EECS 482
Introduction to Operating Systems

Fall 2017

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Slides by: Harsha V. Madhyastha
Implementing reader-writer locks with monitors

- Shared data needed to implement readerStart, readerFinish, writerStart, writerFinish?
  - numReaders
  - numWriters
- Use one lock (rwLock)
- Condition variables?
  - waitingReaders: readers must wait if there are writers
  - waitingWriters: writers must wait if there are readers or writers
Implementing reader-writer locks with monitors

```java
readerStart() {
    rwLock.lock()
    while (numWriters > 0) {
        waitingReaders.wait()
    }
    numReaders++
    rwLock.unlock()
}

readerFinish() {
    rwLock.lock()
    numReaders--
    if (numReaders == 0) {
        waitingReaders.broadcast()
        waitingWriters.signal()
    }
    rwLock.unlock()
}

writerStart() {
    rwLock.lock()
    while (numReaders > 0 || numWriters > 0) {
        waitingWriters.wait()
    }
    numWriters++
    rwLock.unlock()
}

writerFinish() {
    rwLock.lock()
    numWriters--
    waitingReaders.broadcast()
    waitingWriters.signal()
    rwLock.unlock()
}
```
Implementing reader-writer locks with monitors

```java
readerStart () {
    rwLock.lock()
    while (numWriters > 0) {
        waitingReaders.wait()
    }
    numReaders++
    rwLock.unlock()
}

readerFinish() {
    rwLock.lock()
    if (numReaders == 1) {
        waitingWriters.signal()
    }
    numReaders--
    rwLock.unlock()
}

writerStart() {
    rwLock.lock()
    while (numReaders > 0 || numWriters > 0) {
        waitingWriters.wait()
    }
    numWriters++
    rwLock.unlock()
}

writerFinish() {
    rwLock.lock()
    numWriters--
    waitingReaders.broadcast()
    waitingWriters.signal()
    rwLock.unlock()
}
```
Implementing reader-writer locks with monitors

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    }
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}

readerFinish() {
    rwLock.lock()
    numReaders--
    if (numReaders == 0) {
        waitingReaders.broadcast()
        waitingWriters.signal()
    }
    rwLock.unlock()
}

writerStart() {
    rwLock.lock()
    while (numReaders > 0 || numWriters > 0) {
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}

writerFinish() {
    rwLock.lock()
    numWriters--
    waitingReaders.broadcast()
    waitingWriters.signal()
    rwLock.unlock()
}
```
Implementing reader-writer locks with monitors

- What will happen if a writer finishes and there are several waiting readers and writers?

- How long will a writer wait?
Recap

- Multi-threaded code must synchronize access to shared data

- High-level synchronization primitives:
  - **Locks**: Mutual exclusion
  - **Condition variables**: Ordering constraints
  - **Monitors**: Lock + condition variables

- Today: **Semaphores**
Semaphores

- Generalized lock/unlock
- Definition:
  - A non-negative integer (initialized to user-specified value)
  - **down()**: wait for semaphore value to become positive, then atomically decrement semaphore value by 1
    
    ```
    do {
      if (value > 0) {
        value--
        break
      }
    } while (1)
    ```
  - **up()**: increment semaphore value by 1
Two types of semaphores

- **Mutex semaphore** (or **binary semaphore**)
  - Represents single resource (critical section)
  - Guarantees mutual exclusion

- **Counting semaphore** (or **general semaphore**)
  - Represents a resource with many units, or a resource that allows concurrent access (e.g., reading)
  - Multiple threads can “hold” the semaphore
    » Number determined by the semaphore “count”
Benefit of Semaphores

- Mutual exclusion
  - Initial value is 1
  
  ```
  down()
  critical section
  up()
  ```

- Ordering constraints
  - Usually, initial value is 0
  - Example: thread A wants to wait for thread B to finish

<table>
<thead>
<tr>
<th>Thread A</th>
<th>Thread B</th>
</tr>
</thead>
<tbody>
<tr>
<td>down()</td>
<td>do task</td>
</tr>
<tr>
<td>continue execution</td>
<td>up()</td>
</tr>
</tbody>
</table>
Implementing producer-consumer with semaphores

- Semaphore assignments
  - `mutex`: ensures mutual exclusion around code that manipulates coke machine
  - `fullSlots`: counts no. of full slots in the coke machine
  - `emptySlots`: counts no. of empty slots in machine

- Initialization values?
Implementing producer-consumer with semaphores

Semaphore mutex = 1; // mutual exclusion to shared set of slots
Semaphore emptySlots = N; // count of empty slots (all empty to start)
Semaphore fullSlots = 0; // count of full slots (none full to start)

producer {
  // wait for empty slot
  emptySlots.down();

  mutex.down();
  Add coke to the machine
  mutex.up();

  // note a full slot
  fullSlots.up();
}

c consumer {
  // wait for full slot
  fullSlots.down();

  mutex.down();
  Take coke out of machine
  mutex.up();

  // note an empty slot
  emptySlots.up();
}
Implementing producer-consumer with semaphores

- Why do we need different semaphores for fullSlots and emptySlots?
- Does the order of down() matter?
- Does the order of up() matter?
- What if there’s 1 full slot, and multiple consumers call down() at the same time?
- What if a context switch happens between emptySlots.down() and mutex.down()?
- What if fullSlots.up() before mutex.down()?
Reminders

- Group declaration due today
- Project 1 due on Tuesday
- Work through discussion questions about monitors before tomorrow’s discussion section
Comparing monitors and semaphores

- Semaphores provide 1 mechanism that can accomplish both mutual exclusion and ordering (monitors use different mechanisms for each)
  - **Elegant**
  - Can be difficult to use

- Monitor lock = binary semaphore (initialized to 1)
  - `lock()` = `down()`
  - `unlock()` = `up()`
## Condition variable versus semaphore

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<th>Semaphore</th>
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<tr>
<td><code>while(!cond) {wait();}</code></td>
<td><code>down()</code></td>
</tr>
<tr>
<td>Can safely handle spurious wakeups</td>
<td>No spurious wakeups</td>
</tr>
<tr>
<td>Conditional code in user program</td>
<td>Conditional code in semaphore definition</td>
</tr>
<tr>
<td>User writes customized condition; more flexible</td>
<td>Condition specified by semaphore definition (wait if value == 0)</td>
</tr>
<tr>
<td>User provides shared variable; protects with lock</td>
<td>Semaphore provides shared variable (integer) and thread-safe operations on that variable (down, up)</td>
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<td>No memory of past signals</td>
<td>Remembers past up calls</td>
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<td><strong>T1:</strong> wait()</td>
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<tr>
<td><strong>T2:</strong> signal()</td>
<td><strong>T2:</strong> up()</td>
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<tr>
<td><strong>T3:</strong> signal()</td>
<td><strong>T3:</strong> up()</td>
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<td><strong>T4:</strong> wait()</td>
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September 21, 2017

EECS 482 – Lecture 6
Implementing custom waiting condition with semaphores

- Semaphores work best if the shared integer and waiting condition (value==0) map naturally to problem domain

- How to implement custom waiting condition with semaphores?
Producer-consumer with monitors

**Consumer**

```java
cokeLock.lock()

while (numCokes == 0) {
    waitingConsumers.wait()
}

take coke out of machine
numCokes--

waitingProducers.signal()

cokeLock.unlock()
```

**Producer**

```java
cokeLock.lock()

while (numCokes == MAX) {
    waitingProducers.wait()
}

add coke to machine
numCokes++

waitingConsumers.signal()

cokeLock.unlock()
```
Producer-consumer with semaphores (monitor style)

**Consumer**
```java
mutex.down()
while (numCokes == 0) {
    go to sleep
}
take coke out of machine
numCokes--

wake up waiting producer, if any
mutex.up()
```

**Producer**
```java
mutex.down()
while (numCokes == MAX) {
    go to sleep
}
add coke to machine
numCokes++

wake up waiting consumer, if any
mutex.up()
```
Producer-consumer with semaphores (monitor style)

**Consumer**

```java
mutex.down()
while (numCokes == 0) {
    semaphore s = 0
    waitingConsumers.push(&s)
}

s.down()

take coke out of machine
numCokes--
if (!waitingProducers.empty()) {
    waitingProducers.front()->up()
    waitingProducers.pop()
}
mutex.up()
```

**Producer**

```java
mutex.down()
while (numCokes == MAX) {
    semaphore s = 0
    waitingProducers.push(&s)
}

s.down()

add coke to machine
numCokes++
if (!waitingConsumers.empty()) {
    waitingConsumers.front()->up()
    waitingConsumers.pop()
}
mutex.up()
```
Producer-consumer with semaphores (monitor style)

**Consumer**

```c
mutex.down()
while (numCokes == 0) {
    semaphore s = 0
    waitingConsumers.push(&s)
    mutex.up()
    s.down()
    mutex.down()
}
take coke out of machine
numCokes--
if (!waitingProducers.empty()) {
    waitingProducers.front()->up()
    waitingProducers.pop()
}
mutex.up()
```

**Producer**

```c
mutex.down()
while (numCokes == MAX) {
    semaphore s = 0
    waitingProducers.push(&s)
    mutex.up()
    s.down()
    mutex.down()
}
add coke to machine
numCokes++
if (!waitingConsumers.empty()) {
    waitingConsumers.front()->up()
    waitingConsumers.pop()
}
mutex.up()
```
The first commandment

Would you name your kid “Kid”? Or “KidA”? Or “MyKid”? Or “k”?

1. Thou shalt name thy synchronization variables properly.
The third commandment

We gave you monitors so you don’t have to worship the ancient gods!

3. THOU SHALT USE MONITORS INSTEAD OF SEMAPHORES WHENEVER POSSIBLE
The fifth commandment

This is NOT OK:

```java
while(true) {
    mutex.lock();
    if(condition) {
        mutex.unlock();
        break;
    } else {
        mutex.unlock();
        sleep(200);
    }
}
```
The sixth commandment

6. ALL SHARED STATE MUST BE PROTECTED
The seventh commandment

myAtomicFunction() {
    mutex.lock()
    ...
    ...
    ...
    mutex.unlock()
}