15-410

"My computer is 'modern'!"

Synchronization #1
Sep. 17, 2004

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Synchronization

Project 0 feedback plan

- First step: red ink on paper
- Soon: scores (based mostly on test outcomes)

Project 1 alerts

- "make print" ***must work***
  - Please check for completeness
- Doxygen documenation must build
  - Please check for completeness

Project 0 Common Themes

Style/structure

- Integers instead of #defined tokens
  - "2" is not better than "TYPE_DOUBLE"
  - It is much much much worse
  - Don't ever do that
- "Code photocopier" - indicates a problem, often serious
- Bad variable/function names
  - initialize() should not terminate
  - int i; /* number of frogs */ ⇐ Don't apologize; fix the problem!
- Excessively long functions
- while(1) should be *rare*
- Don't make us read...
  - False comments, dead code, extra copies of code
  - Harry Bovik did *not* help you write your P0

Project 0 Common Themes

Style/structure

- Code is *read by people*
  - Us
  - Your partner
  - Your manager
  - ...
- Don't make it painful for us
  - or else...

Project 0 Common Themes

Robustness

- Not checking syscall returns (e.g., tmpfile())
- Not finding last function / not handing unnamed function
- Memory leak (no need for malloc() at all!)
- File-descriptor leak

Project 0 Common Themes

Not following spec

- Hand-verifying addresses (compare vs. 0x0804... 0xc000...)
- Approximating arg-offset info
  - Instead of getting it from the table!!
- Give up via exit()   ⇐ caller never authorized that!
- Stopping trace at hard-coded function name

Semantic mismatch

- \b is a "backspace character"
- Clever hack to "undo" a comma in the output stream?
  - Only when the output stream is a terminal!!!
- Instead of fixing the wrong thing, do the right thing

Outline

Me vs. Chapter 7

- 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

What you write

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

What happens...

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

Mind your P's and Q's

What you write

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

Or maybe this happens...

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

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

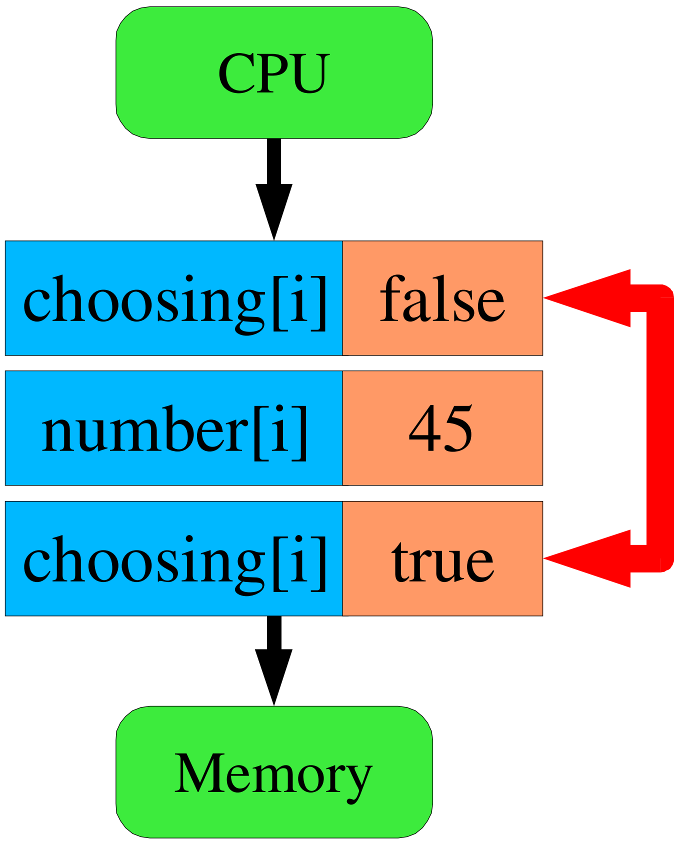
My computer is broken?!

No, your computer is "modern"

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

Crazy?

- Not if you're pounding out pixels!



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/
  - “Double-Checked Locking is Broken” Declaration
- See also "release consistency"

Textbook's memory model

- ...is “what you expect”
- Ok to use simple model for homework, exams

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

Synchronization Fundamentals

Multiple client abstractions

Textbook covers

- **Semaphore, critical region, monitor**

***Very* relevant**

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

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 turn
- Think: M:N threads, M=objects, N=#processors

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

- Must model those that do!

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 force competitors to wait

Probability of collision is "low"

- Many non-colliding invocations per second
- *Must not* use an expensive anti-collision approach!
  - Oh, just make a system call...
- 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 "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)
}
```

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);
```

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 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 involve nonparticipants
- Choosing protocol must have bounded time

Bounded waiting

- Cannot wait forever once you begin entry protocol
- ...bounded number of entries by others

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*

Idea #1 - "Taking Turns"

```
int turn = 0;

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

Mutual exclusion - yes

Progress - *no*

- ***Strict* turn-taking is fatal**
- **If P[i] never tries to enter, P[j] will wait forever**

Idea #2 - "Registering Interest"

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

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

Mutual exclusion – yes

Progress - *almost*

Failing "Progress"

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

It works the rest of the time!

"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)
;
...critical section...
want[i] = false;
```

Proof Sketch of Exclusion

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!

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);`

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, process number)

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)

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 latecomers will pick a larger number...

Bakery Algorithm

Phase 2: Sweep "proving" we have lowest number

```
for (j = 0; j < n; ++j) {
  while (choosing[j])
    ;
  while ((number[j] != 0) &&
   ((number[j], j) < (number[i], i)))
      ;
}
...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 race-condition parties!

  - Two-process solution
  - N-process “Bakery Algorithm”