Topics covered in the lecture

- Classical process synchronization problems
  - Bounded Buffer – Producer/Consumer problem
  - Readers Writers
  - Dining philosopher’s problem

The bounded buffer problem

- Binary semaphore (mutex)
  - Provides mutual exclusion for accesses to buffer pool
  - Initialized to 1

- Counting semaphores
  - empty: Number of empty slots available to produce
    - Initialized to \( n \)
  - full: Number of filled slots available to consume
    - Initialized to 0

Frequently asked questions from the previous class survey

- What happens when a new process joins the set of already executing processes? Is waiting[i] expanded?
- Atomic hardware instructions: so multiple cores cannot run instruction concurrently over same address?
- TSL implemented by developer? Or part of the ISA?
- AMD?
- Mutex:
  - Difference between a semaphore and a mutex?
  - Why use mutex instead of a simple boolean variable?

Some other things to bear in mind

- Producer and consumer must be ready before they attempt to enter critical section

- Producer readiness?
  - When a slot is available to add produced item
    - \( \text{wait}(@empty) \): empty is initialized to \( n \)

- Consumer readiness?
  - When a producer has added new item to the buffer
    - \( \text{wait}(@full) \): full initialized to 0
The Producer

do {
produce item nextp
wait till slot available
wait(empty);
wait(mutex);
add nextp to buffer
signal(mutex);
signal(full);
remainder section
} while (TRUE);

wait(mutex);
wait(full);
signal(mutex);
signal(empty);

wait till slot available
wait(mutex);
remove item from buffer (nextc)
consume nextc
signal(mutex);
signal(consumer
that a slot is available)

Only producer OR consumer
can be in critical section

Allow producer OR consumer
to (re)enter critical section

signal producer that a slot is available to add

The Consumer

do {
remove item from buffer
consume nextc
} while (TRUE);

wait(mutex);
wait(full);
signal(mutex);
signal(empty);

wait till slot available
wait(mutex);
remove item from buffer (nextc)
consume nextc
signal(mutex);
signal(consumer
that a slot is available)

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The Readers-Writers problem

- A database is shared among several concurrent processes
- Two types of processes
  - Readers
  - Writers

Readers-Writers: Potential for adverse effects

- If two readers access shared data simultaneously?
  - No problems
- If a writer and some other reader (or writer) access shared data simultaneously?
  - Chaos

Writers must have exclusive access to shared database while writing

- FIRST readers-writers problem:
  - No reader should wait for other readers to finish; simply because a writer is waiting
  - Writers may starve
- SECOND readers-writers problem:
  - If a writer is ready it performs its write ASAP
  - Readers may starve
Solution to the FIRST readers-writers problem

- Variable int readcount
  - Tracks how many readers are reading object

- Semaphore mutex {1}
  - Ensure mutual exclusion when readcount is accessed

- Semaphore wrt {1}
  1. Mutual exclusion for the writers
  2. First (last) reader that enters (exits) critical section
  - Not used by readers, when other readers are in their critical section

The Writer: When a writer signals either a waiting writer or the readers resume

```c
void
begin()

    wait(wrt);
    writing is performed
    I reader is queued on wrt
    (n-1) readers queued on mutex

    signal(wrt);

    } while (TRUE);
```

The Reader process

```c
do {

    wait(mutex);
    readcount++;
    if (readcount ==1) {
        wait(wrt);
    }
    signal(mutex);
    reading is performed
    wait(mutex);
    readcount--;
    if (readcount ==0) {
        signal(wrt);
    }
    signal(mutex);

    } while (TRUE);
```

The situation

The Problem

1. Philosopher tries to **pick up two closest** {LR} chopsticks
2. Pick up only **1 chopstick at a time**
   - Cannot pick up a chopstick being used
3. Eat only when you have both chopsticks
4. When done, **put down both** the chopsticks

THE DINING PHILOSOPHERS PROBLEM
**Why is the problem important?**

- Represents allocation of **several resources**
- Among several processes
- Can this be done so that it is:
  - Deadlock free
  - Starvation free

**Dining philosophers: Simple solution**

- Each chopstick is a semaphore
  - Grab by executing wait()
  - Release by executing signal()
- Shared data
  - semaphore chopstick[5];
  - All elements are initialized to 1

**Overview of the semaphore solution**

- Processes share a semaphore **mutex**
  - Initialized to 1
- Each process MUST execute
  - **wait** before entering critical section
  - **signal** after exiting critical section

**Incorrect use of semaphores can lead to timing errors**

- Hard to detect
  - Reveal themselves only during specific execution sequences
- If correct sequence is not observed
  - 2 processes may be in critical section simultaneously
- Problems even if **only one** process is not well behaved

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

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Incorrect use of semaphores: [1]
Interchange order of wait and signal

```
do{
    signal(mutex);
    critical section
    wait(mutex);
    remainder section
} while (TRUE);
```

Problem: Several processes simultaneously active in critical section

NB: Not always reproducible

Incorrect use of semaphores: [2]
Replace `signal` with `wait`

```
do{
    wait(mutex);
    critical section
    wait(mutex);
    remainder section
} while (TRUE);
```

Problem: Deadlock!

Incorrect use of semaphores: [3]
What if you omit `signal` AND/OR `wait`?

```
do{
    wait(mutex);
    critical section
    signal(mutex);
    remainder section
} while (TRUE);
```

Omission: Mutual exclusion violated

Omission: Deadlock!

When programmers use semaphores incorrectly problems arise:

- We need a higher-level synchronization construct
  - Monitor

Before we move ahead: Abstract Data Types

- Encapsulates private data with
  - Public methods to operate on them

A monitor is an abstract data type:

- Mutual exclusion provided within the monitor
- Contains:
  - Declaration of variables
  - Defining the instance's state
  - Functions that operate on these variables

Monitor construct ensures that only one process at a time is active within monitor:

```
monitor monitor name {
    //shared variable declarations
    function F1(...) { .. }
    function F2(...) { .. }
    function Fn(...) { .. }
    initialization code(...) { .. }
}
```
Programmer does not code synchronization constraint explicitly

- Basic monitor scheme not sufficiently powerful
  - Provides an easy way to achieve mutual exclusion
  - But ... we also need a way for processes to block when they cannot proceed

This blocking capability is provided by the condition construct

- The condition construct
  - condition x, y;

- Operations on a condition variable
  - wait: e.g. x.wait()
    - Process invoking this is suspended UNTIL
  - signal: e.g. x.signal()
    - Resumes exactly-one suspended process
    - If no process waiting; NO EFFECT on state of x

Semantics of wait and signal

- x.signal() invoked by process P
  - Q is the suspended process waiting on x
- Signal and wait: P waits for Q to leave monitor
- Signal and continue: Q waits till P leaves monitor
- PASCAL: When thread P calls signal
  - P leaves immediately
  - Q immediately resumed

Difference between the signal() in semaphores and monitors

- Monitors (condition variables): Not persistent
  - If a signal is performed and no waiting threads?
    - Signal is simply ignored
    - During subsequent wait operations
    - Thread blocks
- Semaphores
  - Signal increments semaphore value even if there are no waiting threads
  - Future wait operations would immediately succeed!
Dining-Philosophers Using Monitors
Deadlock-free

enum {THINKING, HUNGRY, EATING} state[5];

- state[i] = EATING only if
  - state[(i+4)%5] != EATING &
  - state[(i+1)%5] != EATING

- condition self[5]
  - Delay self when HUNGRY but unable to get chopsticks

Sequence of actions

- Before eating, must invoke pickup()
  - May result in suspension of philosopher process
  - After completion of operation, philosopher may eat

DiningPhilosophers.pickup(i);
    ...
    eat
    ...
DiningPhilosophers.putdown(i);

Possibility of starvation

- Philosopher i can starve if eating periods of philosophers on left and right overlap

- Possible solution
  - Introduce new state: STARVING
  - Chopsticks can be picked up if no neighbor is starving
    - Effectively wait for neighbor’s neighbor to stop eating
    - REDUCES concurrency!

Implementing a Monitor Using Semaphores

The pickup() and putdown() operations

pickup(int i) {
    state[i] = HUNGRY;
    test(i);
    if (state[i] != EATING) {
        delay self if unable to acquire chopstick
        self[i].wait();
    }
}

putdown(int i) {
    state[i] = THINKING;
    test((i+1)%5);
    test((i+4)%5);
    check to see if person on left or right can use the chopstick
}

test() to see if philosopher can eat

test(int i) {
    if (state[(i+4)%5] != EATING &&
        state[i] == HUNGRY &&
        state[(i+1)%5] != EATING) {
        state[i] = EATING;
        self[i].signal();
    }
}
Implementing a monitor using semaphores

- For each monitor
  - Semaphore mutex initialized to 1
- Process must execute
  - `wait(mutex)`: Before entering the monitor
  - `signal(mutex)`: Before leaving the monitor

Implementing a function F in the monitor

```c
wait(mutex);
...
body of function F
...
if (next_count > 0) {
    signal(next);
} else {
    signal(mutex);
}
```

Implementing condition variables:

```c
x_count++;
if (next_count > 0) {
    signal(next);
} else {
    signal(mutex);
}
wait(x_sem);
```

```c
x.wait() Operation
if (x_count > 0) {
    next_count++;
    signal(x_sem);
}
wait(next);
```

```c
x.signal() Operation
x_count--; 
```

Resuming processes within a monitor

- (C1) Several processes suspended on condition x
- (C2) `x.signal()` executed by some process
- Which suspended process should be resumed next?
  - Simple solution: FCFS ordering
  - Process waiting the longest is resumed first

Process resumption: conditional wait

- `x.wait(c)`
- c is an integer expression; evaluated when `wait()` is executed
- Value of c is the priority number
  - Stored with the name of process that is suspended
- When `x.signal()` is executed
  - Process with smallest priority number resumed next
Monitor to allocate a single resource

```java
Monitor ResourceAllocator {
    boolean busy;
    condition x;
    void acquire(int time) {
        if (busy) {
            x.wait(time);
        }
        busy = TRUE;
    }
    void release() {
        busy = FALSE;
        x.signal();
    }
    initialization() {busy = FALSE;}
}
```

An example of conditional waits

```java
Monitor allocates resource based on shortest duration

Monitor to allocate a single resource

Avoiding time dependent errors and ensuring that scheduling algorithm is not defeated

- User processes must make their calls on the monitor in correct sequence
- Ensure that uncooperative processes do not ignore the mutual exclusion gateway
- Should not access resource directly!

The contents of this slide set are based on the following references