CS162
Operating Systems and Systems Programming
Lecture 4

Thread Dispatching

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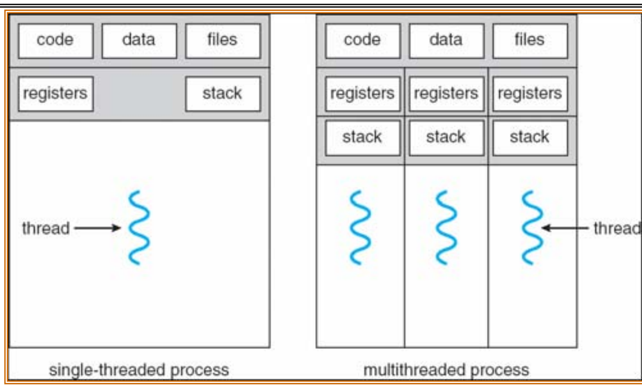
Recall: Modern Process with Multiple Threads

- Process: *Operating system abstraction to represent what is needed to run a single, multithreaded program*
- Two parts:
  - Multiple Threads
    - » Each thread is a *single, sequential stream of execution*
  - Protected Resources:
    - » Main Memory State (contents of Address Space)
    - » I/O state (i.e. file descriptors)
- 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

Recall: 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

Recall: 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, Win 95?, Mac OS X, Win NT to XP, Solaris, HP-UX

- 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

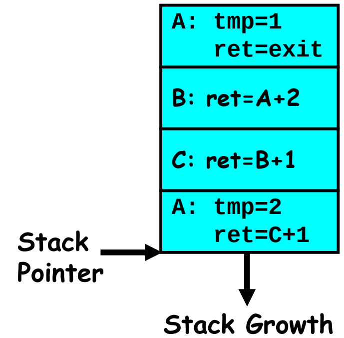
Goals for Today

- Further Understanding Threads
- Thread Dispatching
- Beginnings of Thread Scheduling

Note: Some slides and/or pictures in the following are adapted from slides ©2005 Silberschatz, Galvin, and Gagne. Many slides generated from my lecture notes by Kubiatowicz.

Recall: Execution Stack Example

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



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

MIPS: Software conventions for Registers

0	zero	constant 0
1	at	reserved for assembler
2	v0	expression evaluation &
3	v1	function results
4	a0	arguments
5	a1	
6	a2	
7	a3	
8	t0	temporary: caller saves
. . .		(callee can clobber)
15	t7	

16	s0	callee saves
. . .		(callee must save)
23	s7	
24	t8	temporary (cont'd)
25	t9	
26	k0	reserved for OS kernel
27	k1	
28	gp	Pointer to global area
29	sp	Stack pointer
30	fp	frame pointer
31	ra	Return Address (HW)

- Before calling procedure:
  - Save caller-saves regs
  - Save v0, v1
  - Save ra
- After return, assume
  - Callee-saves reg OK
  - gp,sp,fp OK (restored!)
  - Other things trashed

Single-Threaded Example

- Imagine the following C program:

```
main() {
   ComputePI("pi.txt");
   PrintClassList("clist.text");
}
```

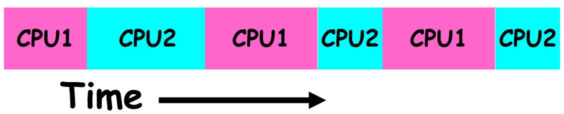
- What is the behavior here?
  - Program would never print out class list
  - Why? ComputePI would never finish

Use of Threads

- Version of program with Threads:

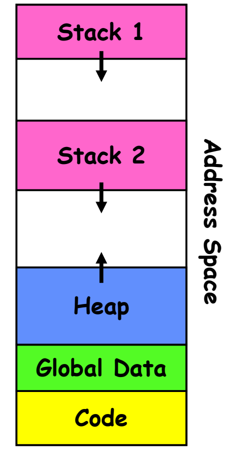
```
main() {
    CreateThread(ComputePI("pi.txt"));
    CreateThread(PrintClassList("clist.text"));
}
```

- What does "CreateThread" do?
  - Start independent thread running given procedure
- What is the behavior here?
  - Now, you would actually see the class list
  - This *should* behave as if there are two separate CPUs



Memory Footprint of Two-Thread Example

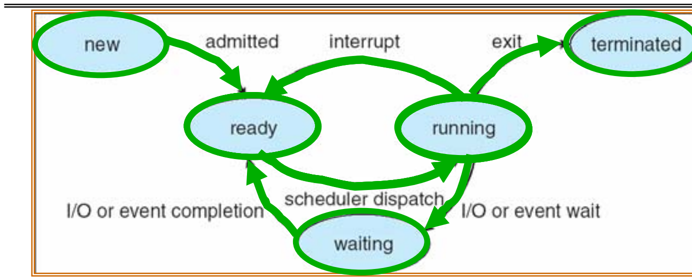
- If we stopped this program and examined it with a debugger, we would see
  - Two sets of CPU registers
  - Two sets of Stacks
- Questions:
  - How do we position stacks relative to each other?
  - What maximum size should we choose for the stacks?
  - What happens if threads violate this?
  - How might you catch violations?



Per Thread State

- Each Thread has a *Thread Control Block* (TCB)
  - Execution State: CPU registers, program counter, pointer to stack
  - Scheduling info: State (more later), priority, CPU time
  - Accounting Info
  - Various Pointers (for implementing scheduling queues)
  - Pointer to enclosing process? (PCB)?
  - Etc (add stuff as you find a need)
- In Nachos: "Thread" is a class that includes the TCB
- OS Keeps track of TCBs in protected memory
  - In Array, or Linked List, or …

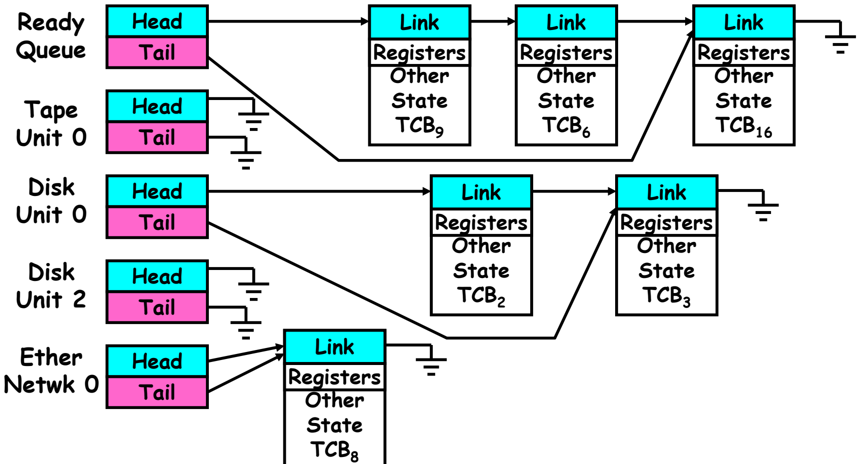
Lifecycle of a Thread (or Process)



- As a thread executes, it changes state:
  - new: The thread is being created
  - ready: The thread is waiting to run
  - running: Instructions are being executed
  - waiting: Thread waiting for some event to occur
  - terminated: The thread has finished execution
- "Active" threads are represented by their TCBs
  - TCBs organized into queues based on their state

Ready Queue And Various I/O Device Queues

- Thread not running ⇒ TCB is in some scheduler queue
  - Separate queue for each device/signal/condition
  - Each queue can have a different scheduler policy



Administrivia

- Audio Podcasts are now available
  - RSS, stream, MP3 downloads
- Group assignments now posted on website
  - Check out the "Group/Section Assignment" link
  - Please attend your newly assigned section

Section	Time	Location	TA
101	Th 10:00-11:00A	81 Evans	Kelvin Lwin
102	Th 12:00-1:00P	155 Barrows	Kelvin Lwin
103	Th 2:00-3:00P	75 Evans	Todd Kosloff
104	Th 4:00-5:00P	B51 Hildebrand	Todd Kosloff
105	F 10:00-11:00A	4 Evans	Thomas Kho

Administrivia

- New Office Hour for me: Tuesday from 2:00-3:00
- Group assignments finished!
  - Look at group link off homepage
  - Issues:
    - » We have a group of three that needs another member in Thursday 2-3 section
    - » We have only three groups in the Thursday 12-1 section
    - » Can we get anyone to move? You will get much better access to your TA
- Time to start Project 1
  - Go to Nachos page: start reading tasks and Nachos code
- Nachos readers:
  - Available from Copy Central now (Required!)
  - Includes lectures and printouts of all of the code
- Make sure that you run the register program
  - This should happen automatically when you login, but you need to avoid hitting control-C

Dispatch Loop

- Conceptually, the dispatching loop of the operating system looks as follows:

```
Loop {
   RunThread();
   ChooseNextThread();
   SaveStateOfCPU(curTCB);
   LoadStateOfCPU(newTCB);
}
```

- This is an *infinite* loop
  - One could argue that this is all that the OS does
- Should we ever exit this loop???
  - When would that be?

Running a thread

Consider first portion: `RunThread()`

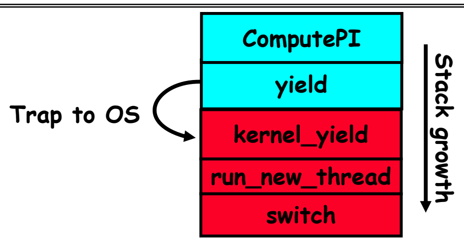
- How do I run a thread?
  - Load its state (registers, PC, stack pointer) into CPU
  - Load environment (virtual memory space, etc)
  - Jump to the PC
- How does the dispatcher get control back?
  - Internal events: thread returns control voluntarily
  - External events: thread gets *preempted*

Internal Events

- Blocking on I/O
  - The act of requesting I/O implicitly yields the CPU
- Waiting on a "signal" from other thread
  - Thread asks to wait and thus yields the CPU
- Thread executes a `yield()`
  - Thread volunteers to give up CPU

```
computePI() {
   while(TRUE) {
      ComputeNextDigit();
      yield();
   }
}
```


Stack for Yielding Thread



- How do we run a new thread?

```
run_new_thread() {
   newThread = PickNewThread();
   switch(curThread, newThread);
   ThreadHouseKeeping(); /* next Lecture */
}
```

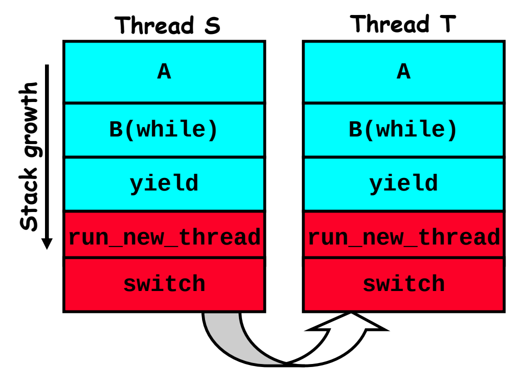
- How does dispatcher switch to a new thread?
  - Save anything next thread may trash: PC, regs, stack
  - Maintain isolation for each thread

What do the stacks look like?

- Consider the following code blocks:

```
proc A() {
   B();

}
proc B() {
   while(TRUE) {
      yield();
   }
}
```



- Suppose we have 2 threads:
  - Threads S and T

Saving/Restoring state (often called "Context Switch)

```
Switch(tCur,tNew) {
   /* Unload old thread */
   TCB[tCur].regs.r7 = CPU.r7;
          …
   TCB[tCur].regs.r0 = CPU.r0;
   TCB[tCur].regs.sp = CPU.sp;
   TCB[tCur].regs.retpc = CPU.retpc; /*return addr*/

   /* Load and execute new thread */
   CPU.r7 = TCB[tNew].regs.r7;
          …
   CPU.r0 = TCB[tNew].regs.r0;
   CPU.sp = TCB[tNew].regs.sp;
   CPU.retpc = TCB[tNew].regs.retpc;
   return; /* Return to CPU.retpc */
}
```

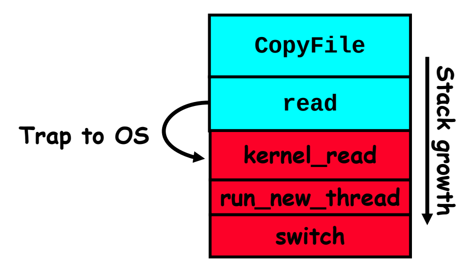

Switch Details

- How many registers need to be saved/restored?
  - MIPS 4k: 32 Int(32b), 32 Float(32b)
  - Pentium: 14 Int(32b), 8 Float(80b), 8 SSE(128b),…
  - Sparc(v7): 8 Regs(32b), 16 Int regs (32b) * 8 windows = 136 (32b)+32 Float (32b)
  - Itanium: 128 Int (64b), 128 Float (82b), 19 Other(64b)
- `retpc` is where the return should jump to.
  - In reality, this is implemented as a jump
- There is a real implementation of switch in Nachos.
  - See switch.s
    - » Normally, switch is implemented as assembly!
  - Of course, it's magical!
  - But you should be able to follow it!

Switch Details (continued)

- What if you make a mistake in implementing switch?
  - Suppose you forget to save/restore register 4
  - Get intermittent failures depending on when context switch occurred and whether new thread uses register 4
  - System will give wrong result without warning
- Can you devise an exhaustive test to test switch code?
  - No! Too many combinations and inter-leavings
- Cautionary tail:
  - For speed, Topaz kernel saved one instruction in switch()
  - Carefully documented!
    - » Only works As long as kernel size < 1MB
  - What happened?
    - » Time passed, People forgot
    - » Later, they added features to kernel (no one removes features!)
    - » Very weird behavior started happening
  - Moral of story: Design for simplicity

What happens when thread blocks on I/O?

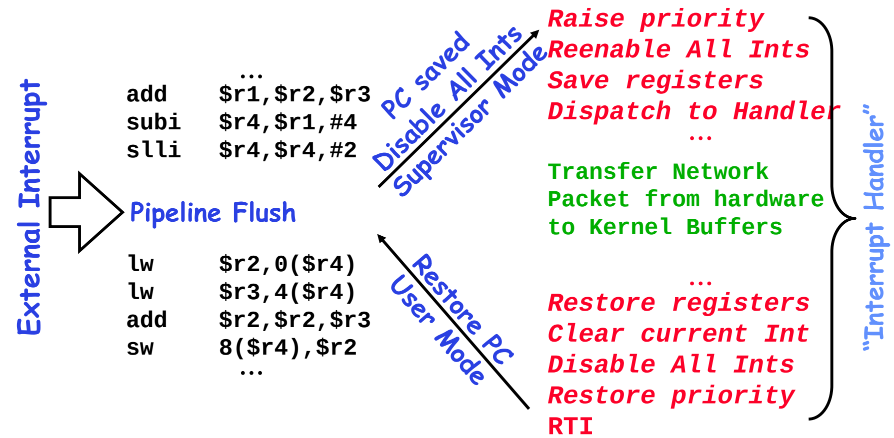


- What happens when a thread requests a block of data from the file system?
  - User code invokes a system call
  - Read operation is initiated
  - Run new thread/switch
- Thread communication similar
  - Wait for Signal/Join
  - Networking

External Events

- What happens if thread never does any I/O, never waits, and never yields control?
  - Could the ComputePI program grab all resources and never release the processor?
    - » What if it didn't print to console?
  - Must find way that dispatcher can regain control!
- Answer: Utilize External Events
  - Interrupts: signals from hardware or software that stop the running code and jump to kernel
  - Timer: like an alarm clock that goes off every some many milliseconds
- If we make sure that external events occur frequently enough, can ensure dispatcher runs

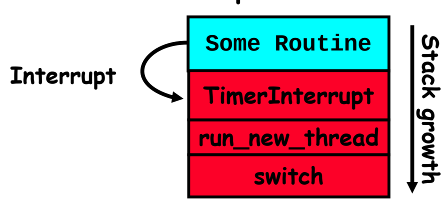
Example: Network Interrupt



- An interrupt is a hardware-invoked context switch
  - No separate step to choose what to run next
  - Always run the interrupt handler immediately

Use of Timer Interrupt to Return Control

- Solution to our dispatcher problem
  - Use the timer interrupt to force scheduling decisions



- Timer Interrupt routine:

```
TimerInterrupt() {
    DoPeriodicHouseKeeping();
    run_new_thread();
}
```

- I/O interrupt: same as timer interrupt except that `DoHousekeeping()` replaced by `ServiceIO()`.

Choosing a Thread to Run

- How does Dispatcher decide what to run?
  - Zero ready threads – dispatcher loops
    - » Alternative is to create an "idle thread"
    - » Can put machine into low-power mode
  - Exactly one ready thread – easy
  - More than one ready thread: use scheduling priorities
- Possible priorities:
  - LIFO (last in, first out):
    - » put ready threads on front of list, remove from front
  - Pick one at random
  - FIFO (first in, first out):
    - » Put ready threads on back of list, pull them from front
    - » This is fair and is what Nachos does
  - Priority queue:
    - » keep ready list sorted by TCB priority field

Summary

- The state of a thread is contained in the TCB
  - Registers, PC, stack pointer
  - States: New, Ready, Running, Waiting, or Terminated
- Multithreading provides simple illusion of multiple CPUs
  - Switch registers and stack to dispatch new thread
  - Provide mechanism to ensure dispatcher regains control
- Switch routine
  - Can be very expensive if many registers
  - Must be very carefully constructed!
- Many scheduling options
  - Decision of which thread to run complex enough for complete lecture