Slide 1

Administrivia

- Homework 2 to be on Web soon, by Monday if not before. Due the following Monday.
- Midterm exam October 12. In syllabus, now also on schedule page on Web.

Slide 2

Message Passing — Review

- 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”.

Slide 3

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.

Slide 4

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");
        }
    }
}
```

Slide 5

Mutual Exclusion With Message-Passing (2)

- 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");
    }
}
```

Slide 6

Synchronization Mechanisms — Recap

- Low-level ways of synchronizing — using shared variables only, using TSL instruction.
- Higher-level mechanisms — semaphores, monitors, message passing. Often built using something lower-level.

Slide 7

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".

Slide 8

Dining Philosophers Problem

- Scenario (originally proposed by Dijkstra, 1972):
  - Five philosophers sitting around a table, each alternating between thinking and eating.
  - Between every pair of philosophers, a fork; philosopher must have two forks to eat.
  - So, neighbors can't eat at the same time, but non-neighbors can.
- Why is this interesting or important? It's a simple example of something more complex than mutual exclusion — multiple shared resources (forks), processes (philosophers) must obtain two resources together. (Why five? smallest number that's "interesting".)

Dining Philosophers — Naive Solution

- Naive approach — we have five mutual-exclusion problems to solve (one per fork), so just solve them.
- Does this work?

Slide 9

Dining Philosophers — Simple Solution

- Another approach — just use a solution to the mutual exclusion problem to let only one philosopher at a time eat.
- Does this work?

Slide 10

Slide 11

Dining Philosophers — Solution

- Another approach — use shared variables to track state of philosophers and semaphores to synchronize.
- I.e., variables are
  - Array of five `state` variables (`states[5]`), possible values `thinking`, `hungry`, `eating`. Initially all `thinking`.
  - Semaphore `mutex`, initial value 1, to enforce one-at-a-time access to `states`.
  - Array of five semaphores `self[5]`, initial values 0, to allow us to make philosophers wait.
- And then the code is somewhat complex . . .

Slide 12

Dining Philosophers — Code

- Shared variables as on previous slide.

Pseudocode for philosopher i:

```
while (true) {
    think();
    down(mutex);
    state[i] = hungry;
    test(i);
    up(mutex);
    down(self[i]);
    eat();
    down(mutex);
    state[i] = thinking;
    test(right(i));
    test(left(i));
    up(mutex);
}
```

Pseudocode for function:

```
void test(i)
{
    if ((state[left(i)] != eating) &&
            state[right(i) != eating) &&
            state[i] == hungry) {
        state[i] = eating;
        up(self[i]);
    }
}
```

Dining Philosophers — Solution Works?

Slide 13

- Could there be problems with access to shared `state` variables? No (because all accesses are "protected" by mutual-exclusion semaphore).
- Do we guarantee that neighbors don't eat at the same time? Yes.
- Do we allow non-neighbors to eat at the same time? Yes.
- Could we deadlock? No.
- Does a hungry philosopher always get to eat eventually? Usually. Exception is when two next-to-neighbors (e.g., 1 and 3) seem to conspire to starve their common neighbor (e.g., 2).

Dining Philosophers, Improved Version

Slide 14

- Original solution allows for scenarios in which one philosopher "starves" because its neighbors alternate eating while it remains hungry.
- Briefly, we could improve this by maintaining a notion of "priority" between neighbors, and only allow a philosopher to eat if (1) neither neighbor is eating, *and* (2) it doesn't have a higher-priority neighbor that's hungry. After a philosopher eats, it lowers its priority relative to its neighbors.

Other Classical Problems

Slide 15

- Readers/writers.
- Sleeping barber.
- And others . . .
- Advice — if you ever have to solve problems like this “for real”, read the literature . . .

Minute Essay

Slide 16

- What’s something you’ve learned from the textbook? (Preferably something interesting, but anything that stuck in your mind is okay.)