# CS162
# Operating Systems and Systems Programming
# Lecture 4

## Thread Dispatching

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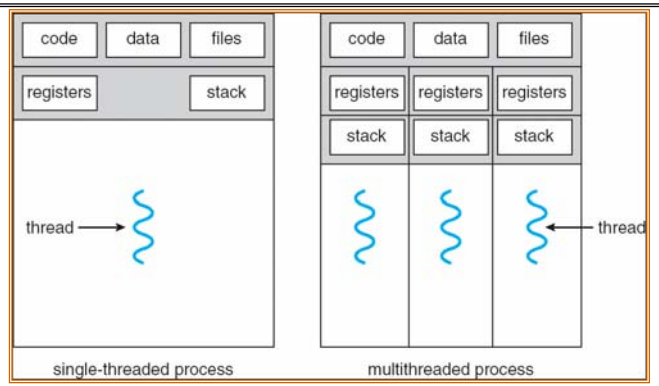
## Recall: Modern Process with Multiple Threads

- 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 Windows 95??? 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
- Did Windows 95/98/ME have real memory protection?
  - No: Users could overwrite process tables/System DLLs

## Goals for Today

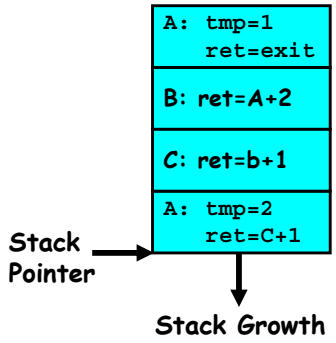
- Further Understanding Threads
- Thread Dispatching
- Beginnings of Thread Scheduling

Note: Some slides and/or pictures in the following are adapted from slides ©2005 Silberschatz, Galvin, and Gagne



## 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");
}
```

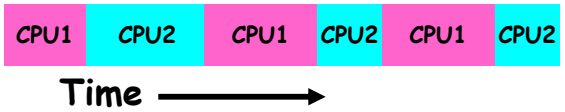
- What is the behavior here?
  - Program would never print out class list
  - Why? ComputePI would never finish

## Use of Threads

- Version of program with Threads:

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

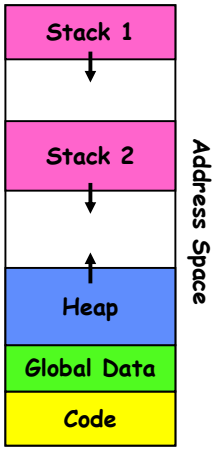
- What does "CreateThread" do?
  - Start independent thread running given procedure
- What is the behavior here?
  - Now, you would actually see the class list
  - This *should* behave as if there are two separate CPUs






## 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?



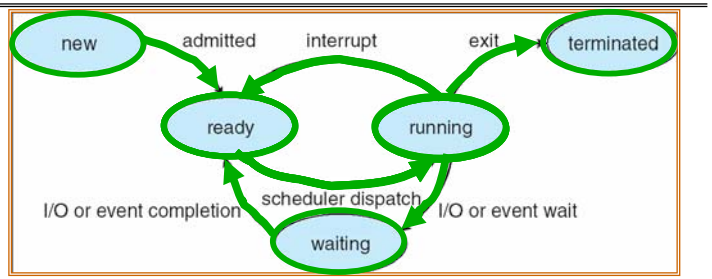



## Per Thread State

- 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 …



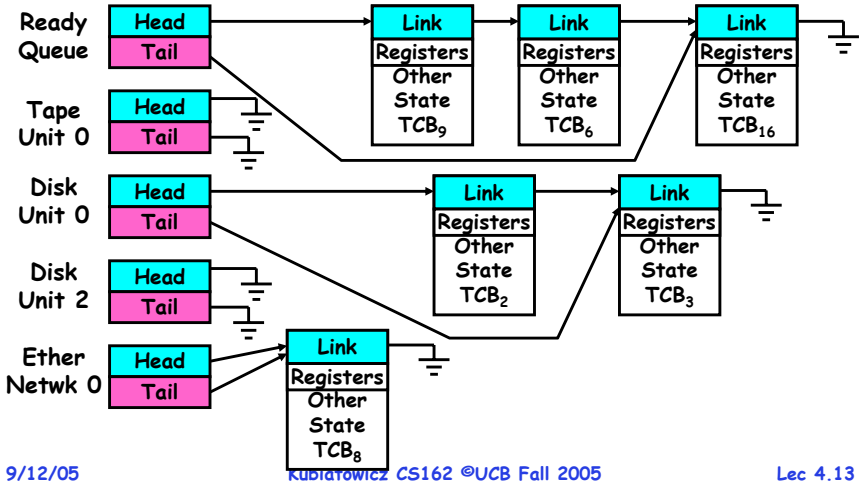
## Lifecycle of a Thread (or Process)




- 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

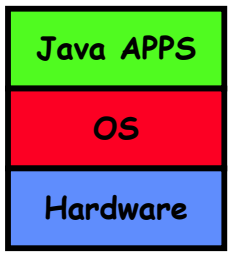
- Group assignments now posted on website
  - Check out the "Group/Section Assignment" link
  - Please attend your newly assigned section
- Nachos readers:
  - Available from Northside Copy Central
  - Includes printouts of all of the code
- Warning: you will be prompted for a passphrase
  - We need to autogenerate ssh keys for you
  - When prompted for a pass phrase, don't forget it!
  - This is needed for group collaboration tools
- Not everyone has run the register program!
  - This should happen automatically when you login, but you need to avoid hitting control-C
- Time to start Project 1
  - Go to Nachos page and start reading up
  - Start reading through the Nachos code (reader)



## Asside: 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?
  - C/C++/ASM? Not terribly high-level. Hard to debug.
  - Java/Lisp? Not quite sufficient – need direct access to HW/memory management

Java OS Structure






## 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?
  - Emergency crash of operating system called "`panic()`"

## 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 *prempted*



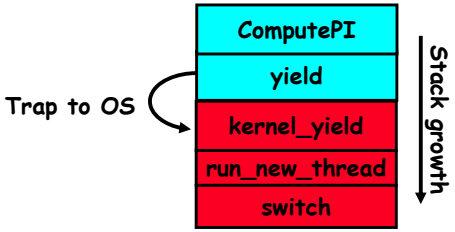
## Internal Events

- 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

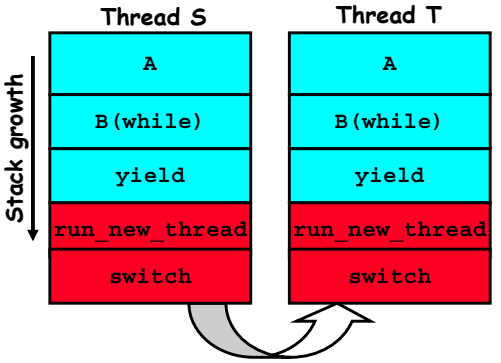


## What do the stacks look like?

- 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), 19Other(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!

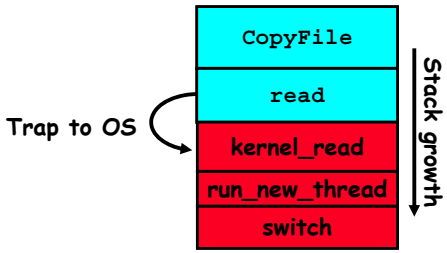


## Switch Details (continued)

- What if you make a mistake in implementing switch?
  - Suppose you forget to save/restore reg 4
  - Get intermittent failures depending on when context switch occurred and whether new thread uses reg 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 (noone removes features!)
    - » Very weird behavior started happening
  - Moral of story: Design for simplicity



## What happens when thread blocks on I/O?



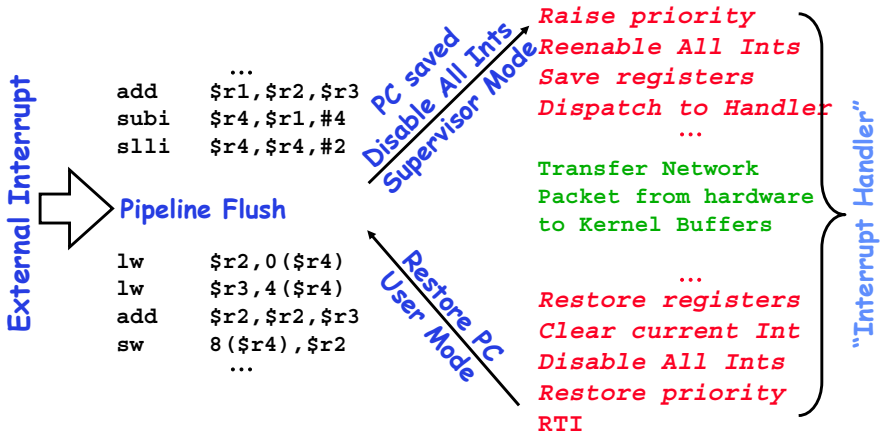

- What happens when a thread requests a block of data from the file system?
  - User code invokes a system call
  - Read operation is initiated
  - Run new thread/switch
- Thread communication similar
  - Wait for Signal/Join
  - Networking

## 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

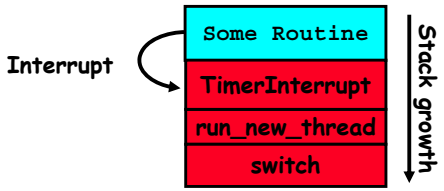



- An interrupt is a hardware-invoked context switch
  - No separate step to choose what to run next
  - Always run the interrupt handler immediately



## 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