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CIS 415: Operating Systems

Processes

Prof. Kevin Butler

Spring 2014

- Last class:
  - Operating system structure
- Today:
  - More basics, system calls, Process Management

Administrivia

- Lab sections: everyone should know where you're going
  - this week: debugging
- Assignment 1: due April 22
- Project 1: out today, due April 24
- Manage your time wisely!

Process Address Space

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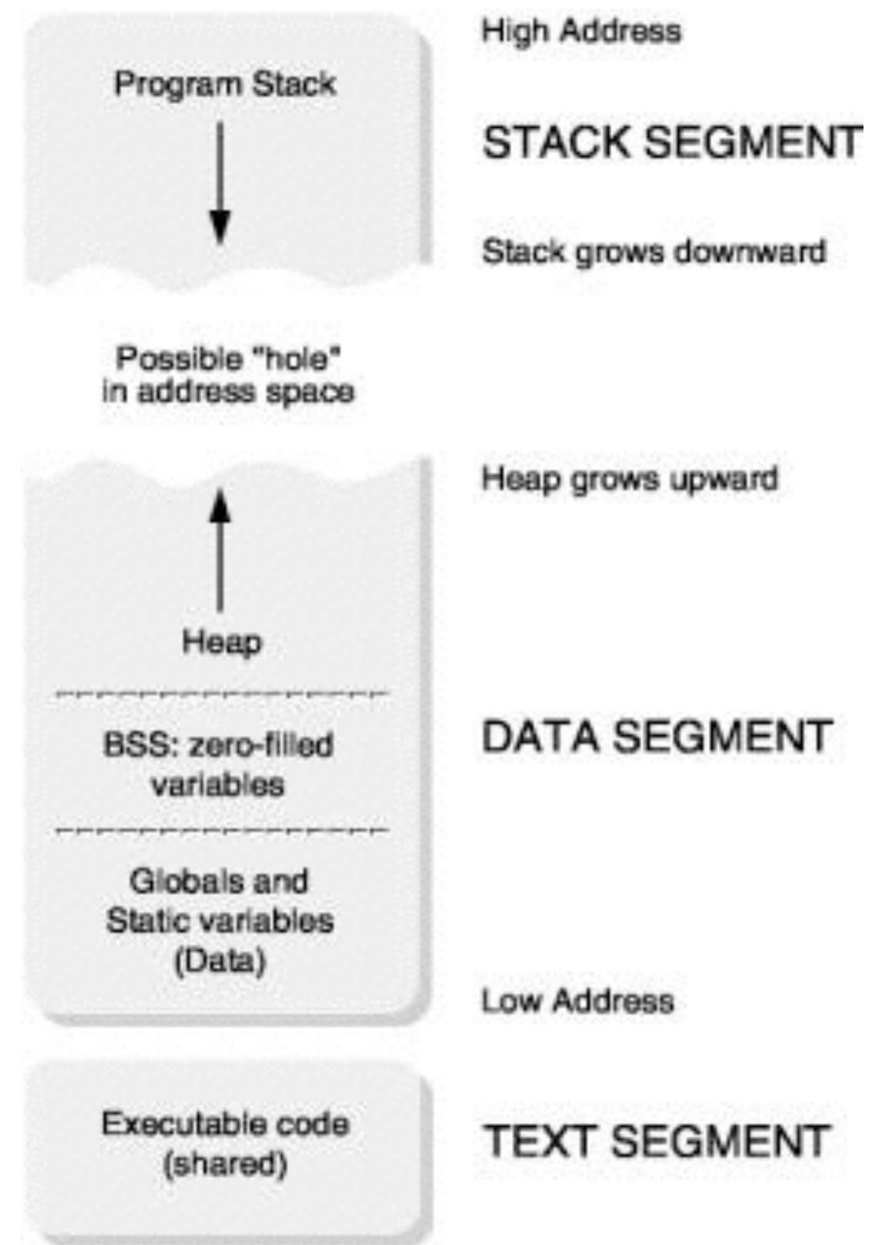
- All locations addressable by the process
- Can restrict use of addresses (RW)
- Restrictions enforced by OS
- Every running program can have its own private address space
  - How?



System Call Handling

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Procedure call in user process	
Initial work in user mode	*(libc)*
Trap instruction to invoke kernel	*(int 0x80)*
Preparation	*(e.g., sys_read, mmap2)*
I/O command	*(read from disk)*
Wait	*(disk is slow)*
Completion	*(interrupt handling)*
Return-from-interrupt instruction	
Final work in user mode	*(libc)*
Ordinary return instruction	

Details on x86 / Linux

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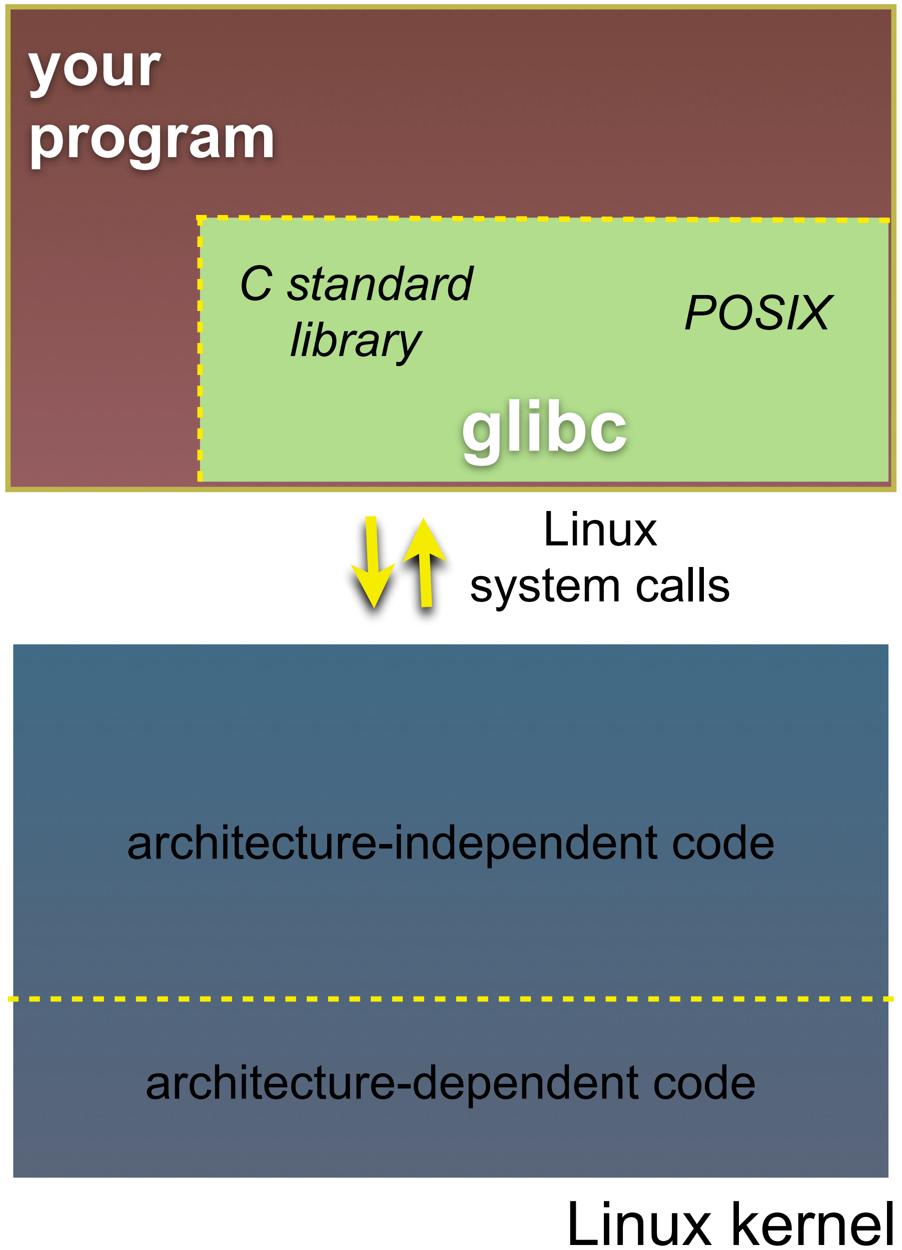
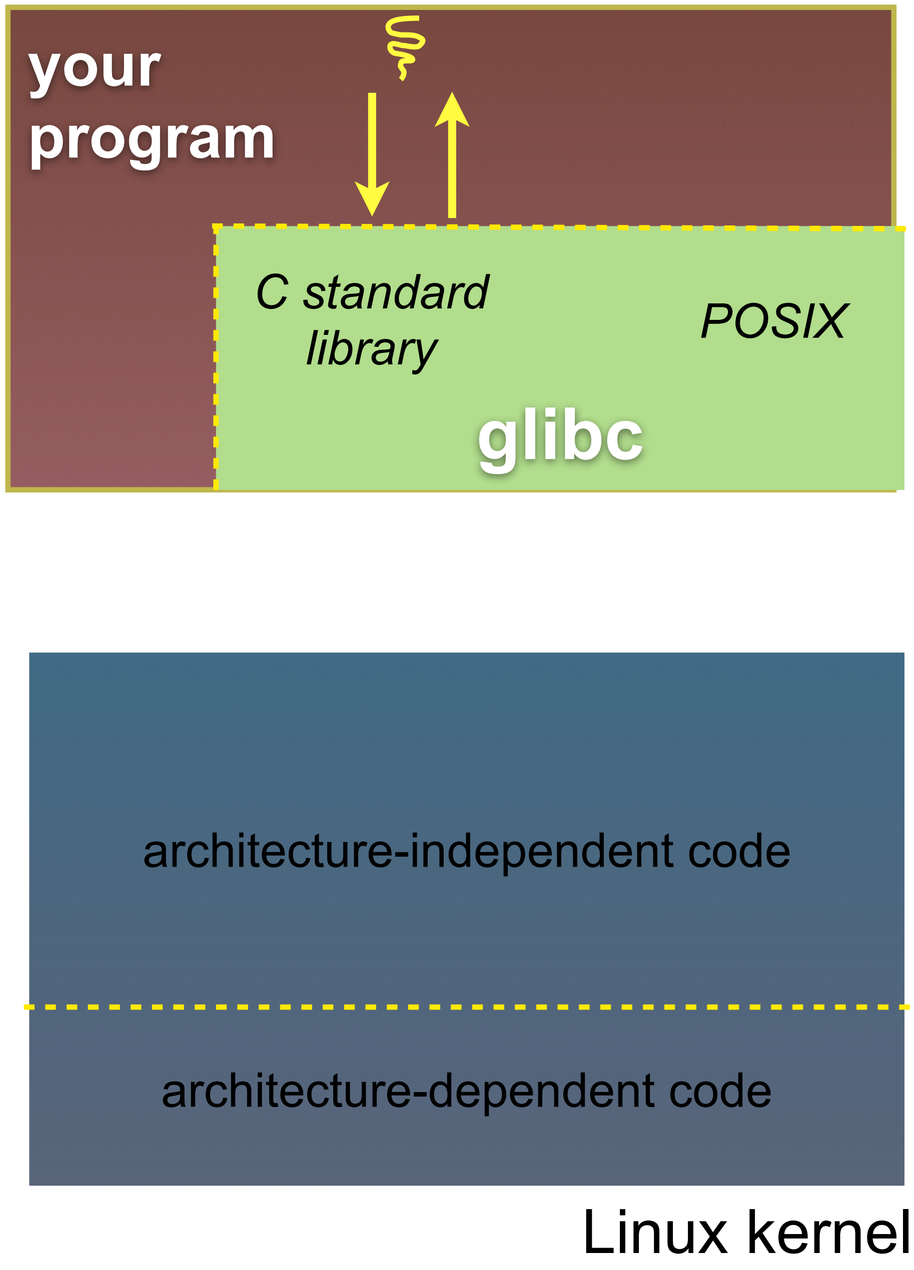
- A more accurate picture:
  - consider a typical Linux process
  - its thread of execution can be several places
    - in your program's code
    - in **glibc**, a shared library containing the C standard library, POSIX support, and more
    - in the Linux architecture-independent code
    - in Linux x86-32/x86-64 code



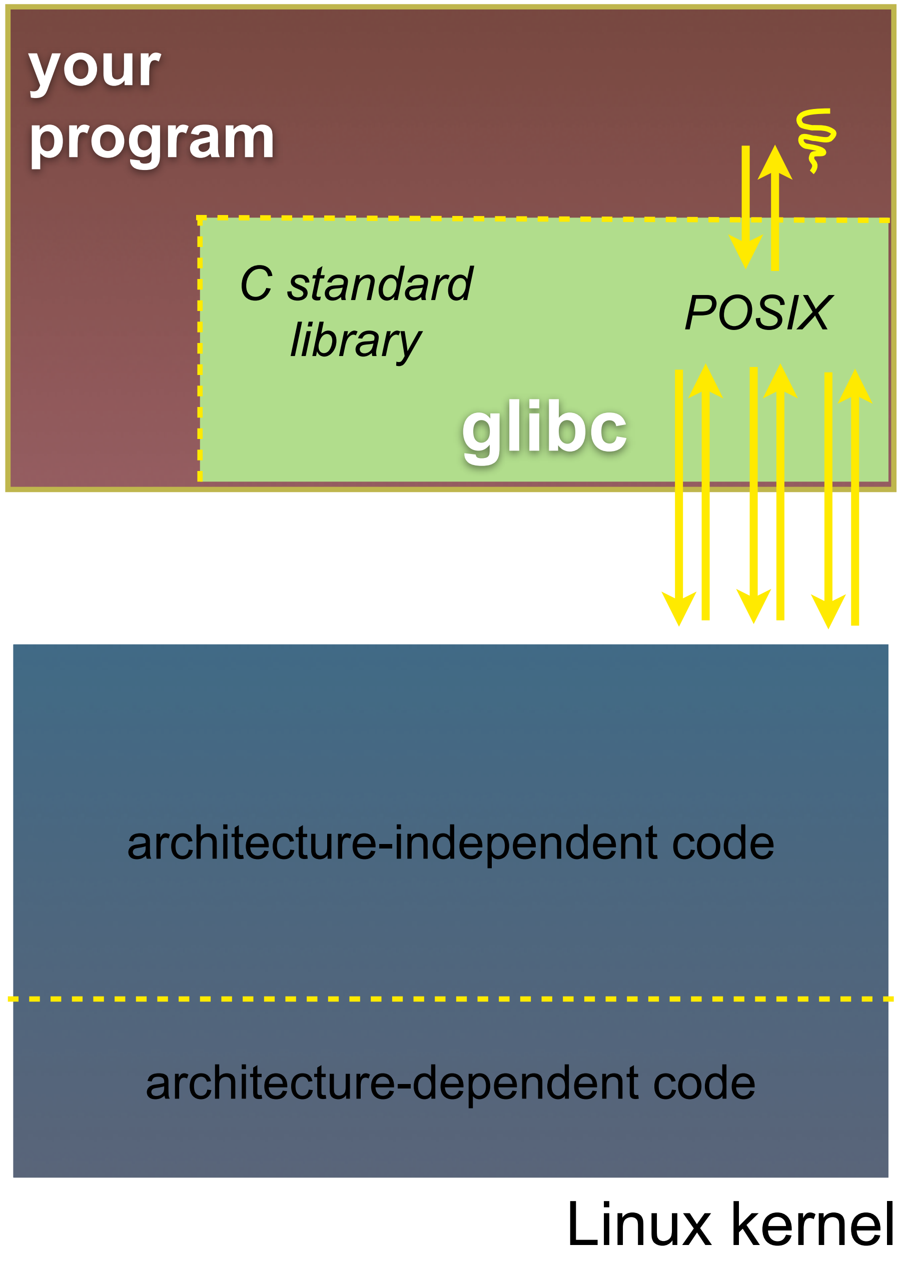
Details on x86 / Linux

- Some routines your program invokes may be entirely handled by glibc
  - without involving the kernel
    - e.g., **strcmp( )** from stdio.h
  - ∃ some initial overhead when invoking functions in dynamically linked libraries
  - but, after symbols are resolved, invoking glibc routines is nearly as fast as a function call within your program itself



Details on x86 / Linux

- Some routines may be handled by glibc, but they in turn invoke Linux system calls
  - e.g., POSIX wrappers around Linux syscalls
    - POSIX readdir( ) invokes the underlying Linux readdir( )
  - e.g., C stdio functions that read and write from files
    - fopen( ), fclose( ), fprintf( ) invoke underlying Linux open( ), read( ), write( ), close( ), etc.



Details on x86 / Linux

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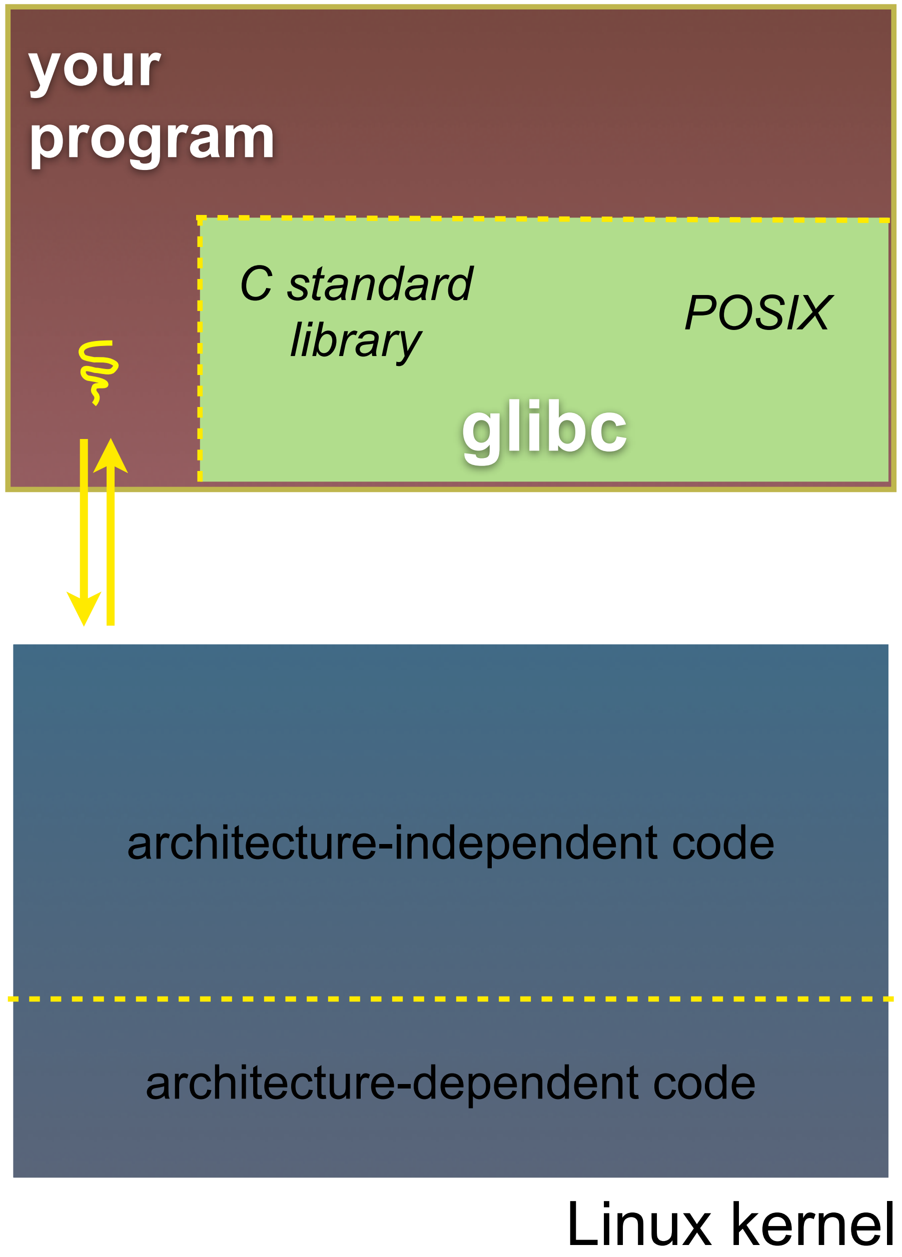
- Your program can choose to directly invoke Linux system calls as well
  - nothing forces you to link with glibc and use it
  - but, relying on directly invoked Linux system calls may make your program less portable across UNIX varieties



File Interface

- Goal: Provide a uniform abstraction for accessing the OS and its resources
- Abstraction: File
  - Use file system calls to access OS services
  - Devices, sockets, pipes, etc.
  - And OS in general

I/O with System Calls

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- Much I/O is based on a streaming model
  - sequence of bytes
- `write()` sends a stream of bytes somewhere
- `read()` blocks until a stream of input is ready
- Annoying details:
  - might fail, can block for a while
  - file descriptors...
  - arguments are pointers to character buffers
  - see the read() and write() man pages

File Descriptors

- A process might have several different I/O streams in use at any given time
- These are specified by a kernel data structure called a *file descriptor*
  - each process has its own table of file descriptors
- `open()` associates a file descriptor with a file
- `close()` destroys a file descriptor
- Standard input and standard output are usually associated with a terminal
  - more on that later

Regular File

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- File has a pathname: /tmp/foo
- Can open the file
  - int fd = open(“/tmp/foo”, O_RDWR)
  - For reading and writing
- Can read from and write to the file
  - bytes = read(fd, buf, max); /* buf get output */
  - bytes = write(fd, buf, len); /* buf has input */

flags for read/write access

pointer to buffer

Socket File

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- File has a pathname: /tmp/bar
  - Files provide a persistence for a communication channel
  - Usually used for local communication (UNIX domain sockets)
- Open, read, and write via socket operations
  - sockfd = socket(AF_UNIX, TCP_STREAM, 0);
  - local.path is set to /tmp/bar
  - bind (sockfd, &local, len)
  - Use sock operations to read and write

Device File

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- Files for interacting with physical devices
  - /dev/null (do nothing)
  - /dev/cdrom (CD-drive)
- Use file system operations, but are handled in device-specific ways
  - `open`, `read`, `write` correspond to device-specific functions
    - Function pointers!
  - Also, use `ioctl` (I/O control) to interact (later)

Sysfs File and `/proc` Files

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- These files enable reading from and writing to kernel
- `/proc` files
  - enable reading of kernel state for a process
- Sysfs files
  - Provide functions that update kernel data
    - File's `write` function updates kernel based on input data

Other System Calls

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- It’s possible to hook the output of one program into the input of another: `pipe()`
- It’s possible to block until one of several file descriptor streams is ready: `select()`
- Special calls for dealing with network
  - `AF_INET` sockets, etc.
- Send a message to other (or all) processes: `signal()`
- Most of these in section 2 of manual
  - e.g., `man 2 select`

Syscall Functionality

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- System calls are the main interface between processes and the OS
  - like an extended "instruction set" for user programs that hide many details
  - first Unix system had a couple dozen system calls
  - current systems have many more (>300 in Linux, >500 in FreeBSD)
  - Understanding the system call interface of a given OS lets you write useful programs under it
- Natural questions to ask:
  - is this the right interface? how to evaluate?
  - how can these system calls be implemented?

Why Processes?

- We have programs, so why do we need processes?

Overview

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- Questions that we explore
  - How are processes created?
    - From binary program to process
  - How is a process represented and managed?
    - Process creation, process control block
  - How does the OS manage multiple processes?
    - Process state, ownership, scheduling
  - How can processes communicate?
    - Interprocess communication, concurrency, deadlock

Supervisor and User Modes

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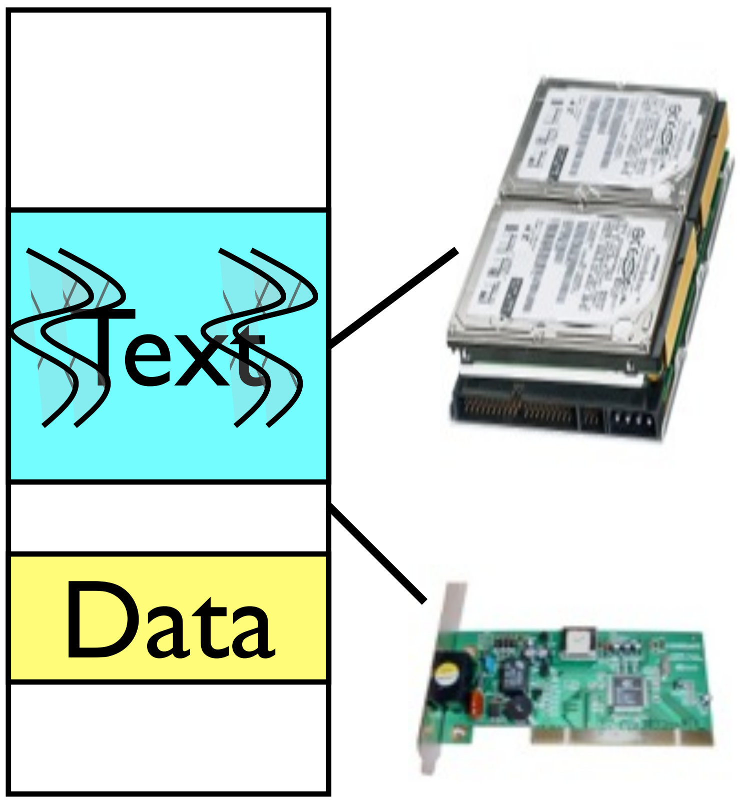
- OS runs in supervisor mode
  - Has access to protected instructions only available in that mode (ring 0)
  - Can manage the entire system
- OS loads processes into user mode
  - Many processes can run in user mode
- How does OS get programs loaded into processes in user mode and keep them straight?

Process

- Address space + threads + resources
- Address space contains code and data of a process
- Threads are individual execution contexts
- Resources are physical support necessary to run the process (memory, disk, …)



Process Address Space

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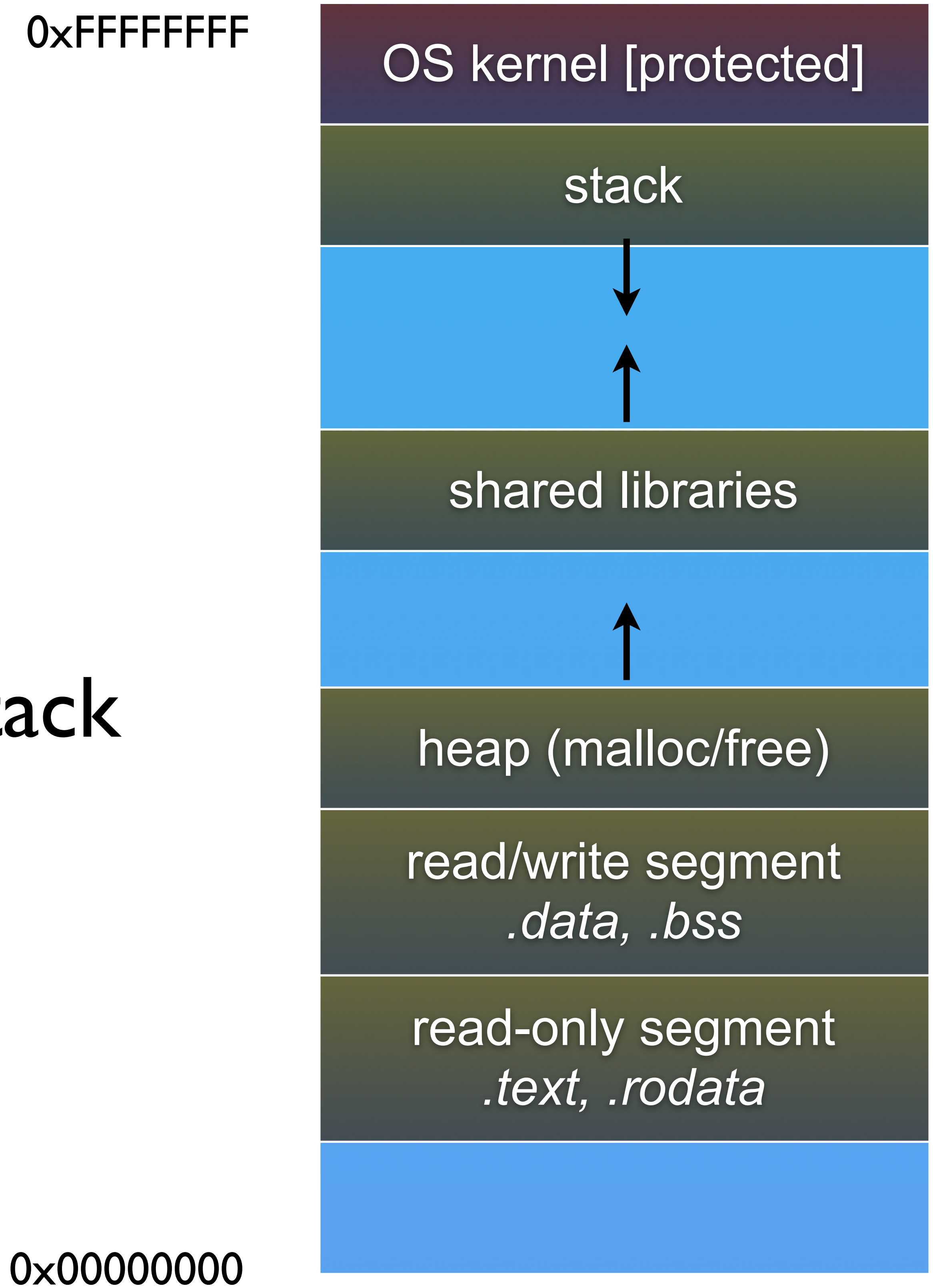
- Program (Text)
- Global Data (Data)
- Dynamic Data (Heap)
- Thread-local Data (Stack)
- Each thread has its own stack



Process Address Space

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```
int value = 5;                          Global

int main()
{
   int *p;                              Stack

   p = (int *)malloc(sizeof(int));      Heap

   if (p == 0) {
      printf("ERROR: Out of memory\n”);
      return 1;
   }

   *p = value;
   printf("%d\n", *p);
   free(p);
   return 0;
}
```

Heap + stack


```c
#include <stdlib.h>

int *copy(int a[], int size) {
  int i, *a2;

  a2 = malloc(
    size * sizeof(int));
  if (a2 == NULL)
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  for (i = 0; i < size; i++)
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}

int main(...) {
  int nums[4] = {2,4,6,8};
  int *ncopy = copy(nums, 4);
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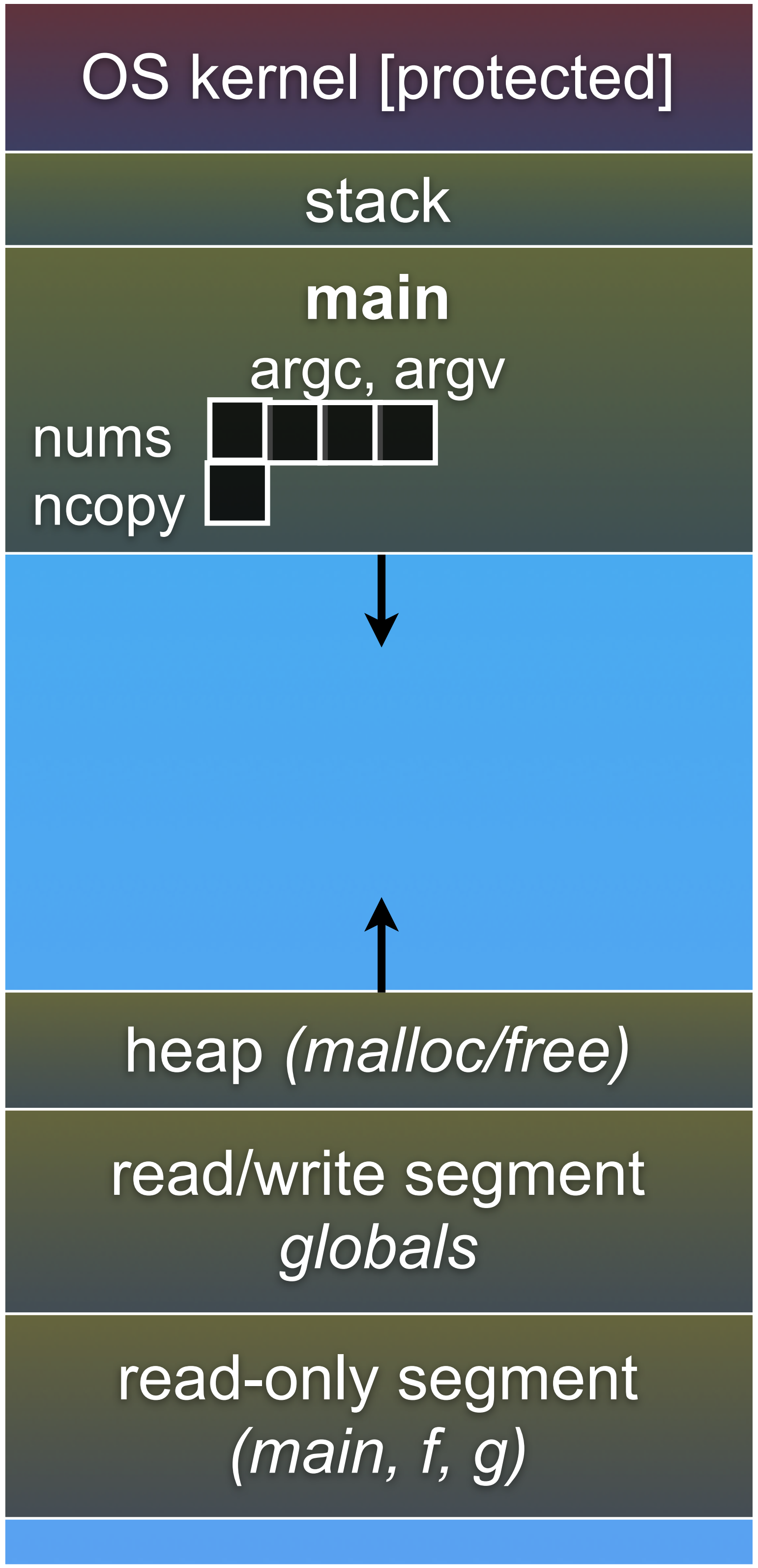

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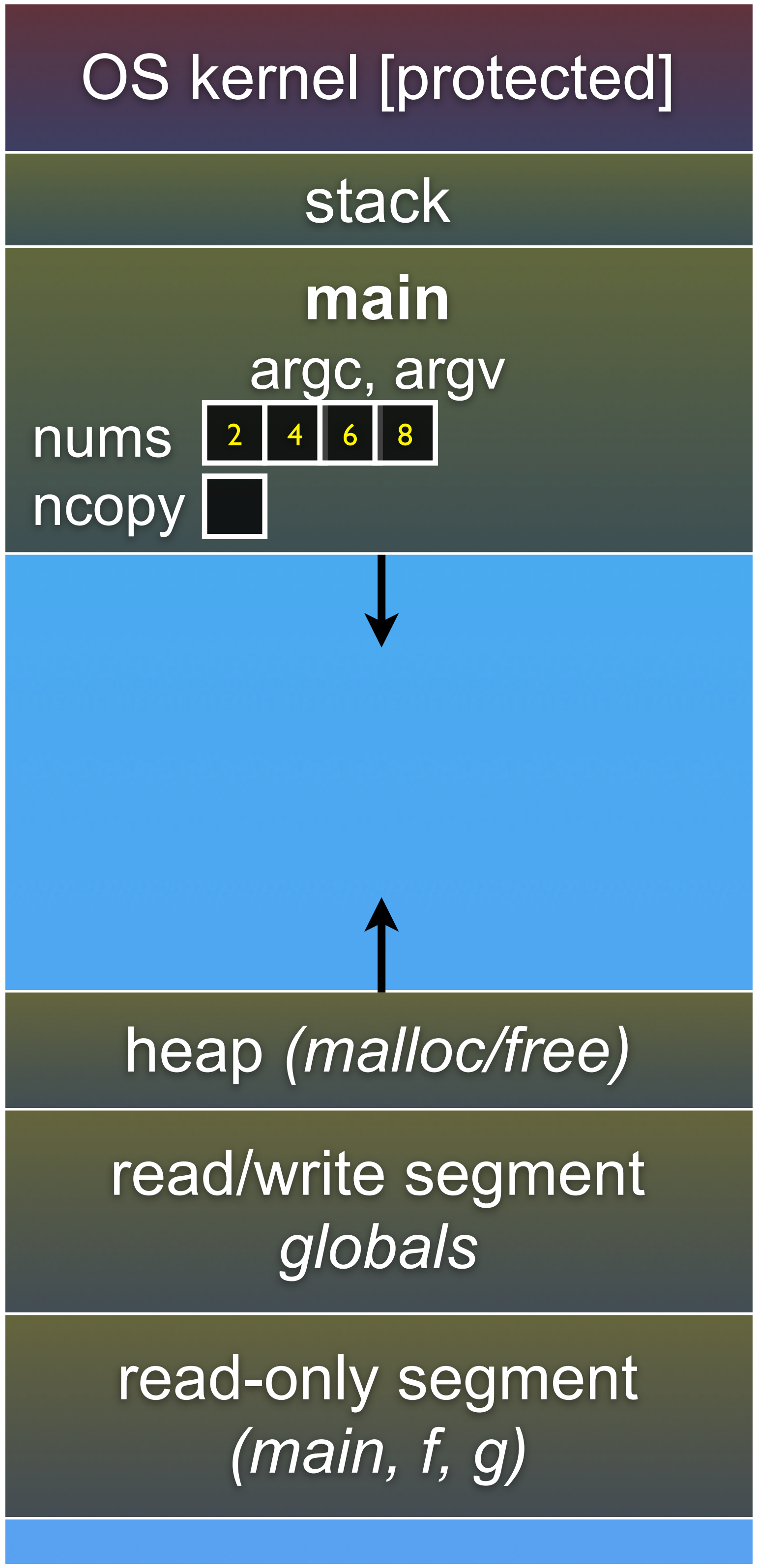

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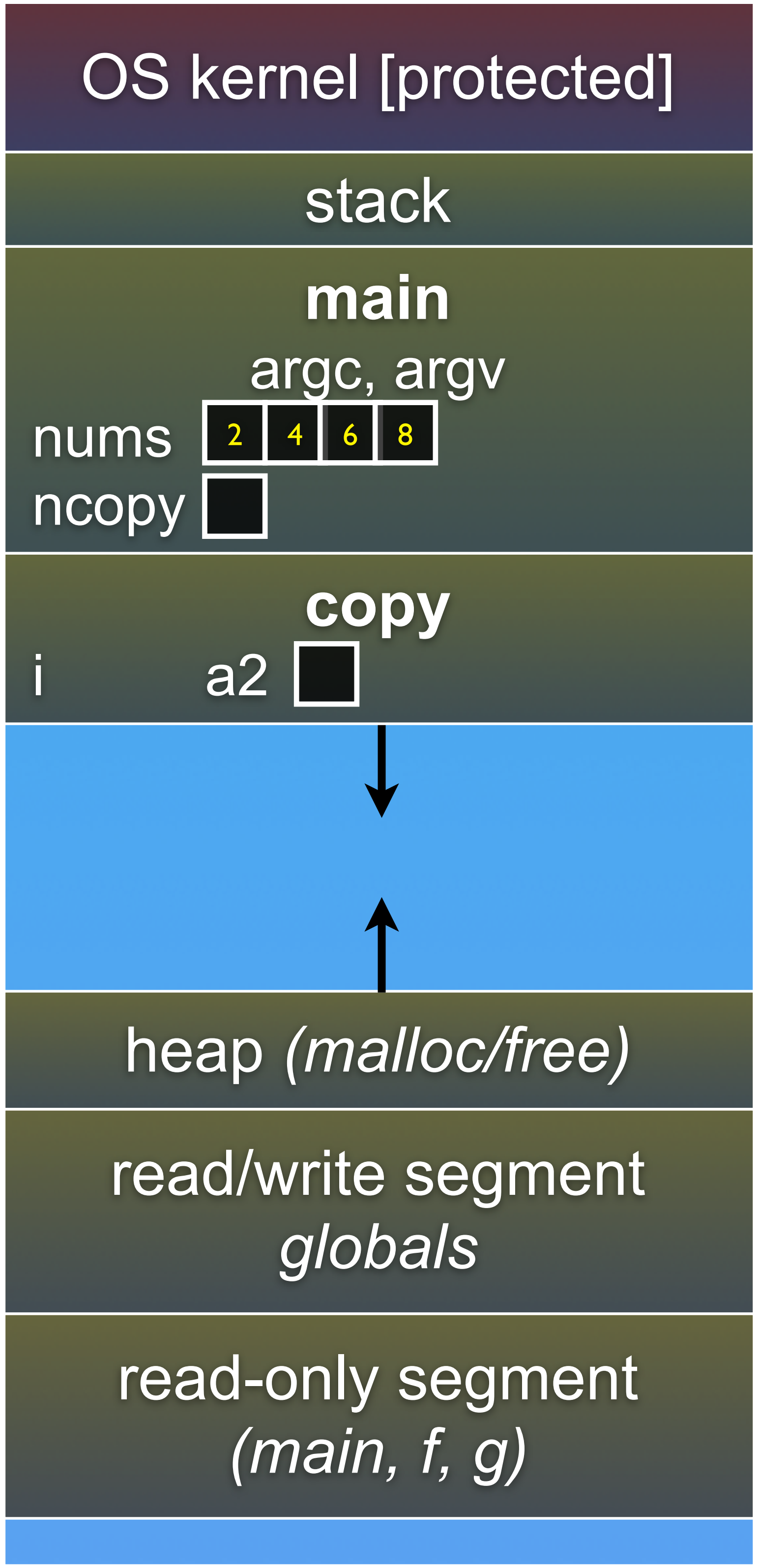

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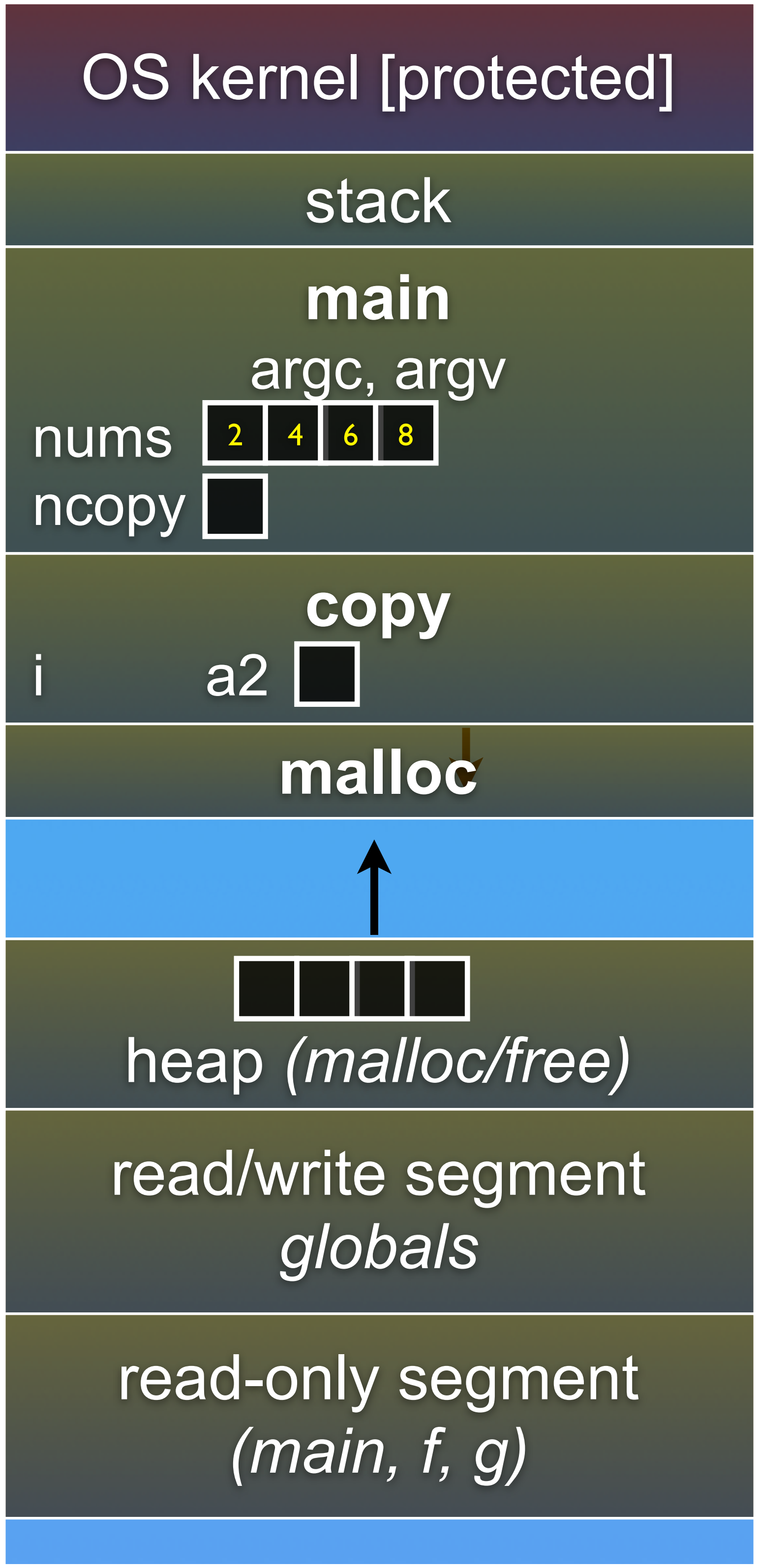

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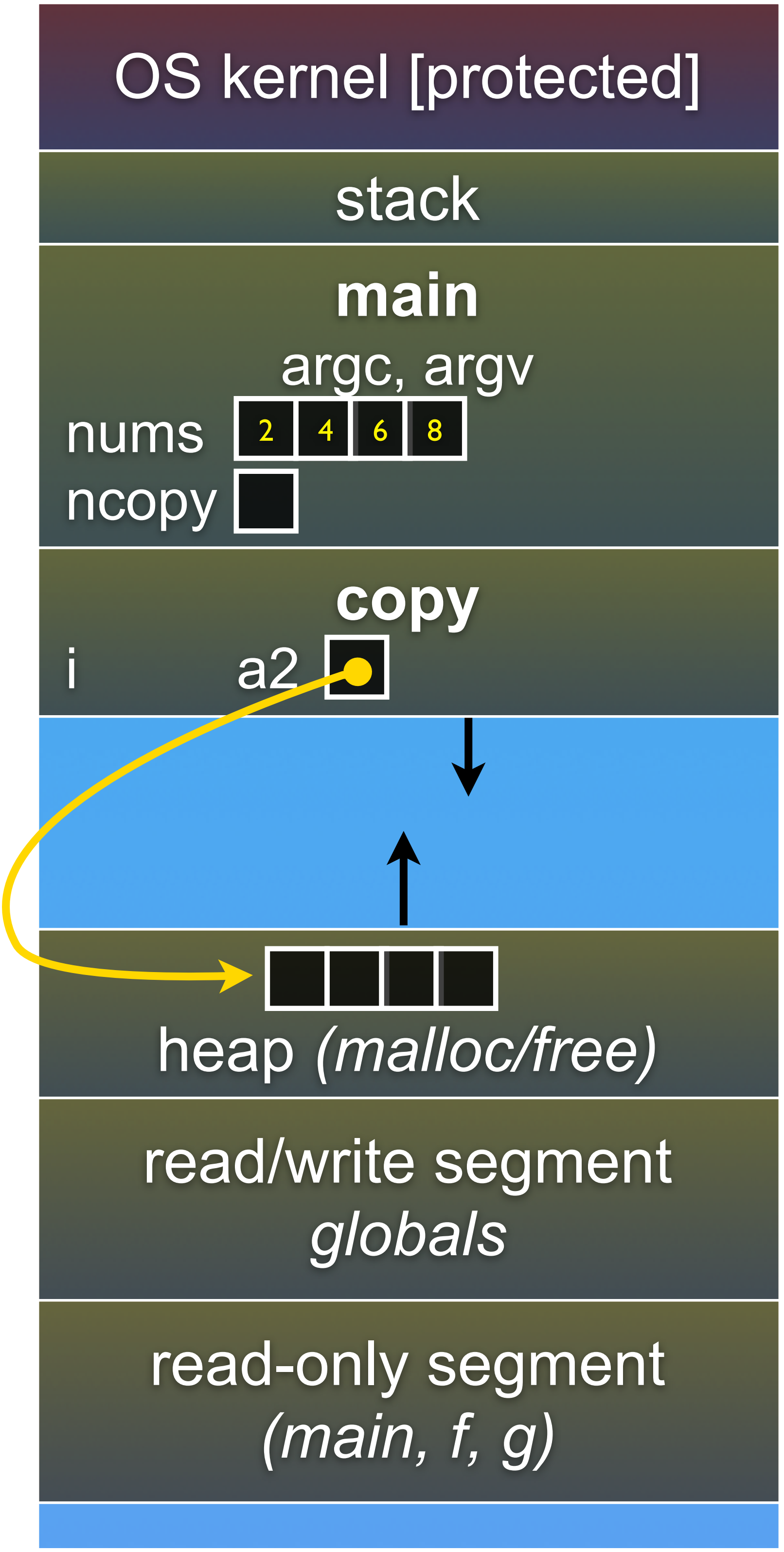

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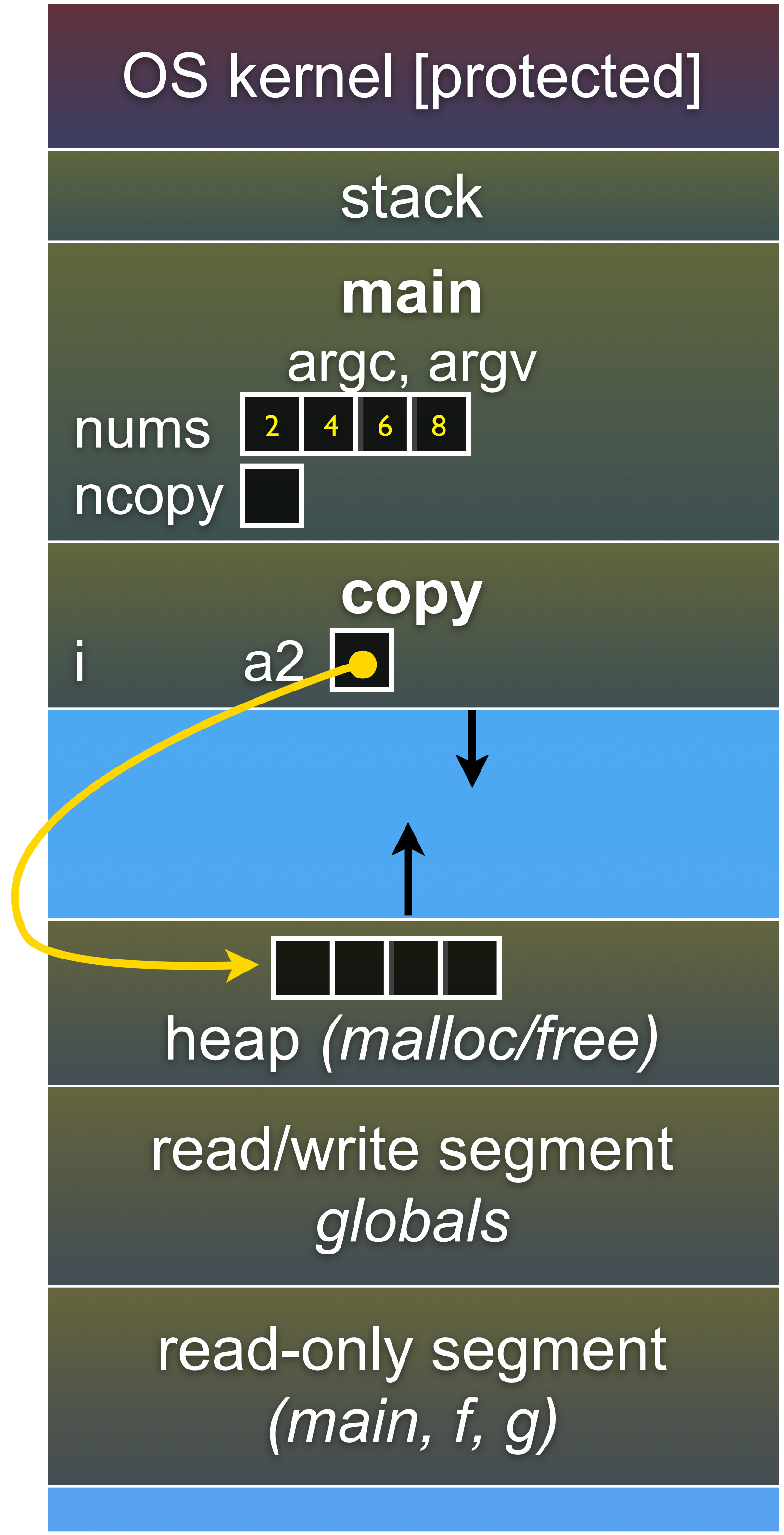

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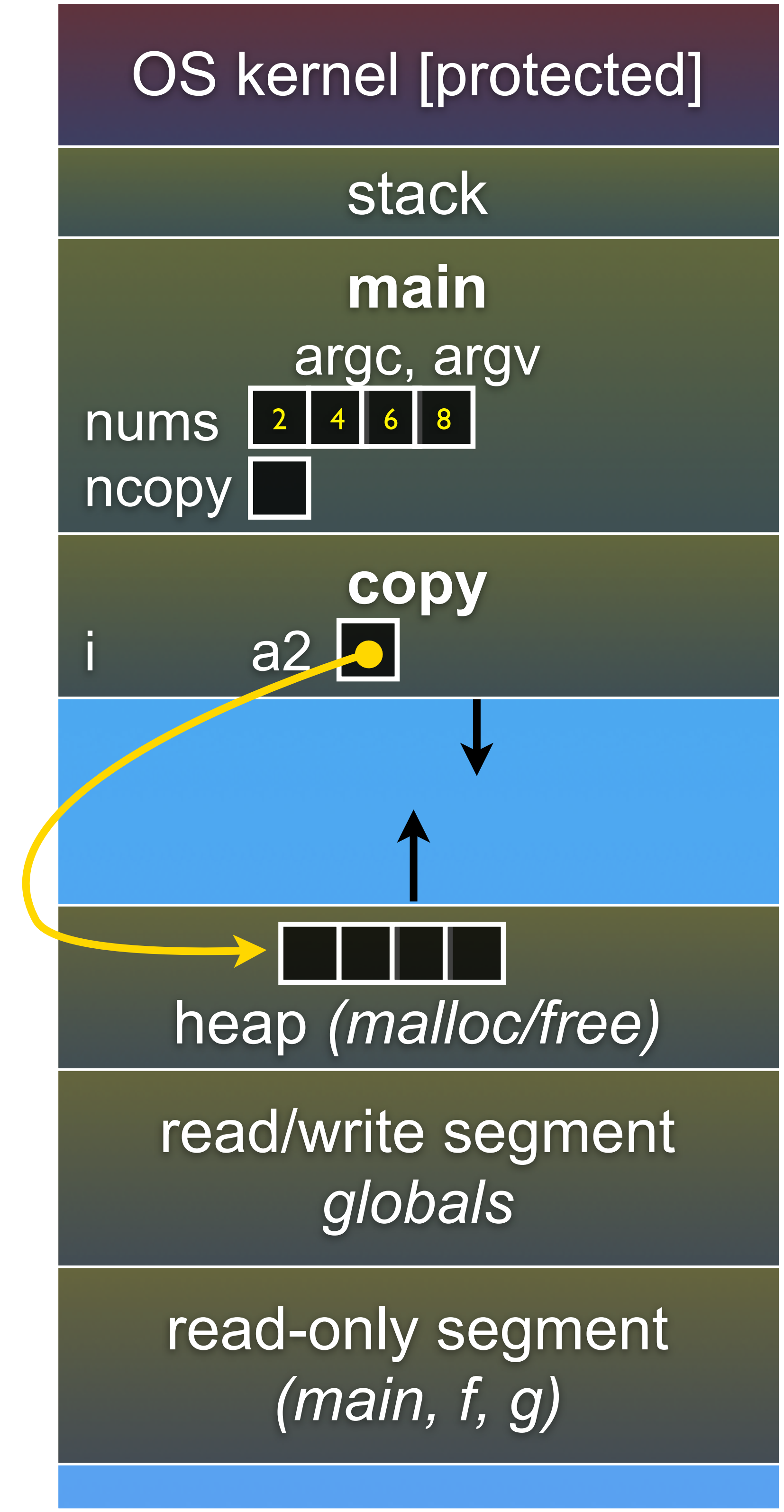

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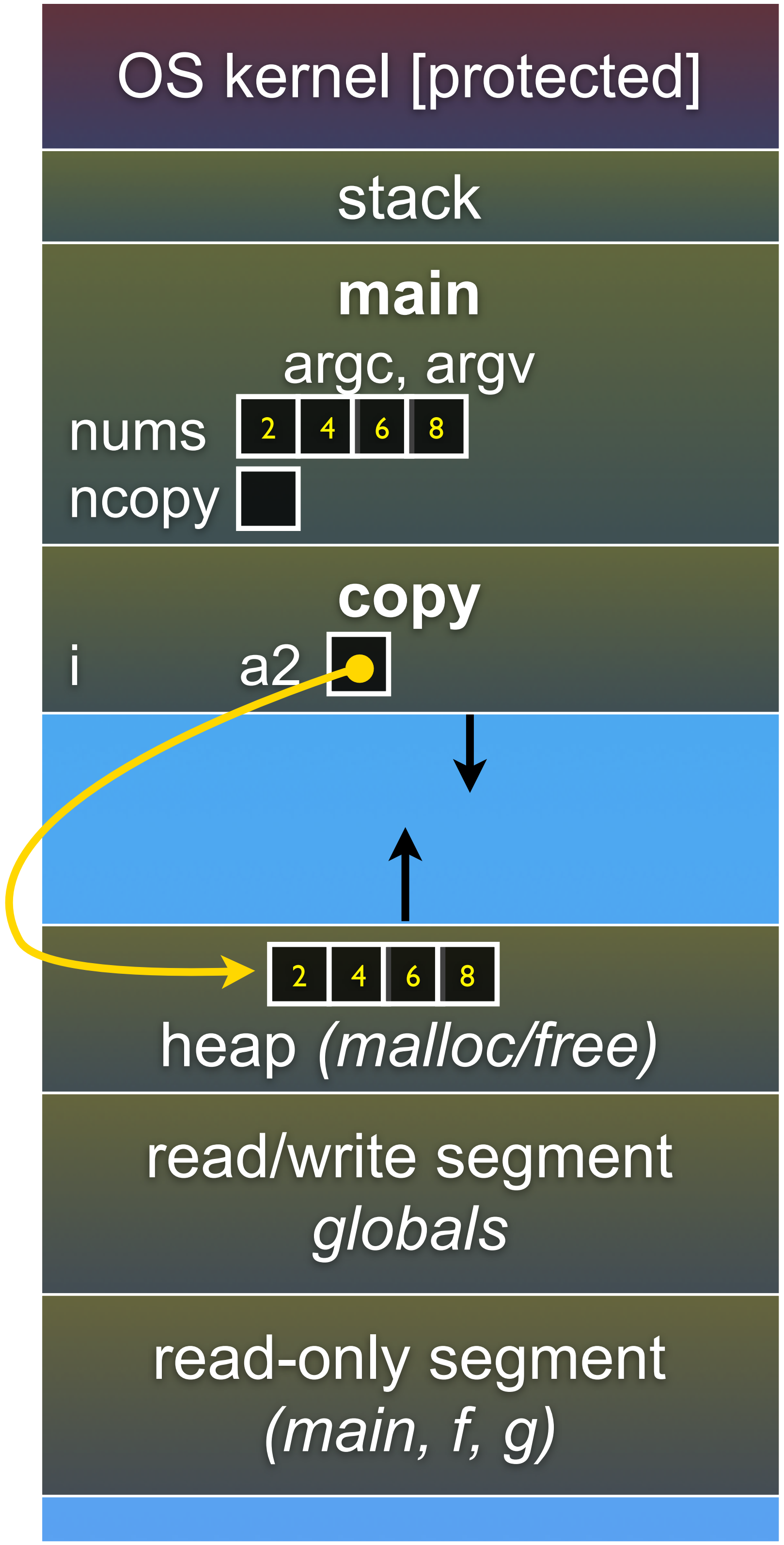

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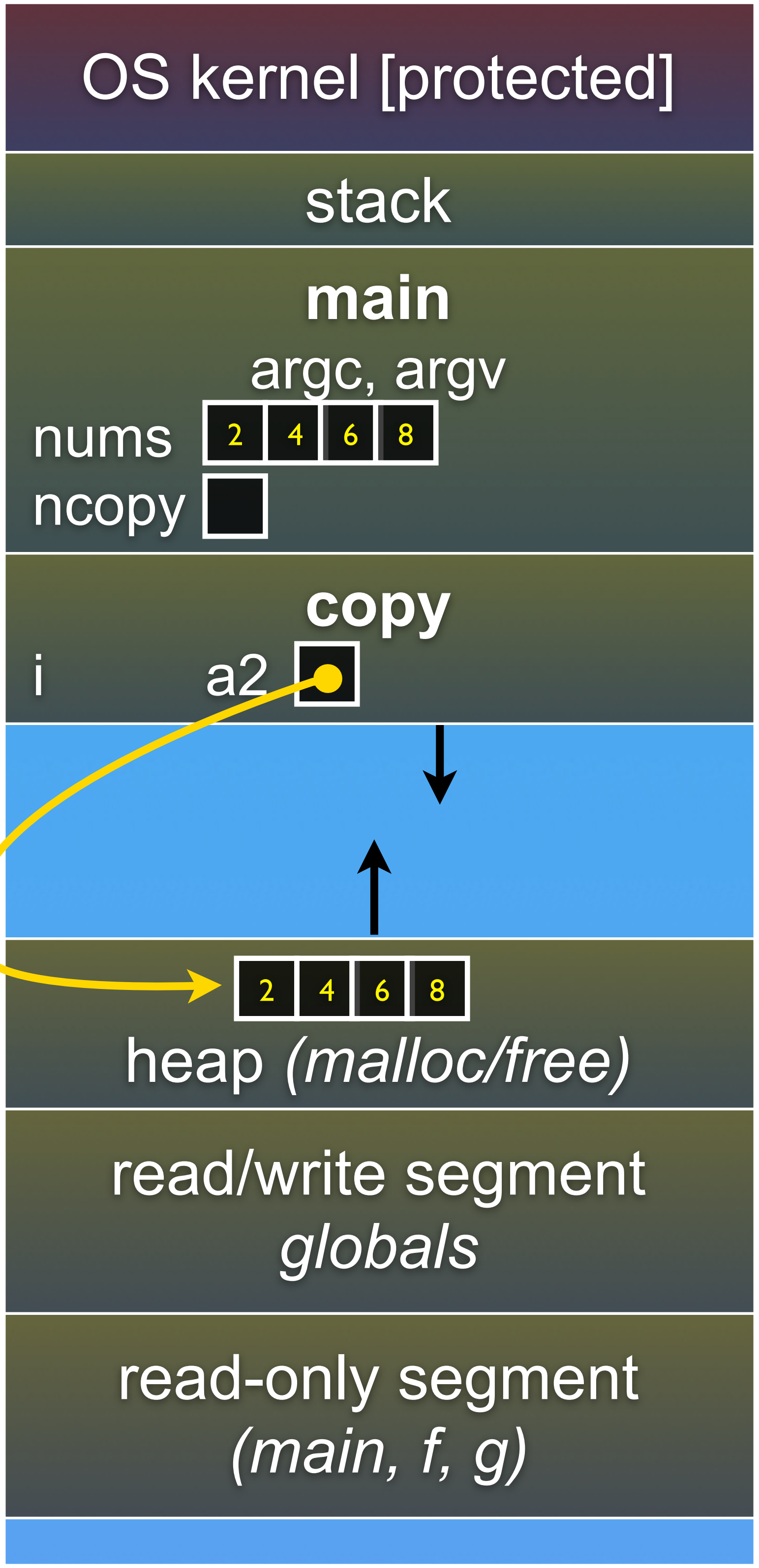

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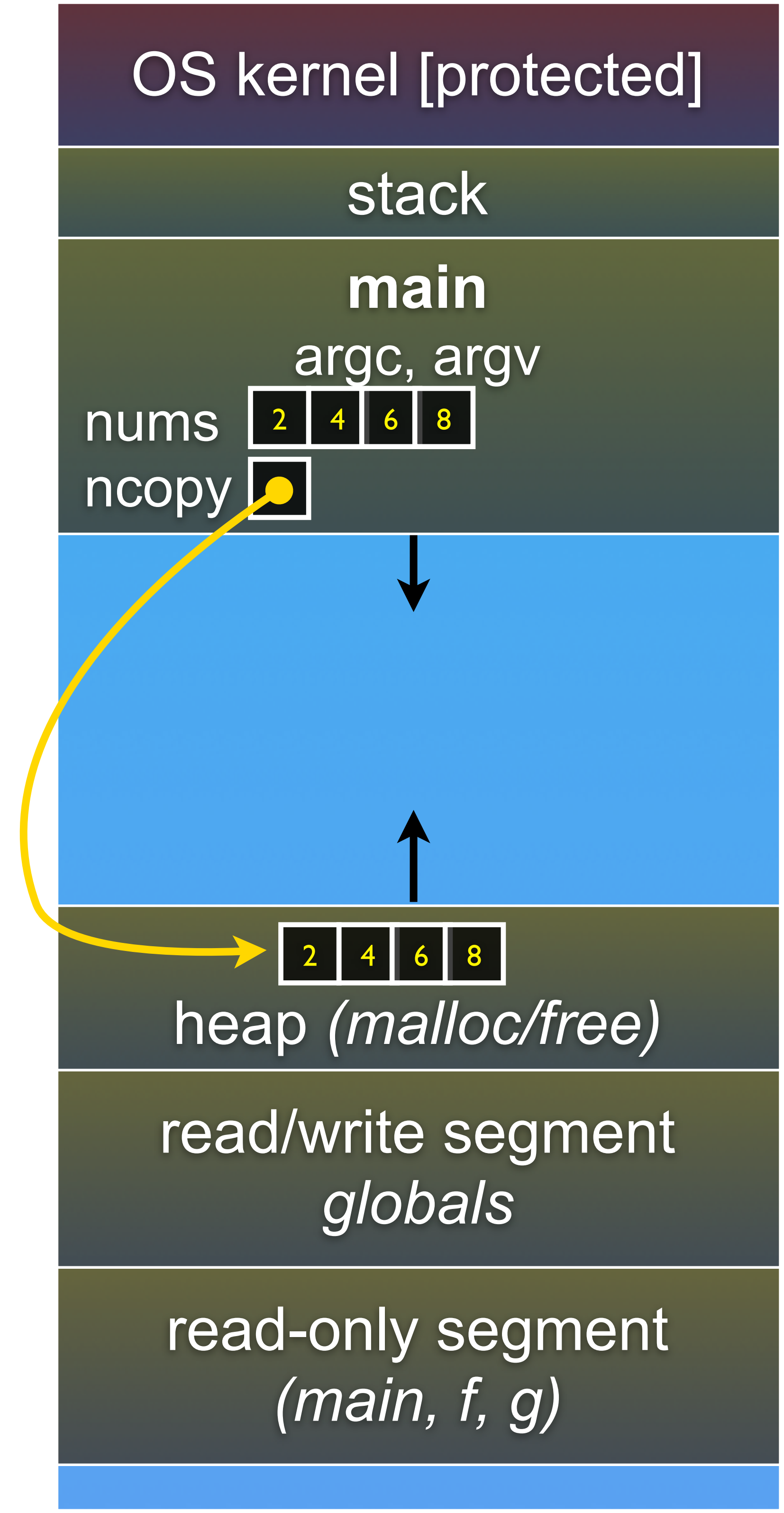

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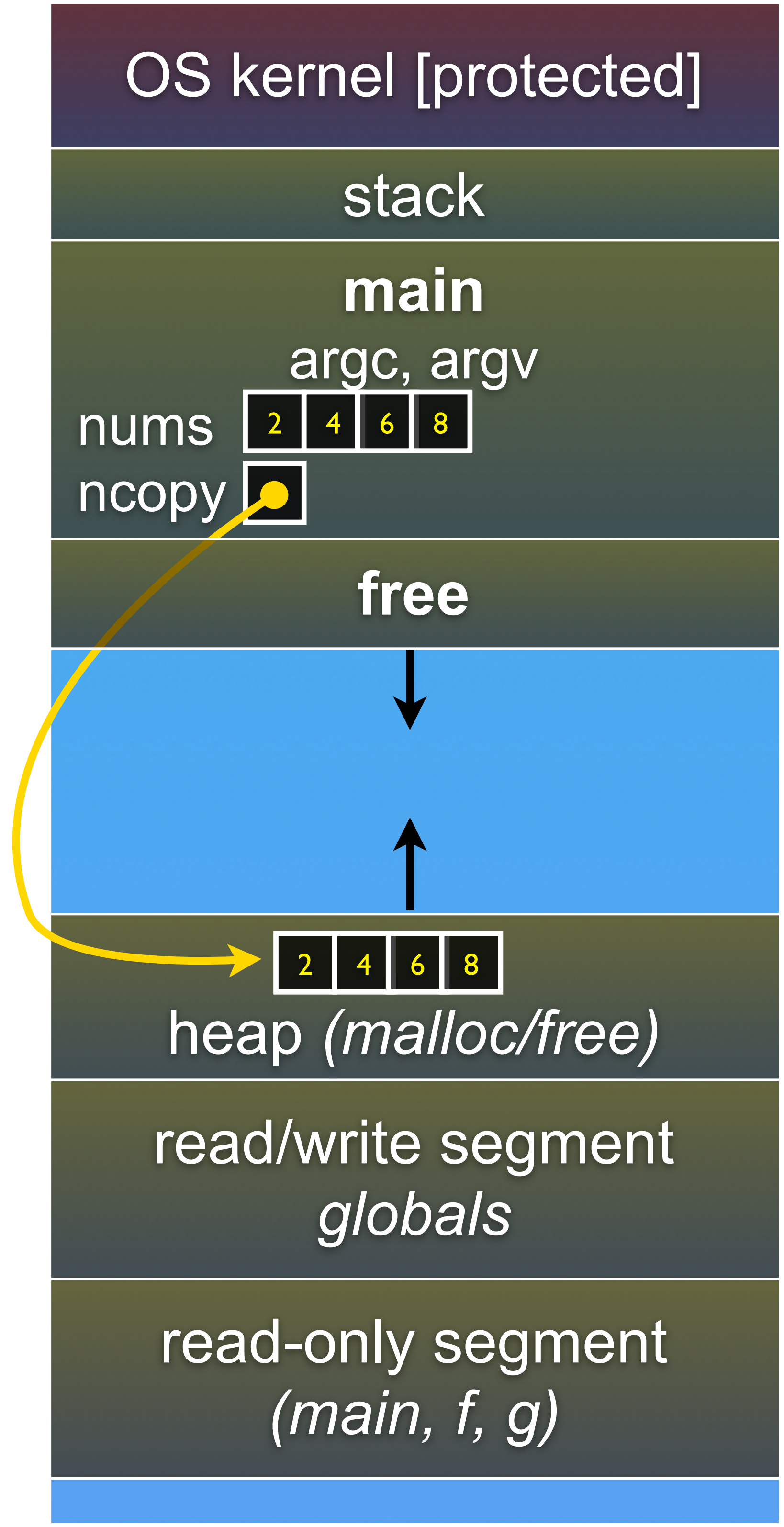

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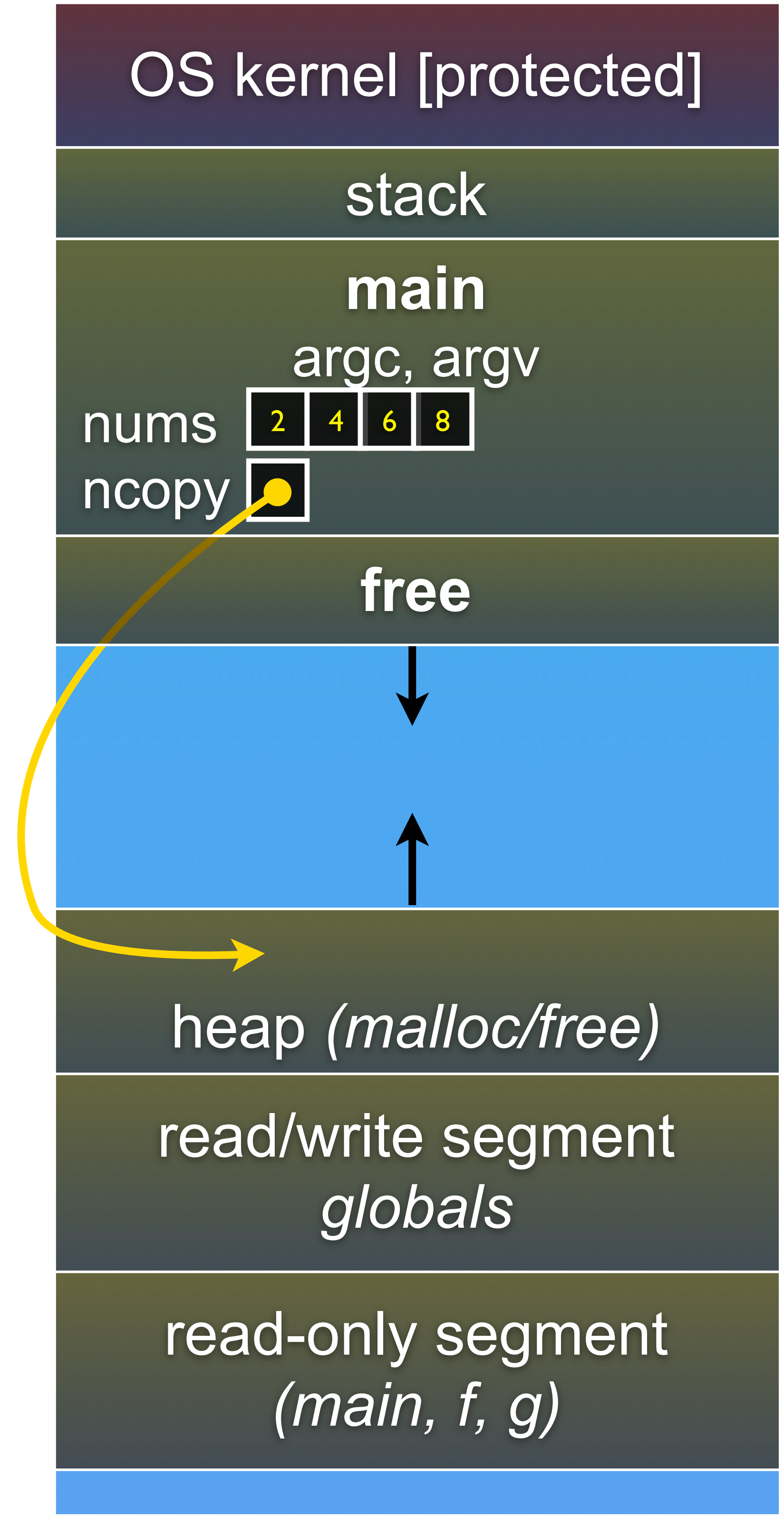

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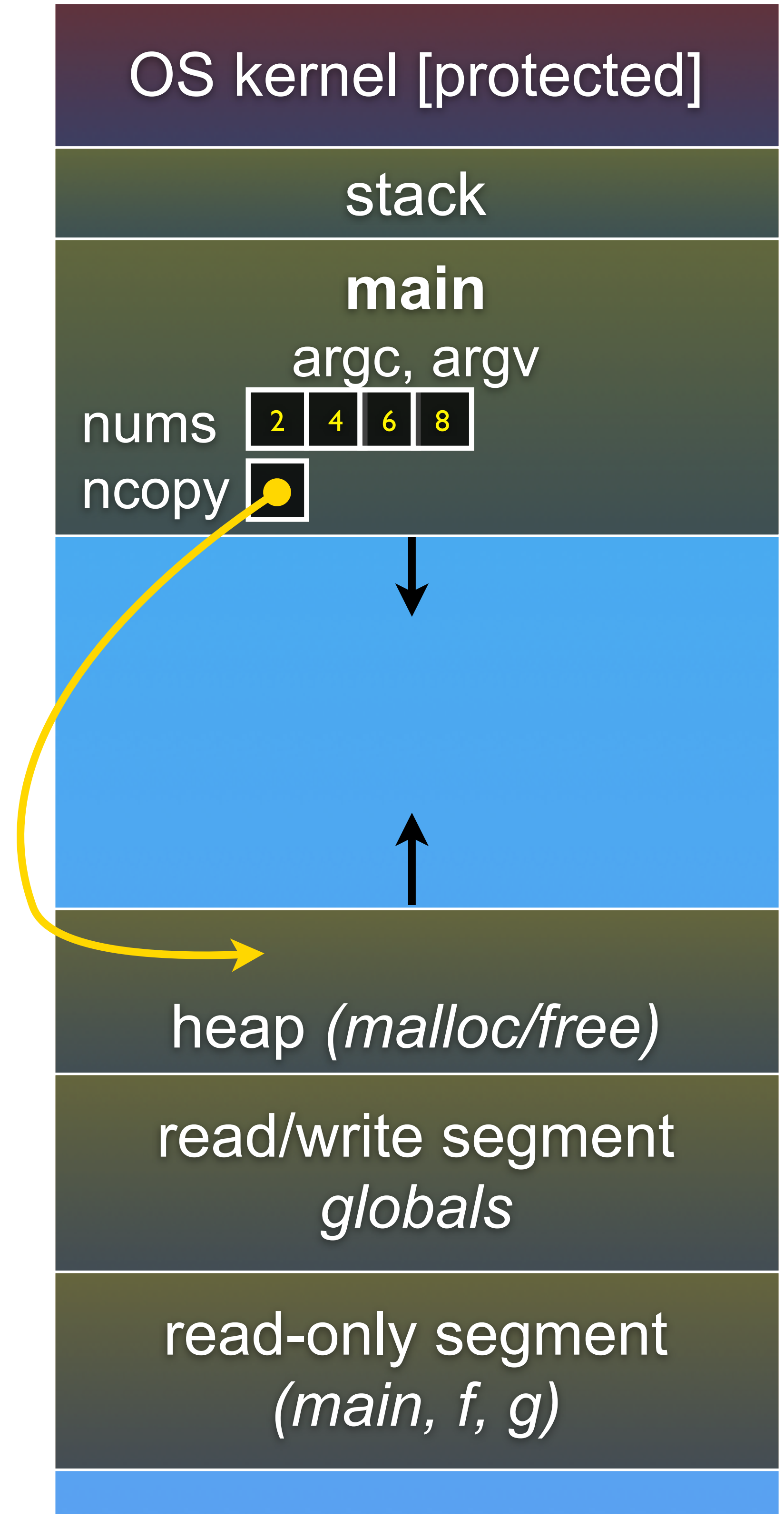

Process Creation

- Parent process create children processes,
  - which, in turn create other processes, forming a tree of processes
- Resource sharing options
  - Parent and children share all resources
  - Children share subset of parent's resources
  - Parent and child share no resources
- Execution options
  - Parent and children execute concurrently
  - Parent waits until children terminate

Process Creation

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- Address space
  - Child duplicate of parent
  - Child has a program loaded into it
- UNIX examples
  - `fork` system call creates new process
  - `exec` system call used after a fork to replace the process's memory space with a new program

Process Creation

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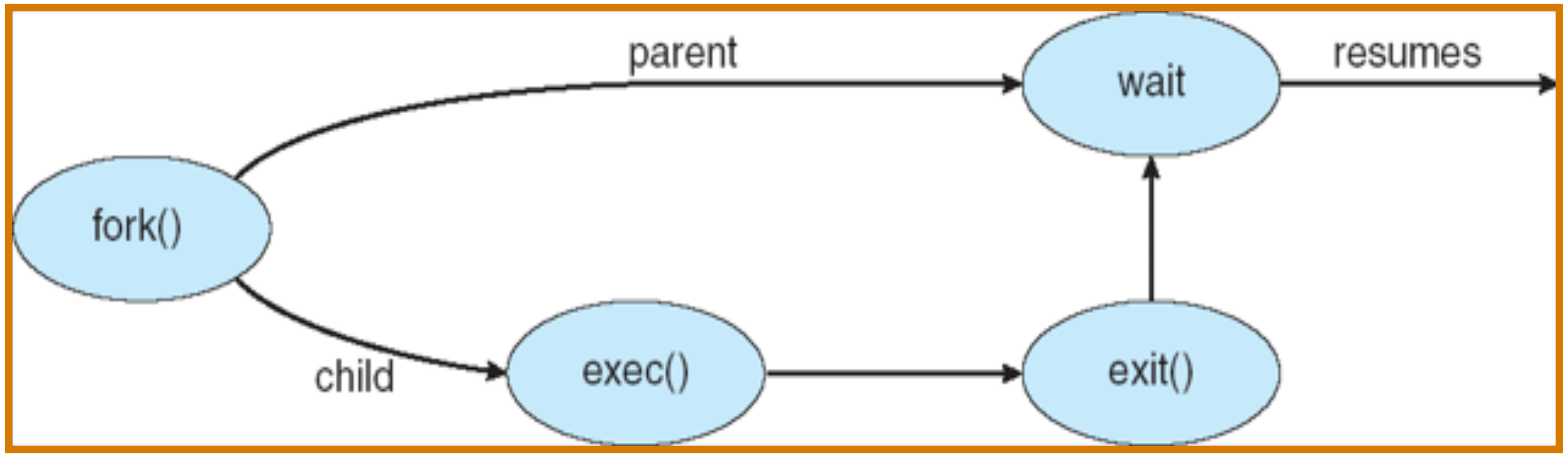
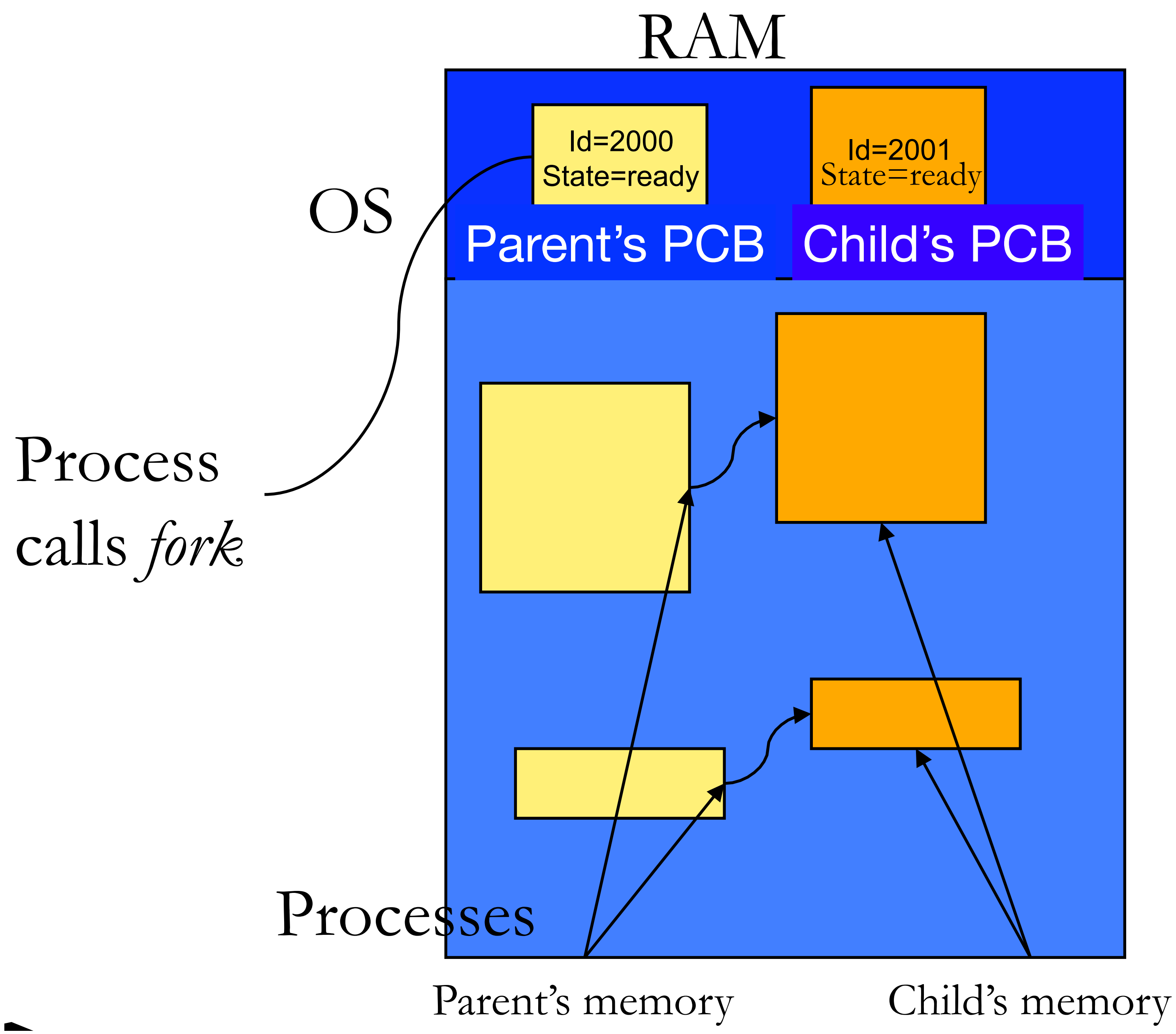
- What happens?
  - New process object in kernel
    - Build process data structures
  - Allocate address space (abstract resource)
    - Later, allocate memory (physical resource)
  - Add to execution queue
    - Runnable?

Process Creation



Process Layout



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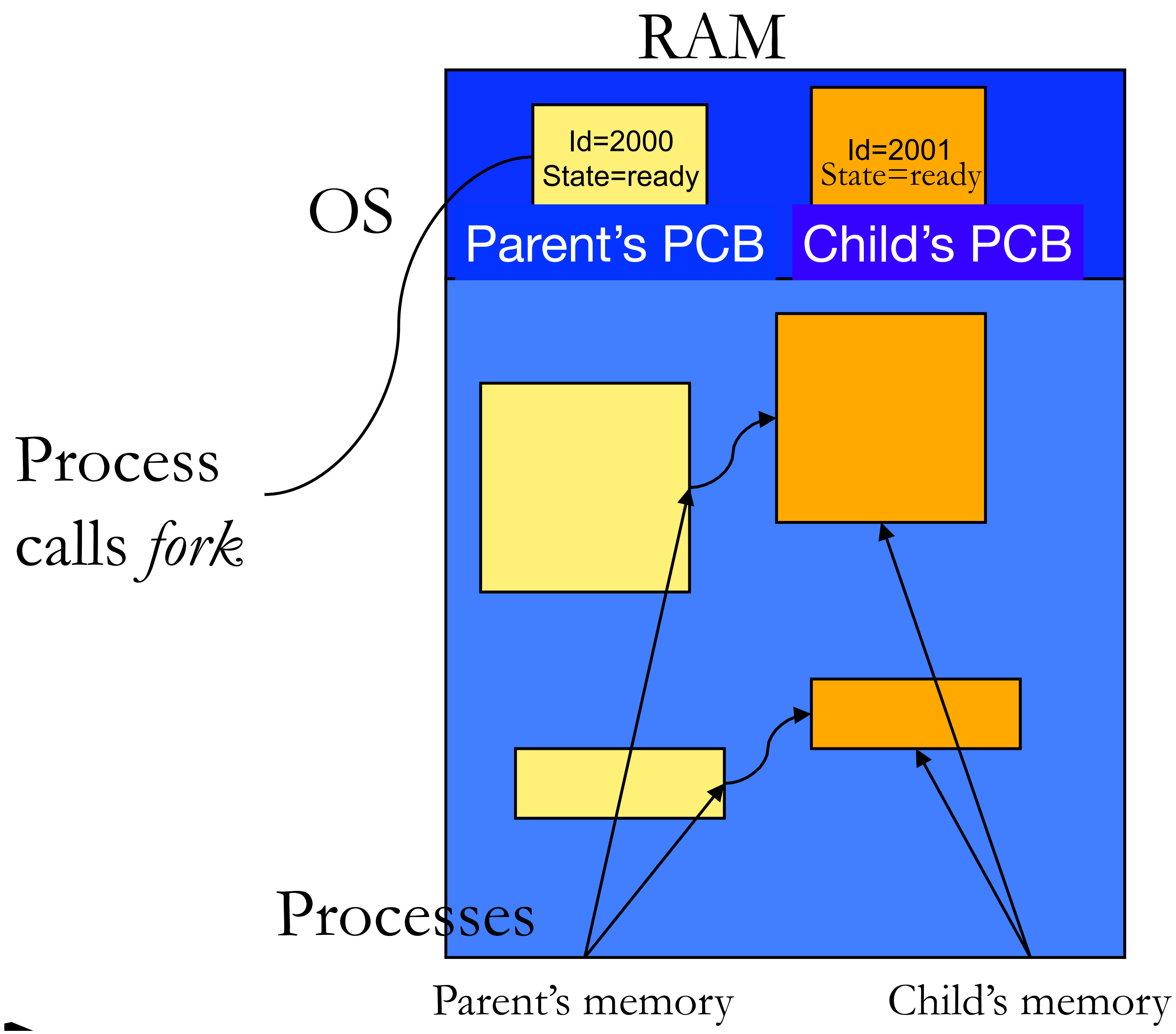
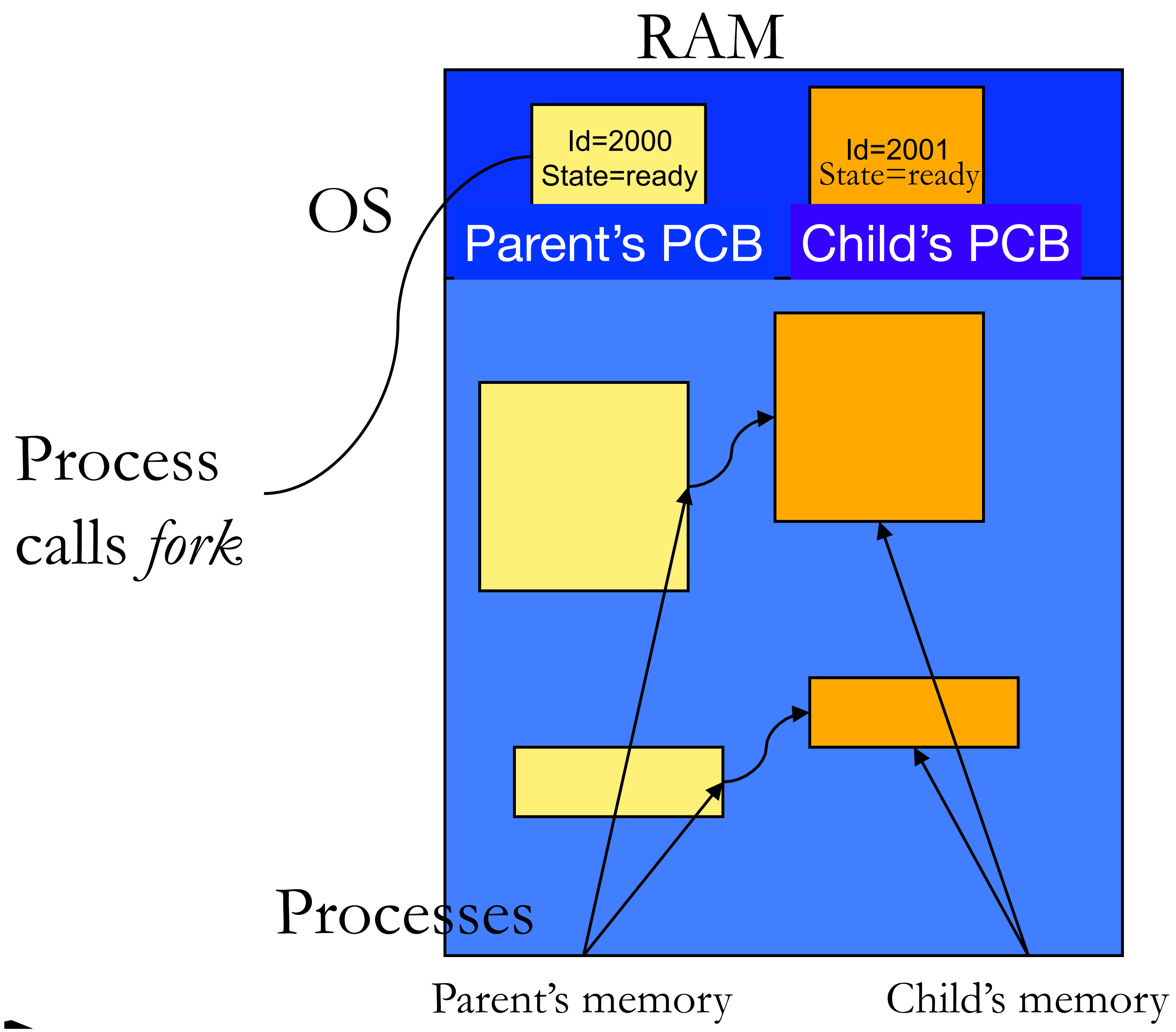


1. PCB with new Id created

2. Memory allocated for child

Initialized by copying over from the parent

Process Layout



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Process Layout

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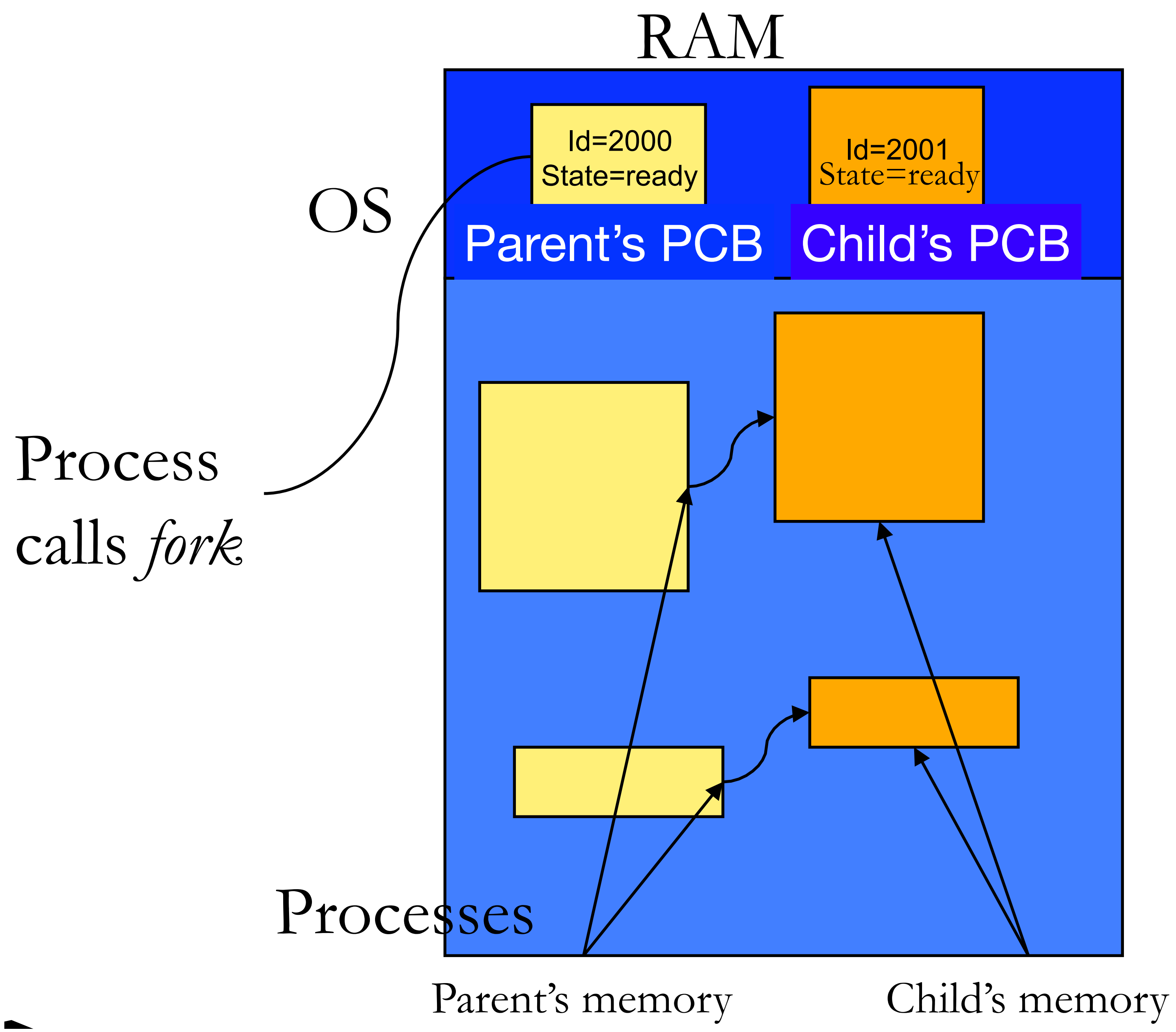

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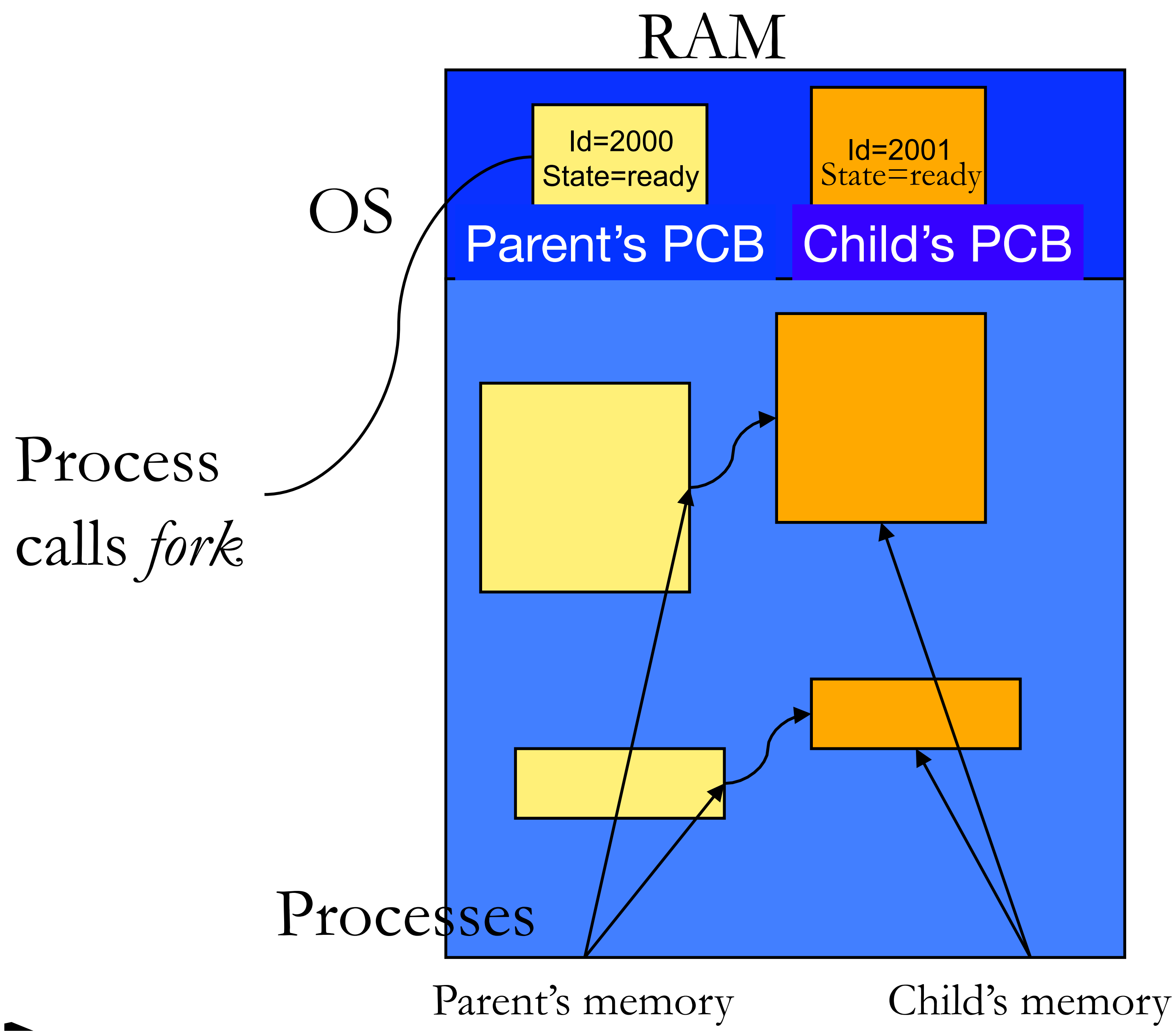

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3. If parent had called **wait**, it is moved to a waiting queue

4. If child had called **exec**, its memory overwritten with new code & data

5. Child added to ready queue, all set to go now!

C Program Forking Separate Process

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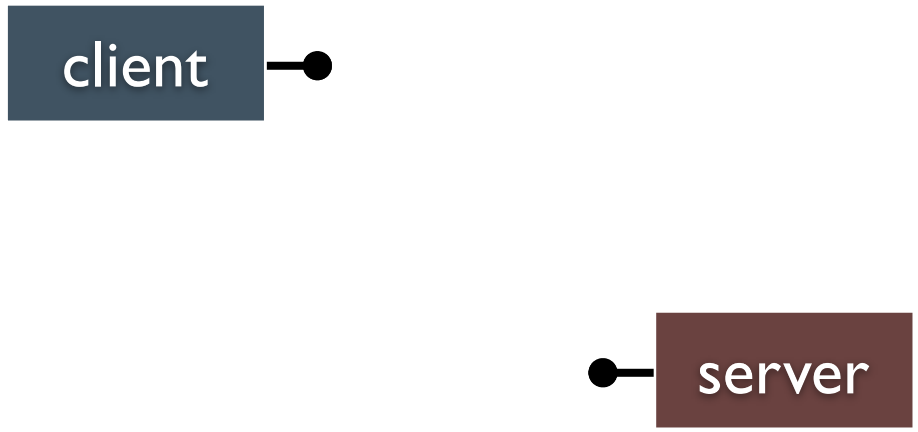
```
int main( )
{
pid_t  pid;
  /* fork another process */
  pid = fork( );
  if (pid < 0) { /* error occurred */
   fprintf(stderr, "Fork Failed");
   exit(-1);
  }
  else if (pid == 0) { /* child process */
   execlp("/bin/ls", "ls", NULL);
  }
  else { /* parent process */
   /* parent will wait for the child to
  complete */
   wait (NULL);
   printf ("Child Complete");
   exit(0);
  }
}
```

Graphically

Graphically



Graphically

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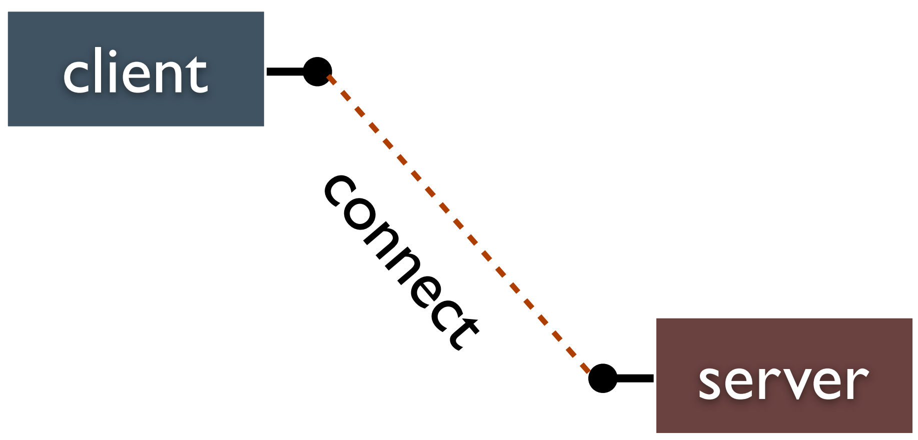
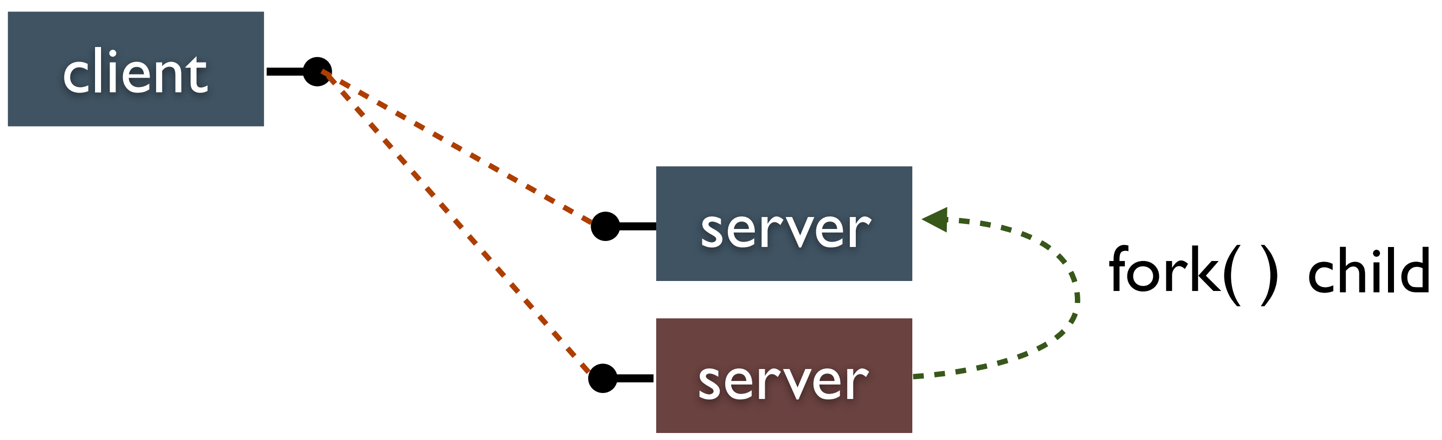


Graphically



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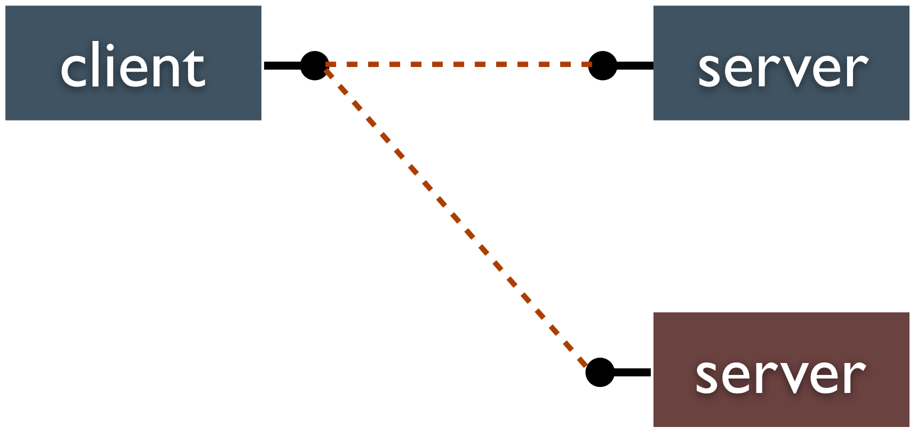
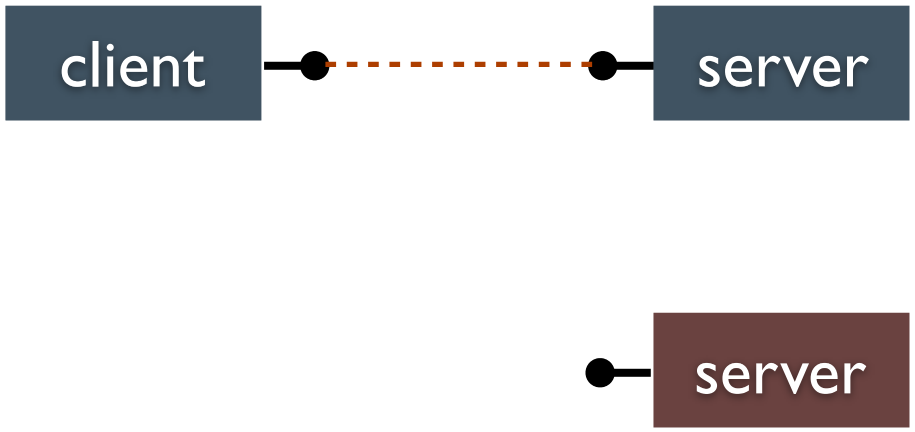


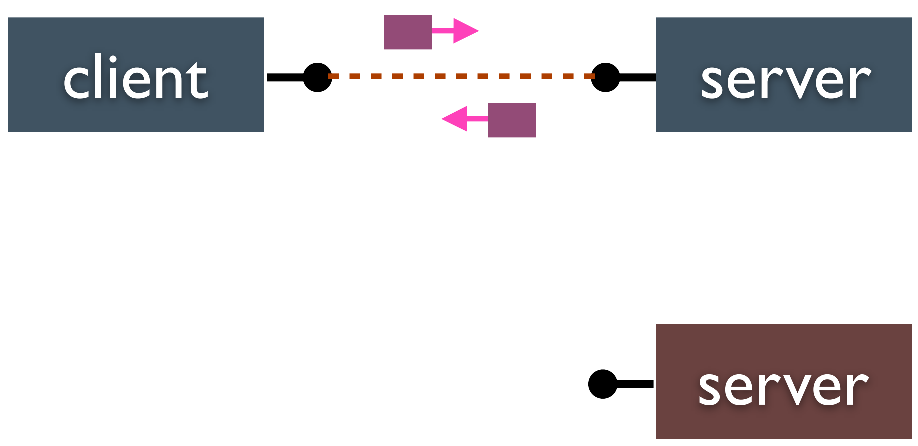
child exit( )'s / parent wait( )'s

Graphically



parent closes its client connection

Graphically



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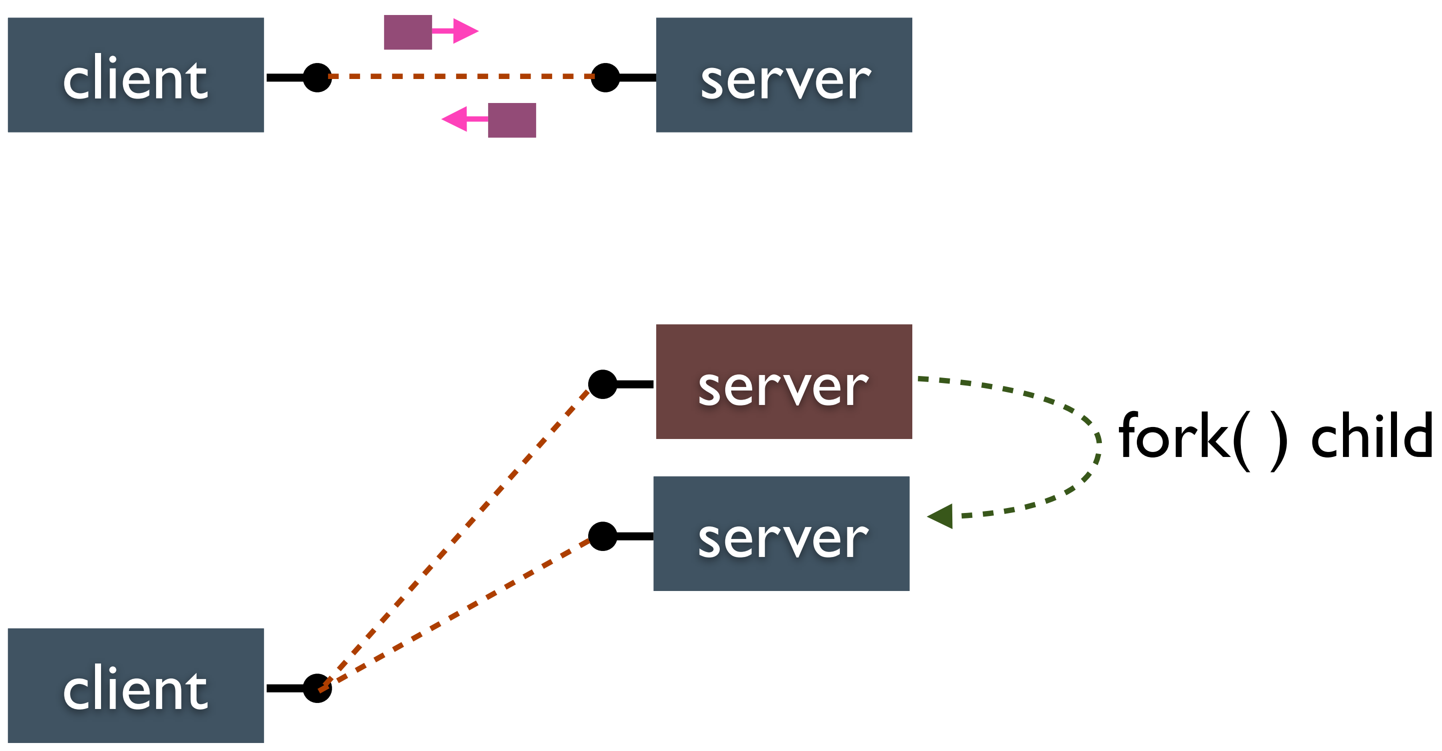

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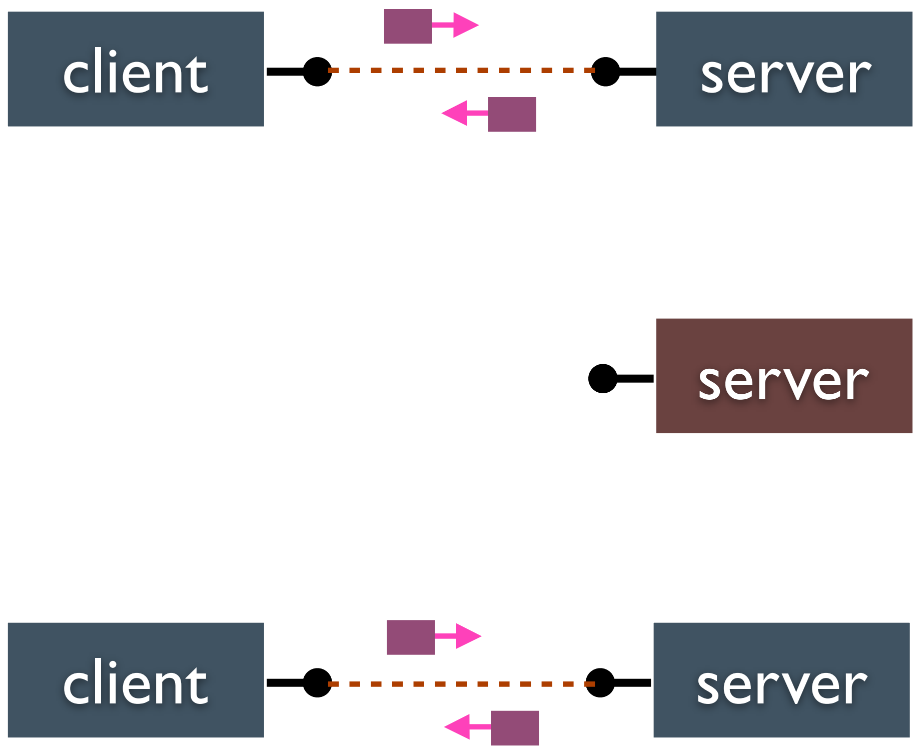
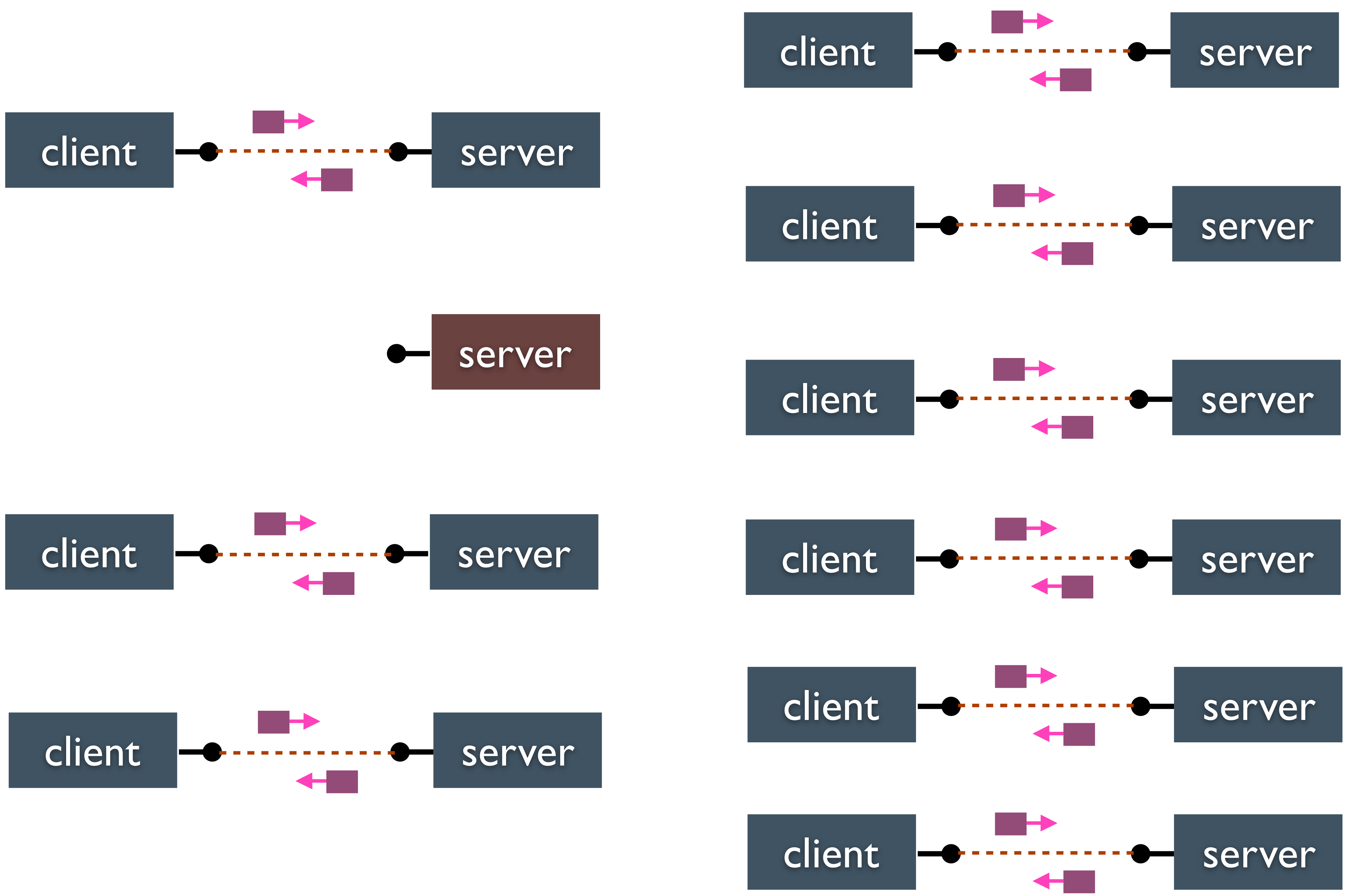


Graphically



Program Creation

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- Design Choices
  - Resource Sharing
    - What resources of parent should the child share?
    - What about after `exec`?
  - Execution
    - Should parent wait for child?
  - What is the relationship between parent and child?
    - Hierarchical or grouped or …?

Program Creation

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- `fork` -- copy address space and all threads
- `forkl` -- copy address space and only calling thread
- `vfork` -- do not copy address space; shared between parent and child
- `exec` -- load new program; replace address space
    - Some resources may be transferred (open file descriptors)
    - Specified by arguments

A tree of processes on a typical system

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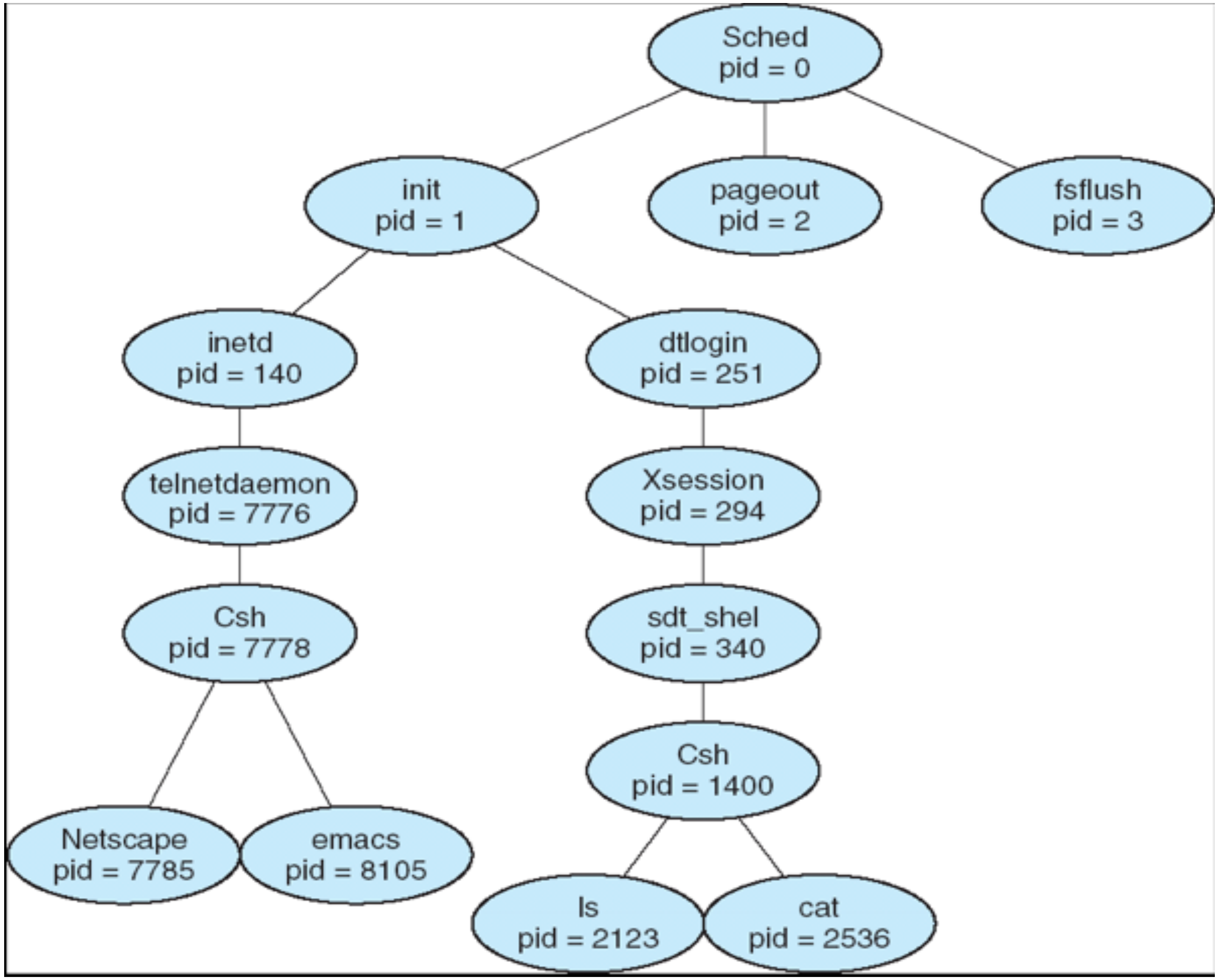

Process Termination

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- Process executes last statement and asks the operating system to delete 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`)
  - 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 parent terminates
    - All children terminated - cascading termination

Executing a Process

- What to execute?
  - Register that stores the program counter
    - Next instruction to be executed
- Registers store state of execution in CPU
  - Stack pointer
  - Data registers
- Thread of execution
  - Has its own stack

Executing a Process

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- Thread executes over the process's address space
  - Usually the text segment
- Until a trap or interrupt…
  - Time slice expires (timer interrupt)
  - Another event (e.g., interrupt from other device)
  - Exception (oops)
  - **System call** (switch to kernel mode)

Relocatable Memory

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- Mechanism that enables the OS to place a program in an arbitrary location in memory
  - Gives the programmer the impression that they own the processor
- Program is loaded into memory at program-specific locations
  - Need virtual memory to do this
- Also, may need to share program code across processes

Process State

- What do we need to track about a process?
  - how many processes?
  - what's the state of each of them?
- Process table: kernel data structure tracking processes on system
- Process control block: structure for tracking *process context*

Scheduling Processes

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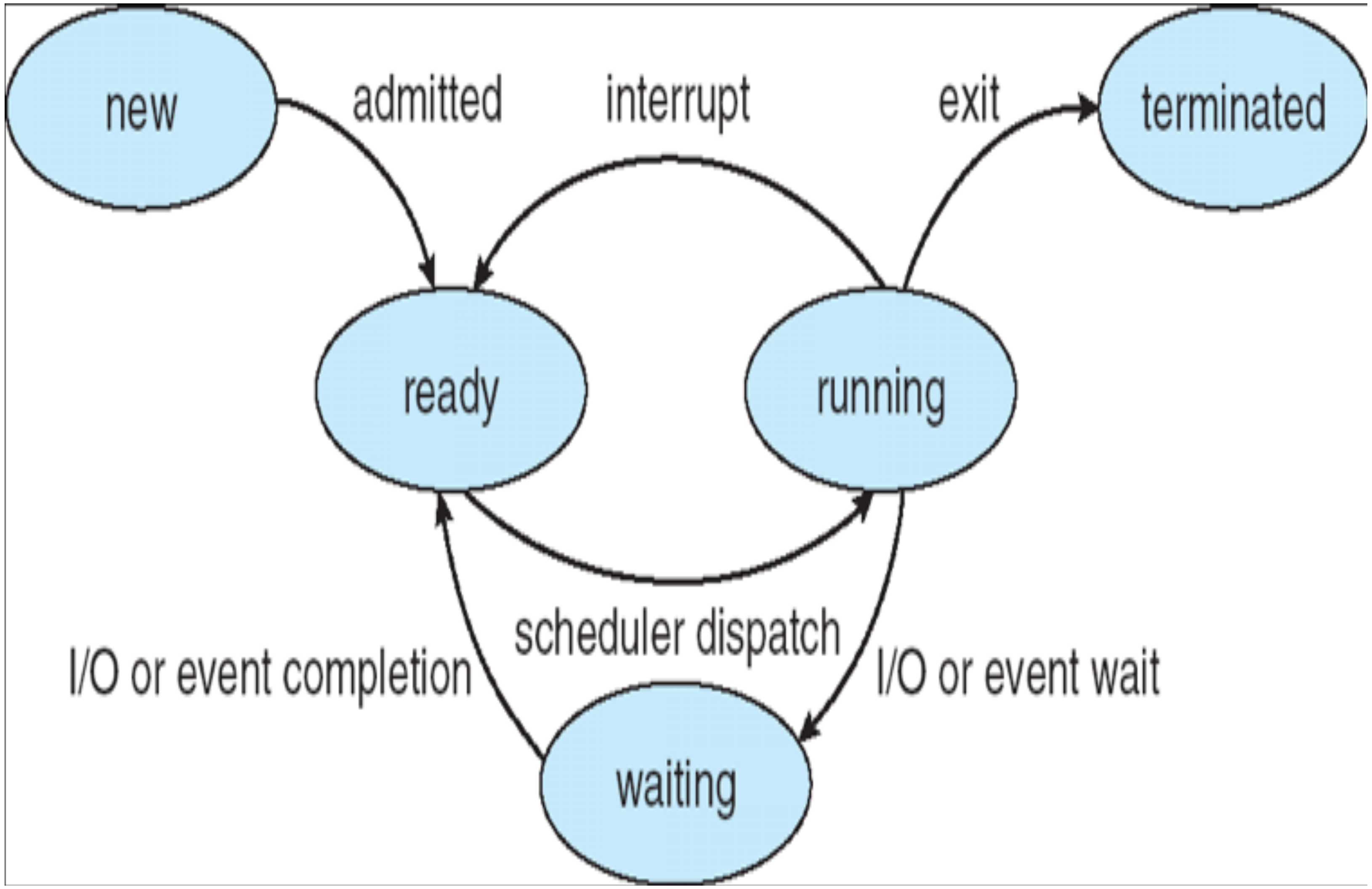
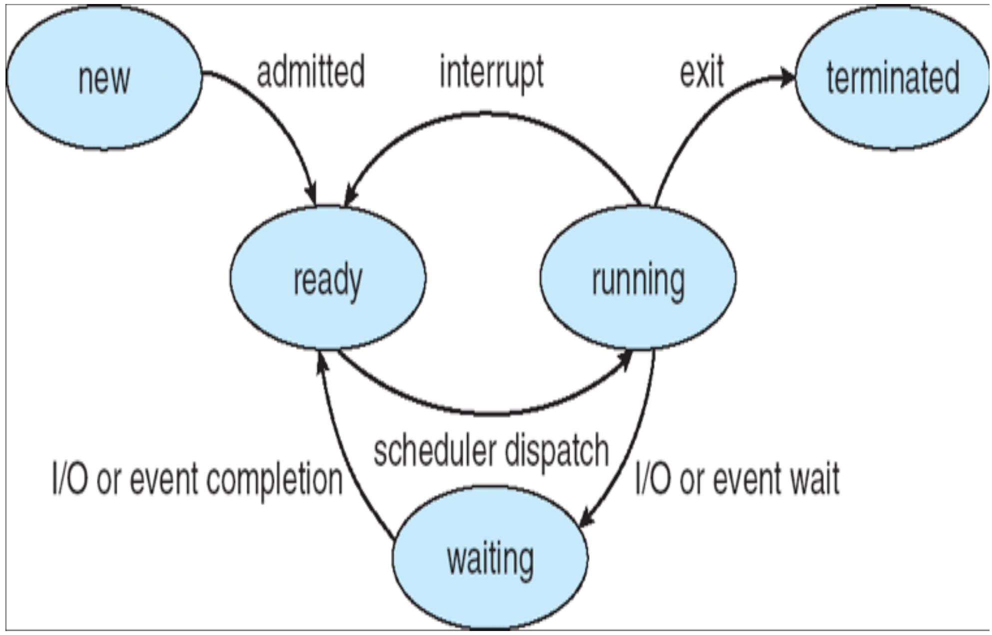
- Processes transition among *execution states*



Process States

- Running
  - Running == in processor and in memory with all resources
- Ready
  - Ready == in memory with all resources, waiting for dispatch
- Waiting
  - Waiting == waiting for some event to occur



State Transitions

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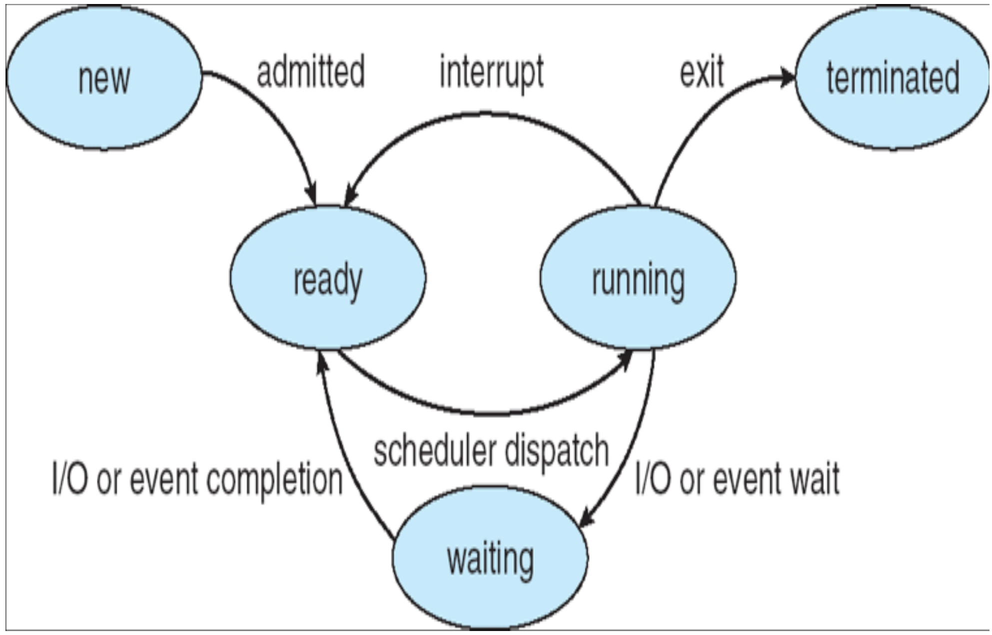
- New Process ==> Ready
  - Allocate resources
  - End of process queue
- Ready ==> Running
  - Head of process queue
  - Scheduled
- Running ==> Ready
  - Interrupt (Timer)
  - Back to end of process queue



State Transitions: Page Fault Handling

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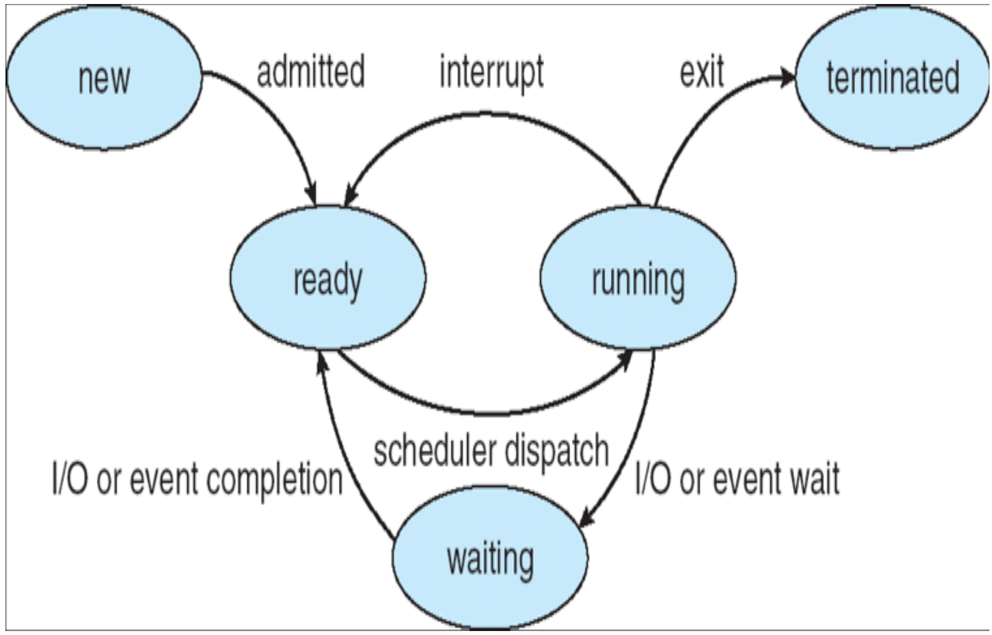
- Running ==> Waiting
  - Page fault exception (similar for syscall or I/O interrupt)
  - Wait for event
- Waiting ==> Ready
  - Event has occurred (page fault serviced)
  - End of process queue (or head?)
- Ready ==> Running
  - As before…



State Transitions: Other Issues

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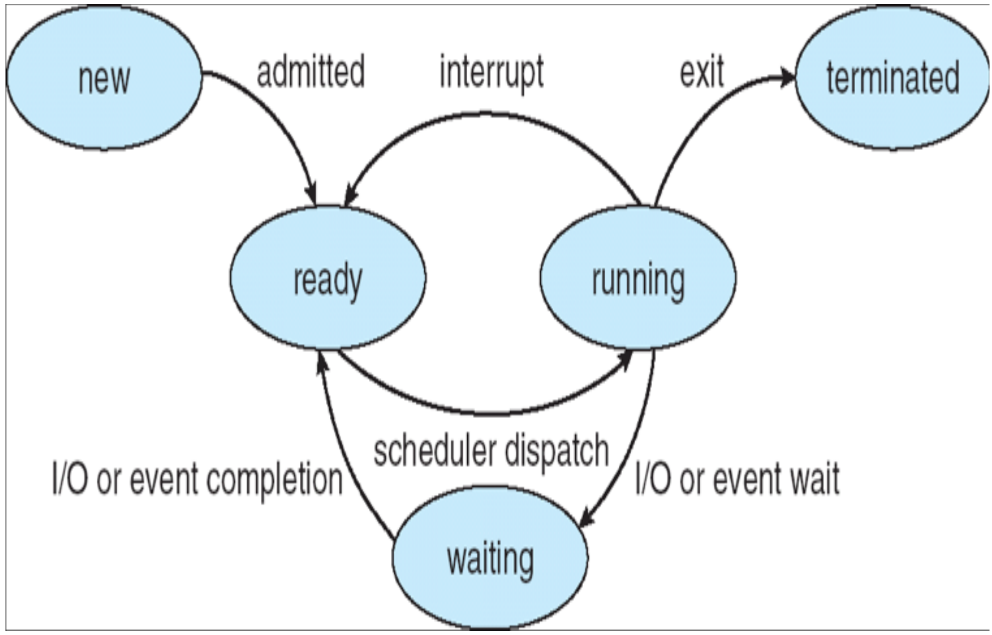
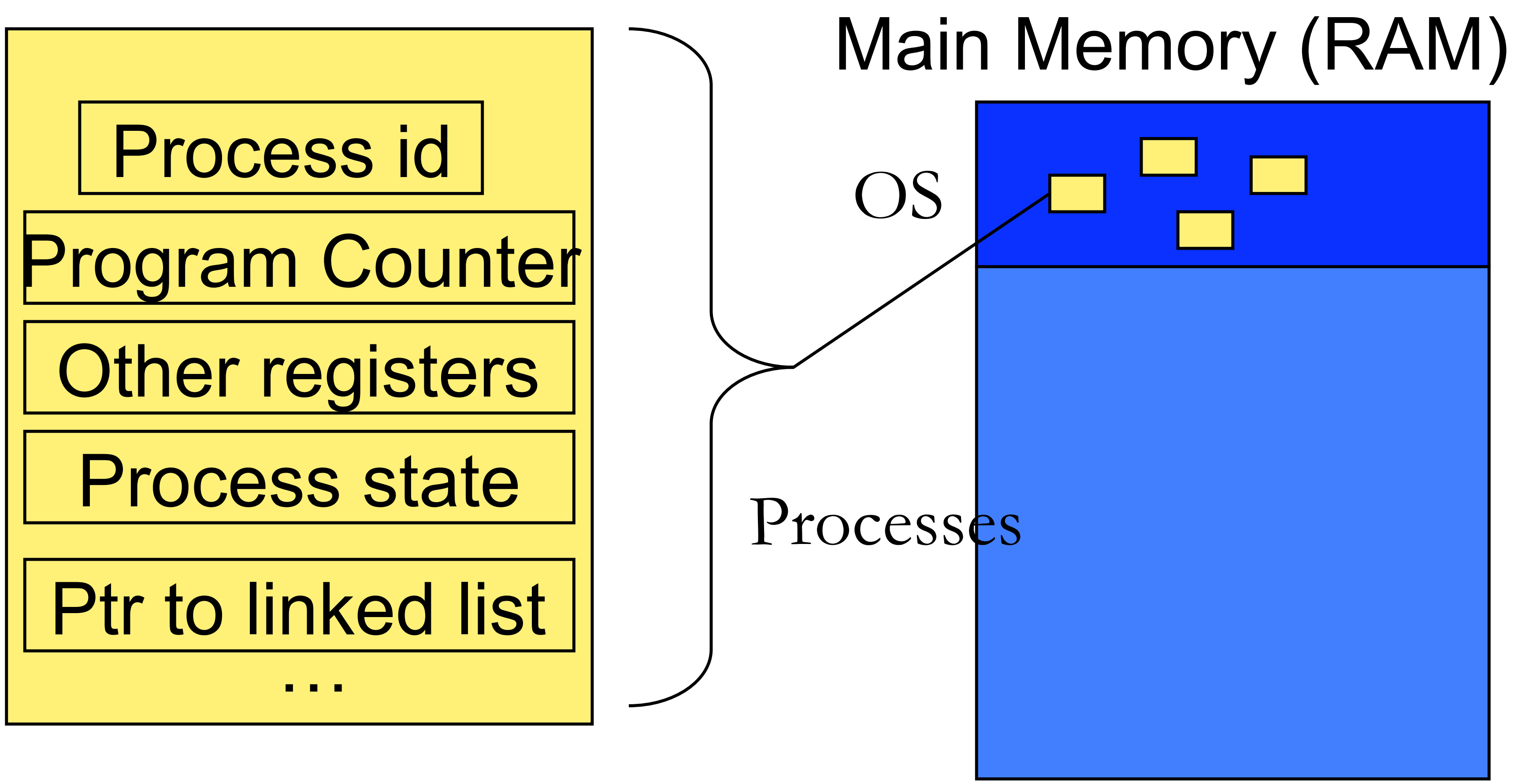
- Priorities
  - Can provide policy indicating which process should run next
    - More when we discuss scheduling…
- Yield
  - System call to give up processor
  - For a specific amount of time (sleep)
- Exit
  - Terminating signal (Ctrl-C)



Process Control Block



- State of running process
- Linked list of process control information

Per Process Control Info

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- Process state
  - Ready, running, waiting (momentarily)
- Links to other processes
  - Children
- Memory Management
  - Segments and page tables
- Resources
  - Open files
- And Much More…

`/proc` File System

- Linux and Solaris
  - ls /proc
  - A directory for each process
- Various process information
  - `/proc/<pid>/io` -- I/O statistics
  - `/proc/<pid>/environ` -- Environment variables (in binary)
  - `/proc/<pid>/stat` -- process status and info

Context Switch

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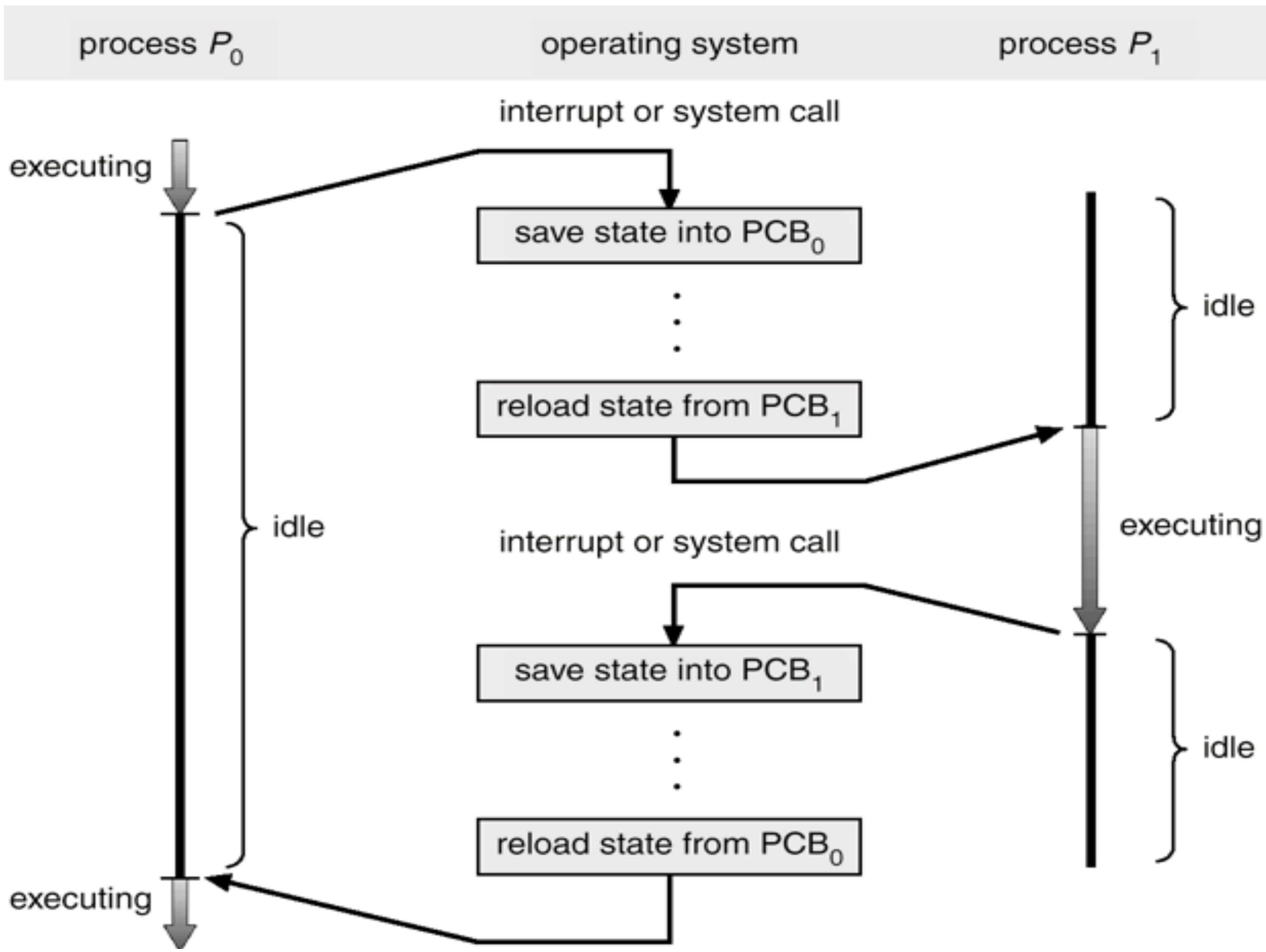
- OS switches from one execution context to another
  - One process to another process
  - Interrupt handling
  - Process to kernel (*mode transition*, not context switch)
- Current Process to New Process
  - Save the state of the current process
    - *Process control block*: describes the state of the process in the CPU
  - Load the saved context for the new process
    - Load the new process's process control block into OS and registers
  - Start the new process
- Does this differ if we are running an interrupt handler?

Context Switch



Context Switch

- No useful work is being done during a context switch
  - Speed it up and limit system calls to things that can't be done in user mode
- Hardware support
  - Multiple register sets (Sun UltraSPARC)
- However, hardware optimization may conflict
  - TLB flush is necessary
  - Different virtual to physical mappings on different processes

Next class

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- IPC