Use of CVs in Project 1

- Incorrect use of condition variables:
  ```java
  while (cond) {
    cv.signal();
    cv.wait();
  }
  ```

- Thread going to sleep should not be of interest to other threads
Interactions between threads

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

- Threads share the same CPU
- Then what is a non-running thread?
States of a Thread

- New
- Running
- Blocked
- Terminated

What if there are more threads than CPUs?
States of a Thread

Why no transition from Ready to Blocked?

- New: Create thread
- Ready: Another thread calls unlock, signal, or up
- Blocked: Wait on lock, wait, or down
- Running: CPU to spare
- Terminated: Switch CPU to another thread, Thread completes execution
Ready threads

- What to do with thread while it’s not running?
  - Must save its private state somewhere

- Thread “context” stored in a “thread control block” (TCB) when thread isn’t running

- What should be stored in TCB?
Process Address Space

- Stack (T1)
- Stack (T2)
- Stack (T3)
- Heap
- Static Data
- Code

Thread 1
- PC (T1)

Thread 2
- PC (T2)

Thread 3
- PC (T3)
Thread context

- To save space in TCB
  - Share code among all threads and store only PC
  - Use multiple stacks and copy only SP to TCB

- Keep track of ready threads (e.g., on a queue)

- Any thread can be in one of three states
  - Running on the CPU
  - TCB is in ready queue
  - Blocked: TCB is in waiting queue of synchronization primitive
Project 2 is out

- Implement a thread library
  - Create threads
  - Switch between threads
  - Manage interactions (locks and CVs)
  - Schedule threads on CPUs

- Due Feb 25th
  - Start early!

- Everyone should now be in a group
Two Perspectives to Execution

- **Thread view:**
  - Running $\rightarrow$ Paused $\rightarrow$ Resume

- **CPU view:**
  - Thread 1 $\rightarrow$ Thread 2 $\rightarrow$ Thread 1
Steps in Switching threads

- Current thread returns (yields) control to OS
- OS chooses next thread to run
- OS saves state of current thread from CPU to its thread control block
- OS loads context of next thread from its thread control block
- 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 are hardware events that transfer control from CPU to OS’s interrupt handler
Steps in Switching threads

- Current thread returns control to OS
- **OS chooses next thread to run**
- OS saves state of current thread from CPU to its thread control block
- OS loads context of next thread from its thread control block
- OS runs next thread

How does the OS choose the next thread to run?
Choosing next thread to run

- 1 ready thread
  - What if thread calls yield?
- >1 ready thread
  - FIFO
  - Priority

- What should CPU do if no ready threads?
  - Modern CPUs suspend their execution and resume on an interrupt
  - `interrupt_enable_suspend()` in Project 2
Steps in Switching threads

- Current thread returns control to OS
- OS chooses new thread to run
- OS saves state of current thread from CPU to its thread control block
- OS loads context of next thread from its thread control block
- OS runs next thread

How do you save the state of the current 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()`
Steps in Switching threads

- Current thread returns control to OS
- OS chooses new thread to run
- OS saves state of current thread from CPU to its thread control block
- OS loads context of next thread from its thread control block
- OS runs next thread

How do you load the TCB of the next thread and run?
Loading context of next thread and running it

- 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

<table>
<thead>
<tr>
<th>Thread 1</th>
<th>Thread 1 output</th>
<th>Thread 2 output</th>
</tr>
</thead>
<tbody>
<tr>
<td>print “start thread 1”</td>
<td>start thread 1</td>
<td>start thread 2</td>
</tr>
<tr>
<td>yield()</td>
<td>start yield: thread 1</td>
<td>start yield: thread 2</td>
</tr>
<tr>
<td>print “end thread 1”</td>
<td>end yield: thread 1</td>
<td>end yield: thread 2</td>
</tr>
<tr>
<td>yield()</td>
<td>end thread 1</td>
<td>end thread 2</td>
</tr>
</tbody>
</table>

print “start yield: thread %d”

switch to next thread (swapcontext)

print “end yield: thread %d”

February 5, 2019