# 15-410

***"My computer is 'modern'!"***

# Synchronization #1
## Sep. 15, 2006

**Dave Eckhardt**

**Bruce Maggs**

# 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;
```

**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”...**

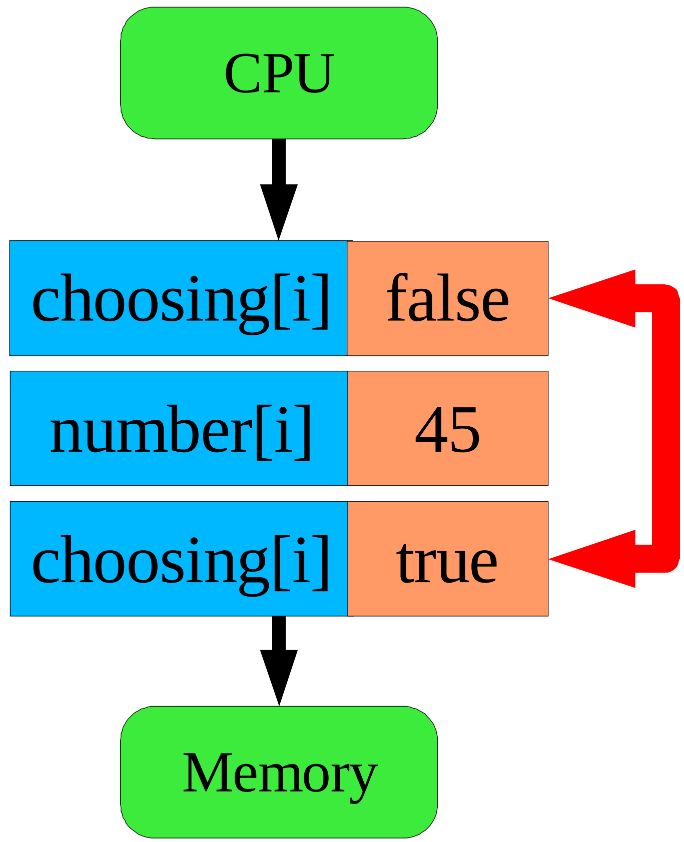
# My Computer is Broken?!

**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/
    - 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**

- **Semaphore, critical region, 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 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**

# 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 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***

# 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**

# Idea #2 - “Registering Interest”

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

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

# 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!**

# 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 with tie breaker”:
  - (ticket number, process number) tuple

# 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 *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”**