15-410

"My computer is 'modern'!"

Synchronization #1
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Notice

Me vs. OSC Chapter 6

- I will cover 6.3 much more than the text does...
  - ...even more than the previous edition did...
  - This is a good vehicle for understanding race conditions

Me vs. OS:P+P Chapter 5

- Philosophically very similar
- Examples and focus are different

Not in the book

- "Atomic sequences vs. voluntary de-scheduling"
  - "Sim City" example

Textbook recommended!

- We will spend ~4 lectures on one chapter (~7 on two)
- This is important stuff
  - Getting a "second read" could be very useful

Outline

An intrusion from the "real world"

Two fundamental operations

Three necessary critical-section properties

Two-process solution

N-process "Bakery Algorithm"

Mind your P's and Q's

Imagine you wrote this code:

```
choosing[i] = true;
number[i] =
  max(number[0], number[1], ...) + 1;
choosing[i] = false;
```

Mind your P's and Q's

Imagine you wrote this code:

```
choosing[i] = true;
number[i] =
  max(number[0], number[1], ...) + 1;
choosing[i] = false;
```

Imagine what is sent out over the memory bus is:

```
number[i] = 11;
choosing[i] = false;
```

Is that ok?

Mind your P's and Q's

Imagine you wrote this code:

```
choosing[i] = true;
number[i] =
  max(number[0], number[1], ...) + 1;
choosing[i] = false;
```

How about this??

```
choosing[i] = false;
number[i] = 11;
```

Is my computer broken???

- "Computer Architecture for $200, Dave"...

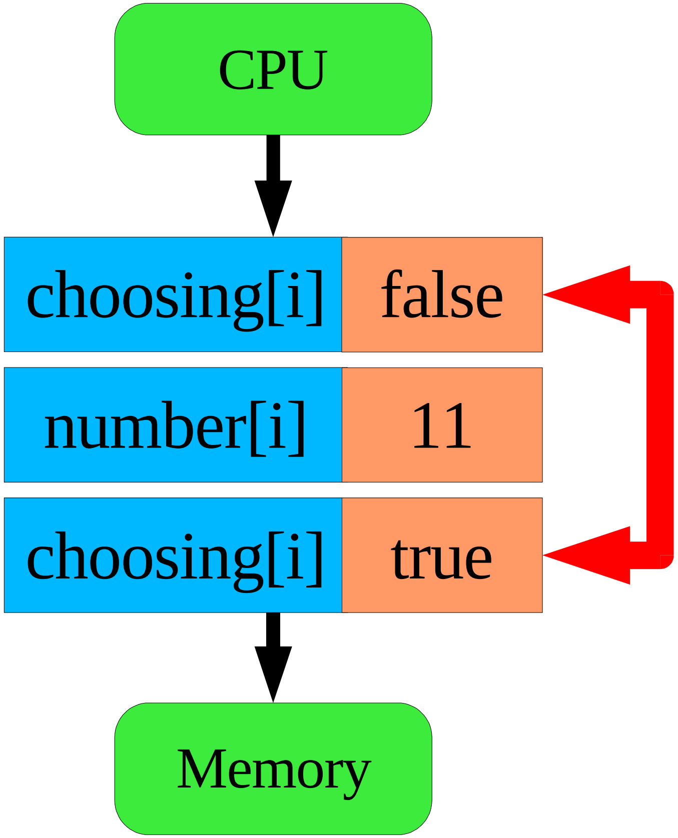
Is my computer broken?!

No, your computer is "modern"

- Processor "write pipe" queues memory stores
- ...*and* coalesces "redundant" writes!

Crazy?

- Not if you're pounding out pixels!



My Computer is Broken?!

Magic "memory barrier" instructions available...

- ...stall processor until write pipe is empty

Ok, now I understand

- Probably not!
  - http://www.cs.umd.edu/~pugh/java/memoryModel/
    - » see "Double-Checked Locking is Broken" Declaration
- See also "release consistency"

Textbook mutual exclusion algorithm memory model

- ...is "what you expect" (pre-"modern")
- Ok to use simple model for homework, exams, P2
  - But it's not right for multi-processor Pentium-4 systems...

Synchronization Fundamentals

Two fundamental operations

- Atomic instruction sequence
- Voluntary de-scheduling

Multiple implementations of each

- Uniprocessor vs. multiprocessor
- Special hardware vs. special algorithm
- Different OS techniques
- Performance tuning for special cases

Be *very clear* on features, differences

- The two operations are more "opposite" than "the same"

Synchronization Fundamentals

Multiple client abstractions use the two operations

Textbook prefers

- "Critical section", semaphore, monitor

***Very* relevant**

- Mutex/condition variable (POSIX pthreads)
- Java "synchronized" keyword (3 flavors)

Synchronization Fundamentals

Two Fundamental operations

- Atomic instruction sequence
- Voluntary de-scheduling

Atomic Instruction Sequence

Problem domain

- ***Short*** **sequence of instructions**
- **Nobody else may interleave same sequence**
  - **or a "related" sequence**
- **"Typically" nobody is competing**

Non-interference

Multiprocessor simulation (think: “Sim City”)

- Coarse-grained “turn” (think: hour)
- Lots of activity within each turn
- Think: M:N threads, M=objects, N=#processors

Most **cars don't interact in a game turn...**

- Must model those that do
- So street intersections can't generally be “processed” by multiple cars at the same time

Commerce

Customer 0	*Customer 1*
`cash = store->cash;`	`cash = store->cash;`
`cash += 50;`	`cash += 20;`
`wallet -= 50;`	`wallet -= 20;`
`store->cash = cash;`	`store->cash = cash;`

Should the store call the police?

Is deflation good for the economy?

Commerce – Observations

Instruction sequences are "short"

- Ok to "mutually exclude" competitors (make them wait)

Probability of collision is "low"

- Many non-colliding invocations per second
  - (lots of stores in the city)
- *Must not* use an expensive anti-collision approach!
  - "Just make a system call" is *not* an acceptable answer
- Common (non-colliding) case must be fast

Synchronization Fundamentals

Two Fundamental operations

- Atomic instruction sequence
- ⇨ Voluntary de-scheduling

Voluntary De-scheduling

Problem domain

- "Are we there yet?"
- "Waiting for Godot"

Example - "Sim City" disaster daemon

```
while (date < 1906-04-18) cwait(date);
while (hour < 5) cwait(hour);
for (i = 0; i < max_x; i++)
  for (j = 0; j < max_y; j++)
    wreak_havoc(i,j);
```

Voluntary De-scheduling

Anti-atomic

- We *want* to be “maximally interleaved against”

Running and making others wait is *wrong*

- Wrong for them – we won't be ready for a while
- Wrong for us – we can't be ready until *they* progress

We don't *want* exclusion

We *want* others to run - they *enable* us

CPU *de*-scheduling is an OS service!

Voluntary De-scheduling

Wait pattern

```
LOCK WORLD
while (!(ready = scan_world())){
  UNLOCK WORLD
  WAIT_FOR(progress_event)
  LOCK WORLD
}
```

Your partner-competitor will

```
SIGNAL(progress_event)
```

Standard Nomenclature

"Traditional CS" code skeleton / naming

```
do {
  entry section
  critical section:
    ...computation on shared state...
  exit section
  remainder section:
    ...private computation...
} while (1);
```

Standard Nomenclature

What's muted by this picture?

- What's *in* that critical section?
  - Quick atomic sequence?
  - Need for a long sleep?

For now...

- Pretend critical section is a brief atomic sequence
- Study the entry/exit sections

Three Critical Section Requirements

Mutual Exclusion

- **At most one thread is executing each critical section**

Progress

- **Choosing protocol must have bounded time**
  - **Common way to fail: choosing next entrant cannot wait for non-participants**

Bounded waiting

- **Cannot wait forever once you begin entry protocol**
- **...bounded number of entries by others**
  - **not necessarily a bounded number of *instructions***

Notation For 2-Process Protocols

Assumptions

- Multiple threads (1 CPU with timer, or multiple CPU's)
- Shared memory, but no locking/atomic instructions

Thread `i` = "us"

Thread `j` = "the other thread"

`i,j` are *thread-local* variables

- {i,j} = {0,1}
- j == 1 – i

This notation is "odd"

- But it *may well appear in an exam question*

Idea #1 - “Taking Turns”

```
int turn = 0;

while (turn != i)
  continue;
...critical section...
turn = j;
```

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Mutual exclusion – yes (make sure you see it)

Idea #1 - "Taking Turns"

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...critical section...
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```

Mutual exclusion – yes (make sure you see it)

Progress - *no*

- ***Strict*** **turn-taking is fatal**
- **If T0 never tries to enter, T1 will wait forever**
  - **Violates the "depends on non-participants" rule**

Idea #2 - "Registering Interest"

```
boolean want[2] = {false, false};

want[i] = true;
while (want[j])
  continue;
...critical section...
want[i] = false;
```

Mutual Exclusion (Intuition)

Thread 0	*Thread 1*
`want[0] = true;`	
`while (want[1]) ;`	
`...enter...`	`want[1] = true;`
	`while (want[0]) ;`
	`while (want[0]) ;`
`want[0] = false;`	`while (want[0]) ;`
	`...enter...`

Mutual Exclusion (Intuition)

Thread 0	*Thread 1*
`want[0] = true;`	
`while (want[1]) ;`	
`...enter...`	`want[1] = true;`
	`while (want[0]) ;`
	`while (want[0]) ;`
`want[0] = false;`	`while (want[0]) ;`
	`...enter...`

How about progress?

Failing “Progress”

Thread 0	*Thread 1*
`want[0] = true;`	
	`want[1] = true;`
`while (want[1]) ;`	
	`while (want[0]) ;`

It works for every ***other*** interleaving!

"Peterson's Solution" (1981)

("Taking turns when necessary")

```
boolean want[2] = {false, false};
int turn = 0;

want[i] = true;
turn = j;
while (want[j] && turn == j)
    continue;
...critical section...
want[i] = false;
```

Proof Sketch of Exclusion

Assume contrary: two threads in critical section

Both in c.s. implies want[i] == want[j] == true

Thus both while loops exited because "turn != j"

Cannot have (turn == 0 && turn == 1)

- So one exited first

w.l.o.g., T0 exited first because "turn ==1" failed

- So turn==0 before turn==1
- So T1 had to set turn==0 before T0 set turn==1
- So T0 could not see turn==0, could *not* exit loop first!

Proof Sketch Hints

- **want[i] == want[j] == true**
  - "want[]" fall away, focus on "turn"
- **turn[] vs. loop exit...**
  - What really happens here?

Thread 0	*Thread 1*
`turn = 1;`	`turn = 0;`
`while (turn == 1);`	`while (turn == 0);`

Bakery Algorithm (Lamport)

More than two processes?

- Generalization based on bakery/deli counter
  - Get monotonically-increasing ticket number from dispenser
  - Wait until monotonically-increasing “now serving” == you
    - » You have lowest number ⇒ all people with smaller numbers have already been served

Multi-process version

- Unlike “reality”, two people can get the same ticket number
- Sort by “ticket number with tie breaker”:
  - (ticket number, process number) tuple

Bakery Algorithm (Lamport)

Phase 1 – Pick a number

- Look at all presently-available numbers
- Add 1 to highest you can find

Phase 2 – Wait until you hold *lowest* number

- Not strictly true: processes may have same number
- Use process-id as a tie-breaker
  - (ticket 7, process 99) > (ticket 7, process 45)
- Your turn when you hold lowest (t,pid)

Bakery Algorithm (Lamport)

```
boolean choosing[n] = { false, ... };
int number[n] = { 0, ... } ;
```

Bakery Algorithm (Lamport)

Phase 1: Pick a number

```
choosing[i] = true;

number[i] =
  max(number[0], number[1], ...) + 1;

choosing[i] = false;
```

Worst case: everybody picks same number!

But at least *next wave* of arrivals will pick a larger number...

Bakery Algorithm (Lamport)

Phase 2: Sweep "proving" we have lowest number

```
for (j = 0; j < n; ++j) {
  while (choosing[j])
    continue;
  while ((number[j] != 0) &&
   ((number[i], i) > (number[j], j)))
      continue;
}
...critical section...
number[i] = 0;
```

Summary

Memory is *weird*

Two fundamental operations - understand!

- ***Brief exclusion*** **for atomic sequences**
- ***Long-term yielding*** **to get what you want**

Three necessary critical-section properties

Understand these "exclusion algorithms" (which are also race-condition parties)

- **Two-process solution**
- **N-process "Bakery Algorithm"**