Slide 1

Administrivia

- Homework 2 on the Web. Due in a week.

Slide 2

Minute Essay From Last Lecture

- Several people mentioned that it was interesting how many system calls are made by what seems like a simple program. Kind of the point of the problem!
- Several commented on the programming problem — difficulty figuring out what `fork` and `execve` do, remembering how to use C, and so forth.

Slide 3

Sidebar: Shared Memory and Synchronization

- Solutions that rely on variables shared among processes assume that assigning a value to a variable actually changes its value in memory (RAM), more or less right away. Fine as a first approximation, but reality may be more complicated, because of various tricks used to deal with relative slowness of accessing memory:

  Optimizing compilers may keep variables' values in registers, only reading/writing memory when necessary to preserve semantics.

  Hardware may include cache, logically between CPU and memory, such that memory read/write goes to cache rather than RAM. Different CPUs' caches may not be in synch.

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Sidebar: Shared Memory and Synchronization, Continued

- So, actual implementations need notion of "memory fence" — point at which all apparent reads/writes have actually been done. Some languages provide standard ways to do this; others (e.g., C!) don't. C's `volatile` ("may be changed by something outside this code") helps some but may not be enough.
- Worth noting, however, that some library functions / constructs include these memory fences as part of their APIs (e.g., Java `synchronized` blocks).

Slide 5

Synchronization Mechanisms — Review/Recap

- Synchronization using only shared variables seems to be tedious and inefficient.
- "Synchronization mechanisms" are more-abstract ways of coordinating what processes do. A key point is providing *something* that potentially makes a process wait.

Slide 6

Synchronization Mechanisms — Semaphores (Review)

- Considered as an ADT — non-negative integer value, two atomic operations (up and down), both atomic.
- Implementation uses integer, queue of waiting process IDs, system calls to block/unblock processes, lower-level mechanism to control access to these shared variables.

Slide 7

Another Synchronization Mechanism — Monitors

- History — Hoare (1975) and Brinch Hansen (1975).
- Idea — combine synchronization and object-oriented paradigm.
- A monitor consists of
  - Data for a shared object (and initial values).
  - Procedures — only one at a time can run.
- "Condition variable" ADT allows us to wait for specified conditions (e.g., buffer not empty):
  - Value — queue of suspended processes.
  - Operations:
    - Wait — suspend execution (and release mutual exclusion).
    - Signal — *if* there are processes suspended, allow *one* to continue. (if not, signal is "lost"). Some choices about whether signalling process continues, or signalled process awakens right away.

Slide 8

Bounded Buffer Problem, Revisited

- Define a `bounded_buffer` monitor with a queue and `insert` and `remove` procedures.
- Shared variables:

```
bounded_buffer B(N);
```

Pseudocode for producers:

```
while (true) {
    item = generate();
    B.insert(item);
}
```

Pseudocode for consumers:

```
while (true) {
    B.remove(item);
    use(item);
}
```

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Bounded-Buffer Monitor

- Data:

```
buffer B(N);  // N constant, buffer empty
int count = 0;
condition full;
condition empty;
```

- Procedures:

```
insert(item itm) {              remove(item &itm) {
    if (count == N)                 if (count == 0)
        wait(full);                     wait(empty);
    put(itm, B);                    itm = get(B);
    count += 1;                     count -= 1;
    signal(empty);                  signal(full);
}                               }
```

- Does this work? (Yes.)

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Implementing Monitors

- Requires compiler support, so more difficult to implement than (e.g.) semaphores.
- Java's methods for thread synchronization are based on monitors . . .

Slide 11

Java's Adaptation of the Monitor Idea

- Data for monitor is instance variables (data for class).
- Procedures for monitor are `synchronized` methods/blocks — mutual exclusion provided by implicit object lock.
- `wait`, `notify`, `notifyAll` methods.
- No condition variables, but above methods provide more or less equivalent functionality.

  Note that the language specs for Java allow spurious wake-ups. So "best practice" is to `wait()` in a loop, re-checking the desired condition. The textbook's bounded-buffer code doesn't do this (?!).

Slide 12

Yet Another Synchronization Mechanism — Message Passing

- Previous synchronization mechanisms all involve shared variables; okay in some circumstances but not very feasible in others (e.g., multiple-processor system without shared memory).
- Idea of message passing — each process has a unique ID; two basic operations:
  - Send — specify destination ID, data to send (message).
  - Receive — specify source ID, buffer to hold received data. Usually some way to let source ID be "any".

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Message Passing, Continued

- Exact specifications can vary, but typical assumptions include:
  - Sending a message never blocks a process (more difficult to implement but easier to work with).
  - Receiving a message blocks a process until there is a message to receive.
  - All messages sent are eventually available to receive (can be non-trivial to implement).
  - Messages from process A to process B arrive in the order in which they were sent.

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Implementing Message Passing

- On a machine with no physically shared memory (e.g., multicomputer), must send messages across interconnection network.
- On a machine with physically shared memory, can either copy (from address space to address space) or somehow be clever.

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Mutual Exclusion, Revisited

- How to solve mutual exclusion problem with message passing?
- Several approaches based on idea of a single “token”; process must “have the token” to enter its critical region.

  (I.e., desired invariant is “only one token in the system, and if a process is in its critical region it has the token.”)
- One such approach — a “master process” that all other processes communicate with; simple but can be a bottleneck.
- Another such approach — ring of “server processes”, one for each “client process”, token circulates.

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Mutual Exclusion With Message-Passing (1)

- Idea — have “master process” (centralized control).

Pseudocode for client process:

```
while (true) {
    send(master, "request");
    receive(master, &msg);
        // assume "token"
    do_cr();
    send(master, "token");
    do_non_cr();
}
```

Pseudocode for master process:

```
bool have_token = true;
queue waitQ;
while (true) {
    receive(ANY, &msg);
    if (msg == "request") {
        if (have_token) {
            send(msg.sender, "token");
            have_token = false;
        }
        else
            enqueue(sender, waitQ);
    }
    else { // assume "token"
        if (empty(waitQ))
            have_token = true;
        else {
            p = dequeue(waitQ);
            send(p, "token");
        }
    }
}
```

Mutual Exclusion With Message-Passing (2)

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- Idea — ring of servers, one for each client.

Pseudocode for client process:

```
while (true) {
    send(my_server, "request");
    receive(my_server, &msg);
        // assume "token"
    do_cr();
    send(my_server, "token");
    do_non_cr();
}
```

Pseudocode for server process:

```
bool need_token = false;
if (my_id == first)
    send(next_server, "token");
while (true) {
    receive(ANY, &msg);
    if (msg == "request")
        need_token = true;
    else { // assume "token"
        if (msg.sender == my_client) {
            need_token = false;
            send(next_server, "token");
        }
        else if (need_token)
            send(my_client, "token");
        else
            send(next_server, "token");
    }
}
```

Synchronization Mechanisms — Recap

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- Low-level ways of synchronizing — using shared variables only, using TSL instruction. All seem tedious and inefficient.
- "Synchronization mechanisms" are more-abstract ways of coordinating what processes do. A key point is providing *something* that potentially makes a process wait. Examples include semaphores, monitors, message passing. Often built using something lower-level.

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Classical IPC Problems

- Literature (and textbooks) on operating systems talk about "classical problems" of interprocess communication.
- Idea — each is an abstract/simplified version of problems O/S designers actually need to solve. Also a good way to compare ease-of-use of various synchronization mechanisms.
- Examples so far — mutual exclusion, bounded buffer.
- Other examples sometimes described in silly anthropomorphic terms, but underlying problem is a simplified version of something "real".
- (To be continued.)

Slide 20

Minute Essay

- Alleged joke (from some random Usenet person):

  A man's P should exceed his V else what's a sema for?

  Do you understand this? (Remember that P is "down" and V is "up".)

Minute Essay Answer

- It's a pun. The idea is roughly that if you never have a situation in which you've attempted more "down" operations than "up" operations, you didn't need a semaphore. (Or that's what I think it means. The author might have another idea!)

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