CSE 451: Operating Systems
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Module 4
Processes

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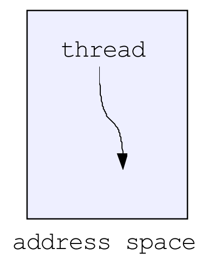
Process management

- This module begins a series of topics on processes, threads, and synchronization
  - this is the most important part of the class
  - there definitely will be several questions on these topics on the midterm
- In this module: processes and process management
  - What is a "process"?
  - What's the OS's process namespace?
  - How are processes represented inside the OS?
  - What are the executing states of a process?
  - How are processes created?
  - How can this be made faster?
  - Shells
  - Signals

What is a "process"?

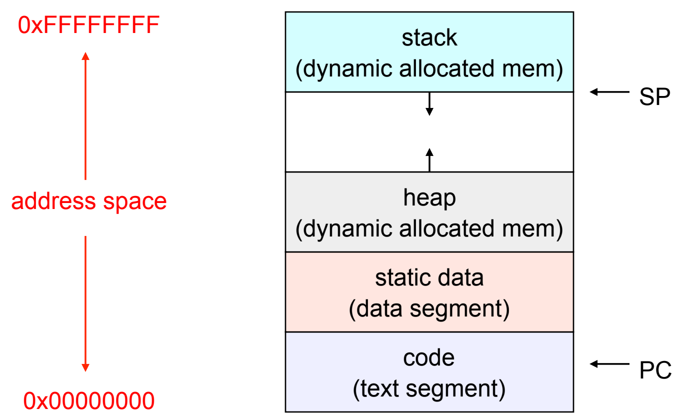
- The process is the OS's abstraction for execution
  - A process is a program in execution
- Simplest (classic) case: a sequential process
  - An address space (an abstraction of memory)
  - A single thread of execution (an abstraction of the CPU)
- A sequential process is:
  - The unit of execution
  - The unit of scheduling
  - The dynamic (active) execution context
    - vs. the program – static, just a bunch of bytes



What's "in" a process?

- A process consists of (at least):
  - An address space, containing
    - the code (instructions) for the running program
    - the data for the running program (static data, heap data, stack)
  - CPU state, consisting of
    - The program counter (PC), indicating the next instruction
    - The stack pointer
    - Other general purpose register values
  - A set of OS resources
    - open files, network connections, sound channels, …
- In other words, it's all the stuff you need to run the program
  - or to re-start it, if it's interrupted at some point

A process's address space (idealized)



The OS's process namespace

- (Like most things, the particulars depend on the specific OS, but the principles are general)
- The name for a process is called a process ID (PID)
  - An integer
- The PID namespace is global to the system
  - Only one process at a time has a particular PID
- Operations that create processes return a PID
  - E.g., fork()
- Operations on processes take PIDs as an argument
  - E.g., kill(), wait(), nice()

Representation of processes by the OS

- The OS maintains a data structure to keep track of a process's state
  - Called the process control block (PCB) or process descriptor
  - Identified by the PID
- OS keeps all of a process's execution state in (or linked from) the PCB when the process isn't running
  - PC, SP, registers, etc.
  - when a process is unscheduled, the execution state is transferred out of the hardware registers into the PCB
  - (when a process is running, its state is spread between the PCB and the CPU)
- Note: It's natural to think that there must be some esoteric techniques being used
  - fancy data structures that you'd never think of yourself

Wrong! It's pretty much just what you'd think of!

The PCB

- The PCB is a data structure with many, many fields:
  - process ID (PID)
  - parent process ID
  - execution state
  - program counter, stack pointer, registers
  - address space info
  - UNIX user id, group id
  - scheduling priority
  - accounting info
  - pointers for state queues
- In Linux:
  - defined in **`task_struct`** (**`include/linux/sched.h`**)
  - over 95 fields!!!

PCBs and CPU state

- When a process is running, its CPU state is inside the CPU
  - PC, SP, registers
  - CPU contains current values
- When the OS gets control because of a …
  - Trap: Program executes a syscall
  - Exception: Program does something unexpected (e.g., page fault)
  - Interrupt: A hardware device requests service

  the OS saves the CPU state of the running process in that process's PCB

- When the OS returns the process to the running state, it loads the hardware registers with values from that process's PCB – general purpose registers, stack pointer, instruction pointer
- The act of switching the CPU from one process to another is called a context switch
  - systems may do 100s or 1000s of switches/sec.
  - takes a few microseconds on today's hardware
- Choosing which process to run next is called scheduling

The OS kernel is not a process

- It's just a block of code!
- (In a microkernel OS, many things that you normally think of as the operating system execute as user-mode processes. But the OS kernel is just a block of code.)

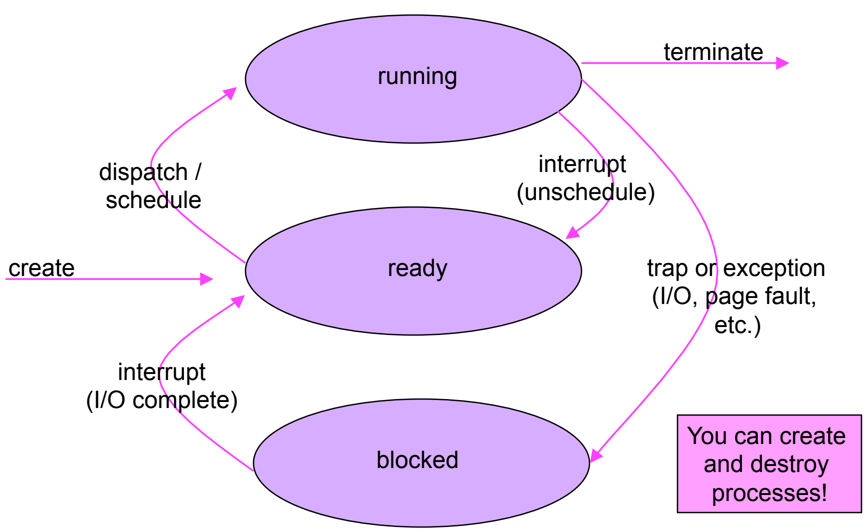
Process ID
Pointer to parent
List of children
Process state
Pointer to address space descriptor
Program counter **stack pointer** **(all) register values**
uid (user id) gid (group id) euid (effective user id)
Open file list
Scheduling priority
Accounting info
Pointers for state queues
Exit ("return") code value

This is (a simplification of) what each of those PCBs looks like inside!

Process execution states

- Each process has an execution state, which indicates what it's currently doing
  - ready: waiting to be assigned to a CPU
    - could run, but another process has the CPU
  - running: executing on a CPU
    - it's the process that currently controls the CPU
  - waiting (aka "blocked"): waiting for an event, e.g., I/O completion, or a message from (or the completion of) another process
    - cannot make progress until the event happens
- As a process executes, it moves from state to state
  - UNIX: run `ps`, STAT column shows current state
  - which state is a process in most of the time?

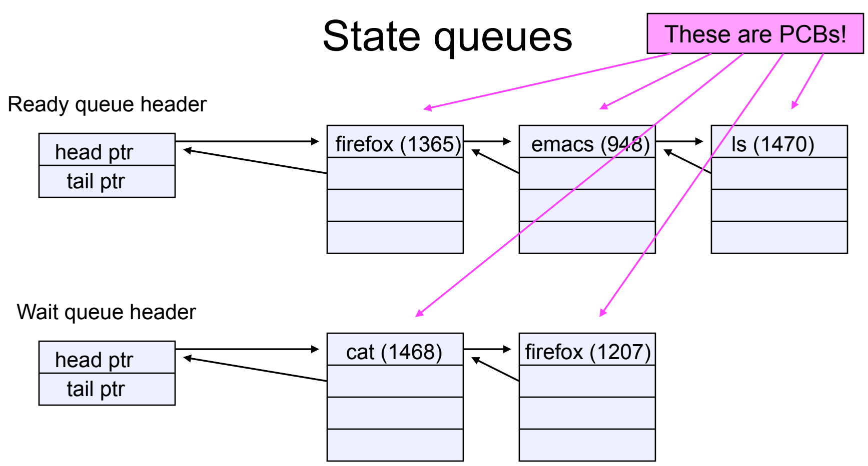
Process states and state transitions



State queues

- The OS maintains a collection of queues that represent the state of all processes in the system
  - typically one queue for each state
    - e.g., ready, waiting, …
  - each PCB is queued onto a state queue according to the current state of the process it represents
  - as a process changes state, its PCB is unlinked from one queue, and linked onto another
- Once again, *this is just as straightforward as it sounds!* The PCBs are moved between queues, which are represented as linked lists. *There is no magic!*

State queues



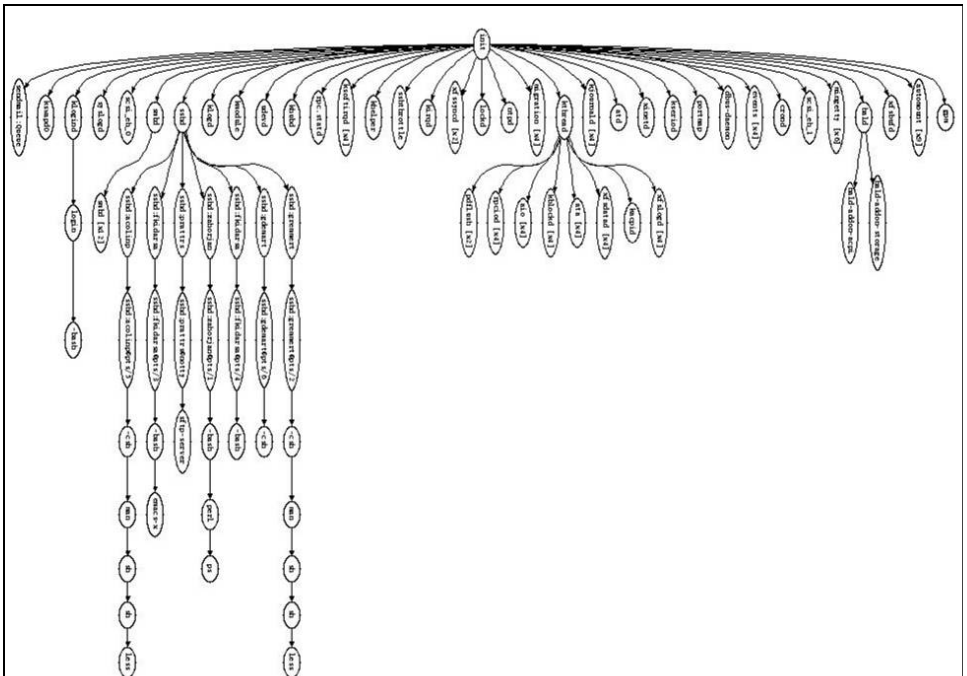
- There may be many wait queues, one for each type of wait (particular device, timer, message, …)

PCBs and state queues

- PCBs are data structures
  - dynamically allocated inside OS memory
- When a process is created:
  - OS allocates a PCB for it
  - OS initializes PCB
  - (OS does other things not related to the PCB)
  - OS puts PCB on the correct queue
- As a process computes:
  - OS moves its PCB from queue to queue
- When a process is terminated:
  - PCB may be retained for a while (to receive signals, etc.)
  - eventually, OS deallocates the PCB

Process creation

- New processes are created by existing processes
  - creator is called the parent
  - created process is called the child
    - UNIX: do **`ps`**, look for PPID field
  - what creates the first process, and when?

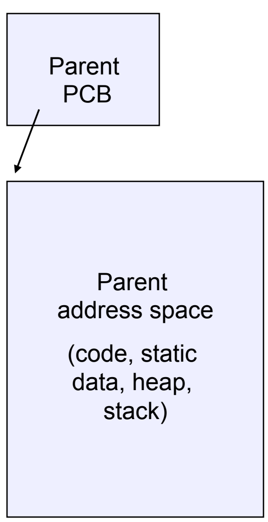


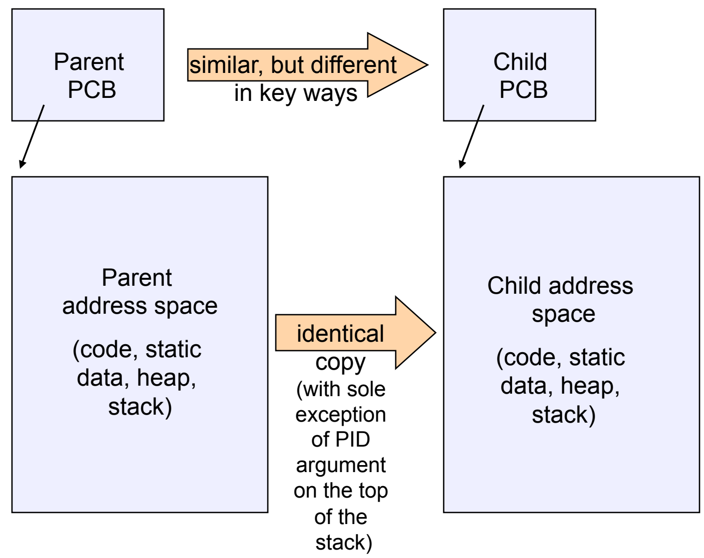
Process creation semantics

- (Depending on the OS) child processes inherit certain attributes of the parent
  - Examples:
    - Open file table: implies stdin/stdout/stderr
    - On some systems, resource allocation to parent may be divided among children
- (In Unix) when a child is created, the parent may either wait for the child to finish, or continue in parallel

UNIX process creation details

- UNIX process creation through **`fork()`** system call
  - creates and initializes a new PCB
    - initializes kernel resources of new process with resources of parent (e.g., open files)
    - initializes PC, SP to be same as parent
  - creates a new address space
    - initializes new address space with a copy of the entire contents of the address space of the parent
  - places new PCB on the ready queue
- the **`fork()`** system call "returns twice"
  - once into the parent, and once into the child
    - returns the child's PID to the parent
    - returns 0 to the child
- **`fork()`** = "clone me"





testparent – use of fork( )

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

int main(int argc, char **argv)
{
  char *name = argv[0];
  int pid = fork();
  if (pid == 0) {
    printf(“Child of %s is %d\n”, name, pid);
    return 0;
  } else {
    printf(“My child is %d\n”, pid);
    return 0;
  }
}
```

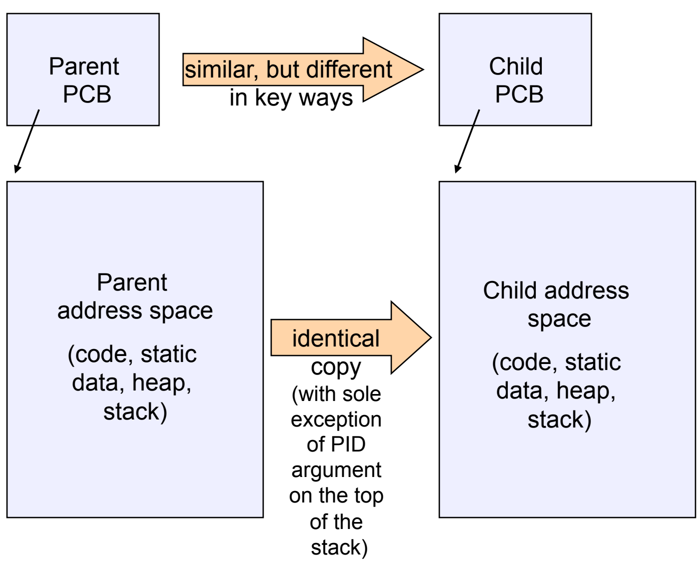
testparent output

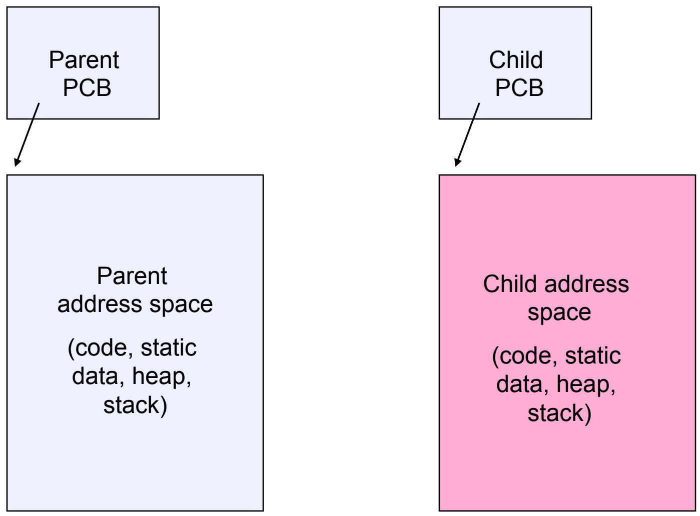
```
spinlock% gcc -o testparent testparent.c
spinlock% ./testparent
My child is 486
Child of testparent is 0
spinlock% ./testparent
Child of testparent is 0
My child is 571
```


exec() vs. fork()

- Q: So how do we start a new program, instead of just forking the old program?
- A: First fork, then exec
  - `int exec(char * prog, char * argv[])`
- **`exec()`**
  - stops the current process
  - loads program 'prog' into the address space
    - i.e., over-writes the existing process image
  - initializes hardware context, args for new program
  - places PCB onto ready queue
  - note: *does not create a new process!*

- So, to run a new program:
  - fork()
  - Child process does an exec()
  - Parent either waits for the child to complete, or not



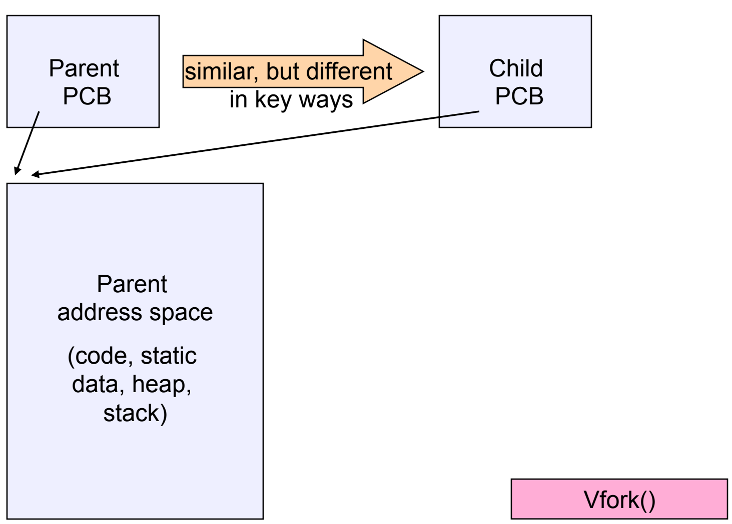


Making process creation faster

- The semantics of fork() say the child's address space is a copy of the parent's
- Implementing fork() that way is slow
  - Have to allocate physical memory for the new address space
  - Have to set up child's page tables to map new address space
  - Have to copy parent's address space contents into child's address space
    - Which you are likely to immediately blow away with an exec()

Method 1: vfork()

- vfork() is the older (now uncommon) of the two approaches we'll discuss
- Instead of "child's address space is a copy of the parent's," the semantics are "child's address space *is* the parent's"
  - With a "promise" that the child won't modify the address space before doing an execve()
    - Unenforced! You use vfork() at your own peril
  - When execve() is called, a new address space is created and it's loaded with the new executable
  - Parent is blocked until execve() is executed by child
  - Saves wasted effort of duplicating parent's address space, just to blow it away



Method 2: copy-on-write

- Retains the original semantics, but copies "only what is necessary" rather than the entire address space
- On fork():
  - Create a new address space
  - Initialize page tables with same mappings as the parent's (i.e., they both point to the same physical memory)
    - No copying of address space contents have occurred at this point – with the sole exception of the top page of the stack
  - Set both parent and child page tables to make all pages read-only
  - If either parent or child writes to memory, an exception occurs
  - When exception occurs, OS copies the page, adjusts page tables, etc.

UNIX shells

```
int main(int argc, char **argv)
{
  while (1) {
    printf ("$ ");
    char *cmd = get_next_command();
    int pid = fork();
    if (pid == 0) {
       exec(cmd);
       panic("exec failed!");
    } else {
       wait(pid);
    }
  }
}
```

Truth in advertising …

- In Linux today, clone is replacing fork (and vfork)
  - clone has additional capabilities/options
- But you need to clearly understand fork as described here

- In Linux today, exec is not a system call; execve is the only "exec-like" system call
  - execve knows whether you have done a fork or a vfork by a flag in the PCB
- But you need to clearly understand exec as described here

Input/output redirection

- $ ./myprog < input.txt > output.txt   # UNIX
  - each process has an open file table
  - by (universal) convention:
    - 0: stdin
    - 1: stdout
    - 2: stderr
- A child process inherits the parent's open file table

- Redirection: the shell …
  - copies its current stdin/stdout open file entries
  - opens input.txt as stdin and output.txt as stdout
  - fork …
  - restore original stdin/stdout

Inter-process communication via signals

- Processes can register event handlers
  - Feels a lot like event handlers in Java, which ..
  - Feel sort of like catch blocks in Java programs
- When the event occurs, process jumps to event handler routine
- Used to catch exceptions
- Also used for inter-process (process-to-process) communication
  - A process can trigger an event in another process using signal

Signals

Signal	Value	Action	Comment
SIGHUP	1	Term	Hangup detected on controlling terminal or death of controlling process
SIGINT	2	Term	Interrupt from keyboard
SIGQUIT	3	Core	Quit from keyboard
SIGILL	4	Core	Illegal Instruction
SIGABRT	6	Core	Abort signal from abort(3)
SIGFPE	8	Core	Floating point exception
SIGKILL	9	Term	Kill signal
SIGSEGV	11	Core	Invalid memory reference
SIGPIPE	13	Term	Broken pipe: write to pipe with no read
SIGALRM	14	Term	Timer signal from alarm(2)
SIGTERM	15	Term	Termination signal
SIGUSR1	30,10,16	Term	User-defined signal 1
SIGUSR2	31,12,17	Term	User-defined signal 2
SIGCHLD	20,17,18	Ign	Child stopped or terminated
SIGCONT	19,18,25		Continue if stopped
SIGSTOP	17,19,23	Stop	Stop process
SIGTSTP	18,20,24	Stop	Stop typed at tty
SIGTTIN	21,21,26	Stop	tty input for background process
SIGTTOU	22,22,27	Stop	tty output for background process

Example use

- You're implementing Apache, a web server
- Apache reads a configuration file when it is launched
  - Controls things like what the root directory of the web files is, what permissions there are on pieces of it, etc.
- Suppose you want to change the configuration while Apache is running
  - If you restart the currently running Apache, you drop some unknown number of user connections
- Solution: send the running Apache process a signal
  - It has registered a signal handler that gracefully re-reads the configuration file