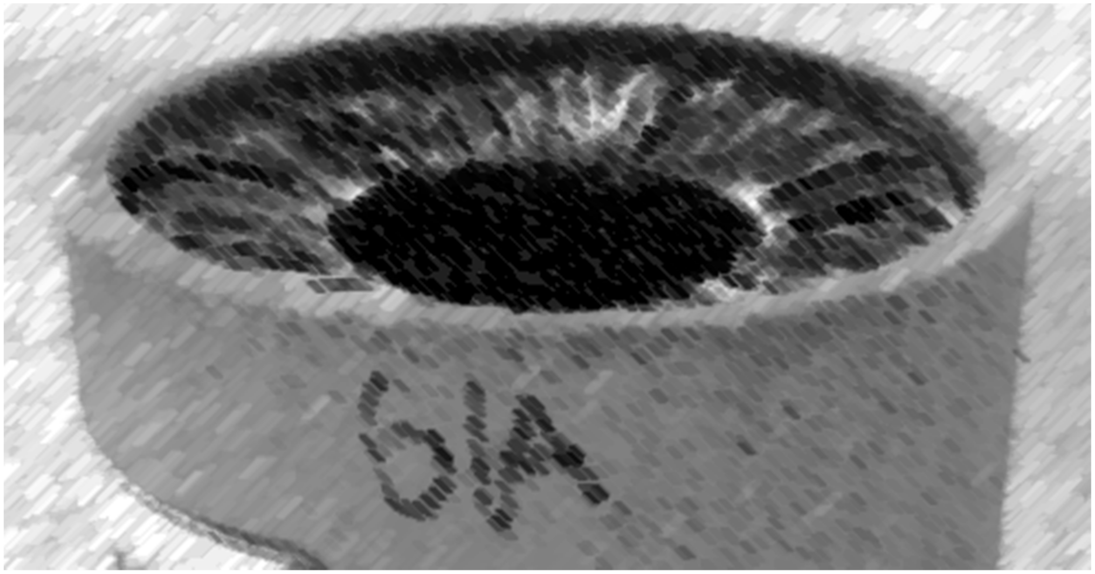

CS61A Lecture 43

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Announcements

- HW13 due tonight
- Scheme contest due Friday
- Special guest lecture by Brian Harvey on Friday at 2pm
  - Attendance is mandatory!!!

The Problem with Shared State

```
def increment():
    count = counter[0]
    sleep(0)
    counter[0] = count + 1
```

May cause the interpreter to switch threads

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

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

```
from queue import Queue
```
Synchronized FIFO queue

```
queue = Queue()

def increment():
    count = queue.get()
```
Waits until an item is available

```
    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

A *lock* ensures that only one thread at a time can hold it

Once it is *acquired*, no other threads may acquire it until it is *released*

```
from threading import Lock

counter = [0]
counter_lock = Lock()

def increment():
    counter_lock.acquire()
    count = counter[0]
    sleep(0)
    counter[0] = count + 1
    counter_lock.release()

other = Thread(target=increment, args=())
other.start()
increment()
other.join()
print('count is now', counter[0])
```

The With Statement

A programmer must ensure that a thread releases a lock when it is done with it

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

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

```
def increment():
    counter_lock.acquire()
    count = counter[0]
    sleep(0)
    counter[0] = count + 1
    counter_lock.release()

def increment():
    with counter_lock:
        count = counter[0]
        sleep(0)
        counter[0] = count + 1
```

Example: Web Crawler

A *web crawler* is a program that systematically browses the Internet

For example, we might write a web crawler that validates links on a website, recursively checking all links hosted by the same site

A parallel crawler may use the following data structures:

- A queue of URLs that need processing
- A set of URLs that have already been seen, to avoid repeating work and getting stuck in a circular sequence of links

These data structures need to be accessed by all threads, so they must be properly synchronized

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

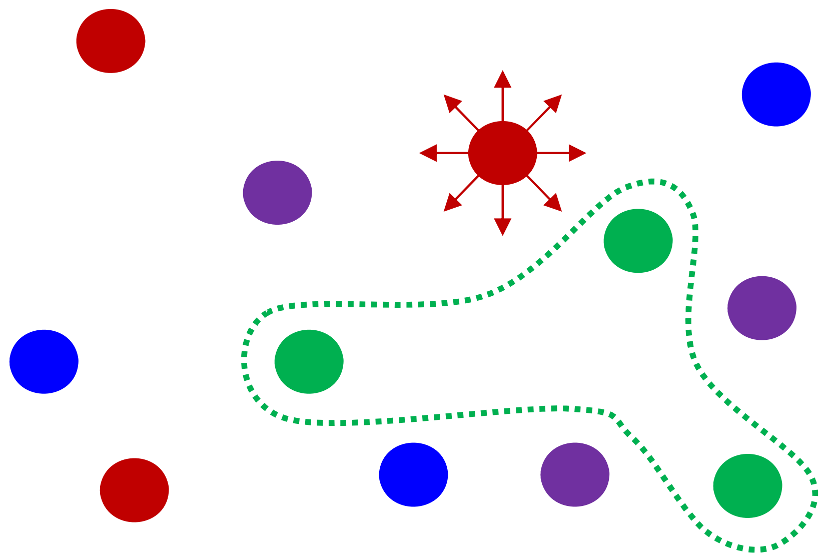
The following illustrates the main synchronization in the web crawler:

```
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



A set of particles all interact with each other (e.g. short range repulsive force)

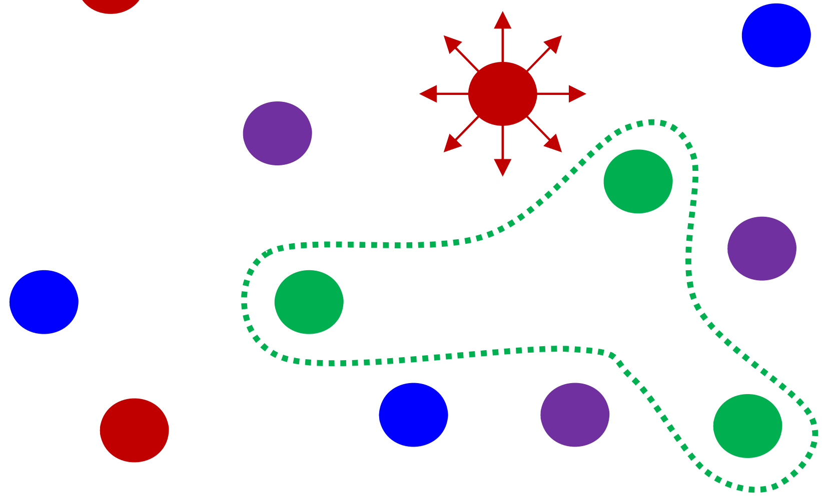
The set of particles is divided among all threads/processes

Forces are computed from particles' positions

- Their positions constitute shared data

The simulation is discretized into timesteps

Example: Particle Simulation



In each timestep, each thread/process must:

Concurrent reads are OK

1. Read the positions of every particle (read shared data)
2. Update acceleration of its own particles (access non-shared data)
3. Update velocities of its own particles (access non-shared data)
4. Update positions of its own particles (write shared data)

Steps 1 and 4 conflict with each other

Writes are to different locations

Solution #1: Barriers

In each timestep, each thread/process must:

1. Read the positions of every particle (read shared data)
2. Update acceleration of its own particles (access non-shared data)
3. Update velocities of its own particles (access non-shared data)
4. Update positions of its own particles (write shared data)

Steps 1 and 4 conflict with each other

We can solve this conflict by dividing the program into *phases*, ensuring that all threads change phases at the same time

A *barrier* is a synchronization mechanism that accomplishes this

```
from threading import Barrier
barrier = Barrier(num_threads)
barrier.wait()
```

Waits until **num_threads** threads reach it

Solution #2: Message Passing

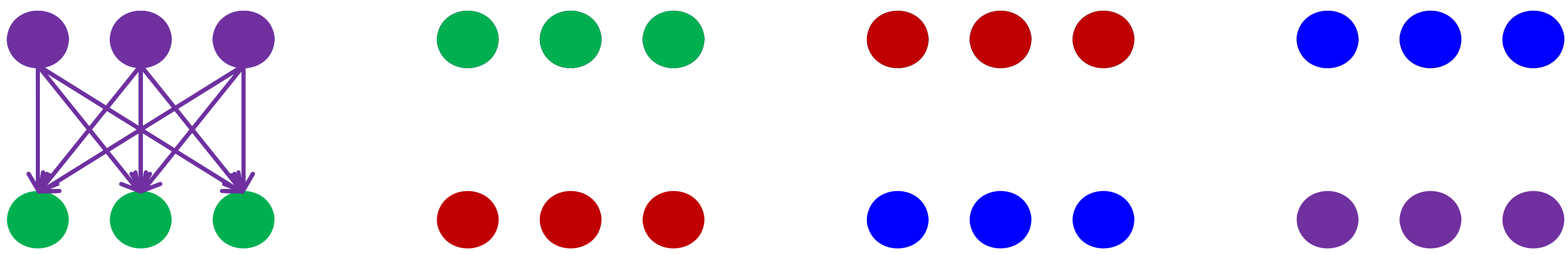
Alternatively, we can explicitly pass state from the thread/process that owns it to those that need to use it

In each timestep, every process makes a copy of its own particles

Then, they do the following **`num_processes-1`** times:

1. Interact with the copy that is present
2. Send the copy to the left, receive from the right

Thus, reads are on copies, so they don't conflict with writes



Summary

Parallelism is necessary for performance, due to hardware trends

But parallelism is hard in the presence of mutable shared state

- Access to shared data must be synchronized in the presence of mutation

Making parallel programming easier is one of the central challenges that Computer Science faces today

Abstraction, Abstraction, Abstraction

The central idea of 61A is *abstraction*

- Not only central in Computer Science, but in any discipline that deals with complex systems

Abstraction is our main tool for managing complexity

- Complex systems have multiple abstraction layers to divide the system as a whole into manageable pieces

Not only did we learn how to *use* abstractions, we learned how to *build* them

- Nothing is magical!
- We saw lots of cool ideas (e.g. objects, rlists, interpreters, logic programming), but we also saw how they work
- 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

Here is a (partial) mapping between CS classes and 61A topics:

- **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

Of course, you will see abstraction everywhere!

Stay Involved!

The community is what makes 61A great (TAs, readers, lab assistants)

The entire teaching staff consists of undergrads like you

- Most of them are sophomores!

If you can, please lab assist for future semesters

- You get units!
- Readers and TAs are often chosen based on their involvement with the course, in addition to grades and other factors

You can apply to be a reader or TA here: https://willow.coe.berkeley.edu/PHP/gsiapp/menu.php

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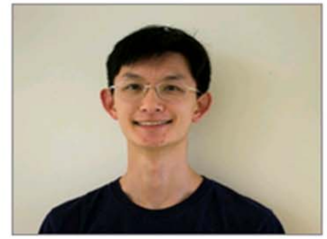
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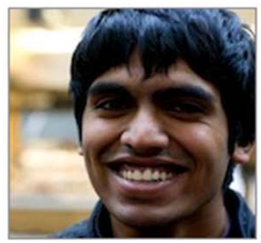
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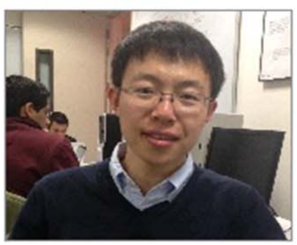
Siyuan (Jack) He


Jian Qiao


Iris Wang


Chenyang Yuan

From all of us:

Thank you for a wonderful semester!

61A Rocks!

Thanks to Andy Qin!

Thanks to Adithya Murali!

Thanks to Lucas Karahadian!