CS162
Operating Systems and Systems Programming
Lecture 2

Concurrency: Processes, Threads, and Address Spaces

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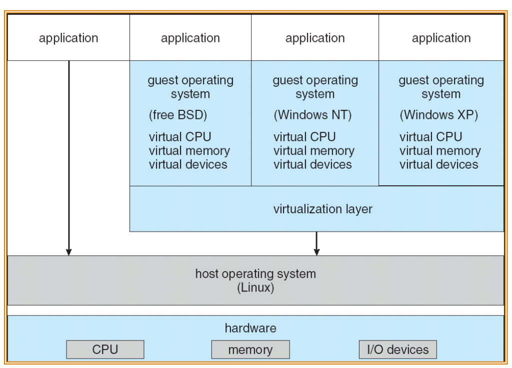
Virtual Machines (Recap)

- Software emulation of an abstract machine
  - Give programs illusion they own the machine
  - Make it look like hardware has features you want
- Two types of VMs
  - System VM: supports the execution of an entire OS and its applications (e.g., VMWare Fusion, Parallels Desktop, Xen)
  - Process VM: supports the execution of a single program; this functionality is typically provided by OS

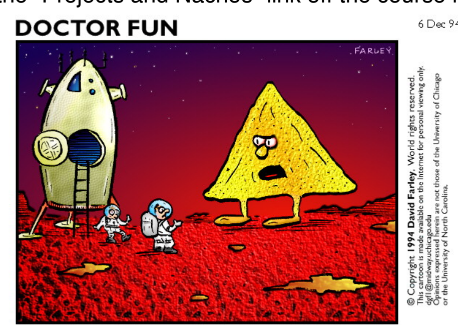
System VMs: Layers of OSs (Recap)

- Useful for OS development
  - When OS crashes, restricted to one VM
  - Can aid testing programs on other OSs



Nachos: Virtual OS Environment (Recap)

- You will be working with Nachos
  - Simulation environment: Hardware, interrupts, I/O
  - Execution of User Programs running on this platform
  - See the "Projects and Nachos" link off the course home page



"This is the planet where nachos rule."

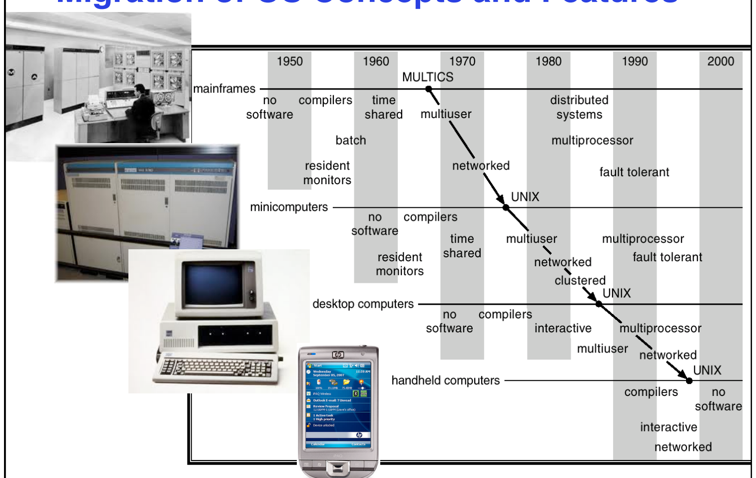
Operating System Roles (Recap)

- OS as a Traffic Cop:
  - Manages all resources
  - Settles conflicting requests for resources
  - Prevent errors and improper use of the computer
- OS as a facilitator ("useful" abstractions):
  - Provides facilities/services that everyone needs
  - Standard libraries, windowing systems
  - Make application programming easier, faster, less error-prone
- Some features reflect both tasks:
  - File system is needed by everyone (Facilitator) …
  - … but File system must be protected (Traffic Cop)

Very Brief History of OS

- Several Distinct Phases:
  - Hardware Expensive, Humans Cheap
    - » Eniac, … Multics
  - Hardware Cheaper, Humans Expensive
    - » PCs, Workstations, Rise of GUIs
  - Hardware Really Cheap, Humans Really Expensive
    - » Ubiquitous devices, Widespread networking
- Rapid Change in Hardware Leads to changing OS
  - Batch ⇒ Multiprogramming ⇒ Timesharing ⇒ Graphical UI ⇒ Ubiquitous Devices
  - Gradual Migration of Features into Smaller Machines
- Situation today is much like the late 60s
  - Small OS: 100K lines/Large: 10M lines (5M browser!)
  - 100-1000 people-years

Migration of OS Concepts and Features



Goals for Today

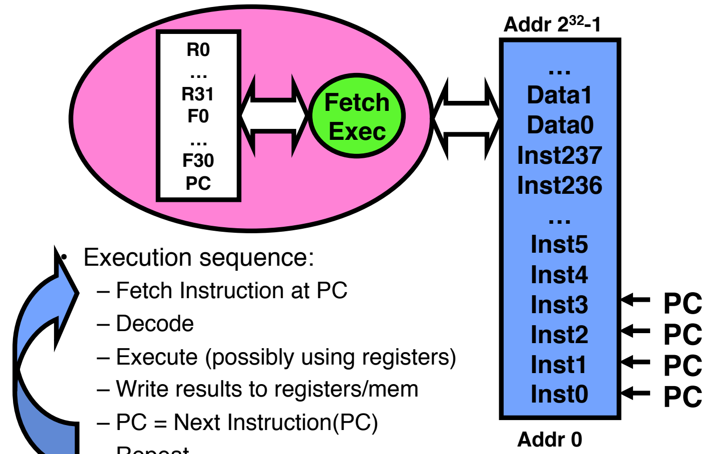
- How do we provide multiprogramming?
- What are **processes**?
- How are they related to **threads** and **address spaces**?

Note: Some slides and/or pictures in the following are adapted from slides ©2005 Silberschatz, Galvin, and Gagne. Slides courtesy of Anthony D. Joseph, John Kubiatowicz, AJ Shankar, George Necula, Alex Aiken, Eric Brewer, Ras Bodik, Ion Stoica, Doug Tygar, and David Wagner.

Threads

- Unit ("thread") of execution:
  - Independent Fetch/Decode/Execute loop
  - Unit of scheduling
  - Operating in some **address space**

Recall (61C): What happens during execution?



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

Uniprograming vs. Multiprograming

- Uniprogramming: *one thread at a time*
  - MS/DOS, early Macintosh, batch processing
  - Easier for operating system builder
  - Get rid of concurrency (only one thread accessing resources!)
  - Does this make sense for personal computers?
- Multiprogramming: *more than one thread at a time*
  - Multics, UNIX/Linux, OS/2, Windows NT – 8, Mac OS X, Android, iOS
  - Often called "multitasking", but multitasking has other meanings (talk about this later)
- ManyCore ⇒ Multiprogramming, right?

Challenges of Multiprograming

- Each application wants to own the machine → **virtual machine abstraction**
- Applications compete with each other for resources
  - Need to arbitrate access to shared resources → **concurrency**
  - Need to protect applications from each other → **protection**
- Applications need to communicate/cooperate with each other → **concurrency**

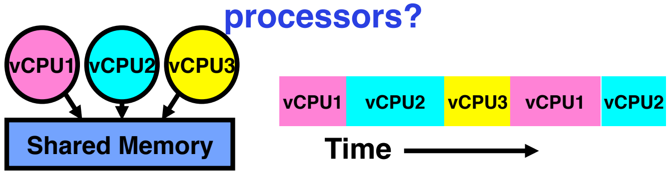
Processes

- **Process:** unit of resource allocation **and** execution
  - Owns memory (address space)
  - Owns file descriptors, file system context, …
  - Encapsulate one or more threads sharing process resources
- Why **processes**?
  - Navigate fundamental tradeoff between protection and efficiency
  - Processes provides memory protection while threads don't (share a process memory)
  - Threads more efficient than processes (later)
- Application instance consists of one or more processes

The Basic Problem of Concurrency

- The basic problem of concurrency involves resources:
  - Hardware: single CPU, single DRAM, single I/O devices
  - Multiprogramming API: processes think they have exclusive access to shared resources
- OS has to coordinate all activity
  - Multiple processes, I/O interrupts, …
  - How can it keep all these things straight?
- Basic Idea: Use Virtual Machine abstraction
  - Simple machine abstraction for processes
  - Multiplex these abstract machines
- Dijkstra did this for the "THE system"
  - Few thousand lines vs 1 million lines in OS 360 (1K bugs)

How can we give the illusion of multiple processors?



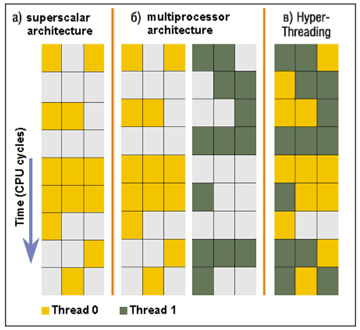
- Assume a single processor. How do we provide the illusion of multiple processors?
  - Multiplex in time!
- Each virtual "CPU" needs a structure to hold:
  - Program Counter (PC), Stack Pointer (SP)
  - Registers (Integer, Floating point, others…?)
- How switch from one virtual CPU to the next?
  - 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 is common in:
  - Embedded applications
  - Windows 3.1/Early Macintosh (switch only with yield)
  - Windows 95—ME (switch with both yield and timer)

Modern Technique: Simultaneous MultiThreading/Hyperthreading

- Hardware technique
  - Exploit natural properties of superscalar processors to provide illusion of multiple processors
  - Need to replicate registers, but higher utilization of processor resources
- Can schedule each thread as if were separate CPU
  - But, non-linear speedup!



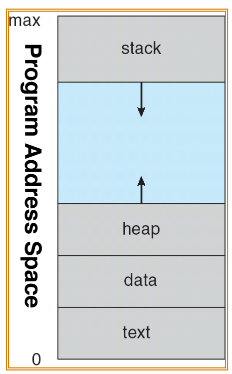
- Original technique called "Simultaneous Multithreading"
  - See http://www.cs.washington.edu/research/smt/index.html
  - SPARC, Pentium 4/Xeon ("Hyperthreading"), Power 5

How to protect threads from one another?

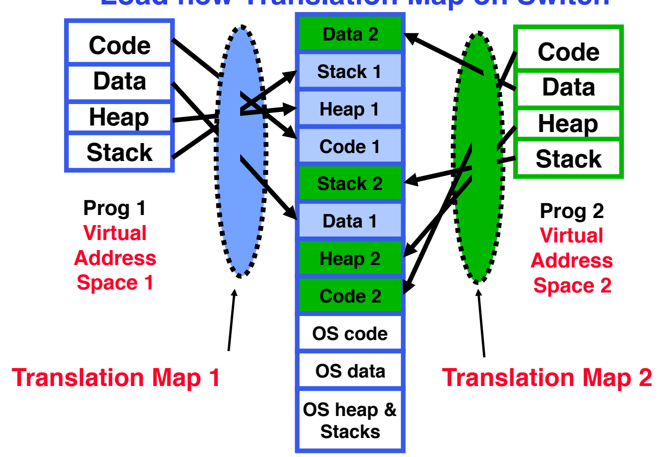
1. Protection of memory
   - Every thread does not have access to all memory
2. Protection of I/O devices
   - Every thread does not have access to every device
3. Protection of access to processor: preemptive switching from thread to thread
   - Use of timer
   - Must not be possible to disable timer from usercode

Recall: Program's Address Space

- Address space ⇒ the set of accessible addresses + associated states:
  - For a 32-bit processor there are 2^{32} = 4 billion addresses
- 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



Physical Address Space

Administrivia

- We are using Piazza instead of the newsgroup
  - Got to http://www.piazza.com/berkeley/spring2013/cs162
  - Make an account and join Berkeley, CS 162
  - Please ask questions on Piazza instead of emailing TAs
- Already registered and need an account form?
  - See a TA after class/section or email cs162@cory
  - Department will process the waitlist until Wednesday
- Don't know Java well?
  - Take CS 9G self-paced Java course
  - Read David Eck's free Java book
- We may have pop quizzes…

Administrivia: Project Signup

- Project Signup: Use "*Group/Section Signup*" Link
  - 4-5 members to a group, *everyone must attend the same section*
    - » The sections assigned to you by Telebears are temporary!
  - Only submit once per group! Due Thu (1/31) by 11:59PM
    - » Everyone in group must have logged into their cs162-xx accounts once before you register the group, *Select at least 3 potential sections*
- New section assignments: Watch "*Group/Section Assignment*" Link
  - Attend new sections NEXT week

Section	Time	Location	TA
101	Tu 10:00A-11:00A	6 Evans	David
102	Tu 11:00A-12:00P	75 Evans	David
103	Tu 1:00P-2:00P	75 Evans	Neeraja
104	Tu 3:00P-4:00P	2070 VLSB	Daniel
105	Tu 11:00A-12:00P	3105 Etcheverry	Daniel
106	Tu 1:00P-2:00P	385 LeConte	Wesley
107	Tu 2:00P-3:00P	71 Evans	Neeraja
108	Tu 6:00P-7:00P	71 Evans	Wesley

Administrivia: Projects

- First two projects are based on Nachos
  - Start reading walkthrough and code NOW
- Second two projects will add more OS and systems components: in-memory key-value store
  - Project 3: single server key-value store:
    - » PUT/GET RPCs, in-memory hash-table management
  - Project 4: distributed key-value store:
    - » Two phase commit for replication, data/communication encryption

Administrivia: Laptop/Smartphone Policy

- Discussion sections: closed-laptop/smartphone policy
- Lecture:
  - Closed laptops and smartphones, **highly** preferred
  - If you really have to use a laptop, please stay in the back of the class (to minimize disruption)

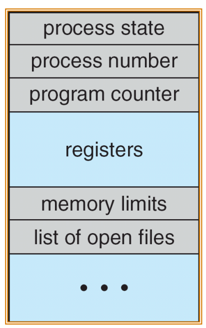
5min Break

Traditional UNIX Process

- Process: *Operating system abstraction to represent what is needed to run a single program*
  - Often called a "HeavyWeight 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 (i.e., thread)
    - » 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

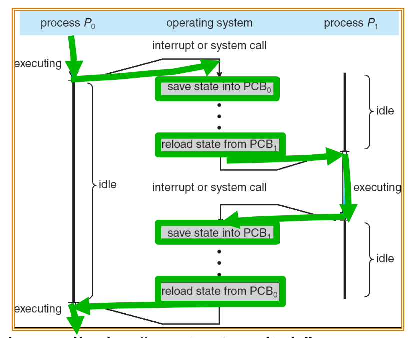
How do we Multiplex Processes?

- 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 (Scheduling):
  - 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
  - Example mechanisms:
    - » Memory Mapping: Give each process their own address space
    - » Kernel/User duality: Arbitrary multiplexing of I/O through system calls



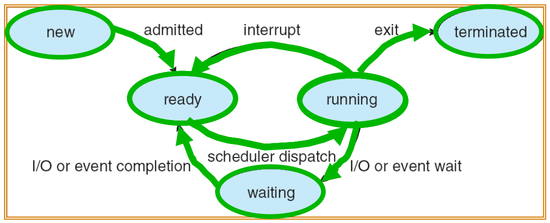
Process Control Block

CPU Switch From Process to Process



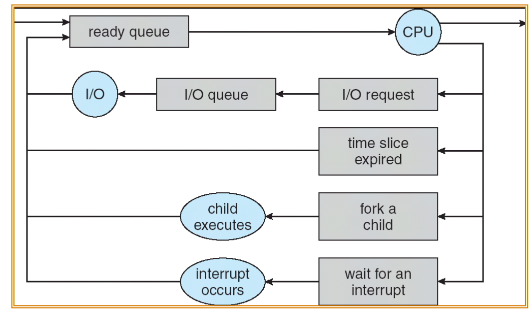
- This is also called a "context switch"
- Code executed in kernel above is overhead
  - Overhead sets minimum practical switching time
  - Less overhead with SMT/Hyperthreading, but… contention for resources instead

Lifecycle of a Process



- 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

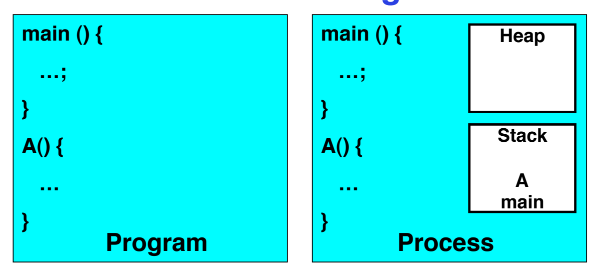


- PCBs move from queue to queue as they change state
  - Decisions about which order to remove from queues are Scheduling decisions
  - Many algorithms possible (few weeks from now)

What does it take to create a process?

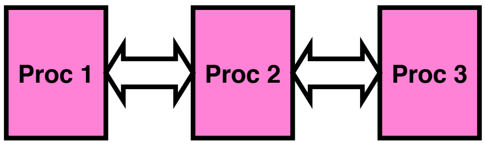
- Must construct new PCB
  - Inexpensive
- Must set up new page tables for address space
  - More expensive
- Copy data from parent process? (Unix `fork()`)
  - Semantics of Unix `fork()` are that the child process gets a complete copy of the parent memory and I/O state
  - Originally *very* expensive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

Process =? Program



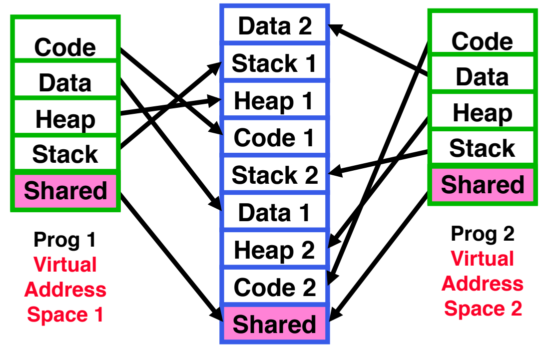
- More to a process than just a program:
  - Program is just part of the process state
  - I run emacs on lectures.txt, you run it on homework.java – same program, different processes
- Less to a process than a program:
  - A program can invoke more than one process
  - cc starts up cpp, cc1, cc2, as, and ld

Multiple Processes Collaborate on a Task



- Need Communication mechanism:
  - Separate address spaces isolates processes
  - 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

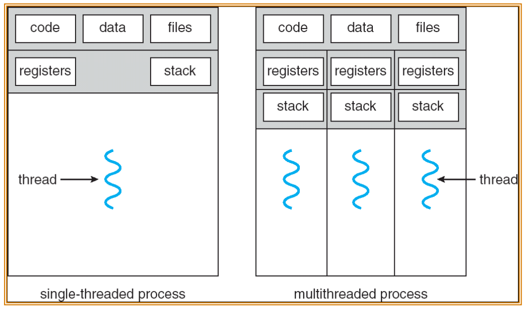
Inter-process Communication (IPC)

- 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`*`)` – message size fixed or variable
  - `receive(`*`message`*`)`
- If *P* and *Q* wish to communicate, they need to:
  - establish a *communication channel* between them
  - exchange messages via send/receive
- Implementation of communication link
  - physical (e.g., shared memory, hardware bus, syscall/trap)
  - logical (e.g., logical properties)

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?
  - Discuss 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

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, HP-UX, Win NT to 8, Solaris, OS X, Android, iOS**

- Real operating systems have either
  – One or many address spaces
  – One or many threads per address space

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
- Book talks about processes
  - When this concerns concurrency, really talking about thread portion of a process
  - When this concerns protection, talking about address space portion of a process