15-410

The Thread
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"Real concurrency – in which one program actually continues to function while you call up and use another – is more amazing but of small use to the average person. How many programs do you have that take more than a few seconds to perform any task?" – NYT, 4/25/1989

Synchronization

Partner sign-up!

- Approximately 6 students un-partnered
- I have spammed the un-signed... note that SH 125 is a good place to meet potential partners!

Project 1

- By end of Wednesday...
  - Console (output) should be “doing something”, “not far”
  - Should have “some progress” for kbd, timer
    - » Should really have at least “solid design”
    - » Better to have handled one interrupt once

Write good code

- Console driver will be used *(and extended)* in P3

Synchronization

Simics issues

- Simics doesn't simulate time with 100% accuracy
  - Mentioned in handout, but:
    - » Sometimes it runs slower (“of course”)
    - » Sometimes it runs faster (!)
- Simics doesn't blink
  - Not your fault
- Arrow keys may not work “so well”
  - If you get a strange message, tell us about your setup
  - Crash box!

Readings

Textbook chapters

- OSC
  - Already: Chapters 1 through 3
  - Today: Chapter 4 (roughly)
  - Soon: Chapters 6 & 7
    - » Transactions (6.9) will be deferred
- OS:P+P
  - Already: Chapters 1 through 3
  - Today: Chapter 4 (roughly/partly)
  - Soon: Chapter 6

Book Report Goals

There's more than one way to do it

- But you don't have time to try all the ways in 410
- Reading about other ways is good, maybe fun

Habituation

- Long-term career development requires study

Writing skills (a little!)

- “Summarizing” a book in a page is tough

Book Report Goals

Some of you are going to grad. school

Some of you are wondering about grad. school

Some of you are *in* grad. school

- **You should be able to read a Ph.D. dissertation**

More generally

- **Looking at something *in depth* is different**
- **Not like a textbook**

Book Report

Read the "handout"

Browse the already-approved list

Pick something (soon)

- "Don't make me stop the car..."

Read a bit before you sleep at night

- or: before you sleep in the morning
- and/or: Thanksgiving break / Spring break

Assignment recommended by previous OS students!

- They recommend starting early, too

Road Map

Thread lecture

Synchronization lectures

- Probably *three*

Yield lecture

This is important

- When you leave here, you will use threads
- Understanding threads will help you understand the kernel

Please make sure you *understand* threads

- We'll try to help by assigning you P2

Outline

Thread = schedulable registers

- **(that's *all* there is)**

Why threads?

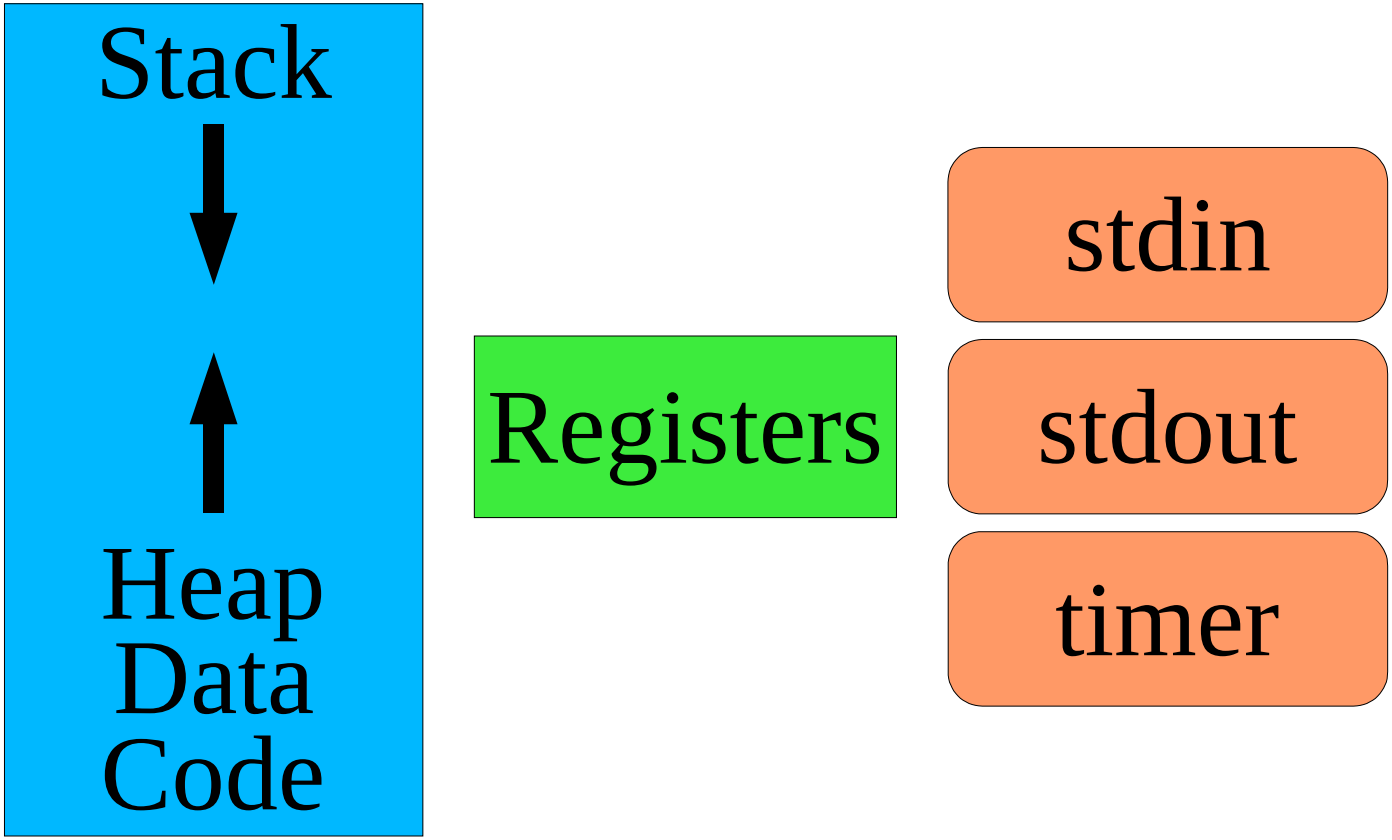
Thread flavors (ratios)

(Against) cancellation

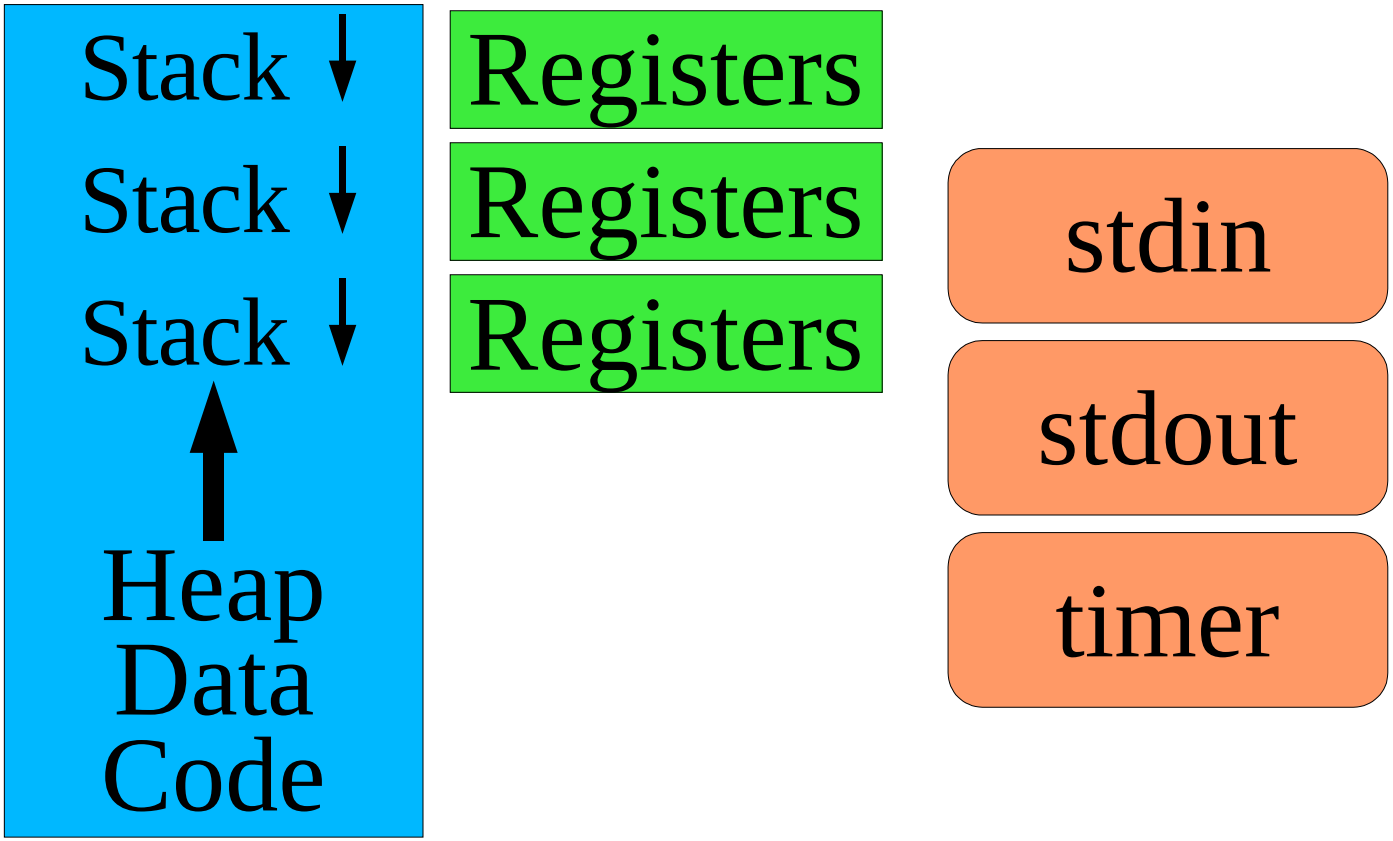
Race conditions

- **1 simple, 1 ouch**
- ***Make sure you really understand this***

Single-threaded Process



Multi-threaded Process



What does that *mean*?

Three stacks

- Three sets of “local variables”

Three register sets

- Three stack pointers
- Three %eax's (etc.)

Three *schedulable RAM mutators*

- (heartfelt but partial apologies to the ML crowd)

Three potential bad interactions

- A/B, A/C, B/C ... this pattern gets worse fast...

Why threads?

Shared access to data structures

Responsiveness

Speedup on multiprocessors

Shared access to data structures

Database server for multiple bank branches

- Verify multiple rules are followed
  - Account balance
  - Daily withdrawal limit
- Multi-account operations (transfer)
- Many accesses, each modifies tiny fraction of database

Server for a multi-player game

- Many players
- Access (& update) shared world state
  - Scan multiple objects
  - Update one or two objects

Shared access to data structures

Process per player?

- *Processes* share objects only via system calls
- Hard to make game objects = operating system objects

Process per game object?

- "Scan multiple objects, update one"
- Lots of message passing between processes
- Lots of memory wasted for lots of processes
- *Slow*

Shared access to data structures

Thread **per player**

- Game objects inside single memory address space
- Each thread can access & update game objects
- Shared access to OS objects (files)

Thread-switch is cheap

- Store N registers
- Load N registers

Responsiveness

"Cancel" button vs. decompressing large JPEG

- Handle mouse click *during* 10-second process
  - Map (x,y) to "cancel button" area
  - Change color / animate shadow / squeak / ...
  - Verify that button-release happens in button area of screen
- ...without JPEG decompressor understanding clicks
- Actually *stopping* the decompressor is a separate issue
  - Threads allow the user to register intent while it's running

Multiprocessor speedup

More CPUs can't help a single-threaded process!

PhotoShop color dither operation

- Divide image into regions
- One dither thread per CPU
- Can (sometimes) get linear speedup

Kinds of threads

User-space (N:1)

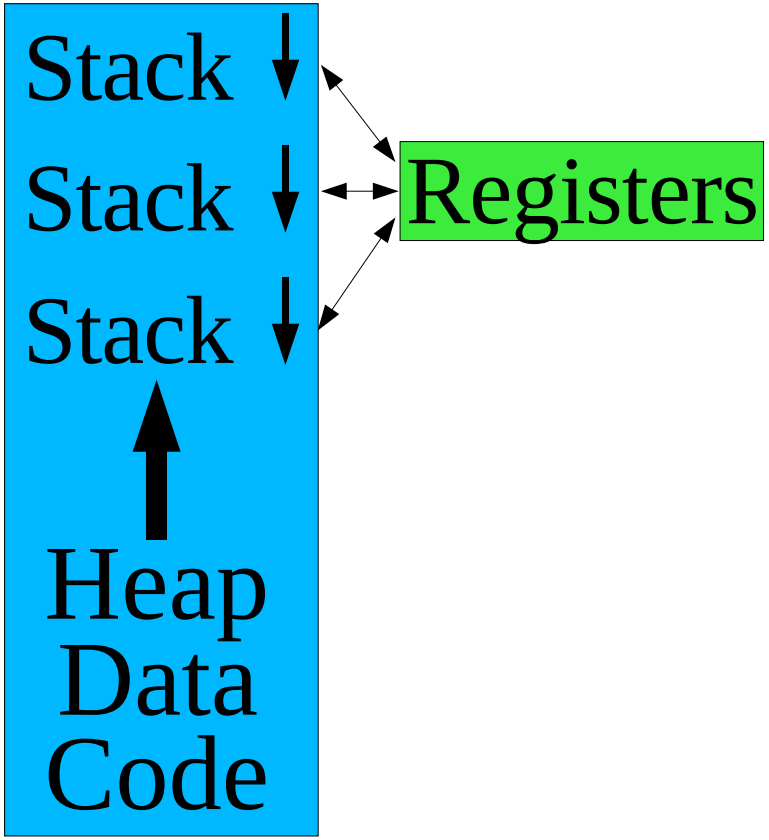
Kernel threads (1:1)

Many-to-many (M :N)

User-space threads (N:1)

Internal threading

- Thread library adds threads to a process
- Thread switch "just swaps registers"
  - Small piece of asm code
  - Maybe called yield()



User-space threads (N:1)

+ No change to operating system

- Any system call probably blocks all “threads”
  - “The process” makes a system call
  - Kernel blocks “the process”
  - (special non-blocking system calls can help)

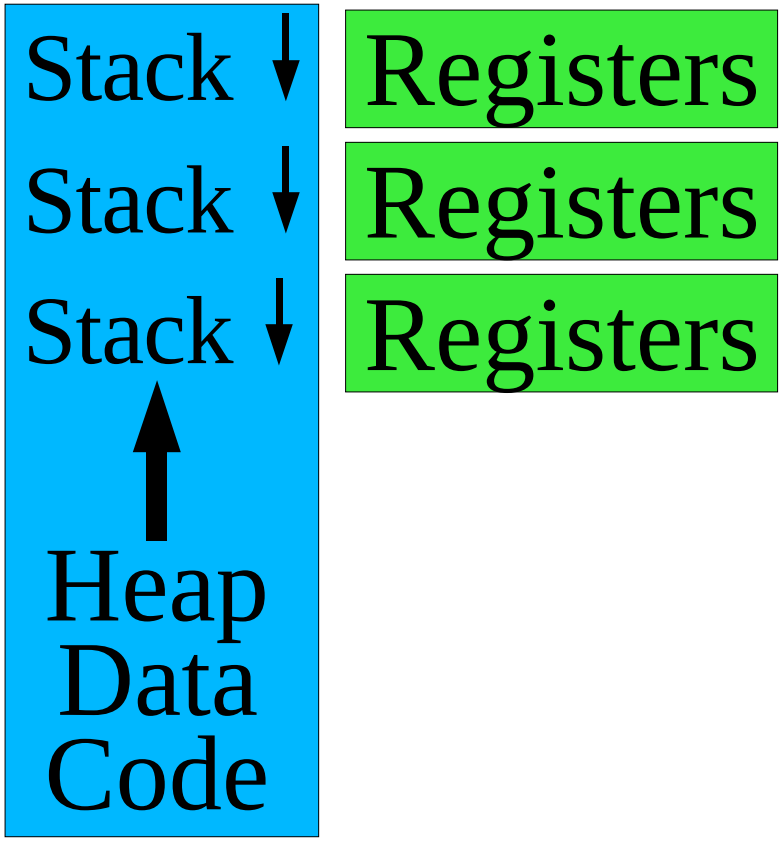
- “Cooperative scheduling” awkward/insufficient
  - Must manually insert many calls to yield()

- Cannot go faster on multiprocessor machines

Pure kernel threads (1:1)

OS-supported threading

- OS knows thread/process ownership
- Memory regions shared & reference-counted



Pure kernel threads (1:1)

"Every thread is sacred"

- Kernel-managed register set
- Kernel stack for when the thread is running kernel code
- "Real" (timer-triggered) scheduling

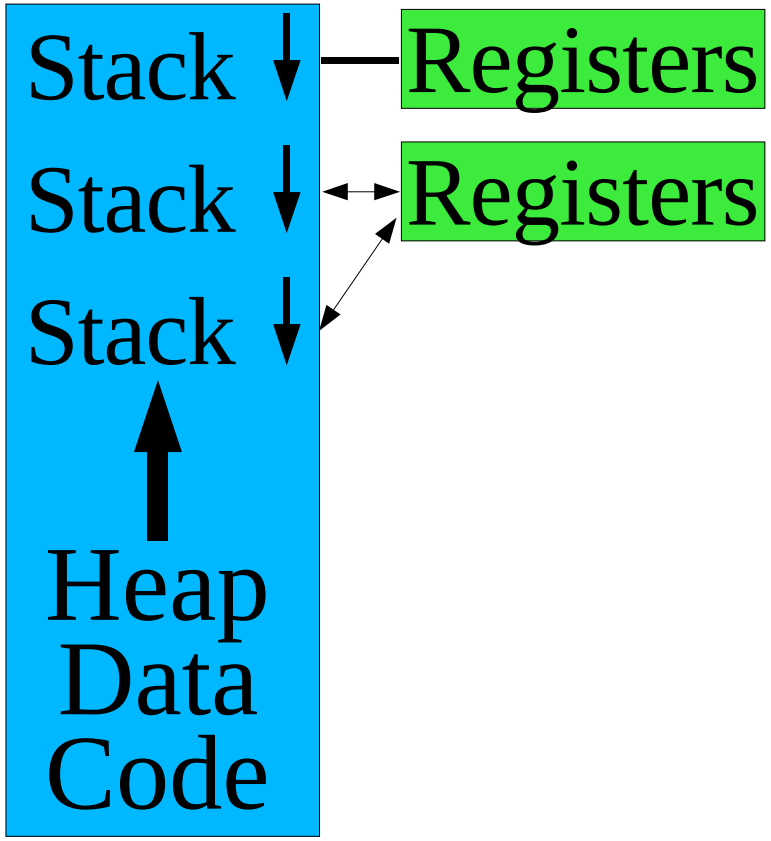
Features

+ Program runs faster on a multiprocessor
+ CPU-hog threads don't get all the CPU time
- User-space libraries must be rewritten to be "thread safe"
- Requires more kernel memory
  - 1 PCB ⇒ 1 TCB + N tCB's,
  - 1 k-stack ⇒ N k-stacks

Many-to-many (M:N)

Middle ground

- OS provides kernel threads
- M user threads *share* N kernel threads



Many-to-many (M:N)

Sharing patterns

- Dedicated
  - User thread 12 owns kernel thread 1
- Shared
  - 1 kernel thread per hardware CPU
  - Each kernel thread executes next runnable user thread
- Many variations, see text

Features

- Great when all the schedulers work together as you expected!

(Against) Thread Cancellation

Thread cancellation

- We don't want the result of that computation
  - (“Cancel button”)
- Two kinds – “asynchronous”, “deferred”

Asynchronous (immediate) cancellation

- Stop execution *now*
  - Run 0 more instructions (at least, in user space)
  - Free stack, registers
  - Poof!
- Hard to garbage-collect resources (open files, ...)
- Difficult to maintain data-structure consistency!

(Against) Thread Cancellation

Deferred ("pretty please") cancellation

- Write down “Dear Thread #314, Please go away.”
- Threads must check for cancellation
- Or define safe cancellation points
  - “Any time I call close() it's ok to zap me”

The only safe way

- Unless your threads are running very unusual code!

Race conditions

What you think

```
ticket = next_ticket++; /* 0 ⇒ 1 */
```

What really happens (in general)

```
ticket = temp = next_ticket;     /* 0 */
++temp;          /* 1, but not visible */
next_ticket = temp;   /* 1 is visible */
```

Murphy' s Law (of threading)

The world may *arbitrarily interleave* execution

- **Multiprocessor**
  - **N threads executing instructions *at the same time***
  - **Of course effects are interleaved!**
- **Uniprocessor**
  - **Only one thread running at a time...**
  - **But N threads runnable, timer counting down toward zero...**

The world will choose the *most painful* interleaving

- **"Once chance in a million" happens every minute**

Race Condition – Your Hope

T0		*T1*	
`tkt = tmp = n_tkt;`	0		
`++tmp;`	1		
`n_tkt = tmp;`	1		
		`tkt = tmp = n_tkt;`	1
		`++tmp;`	2
		`n_tkt = tmp;`	2

T0 has ticket 0, T1 has ticket 1. next_tkt has value 2. Your boss is happy.

Race Condition – Your Bad Luck

T0		*T1*	
`tkt = tmp = n_tkt;`	0		
		`tkt = tmp = n_tkt;`	0
`++tmp;`	1		
		`++tmp;`	1
`n_tkt = tmp;`	1		
		`n_tkt = tmp;`	1

T0 has ticket 0, T1 has ticket 0. next_tkt has value 1. Your boss is not entirely happy.

What happened?

Each thread did "something reasonable"

- ...assuming no other thread were touching those objects
- ...that is, assuming *"mutual exclusion"*

The world is cruel

- Any possible scheduling mix *will* happen sometime
- The one you fear will happen...
- The one you didn't think of will happen...

The #! shell-script hack

What's a “shell script”?

- A file with a bunch of (shell-specific) shell commands

```
#!/bin/sh
echo “My hovercraft is full of eels.”
sleep 10
exit 0
```

- Or: a security race-condition just waiting to happen...

The #! shell-script hack

What's "#!"?

- A venerable hack

You say

- execl("/foo/script", "script", "arg1", 0);

/foo/script “executable file” begins...

- #!/bin/sh

The kernel rewrites your system call...

- execl("/bin/sh" "/foo/script" "arg1" , 0);

The shell does

- open("/foo/script", O_RDONLY, 0);

The setuid invention

U.S. Patent #4,135,240

- Dennis M. Ritchie
- January 16, 1979

The concept

- A program with *stored privileges*
- When executed, runs with *two* identities
  - invoker's identity
  - program owner's identity
- Can switch identities at will
  - Open some files as invoker
  - Open other files as program-owner

Setuid example - printing a file

Goals

- Every user can queue files
- Users cannot delete other users' files

Solution

- Queue directory owned by user `printer`
- Setuid `queue-file` program
  - Create queue file as user `printer`
  - Copy joe's data as user `joe`
- Also, setuid `remove-file` program
  - Allows removal only of files you queued
- User `printer` mediates user `joe`'s queue access

Race condition example

Process 0	*Process 1*
`ln -s /bin/lpr /tmp/lpr`	
	`run /tmp/lpr`
	`[setuid to user “printer”]`
	`start “/bin/sh /tmp/lpr...”`
`rm /tmp/lpr`	
`ln -s /my/exploit /tmp/lpr`	
	`script = open(“/tmp/lpr”);`
	`execute /my/exploit`

What happened?

Intention

- Assign privileges to program contents

What happened?

- First, name was mapped to privileges
  - (name ⇒ file, file ⇒ privileges)
- Next, program name was re-bound to a different file
- Then, name was mapped to contents
  - (name ⇒ different file, different file ⇒ different contents)

How would you fix this?

How to solve race conditions?

Carefully analyze operation sequences

Find subsequences which must be *uninterrupted*

- **"Critical section"**

Use a *synchronization mechanism*

- **Next time!**

Summary

Thread: What, why

Thread flavors (ratios)

Race conditions

- ***Make sure you really understand this***

Further Reading

Setuid Demystified

- Hao Chen, David Wagner, Drew Dean
- http://www.cs.berkeley.edu/~daw/papers/setuid-usenix02.pdf
- "Abandon hope all ye who enter here"

The "cancel button problem"

- "Attentiveness: Reactivity at Scale"
  - Gregory S. Hartman
  - CMU-ISR-10-111.pdf
  - (on the book-report list)