EECS 482
Introduction to Operating Systems

Winter 2018

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Monitors vs. Semaphores

- Monitors:
  - Custom user-defined conditions
  - Developer must control access to variables

- Semaphores:
  - Access to value is thread-safe
  - Only condition is *"(value == 0)"*

- How to implement custom waiting condition with semaphores?

Implementing condition variables with semaphores

```
queue waiters = {};   // list of semaphores inserted by waiting threads

wait(mutex m) {
    // create a new semaphore
    semaphore s = 0;

    // add new semaphore to
    // waiting list
    waiters.insert(&s);

    m.up();          }
    // go to sleep   }  Not atomic
    s.down();        }
    m.down();
}

signal() {
    // nothing to do if no waiters
    if (waiters.empty()) {
        return;
    }

    // wake up one of the waiters
    semaphore s = waiters.front();
    s.up();

    // remove waiter from queue
    waiters.pop();
}
```

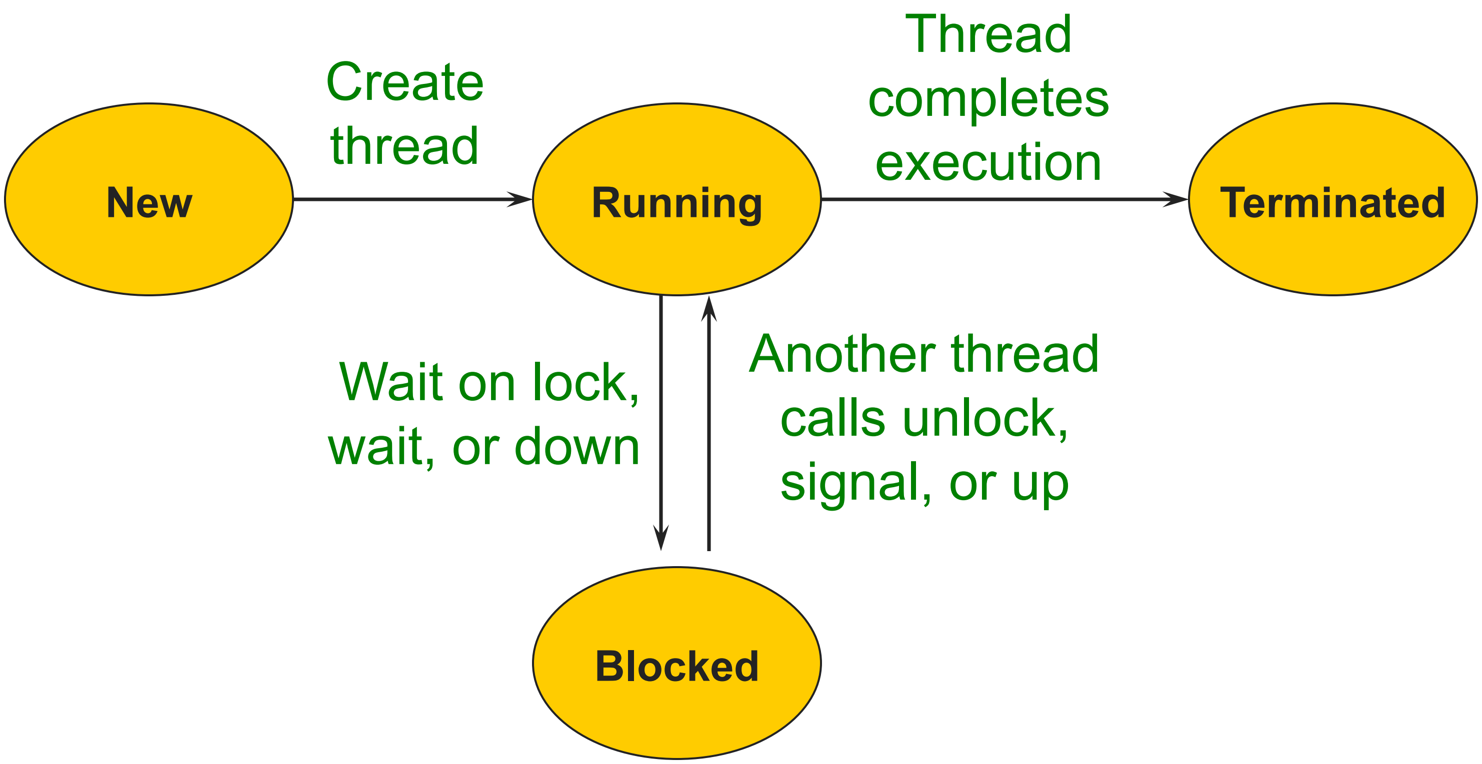
Exercise to try ...

- Given implementations of mutex and condition variable, how to implement a semaphore?

Interactions between threads

- Threads must synchronize access to shared data
- High-level synchronization primitives:
  - Locks
  - Condition variables
  - Monitors
  - Semaphores
- Threads share the same CPU

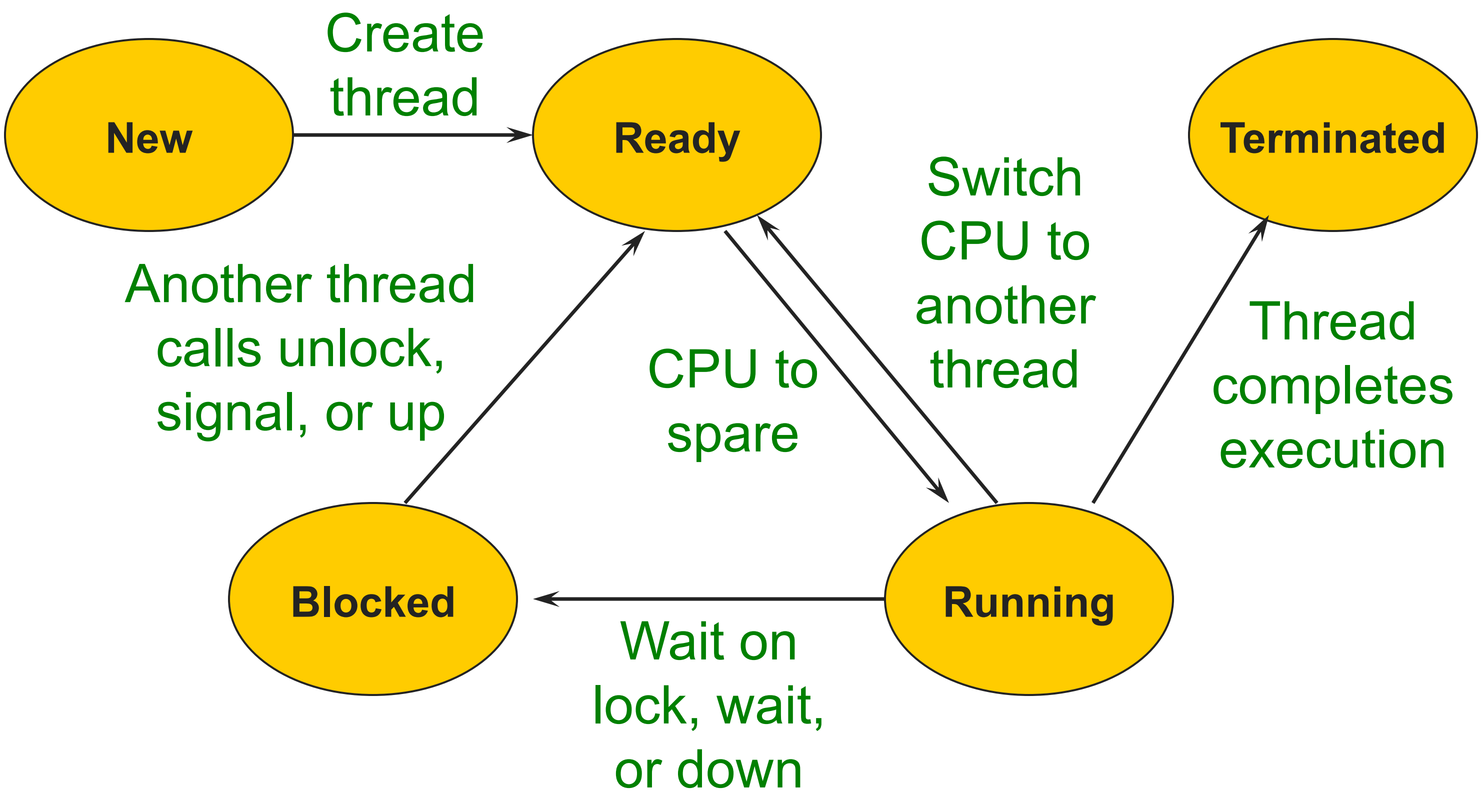
States of a Thread



What if there are more threads than CPUs?

States of a Thread

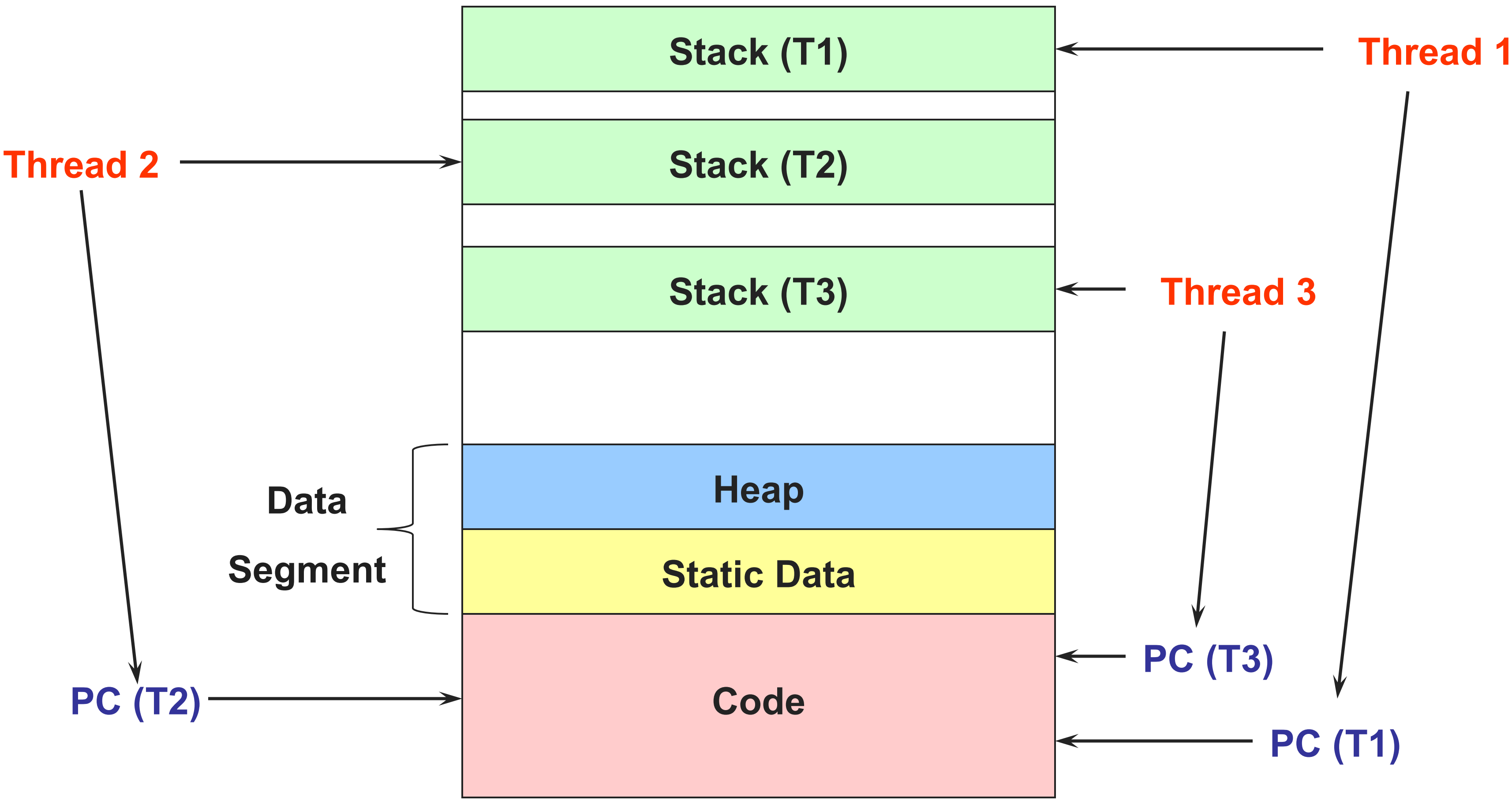
Why no transition from Ready to Blocked?



Ready threads

- What to do with thread while it's not running?
  - Essentially, a "paused" execution
  - Must save its private state somewhere
- Thread control block (TCB)
  - Per-thread OS data structure for thread info
  - Store thread "context" when not running
- What context should be stored in TCB?

Process Address Space



Thread context

- To save space in TCB
  - Share code among all threads and store only PC
  - Use multiple stacks and copy only SP
  - Also need to store general-purpose registers
- Keep track of ready threads (e.g., queue of TCBs)
- Now, any thread can be
  - Running on the CPU
  - Ready with TCB on ready queue
  - Blocked with TCB in waiting queue of lock, CV, etc.

Project 2 is out

- Implement a thread library
  - Create threads
  - Switch between threads
  - Manage interactions (locks and CVs)
  - Schedule threads on CPUs
- Due February 17th
  - Start right away!
- Everyone should now be in a group

Differences compared to P1

- Much harder!
- 15% of grade
- Test cases will be graded
- Hand grading to check for good coding practices, efficiency, no duplication of code, etc.

Two Perspectives to Execution

- Thread view:
  - Running → (Paused) → Resume
- CPU view:
  - Thread 1 → Thread 2 → Thread 1

Context switch

1. Current thread returns control to OS
2. OS chooses new thread to run
3. OS saves current thread state: CPU to TCB
4. OS loads context of next thread: TCB to CPU
5. OS runs next thread

How does thread return control back to OS?

Returning control to OS

- Three types of internal events:
  - Thread calls wait(), lock(), etc.
  - Thread requests OS to do some work (e.g., I/O)
  - Thread voluntarily gives up CPU with yield()
- Are these enough?

- Also need external events:
  - Interrupts (e.g., timer, I/O)
  - are hardware events that transfer control from thread to OS interrupt handler

Interrupts

- Hardware events (implemented by CPU)
- Stop current execution (e.g., thread function)
- Start running OS interrupt handler

- OS registers handlers in interrupt vector table
- Example: timer interrupt
  - OS may set timer to go off every 10 ms
  - Guarantees that it will get control back in <= 10 ms

Context switch

1. Current thread returns control to OS
2. OS chooses new thread to run
3. OS saves current thread state: CPU to TCB
4. OS loads context of next thread: TCB to CPU
5. OS runs next thread

Choosing next thread to run

- 1 ready thread: just run it
  - What if only thread that exists calls yield?
- >1 ready thread: need to make a decision
  - CPU's scheduling policy
  - Lots of options: FIFO, priority, round robin, etc.
- What should CPU do if no ready threads?
  - Modern CPUs suspend their execution and resume on an interrupt
  - *interrupt_enable_suspend()* in Project 2

Context switch

1. Current thread returns control to OS
2. OS chooses new thread to run
3. OS saves current thread state: CPU to TCB
4. OS loads context of next thread: TCB to CPU
5. OS runs next thread

Saving state of current thread

- Save registers, PC, stack pointer
- Tricky to get right!
  - Why won't the following code work?

```
100    save PC
101    switch to next thread
```

- Involves tricky assembly-language code
- In Project 2, we'll use Linux's *swapcontext()*

Context switch

1. Current thread returns control to OS
2. OS chooses new thread to run
3. OS saves current thread state: CPU to TCB
4. OS loads context of next thread: TCB to CPU
5. OS runs next thread

Load context and run

- How to load registers?
- How to load stack?
- How to resume execution?
- Who is carrying out these steps?
- How does thread that gave up control run again?

Example of thread switching

```
Thread 1
        print "start thread 1"
        yield()
        print "end thread 1"

Thread 2
        print "start thread 2"
        yield()
        print "end thread 2"

yield()
        print "start yield: thread %d"
        switch to next thread (swapcontext)
        print "end yield: thread %d"
```

Thread 1 output	Thread 2 output
start thread 1	
start yield: thread 1	
	start thread 2
	start yield: thread 2
end yield: thread 1	
end thread 1	
	end yield: thread 2
	end thread 2

Creating a new thread

- Create a running thread? Seems challenging
- Instead, create paused thread
  - Key idea: pretend it was running, put on readyq
  - Then just wait for it to be scheduled!
- Implication:
  - Construct TCB as if it were paused at thread start

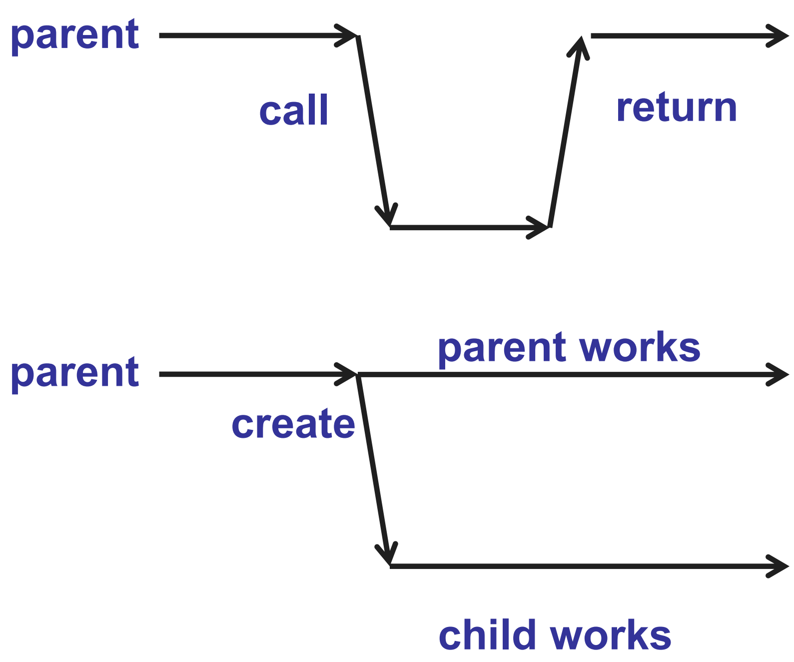
Recipe for creating a thrad

1. Allocate and initialize TCB
   - Set PC to start of thread function
   - Set general-purpose registers to func parameters
2. Allocate and initialize stack
   - What goes on stack?
   - Set TCB stack pointer to stack top
   - *getcontext()* and *makecontext()* in Project 2
3. Add TCB to ready queue

- Note: fork() creates a process, discuss later

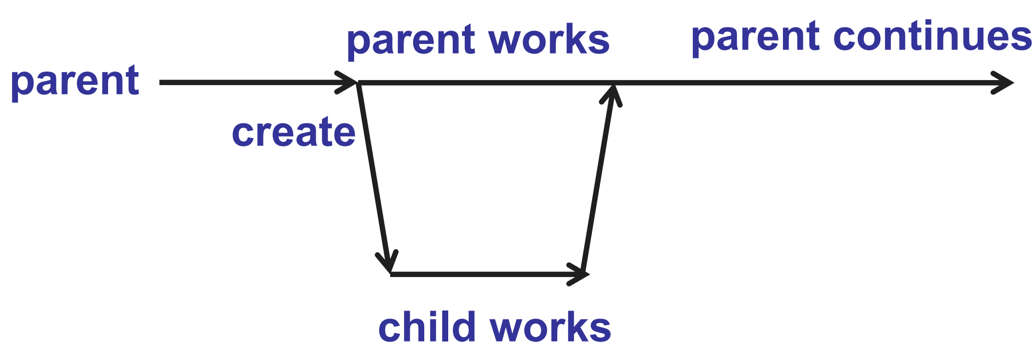
How to use new thread

- Creating a thread is like an asynchronous procedure call



Synchronizing with child

- What if parent wants to work for a while, then wait for child to finish?



Synchronizing with child

```
parent()
        create child thread
        print "parent works"
        …
        print "parent continues"
        …

child()
        …
        print "child is done"
```

When would this work?

Desired output

parent works
child is done
parent continues

OR

child is done
parent works
parent continues

Synchronizing with child

```
parent()
      create child thread
      print "parent works"
      …
      yield()
      print "parent continues"
      …

child()
      …
      print "child is done"
```

Desired output

parent works
child is done
parent continues

OR

child is done
parent works
parent continues

Does this work?

Synchronizing with join

```
parent()
      create child thread
      print "parent works"
      …
      childThread.join()
      print "parent continues"
      …

child()
      …
      print "child is done"
```

Desired output

parent works
child is done
parent continues

OR

child is done
parent works
parent continues

How to make do without join?

Synchronizing with monitors

```
parent()
      childDone = 0
      create child thread
      print "parent works"
      lock()
      while (!childDone)
          wait()
      unlock()
      print "parent continues"

child()
      print "child is done"
      lock()
      childDone = 1
      signal()
      unlock()
```

Desired output

parent works
child is done
parent continues

OR

child is done
parent works
parent continues

Project 2 update

- You can now do a substantial part of project 2
  - Thread create
  - Context switch
  - Thread join
- Next topic: implementing synchronization
  - Need to protect OS data structures (ready queue)
  - Need to block without (much) busy waiting