CSCI 3753
Operating Systems

Processes

Lecture Notes By

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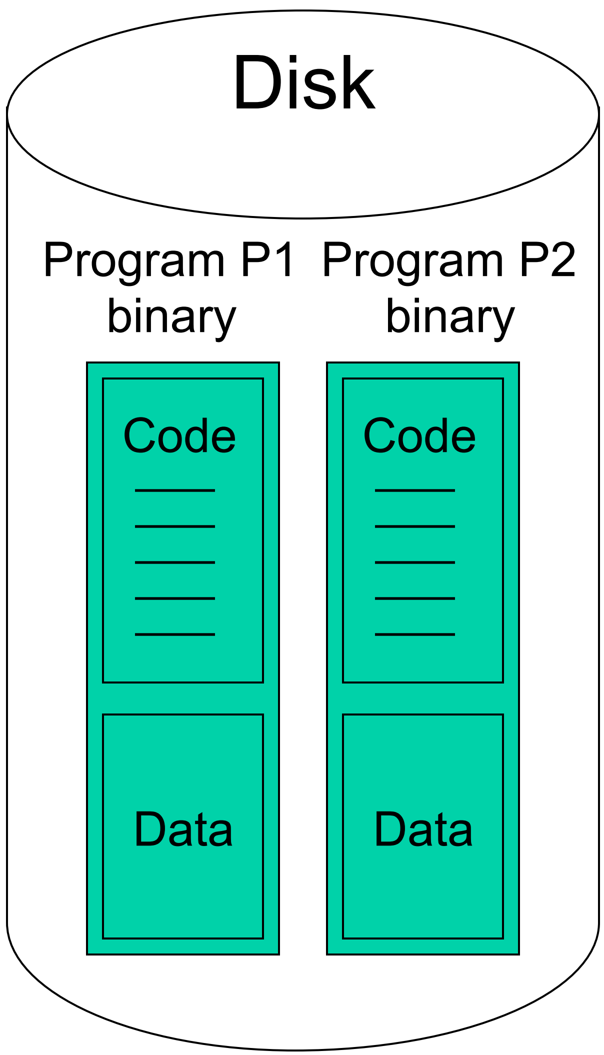
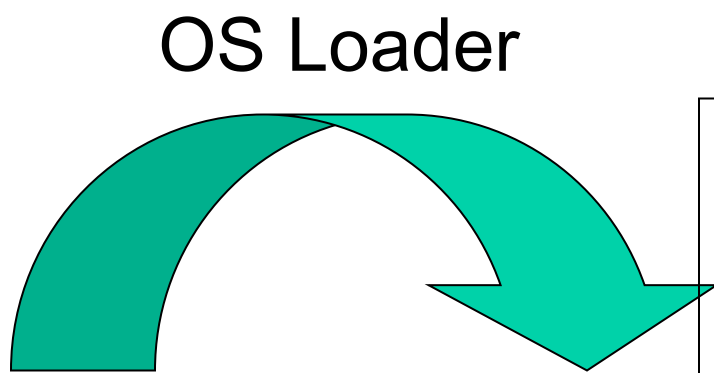
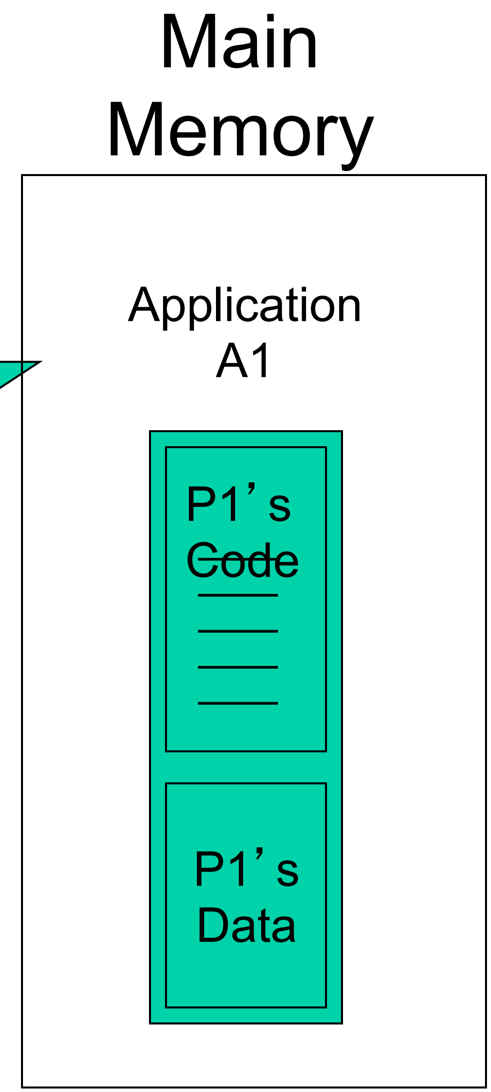
Loading a Program into Memory



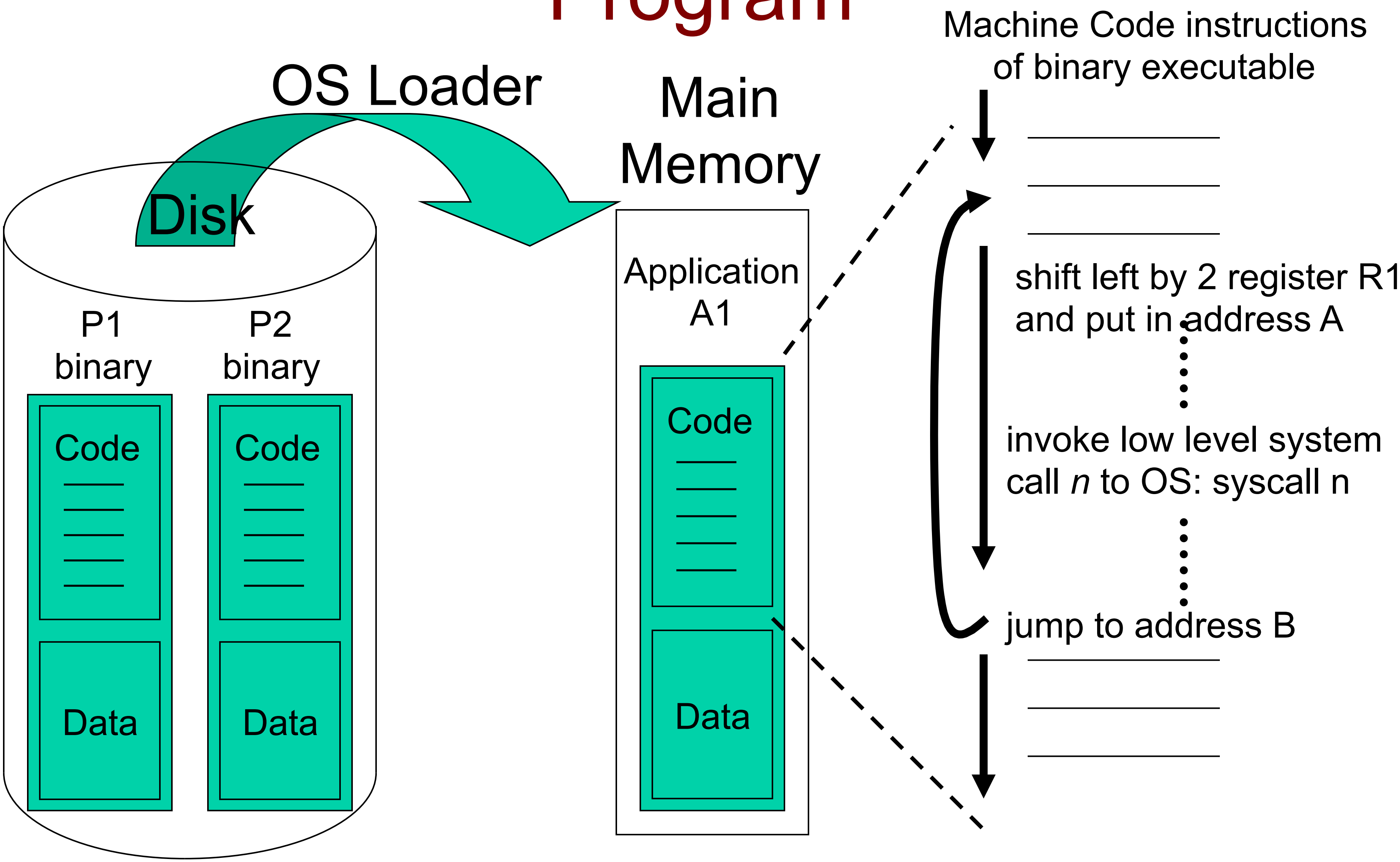




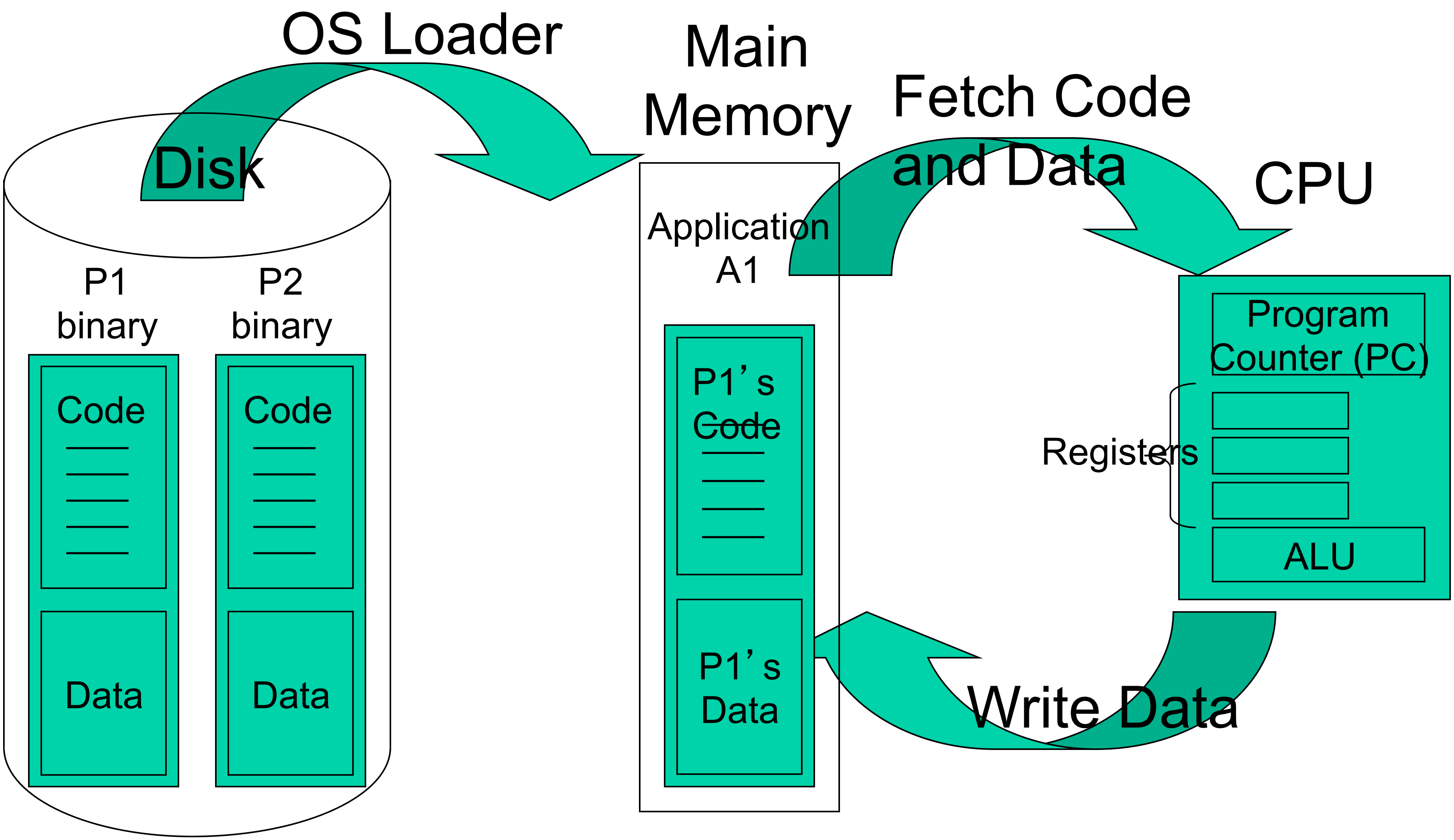
- Invoked by typing a program name in shell or double-clicking on its icon
- Copies P1 from disk to RAM

In reality, more complex, execve system call and paging are involved

Loading and Executing a Program

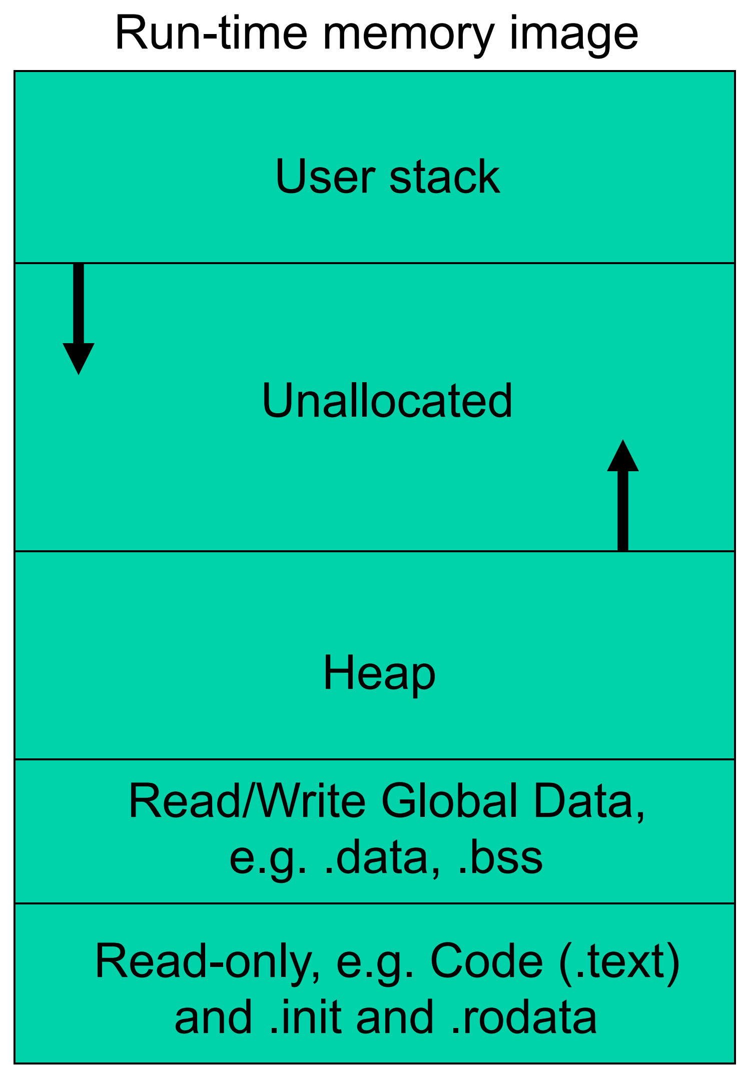


Loading and Executing a Program



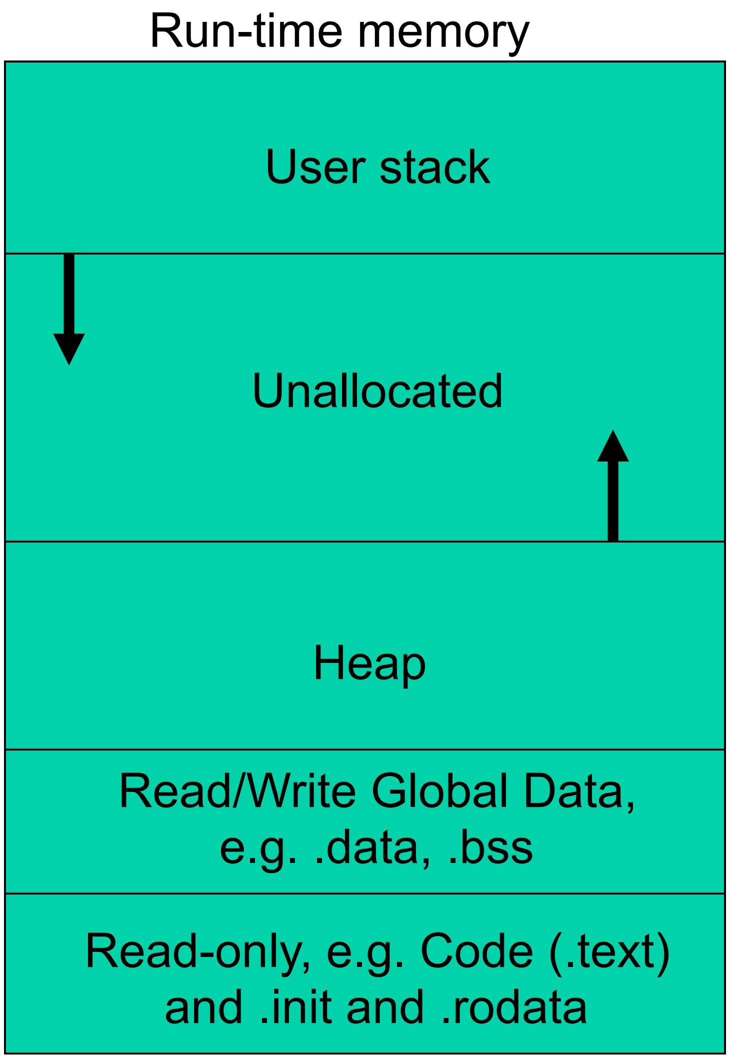
Loading Executable Object Files

- When a program is loaded into RAM, it becomes an actively executing application
- The OS allocates a stack and heap to the app in addition to code and global data.
  - A call stack is for local variables, function parameters and return addresses
  - A heap is for dynamic variables, e.g. *malloc(), new*
  - Usually, stack grows downward from high memory, heap grows upward from low memory, but this architecture-specific

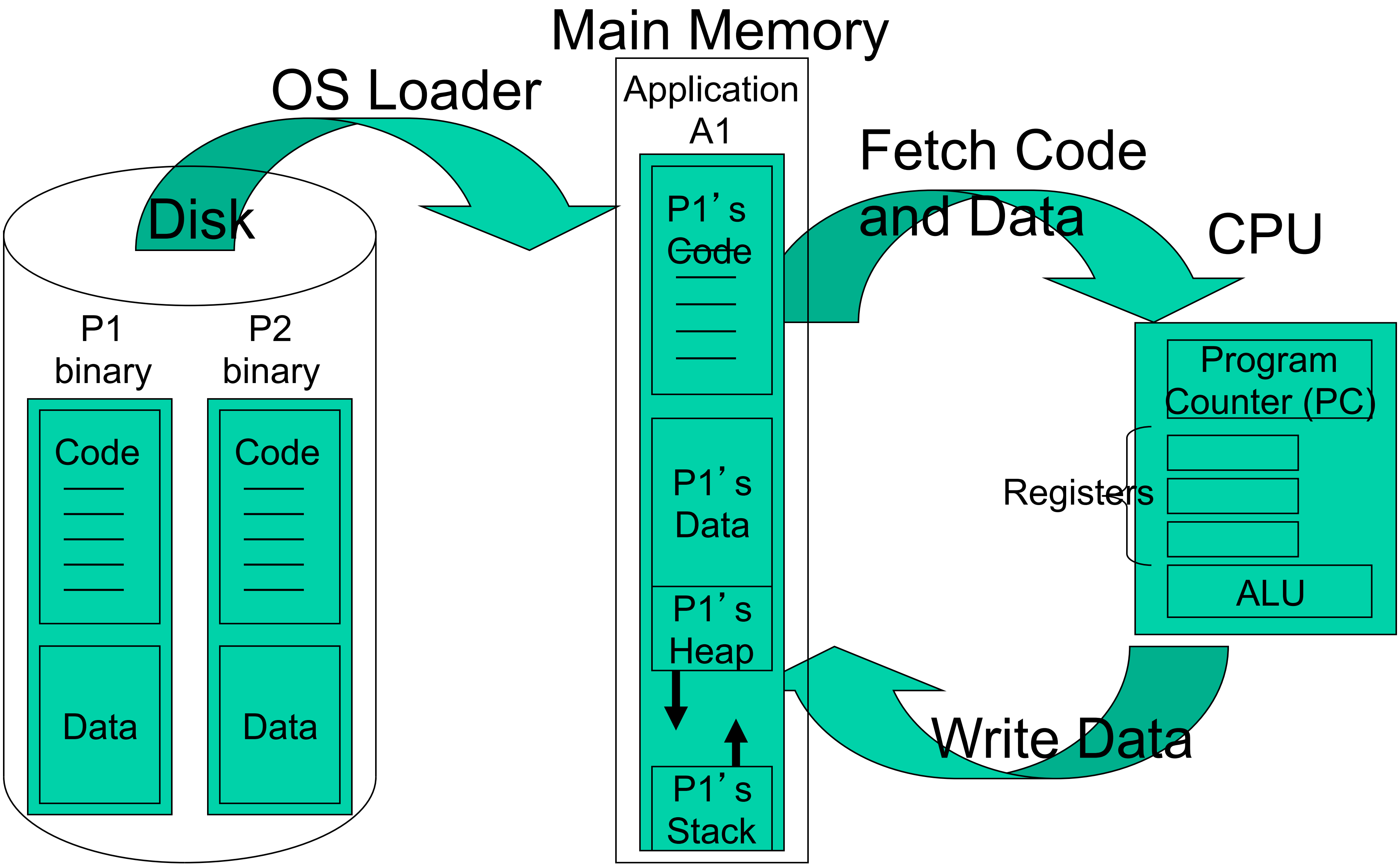


Running Executable Object Files

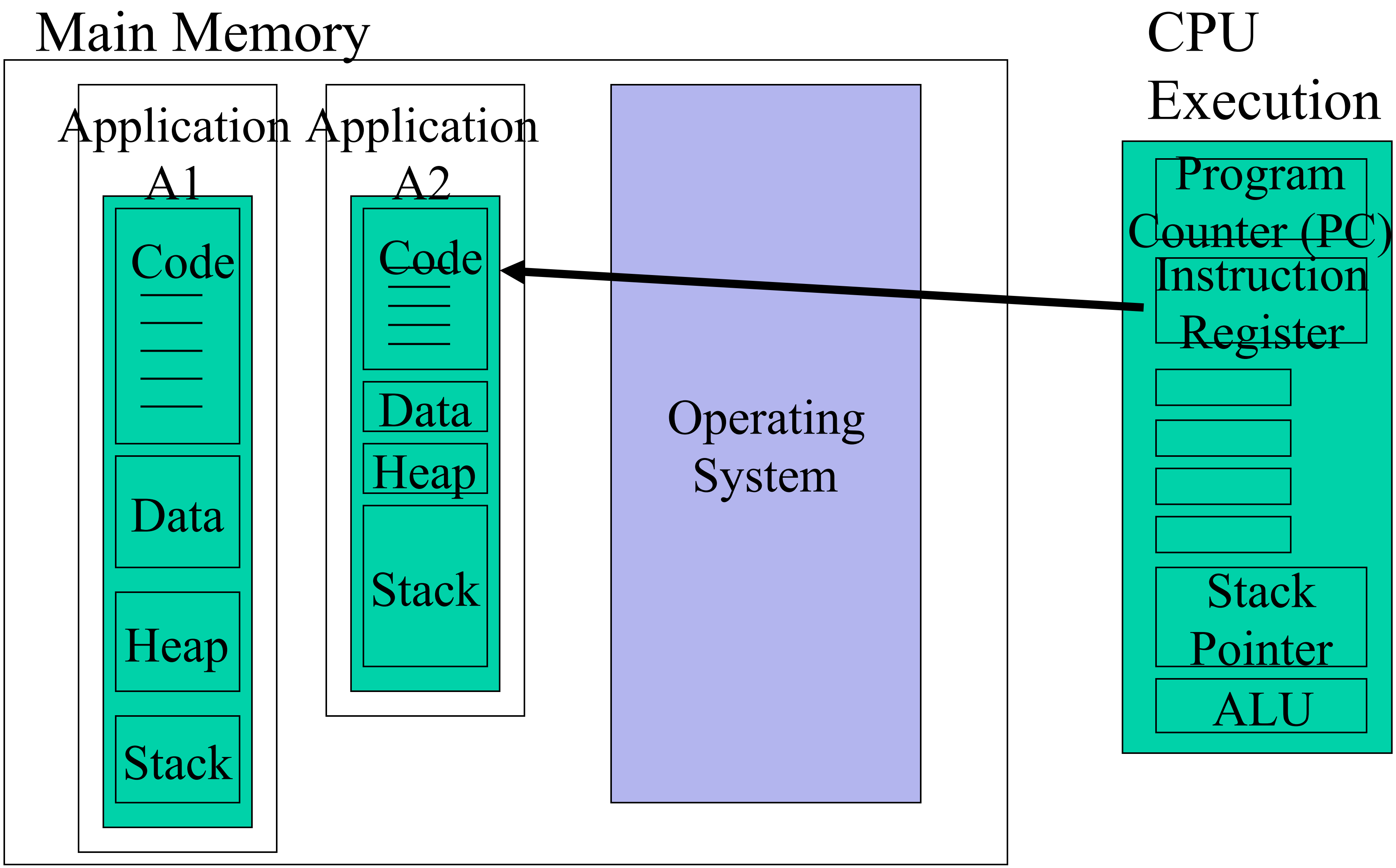
- Stack contains local variables
  - As main() calls function f1, we allocate f1's local variables on the stack
  - If f1 calls f2, we allocate f2's variables on the stack below f1's, thereby growing the stack, etc…
  - When f2 is done, we deallocate f2's local variables, popping them off the stack, and return to f1
- Stack dynamically expands and contracts as program runs and different levels of nested functions are called
- Heap contains run-time variables/ buffers
  - Obtained from malloc()
  - Program should free() the malloc'ed memory
- Heap can also expand and contract during program execution



Loading and Executing a Program – a more complete picture

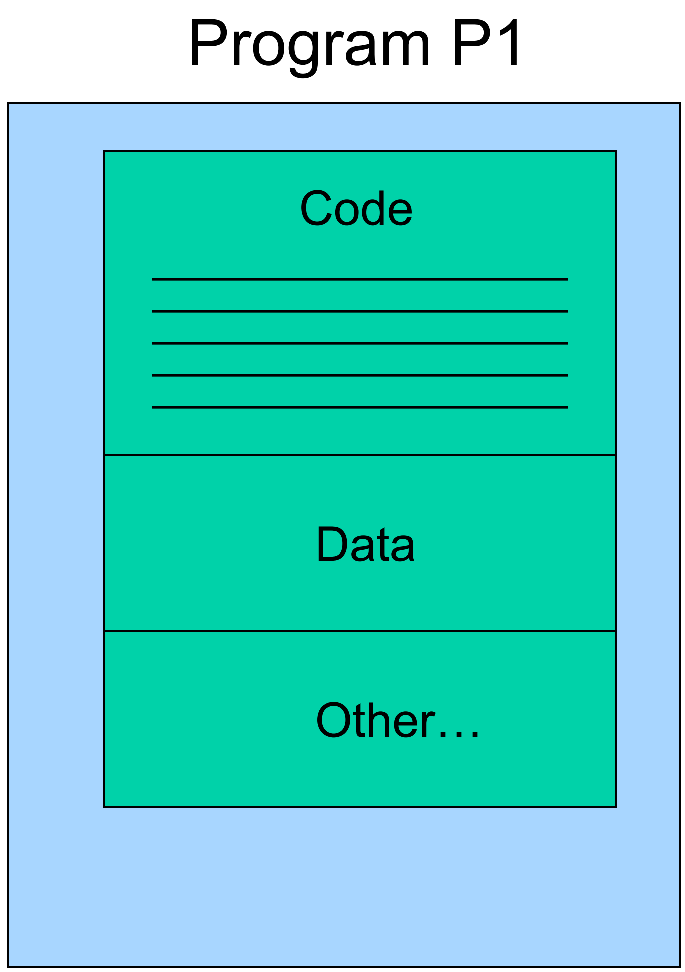


Multiple Applications + OS

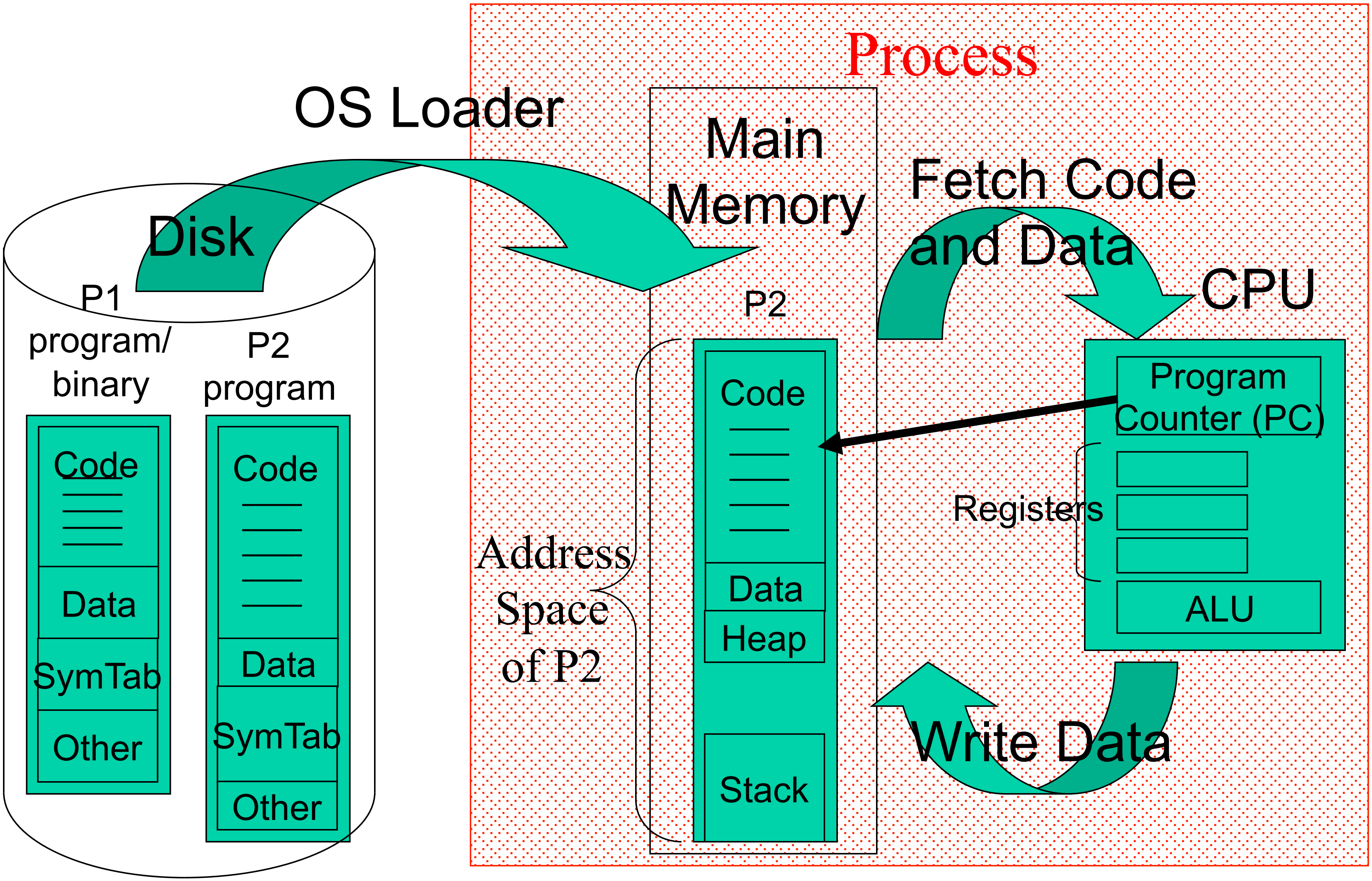


Chapter 3: What is a Process?

- A software *program* consist of a sequence of code instructions and data stored on disk
  - A program is a *passive* entity
- A *process* is a program *actively executing* from main memory within its *own address space*

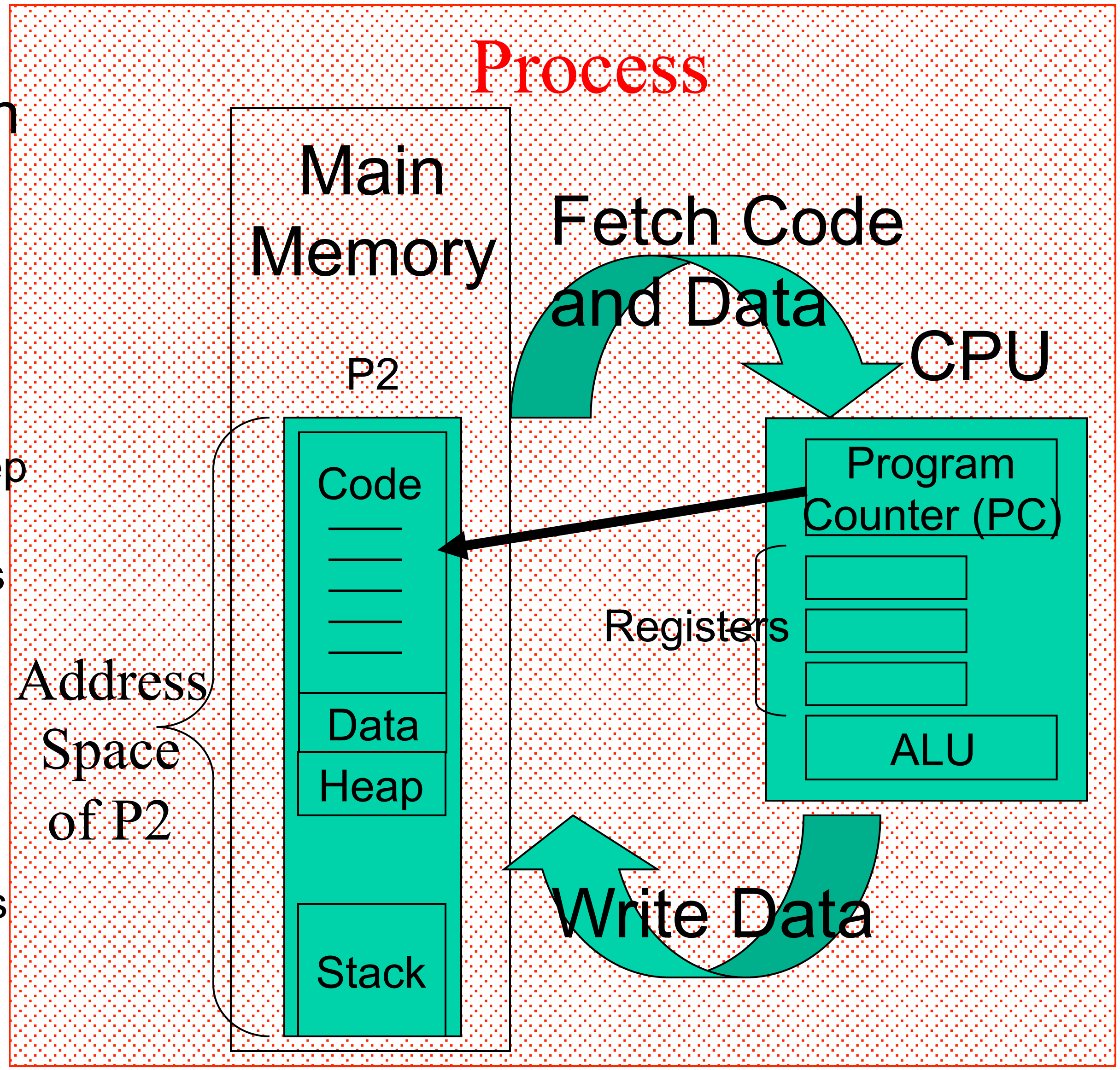


What Is a Process? (2)



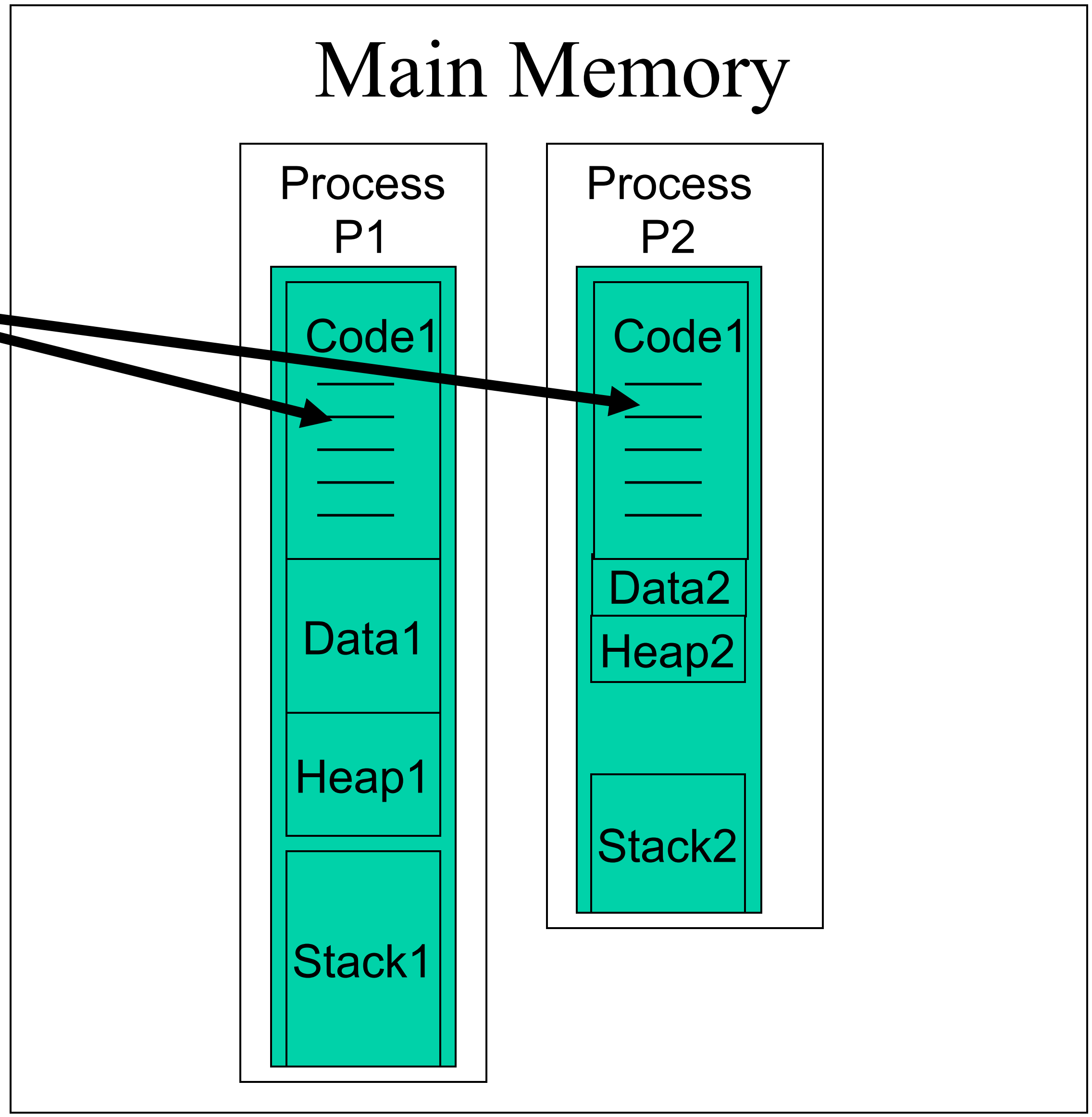
What is a Process? (3)

- A *process* is a program *actively executing* from main memory
  - has a Program Counter (PC) and execution state associated with it
    - CPU registers keep state
    - OS keeps process state in memory
    - it's alive!
  - Owns its own *address space*
    - a limited set of (virtual) addresses that can be accessed by the executing code

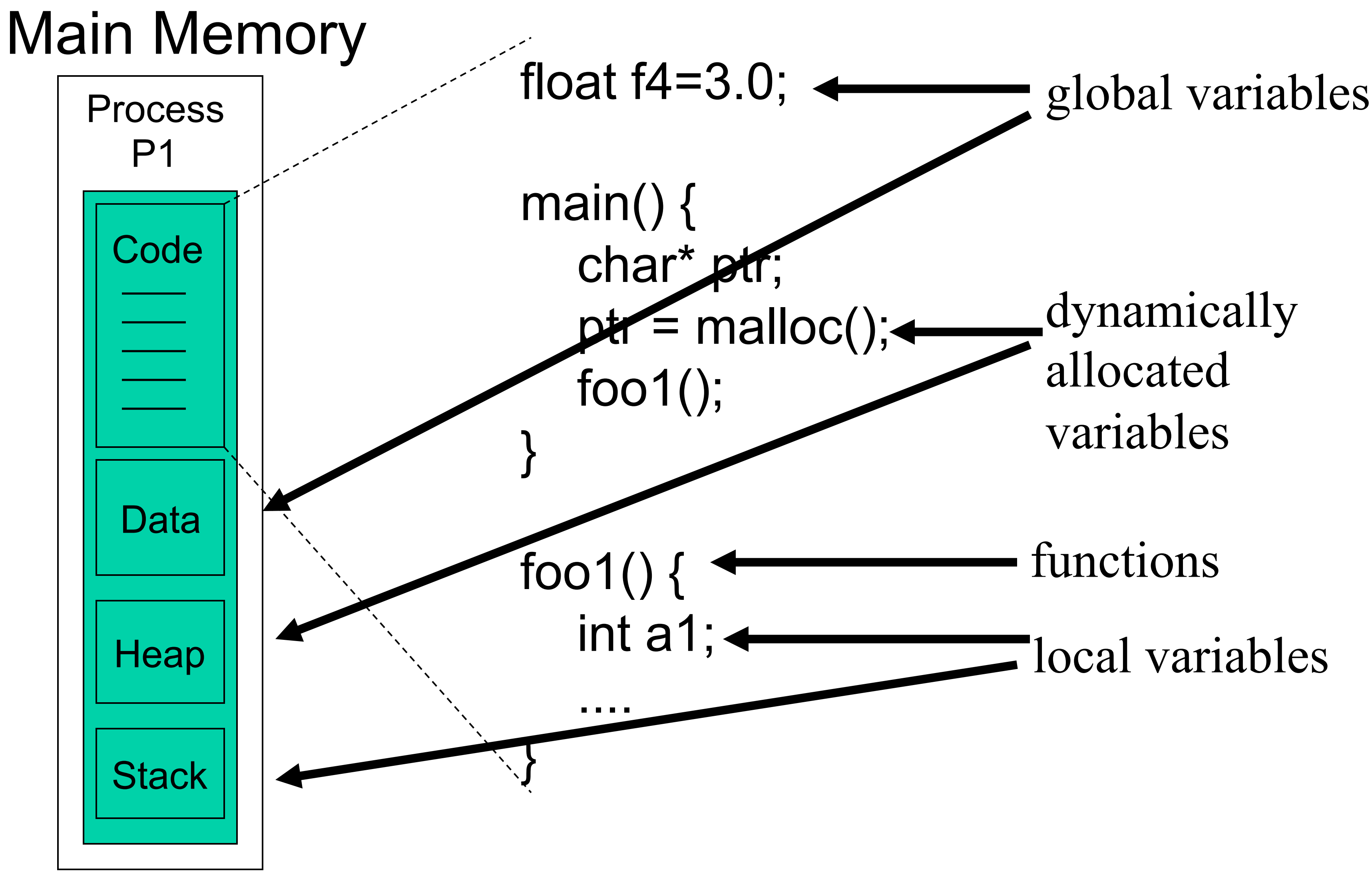


What is a Process? (4)

- 2 processes may execute the same program code, but they are considered *separate execution* sequences
  - e.g. two shell terminals

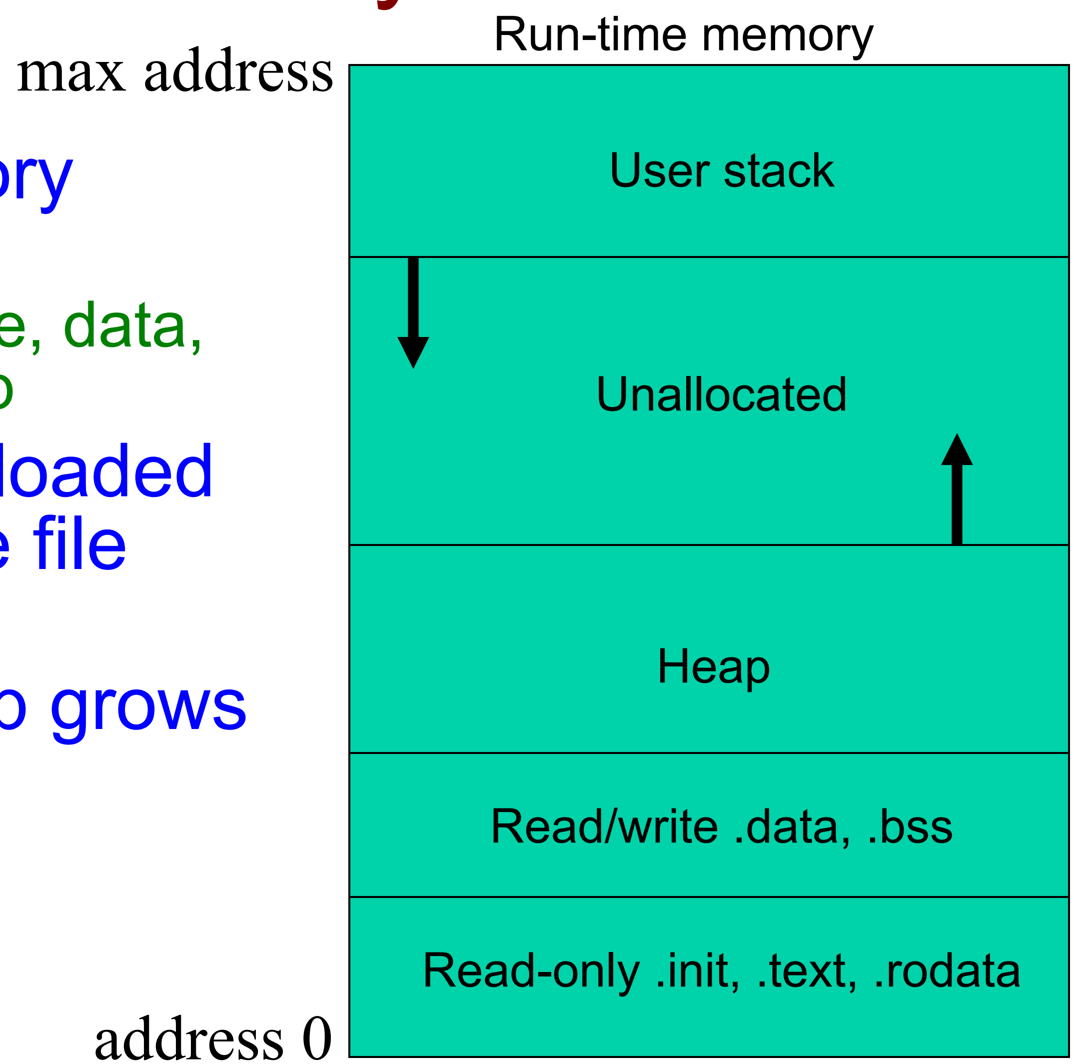


How is a Process Structured in Memory?



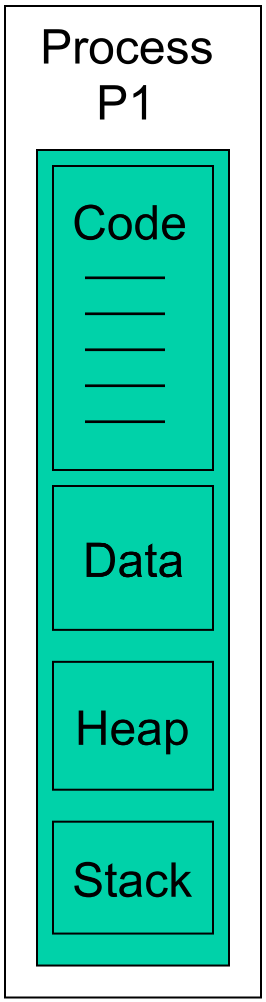
How is a Process Structured in Memory?

- Run-time memory image
  – Essentially code, data, stack, and heap
- Code and data loaded from executable file
- Stack grows downward, heap grows upward



A Process Executes in its Own Address Space

Main Memory

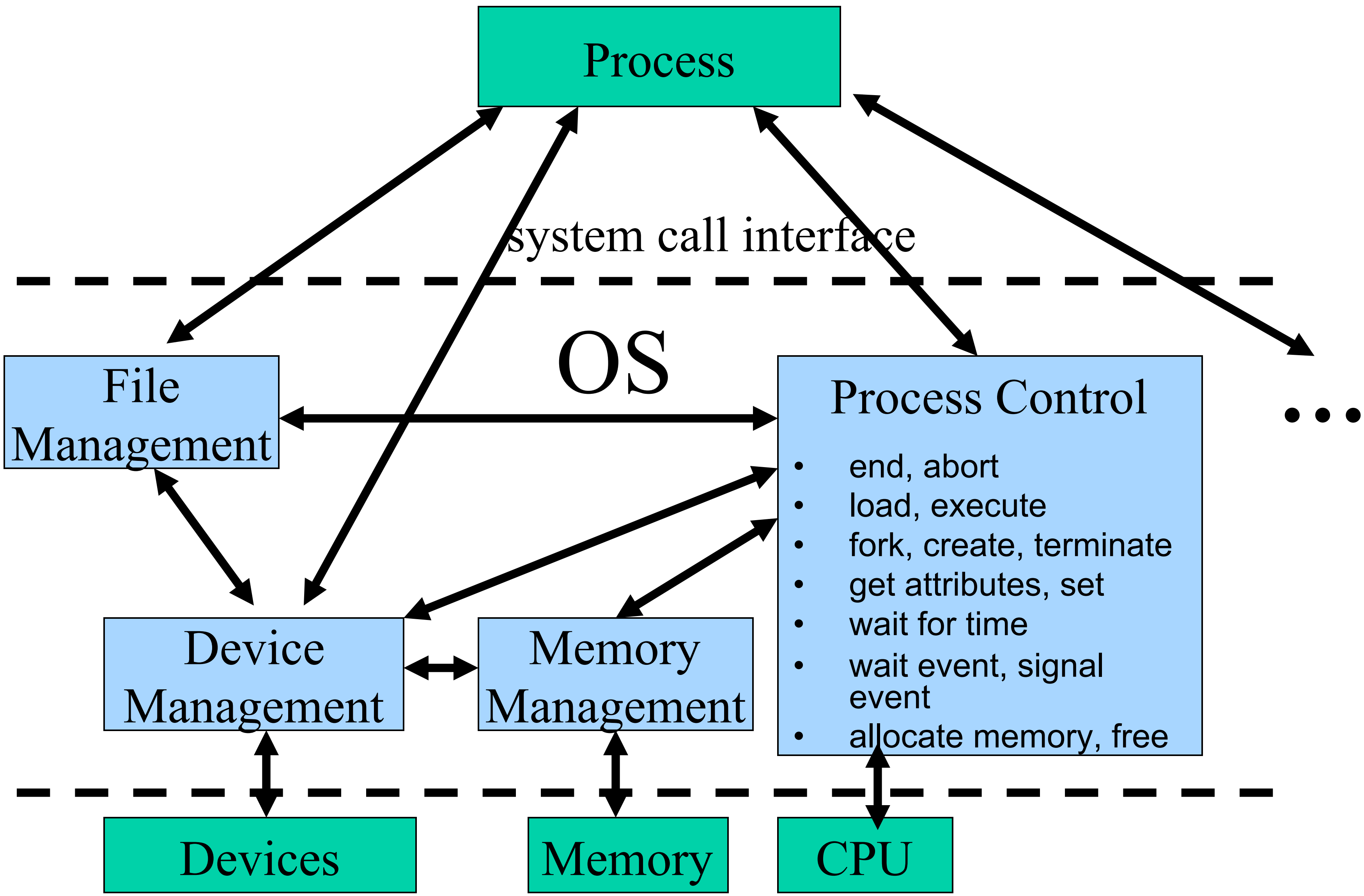


- OS tries to provide the illusion or *abstraction* to the process that it executes
  - in its own subset of RAM, i.e. its own address space
  - on its own subset (time slice) of the CPU

Applications and Processes

- Application = Σ_i Processes$_i$
  - e.g. a server could be split into multiple processes, each one dedicated to a specific task (UI, computation, communication, etc.)
  - The Application's various processes talk to each other using Inter-Process Communication (IPC). We'll see various forms of IPC later.

Process Management



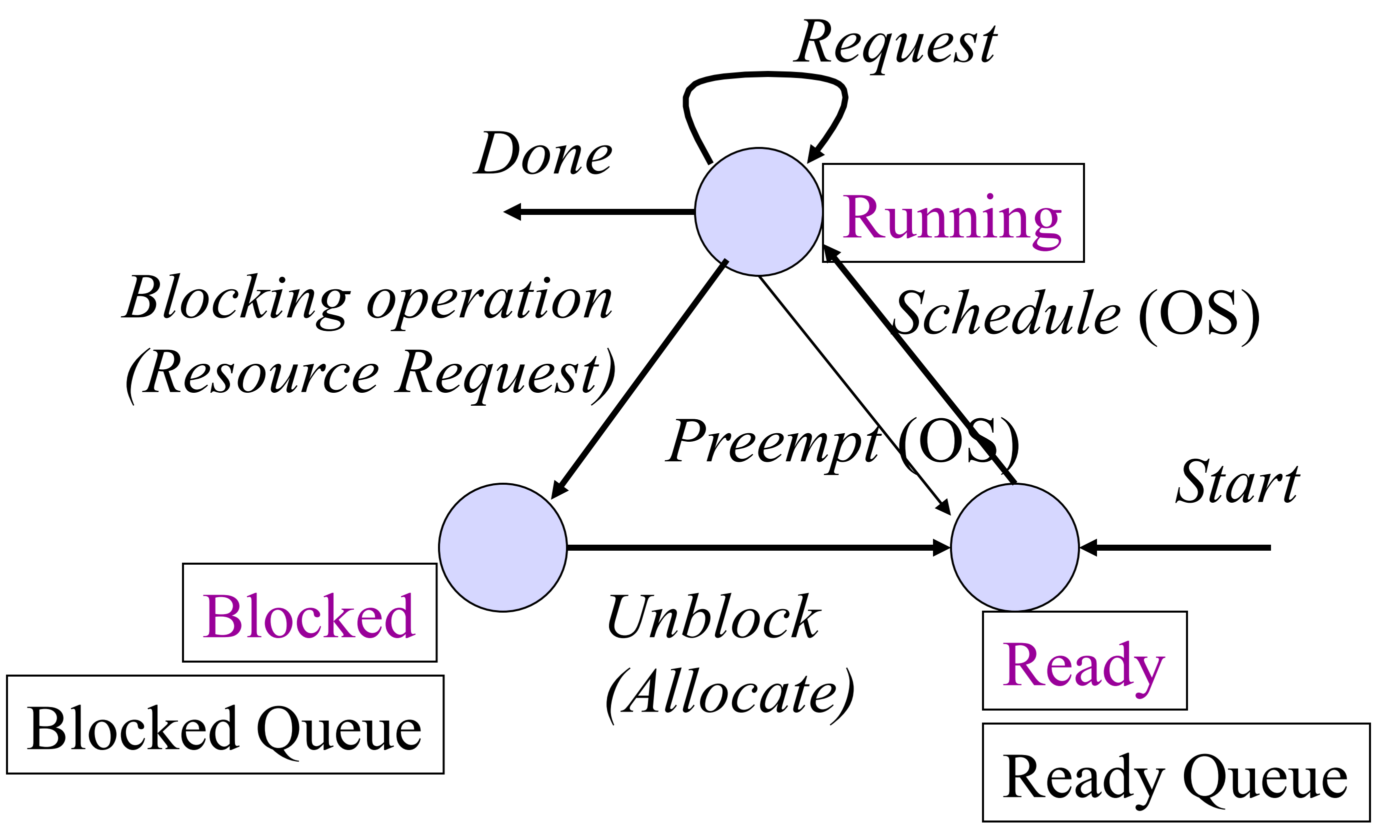
Process Manager

- Creation/deletion of processes (and threads)
- Synchronization of processes (and threads)
- Managing process state
  - Processor state like PC, stack ptr, etc.
  - Resources like open files, etc.
  - Memory limits to enforce an address space
- Scheduling processes
- Monitoring processes
  - Deadlock, protection

Process State

- Memory image: Code, data, heap, stack
- Process state, e.g. ready, running, or waiting
- Accounting info, e.g. process ID
- Program counter
- CPU registers
- CPU-scheduling info, e.g. priority
- Memory management info, e.g. base and limit registers, page tables
- I/O status info, e.g. list of open files

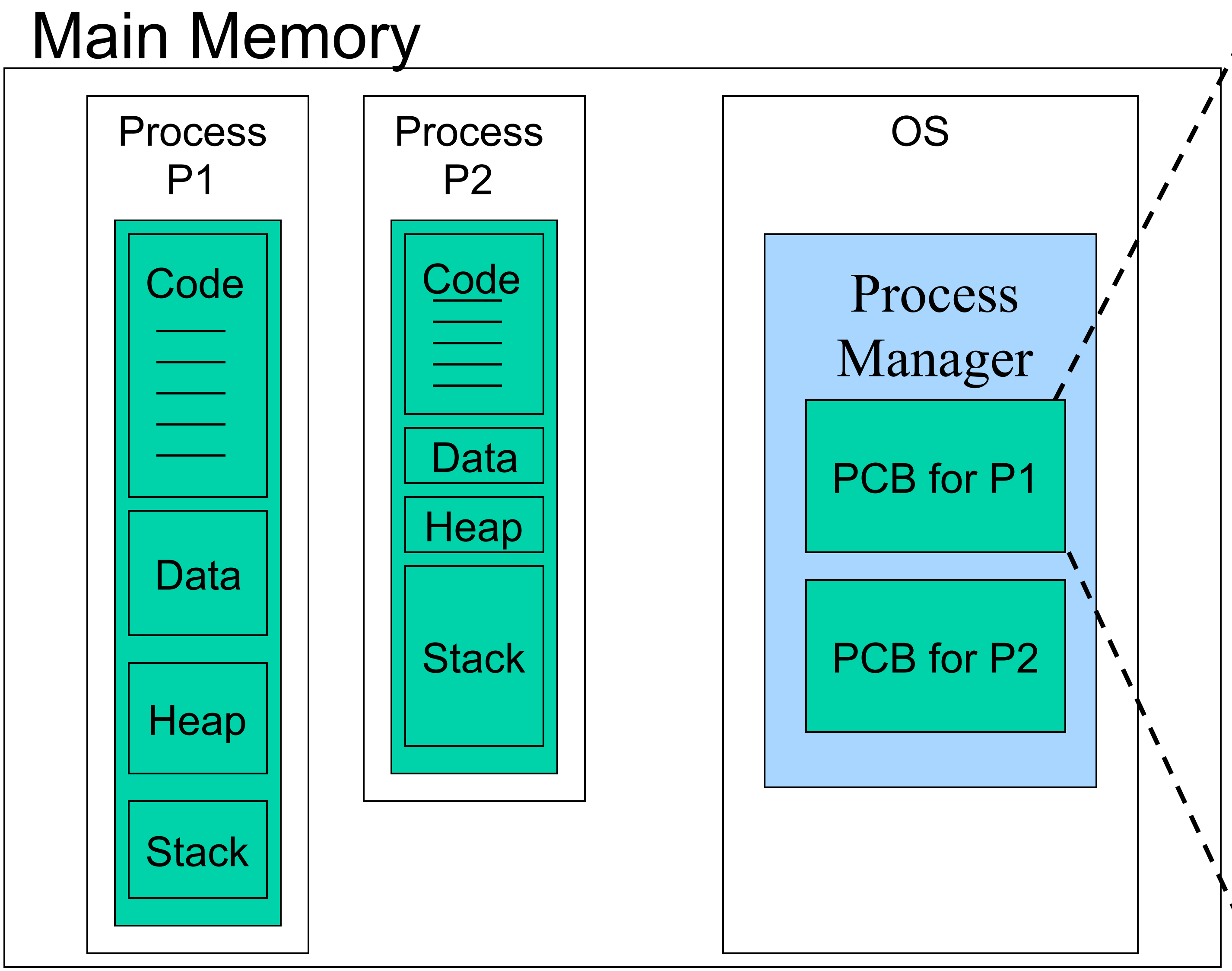
Process State Diagram



Process Control Block

- Each process is represented in OS by a process control block (PCB).
- PCB: Complete information of a process
- OS maintains a PCB table containing one entry for every process in the system.
- PCB table is typically of fixed size. This size determines the maximum number of processes an OS can have
  - The actual maximum may be less due to other resource constraints, e.g. memory.

Process Control Block (PCB)



A PCB is also called a Process Descriptor

- Process state, e.g. ready, running, or waiting
- accounting info, e.g. process ID
- Program Counter
- CPU registers
- CPU-scheduling info, e.g. priority
- Memory management info, e.g. base and limit registers, page tables
- I/O status info, e.g. list of open files

Context Switch

- Running state → Ready state
- Running state → Blocked state
- Switching the CPU from currently running process to another process
  - Save the state of the currently running process in its PCB
  - Load the saved state of new process scheduled to run from its PCB
  - Context switch time is pure overhead: 1 – 1000 microseconds.
  - An important goal in OS design is to minimize context switch time.

Creating Processes

- In Windows, there is a CreateProcess() call
  - Pass an argument to *CreateProcess()* indicating which program to start running
  - Invokes a system call to OS that then invokes process manager to:
    - allocate space in memory for the process
    - Set up PCB state for process, assigns PID, etc.
    - Copy code of program name from hard disk to main memory, sets PC to entry point in *main()*
    - Schedule the process for execution
  - As we will see, this combines UNIX's *fork()* and exec() system calls and achieves the same effect

Creating Processes in UNIX

- Use *fork()* command to create/spawn new processes from within a process
  - When a process (called parent process) calls *fork ()*, a new process (called child process) is created
  - Child process is an exact copy of the parent process
    - All addresses are appropriately mapped – We'll see this later under memory management
  - The child starts executing at the same point as the parent, namely just after returning from the *fork()* call

fork ()

- The fork() call returns an *int* value
  - In the parent process, returned value is child's PID
  - In the child, returned value is 0
  - Since both parent and child execute the same code starting from the same place, i.e. just after the fork(), then to differentiate the child's behavior from the parent's, you could add code:

```
PID = fork();
if (PID==0) { /* child */
   codeforthechild();
   exit(0);
}
/* parent's code here */
```

Loading Processes

- The exec() system call loads program code into the calling process's memory (same address space!), clears the stack, and begins executing the new code at its main entry point
  - The calling code is erased!
  - Use *fork()* and *exec()* (actually *execve()*) to create a new process executing a new program in a new address space

```
PID = fork();
if (PID==0) { /* child */
    exec("/bin/ls");
    exit(0);
}
/* the parent's code here */
```

More on Processes

- Copying the entire code of a parent into a child can be expensive on a *fork()*, so
  - at start, child can share parent's code pages. Only create a copy on a write.
- The *wait()* system call is used by a parent process to be informed of when a child has completed, i.e. called *exit()*
  - Once the parent has called *wait()*, the child's PCB and address space can be freed

More about this in recitation

Process Hierarchy

- OS creates a single process at the start up.
- An existing process can spawn one or more new processes during execution
  - Parent-child relationship
  - A parent process may have some control over its child process(es): suspend/activate execution; wait for termination; etc.
- A tree-structured hierarchy of processes
- Process hierarchy in Unix

<Figure>

Context Switch

- Linux allocates two stacks for each process: a user stack that resides in the user address space and a kernel stack that resides in the kernel
  - Kernel stack is used when the process is executing in the kernel (supervisor mode)
  - Kernel stack is needed for security purposes
  - OS allocates 8 KB for each kernel stack
  - Process's PCB is actually stored at one end of this space and the (kernel) stack starts from the other end
- Linux OS provides *schedule*( ), which is invoked by the timer interrupt to schedule a new process on the CPU
- The schedule( ) function calls another function *switch_to* ( ), which does the actual context switching

schedule and switch_to( ) function

- Here is an outline of schedule and switch_to functions (*actual implementations are in assembly code*)

```
schedule( )
{
    disable_interrupts;
    prev_proc = process id of running process
    next_proc = process id of the next process to run
    update ready_queue, system_queue, etc.
    switch_to (prev_proc, next_proc);
    running_process = prev_proc;
    enable_interrupts;
}

switch_to (prev_proc, next_proc)
{
    save the state of prev_proc in prev_proc's kernel stack
    load the state of next_proc from next_proc's kernel stack
}
```

Context switch Example

- For simplicity, we will assume a single stack
- Suppose P1 and P2 alternate their execution on CPU
- Lets assume P1 is running and a timer interrupt occurs to preempt this process

P1's stack

switch_to( ) function info
schedule( ) function info
timer interrupt service routing info
foo ( ) info (called from main( ))
main( ) function info

switch_to (p1, p2)
{
  save p1's state
  load p2's state
}

P1's instruction ptr

- Since P2’s state is loaded, P2 starts running
- Lets assume a timer interrupt occurs to preempt this process

P2’s stack

switch_to( ) function info
schedule( ) function info
timer interrupt service routing info
bar ( ) info (called from main( ))
main( ) function info

```
switch_to (p2, p1)
{
    save p2’s state
    load p1’s state
}
```

P2’s instruction ptr

- Now P1 starts running, since its state is loaded
- P1's instruction pointer is pointing to the end of its switch_to ( ), so that function will return
- Next, last two statements of the schedule function will execute and that function will return
- Next, the timer interrupt service routine completes and returns
- Finally, the execution of the foo( ) function resumes from the point where it was executing before P1 was preempted