CSCE 313-200
Introduction to Computer Systems
Spring 2018

Processes

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January 25, 2018

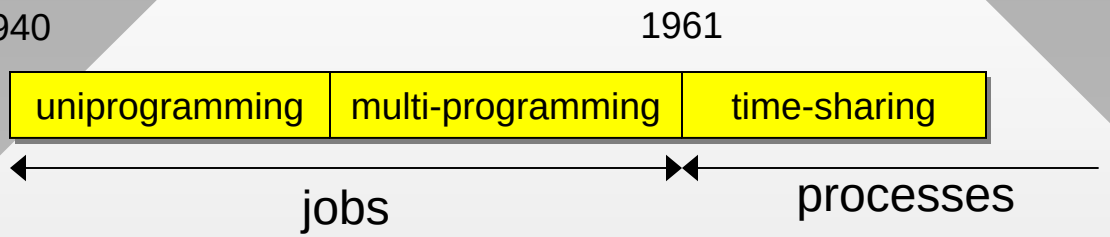
Chapter 3: Roadmap

- 3.1 What is a process?
- 3.2 Process states
- 3.3 Process description
- 3.4 Process control
- 3.5 Execution of the OS
- 3.6 Security issues
- 3.7 Unix process management

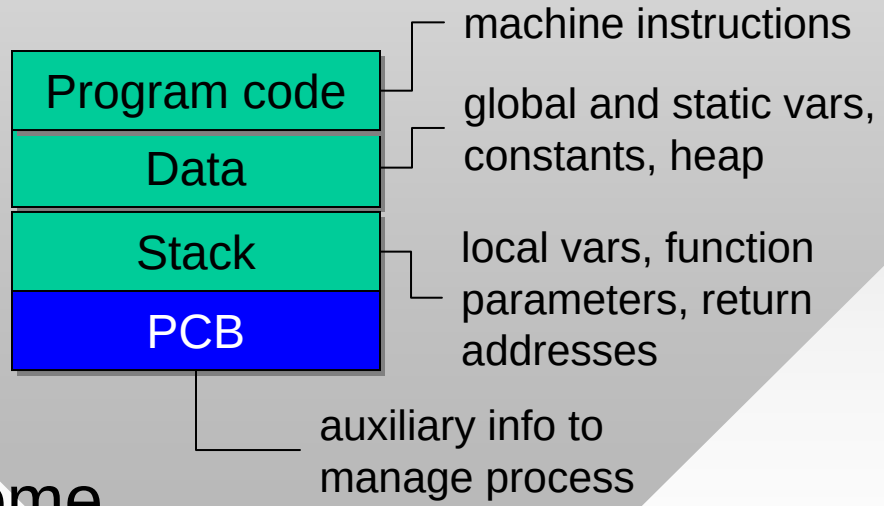
Part II

Chapter 3: Processes
Chapter 4: Threads
Chapter 5: Concurrency
Chapter 6: Deadlocks

Processes

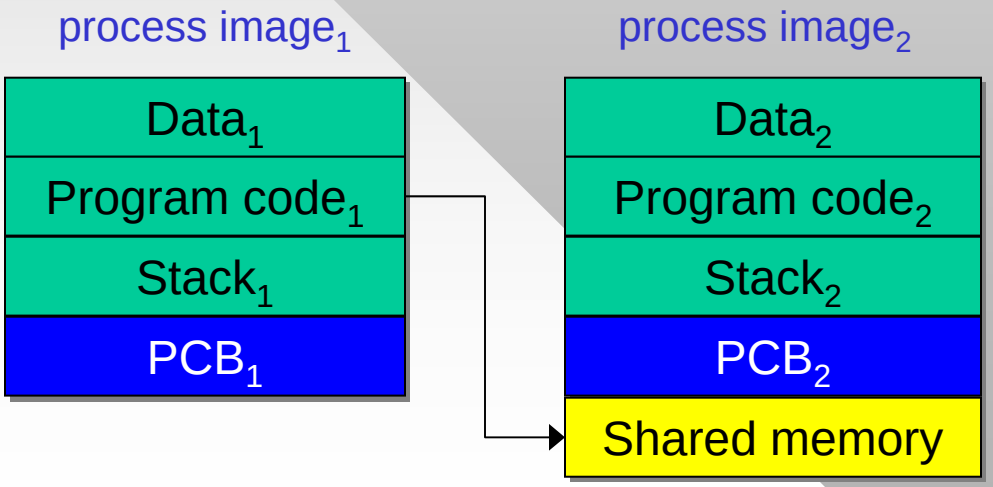


- From the 1960s, jobs were described by a special data structure that allowed the OS to systematically monitor, control, and synchronize them
- This became known as a process, which consists of:
  - Program in execution
  - Data
  - Stack
  - Process Control Block (PCB)
- Note that programs stored on disk do not become processes until they are started

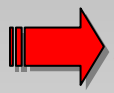


Processes

- Process image with shared memory
  - If shared memory is created by a process, it can be accessed in other processes in the system
  - This is called *memory mapping*
  - Just like named pipes, shared memory in Windows is addressable using some unique name



Chapter 3: Roadmap



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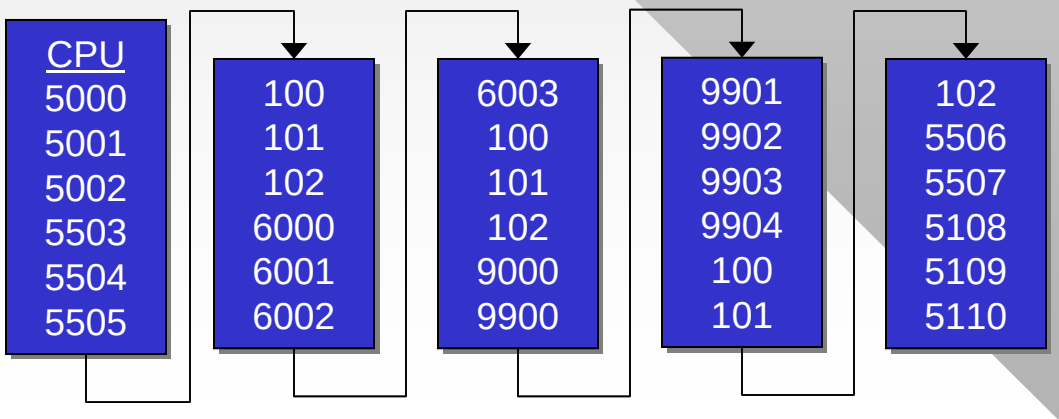
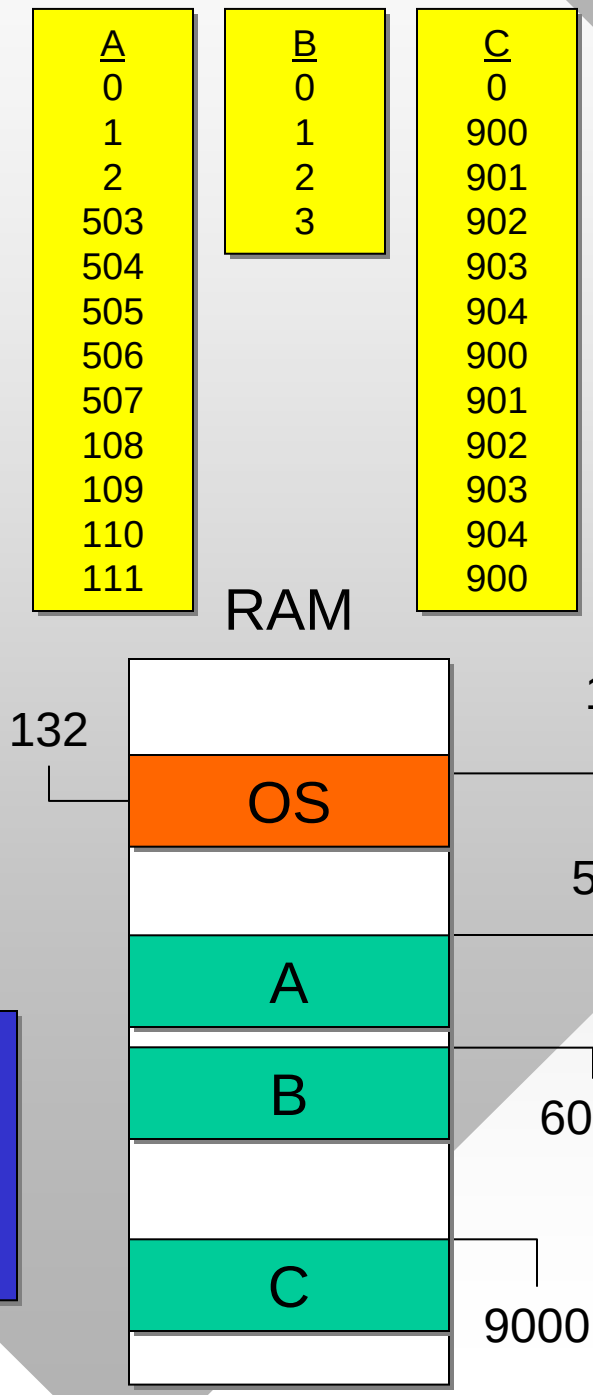
Process States

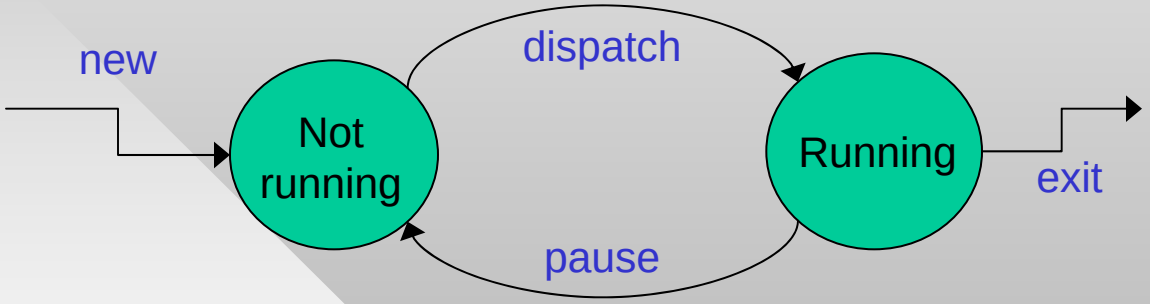
- Process trace
  - Offsets (i.e., relative addresses) of instructions executed by a process
- CPU trace
  - Sequence of absolute addresses executed by the CPU
  - Suppose OS allows 6 CPU instructions in a slice, needs 3 to perform a process switch



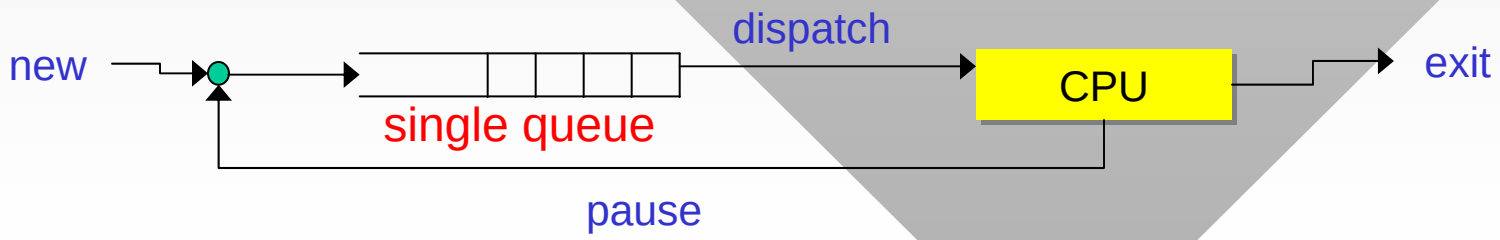


Process States

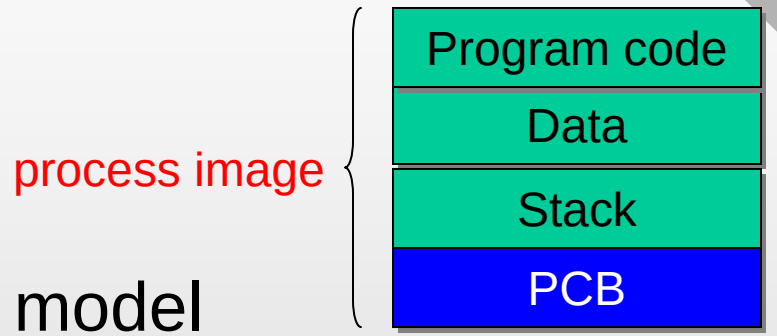
- This brings us to the issue of how the OS keeps track of the processes
- Simple *2-state model*:



- Implementation:



Process States

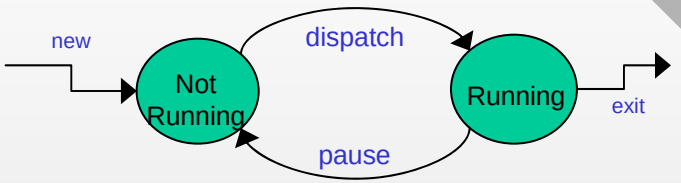


- Process creation in 2-state model
  - OS creates a PCB, loads necessary code and data in RAM, and moves process to the Not Running state
- Possible reasons for creation
  - Ready for next job in batch mode (old supercomputers)
  - User demand (command-line, login-related)
  - Needed by OS to serve a request
  - Explicitly spawned by a user program (e.g., CC.exe in hw #1)
- Original process is *parent*, spawned process *child*
  - Child may inherit access to certain open handles
  - Parent usually has full access rights to control the child (e.g., set its priority/affinity or terminate it)

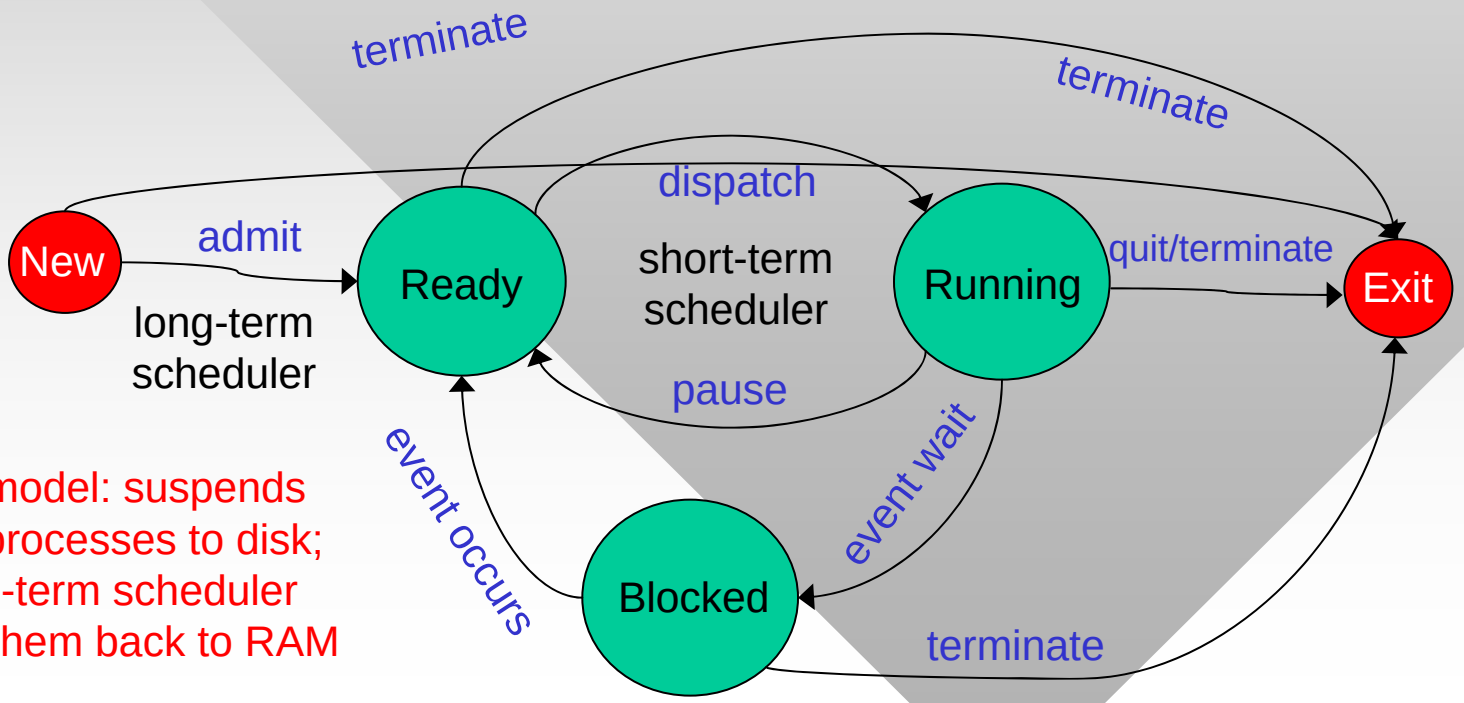
Process States

- Process termination
  - Normal completion
  - Access violation
  - Arithmetic error
  - Invalid instruction
  - Privileged instruction
  - User request (e.g., Ctrl-C)
  - Request by another process
- More rare cases
  - Not enough RAM (bad_alloc)
  - Time limit exceeded
  - I/O failure
  - Parent termination
- Stealthy crashes
  - Severe stack corruption may cause program to quit without any warning or error
- If code crashes in Release mode, will it crash in Debug?
  - Not necessarily
  - Some bugs can be seen only in release mode
  - Reasons?
- What about vice versa?

Process States



- Notice that 2-state model has no simple way of selecting the next ready process
  - Some might be blocked on I/O or events
- Next version, called *5-state model*, solves this:



7-state model: suspends blocked processes to disk; medium-term scheduler activates them back to RAM

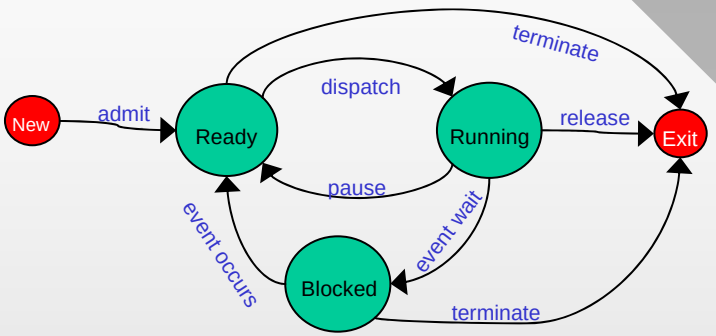
Process States

- Process creation in 5-state model
  - When the OS creates a PCB, it moves the process to New
  - However, data/code may still be on disk
- Given enough RAM, process is admitted to Ready
  - Code/data is loaded (fully or partially depending on whether virtual memory is available)
- Upon termination
  - Process memory is released, PCB is moved to the Exit state
  - May be beneficial to retain some PCB information (e.g., process exit code, PID, process handle)
  - Queries about a terminated process can be resolved using the PCB in the Exit state

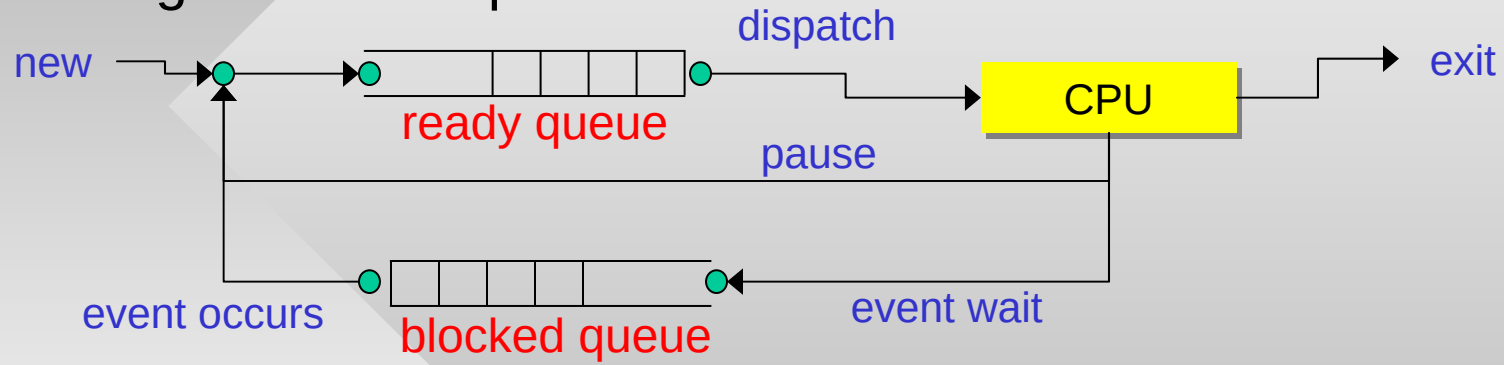
Process States

- Common transitions
  - Ready → Running: scheduler decides based on its policy (e.g., round-robin, strict priority, weighted round-robin)
  - Running→ Ready: either 1) time slice is over or 2) pre-empted by a higher-priority process in the Ready state
  - Running → Blocked: one of three options: process 1) voluntarily sleeping; 2) waiting for other processes (i.e., IPC); 3) waiting for I/O devices
  - Blocked → Ready: event signaled
  - Running → Exit: quits normally, crashes, or forced to quit
- Rarer cases
  - Ready → Exit, New→Exit, or Blocked → Exit: forced termination by user, OS, or another process

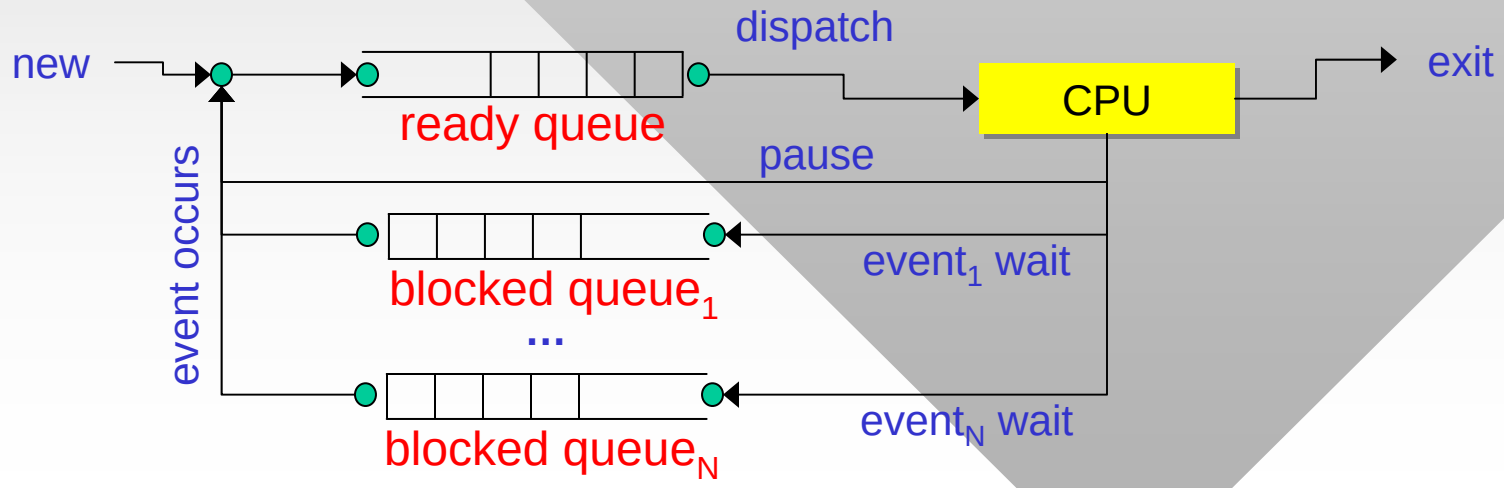
Process States



- Implementing 5-state model
  - Single blocked queue



  - Multiple blocked queues



Implementation Notes

- Example: weighted RR queuing
  - Accommodated by splitting each logical queue into K *physical* queues, one for each priority in the system
  - Overhead is O(1) for removal and addition of processes
  - Each physical queue i has weight w_i
  - Draw processes from queues with probability proportional to their weights (ignore empty queues)
- Can a process wait for multiple events?
  - Example: wait until *any* (or *all*) of the following occurs: message arrives from some pipe, packet is received from the network, mutex allows entry into some critical section
  - Which of the two modes is more often used?

Implementation Notes

- How to achieve multi-event wait in the kernel?
  - "Any" mode: add process to multiple queues, whichever pops it first unblocks it (other copies can be marked inactive)
  - "All" mode: difficult problem if the OS must ensure fairness, non-starvation, deadlock avoidance, and maximum efficiency
- WaitForMultipleObjects takes up to 64 handles
  - Works in either "any" or "all" mode
  - Wait expires based on a timeout
- There are cases (e.g., pipes, files) where read/write operations block potentially forever
  - To prevent deadlocking, APIs must support *non-blocking* (*asynchronous*) mode, where control is returned to the process regardless of whether data is ready or not

Implementation Notes

- Asynchronous notification
  - *Polling*: the process must periodically check on the status of the pending operation (Unix, Windows)
  - *Event-driven*: the API works with a special event handle that gets signaled when the operation is finished (Windows)
  - *Callback*: OS calls a specific function in the process (GUI applications such as MFC)
  - *I/O Completion Ports (IOCP)*: OS send notifications regarding previous requests into a shared queue that the process can read (Windows)
- If more than one request is pending to a given handle, the mode is called *overlapped*
  - See extra credit in homework #1 part 3

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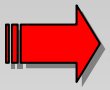
3.2 Process states



3.3 Process description

3.4 Process control

3.5 Execution of the OS

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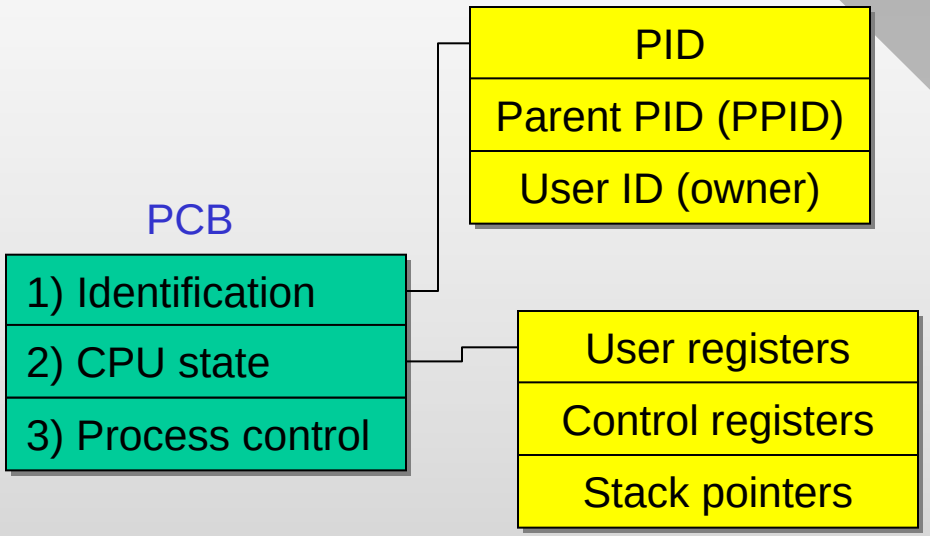
Process Description

- Process Control Block split into 3 general parts
- 1) Identification
  - Process ID (PID)
  - PPID sometimes needed to verify inherited rights
  - User/group IDs
- 2) CPU state is used during context (process) switches
  - User-modified registers (30-100 depending on the architecture)
  - Control registers (e.g., PC, flags)
  - Various stack pointers

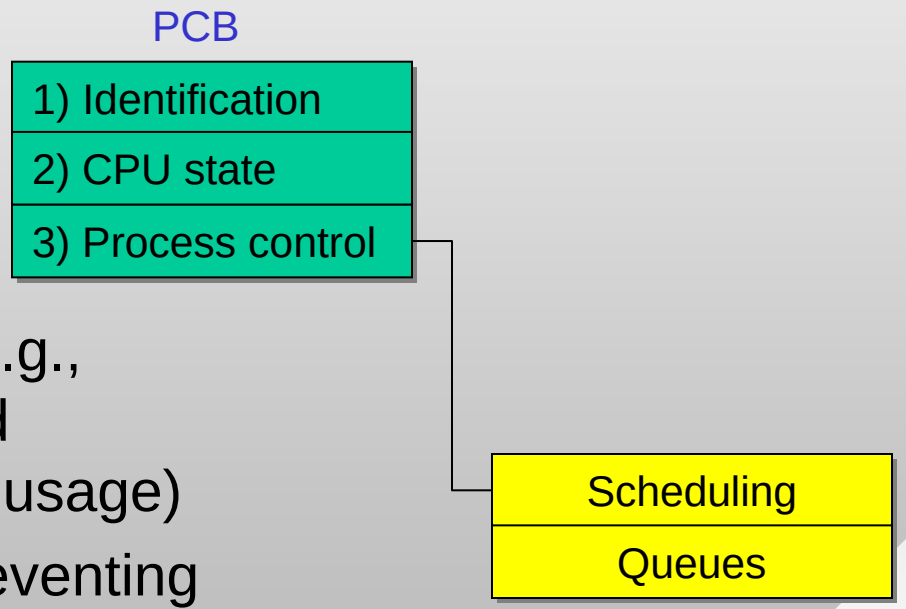


- Context switch entails
  - Storing all CPU/FPU registers into PCB of running process
  - Deciding which process to run next
  - Loading registers from context of that process

Process Description

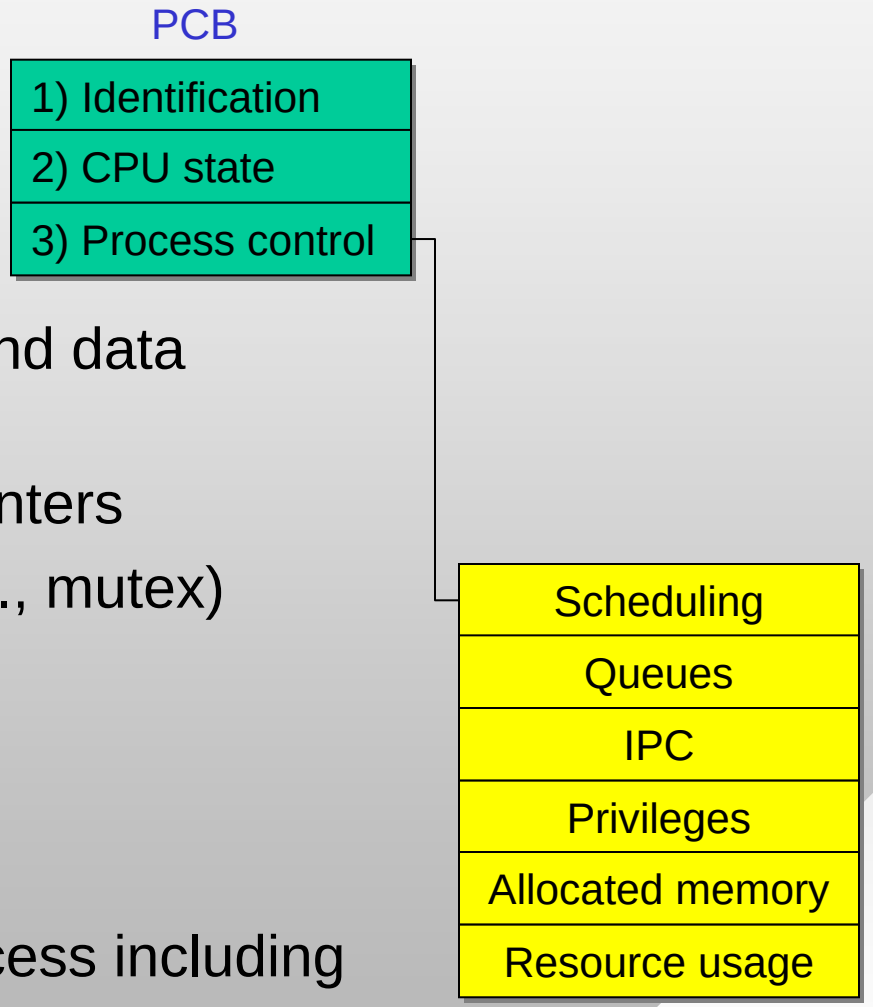
3) Process control information

- Scheduling
  - Process state (e.g., ready, running, blocked)
  - Priority class
  - Info that helps scheduler (e.g., current wait time, estimated completion time, past CPU usage)
  - Events (if any) currently preventing the process from being ready
- Queues
  - Various wait queues the process is part of (e.g., scheduler, device I/O)



Process Description

- Inter-process communication (IPC)
  - Message-passing handles and data (e.g., pipes, mailslots)
  - Shared memory handles/pointers
  - Synchronization objects (e.g., mutex)
- Privileges
  - Various system permissions
- Allocated memory
  - Virtual memory used by process including pages in pagefile
- Resource usage
  - Other open handles and various accounting



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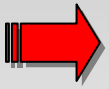

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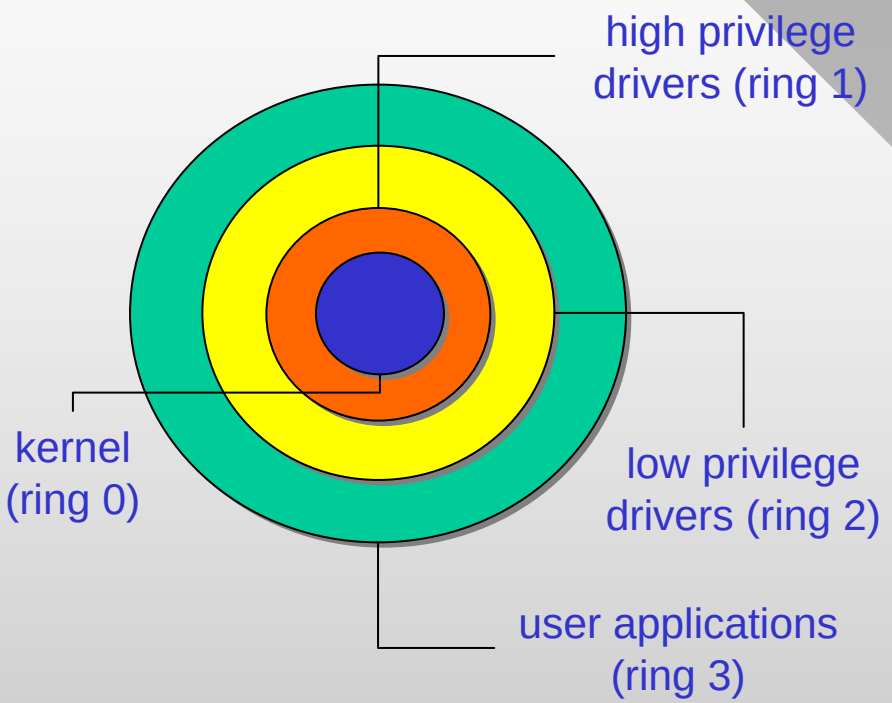
Execution Modes

- CPU provides at least 2 execution modes
  - User mode prohibits all I/O instructions, virtual table manipulation, access to blocks of RAM not owned by process, and modification of certain registers
  - Kernel mode has no restrictions
- Some architectures allow more than 2 modes
  - These are often called protection rings
  - More granularity to allow “intermediate” privileges to certain processes (e.g., printer driver should be able to perform I/O, but not modify virtual memory tables)
- Intel/AMD CPUs support 4 execution levels
  - Some older supercomputers had 8

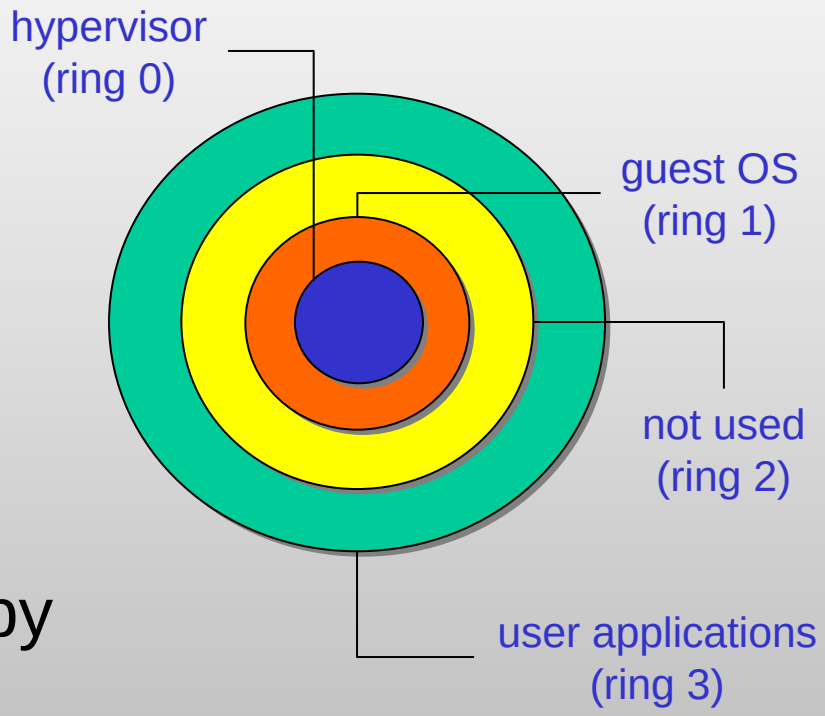
Execution Modes



- Consider a hypothetical 4-ring system:
  - Ring 3 always user mode
  - Ring 0 always kernel
  - Rings 1 and 2 depend on the implementation
- Windows and Linux support only rings 0 and 3
  - Partly because other architectures these can run on (e.g., PowerPC and MIPS) traditionally had only 2 modes
  - Partly to reduce complexity
- Main drawback of 2-level systems
  - Any driver crash bluescreens the system and forces a reboot

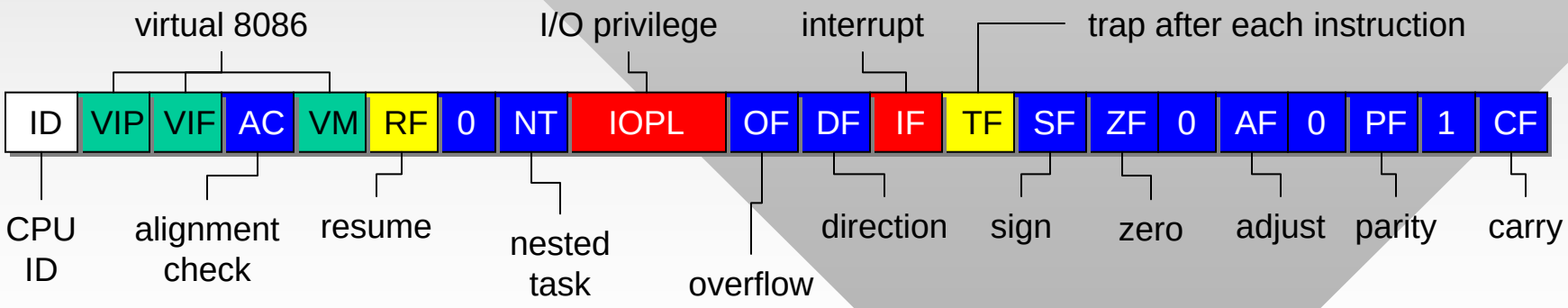
Execution Modes

- Microsoft virtualization server (Hyper-V) is an exception
  - Virtual machines (VM) allow multiple guest OSes to run transparently on the CPU
- Guest OSes are managed by the virtual machine monitor (VMM) called hypervisor
  - In contrast to normal kernels that are called supervisors
- Hypervisor runs in ring 0, guest OS in ring 1
  - AMD-V was supported starting with Athlon 64 (2006) and Intel VT-x starting with Pentium 4 (2005)



Mode Switch

- CPU support for changing execution mode
  - On some architectures special register called Program Status Word (PSW) tracks current mode
- On Intel, protection is scattered across many registers
  - CPL (current privilege level): 2 bits in CS (code segment) reg
  - DPL (data privilege level): 2 bits in virtual table of the segment
  - IOPL (I/O privilege level): 2 bits in EFLAGS register



- I/O requires CPL $\leq$ IOPL; data access CPL $\leq$ DPL

Mode Switch

- Upon interrupt or kernel call (syscall)
  - CPL cleared to 0
  - Old values of registers are stored in stack (and later in PCB if a context switch occurs)
  - Execution passed to kernel address
  - Interrupt return (iret) causes old values to be restored
- Violations of current execution mode must be supported by the CPU
  - Throws a general protection fault if it detects attempts to circumvent kernel defenses (e.g., read/write or execute parts of memory with insufficient CPL, modify certain flags, execute I/O instructions, exceed allocated segment size)
  - OS intercepts these interrupts and terminates the process

Context (Process) Switch

- OS can switch processes whenever it gains control (i.e., runs)
- When does the OS run?
- Three main instances:
  - External interrupt
  - CPU exception/fault/trap
  - System call
- Interrupts
  - Timer (e.g., slice over)
  - I/O (e.g., device ready)
- CPU Traps
  - Invalid instructions
  - Protection violations
  - Memory faults (e.g., virtual page not in RAM)
  - Arithmetic errors
- System calls
  - Kernel-level APIs invoked by user process
- Kernel may return control to current process, let it continue

Context (Process) Switch

- In fact, most non-timer interrupts do not switch processes
  - Short routines record interrupt conditions, reset the device, and return to user mode quickly
  - Later, other parts of the kernel (e.g., svchost.exe) perform full handling of the interrupt
  - Implemented via Deferred Procedure Calls (DPC) in Windows
- Process switch typically occurs only when either:
  - Time slice expires or process blocks on API
- Note that process switch requires mode switch, but not vice versa!
  - Q: Which of the two is more expensive?
- A: Process switch
  - Transition to kernel mode, selection of task to run, saving/restoring registers

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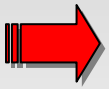

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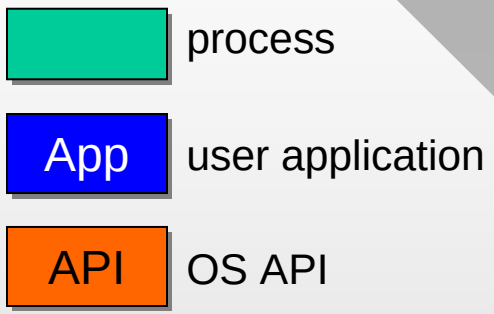
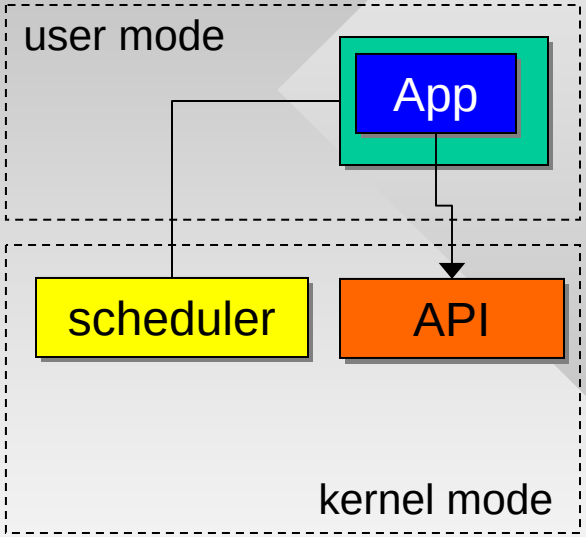
Execution of the OS



- Three ways to execute calls to OS

A

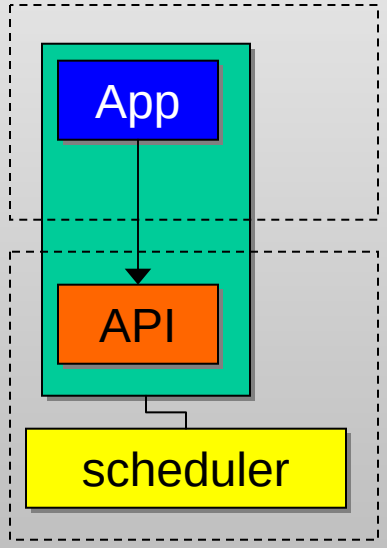


API executes in kernel outside any process

2 user-OS context switches and 2 mode switches

old monolithic Unix

B

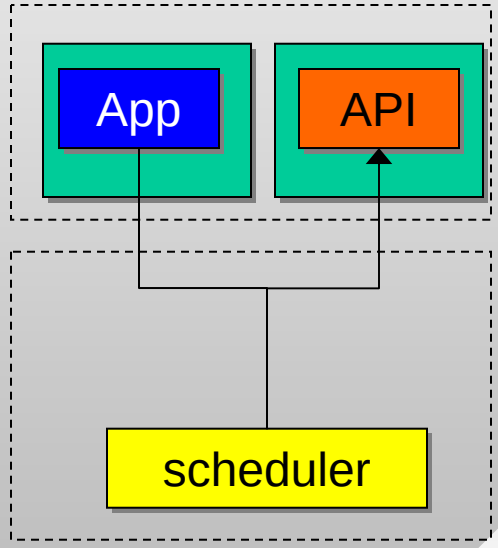


API executes in kernel mode as part of process

2 mode switches

Windows/Linux

C



API executes as separate user process

2 process context switches and 4 mode switches

micro-kernels

Execution of the OS

- Method A
  - Scheduler cannot interrupt the API when its running
  - 2 extra context switches per call compared to method B
- Method C (micro-kernels)
  - High switching overhead, but allows rapid user-mode API development
  - Better security as untrusted components (e.g., drivers) run in user mode
  - Certain high-security (e.g., military) applications
- Method B
  - Fastest switch to APIs, but less secure and more complex to develop
  - APIs must be *re-entrant*
  - Kernel attaches its own stack to each process image