CS4231
Parallel and Distributed Algorithms

Lecture 2

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Review of Last Lecture

- Mutual exclusion problem in shared-memory systems
- Software solutions
  - Unsuccessful attempts
  - Peterson’s algorithm
  - Bakery algorithm
- Hardware solutions
  - Disabling interrupts to prevent context switch
  - Special machine-level instructions

Today's Roadmap

- Chapter 3 "Synchronization Primitives"
- Why do we need synchronization primitives?
- Synchronization primitive: Semaphore
- Synchronization primitive: Monitor

The Busy Wait Problem

- Solutions developed in last lecture has a common busy wait problem
  - Wastes CPU cycles
  - We want to release the CPU to other processes
  - Need OS support

- Synchronization primitives
  - OS-level APIs that the program may call
  - Don't worry about how they are implemented
- Semaphores
- Monitors

Semaphore Semantics

- (Figure 3.1 and 3.2 in the textbook can be confusing, you can ignore that.)
- Internally, each semaphore has
  - A boolean *value* – initially true
  - A *queue* of blocked processes – initially empty

```
P():
    if (value == false) {
        add myself to queue
        and block;
    }
    value = false;
```

Executed atomically (e.g., interrupt disabled)

(if blocks, will context switch to some other process)

```
V():
    value = true;
    if (queue is not empty) {
        wake up one arbitrary
        process on the queue
    }
```

Executed atomically (e.g., interrupt disabled)

Example: P0 invokes P() when value is false, and then P1 invokes V()

Process 0	*Process 1*

P():
    if (*value* == false) {
        add myself to *queue*
        and block;
    }	

	V():
	    value = true;
	    if (queue is not empty) {
	        wake up one arbitrary
	        process on the queue
	    }

~~*value* = false;~~	

P0 blocks and P1 takes over

Semaphore Semantics

- Exactly one process is waken up in V()
  - The process waken up is chosen arbitrarily
  - Some implementations choose the first process on the queue – Should always check the API semantics for the system you are using

Using Semaphore for Mutual Exclusion

- RequestCS() { P(); }
- ReleaseCS() { V(); }
- The nice thing about this mutual exclusion design is no busy waiting

Dining Philosopher Problem (Dijkstra'65)

- 5 philosophers, 5 chopsticks
- Use 5 semaphores, one for each chopstick:
  - Chopstick[1..5]

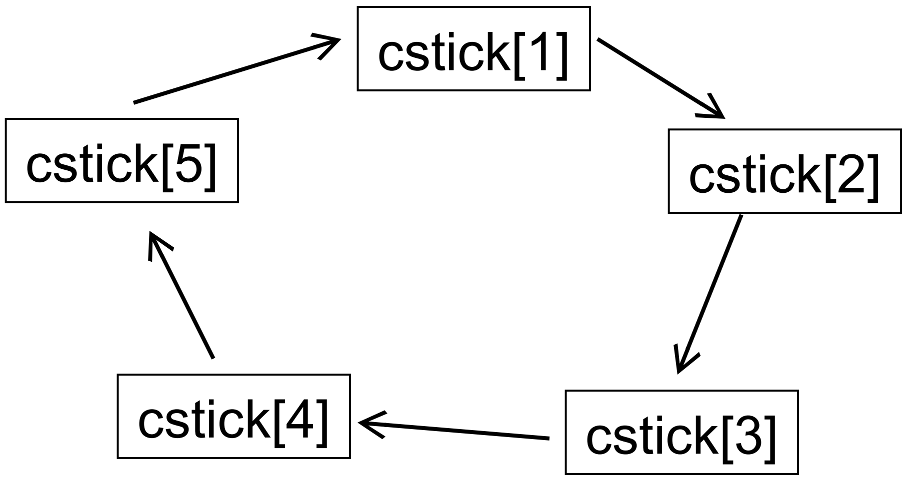
Philosopher i

```
while (true) {
    //think for a while, getting hungry
    chopstick[i].P();
    chopstick[(i+1) % 5].P();
        //eat now; (critical section)
    chopstick[i].V();
    chopstick[(i+1) % 5].V();
}
```

The Danger of Deadlock

philosopher 1	*philosopher 2*	*philosopher 3*	*philosopher 4*	*philosopher 5*
cstick[1].P();	cstick[2].P();	cstick[3].P();	cstick[4].P();	cstick[5].P();
cstick[2].P();	cstick[3].P();	cstick[4].P();	cstick[5].P();	cstick[1].P();

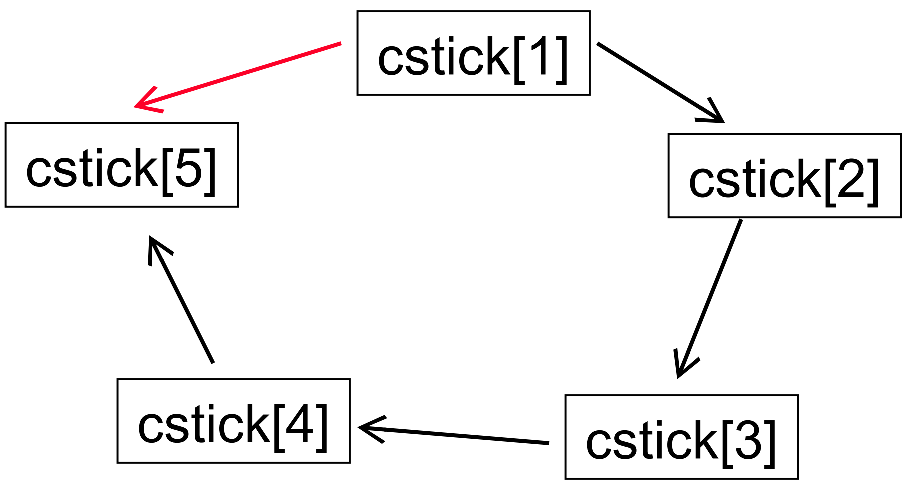
- It is possible for all processes to block
  - Deadlock !



Avoiding Deadlock

philosopher 1	*philosopher 2*	*philosopher 3*	*philosopher 4*	*philosopher 5*
cstick[1].P();	cstick[2].P();	cstick[3].P();	cstick[4].P();	cstick[1].P();
cstick[2].P();	cstick[3].P();	cstick[4].P();	cstick[5].P();	cstick[5].P();

- Avoid cycles (or have a total ordering of the chopsticks)



Today's Roadmap

- Chapter 3 "Synchronization Primitives"
- Why do we need synchronization primitives?
- Synchronization primitive: Semaphore
- Synchronization primitive: Monitor
  - Monitor semantics
  - Using monitors to solve synchronization problems

Monitors

- Semaphore are quite low-level
  - Monitors are higher-level and easier to use
  - You can always use one to implement the other

- Java only has monitors

Monitor Semantics

- Monitor object M
- Every object in Java is a monitor

Like a critical section

```
synchronized (object) {
    ....
    ....
    ....
}
```

enterMonitor():

enter monitor if no one is in; otherwise add myself to the monitor-queue and block;

exitMonitor():

If monitor-queue is not empty, pick one arbitrary process from monitor-queue and unblock it

sometime we also say that a monitor has a monitor lock

Monitor Semantics

- Each monitor has two queues of blocked processes
  - monitor-queue and wait-queue
- Three special methods for using when inside a monitor

```
synchronized (object) {
    ….
    object.wait();
    ….
    object.notify();
    ….
    object.notifyAll();
    ….
}
```

Add myself to the wait-queue, exit monitor, and then block --- all done atomically

If wait-queue is not empty, pick one arbitrary process from wait-queue and unblock it

If wait-queue is not empty, unblock all processes in wait-queue

Two Kinds of Monitors

Process 0	*Process 1*

synchronized (object) {
….
object.wait();	

	synchronized (object) {
	….
	object.notify();

which process should continue execution at this point?	
}	}

Only one process can be inside the monitor: Two possibilities….

First kind: Hoare-style Monitor

Process 0	*Process 1*

synchronized (object) {
    ….
    object.wait();	

	synchronized (object) {
	    ….
	    object.notify();

…. }	
	…. }

process 0 takes over the execution

First kind: Hoare-style Monitor

Process 0	*Process 1*
synchronized (object) { if (x != 1) object.wait();	

	synchronized (object) {
	    x=1;
	    object.notify();

assert(x == 1); // x must be 1
    x = 2;
}	

	// x may no longer be 1 here }

process 0 takes over the execution

Second kind: Java-style Monitor

Process 0	*Process 1*

synchronized (object) {
    ….
    object.wait();	

	synchronized (object) {
	    ….
	    object.notify();

	…. }
…. }	

process 1 continues execution

Second kind: Java-style Monitor

Process 0	*Process 1*
synchronized (object) { if (x != 1) object.wait();	

	synchronized (object) {
	    x=1;
	    object.notify();

	assert(x == 1); // x must be 1
	    x=2;
	}

// needs to acquire monitor lock
    // x may not be 1 here
}	

process 1 continues execution

Second kind: Java-style Monitor

Process 0	*Process 1*

synchronized (object) {
while (x != 1)
object.wait();	

	synchronized (object) {
	x=1;
	object.notify();

	assert(x == 1); // x must be 1
	x=2;
	}

assert(x == 1); // if P0 gets here
}	

process 1 continues execution

Two kinds of monitors: More

- Java-style monitor is more popular
  - But you should always check the semantics of the monitor if you are not using Java

- Synchronization code is extremely difficult (if not impossible) to debug
  - There are bugs that people fail to debug after many years
  - Need to get it right the first time

Other Ways of Using Monitor in Java

```
public synchronized void
    myMethod () {
    ....
    ....
    ....

}
```

=

```
public void myMethod () {
    synchronized (this) {
        ....
        ....
        ....
    }
}
```

static methods can also be synchronized – the monitor lock is class wide

Nested Monitor in Java

```
synchronized (ObjA) {
    synchronized (ObjB) {
        ObjB.wait();
    }
}
```

```
synchronized (ObjA) {
    synchronized (ObjB) {
        ObjB.notify();
    }
}
```

- Here Java only releases the monitor lock on ObjB and not the monitor lock on ObjA.
- Hence this piece of code will block and will not reach ObjB.notify() – deadlock!
- Different monitor implementations may differ in how nested monitors are implemented – check the spec to tell…

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The Producer-Consumer Problem

- A circular buffer of size n
- A single producer and a single consumer
- Producer places item to the end of the buffer if
  - Buffer is not full
- Consumer removes item from the head of the buffer if
  - Buffer is not empty
- Example: hard drive as producer and printer as consumer

Using Monitor to Solve the Producer/Consumer problem

object sharedBuffer;

```
void produce() {
    synchronized (sharedBuffer) {
        if (sharedBuffer is full)
            sharedBuffer.wait();
        add an item to sharedBuffer;
        if (sharedBuffer *was* empty)
            sharedBuffer.notify();
    }
}
```

```
void consume() {
    synchronized (sharedBuffer) {
        if (sharedBuffer is empty)
            sharedBuffer.wait();
        remove item from sharedBuffer;
        if (sharedBuffer *was* full)
            sharedBuffer.notify();
    }
}
```

Using Monitor to Solve the Producer/Consumer problem

object sharedBuffer;

```
void produce() {
    synchronized (sharedBuffer) {
        if (sharedBuffer is full)
            sharedBuffer.wait();
        add an item to sharedBuffer;
        if (sharedBuffer *was* empty)
            sharedBuffer.notify();
    }
}
```

notification is lost if no process is waiting – very different semantics from V()

The Reader-Writer Problem

- Multiple readers and writers are accessing a file
  - A writer must have exclusive access
  - But readers may simultaneously access the file

int numReader, numWriter; Object object;

```
void writeFile() {
    synchronized (object) {
        while (numReader > 0 ||
                 numWriter > 0)
            object.wait();
        numWriter = 1;
    }
    // write to file;
    synchronized (object) {
        numWriter = 0;
        object.notifyAll();
    }
}
```

```
void readFile() {
 synchronized (object) {
        while (numWriter > 0)
            object.wait();
        numReader++;
   }
   // read from file;
   synchronized (object) {
        numReader--;
        object.notify();
   }
}
```

you can prove that it must be a writer who is notified

The Starvation Problem

- Writers may get starved if there is a continuous stream of readers
  - There's a way to avoid that….will be your homework…

Summary

- Why do we need synchronization primitives
  - Busy waiting waste CPU
  - But synchronization primitives need OS support
- Semaphore:
  - Using semaphore to solve dining philosophers problem
  - Avoiding deadlocks
- Monitor:
  - Easier to use than semaphores / more popular
  - Two kinds of monitors
  - Using monitor to solve producer-consumer and reader-writer problem

Homework Assignment

- Page 51:
  - Problem 3.3, 3.4, 3.6
  - All using monitors and not semaphores

- Homework due a week from today
- Read Chapter 4, Chapter 5.1, 5.2