Review: History of OS

- Why Study?
  - To understand how user needs and hardware constraints influenced (and will influence) operating systems

- 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 ⇒ Timeshare ⇒ Graphical UI
  ⇒ Ubiquitous Devices ⇒ Cyberspace/Metaverse/??
  - 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

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Review: Migration of OS Concepts and Features

- Policy vs. Mechanism
  - Policy: What do you want to do?
  - Mechanism: How are you going to do it?
  - Should be separated, since policies change

- Algorithms used
  - Linear, Tree-based, Log Structured, etc...

- Event models used
  - threads vs event loops

- Backward compatibility issues
  - Very important for Windows 2000
  - POSIX tries to help here

- System generation/configuration
  - How to make generic OS fit on specific hardware
Goals for Today

- How do we provide multiprogramming?
- What are Processes?
- How are they related to Threads and Address Spaces?

Concurrency

- "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
  - MULTIX, UNIX, OS/2, Windows NT/2000/XP
  - 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 keep this 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

Recall (61C): What happens during execution?

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

Addr $2^{32} - 1$

... Data1 Data0
... Inst237 Inst236
... Inst5 Inst4 Inst3 Inst2 Inst1 Inst0
Addr 0

PC
PC
PC
PC
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)
  - Registers (Integer, Floating point, others...?)
- How switch from one CPU to the next?
  - Save PC and registers in current state block
  - Load PC 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)

Modern Technique: SMT/Hyperthreading

- Hardware technique
  - Exploit natural properties of superscalar processors to provide illusion of multiple processors
  - Higher utilization of processor resources
- Can schedule each thread as if were separate CPU
  - However, not linear speedup!
  - If have multiprocessor, should schedule each processor first
- Original technique called "Simultaneous Multithreading"
  - See http://www.cs.washington.edu/research/smt/
  - Alpha, SPARC, Pentium 4 ("Hyperthreading"), Power 5

How to protect threads from one another?

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

<table>
<thead>
<tr>
<th>Program Address Space</th>
</tr>
</thead>
<tbody>
<tr>
<td>stack</td>
</tr>
<tr>
<td>heap</td>
</tr>
<tr>
<td>data</td>
</tr>
<tr>
<td>text</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Virtual Address Space 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code 1</td>
</tr>
<tr>
<td>Stack 1</td>
</tr>
<tr>
<td>Heap 1</td>
</tr>
<tr>
<td>Code 2</td>
</tr>
<tr>
<td>Stack 2</td>
</tr>
<tr>
<td>Heap 2</td>
</tr>
<tr>
<td>OS code</td>
</tr>
<tr>
<td>OS data</td>
</tr>
<tr>
<td>OS heap &amp; Stacks</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Virtual Address Space 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code</td>
</tr>
<tr>
<td>Data 2</td>
</tr>
<tr>
<td>Stack 1</td>
</tr>
<tr>
<td>Heap 1</td>
</tr>
<tr>
<td>Code 2</td>
</tr>
<tr>
<td>Stack 2</td>
</tr>
<tr>
<td>Heap 2</td>
</tr>
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<tr>
<td>OS data</td>
</tr>
<tr>
<td>OS heap &amp; Stacks</td>
</tr>
</tbody>
</table>

Administrivia: Time for Project Signup

- **Project Signup:**
  - Only submit once per group!
  - Everyone in group must have logged into their cs162-xx accounts before you register the group
  - Make sure that you select at least 2 potential sections
  - **Due date:** Today by 11:59pm
- Will have sections assigned by end of week
  - Go to new sections next week!

<table>
<thead>
<tr>
<th>Section</th>
<th>Time</th>
<th>Location</th>
<th>TA</th>
</tr>
</thead>
<tbody>
<tr>
<td>101</td>
<td>Tu 1:00-2:00P</td>
<td>310 Hearst Mining</td>
<td>Dominic</td>
</tr>
<tr>
<td>102</td>
<td>W 10:00-11:00A</td>
<td>2 Evans</td>
<td>Rajesh</td>
</tr>
<tr>
<td>103</td>
<td>W 11:00-12:00P</td>
<td>85 Evans</td>
<td>Rajesh</td>
</tr>
<tr>
<td>104</td>
<td>W 1:00-2:00P</td>
<td>85 Evans</td>
<td>Chris</td>
</tr>
<tr>
<td>105</td>
<td>W 2:00-3:00P</td>
<td>85 Evans</td>
<td>Chris</td>
</tr>
</tbody>
</table>

Administrivia (2)

- **Cs162-xx accounts:**
  - Make sure you got an account form
  - If you haven't logged in yet, you need to do so
- **Email addresses**
  - We need an email address from you
  - If you haven't given us one already, you should get prompted when you log in again
- **Nachos readers:**
  - Available from Northside Copy Central
  - Includes printouts of all of the code
- **Next Week: Start Project 1**
  - Go to Nachos page and start reading up
Traditional UNIX Process

• Process: Operating system abstraction to represent what is needed to run a single program
  - Often called a “HeavyWeight Process”
  - Formally: a 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 (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
  - Sample mechanisms:
    » Memory Mapping: Give each process their own address space
    » Kernel/User duality: Arbitrary multiplexing of I/O through system calls

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

Diagram of Process State

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

Multiple Processes to Contribute on Task

• High Creation/memory Overhead
• (Relatively) High Context-Switch Overhead
• 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 link between them
  - exchange messages via send/receive
- Implementation of communication link
  - physical (e.g., shared memory, hardware bus)
  - logical (e.g., shared memory, hardware bus)

**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 of a process
- Address spaces encapsulate protection
  - Keeps buggy program from trashing the system
  - “Passive” component of a process
Examples of multithreaded programs

- Embedded systems
  - Elevators, Planes, Medical systems, Wristwatches
  - Single Program, concurrent operations
- Most modern OS kernel
  - 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 uniprocessed:
  - 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, Temporary variables
  - return PCs are kept while called procedures are executing

Execution Stack Example

```c
A(int tmp) {
  if (tmp<2)
    B();
  printf(tmp);
}
B() {
  C();
}
C() {
  A(2);
}
A(1);
```

Stack Growth

- Stack holds temporary results
- Permits recursive execution
- Crucial to modern languages
### Classification

<table>
<thead>
<tr>
<th># threads Per AS</th>
<th># of addr spaces</th>
<th>One</th>
<th>Many</th>
</tr>
</thead>
<tbody>
<tr>
<td>One</td>
<td>MS/DOS, early Macintosh</td>
<td>Traditional UNIX</td>
<td></td>
</tr>
<tr>
<td>Many</td>
<td>Embedded systems (Geoworks, VxWorks, JavaOS, etc)</td>
<td>Mach, OS/2, Linux Windows 95???, Win NT to XP, Solaris, HP-UX, OS X</td>
<td></td>
</tr>
</tbody>
</table>

- Real operating systems have either
  - One or many address spaces
  - One or many threads per address space
- Did Windows 95/98/ME have real memory protection?
  - No: Users could overwrite process tables/System DLLs

### Example: Implementation Java OS

- Many threads, one Address Space
- Why another OS?
  - Recommended Minimum memory sizes:
    - UNIX + X Windows: 32MB
    - Windows 98: 16-32MB
    - Windows NT: 32-64MB
    - Windows 2000/XP: 64-128MB
  - What if want a cheap network point-of-sale computer?
    - Say need 1000 terminals
    - Want < 8MB
- What language to write this OS in?
  - Java/Lisp? Not quite sufficient – need direct access to HW/memory management

### 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