15-410
"My computer is 'modern'!"

Synchronization #1
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Synchronization

Partner sign-up!

- ~5 groups have one-way sign-up (both, please)
- Today I expect to start spamming the un-signed

Simics issues

- Simics doesn't simulate time with 100% accuracy
    - Mentioned in handout, but:
        - » Sometimes it runs slower ("of course")
        - » Sometimes it runs faster (!)
- Simics doesn't blink
    - Not your fault

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Outline

Me vs. 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
- Mind your P's and Q's
- Atomic sequences vs. voluntary de-scheduling
  - "Sim City" example
- You *will* need to read the chapter
- Hopefully my preparation/review will clarify it

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;
```

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

Mind your P's and Q's

Or maybe this:

```
choosing[i] = false;
number[i] =
    max(number[0], number[1], ...) + 1;
```
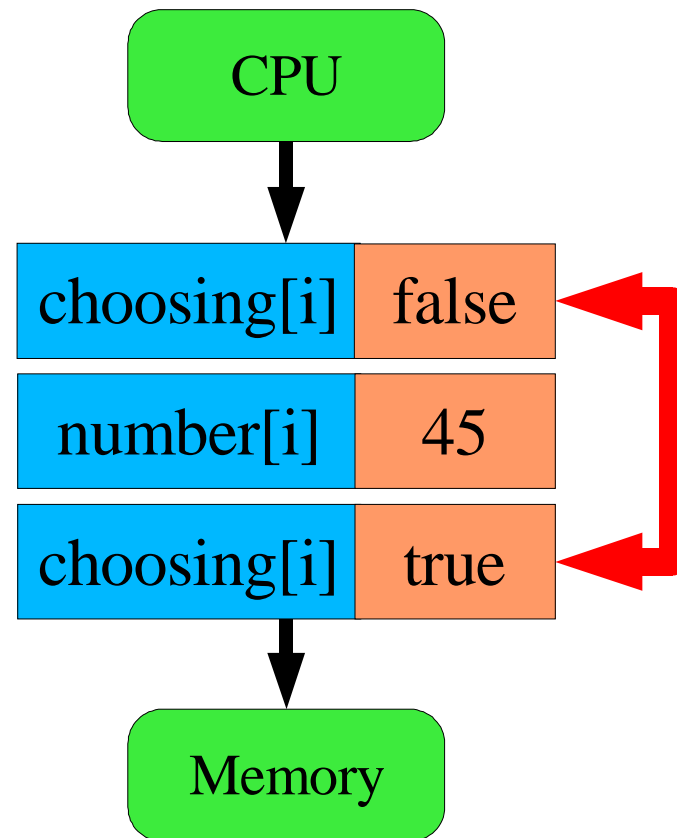
"Computer Architecture for $200, Dave"...

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My Computer is Broken?!

No, your computer is "modern"

- Processor "write pipe" queues memory stores

- ...*and* coalesces "redundant" writes!

Crazy?

- Not if you're pounding out pixels!

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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...

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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"

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Synchronization Fundamentals

Multiple client abstractions use the two operations

Textbook prefers

- Semaphore, critical region, monitor

Very **relevant**

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

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Synchronization Fundamentals

Two Fundamental operations

⇨ Atomic instruction sequence

Voluntary de-scheduling

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Atomic Instruction Sequence

Problem domain

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

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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

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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?

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Commerce – Observations

Instruction sequences are "short"

- Ok to force competitors to 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

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Synchronization Fundamentals

Two Fundamental operations

Atomic instruction sequence

⇨ Voluntary de-scheduling

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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);
```

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Voluntary De-scheduling

Anti-atomic

- We *want* to be "interrupted"

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

Textbook's code skeleton / naming

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

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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 process executing critical section

Progress

- Choosing next entrant cannot wait for non-participants
- Choosing protocol must have bounded time

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

process[i] = "us"

process[j] = "the other process"

i,j are *process-local* variables

- {i,j} = {0,1}
- j == 1 –i

This notation is "odd"

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

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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)

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Idea #1 - "Taking Turns"

```
int turn = 0;

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

Mutual exclusion –yes (make sure you see it)

Progress - *no*

- *Strict* turn-taking is fatal
- If P[0] never tries to enter, P[1] will wait forever
  - Violates the "depends on non-participants" rule

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Idea #2 - "Registering Interest"

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

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

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Mutual Exclusion (Intuition)

Process 0	Process 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"

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

It works for every **other** interleaving!

"Taking Turns When Necessary"

Rubbing two ideas together

```
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 processes 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., P0 exited first

- So turn==0 before turn==1
- So P1 had to set turn==0 before P0 set turn==1
- So P0 could not see turn==0, could *not* exit loop first!

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Proof Sketch Hints

want[i] == want[j] == true

"want[]" fall away, focus on "turn"

turn[] vs. loop exit...

What really happens here?

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

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Bakery Algorithm

More than two processes?

- Generalization based on bakery/deli counter
  - Get monotonically-increasing ticket number from dispenser
  - Wait until monotonically-increasing "now serving" == you

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

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Bakery Algorithm

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 45) < (ticket 7, process 99)
- Your turn when you hold lowest (t,pid)

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Bakery Algorithm

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

Bakery Algorithm

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 *subsequent* arrivals will pick a larger number...

Bakery Algorithm

Phase 2: Sweep "proving" we have lowest number

```
for (j = 0; j < n; ++j) {
    while (choosing[j])
        continue;
    while ((number[j] != 0) &&
        ((number[j], j) < (number[i], i)))
            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 algorithms / race-condition parties!
- Two-process solution
- N-process "Bakery Algorithm"

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