Operating Systems
(1DT020 & 1TT802)

Lecture 2
Processes, threads, process dispatching

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http://www.it.uu.se/edu/course/homepage/os/vt08

What is an Operating System ?

- No universally accepted definition
  - "Everything a vendor ships when you order an operating system" is good approximation
  - "The one program running at all times on the computer" is the kernel.

☛An OS is responsible of 2 main tasks:

- Provide a virtual machine abstraction
  - » Turn hardware/software peculiarities into what programmers want/need
  - ☞application program view: an OS extends the processor's instruction set with new (complex) instructions accessible via system calls.
- Resources (Hardware and Software) management, sharing and protection
  - » Optimize for convenience, utilization, security, reliability, etc.

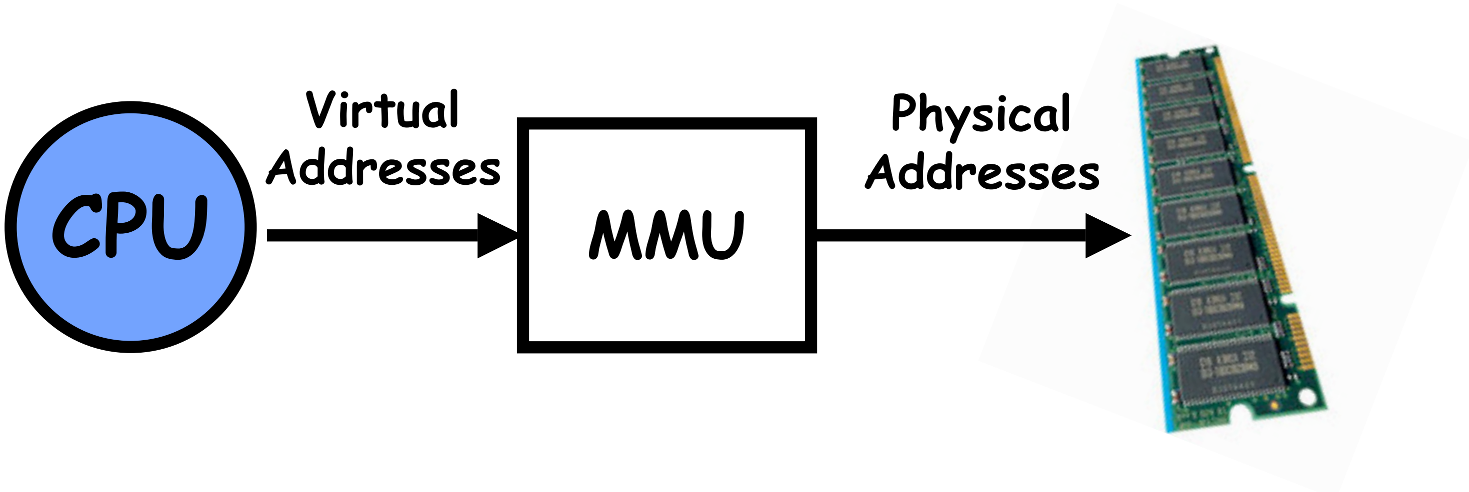
☞The 2 tasks are not separate

Example: Protecting Programs from Each Other

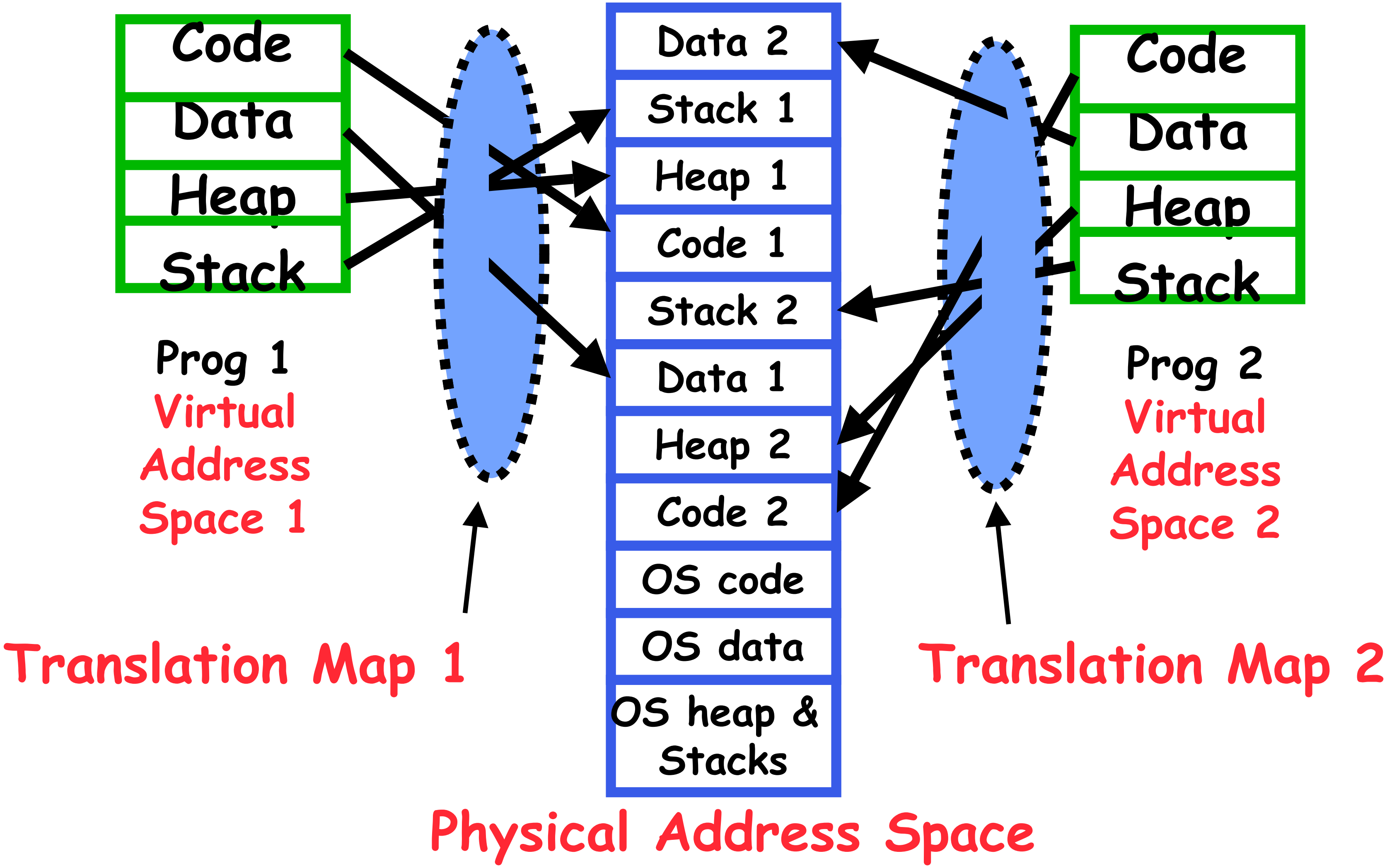
- **Problem: Run multiple applications in such a way that they are protected from one another**
- **Goal:**
  - **Keep User Programs from Crashing OS**
  - **Keep User Programs from Crashing each other**
  - **[Keep Parts of OS from crashing other parts?]**
- **(Some of the required) Mechanisms:**
  - **Address Translation**
  - **Dual Mode Operation**
- **Simple Policy:**
  - **Programs are not allowed to read/write memory of other Programs or of Operating System**

Address Translation

- **Address Space**
  - A group of memory addresses usable by something
  - Each program and kernel has potentially different address spaces.
- **Address Translation:**
  - Translate from Virtual Addresses (emitted by CPU) into Physical Addresses (of memory)
  - Mapping *often* performed in Hardware by Memory Management Unit (MMU)



Example of Address Translation



- **Translation helps protection:**
  - Control translations, control access
  - Users Should not be able to change Translation map

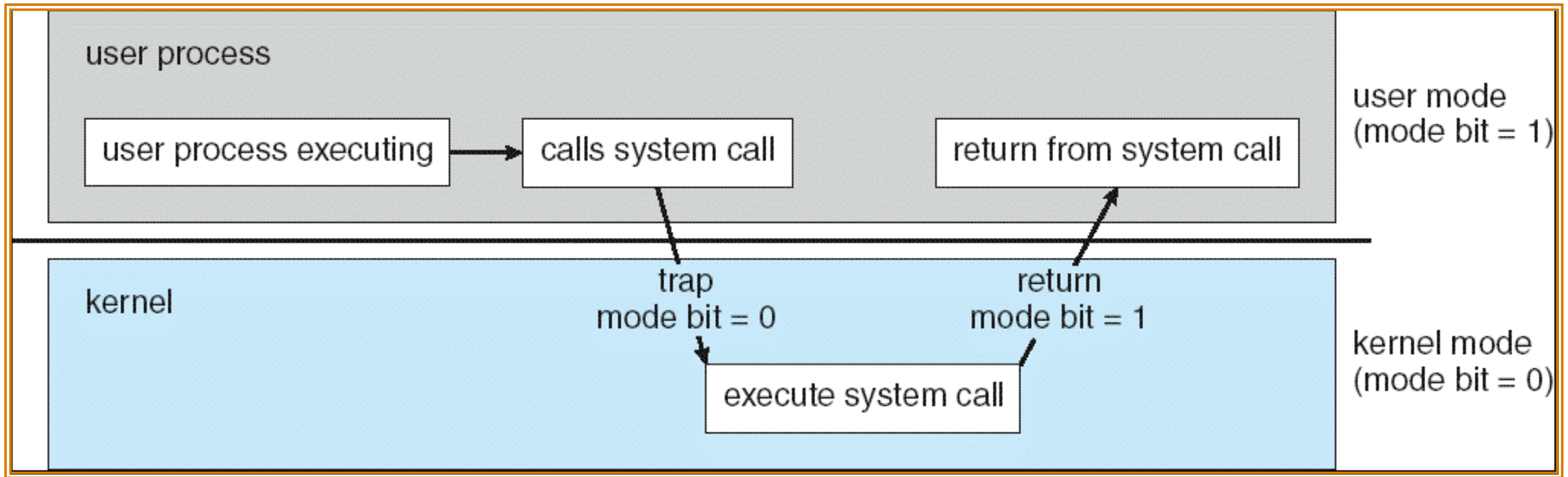
Goals for Today

- Finish goals of last lecture
- How do we provide multiprogramming?
- What are Processes?
- How are they related to Threads and Address Spaces?

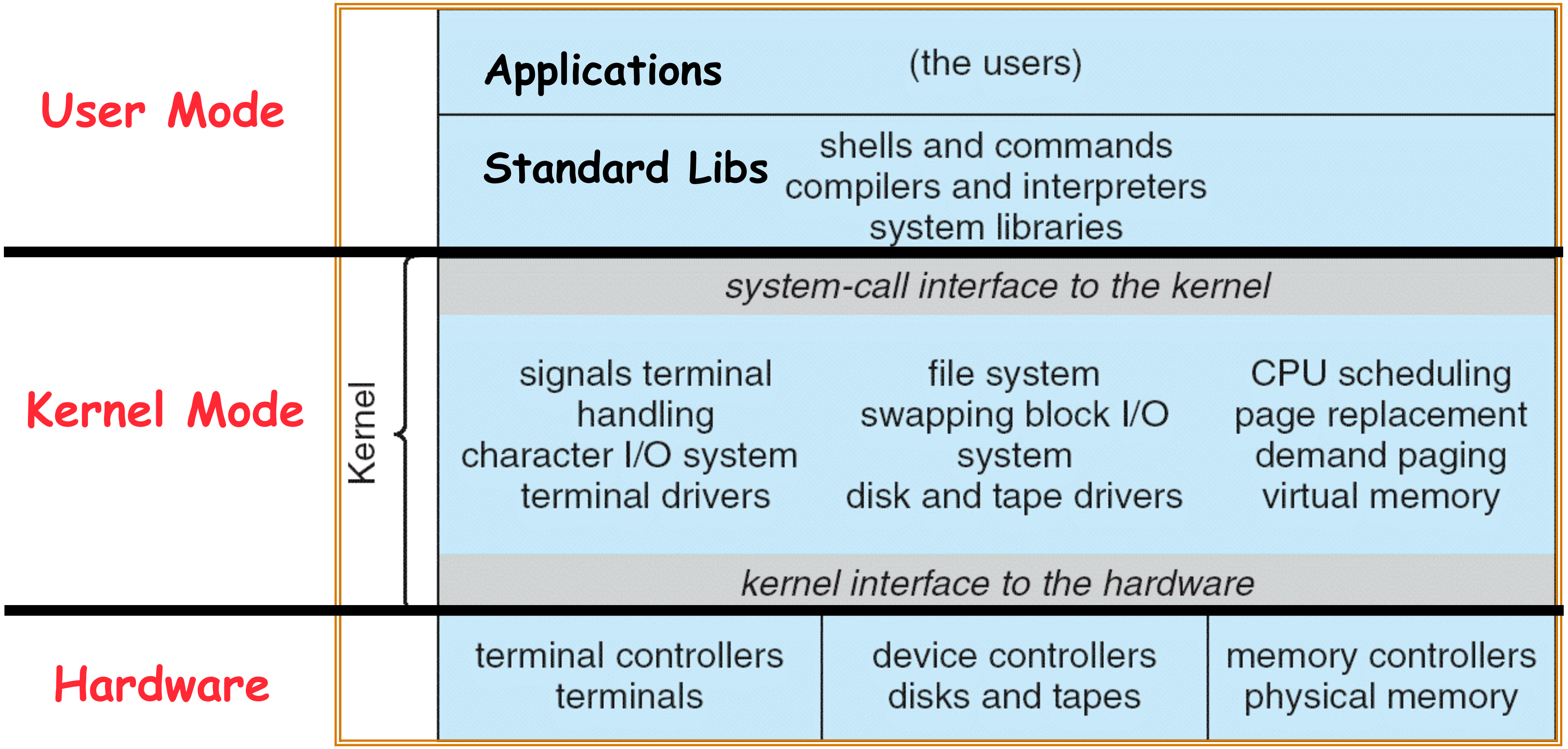
Note: Some slides and/or pictures in the following are adapted from slides ©2005 Silberschatz, Galvin, and Gagne, others from Kubiatowicz - CS162 ©UCB Fall 2007 (University of California at Berkeley)

Dual Mode Operation

- **Hardware provides at least two modes:**
  - **"Kernel" mode (or "supervisor" or "protected")**
  - **"User" mode: Normal programs executed**
- **Some instructions/ops prohibited in user mode:**
  - **Example: cannot modify page tables in user mode**
    - » **Attempt to modify ⇒ Exception generated**
- **Transitions from user mode to kernel mode:**
  - **System Calls, Interrupts, Other exceptions**



UNIX System Structure



OS Systems Principles

- **OS as illusionist:**
  - Make hardware limitations go away
  - Provide illusion of dedicated machine with infinite memory and infinite processors
- **OS as government:**
  - Protect users from each other
  - Allocate resources efficiently and fairly
- **OS as complex system:**
  - Constant tension between simplicity and functionality or performance
- **OS as history teacher**
  - Learn from past
  - Adapt as hardware tradeoffs change

Why Study Operating Systems?

- OS are complex systems:
  - How can you manage complexity for future projects?
- Buying and using a personal computer:
  - Why different PCs with same CPU behave differently
  - How to choose a processor (Opteron, Itanium, Celeron, Pentium, Hexium)? [Ok, made last one up]
  - Should you get Windows XP, Vista, Linux, Mac OS …?
- Security, viruses, and worms
  - What exposure do you have to worry about?
- Discover what is in the black box ! ☺

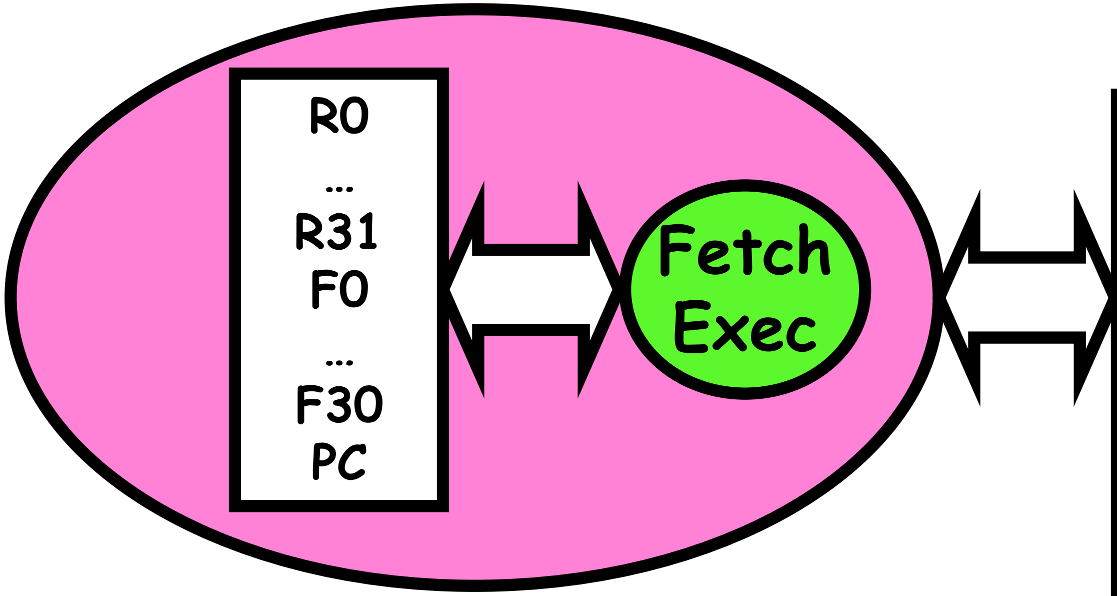
Concurrency

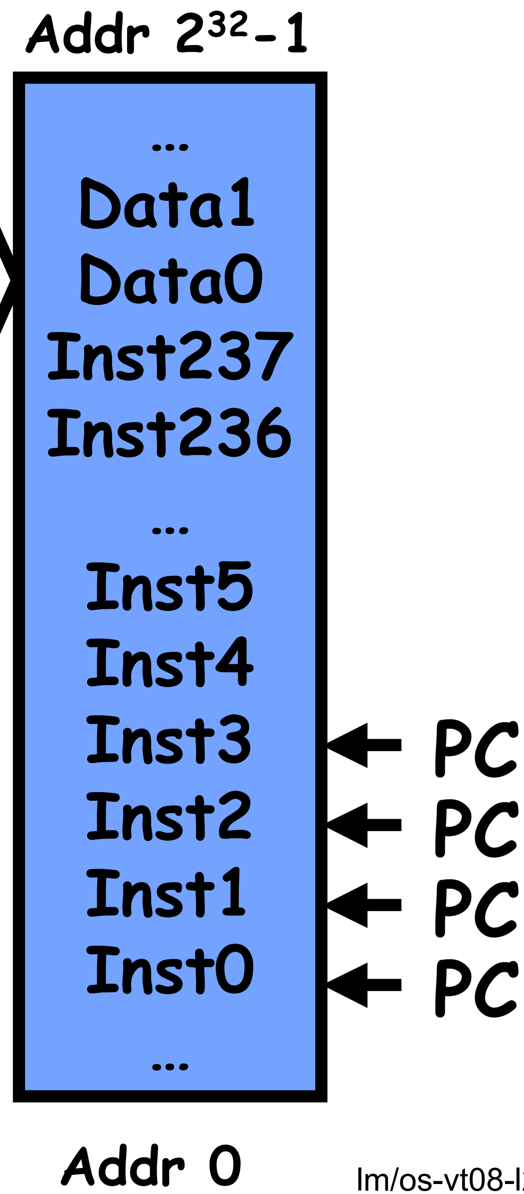
- **Stream ("thread") of execution**
  - **Independent Fetch/Decode/Execute loop**
  - **Operating in some Address space**
- **Uniprogramming: *one thread at a time***
  - **MS/DOS, early Macintosh, batch processing**
  - **Easier for operating system builder**
  - **Get rid concurrency by defining it away**
  - **Does this make sense for personal computers?**
- **Multiprogramming: *more than one thread at a time***
  - **Multics, UNIX/Linux, OS/2, Windows NT/2000/XP, Mac OS X**
  - **Often called "multitasking", but multitasking has other meanings (talk about this later)**

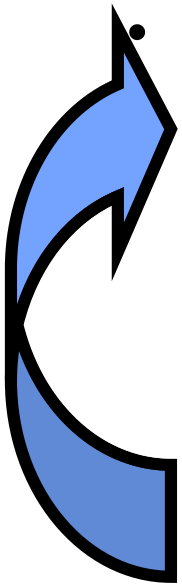
The Basic Problem of Concurrency

- The basic problem of concurrency involves resources:
  - Hardware: single CPU, single DRAM, single I/O devices
  - Multiprogramming API: users think they have exclusive access to machine
- OS Has to coordinate all activity
  - Multiple users, I/O interrupts, …
  - How can it keep all these things straight?
- Basic Idea: Use Virtual Machine abstraction
  - Decompose hard problem into simpler ones
  - Abstract the notion of an executing program
  - Then, worry about multiplexing these abstract machines
- Dijkstra did this for the “THE system”
  - Few thousand lines vs 1 million lines in OS 360 (1K bugs)

Recall (Computer Architecture): What happens during execution?

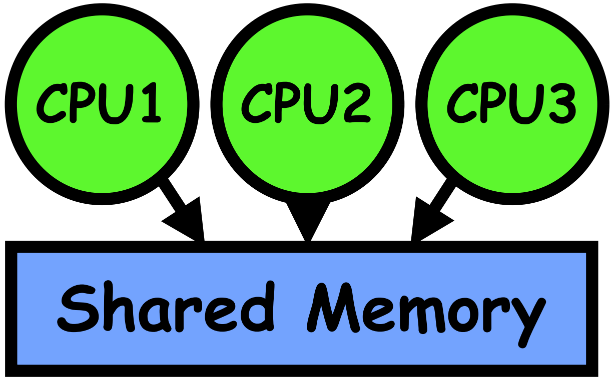


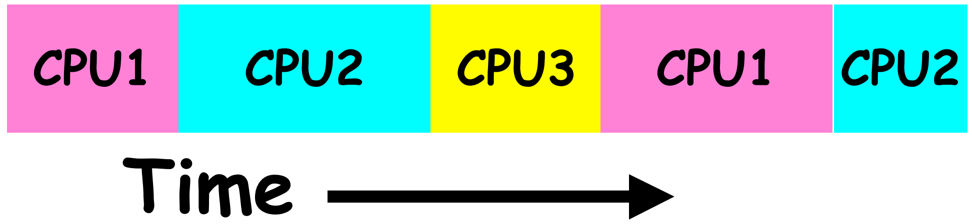




- **Execution sequence:**
  - Fetch Instruction at PC
  - Decode
  - Execute (possibly using registers)
  - Write results to registers or memory
  - PC = Next Instruction(PC)
  - Repeat

How can we give the illusion of multiple processors?





- How do we provide the illusion of multiple processors?
  – Multiplex in time!
- Each virtual “CPU” needs a structure to hold:
  – Program Counter (PC), Stack Pointer (SP)
  – Registers (Integer, Floating point, others…?)
- How do we switch from one CPU to the next?
  – Save PC, SP, and registers in current state block
  – Load PC, SP, and registers from new state block
- What triggers switch?
  – Timer, voluntary yield, I/O, other things

Properties of this simple multiprogramming technique

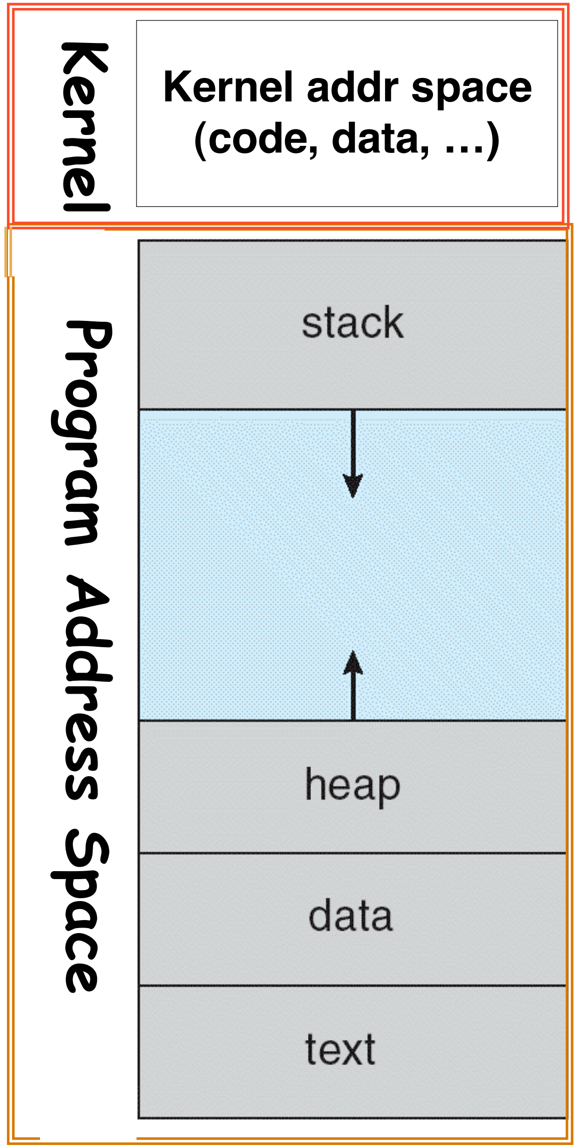
- All virtual CPUs share same non-CPU resources
  - I/O devices the same
  - Memory the same
- Consequence of sharing:
  - Each thread can access the data of every other thread (good for sharing, bad for protection)
  - Threads can share instructions (good for sharing, bad for protection)
  - Can threads overwrite OS functions?
- This (unprotected) model common in:
  - Embedded applications
  - Windows 3.1/Machintosh (switch only with yield)
  - Windows 95—ME? (switch with both yield and timer)

How to protect threads from one another?

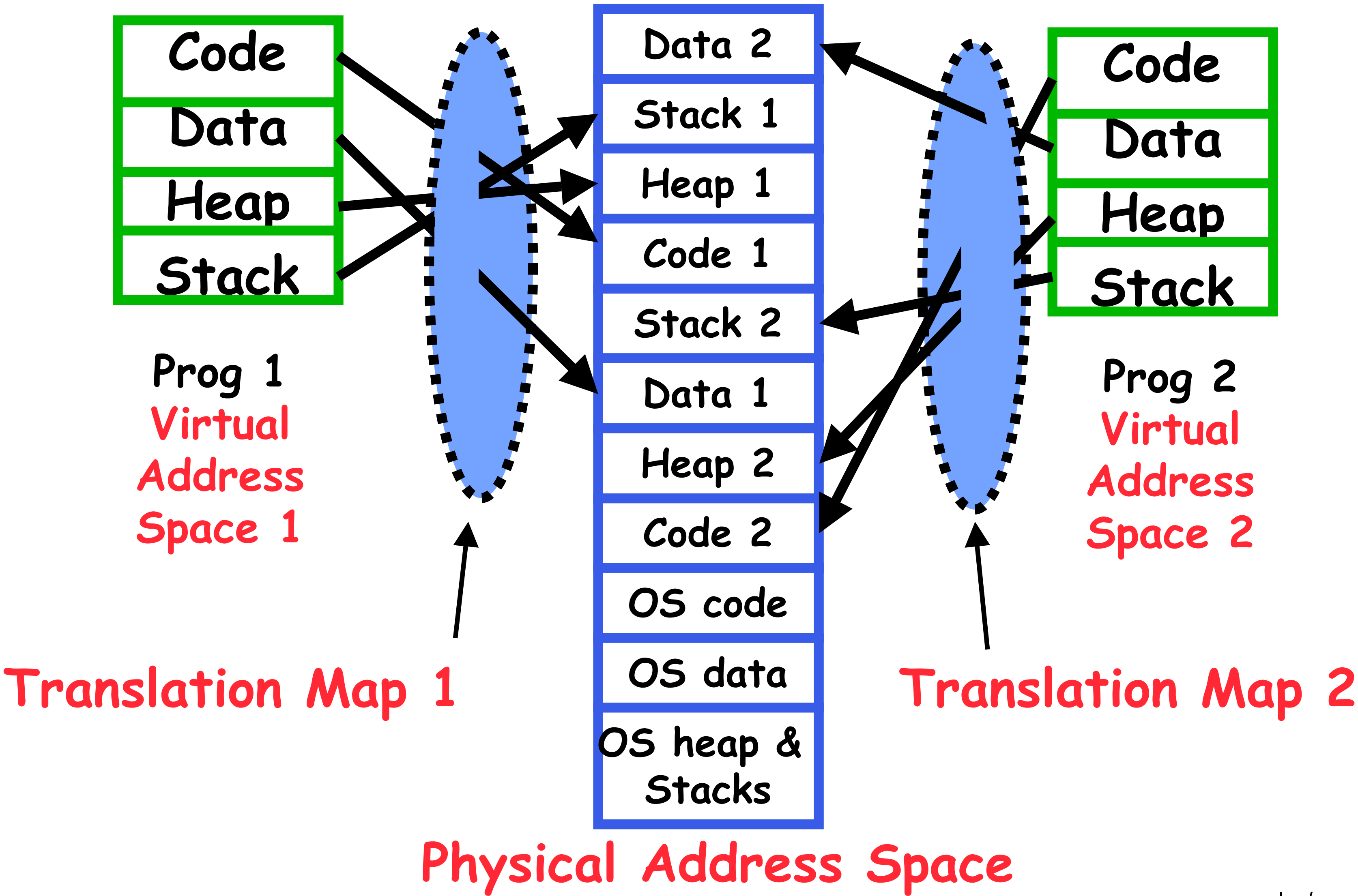
- **Need three important things:**
  1. **Protection of memory**
     - » **Every task does not have access to all memory**
  2. **Protection of I/O devices**
     - » **Every task does not have access to every device**
  3. **Preemptive switching from task to task**
     - » **Use of timer**
     - » **Must not be possible to disable timer from user code**

Recall: Program's Address Space

- **Address space ⇒ the set of accessible addresses + state associated with them:**
  - For a 32-bit processor there are 2^{32} = 4 billion addresses
  - Divided in user program address space and kernel address space
- **What happens when you read or write to an address?**
  - Perhaps Nothing
  - Perhaps acts like regular memory
  - Perhaps ignores writes
  - Perhaps causes I/O operation
    - » (Memory-mapped I/O)
  - Perhaps causes exception (fault)



Providing Illusion of Separate Address Space: Load new Translation Map on Switch



Traditional UNIX Process

- **Process: *Operating system abstraction to represent what is needed to run a single program***
  - **Often called a "Heavy Weight Process"**
  - **Formally: a single, sequential stream of execution in its *own* address space**
- **Two parts:**
  - **Sequential Program Execution Stream**
    - » **Code executed as a *single, sequential* stream of execution**
    - » **Includes State of CPU registers**
  - **Protected Resources:**
    - » **Main Memory State (contents of Address Space)**
    - » **I/O state (i.e. file descriptors)**
- **Important: There is no concurrency in a heavyweight process**

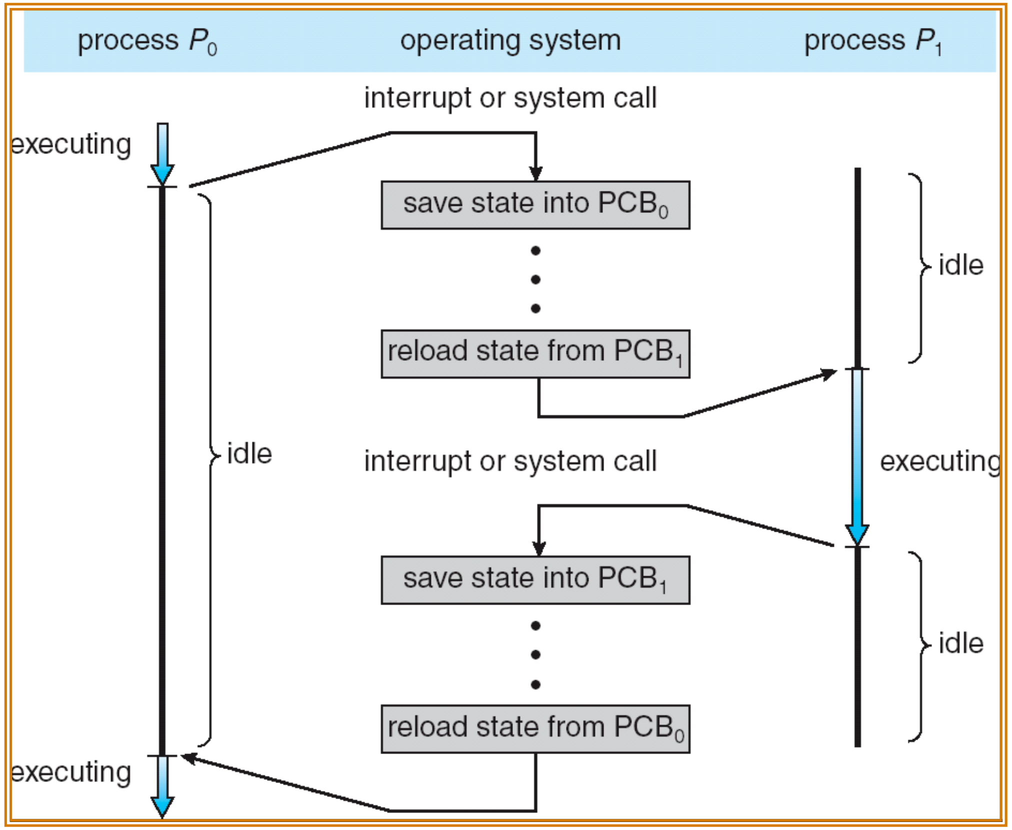
How do we multiplex processes?

- **The current state of process held in a process control block (PCB):**
  - This is a "snapshot" of the execution and protection environment
  - Only one PCB active at a time
- **Give out CPU time to different processes (CPU Scheduling or Process dispatching):**
  - Only one process "running" at a time
  - Give more time to important processes
- **Give pieces of resources to different processes (Protection):**
  - Controlled access to non-CPU resources
  - Sample mechanisms:
    - » Memory Mapping: Give each process their own address space
    - » Kernel/User duality: Arbitrary multiplexing of I/O through system calls

pointers	process state
process id	
program counter	
other registers	
memory limits	
list of open files	
⋮	

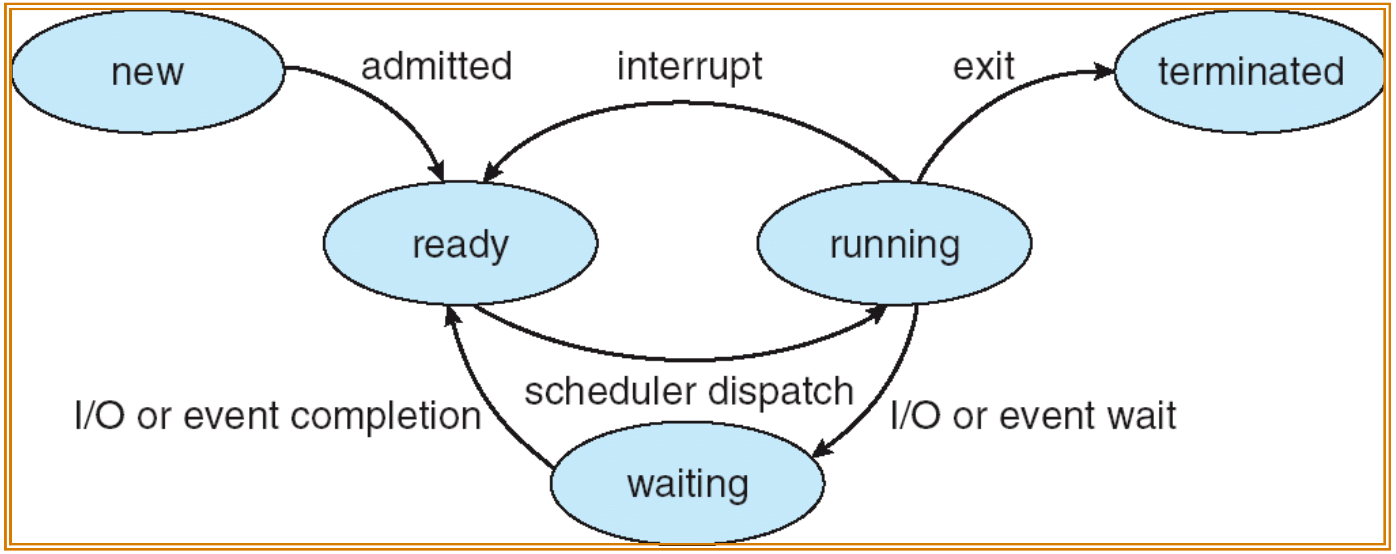
Process Control Block

CPU Switch From Process to Process



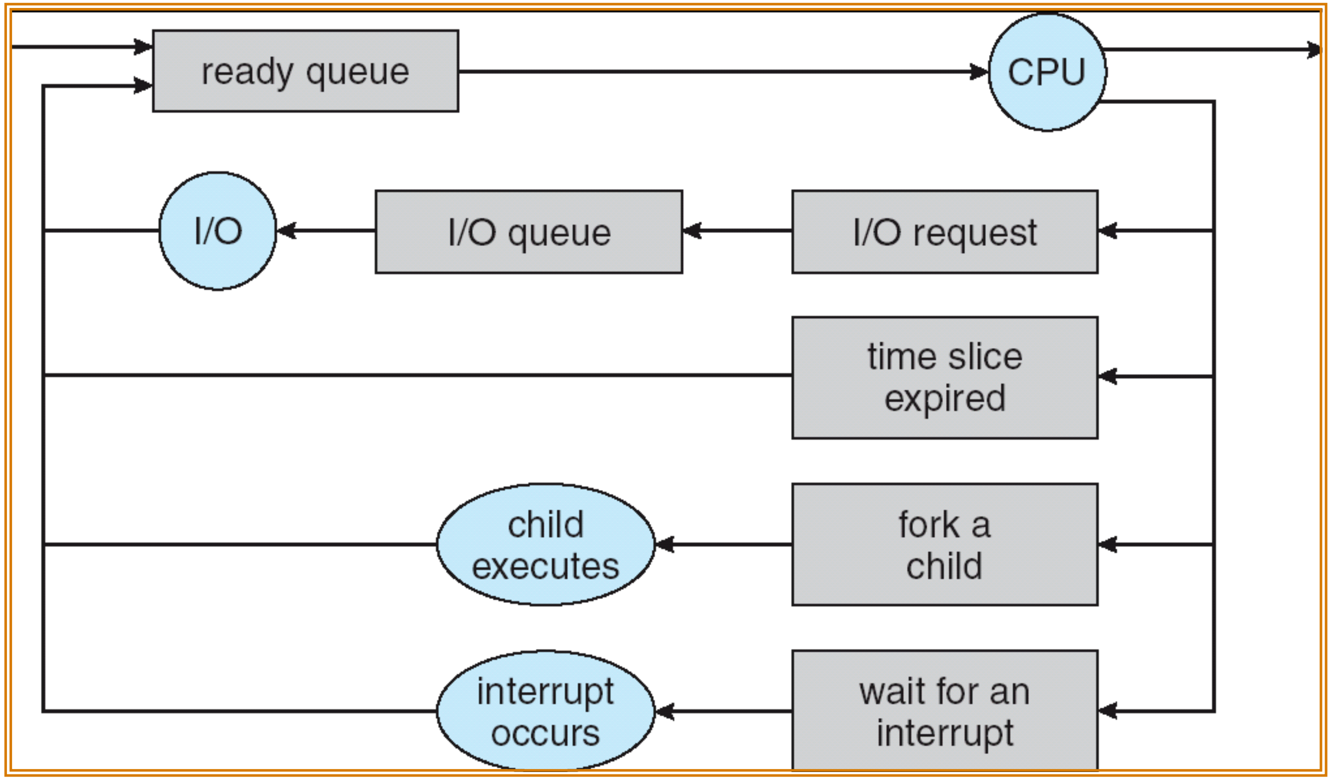
- **This is also called a "context switch"**
- **How long does it take to switch from one process to another ?**
- **Code executed in kernel above is overhead**
  - **Overhead sets minimum practical switching time**
  - **Less overhead with SMT/hyperthreading, but… contention for resources instead**

Diagram of Process State



- **As a process executes, it changes *state***
  - new: **The process is being created**
  - ready: **The process is waiting to run**
  - running: **Instructions are being executed**
  - waiting: **Process waiting for some event to occur**
  - terminated: **The process has finished execution**

Process Scheduling



- **PCBs move from queue to queue as they change state**
  - **Decisions about which order to remove from queues are Scheduling decisions**
  - **Many algorithms possible**

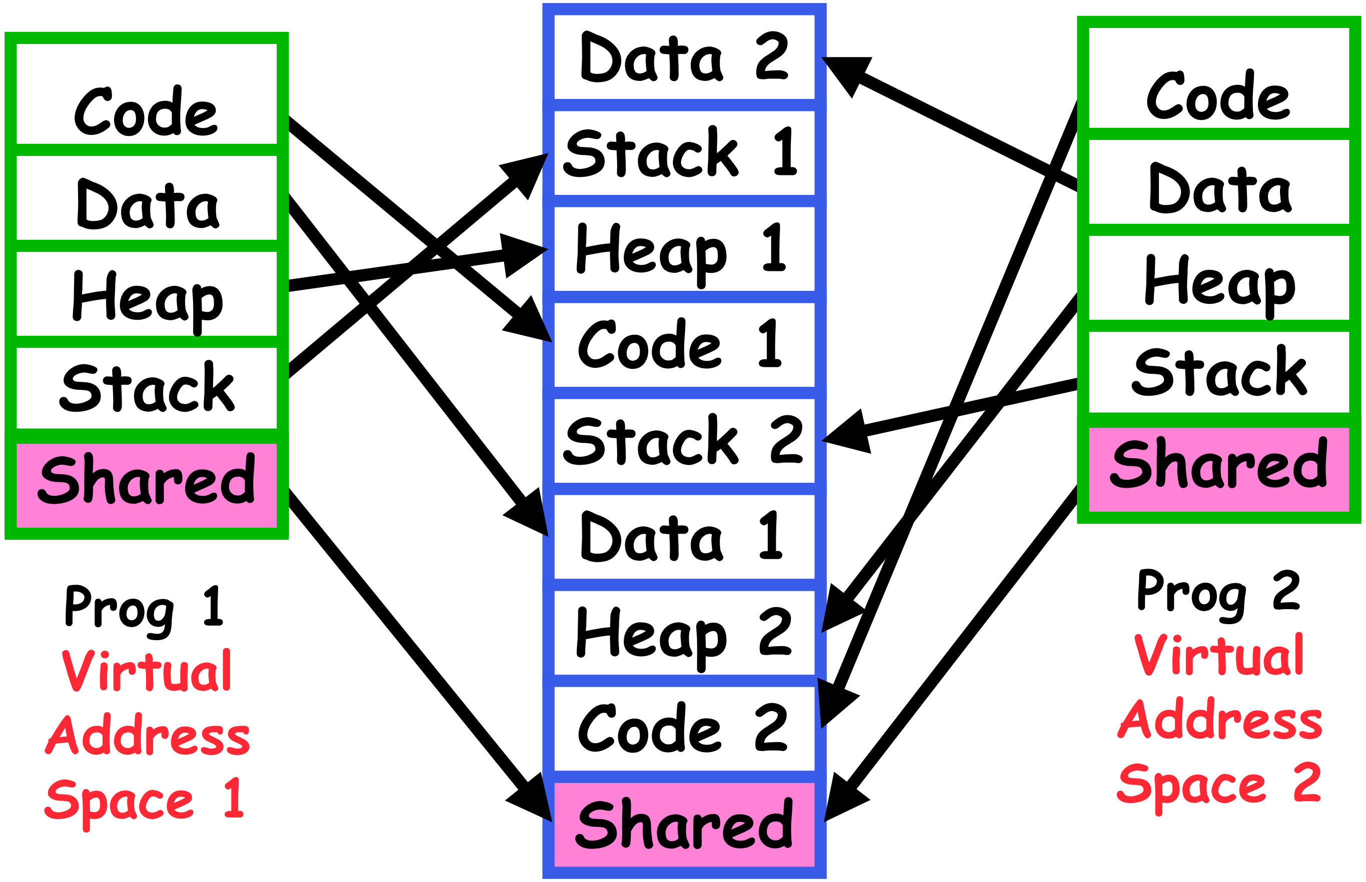
What does it take to create a process?

- Must construct new PCB
  - Inexpensive
- Must set up new translation map for address space
  - More expensive
- Copy data from parent process? (Unix `fork()`)
  - Semantics of Unix `fork()` are that the child process gets a complete copy of the parent memory and I/O state
  - Originally *very* expensive
  - Much less expensive with “copy on write”
- Copy I/O state (file handles, etc)
  - Medium expense

Multiple Processes Collaborate on a Task

- (Relatively) High Context-Switch Overhead
- Separate address spaces isolates processes
- Need Inter-Process Communication mechanism (IPC):
  - Shared-Memory Mapping
    - » Accomplished by mapping addresses to common DRAM
    - » Read and Write through memory
  - Message Passing
    - » `send()` and `receive()` messages
    - » Works across network

Shared Memory Communication



- **Communication occurs by "simply" reading/writing to shared address page**
  - **Really low overhead communication**
  - **Introduces complex synchronization problems**

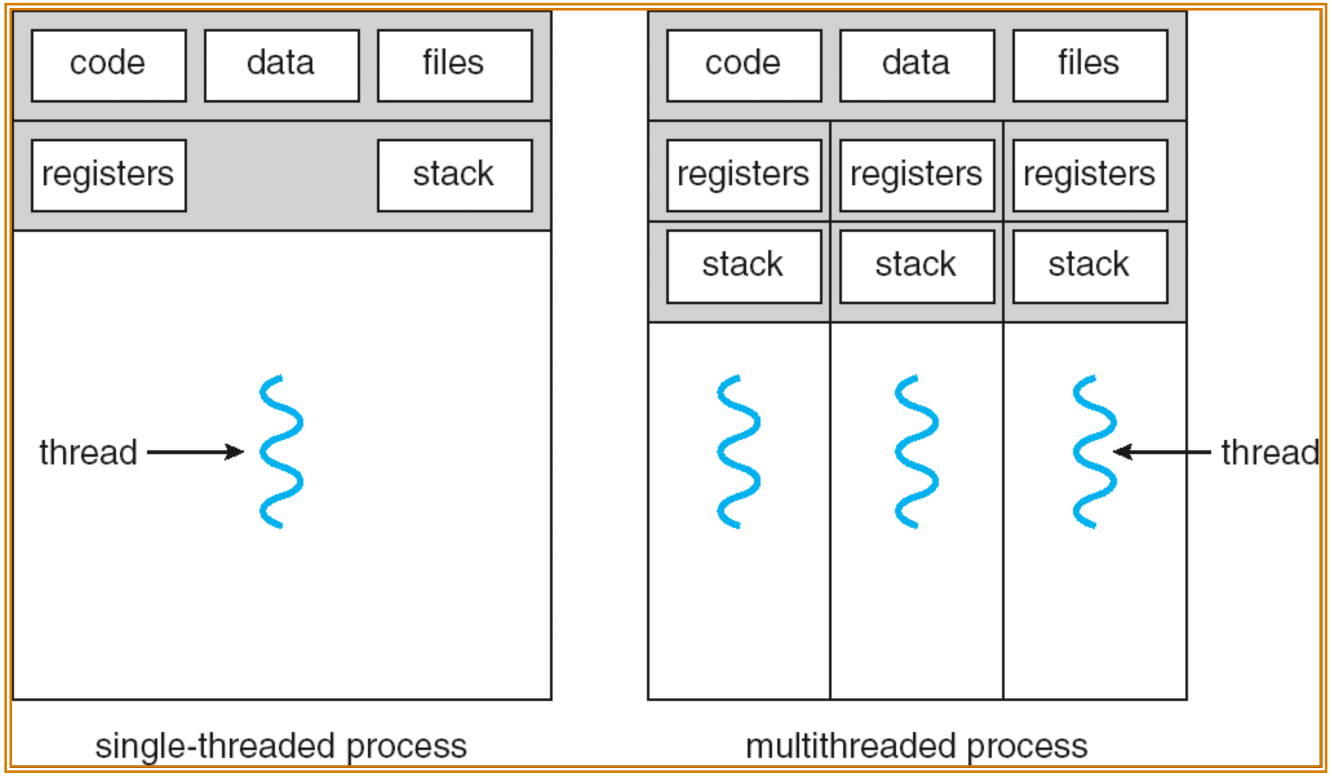
Message Passing Communication

- **Mechanism for processes to communicate and to synchronize their actions**
- **Message system – processes communicate with each other without resorting to shared variables**
- **Provides two operations:**
  - `send`(***message***) **– message size fixed or variable**
  - `receive`(***message***)
- **If *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, system calls/traps)**
  - **logical (software)**

Modern “Lightweight” Process with Threads

- **Thread:** ***a sequential execution stream within process*** **(Sometimes called a “Lightweight process”)**
  - **Process still contains a single Address Space**
  - **No protection between threads**
- **Multithreading:** ***a single program made up of a number of different concurrent activities***
  - **Sometimes called multitasking, as in Ada…**
- **Why separate the concept of a thread from that of a process?**
  - **Deal with the “thread” part of a process (concurrency) separate from the “address space” (Protection)**
- **Heavyweight Process ≡ Process with one thread**

Single and Multithreaded Processes



- Threads encapsulate concurrency: "Active" component
- Address spaces encapsulate protection: "Passive" part
  - Keeps buggy program from trashing the system
- Why have multiple threads per address space?

Examples of multithreaded programs

- **Embedded systems**
  - Elevators, Planes, Medical systems, Wristwatches
  - Single Program, concurrent operations
- **Most modern OS kernels**
  - Internally concurrent because have to deal with concurrent requests by multiple users
  - But no protection needed within kernel
- **Database Servers**
  - Access to shared data by many concurrent users
  - Also background utility processing must be done

Examples of multithreaded programs (con't)

- **Network Servers**
  - Concurrent requests from network
  - Again, single program, multiple concurrent operations
  - File server, Web server, and airline reservation systems
- **Parallel Programming (More than one physical CPU)**
  - Split program into multiple threads for parallelism
  - This is called Multiprocessing
- **Some multiprocessors are actually uniprogrammed:**
  - Multiple threads in one address space but one program at a time

Thread State

- **State shared by all threads in process/addr space**
  - Contents of memory (global variables, heap)
  - I/O state (file system, network connections, etc)
- **State "private" to each thread**
  - Kept in TCB ≡ Thread Control Block
  - CPU registers (including, program counter)
  - Execution stack – what is this?

- **Execution Stack**
  - Parameters, local variables, temporary storage
  - return PCs are kept while called procedures are executing

Classification

# threads Per AS: / # of addr spaces:	One	Many
One	MS/DOS, early Macintosh	Traditional UNIX
Many	Embedded systems (Geoworks, VxWorks, JavaOS,etc) JavaOS, Pilot(PC)	Mach, OS/2, Linux Windows 9x??? Win NT to XP, Solaris, HP-UX, OS X

- Real operating systems have either
  - One or many address spaces
  - One or many threads per address space
- Windows 95/98/ME did not have real memory protection
  - Users could overwrite process tables/System DLLs

Summary

- **Processes have two parts**
  - **Threads (Concurrency)**
  - **Address Spaces (Protection)**
- **Concurrency accomplished by multiplexing CPU Time:**
  - **Unloading current thread (PC, registers)**
  - **Loading new thread (PC, registers)**
  - **Such context switching may be voluntary (`yield()`, I/O operations) or involuntary (timer, other interrupts)**
- **Protection accomplished restricting access:**
  - **Memory mapping isolates processes from each other**
  - **Dual-mode for isolating I/O, other resources**