Announcements

- HW13 due tonight

- Scheme contest due Friday

- Special guest lecture by Brian Harvey on Friday at 2pm
  - Attendance is mandatory!!!
def increment():
    count = counter[0]
    sleep(0)  # May cause the interpreter to switch threads
    counter[0] = count + 1

Given a switch at the `sleep` call, here is a possible sequence of operations on each thread:

Thread 0
read counter[0]: 0
calculate 0 + 1: 1
write 1 -> counter[0]

Thread 1
read counter[0]: 0

Thread 1 (continued)
calculate 0 + 1: 1
write 1 -> counter[0]

The counter ends up with a value of 1, even though it was incremented twice!
Synchronized Data Structures

Some data structures guarantee synchronization, so that their operations are atomic

```python
from queue import Queue

queue = Queue()

def increment():
    count = queue.get()
    sleep(0)
    queue.put(count + 1)

other = Thread(target=increment, args=())
other.start()
queue.put(0)  # Add initial value of 0
increment()
other.join()
print('count is now', queue.get())
```
Manual Synchronization with a Lock
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from threading import Lock

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counter_lock = Lock()

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The With Statement

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This can be very error-prone, particularly if an exception may be raised.

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The `with` statement takes care of acquiring a lock before its suite and releasing it when execution exits its suite for any reason.

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def increment():
    with counter_lock:
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        counter[0] = count + 1
```
Example: Web Crawler
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- A queue of URLs that need processing.
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They synchronized `Queue` class can be used for the URL queue.
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They synchronized Queue class can be used for the URL queue.

There is no synchronized set in the Python library, so we must provide our own synchronization using a lock.
Synchronization in the Web Crawler
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The following illustrates the main synchronization in the web crawler:
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```python
def put_url(url):
    """Queue the given URL.""
    queue.put(url)

def get_url():
    """Retrieve a URL.""
    return queue.get()
```
The following illustrates the main synchronization in the web crawler:

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def put_url(url):
    """Queue the given URL.""
    queue.put(url)

def get_url():
    """Retrieve a URL.""
    return queue.get()

def already_seen(url):
    """Check if a URL has already been seen.""
    with seen_lock:
        if url in seen:
            return True
        seen.add(url)
    return False
```
Example: Particle Simulation
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The simulation is discretized into timesteps
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barrier.wait()  # Waits until num_threads threads reach it
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Thus, reads are on copies, so they don’t conflict with writes.
Summary
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But parallelism is hard in the presence of mutable shared state.
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But parallelism is hard in the presence of mutable shared state:

- Access to shared data must be synchronized in the presence of mutation.
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But parallelism is hard in the presence of mutable shared state:

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Making parallel programming easier is one of the central challenges that Computer Science faces today.
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- Simple and compact implementations provide very powerful abstractions
61A Topics in Future Courses
You will see the topics you learned here many times over your academic career and beyond.
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- **61B**: Object-oriented programming, inheritance, multiple representations, recursive data (rlists and trees), orders of growth
- **61C**: MapReduce, Parallelism
- **70**: Recursion/induction, halting problem
- **162**: Parallelism
- **164**: Recursive data, interpretation, declarative programming
- **170**: Recursive data, orders of growth, logic
- **172**: Halting problem
- **186**: Declarative programming
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Of course, you will see abstraction everywhere!
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You can apply to be a reader or TA here:
https://willow.coe.berkeley.edu/PHP/gsiapp/menu.php
From all of us:
Thank you for a wonderful semester!
61A Rocks!
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Thanks to Andy Qin!
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Thanks to Lucas Karahadian!
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Thanks to Andy Qin!

I swear it wasn’t me!

Thanks to Adithya Murali!

Thanks to Lucas Karahadian!