UNIVERSITY of WISCONSIN-MADISON
Computer Sciences Department

CS 537
Intro to Operating Systems

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Classic Examples and Monitors

Questions answered in these notes:

- Semaphore Examples: Dining Philosophers and Reader/Writers
- Monitors and condition variables: Three styles
  - Hoare
  - Mesa
  - Java

Reading

- See Homepage

Two Classes of Semaphore Problems

Uniform resource usage w/ simple scheduling contraints

- No other variables to express relationships
- Use one semaphore for every constraint
- Examples: Thread join and producer/consumer (Previous Lecture)

Complex patterns of resource usage

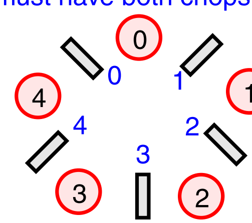
- Can't capture relationships with only semaphores
- Need extra state variables to record information
- Use of semaphores
  - One for mutual exclusion for state variables
  - One for each class of waiting

Try to cast problems into first type

Today: Two examples that use second approach

Dining Philosophers

Each philosopher must have both chopsticks to eat



Philosophers alternate between thinking and eating

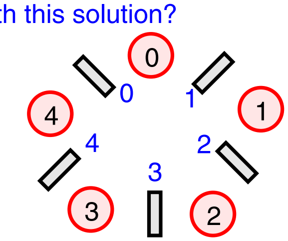
```
class Philosopher implements Runnable {
    int i; // which Philosopher am I?
    public void run() {
        while (true) {
            think();
            take_chopsticks(i);
            eat();
            put_chopsticks(i);
        }
```


Dining Philosophers: Attempt 1

Represent each chopstick with a semaphore; Grab right then left

```
Semaphore chopstick[5] = Initialize each to 1;
void take_chopsticks(int i) {
    chopstick[i].P();
    chopstick[i+1 % 5].P();
}
void put_chopsticks(int i) {
    chopstick[i].V();
    chopstick[i+1 % 5].V();
}
```

What is wrong with this solution?

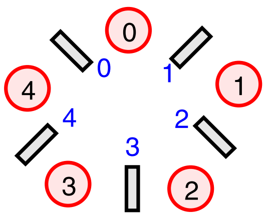


Dining Philosophers: Attempt 2

Grab lower-numbered chopstick first, then higher-numbered

```
Semaphore chopstick[5] = 1;
void take_chopsticks(int i) {
    if (i < 4) {
        chopstick[i].P();
        chopstick[i+1].P();
    } else {
        chopstickchopstick[0];
        chopstick[4];
    }
}
```

What is wrong with this solution?



Dining Philosophers: How to Approach

Guarantee two goals

- Safety: Make sure nothing bad happens
- Liveness: Make sure something good happens when it can

Introduce state variable for each philosopher i

- state[i]: THINKING, HUNGRY, or EATING

Safety: No two adjacent philosophers are eating simultaneously

- for all i: !(state[i] == EATING && state[i+1 % 5] == EATING)

Liveness: No philosopher is hungry unless a neighber is eating

- for all i: !(state[i] == HUNGRY &&
  (state[i+4 % 5]!=EATING && state[i+1 % 5]!=EATING))

Dining Philosophers: Solutions

```
Semaphore mayEat[5] = { 0, 0, 0, 0, 0};
Semaphore mutex = 1;
final static public int THINKING = 0; final static public int HUNGRY = 1;
final static public int EATING = 2;
int state[5] = { THINKING, THINKING, THINKING, THINKING, THINKING};
void take_chopsticks(int i) {
    mutex.P();
    state[i] = HUNGRY;
    testSafetyAndLiveness(i);
    mutex.V();
    mayEat[i].P();
}
void put_chopsticks(int i) {
    mutex.P();
    state[i] = THINKING;
    test(i+1 % 5);
    test(i+4 % 5);
    mutex.V();
}
void testSafetyAndLiveness(int i) {
    if (state[i]==HUNGRY&&state[i+4%5]!=EATING&&state[i+1%5]!=EATING) {
        state[i] = EATING;
        mayEat[i].V(); } }
```


Readers and Writers Problem Statement

Two different classes of users

- Any number of readers can access data
- Each writer must have exclusive access

Two possibilities for priorities

- 1 -- No reader waits unless writer in critical section
  - Writers can starve
  - Solution presented in text book
- 2 -- No writer waits longer than absolute minimum
  - Readers can starve
  - Much more difficult, solution here

Four state variables:

- ActiveReaders, WaitingReaders, ActiveWriters, WaitingWriters

Three semaphores:

- mutex = ??, OKToRead = ??, OKToWrite = ??

Readers and Writers Implementation

Reader Process:
```
mutex.P();
if (ActiveWriters
      + WaitingWriters==0){
      OKToRead.V();
      ActiveReaders++;
} else WaitingReaders++;
mutex.V();
OKToRead.P();
// Do read
mutex.P();
ActiveReaders--;
if (ActiveReaders==0 &&
      WaitingWriters>0) {
      OKToWrite.V();
      ActiveWriters++;
      WaitingWriters--;
}
mutex.V();
```

Writer Process:
```
mutex.P();
if (ActiveWriters+ActiveReaders
      +WaitingWriters == 0) {
      OKToWrite.V();
      ActiveWriters++;
} else WaitingWriters++;
mutex.V();
OKToWrite.P();
// Do write
mutex.P();
ActiveWriters--;
if (WaitingWriters > 0) {
      OKToWrite.V();
      ActiveWriters++;
      WaitingWriters--;
} else
      while (WaitingReaders > 0) {
            OKToRead.V();
            ActiveReaders++;
            WaitingReaders--;
      }
mutex.V();
```


Monitors

Even higher-level data abstraction for concurrent accesses

- Implicit locks for mutex
- Zero or more **condition variables** for scheduling constraints

Programming language construct

- Examples: Mesa language from Xerox and Java from Sun
- Acquire monitor lock when call *synchronized* methods in class

Java example

```
class Queue {
    int head, tail; // shared data
    // compiler add Lock lock = new Lock();

    public synchronized Add(val) {
        // adds lock.Acquire();
        // code to add val to queue
        // adds lock.Release();
    }
    public synchronized int Remove(){
        // adds lock.Acquire();
        // code to remove from queue
        // adds lock.Release();
    }
}
```


Condition Variables

- Three basic atomic operations
  - Slightly different semantics depending on Hoare-style or Mesa-style
- wait()
  - Release monitor lock, sleep, reacquire lock when awoken
  - **Usage:** `if (!expression) condition.wait();`
- signal() (notify() in Java)
  - Wake **one** process waiting on condition (if there is one)
  - **Hoare:** Signaller relinquishes lock and processor to waiter (Theory)
  - **Mesa and Java:** Signaller keeps lock and processor (Practice)
  - No history in condition variable
- broadcast() (notifyAll() in Java)
  - Wake **all** processes waiting on condition
  - Useful when condition processes are waiting for varies

Hoare-style Semantics

- Producer/Consumer with bounded buffers

```
Condition empty, full;
int fullEntries = 0;
```

Producer Monitor

```
if (fullEntries == MAX) {
   // compiler adds lock.release()
   empty.wait();
   // adds lock.acquire()
}
FillBuffer();
fullEntries++;
full.signal();
```

Consumer Monitor

```
if (fullEntries == 0) {
    // lock.release()
    full.wait();
    // lock.acquire()
}
UseBuffer();
fullEntries--;
empty.signal();
```

Guaranteed to run signalled process immediately

Mesa-style Semantics

- Producer/Consumer with bounded buffers

```
Condition empty, full;
int fullEntries = 0;
```

Producer Monitor

```
while (fullEntries == MAX) {
   // lock.release();
   empty.wait();
   // lock.acquire();
}
FillBuffer();
fullEntries++;
full.signal();
```

Consumer Monitor

```
while (fullEntries == 0) {
   // lock.release();
   full.wait();
   // lock.acquire();
}
UseBuffer();
fullEntries--;
empty.signal();
```

Another process may be scheduled before signalled process runs

- Implication: Must recheck condition with while() loop

Java-style Semantics

- Producer/Consumer with bounded buffers

```
// compiler adds one Condition implicitly for each object
int fullEntries = 0;
```

Producer Monitor

```
synchronized AddToBuffer () {
    while (fullEntries == MAX) {
      // lock.release();
      wait();
      // lock.acquire();
    }
    FillBuffer();
    fullEntries++;
    notify();
}
```

Consumer Monitor

```
synchronized RemoveFromBuffffer(){
    while (fullEntries == 0) {
      // lock.release();
      wait();
      // lock.acquire()
    }
    UseBuffer();
    fullEntries--;
    notify();
}
```

Share one condition variable between producer and consumer

Will this work?

Java with notifyAll()

- Producer/Consumer with bounded buffers

```
// compiler adds one Condition implicitly for each object
int fullEntries = 0;
```

Producer Monitor

```
synchronized AddToBuffer () {
    while (fullEntries == MAX) {
      // lock.release()
      wait();
      // lock.acquire()
    }
    FillBuffer();
    fullEntries++;
    notifyAll();
}
```

Consumer Monitor

```
synchronized RemoveFromBuffffer(){
    while (fullEntries == 0) {
      // lock.release()
      wait();
      // lock.acquire()
    }
    UseBuffer();
    fullEntries--;
    notifyAll();
}
```

Wake up all waiting processes with notifyAll()

Will this work? Is it efficient?