Operating Systems

Processes

Lecture 3

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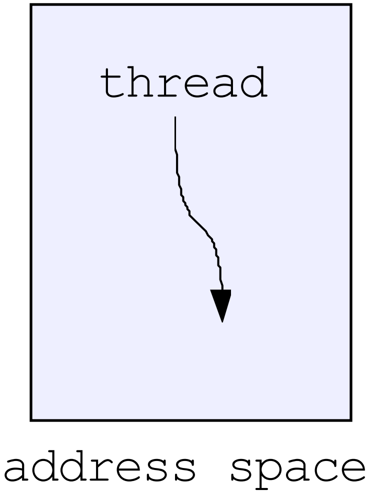
Overview

- Process
- Process control block
- Process state
- Context switch
- Process creation and termination

What is a “process”?

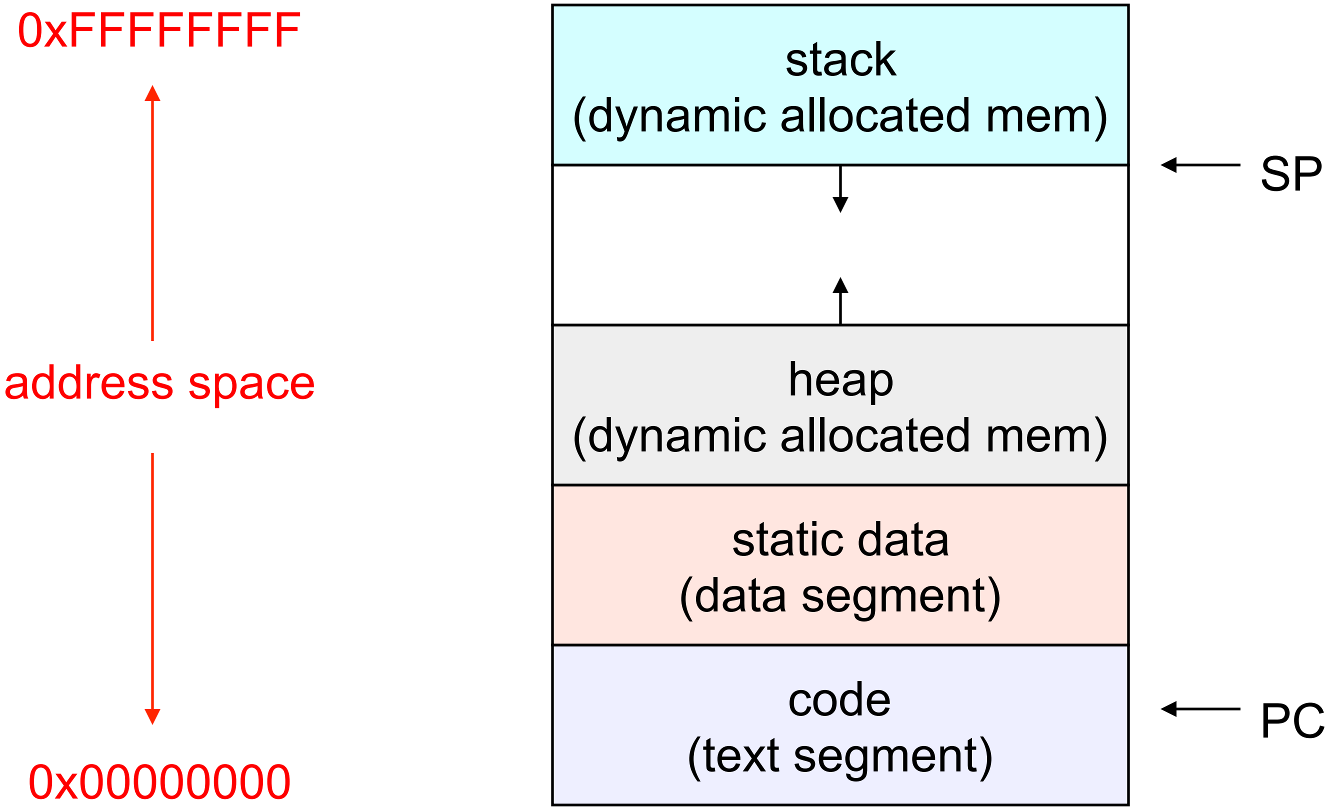
- The process is the OS’s abstraction for execution
  - A process is a program in execution
- Simplest (classic) case: a sequential process
  - An address space (an abstraction of memory)
  - A single thread of execution (an abstraction of the CPU)
- A sequential process is:
  - The unit of execution
  - 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, everything needed to run the program
  - or to re-start, if interrupted

A process's address space (idealized)



The OS process namespace

- 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()

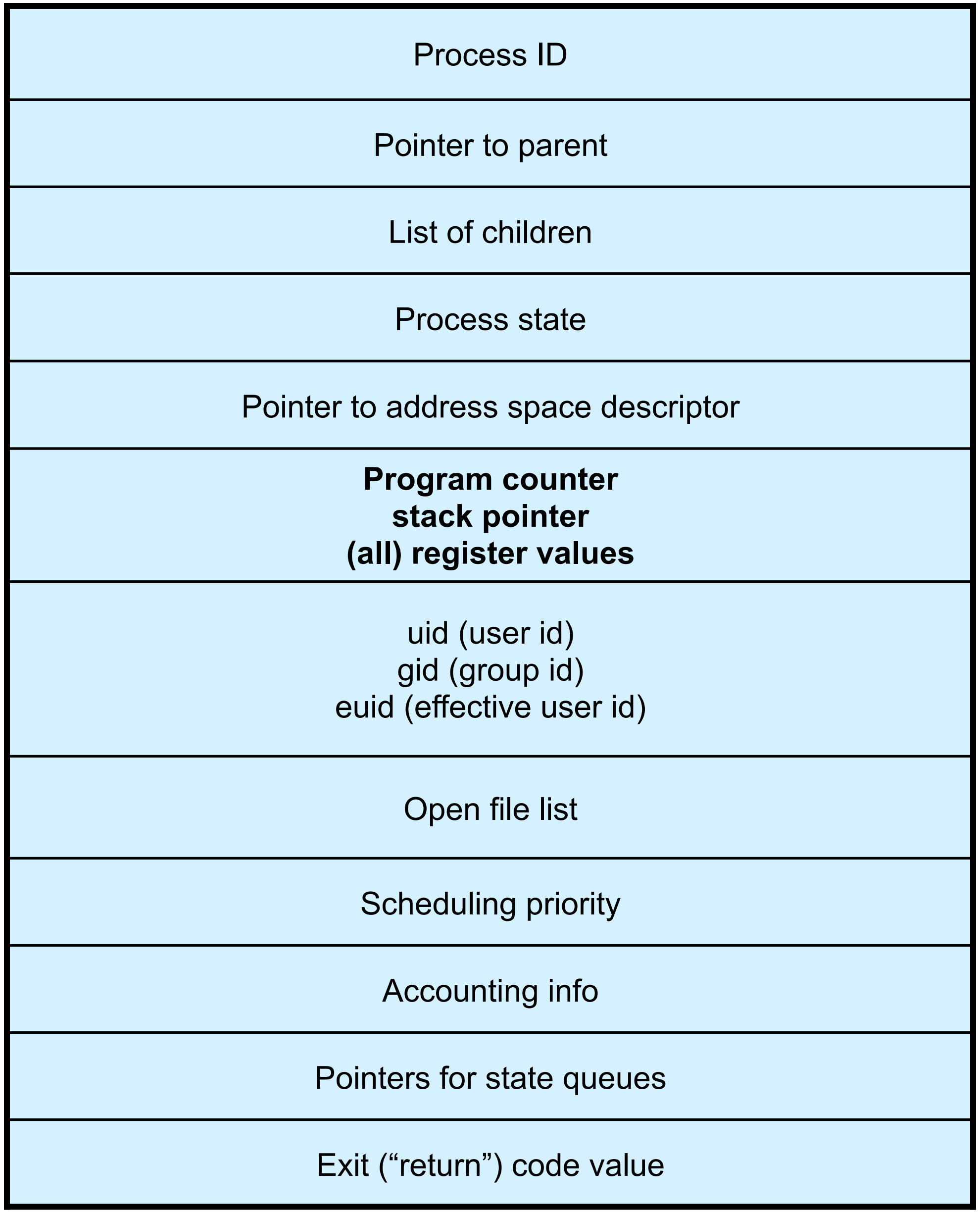
Representation of processes by the OS

- 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 state is transferred out of the hardware into the PCB
  - (when a process is running, its state is spread between the PCB and the CPU)

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!!!



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

PCBs and CPU state

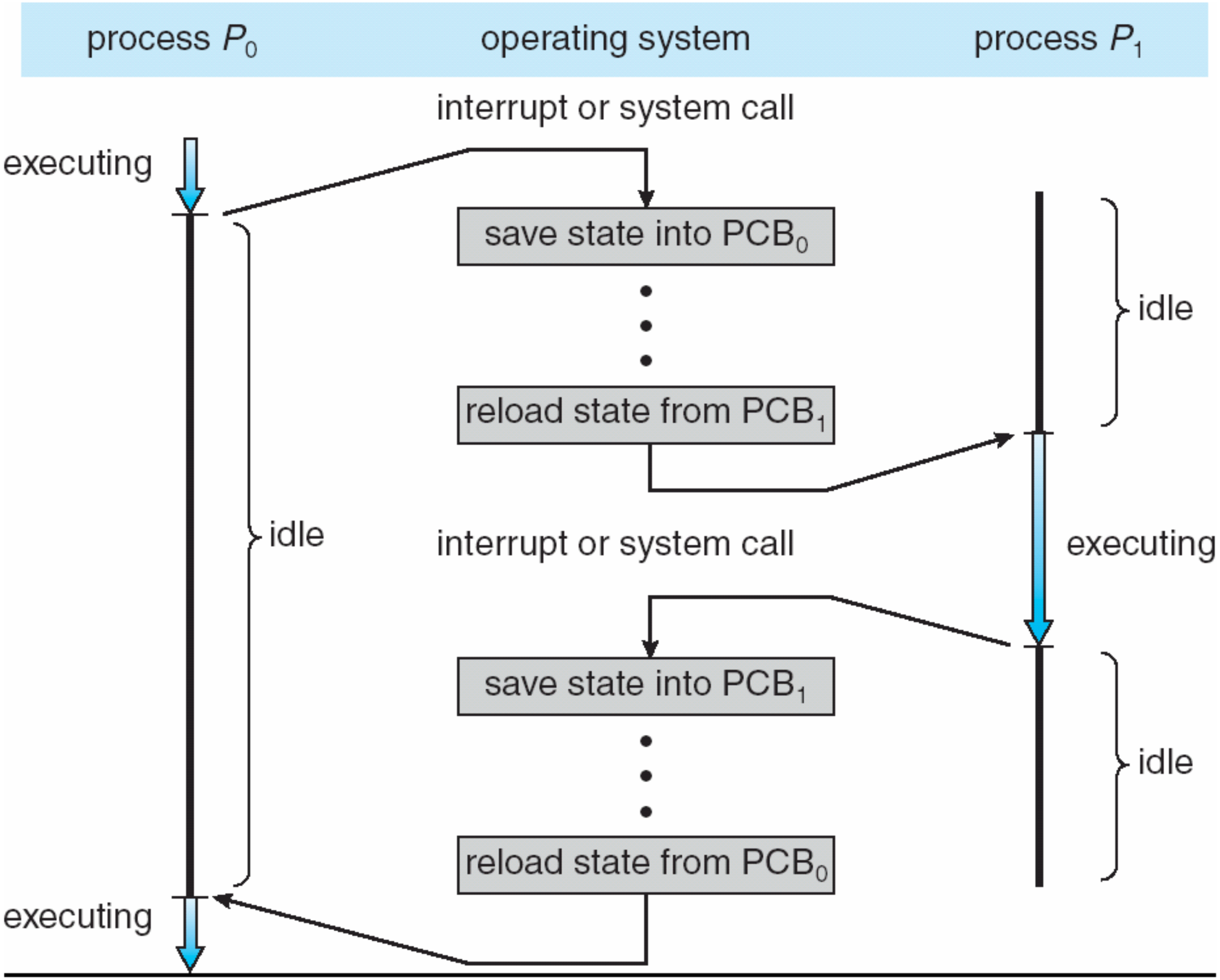
- When a process is running, its CPU state is inside the CPU
  - PC, SP, registers
  - CPU contains current values
- When the OS gets control because of a …
  - Trap: Program executes a syscall
  - Exception: Program does something unexpected (e.g., page fault)
  - Interrupt: A hardware device requests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

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

PCBs and CPU state

- When the OS returns the process to the running state
  - it loads the hardware registers with values from that process's PCB
  - eg 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
  - Still expensive relative to thread based context switches
- Choosing which process to run next is called scheduling

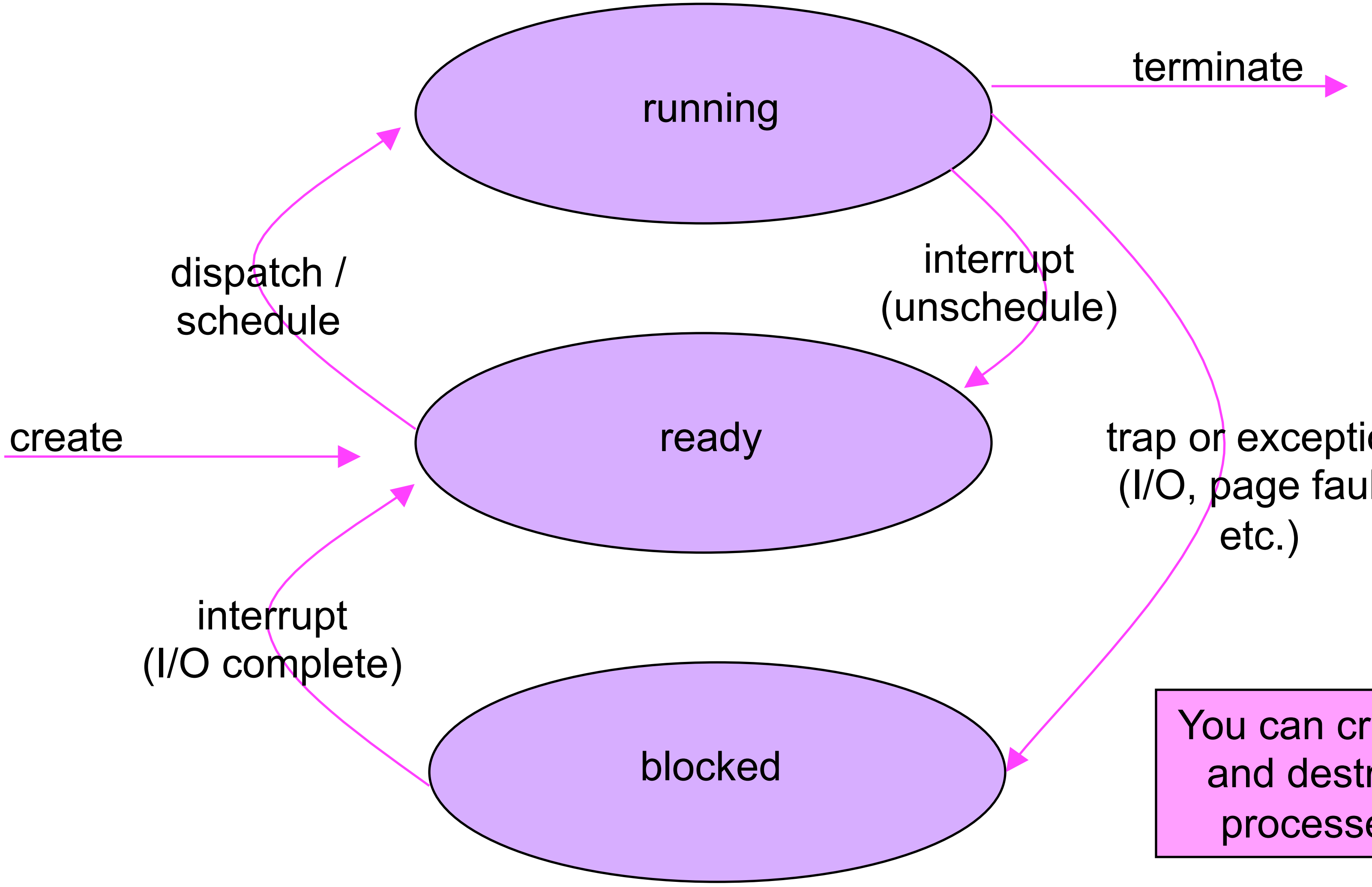
Process context switch



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 `top`, STAT column shows current state
  - which state is a process in most of the time?

Process states and state transitions

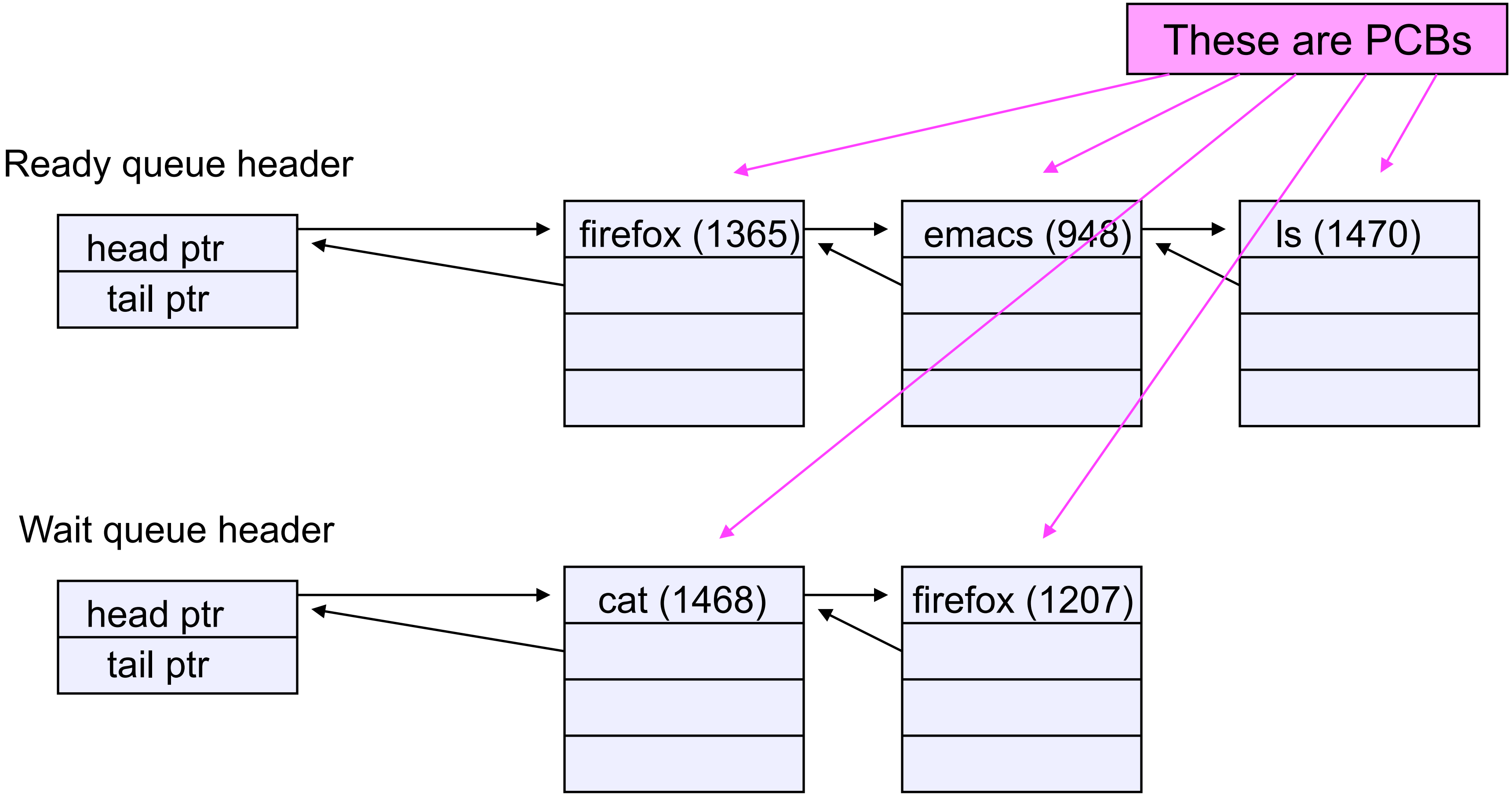


You can create and destroy processes

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
- The PCBs are moved between queues, which are represented as linked lists

State queues



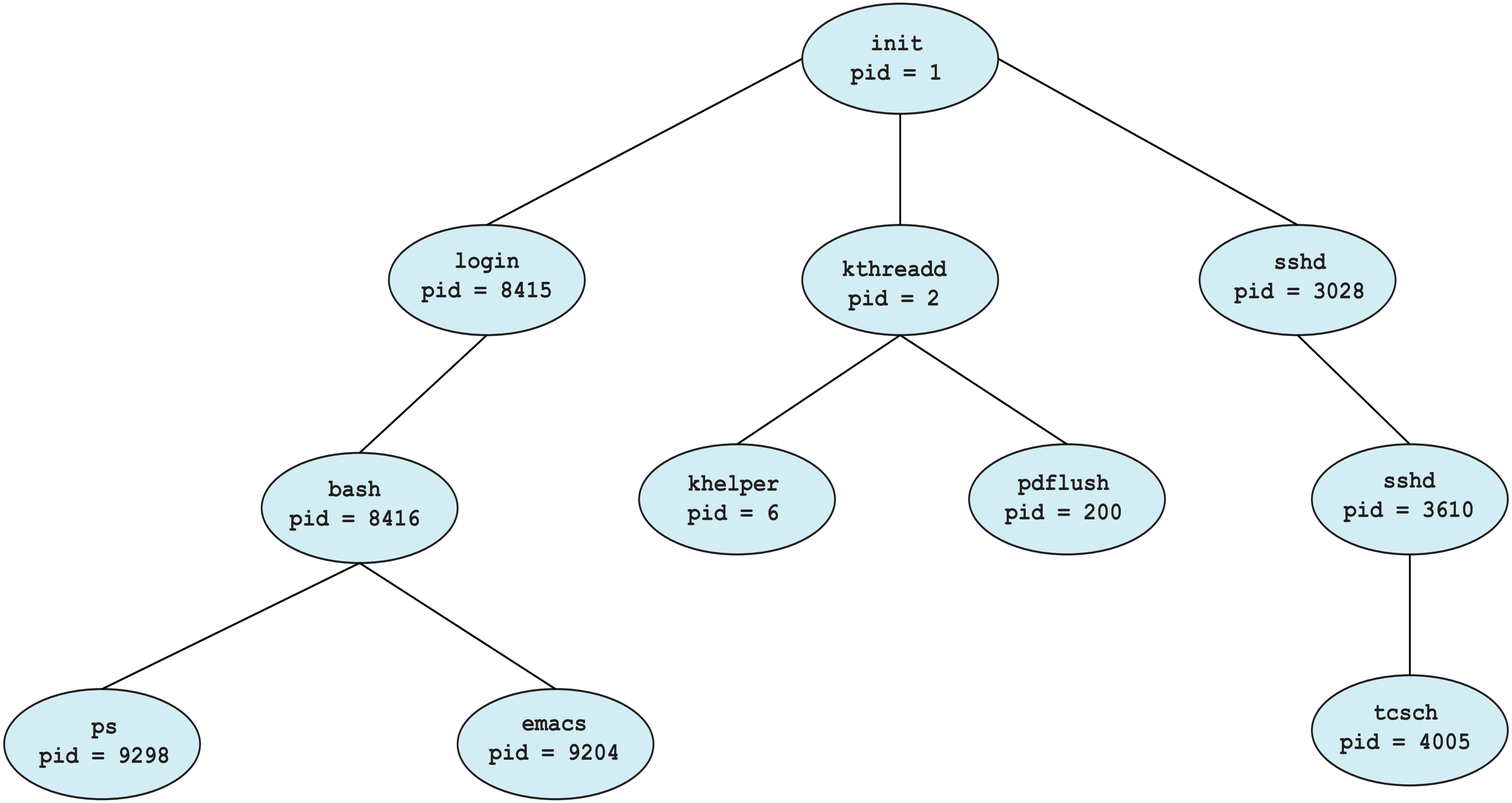
- There may be many wait queues, one for each type of wait (particular device, timer, message, …)

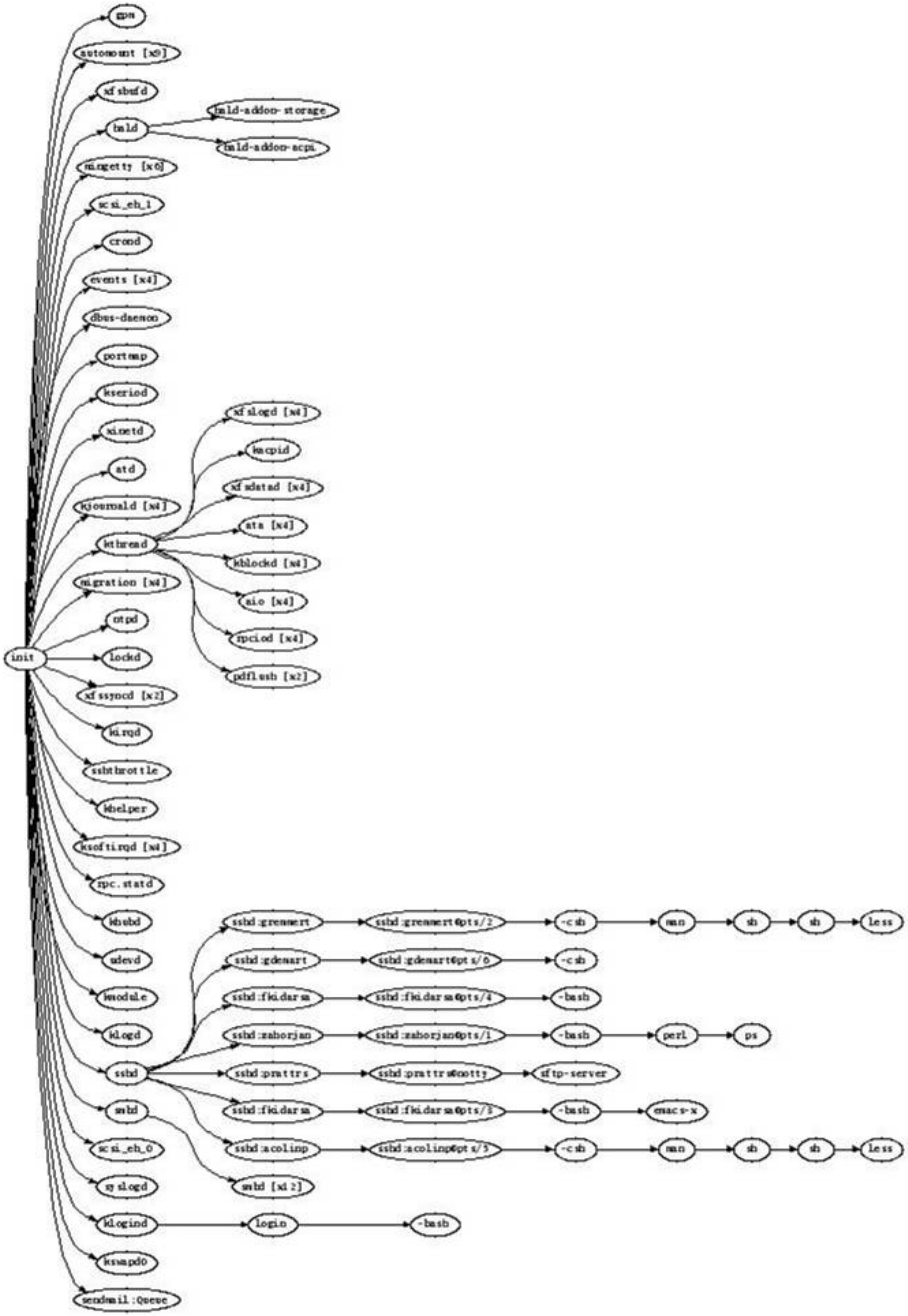
PCBs and state queues

- 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 -ef`, look for PPID field
  - what creates the first process, and when?


init
pid = 1
login
pid = 8415
kthreadd
pid = 2
sshd
pid = 3028
bash
pid = 8416
khelper
pid = 6
pdflush
pid = 200
sshd
pid = 3610
ps
pid = 9298
emacs
pid = 9204
tcsch
pid = 4005

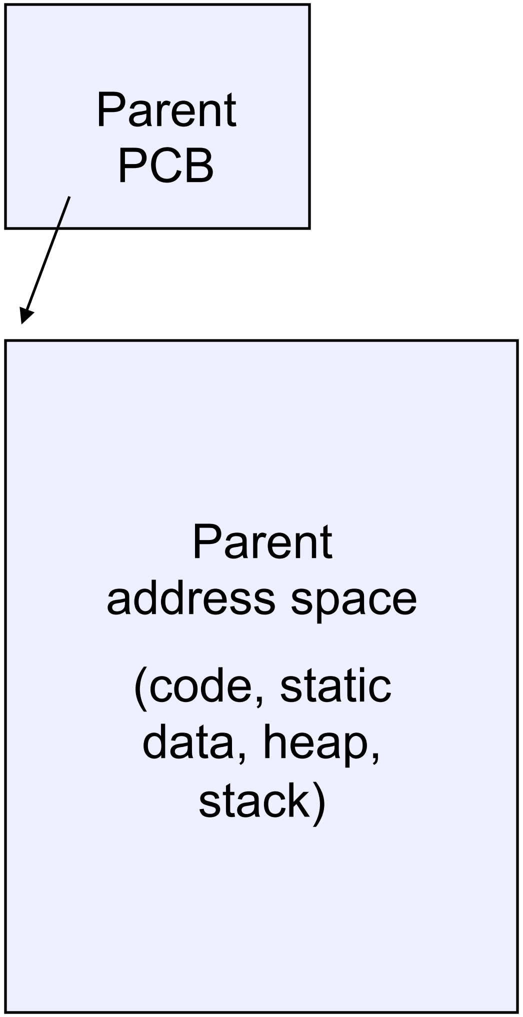

gpm
automount [x9]
xfsbufd
hald
hald-addon-storage
hald-addon-acpi
mingetty [x6]
scsi_eh_1
crond
events [x4]
dbus-daemon
portmap
kseriod
xinetd
atd
kjournald [x4]
kthread
xfslogd [x4]
kacpid
xfsdatad [x4]
ata [x4]
kblockd [x4]
aio [x4]
rpciod [x4]
pdflush [x2]
migration [x4]
ntpd
init
lockd
xfssyncd [x2]
kirqd
sshthrottle
khelper
ksoftirqd [x4]
rpc.statd
khubd
udevd
kmodule
klogd
sshd
sshd:grenmert
sshd:grenmert@pts/2
-csh
man
sh
sh
less
sshd:gdemart
sshd:gdemart@pts/6
-csh
sshd:fkidarsa
sshd:fkidarsa@pts/4
-bash
sshd:zaborjan
sshd:zaborjan@pts/1
-bash
perl
ps
sshd:prattrs
sshd:prattrs@notty
sftp-server
sshd:fkidarsa
sshd:fkidarsa@pts/3
-bash
emacs-x
sshd:acolinp
sshd:acolinp@pts/5
-csh
man
sh
sh
less
smbd
smbd [x12]
scsi_eh_0
syslogd
klogind
login
-bash
kswapd0
sendmail: Queue

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

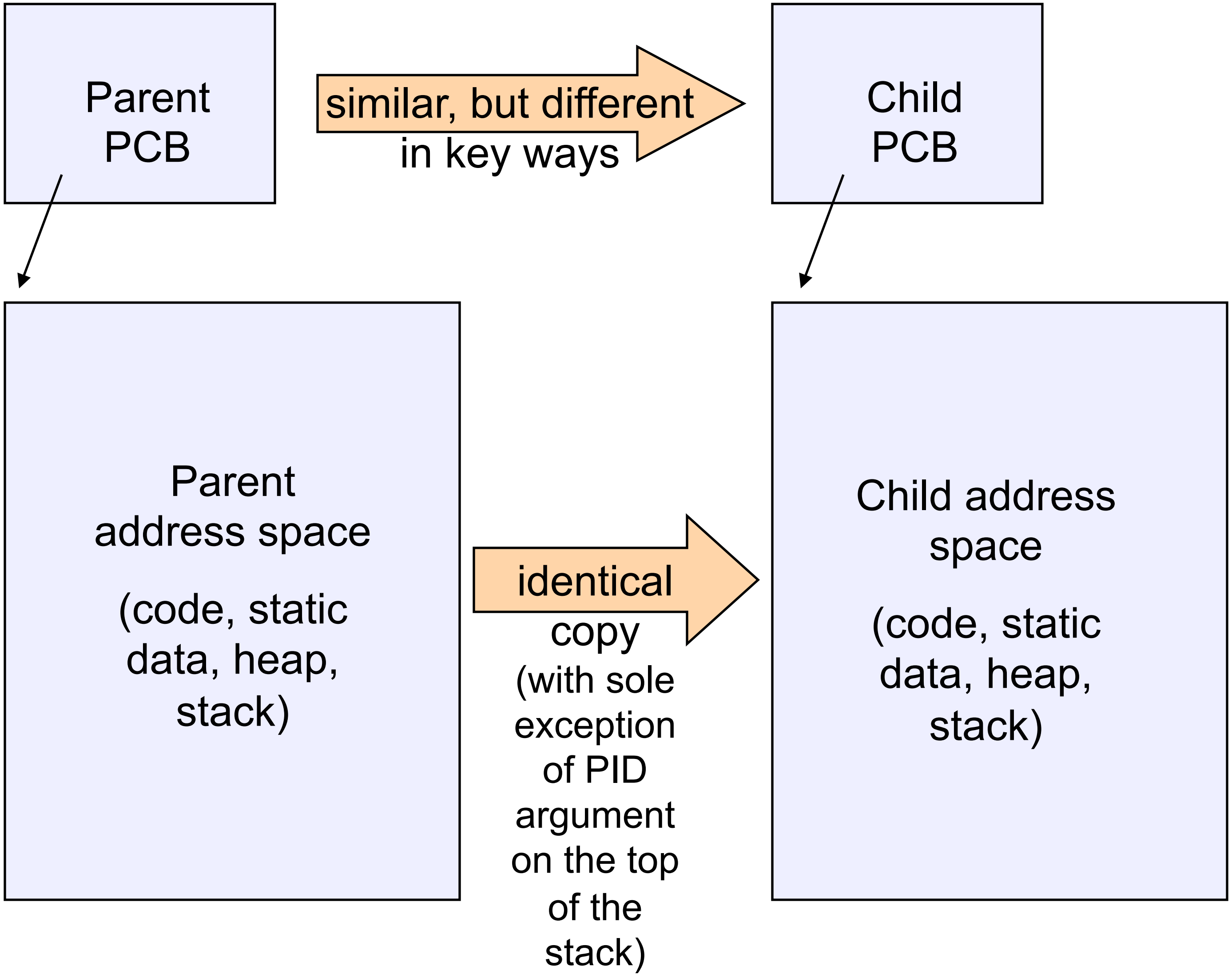
- UNIX process creation through **`fork()`** system call
  - creates and initializes a new PCB
    - initializes kernel resources of new process with resources of parent (e.g., open files)
    - initializes PC, SP to be same as parent
  - creates a new address space
    - initializes new address space 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"



Parent PCB

Parent address space

(code, static data, heap, stack)



Parent PCB

similar, but different in key ways

Child PCB

Parent address space

(code, static data, heap, stack)

identical copy (with sole exception of PID argument on the top of the stack)

Child address space

(code, static data, heap, stack)

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;
  }
}
```

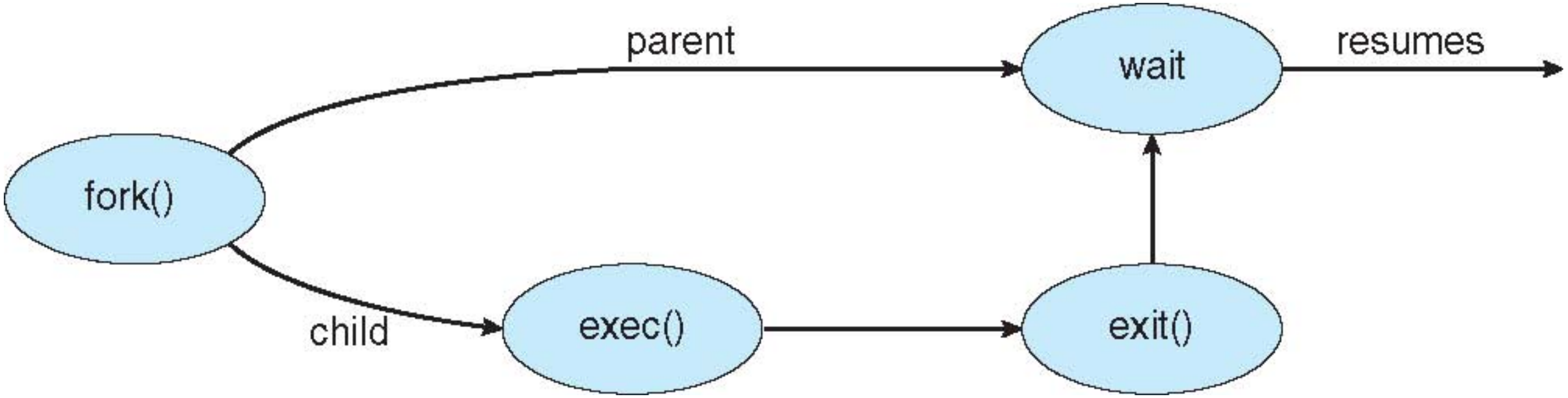
testparent output

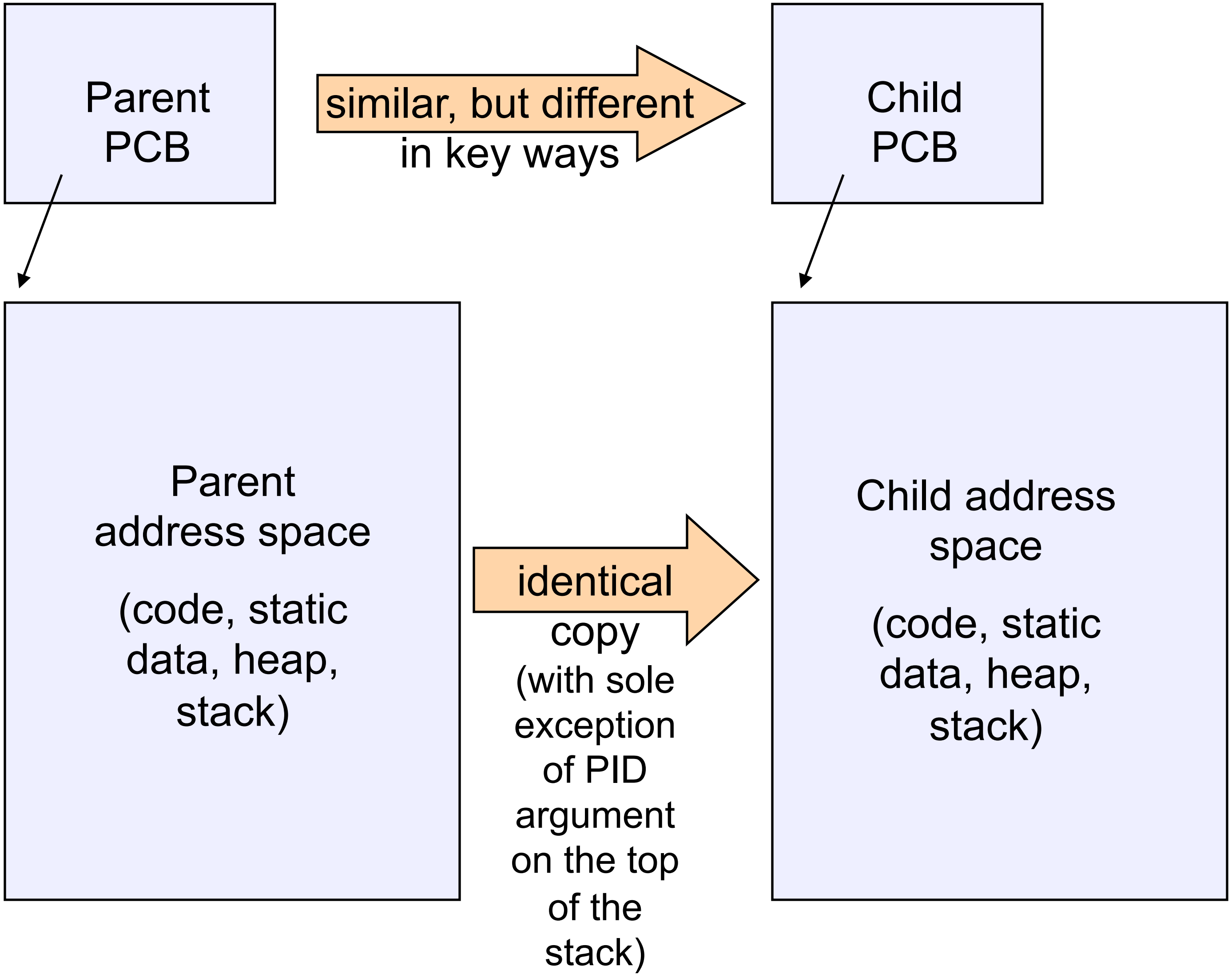
```
spinlock% gcc -o testparent testparent.c
spinlock% ./testparent
My child is 486
Child of testparent is 0
spinlock% ./testparent
Child of testparent is 0
My child is 571
```

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!*

exec() and fork()





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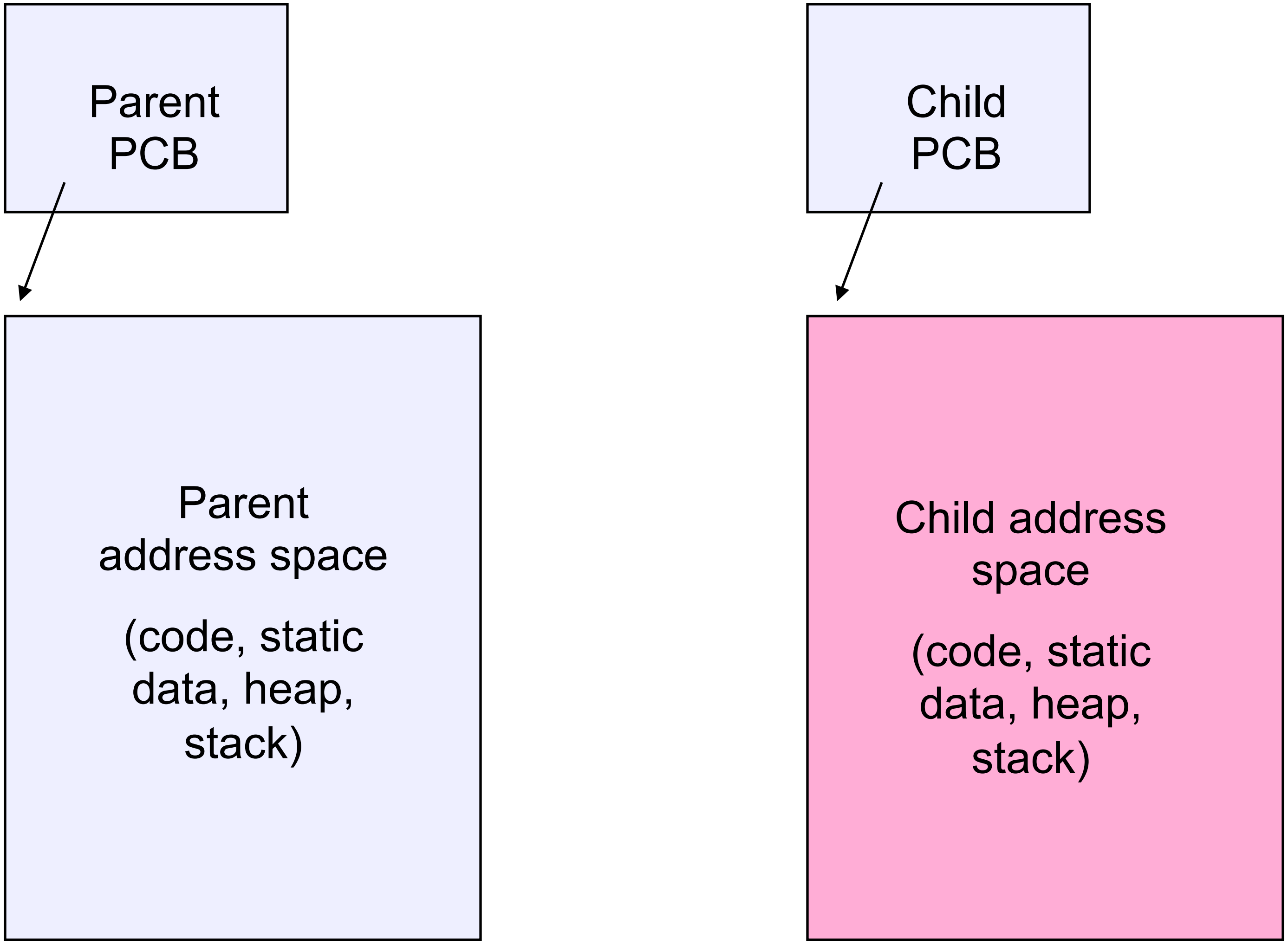
Child address space

(code, static data, heap, stack)



Parent PCB

Parent address space

(code, static data, heap, stack)

Child PCB

Child address space

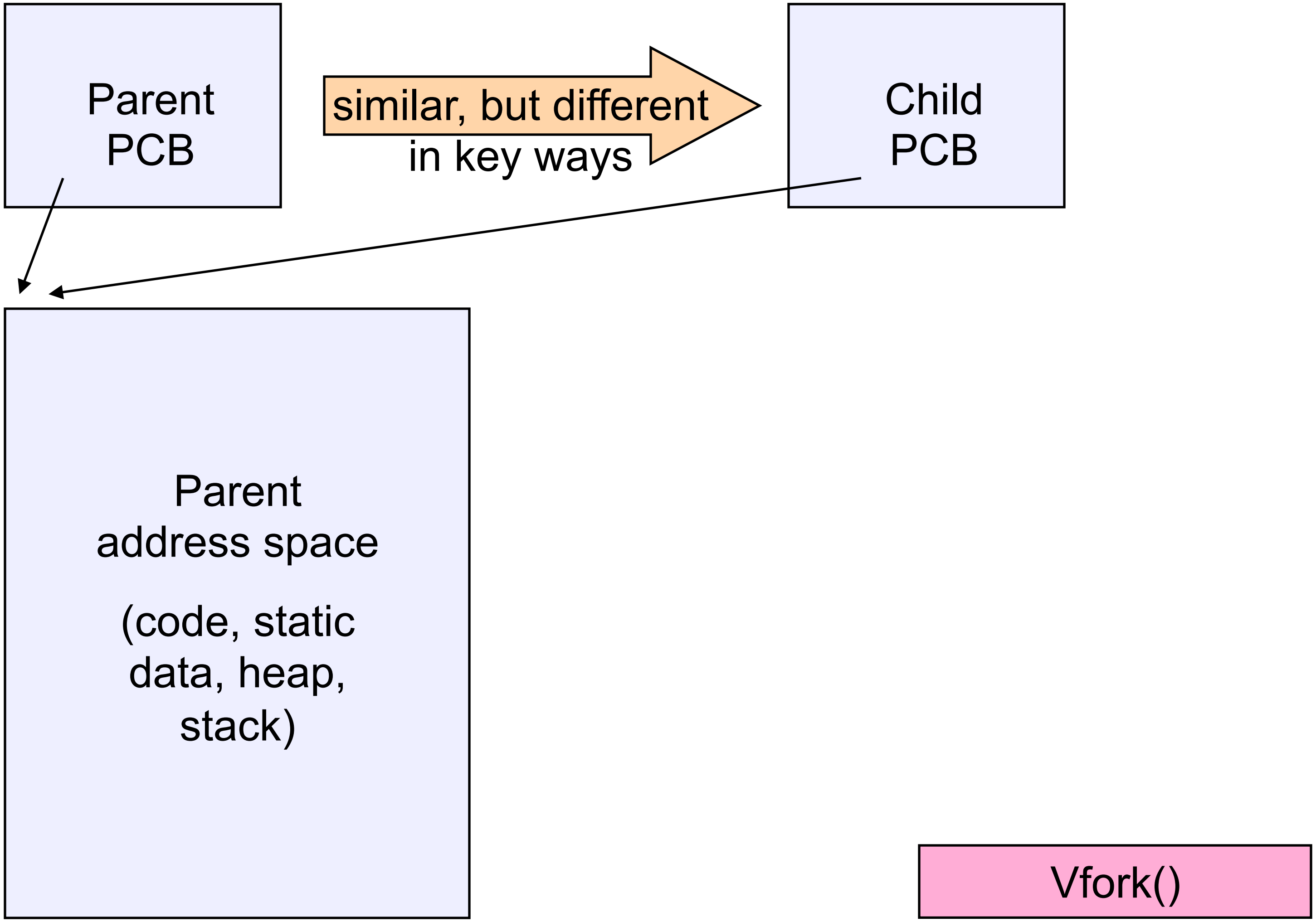
(code, static data, heap, stack)

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 destroy 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



Parent PCB

similar, but different in key ways

Child PCB

Parent address space

(code, static data, heap, stack)

Vfork()

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);
    }
  }
}
```

Summary

- Process
- Process control blocck
- Process state
- Context switch
- Process creation and termination
- Next time
  - threads