15-410

"...process_switch(P2) 'takes a while'..."

Yield
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Synchronization

Thread library due tonight

- Please follow hand-in procedure on Projects page

Synchronization

Thread library due tonight

- Just kidding!

Who has...

- ...read handouts?
- ...unpacked tarball?
- ...issued a system call?
- ...drawn stack pictures?
- ...had a thread killed due to a page fault?

Synchronization

We hope you use the milestones and attack plan

- Pitfalls exist and we hope to steer you away
- Please don't wait "just one week" to find out when the milestones are...
  - ...if you haven't read the handouts yet, please do so *today*.

Take advantage of course staff

- If you see me I may require you to draw pictures
- Because this is very likely to help you

Review material if necessary

- We genuinely expect you to be operating from the "Questions" and "Debugging" lecture material
- If you missed class or were late, please review them as necessary

Outline

Context switch

- Motivated by yield()
- This is a *core idea* of this class
  - You will benefit if your P3 context switch is clean and solid
  - There's more than one way to do it
    - Even more than one *good* way
    - As with P2 `thread_fork`, part of the design is figuring out what parameters `context_switch()` should take...
- This lecture is "early"
  - Struggle with it today
  - Hopefully it'll be easier when you struggle with it in P3
- Note: today we'll talk about every kind of thread *but* P2

Mysterious yield()

```
T1() {
   while (1)
    yield(T2);
}
```

```
T2() {
   while (1)
    yield(T1);
}
```

User-space Yield

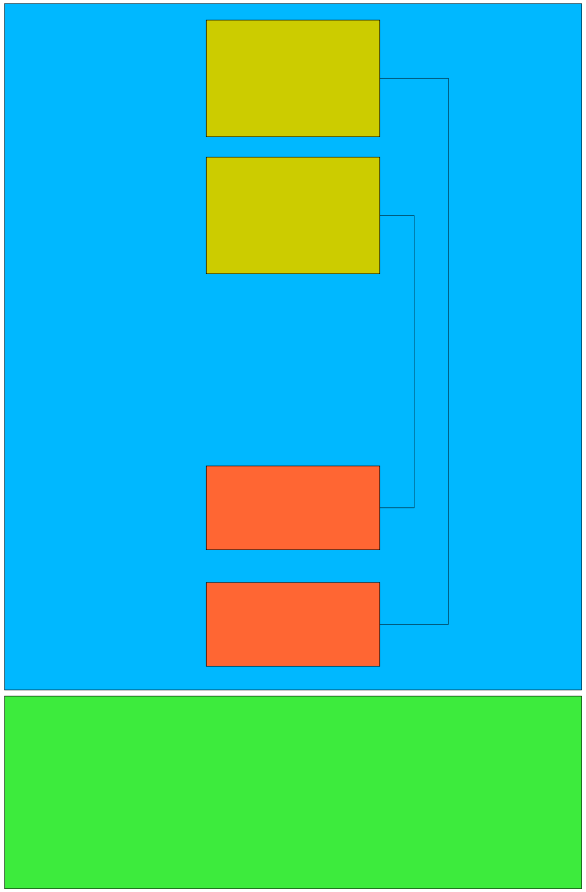
Consider *pure user-space threads*

- You implement threads inside a single-threaded process
- There is no `thread_fork`...
- The opposite of Project 2

What is a thread in that world?

- A stack
- "Thread control block" (TCB)
  - Locator for register-save area
  - Housekeeping information

Big Picture



User-space Yield

yield(user-thread-3)

- **save my registers on stack**
- ***/* magic happens here */***
- **restore thread 3's registers from thread 3's stack**
- **return;** ***/* to thread 3! */***

Todo List

Save

- General-purpose registers
  - (floating-point registers: omitted)
- Stack pointer
- Program counter

Which value to save for each?

- The value we want the register to have after the restore is done

Restore

- Same list as “save”
- Not *our* values: the *target's* values

No magic!

```
/* C+asm() for slide notation only! */

yield(user-thread-3){
  save registers on stack     /* asm(...) */
  tcb->sp = get_esp();        /* asm(...) */
  tcb->pc = &there;           /* gcc ext. */
  tcb = findtcb(user-thread-3);
  set_esp(tcb->sp);           /* asm(...) */
  jump(tcb->pc);              /* asm(...) */
there:
  restore registers from stack /* asm() */
  return;
}
```

The Program Counter

What values can the PC (%eip) contain?

- In a pure user-thread environment, thread switch happens *only in yield()*
- Yield sets saved PC to address of first "restore registers" instruction

All non-running threads have the *same* saved PC

- Please make sure this makes sense to you

Remove Unnecessary Code – 1

```
yield(user-thread-3){
  save registers on stack
  tcb->sp = get_esp();
  ~~tcb->pc = &there;~~
  tcb = findtcb(user-thread-3);
  set_esp(tcb->sp);
  jump(~~tcb->pc~~ &there);
there:
  restore registers from stack
  return
}
```

Remove Unnecessary Code – 2

```
yield(user-thread-3){
  save registers on stack
  tcb->sp = get_esp();
  tcb->pc = &there;
  tcb = findtcb(user-thread-3);
  set_esp(tcb->sp);
  jump(tcb->pc=&there);
there:
  restore registers from stack
  return
}
```

Remove Unnecessary Code – 3

```
yield(user-thread-3){
  save registers on stack
  tcb->sp = get_esp();
  tcb = findtcb(user-thread-3);
  set_esp(tcb->sp);
  restore registers from stack
  return
}
```

User Threads vs. Kernel Processes

What if a *process* yields to another?

- "Compare & contrast, in no more than 1,000 words..."

User threads

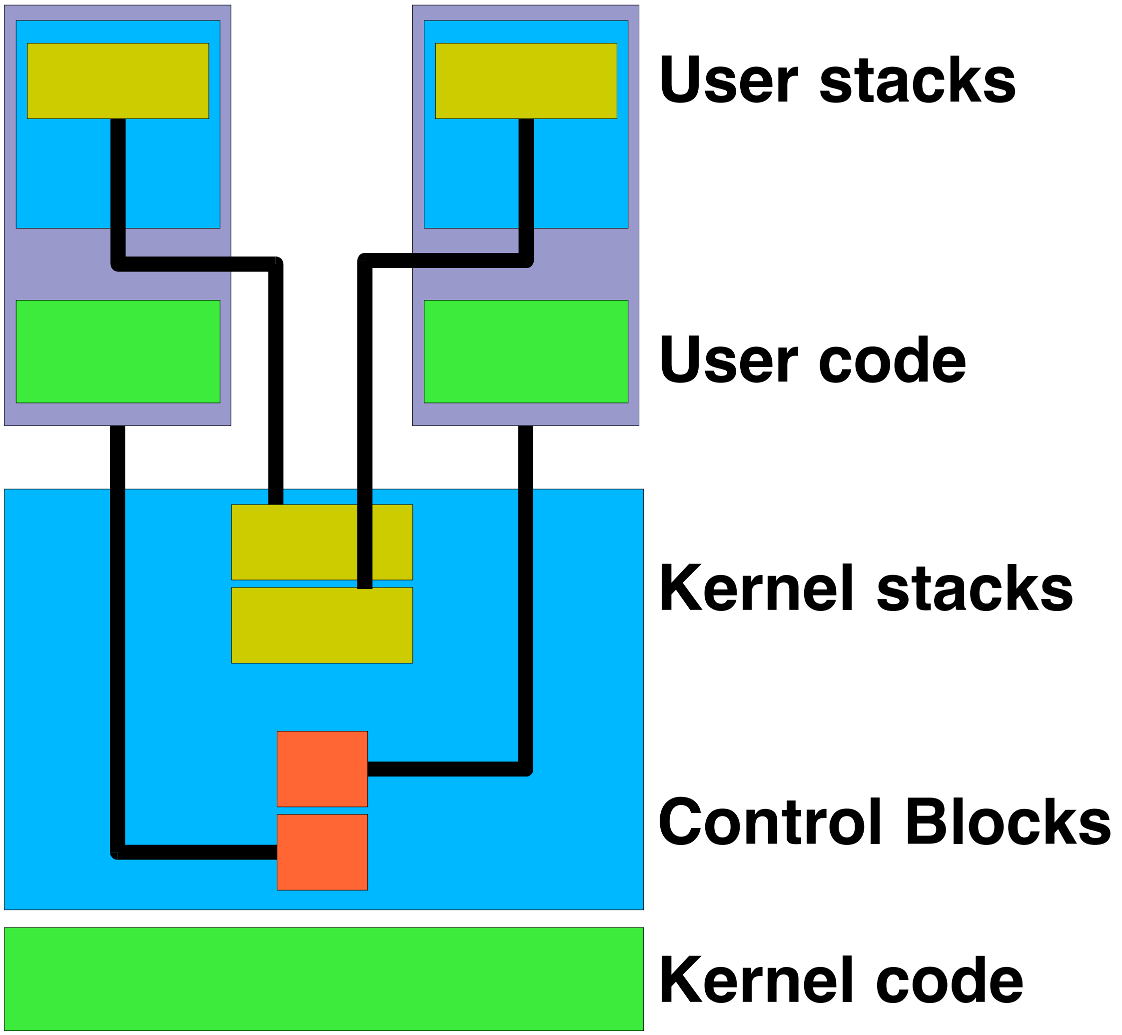
- Share memory
- Threads not protected from each other

Processes

- Do *not* generally share memory
- P1 must *not* modify P2's saved registers

Where are process save areas and control blocks?

Kernel Memory Picture



P1's Yield(P2) steps

P1 calls yield(P2)

Syscall stub: INT 50 ⇒ *boom!*

Processor trap protocol

- Saves some registers on P1's kernel stack
  - This is a *stack switch* (user ⇒ kernel), intel-sys.pdf 5.10
  - Top-of-kernel-stack specified by %esp0
  - Trap frame (x86): %ss & %esp, %eflags, %cs & %eip

Assembly-language wrapper

- Saves more registers
- Starts C trap handler

Then...?

P1's Yield(P2) steps

```
int sys_yield(int pid) {
  return (process_switch(pid));
}
```

Assembly-language wrapper

- Restores registers from P1's kernel stack, modulo %eax

Processor return-from-trap protocol (aka IRET)

- Restores %ss & %esp, %eflags, %cs & %eip

INT 50 instruction "completes"

- Back in user-space

P1 yield() library routine returns

What happened to P2??

process_switch(P2) "takes a while"

- When P1 calls it, it "returns" to P2
- When P2 calls it, it "returns" to P1 (eventually)

Inside process_switch()

ATOMICALLY

```
enqueue_tail(runqueue, cur_pcb);
save registers    /* P1's stack */
cur_pcb = dequeueID(runqueue, P2);
stackpointer = cur_pcb->sp;
restore registers /* P2's stack */
return;

/* some details omitted */
```

User-mode Yield vs. Kernel-mode

Kernel context switches happen for more reasons

- **good old yield(), but also...**
- **Message passing from P1 to P2**
- **P1 blocked on disk I/O, so run P2**
- ***CPU preemption by clock interrupt***

I/O completion Example

P1 calls read()

In kernel

- read() starts disk read
- read() calls condition_wait(&buffer); /* details vary */
- condition_wait() calls process_switch()
  - In general, we *want* somebody else to run
- process_switch() returns *to P2*

I/O Completion Example

While P2 is running

- Disk completes read, interrupts P2 into kernel
- Interrupt handler calls condition_signal(&buffer);

Now what?

I/O Completion Example

While P2 is running

- Disk completes read, interrupts P2 into kernel
- Interrupt handler calls condition_signal(&buffer);

Option 1

- condition_signal() marks P1 as runnable, returns
- Interrupt handler returns to P2

I/O Completion Example

While P2 is running

- Disk completes read, interrupts P2 into kernel
- Interrupt handler calls condition_signal(&buffer);

Option 1

- condition_signal() marks P1 as runnable, returns
- Interrupt handler returns to P2

Option 2

- condition_signal() calls process_switch(P1) ("only fair")
- P2 will finish the interrupt handler *much later*
  - Remember in P3 to confront implications of this!

Clock interrupts

P1 doesn't "ask for" clock interrupt

- Clock handler *forces* P1 into the kernel
  - Kernel stack looks like a "system call"
    - As if user process had called handle_timer()
  - But it was involuntary

P1 doesn't say who to yield to

- (it didn't make the "system call")
- *Scheduler* chooses next process

Summary

Similar steps for user space, kernel space

Primary differences

- Kernel has open-ended competitive scheduler
- Kernel more interrupt-driven

Implications for 410 projects

- P2: firmly understand thread stacks
  - thread_create() stack setup
  - cleanup
  - race conditions
- P3: firmly understand kernel context switch

Advice: draw pictures of stacks