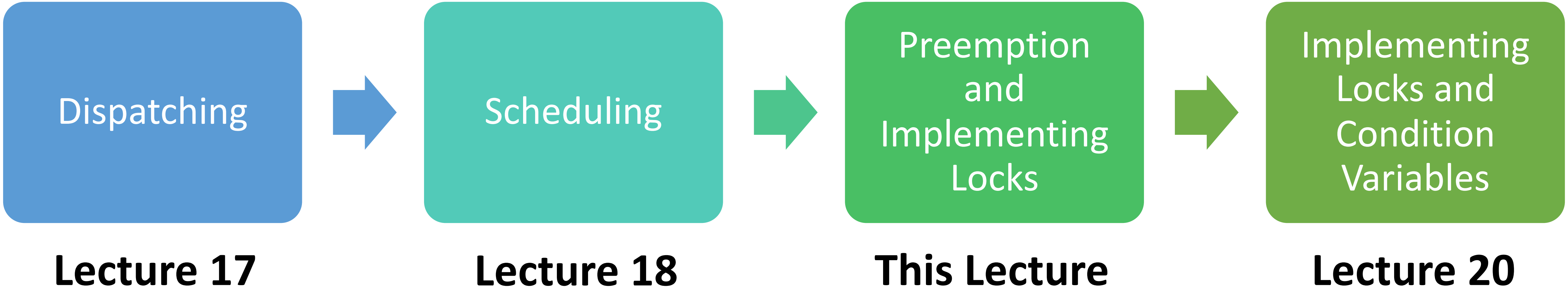
CS111, Lecture 19

Preemption and Implementing Locks

😷 masks recommended

CS111 Topic 3: Multithreading, Part 2

Multithreading - *How can we have concurrency within a single process?* ***How does the operating system support this?***



Dispatching → Scheduling → Preemption and Implementing Locks → Implementing Locks and Condition Variables

Lecture 17

Lecture 18

This Lecture

Lecture 20

assign5: implement your own version of **thread**, **mutex** and **condition_variable**!

Learning Goals

- Learn about the assign5 infrastructure and how to implement a dispatcher/scheduler with *preemption*
- Understand more about how interrupts work and how they can cause race conditions
- Use our understanding of threads and interrupts to implement locks

Plan For Today

- **Recap:** Scheduling
- Preemption and Interrupts
- Implementing Locks

```
cp -r /afs/ir/class/cs111/lecture-code/lect19 .
```

Plan For Today

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Scheduling

Key Question: How does the operating system decide which thread to run next? (e.g. many **ready** threads). Assume just 1 core.

We discussed 4 main designs:

1. **First-come-first-serve (FIFO / FCFS):** keep threads in ready queue, add threads to the back, run thread from front until completion or blocking.
2. **Round Robin:** run thread for one time slice, then add to back of queue if wants more time
3. **Shortest Remaining Processing Time (SRPT):** pick the thread that will complete or block the soonest and run it to completion.
4. **Priority-Based Scheduling:** threads have priorities, and we have one ready queue per priority. Threads adjust priorities based on time slice usage, or based on recent CPU usage (4.4 BSD Unix)

Shortest Remaining Processing Time

SRPT: pick the thread that will finish the most quickly and run it to completion. This is the optimal solution for minimizing average response time.

What are some problems/challenges with the SRPT approach?

Problem #1: how do we know which one will finish most quickly? (we must be able to predict the future…)

Problem #2: if we have many short-running threads and one long-running one, the long one will not get to run

SRPT

Another advantage of SRPT: improves overall resource utilization

- If a thread is **I/O-Bound** – e.g. constantly reading from disk (frequently waits for disk), it will get priority vs. thread that needs lots of CPU time – **CPU Bound**.
  - “I/O-Bound” - the time to complete them is dictated by how long it takes for some external mechanism to complete its work (disk, network)
  - “CPU-Bound” - the time to complete them is dictated by how long it takes us to do the CPU computation

Gives preference to those who need the least.

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- **Recap:** Scheduling
- **Preemption and Interrupts**
- Implementing Locks

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```

Preemption and Interrupts

On assign5, you'll implement a **combined scheduler+dispatcher** using the Round Robin approach.

- *Preemptive*: threads can be kicked off in favor of others (after time slice)

To implement this, we've provided a **timer** implementation that lets you run code every X microseconds.

- Fires a timer interrupt at specified interval

Idea: we can use the timer handler to trigger a context switch!

Timer Demo

```
// this program runs timer_interrupt_handler every 0.5 seconds


void timer_interrupt_handler() {
    cout << "Timer interrupt occurred!" << endl;
}

int main(int argc, char *argv[]) {
    // specify microsecond interval and function to call
    timer_init(500000, timer_interrupt_handler);
    while (true) {}
}
```

interrupt.cc

Timer and Interrupts

We can use the timer to trigger a context switch!

- For simplicity, on assign5 we'll always do a context switch when the timer fires (e.g. even if a thread finished early, and another started early, we still switch every X ms)
- **Want to avoid:** what if the timer goes off while we are handling the timer going off?
- **Key detail:** the timer disables interrupts when running your timer handler, to avoid the timer interrupting itself. Interrupts are re-enabled once the handler finishes.
- Interrupt disabling is global state (not per thread), cannot be done by user programs.

Timer Demo

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    // specify microsecond interval and function to call
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    while (true) {}
}
```

Interrupts globally disabled at start

Interrupts globally re-enabled after

interrupt.cc

Approximate timer.cc Code

```
void timer_interrupt() {
    if (!enabled_flag) {
        interrupted = 1;
        return;
    }

    intr_enable(false);
    timer_handler();
    intr_enable(true);
}
```

Timer and Interrupts

We can use the timer to trigger a context switch! Let’s see what this looks like.

`context-switch-preemption-buggy.cc`

Enabling/Disabling Interrupts

If we are switching between two already-running threads, interrupts will always be properly enabled and disabled.   Let’s see how! (Note: assumption we are running on a single-core system)

Enabling/Disabling Interrupts

Interrupts
ON

Thread #1 (Running)

```
void timer_interrupt_handler() {
    ...
context_switch(*nonrunning_thread,
               *current_thread);
}



int main(int argc, char *argv[]) {
    ...
    while (true) {
        cout << "I am the main thread"
             << endl;
    }
}
```

Thread #2

```
void timer_interrupt_handler() {
    ...
context_switch(*nonrunning_thread,
               *current_thread);
}



void other_func() {
    while (true) {
        cout << "Other thread here!
Hello." << endl;
    }
}
```

Enabling/Disabling Interrupts

Interrupts
OFF

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Timer! ⏰

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Thread #2 (Running)

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Timer! ⏰

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```
void other_func() {
    while (true) {
        cout << "Other thread here!
Hello." << endl;
    }
}
```

Enabling/Disabling Interrupts

What about when a thread runs for the first time? Will interrupts be enabled?

Will interrupts be enabled when Thread #2 first runs?

Interrupts
ON

Thread #1 (Running)

```
void timer_interrupt_handler() {
    ...
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               *current_thread);
}



int main(int argc, char *argv[]) {
    ...
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    }
}
```

Thread #2

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void other_func() {
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```

Respond on PollEv: pollev.com/cs111
or text CS111 to 22333 once to join.

Enabling/Disabling Interrupts

Interrupts
ON

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```

Timer! ⏰

Thread #2

```
void timer_interrupt_handler() {
    ...
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}



void other_func() {
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Enabling/Disabling Interrupts

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Enabling/Disabling Interrupts

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int main(int argc, char *argv[]) {
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Thread #2 (Running)

```
void timer_interrupt_handler() {
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context_switch(*nonrunning_thread,
               *current_thread);
}



void other_func() {
    while (true) {
        cout << "Other thread here!
Hello." << endl;
    }
}
```

Problem: when we start executing another thread for the first time, it won’t re-enable interrupts, so the timer won’t be heard anymore!

Demo: context-switch-preemption-buggy.cc

Enabling Interrupts

Solution: manually enable interrupts when a thread is first run.

```
void other_func() {
    intr_enable(true);  // provided func to enable/disable
    while (true) {
        cout << "Other thread here!  Hello." << endl;
    }
}
```

You'll need to do this on assign5 when a thread is first run.

Interrupts So Far

- Interrupts can be turned on and off globally
- When the timer fires, it disables interrupts while the timer handler is running, and re-enables them after
- We must make sure that the *new* thread always enables interrupts when it is switched to

Plan For Today

- **Recap:** Scheduling
- Preemption and Interrupts
- **Implementing Locks**

```
cp -r /afs/ir/class/cs111/lecture-code/lect19 .
```

Implementing Locks

Now that we understand how thread dispatching/scheduling works, we can write our own **mutex** implementation! Mutexes need to block threads (functionality the dispatcher / scheduler provides).

What does the design of a lock look like? What state does it need?

- Track whether it is locked / unlocked
- The lock “owner” (if any) – perhaps combine with first bullet
- A list of threads waiting to get this lock

Implementing Locks

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- Track whether it is locked / unlocked
- The lock “owner” (if any) – perhaps combine with first bullet
- A list of threads waiting to get this lock

We can keep a queue of threads (for fairness).

Lock

1. If this lock is unlocked, mark it as locked by the current thread
2. Otherwise, add the current thread to the back of the waiting queue

```
// Instance variables
int locked = 0;
ThreadQueue q;

void Lock::lock() {
    if (!locked) {
        locked = 1;
    } else {
        q.add(currentThread);
        blockThread();  // block/switch to next ready thread
    }
}
```

Unlock

1. If no-one is waiting for this lock, mark it as unlocked
2. Otherwise, keep it locked, but unblock the next waiting thread

```
// Instance variables
int locked = 0;
ThreadQueue q;

void Lock::unlock() {
    if (q.empty()) {
        locked = 0;
    } else {
        unblockThread(q.remove()); // add to ready queue
    }
}
```

Unlock

1. If no-one is waiting for this lock, mark it as unlocked
2. Otherwise, keep it locked, but unblock the next waiting thread

```
// Instance variables
int locked = 0;
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void Lock::unlock() {
    if (q.empty()) {
        locked = 0;
    } else {
        unblockThread(q.remove()); // add to ready queue
    }
}
```

Implementing Locks

With our understanding of threads and how they are run and switched between, we can understand how a mutex works – cool!

Question: could race conditions occur in our mutex implementation?

Yes. We can be interrupted at any time to switch to another thread.

We can have race conditions *within the thing that helps us prevent race conditions?* How are we supposed to fix *that*?

- We can't use a mutex, because we're writing the code to implement it!

More next time…

Recap

- Recap: Scheduling
- Preemption and Interrupts
- Implementing Locks

Lecture 19 takeaway: To implement preemption and locks, we must make sure to correctly enable and disable interrupts. Locks consist of a waiting queue and context switching to make threads sleep.

Next time: More about mutex and condition variable implementations