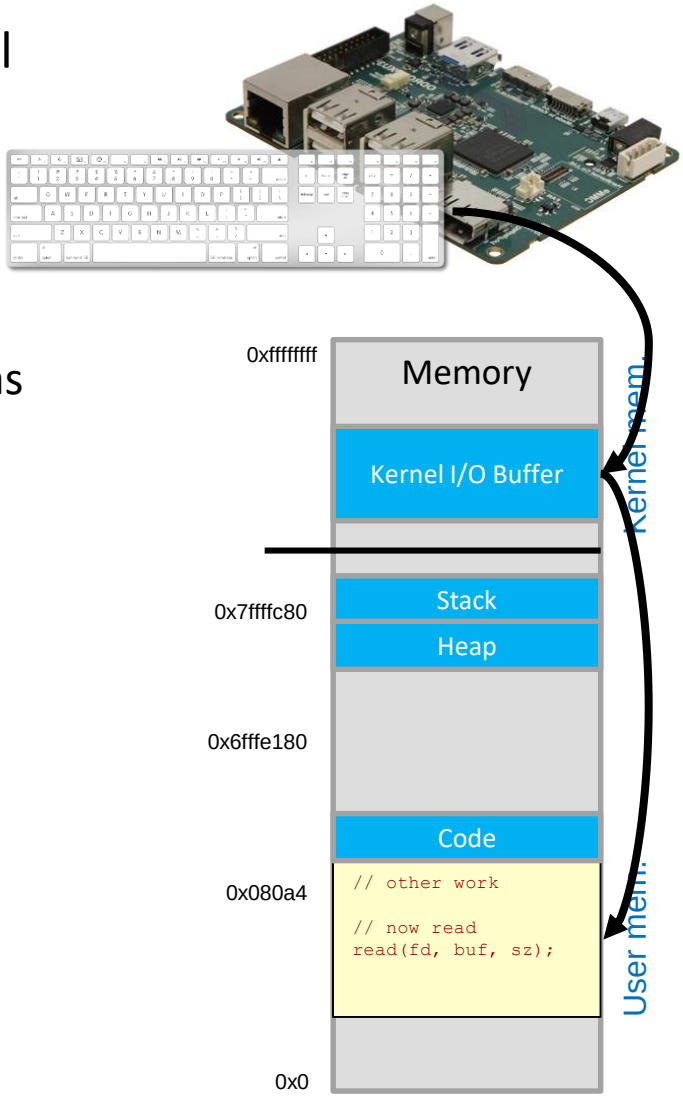
flags	padding
sector	
cylinder	

Memory View

```
// Call OS syscall
write(fd,
      &myop,
      sizeof(DiskOp));
```

Common I/O Syscall Characteristics

- Unix and many other OSs try to interact with all I/O devices with a common set of syscalls
- Most OSs I/O syscall characteristics
  - **Kernel buffering**: Input data is internally buffered in the kernel before the user process can read. Output data is buffered in the kernel as well and then passed to the I/O device from the kernel
  - Provides decoupling of speed (flow control)

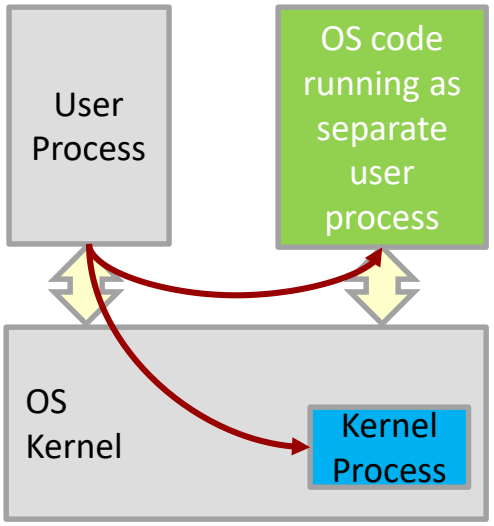


Common I/O Syscalls

- open(name) : fd
  - Returns a new descriptor to the device with path "name"
  - In Unix all devices map to a filename (i.e. a USB serial connection lives at /dev/tty.usbmodemXXX)
- read(fd, buffer, size) : int
  - Reads at most size bytes of data into buffer from the device specified by fd, returning the number of bytes ***actually*** read
- write(fd, buffer, size) : int
  - Writes size bytes from buffer to the device specified by fd
- close(fd)
- select(fd_array[], fd_array_size) : fd
  - Waits for data to be available for reading on any of the fds in fd_array and returns the first fd that can be read
- dup2(fromFd, toFd)
  - Copies the state (position/status) of the file specified by fromFd to the descriptor located at toFd
  - Often used to redirect stdin and stdout of a process
- pipe(fd[2])
  - Creates a pipe for unidirectional communication between two processes (fd[0] is the read side of the pipe and fd[1] the write side)

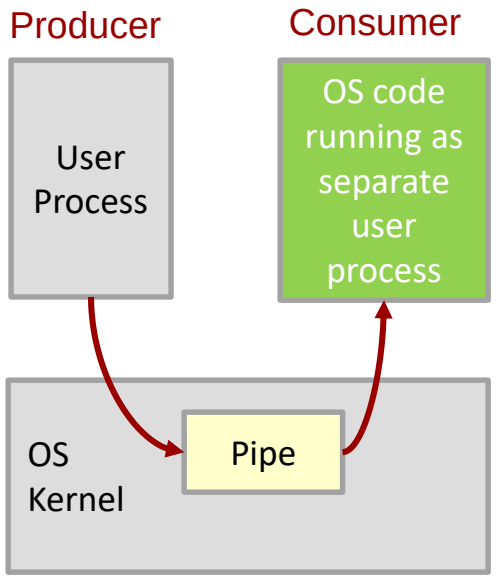
Inter-Process Communication (IPC)

- A core service a kernel must provide is a method of inter-process communication (IPC)
- If OS services run as separate processes then we need a way to communicate between those processes
- Common models
  - Producer-consumer
  - Client/server
  - Regular files



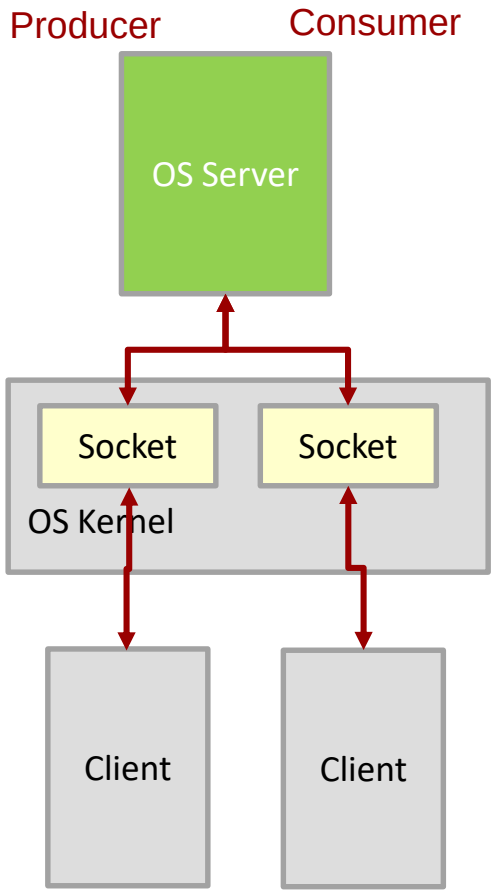
Pipes

- A pipe is a unidirectional buffer for communication between two processes
  - Uses two file descriptors (one for the write side and one for the read side)
  - Acts as a queue/stream
  - Can be "named" so processes know who to connect to
    - Mapped to the file system as in `/tmp/myfifo`
- Sample code
  - http://man7.org/linux/man-pages/man2/pipe.2.html



Client/Server

- 2-way communication:
  - Client requests
  - Server responds
- Some methods
  - Message queues, sockets, shared memory, etc.
- select() syscall
  - Blocks until activity on 1 of N descriptors
  - `int select(int nfds, fd_set *readfds, fd_set *writefds, fd_set *exceptfds, struct timeval *timeout);`



Socket, Select() Example

- Select waits for any event to occur on a set of descriptors
  - Can be file, socket, pipe, etc. descriptors

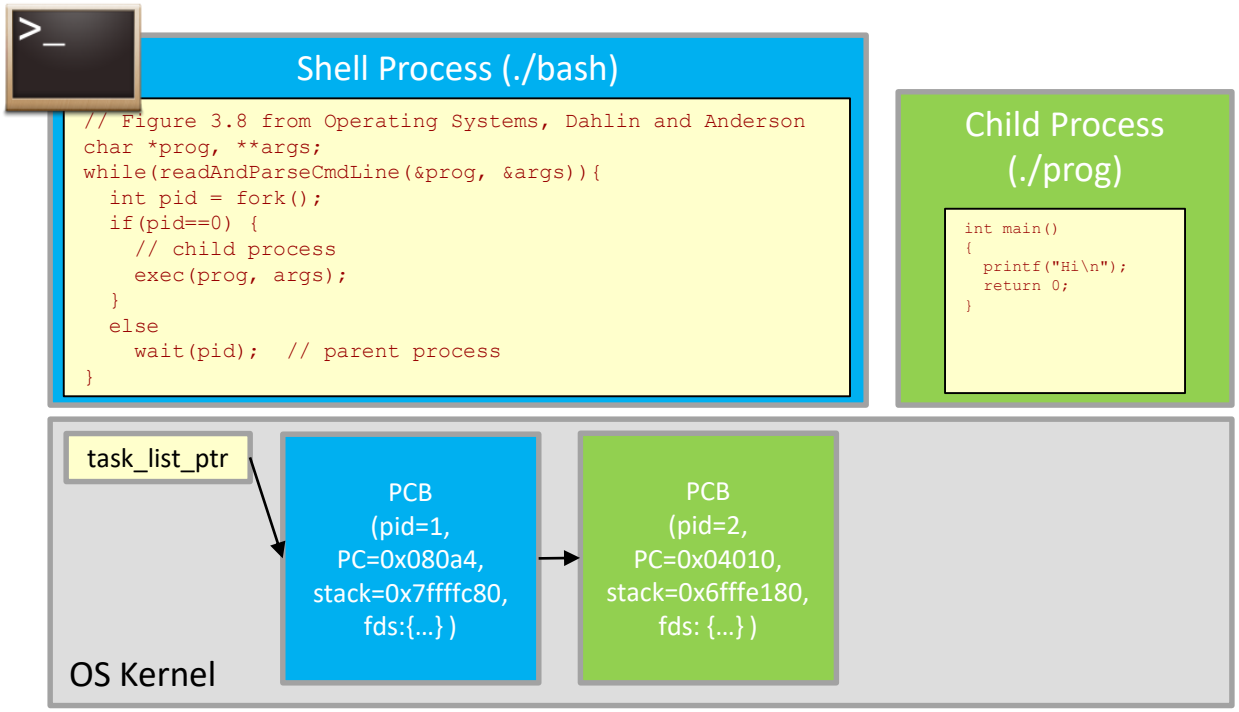
```
  int listener = _srvsocket->getSockDesc();
  fd_set read_fds;
  FD_ZERO(&read_fds);
  FD_SET(listener,&read_fds);
  int fdmax = listener;

  while(1) {
    memcpy(&read_fds, &master, sizeof(master));
    if( select(fdmax +1,&read_fds,NULL,NULL,NULL) == -1){
      cerr << "Error: select" << endl;
      return 1;
    }
    for(int i = 0; i<=fdmax;i++){
      if(FD_ISSET(i,&read_fds)){
#ifdef DEBUG
        cerr << "FD " << i << " is set"<< endl;
#endif
        // A new connection is being made
        if(i == listener){
            int new_sock = accept(listener, ...);
            fd_max = max(listener, new_sock);
            FD_SET(int new_sock,&read_fds);
        }
        // Current connection, message event
        else {
            read(i, ...);
        }
      }
    }
  }
```

CASE STUDY 1: SHELLS

Shells

- The shell/terminal/command line is just a user process that reads inputs that indicate other programs to run (i.e. command lines)
  - $ ./prog1 hello 5
- The shell then forks a new process and execs the specified program



Abstract View

stdin and stdout

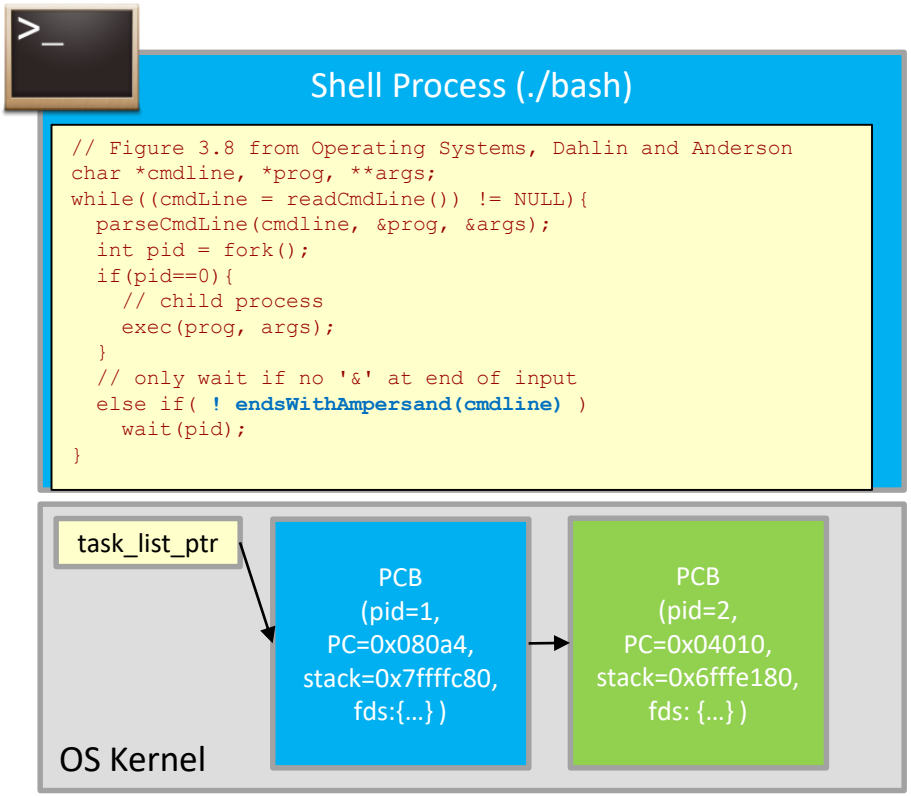
- Processes generally have two given file descriptors
  - **stdin (fd=0)**: read input from the system (generally the keyboard)
  - **stdout (fd=1)**: write output to the system (generally the terminal/screen)
- Shells usually allow redirection of stdin and stdout

Process Management Review

- Recall Unix allows the parent process to perform child process setup before it execs the program
  - Separate process creation, environment setup, and program startup with **separate** system calls
    - Create process with `fork()` system call
    - Setup environment with possible calls to `open(), close(), dup2()`
    - Load program image and start execution with `exec(…)` system call
- Shells can use this capability to perform I/O redirection and/or piping
  - $ ./prog1 > output.txt
    - Redirects stdout to output.txt file
  - $ ./prog1 < input.txt
    - Redirects stdin to come from input.txt
  - $ ./prog1 < input.txt > output.txt
    - Redirects both input and output
  - $ ./prog1 | ./prog2
    - Pipe output (stdout) of prog1 as the input (stdin) of prog2

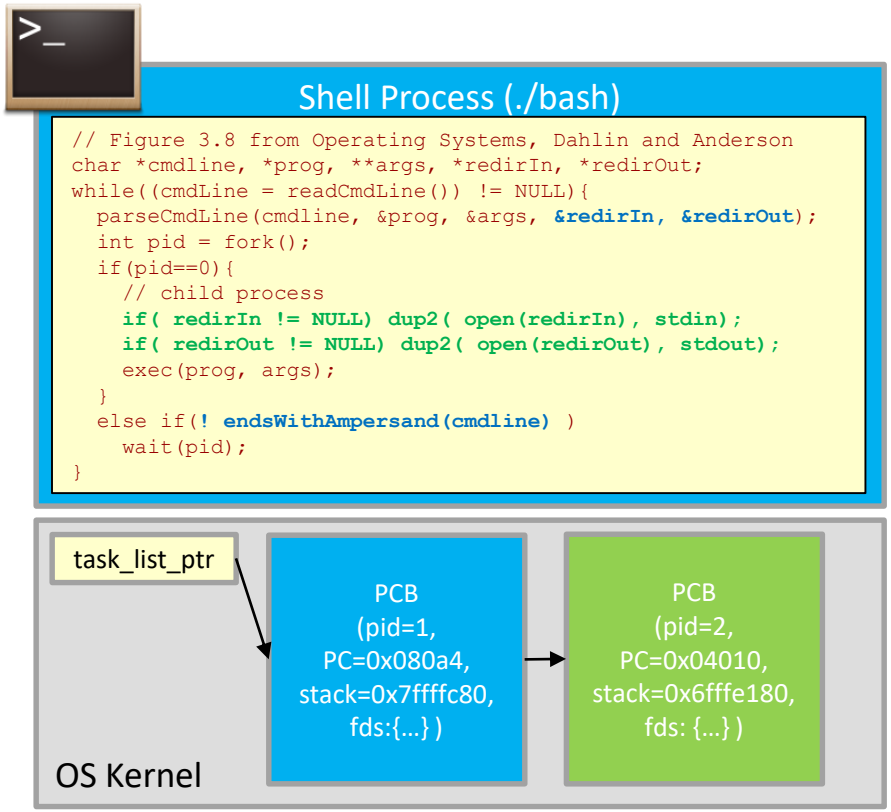
To Wait or Not

- Recall how many shells allow you to continue processing new shell commands while the exec'd program runs by placing '&' at the end of the command line
  - $ ./prog1 hello 5 &
- This just causes the shell to skip the call to **wait**



I/O Redirection

- Redirection can be applied before the child process calls **exec** by replacing the stdin and stdout file descriptors with those of the specified files
  - $ ./prog1 < input.txt > output.txt



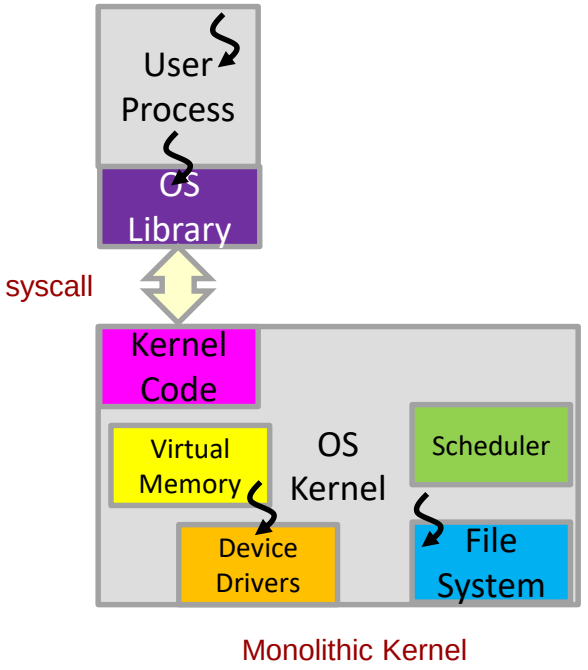
Piping

- Challenge: Consider how a shell would handle piping
  - ./prog1 | ./prog2
- High-level approach (order may vary)
  - Create a pipe which returns two fd's (for the read and write sides of the pipe)
  - Fork each process (prog1 and prog2)
  - Set the write fd of the pipe as the stdout fd of prog1
  - Set the read fd of the pipe as the stdin fd of prog2
  - Exec prog1 and wait for it to complete
  - Exec prog2 and wait for it to complete

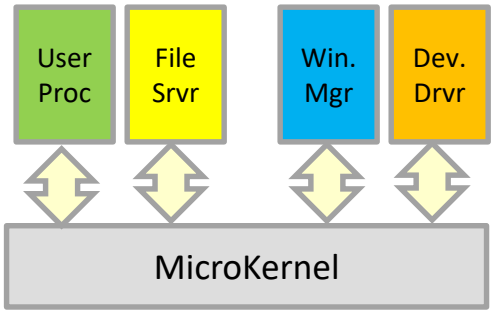
KERNEL ORGANIZATION

Approaches

- Monolithic Kernel
  - Majority of services compiled and execute as part of the kernel (not as a user service) in the same address space
  - Most commercial operating systems
    - Why? What get's optimized: safety, flexibility, performance?
  - Generally allows better performance
- Microkernel
  - Majority of services run as user-level processes (separate address spaces)
  - Allows better safety and some flexibility
  - Ex. Mach, NeXT
- Syscalls can make the differences transparent

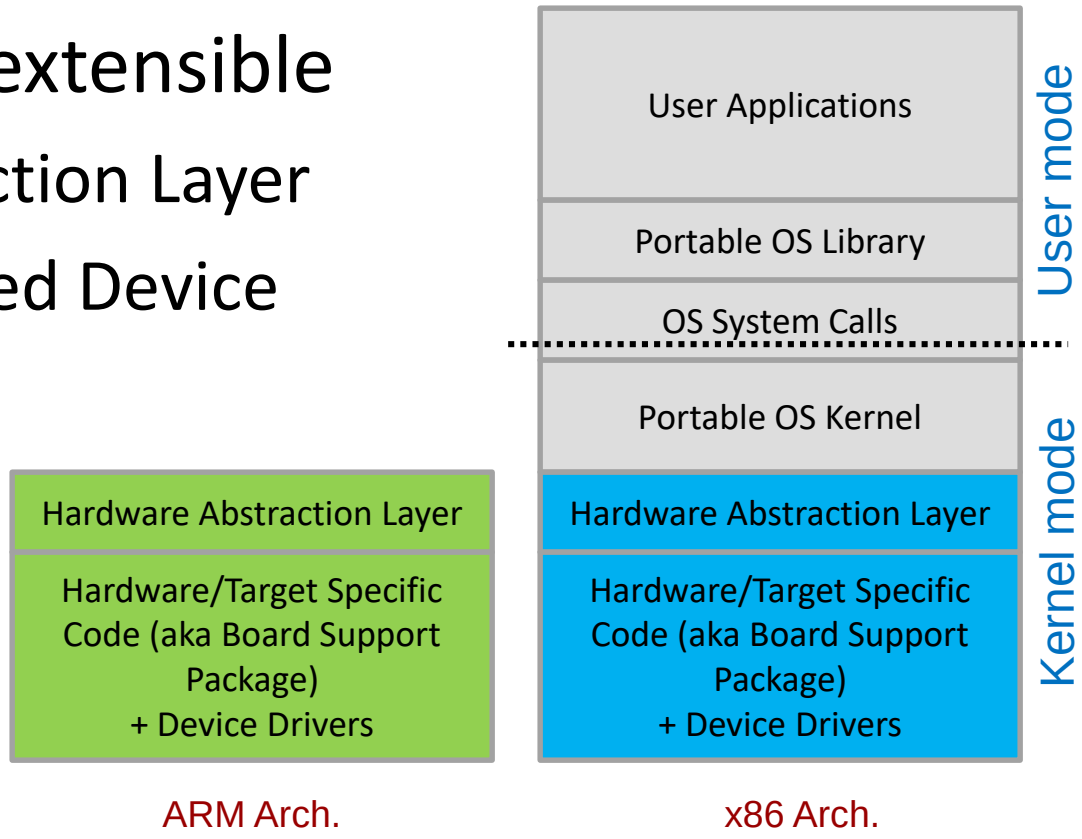


Monolithic Kernel



Monolithic Kernel

- General features to make them portable & extensible
  - Hardware Abstraction Layer
  - Dynamically loaded Device Drivers



Hardware Abstraction Layer

- Provide functions and abstract models of devices
  - OS is written to use these functions & models
  - To support a new HW target just re-implement those functions
- Examples:
  - Interrupt handling
  - System call handling (low level)
  - Process context switches
  - Low-level VM operations like loading a page table etc.
  - Timer handling

http://elixir.free-electrons.com/linux/v4.11.3/source

Dynamically Loadable Device Drivers

- 70% of Linux source code is drivers
  - In many general purpose systems we won't know all the attached HW devices
  - So we can't provide an OS with everything built in
- Dynamically Loadable Device Drivers
  - Not compiled directly into kernel but loaded as a shared library when needed
  - On boot or hot plug, OS discovers devices and then loads appropriate drivers
  - Common interface to allow applications to be written to interface to various HW devices regardless of actual implementation

Device Driver Issues

- According to OS:PP 2nd Ed. up to 90% of system crashes are due to device drivers, not kernel
  - Bugs in 3rd party device driver code
  - OS Updates cause device drivers to not work
- Mitigations
  - Code inspection (Linux requires peer evaluation of driver code, and then driver becomes part of Linux and is actively maintained in each kernel release)
  - Bug Tracking (Reports sent to vendor upon crash)
  - User-level device drivers
    - Provide flexible syscalls so that device drivers can run in user mode and thus prevent kernel crashes
  - Virtual machine or sandboxed device drivers
    - Run device driver in a protected environment

Resources & Examples

- Process Control Block (task_struct): /usr/src/linux-headers-3.13.0-24-generic/include/linux/sched.h
  - Around line 1042
- Syscalls: http://man7.org/linux/man-pages/man2/syscalls.2.html
  - Defined in <unistd.h>