Bucknell UNIVERSITY

Processes and More

CSCI 315 Operating Systems Design

Department of Computer Science

Notice: The slides for this lecture have been largely based on those accompanying the textbook *Operating Systems Concepts*, 10th ed., by Silberschatz, Galvin, and Gagne. Many, if not all, the illustrations contained in this presentation come from this source.

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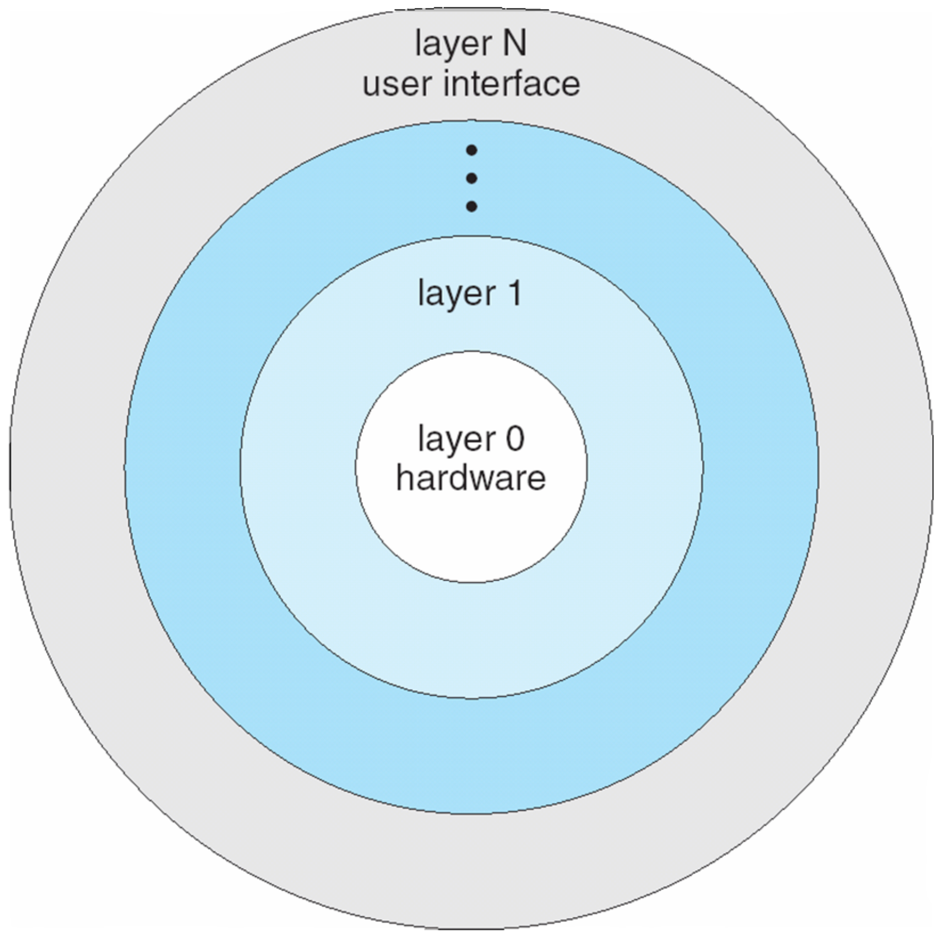
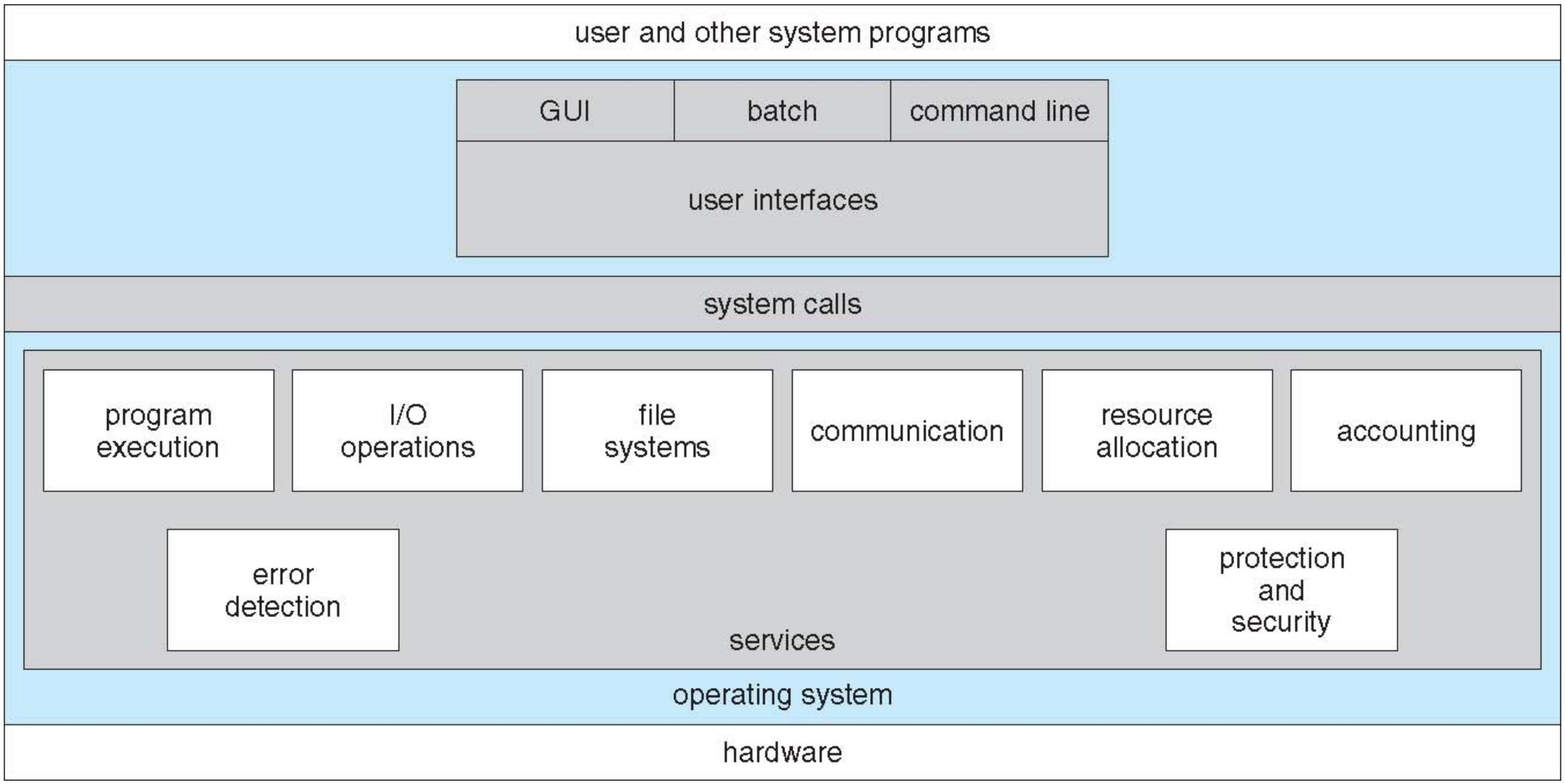
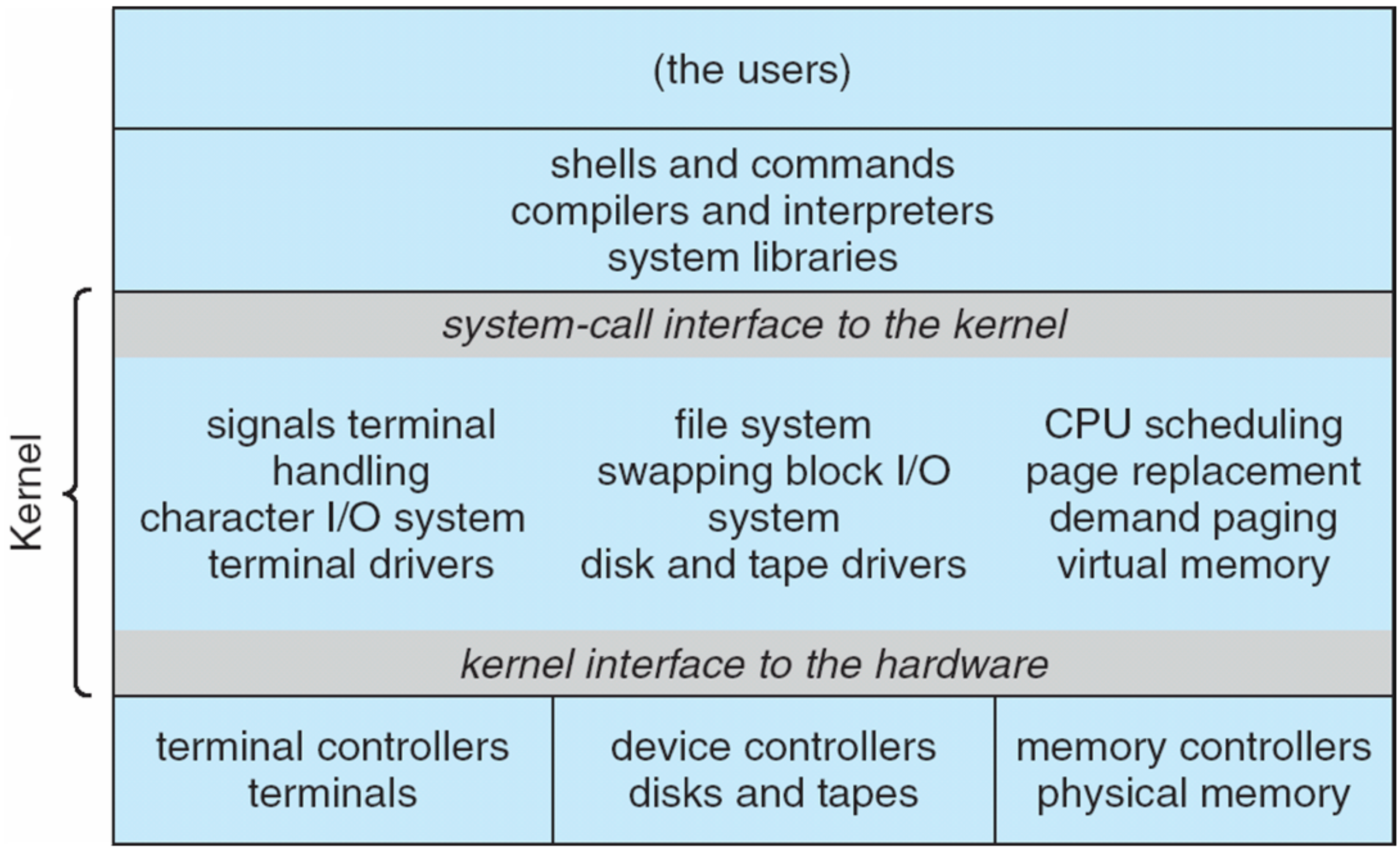
Abstractions and Layers



OS Services


user and other system programs
GUI
batch
command line
user interfaces
system calls
program execution
I/O operations
file systems
communication
resource allocation
accounting
error detection
protection and security
services
operating system
hardware

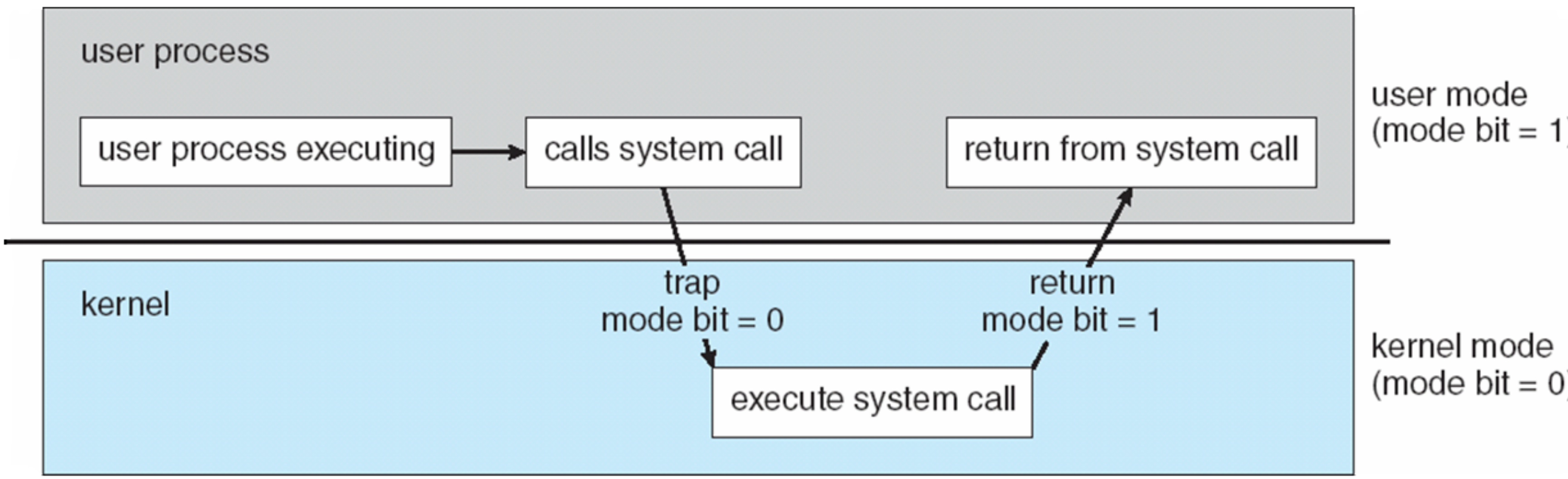
Unix Structure



OS Operations

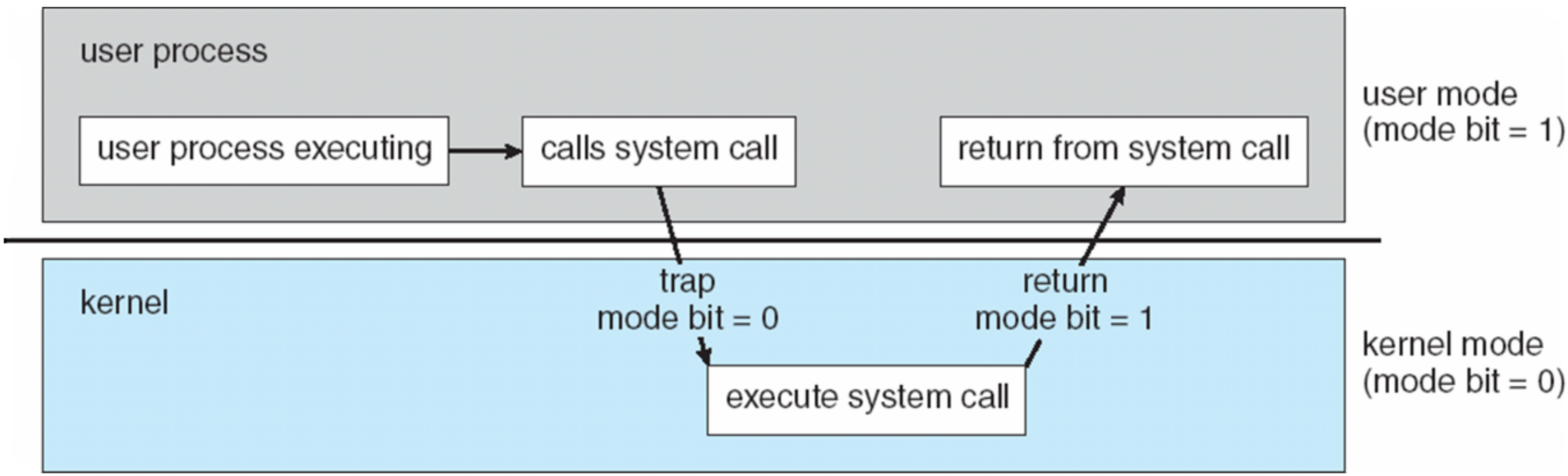
- **Interrupt driven** by hardware
- Software error or request creates **exception** or **trap**
  - Division by zero, request for operating system service
- Other process problems include infinite loop, processes modifying each other or the operating system
- **Dual-mode** operation allows OS to protect itself and other system components
  - **User mode** and **kernel mode**
  - **Mode bit** provided by hardware
    - Provides ability to distinguish when system is running user code or kernel code
    - Some instructions designated as **privileged**, only executable in kernel mode
    - System call changes mode to kernel, return from call resets it to user
- Increasingly CPUs support multi-mode operations
- i.e. **virtual machine manager** (**VMM**) mode for guest **VMs**

User and Kernel Modes

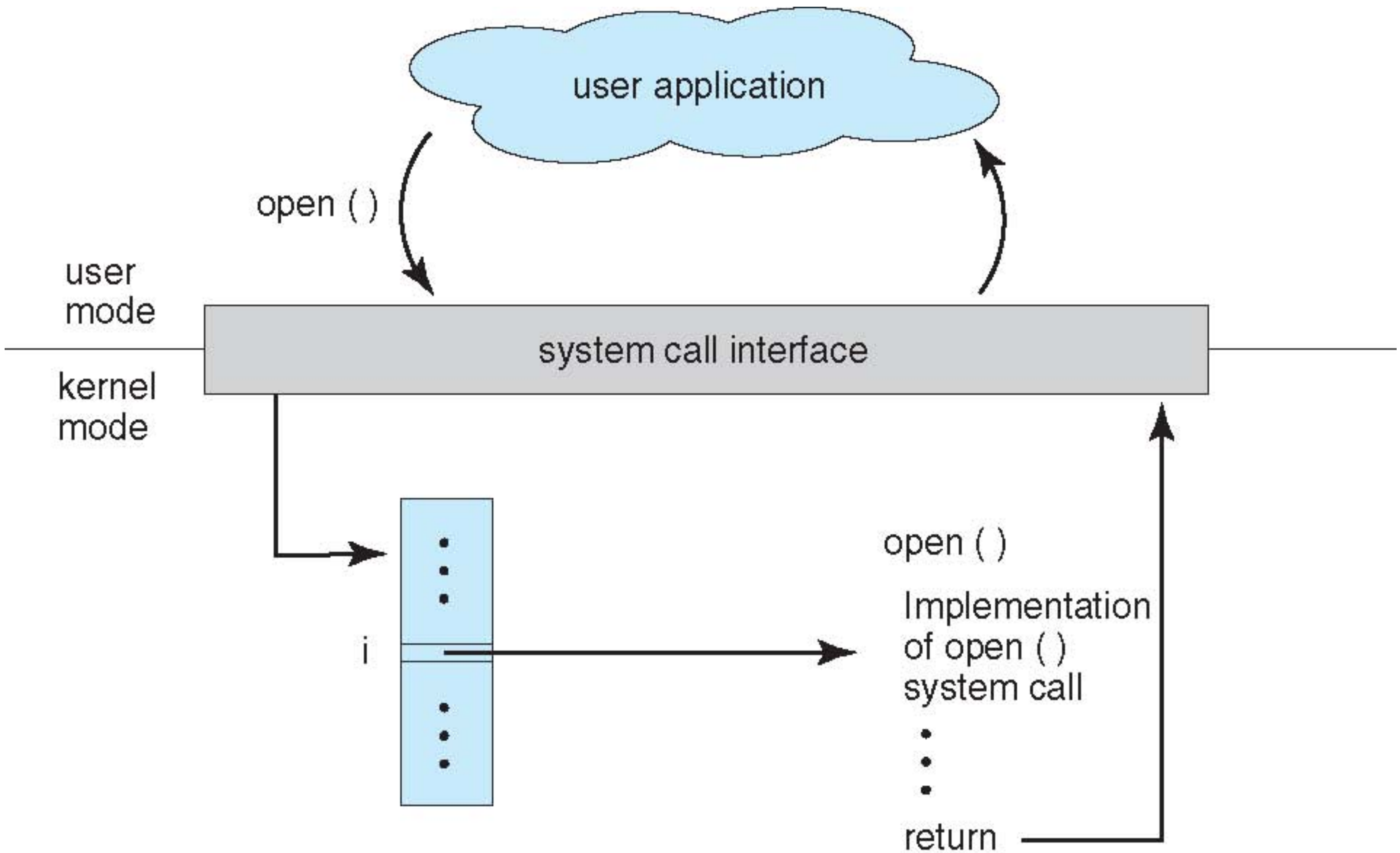


Hardware Support for the OS

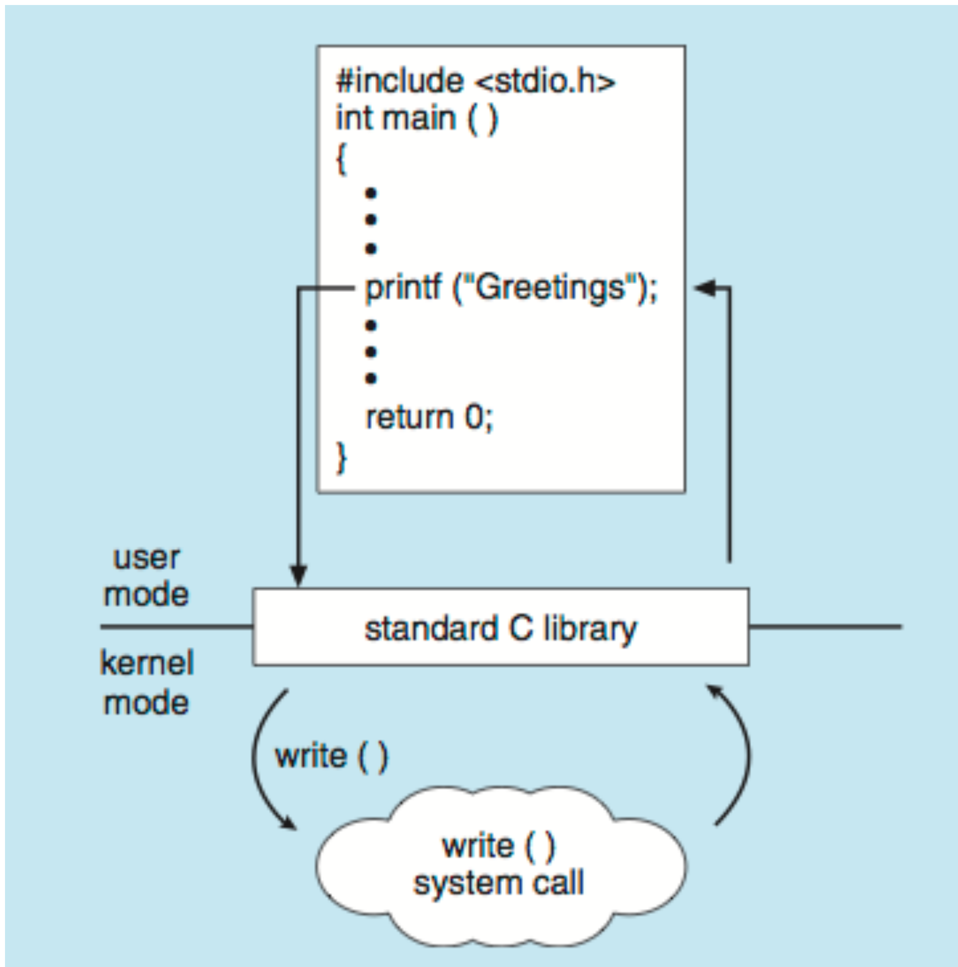
- **Two classes of instructions:** one class for anyone to use, others with **privileged** use (for the OS kernel).
- Need to be able to switch between **user mode** and **kernel mode**.
- If a user runs a privileged instruction, an exception is raised.
- To switch to kernel mode, you need to trap to the kernel.



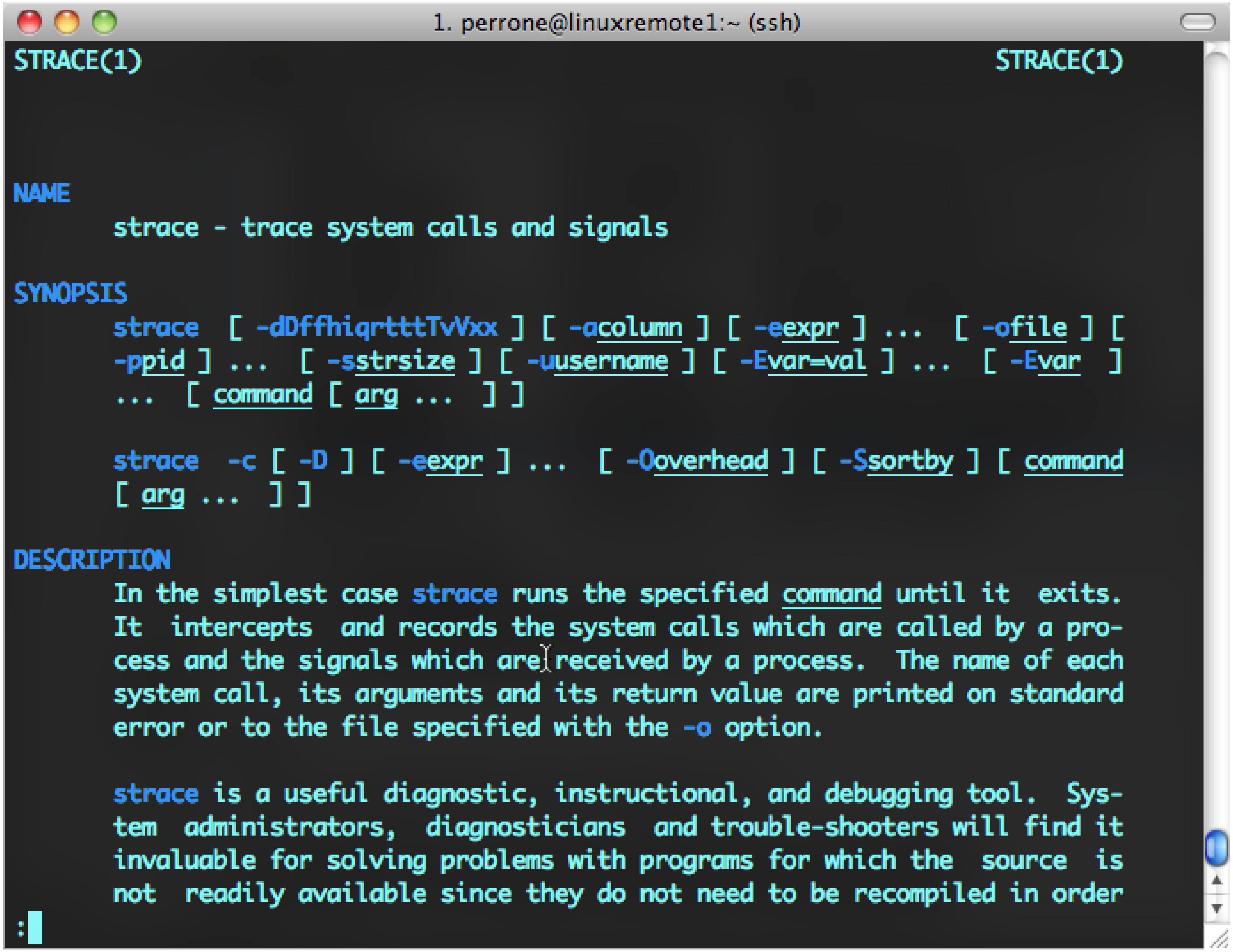
System Calls and the OS



System Calls and Libraries



strace



1. perrone@linuxremote1:~ (ssh)

STRACE(1) STRACE(1)

NAME
    strace - trace system calls and signals

SYNOPSIS
    strace [-dDffhiqrtttTvVxx] [-acolumn] [-eexpr] ... [-ofile] [-ppid] ... [-sstrsize] [-uusername] [-Evar=val] ... [-Evar] ... [command [arg ...]]

    strace -c [-D] [-eexpr] ... [-Ooverhead] [-Ssortby] [command [arg ...]]

DESCRIPTION
    In the simplest case strace runs the specified command until it exits. It intercepts and records the system calls which are called by a process and the signals which are received by a process. The name of each system call, its arguments and its return value are printed on standard error or to the file specified with the -o option.

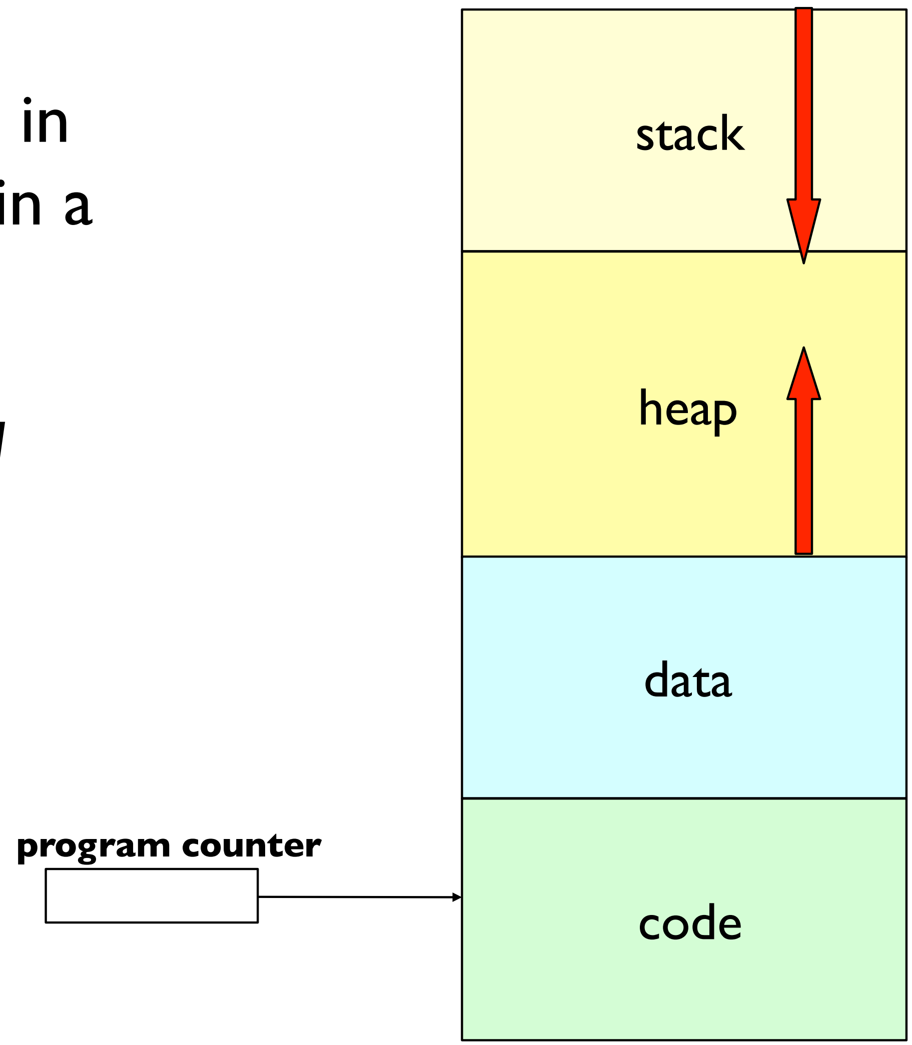
    strace is a useful diagnostic, instructional, and debugging tool. System administrators, diagnosticians and trouble-shooters will find it invaluable for solving problems with programs for which the source is not readily available since they do not need to be recompiled in order

:

Process Concept

- Process – a program in execution; the code in a process executes sequentially. *(Ahem, mostly. To be discussed later.)*

- A process includes:
  - program counter,
  - stack,
  - data section.



Creating *processes* in Unix

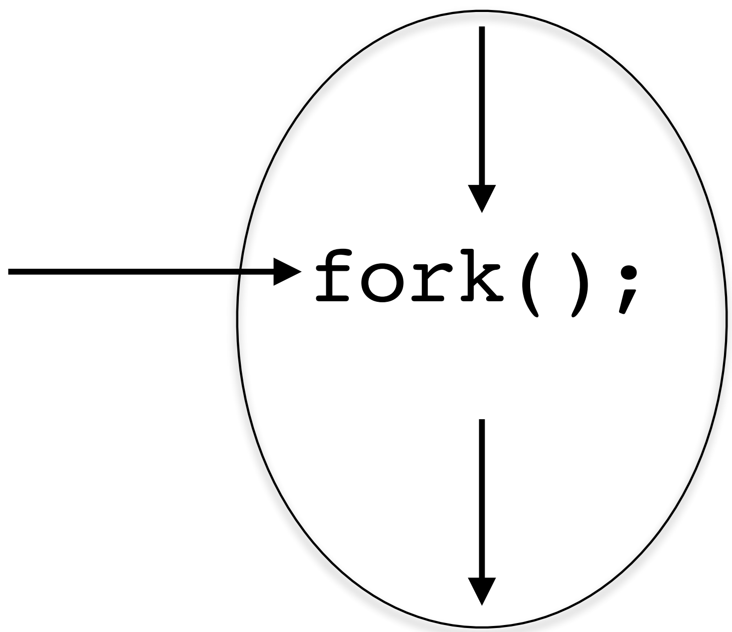
(Always RTFMP)

perrone@linuxremote1:~ (ssh) ⌥⌘1

```
FORK(2)                          Linux Programmer's Manual                          FORK(2)



NAME
       fork - create a child process

SYNOPSIS
       #include <unistd.h>

       pid_t fork(void);

DESCRIPTION
       fork()  creates a new process by duplicating the calling process.  The new process, referred to as the child, is an exact
       duplicate of the calling process, referred to as the parent, except for the following points:

       *  The child has its own unique process ID,  and  this  PID  does  not  match  the  ID  of  any  existing  process  group
          (setpgid(2)).

       *  The child's parent process ID is the same as the parent's process ID.

       *  The child does not inherit its parent's memory locks (mlock(2), mlockall(2)).

       *  Process resource utilizations (getrusage(2)) and CPU time counters (times(2)) are reset to zero in the child.

       *  The child's set of pending signals is initially empty (sigpending(2)).

 Manual page fork(2) line 1 (press h for help or q to quit)
```

Forking

(yeah, it’s a thing, a Unix thing)



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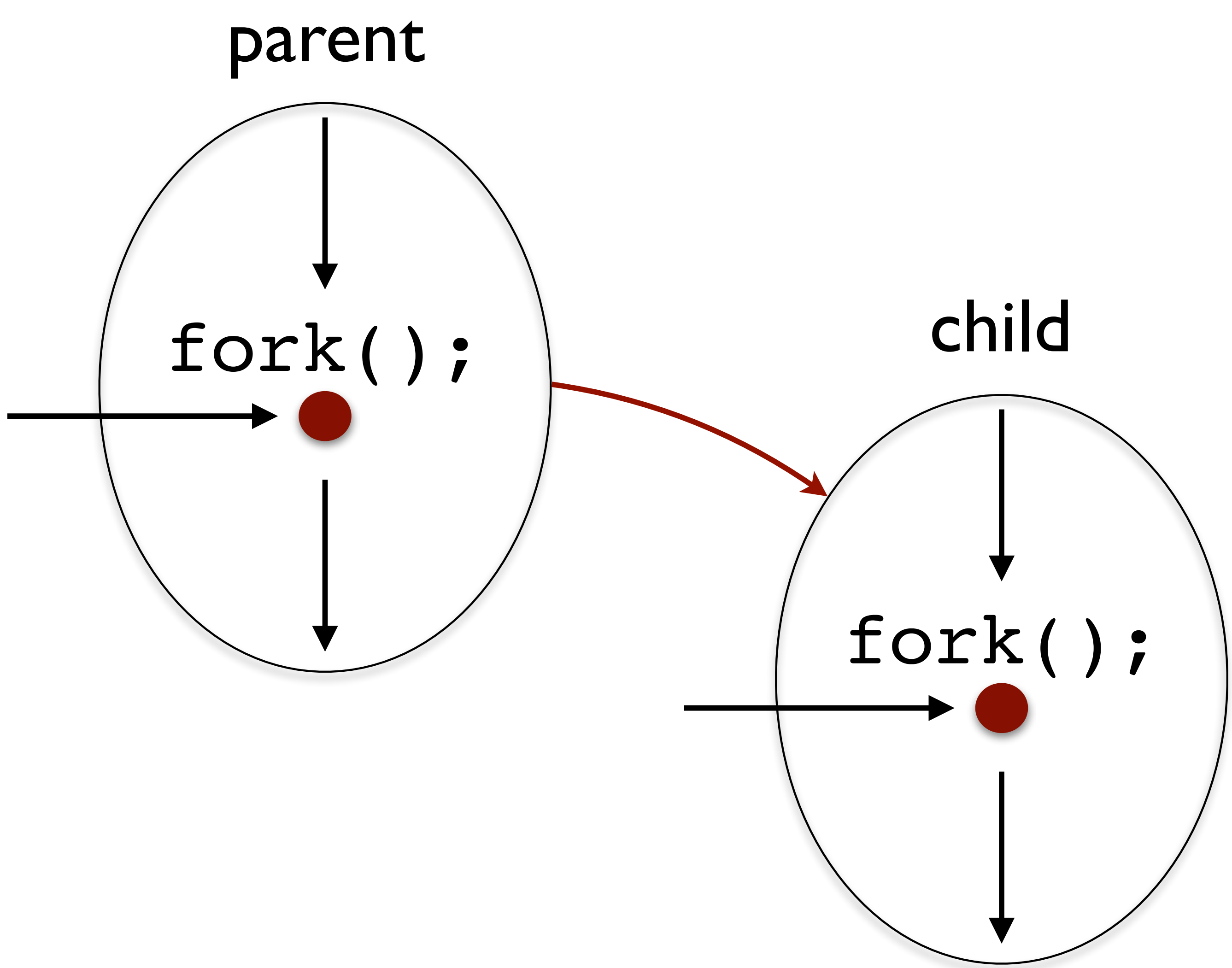
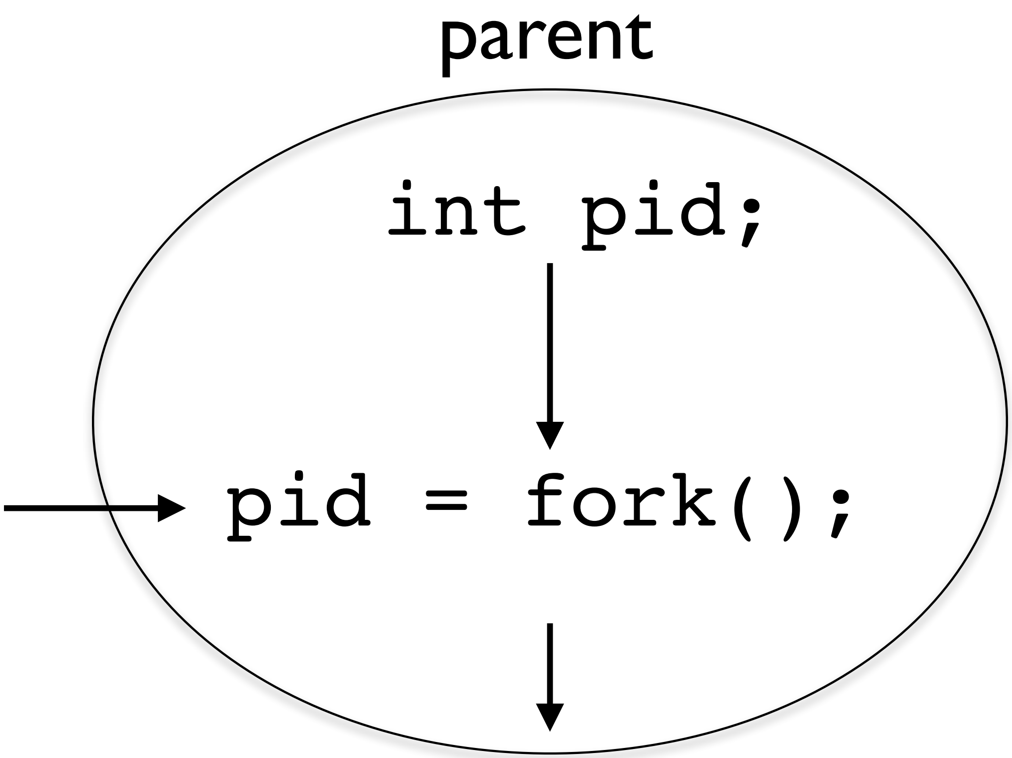


Forking

(what that return value is for)



Forking

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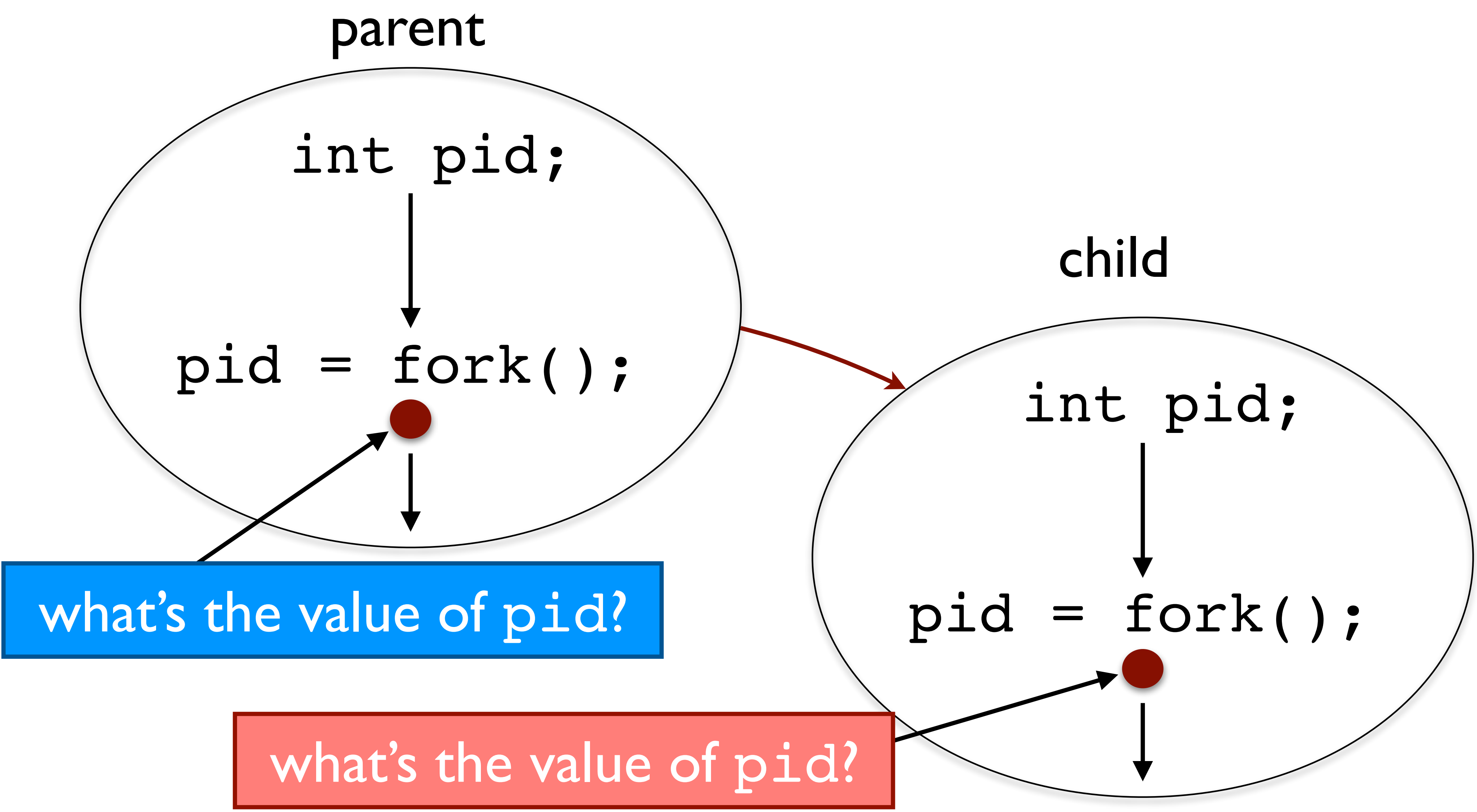


Using `fork` safely

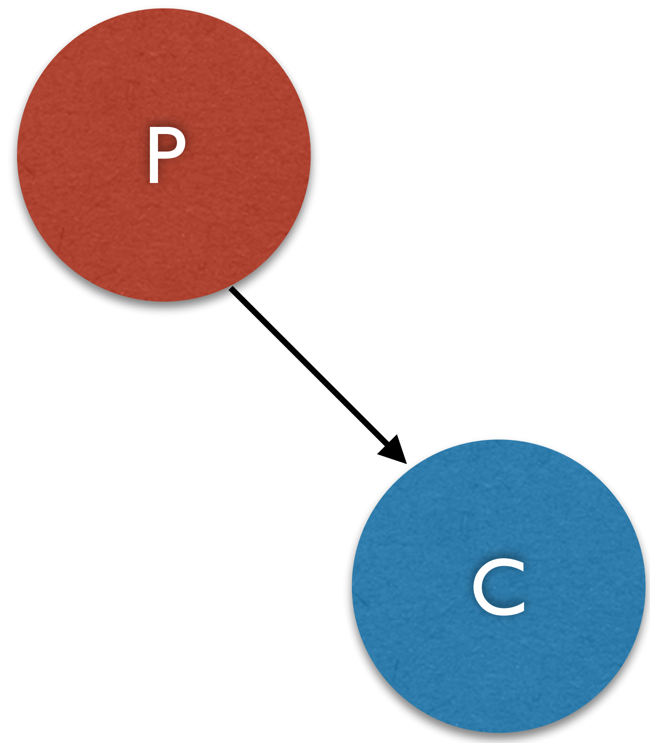
```
int pid;
…
pid = fork();
if (0 != pid) {
   // code of the parent
   …
} else {
   // code of the child
   …
}
…
```

Using `fork` safely

```
int pid;
…
pid = fork();
if (0 != pid) {
   // code of the parent
   …
} else {
   // code of the child
   …
}
…
```

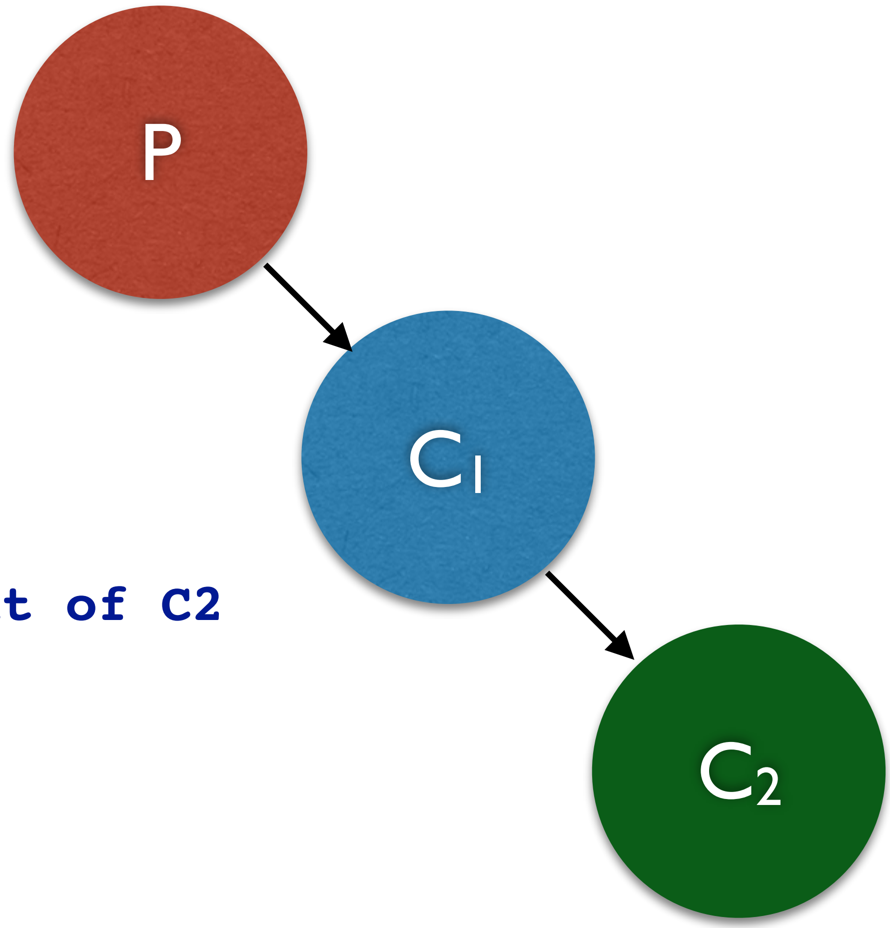
Using `fork` safely

```
int pid;
…
pid = fork();
if (0 != pid) {
   // code of parent P
   …
} else {
   // code of child C
   …
}
…
```



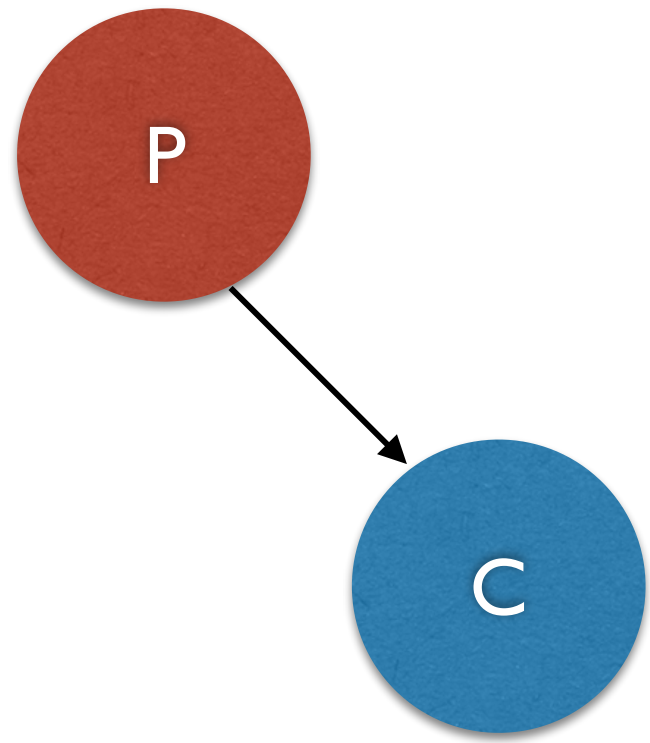
Using `fork` safely

```
int pid1, pid2;
pid1 = fork();
if (0 != pid1) {
  // code of parent P
  …
} else {
  // code of child C1
  if (0 != pid2) {
    // code of child C1, parent of C2
    …
  } else {
    // code of child C2
    …
  }
}
```



Using `fork` even more safely

```
int pid;
pid = fork();
if (-1 != pid) {
    // error handling
    …
} else if (0 != pid) {
   // code of parent P
   …
} else {
   // code of child C
   …
}
```



Joining *processes* in Unix

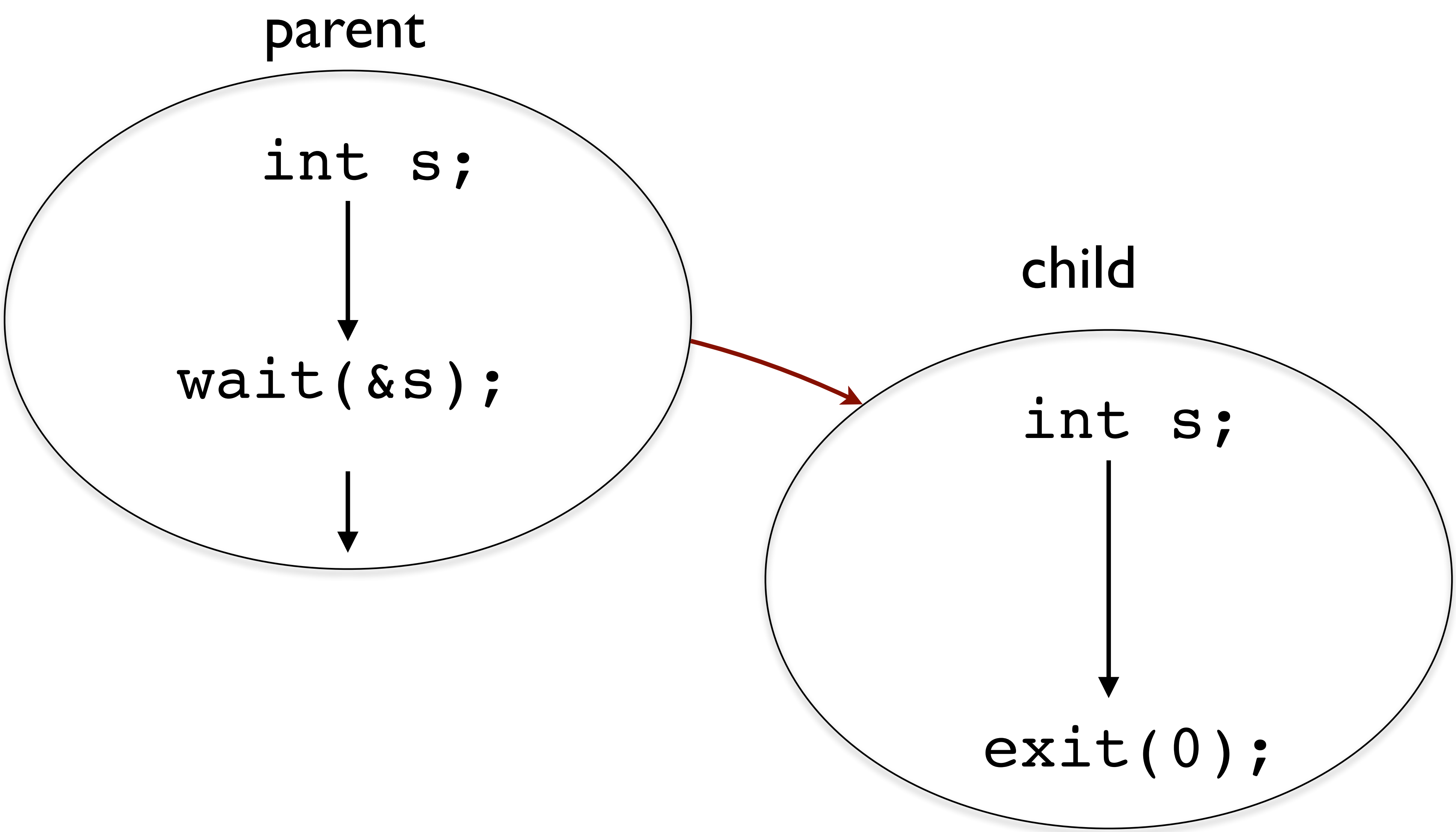
(Always RTFMP)

perrone@linuxremote1:~ (ssh)

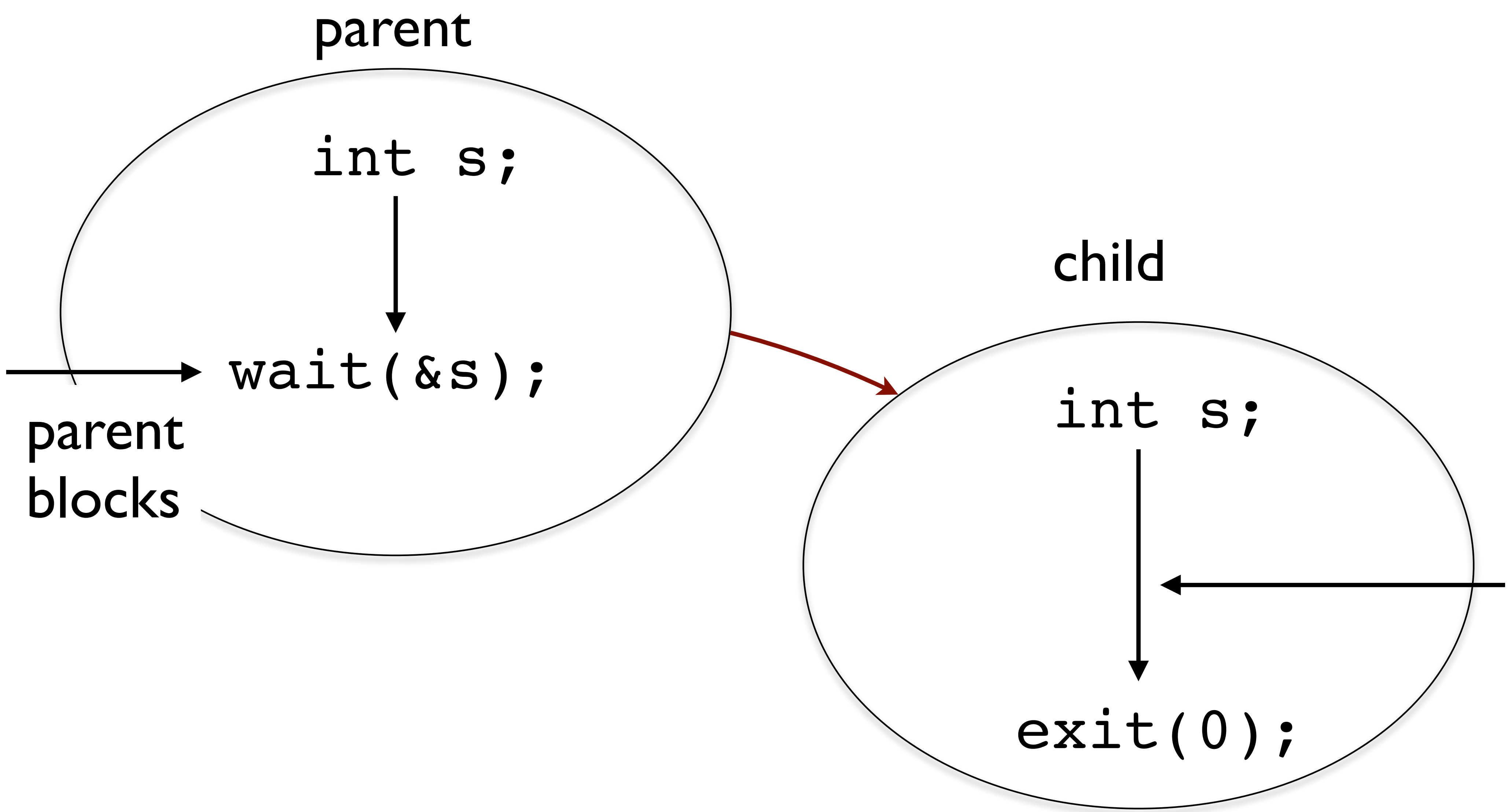
```
WAIT(2)                        Linux Programmer's Manual                        WAIT(2)



NAME
       wait, waitpid, waitid - wait for process to change state

SYNOPSIS
       #include <sys/types.h>
       #include <sys/wait.h>

       pid_t wait(int *status);

       pid_t waitpid(pid_t pid, int *status, int options);

       int waitid(idtype_t idtype, id_t id, siginfo_t *infop, int options);

   Feature Test Macro Requirements for glibc (see feature_test_macros(7)):

       waitid():
           _SVID_SOURCE || _XOPEN_SOURCE >= 500 || _XOPEN_SOURCE && _XOPEN_SOURCE_EXTENDED
           || /* Since glibc 2.12: */ _POSIX_C_SOURCE >= 200809L

DESCRIPTION
       All  of  these  system calls are used to wait for state changes in a child of the calling process, and obtain information
       about the child whose state has changed.  A state change is considered to be: the child terminated; the child was stopped
       by  a signal; or the child was resumed by a signal.  In the case of a terminated child, performing a wait allows the sys-
 Manual page wait(2) line 1 (press h for help or q to quit)
```

Waiting

(the inverse of forking)



Waiting
(the inverse of forking)



Waiting

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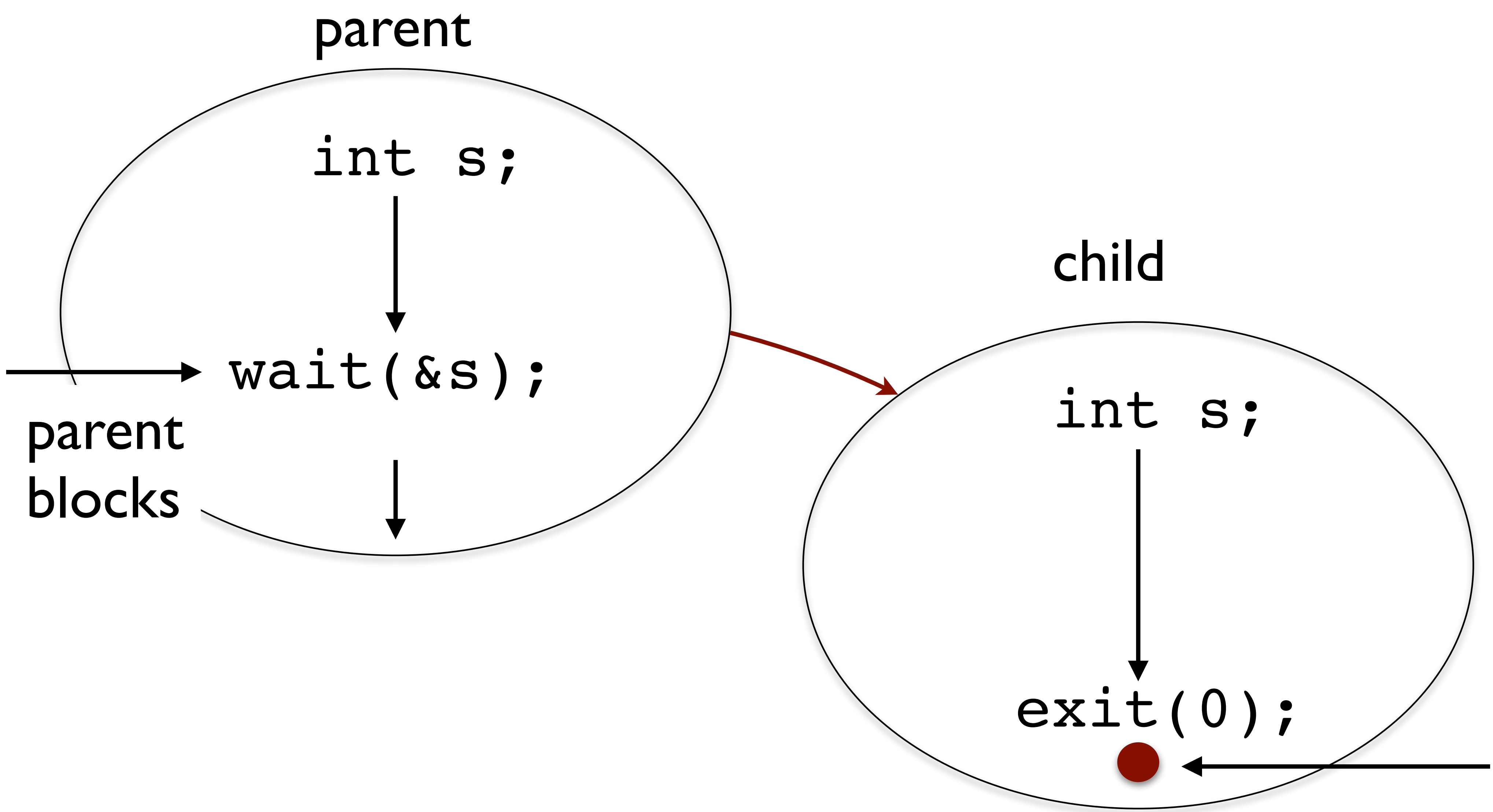
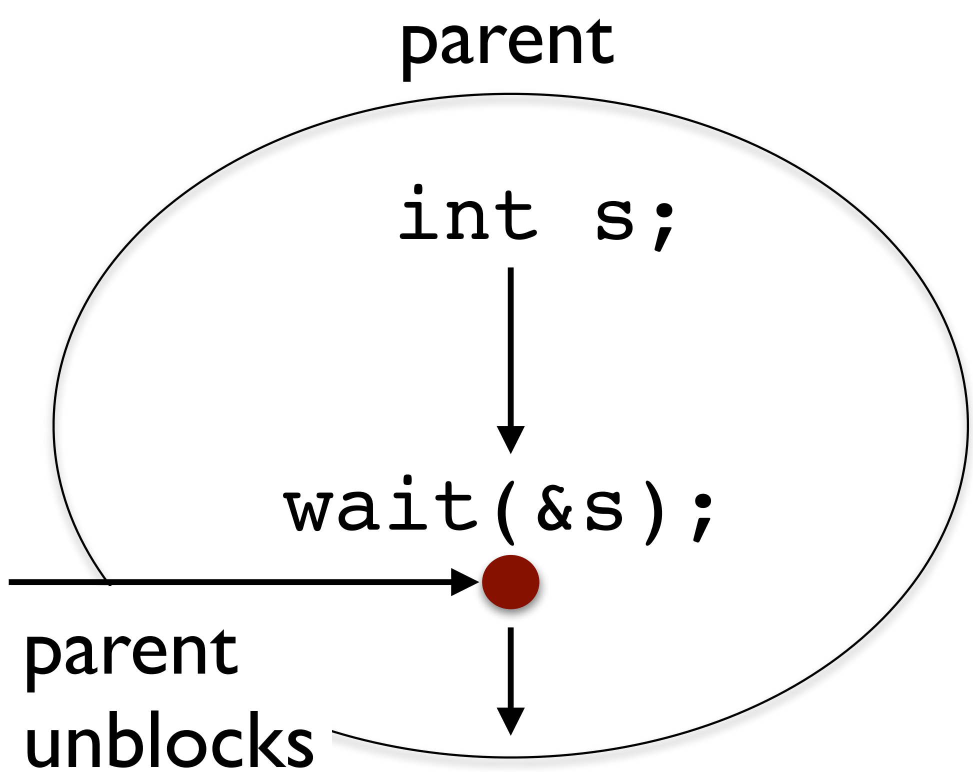


Waiting

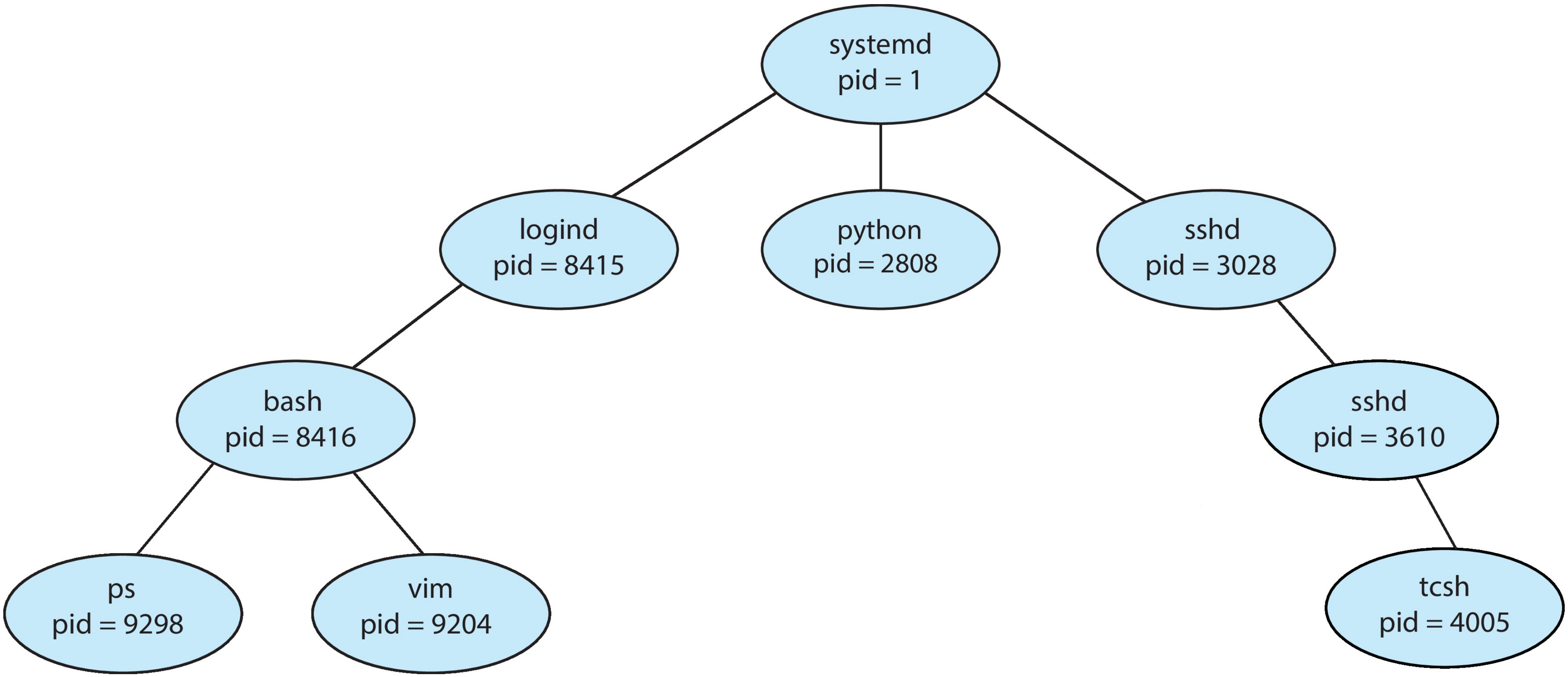
(the inverse of forking)



Linux Process Control

- `ps(1)`
- `top(1)` (MacOS X: make your terminal wide)
- `htop(1)`
- `pstree(1)`
- `kill(1)`

Processes in Linux

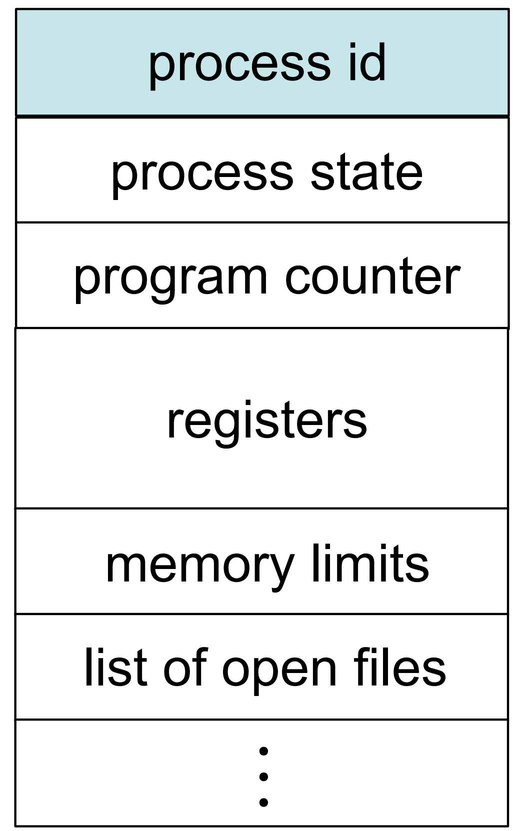


Process Control Block (PCB)

OS bookkeeping information associated with each process:

- Process state,
- Program counter,
- CPU registers,
- CPU scheduling information,
- Memory-management information,
- Accounting information,
- I/O status information,

⋮

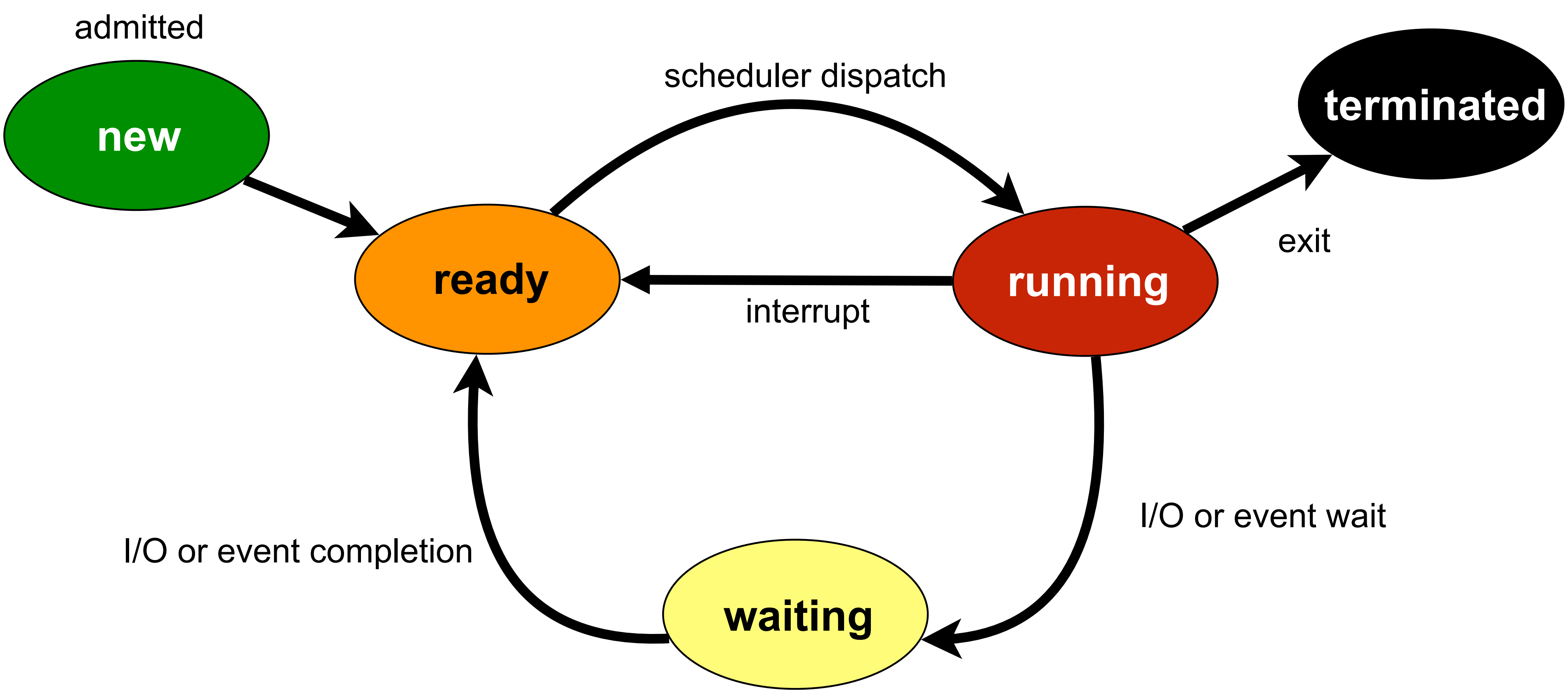


Process State

As a process executes, it changes ***state***:

- **new**: The process is being created.
- **running**: Instructions are being executed.
- **waiting**: The process is waiting for some event to occur.
- **ready**: The process is waiting to be assigned to a processor.
- **terminated**: The process has finished execution.

Process State Transition Diagram

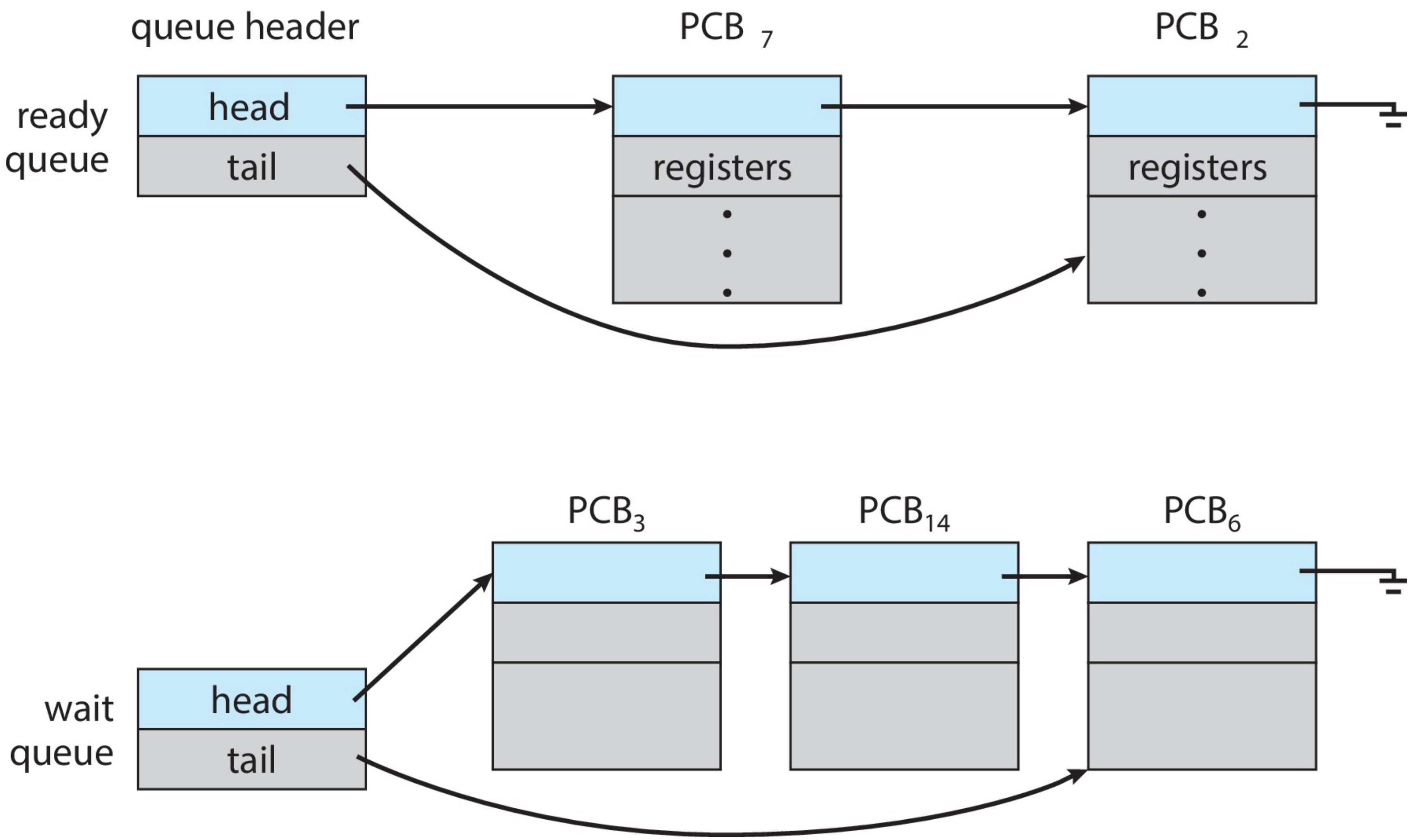


Process Scheduling Queues

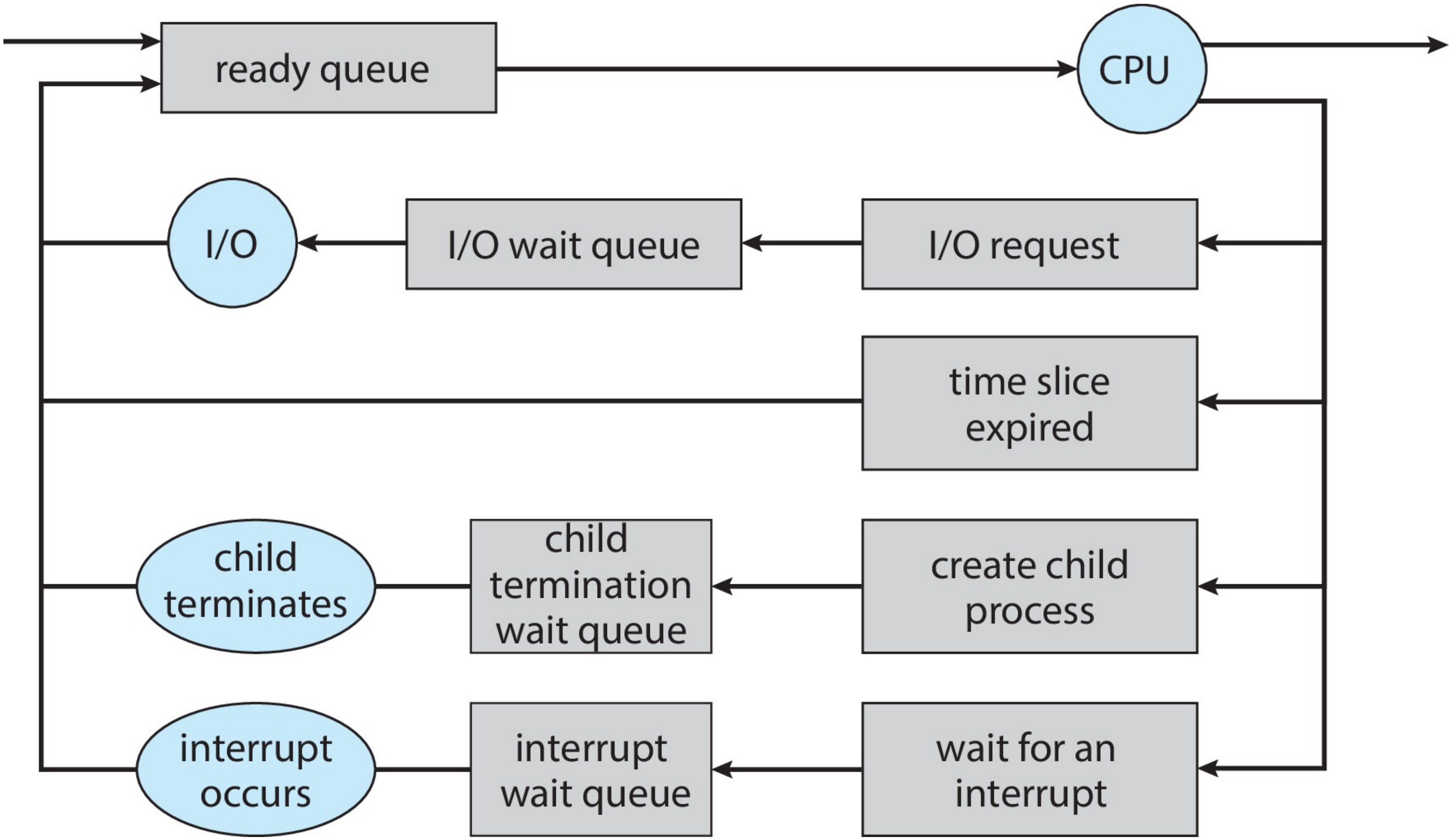
- ***Job queue*** – set of all processes in the system.
- ***Ready queue*** – set of all processes residing in main memory, ready and waiting to execute.
- ***Device queues*** – set of processes waiting for an I/O device.

Processes migrate between the various queues.

Processes and OS Queues



Process Scheduling



Schedulers

- ***Long-term scheduler*** (or job scheduler) – selects which processes should be brought into the ready queue
- ***Short-term scheduler*** (or CPU scheduler) – selects which process should be executed next and allocates CPU

Schedulers

- **Long-term scheduler** is invoked very infrequently (seconds, minutes) ⇒ (may be slow; controls the *degree of multiprogramming*)
- **Short-term scheduler** is invoked very frequently (milliseconds) ⇒ (must be fast)

Processes can be described as either:

- ***I/O-bound process*** – spends more time doing I/O than computations, many short CPU bursts

- ***CPU-bound process*** – spends more time doing computations; few very long CPU bursts

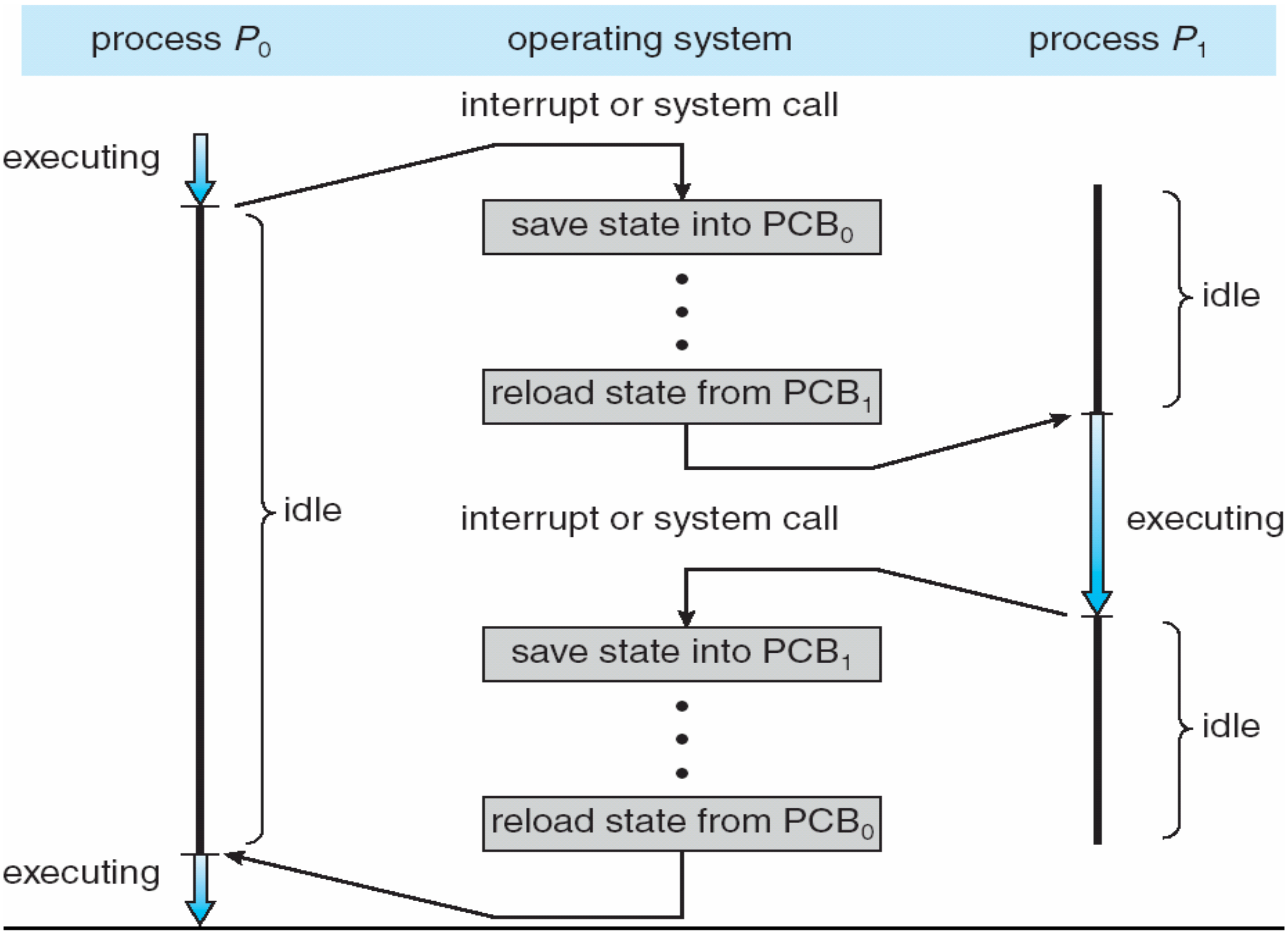
Context Switch

- When CPU switches to another process, the system must save the state of the old process and load the saved state for the new process.

- Context-switch time is **overhead**; the system does no useful work while switching.

- Time dependent on hardware support.

CPU Switching



Process Creation

- Parent process create children processes, which, in turn can create other processes, forming a tree of processes.

- Resource sharing:
  - Parent and children share all resources,
  - Children share subset of parent's resources,
  - Parent and child share no resources.

- Execution:
  - Parent and children execute concurrently,
  - Parent may wait until children terminate.

Process Creation (Cont.)

- Address space:
  - Child has duplicate of parent's address space, or
  - Child can have a program loaded onto it.

- UNIX examples:
  - **fork** system call creates new process and returns with a pid (0 in child, > 0 in the parent),
  - **exec** system call can be used after a **fork** to replace the process' memory space with a new program.

Process Termination

- Process executes last statement and asks the operating system to terminate it (**exit**)
  - Output data from child to parent (via **wait**)
  - Process' resources are deallocated by operating system
- Parent may terminate execution of children processes (**abort**) if:
  - Child has exceeded allocated resources,
  - Task assigned to child is no longer required,
  - If parent is exiting (some operating system do not allow child to continue if its parent terminates)
    - All children terminated - *cascading termination*

Cooperating Processes

- An ***independent*** process **cannot** affect or be affected by the execution of another process.
- A ***cooperating*** process **can** affect or be affected by the execution of another process.
- Advantages of process cooperation:
  - Information sharing,
  - Computation speed-up,
  - Modularity,
  - Convenience.

Interprocess Communication (IPC)

- Mechanism for processes to communicate and to synchronize their actions
- Message system – processes communicate with each other without resorting to shared variables
- IPC facility provides two operations:
  - **send**(*message*)**,** **receive**(*message*)
    - where *message* has fixed or variable size
- If processes *P* and *Q* wish to communicate, they need to:
  - establish a *communication link* between them
  - exchange messages via send/receive
- Implementation of communication link
  - physical (e.g., shared memory, hardware bus)
  - logical (e.g., logical properties)

IPC Properties

- **Buffering**
- **Capacity**
- **Synchronization**
- **Service model**
- **Shared memory**
- **Direct or indirect**

Buffering

Queue of messages attached to the link; implemented in one of three ways:

1. Zero capacity – 0 messages
   Sender must wait for receiver (rendezvous).
2. Bounded capacity – finite length of *n* messages.
   Sender must wait if link full.
3. Unbounded capacity – infinite length. Sender never waits.

Synchronization

- *Message passing* may be either blocking or non-blocking.
- **Blocking** is considered **synchronous**:
  - **Blocking send** has the sender block until the message is received.
  - **Blocking receive** has the receiver block until a message is available.
- **Non-blocking** is considered **asynchronous**
  - **Non-blocking** send has the sender send the message and continue.
  - **Non-blocking** receive has the receiver receive a valid message or null.

Implementation Questions

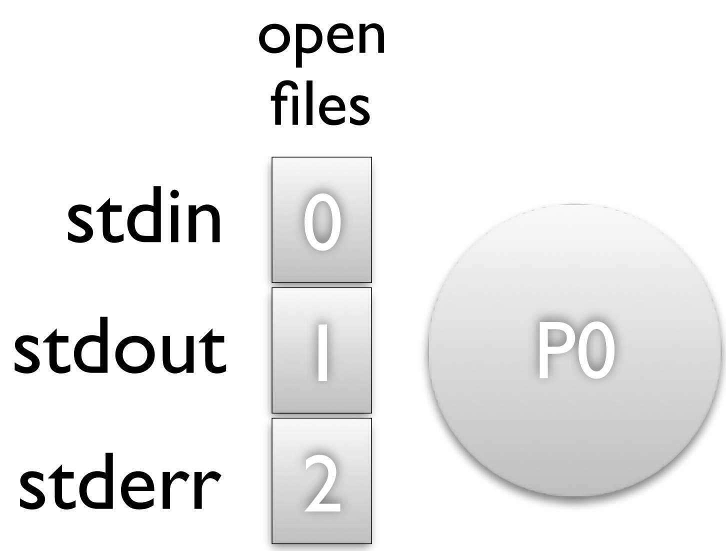
- How are links established?
- Can a link be associated with more than two processes?
- How many links can there be between every pair of communicating processes?
- What is the capacity of a link?
- Is the size of a message that the link can accommodate fixed or variable?
- Is a link unidirectional or bi-directional?

Unix pipe(2)

- Point to point
- Unidirectional
- For processes related by birth (same machine)
- Reliable delivery
- Stream of bytes
- FIFO
- Virtually identical to reading and writing to a file (low level file I/O)

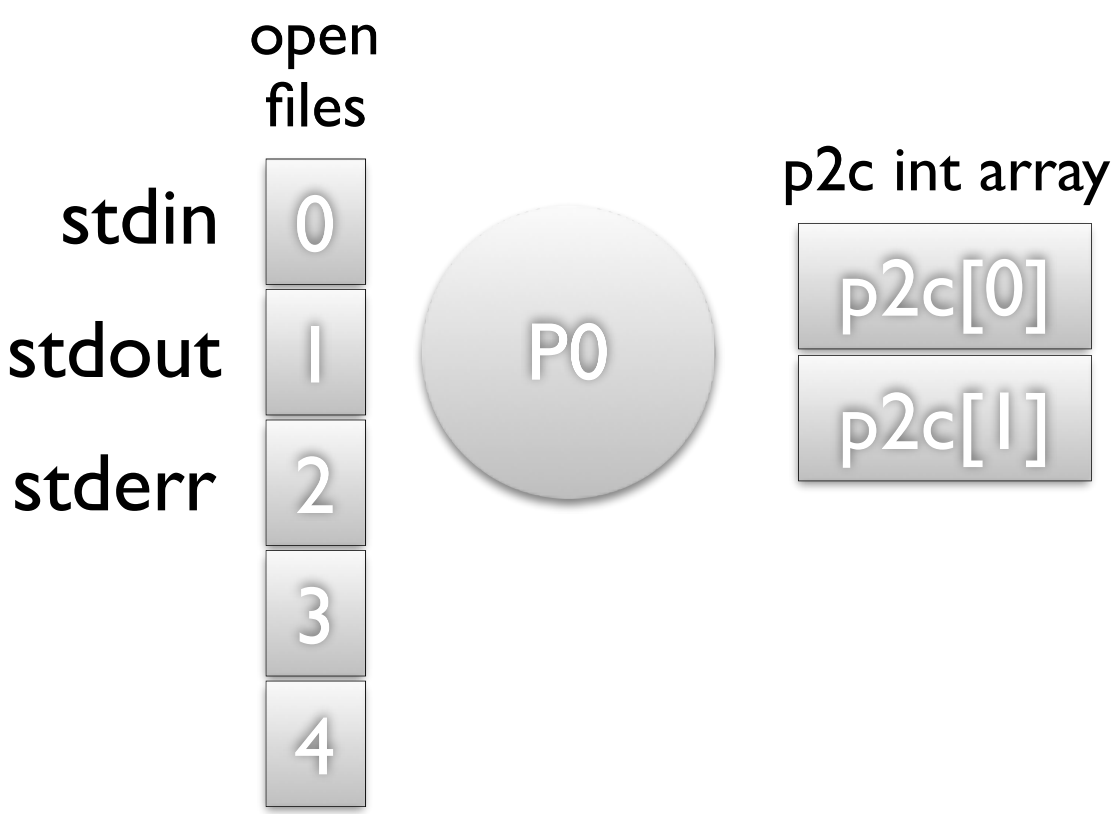
Unix pipe(2)

A process P0 is born



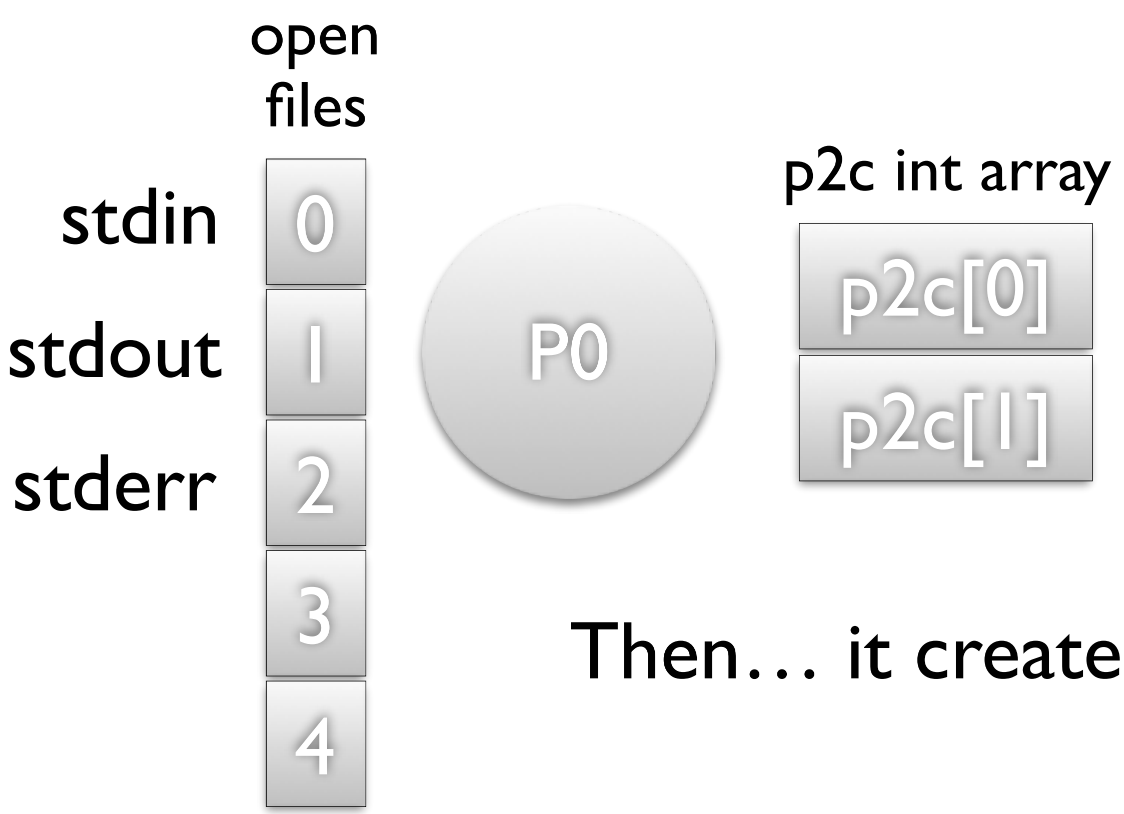
Before creating a child with whom it will communicate, it creates a pipe (system call).

Unix pipe(2)



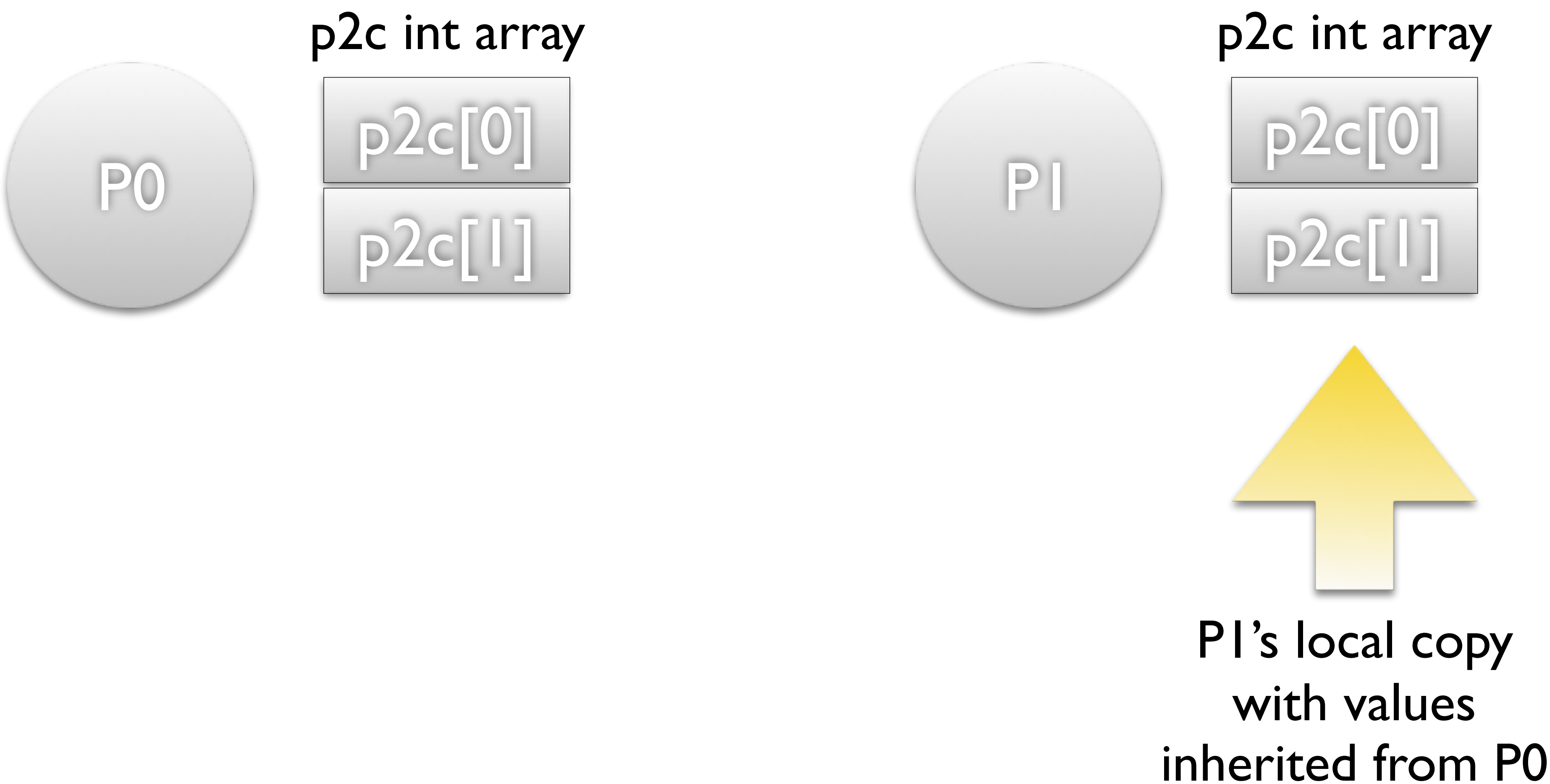
open
files
stdin
stdout
stderr
0
1
2
3
4
P0
p2c int array
p2c[0]
p2c[1]

Unix pipe(2)

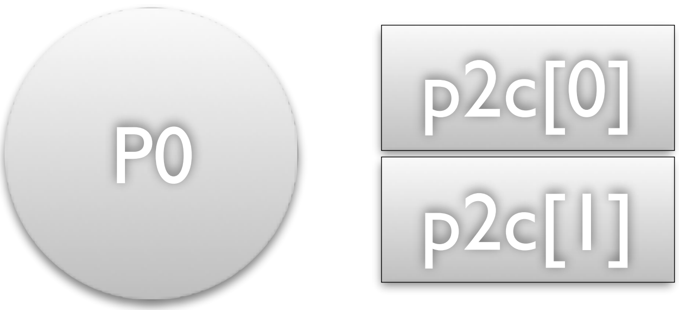


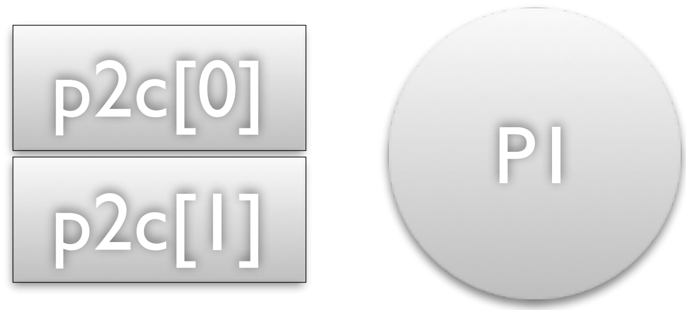
Then… it creates child P1 with fork

Unix pipe(2)


p2c int array
P0
p2c[0]
p2c[1]
p2c int array
P1
p2c[0]
p2c[1]
P1's local copy
with values
inherited from P0

Unix pipe(2)

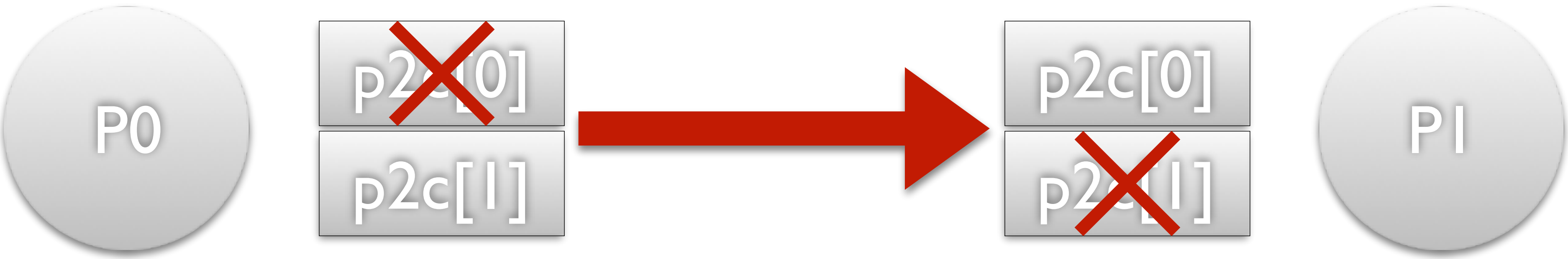




P0 closes the input end of the pipe (index 0)

P1 closes the output end of the pipe (index 1)

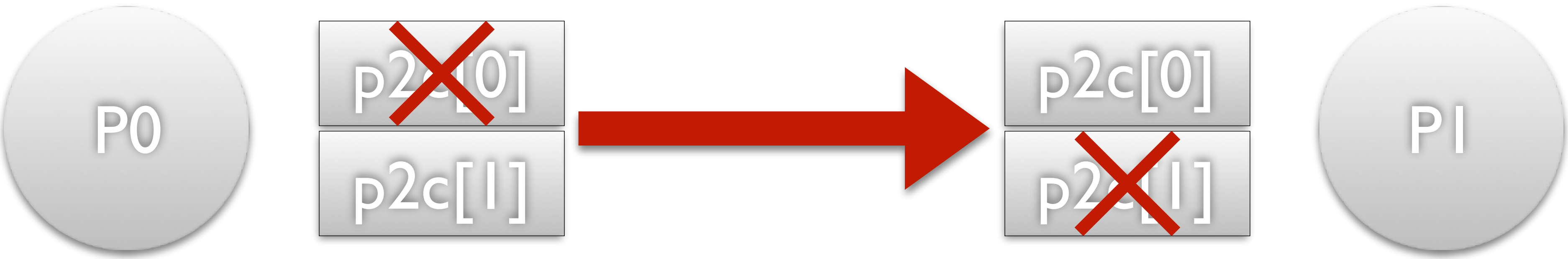
Unix pipe(2)



P0 closes the input end of the pipe (index 0)

P1 closes the output end of the pipe (index 1)

Unix pipe(2)



P0 writes to file descriptor p2c[1]

write(2)

P1 reads from file descriptor p2c[0]

read(2)

IPC Mechanisms

- File
- Pipe
- Named pipe
- Shared memory
- Message passing
- Mailbox
- Remote procedure calls
- Sockets (TCP, datagram)

- What are the properties of each?
- What are the advantages and disadvantages of each?
- How do you select one to use?

Direct Communication

- Processes must name each other explicitly:
  - **send** (*P, message*) – send a message to process P
  - **receive**(*Q, message*) – receive a message from process Q

- Properties of communication link
  - Links are established automatically
  - A link is associated with exactly one pair of communicating processes
  - Between each pair there exists exactly one link
  - The link may be unidirectional, but is usually bi-directional

Indirect Communication

- Messages are directed and received from mailboxes (also referred to as ports)
  - Each mailbox has a unique id
  - Processes can communicate only if they share a mailbox
- Properties of communication link
  - Link established only if processes share a common mailbox
  - A link may be associated with many processes
  - Each pair of processes may share several communication links
  - Link may be unidirectional or bi-directional

Indirect Communication

- Operations:
  - create a new mailbox,
  - send and receive messages through mailbox,
  - destroy a mailbox.
- Primitives are defined as:

send(*A*, *message*) – send a message to mailbox A,

receive(*A*, *message*) – receive a message from mailbox A.

Indirect Communication

- Mailbox sharing
  - P_1, P_2, and P_3 share mailbox A
  - P_1, sends; P_2 and P_3 receive
  - Who gets the message?
- Solutions
  - Allow a link to be associated with at most two processes
  - Allow only one process at a time to execute a receive operation
  - Allow the system to select arbitrarily the receiver. Sender is notified who the receiver was.