CS 4410
Operating Systems

Synchronization
Monitors

Summer 2013

Cornell University

Today

- What are the monitors and how can we use them?
- Monitor Semantics/Structure
- Solving synchronization problems with monitors
- Comparison with semaphores
- Mapping to Real Languages

Semaphors: Common programming errors

Process i

```
P(S)
CS
P(S)
```

Process j

```
V(S)
CS
V(S)
```

Process k

```
P(S)
CS
```

Process m

```
P(S)
if(something or other)
    return;
CS
V(S)
```

Revisiting semaphores!

- **Semaphores** are very “low-level” primitives
  - Users could easily make small **errors**
  - Similar to programming in assembly language
  - Small error brings system to grinding halt
  - Very **difficult to debug**

- Also, we seem to be using them in two ways
  - For **mutual exclusion**, the “real” abstraction is a critical section
  - But the bounded buffer example illustrates something different, where threads “**communicate**” using semaphores

- Simplification: Provide concurrency support in compiler
  - **Monitors**

Monitors

- Hoare 1974
- Abstract Data Type for handling/defining shared resources
- Comprises:
  - Shared Private Data
    - The resource
    - Cannot be accessed from outside
  - Procedures that operate on the data
    - Gateway to the resource
    - Can only act on data local to the monitor
  - Synchronization primitives
    - Among threads that access the procedures

Monitor Semantics

- Monitors guarantee mutual exclusion
  - Only one thread can execute a monitor procedure at any time.
    - “in the monitor”
  - If second thread invokes a monitor procedure at that time
    - It will block and wait for entry to the monitor
    - Need for a wait queue

Structure of a Monitor

```
Monitor monitor_name
{
      // shared variable declarations

      procedure P1(. . . .) {
          . . . .
      }

      procedure P2(. . . .) {
          . . . .
      }
      .
      .
      procedure PN(. . . .) {
          . . . .
      }

      initialization_code(. . . .) {
          . . . .
      }
}
```

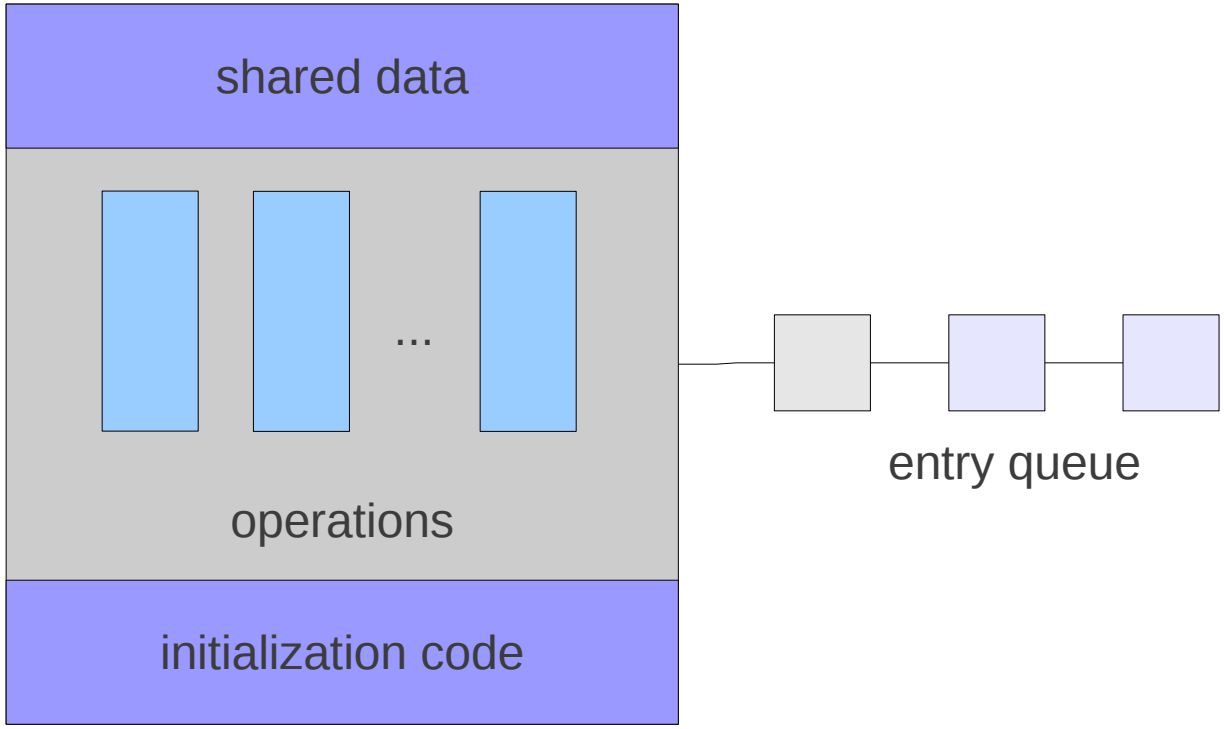
For example:

```
Monitor stack
{
      int top;
      void push(any_t *) {
          . . . .
      }

      any_t * pop() {
          . . . .
      }

      initialization_code() {
          . . . .
      }
}
```

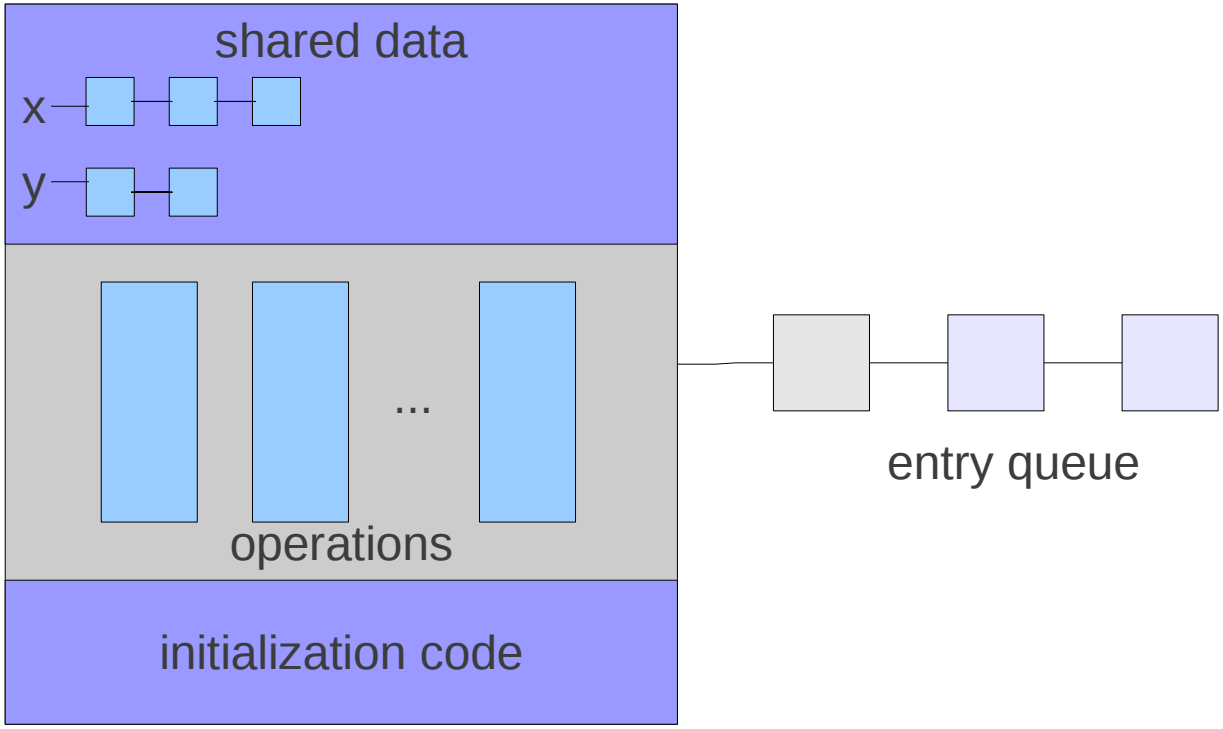
Structure of a Monitor



Synchronization Using Monitors

- Defines Condition Variables:
  - condition x;
  - Provides a mechanism to wait for events.
- 3 atomic operations on *Condition Variables*
  - x.wait(): release monitor lock, sleep until woken up
    - Condition variables have a waiting queue
  - x.notify(): wake one process waiting on condition (if there is one)
    - No history associated with signal
    - Notify and wait
    - Notify and continue
  - x.notifyAll(): wake all processes waiting on condition
    - Useful for resource manager

Synchronization Using Monitors



Types of wait queues

- Monitors have two kinds of “wait” queues
  - Entry to the monitor: has a queue of threads waiting to obtain mutual exclusion so they can enter
  - Condition variables: each condition variable has a queue of threads waiting on the associated condition

A Simple Monitor

```
Monitor EventTracker {
  int numburgers = 0;
  condition hungrycustomer;

  void customerenter() {
    if (numburgers == 0)
      hungrycustomer.wait()
    numburgers -= 1
  }

  void produceburger() {
    ++numburgers;
    hungrycustomer.signal();
  }
}
```

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```

- Because condition variables lack state, all state must be kept in the monitor
- The condition for which the threads are waiting is necessarily made explicit in the code
  - Numburgers > 0
- What happens if there are lots of customers?
- **Signal and wait** vs. **Signal and continue** semantics

A Simple Monitor

```
Monitor EventTracker {
  int numburgers = 0;
  condition hungrycustomer;

  void customerenter() {
    while (numburgers == 0)
      hungrycustomer.wait()
    numburgers -= 1
  }

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}
```

- Because condition variables lack state, all state must be kept in the monitor
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- What happens if there are lots of customers?
- **Signal and wait** vs. **Signal and continue** semantics

Producer-Consumer using Monitors

```
Monitor Producer_Consumer {
  any_t buf[N];
  int n = 0, tail = 0, head=0;
  condition not_empty, not_full;

  void put(char ch) {
    if(n == N)
      wait(not_full);
    buf[head%N] = ch;
    head++;
    n++;
    signal(not_empty);
  }

  char get()  {
    if(n == 0)
      wait(not_empty);
    ch = buf[tail%N];
    tail++;
    n--;
    signal(not_full);
    return ch;
  }
}
```

Readers and Writers

```
Monitor ReadersNWriters {

 int WaitingWriters, WaitingReaders,
     NReaders, Nwriters;
 Condition CanRead, CanWrite;

Void BeginWrite()  {





 }

 Void EndWrite()
 {

 }
```

```
Void BeginRead(){

}

Void EndRead(){

}

}
```

Readers and Writers

```
Monitor ReadersNWriters {

 int WaitingWriters, WaitingReaders,
     NReaders, NWriters;
 Condition CanRead, CanWrite;

Void BeginWrite()
 {

      NWriters = 1;
 }

 Void EndWrite()
 {
      NWriters = 0;

 }
```

```
Void BeginRead(){

    ++NReaders;

}

Void EndRead() {

    --NReaders

}

}
```

Readers and Writers

```
Monitor ReadersNWriters {

 int WaitingWriters, WaitingReaders,
     NReaders, NWriters;
 Condition CanRead, CanWrite;

Void BeginWrite(){

     NWriters = 1;}

 Void EndWrite() {
       NWriters = 0;
       if(WaitingReaders)
           Signal(CanRead);
       else
           Signal(CanWrite); }
```

```
Void BeginRead() {

     ++NReaders;

                    }

Void EndRead(){

     if(--NReaders == 0)

          Signal(CanWrite); }

}
```

Readers and Writers

```
Monitor ReadersNWriters {

  int WaitingWriters,
WaitingReaders,NReaders, NWriters;
  Condition CanRead, CanWrite;

 Void BeginWrite(){
       if(NWriters == 1 || NReaders > 0)
       {
            ++WaitingWriters;
           wait(CanWrite);
           --WaitingWriters;
       }
       NWriters = 1; }

  Void EndWrite(){
        NWriters = 0;
        if(WaitingReaders)
             Signal(CanRead);
        else
             Signal(CanWrite);}

 Void BeginRead(){

       if(NWriters == 1 || WaitingWriters > 0)

       {

             ++WaitingReaders;

             Wait(CanRead);

             --WaitingReaders;

       }

       ++NReaders;

       Signal(CanRead);}


  Void EndRead(){

        if(--NReaders == 0)

                Signal(CanWrite); }

}
```

Understanding the Solution

- A reader can enter if
  - There are no writers active or waiting
- When a writer finishes, it checks to see if any readers are waiting
  - If so, it lets one of them enter
  - That one will let the next one enter, etc…
- Similarly, when a reader finishes, if it was the last reader, it lets a writer in (if any is there)
- Do not forget: For **Signal and Continue semantics** we have '**while'** instead of **'if'** at BeginWrite and BeginRead!

Understanding the Solution

- It wants to be fair
  - If a writer is waiting, readers queue up
  - If a reader (or another writer) is active or waiting, writers queue up
  - … this is mostly fair, although once it lets a reader in, it lets ALL waiting readers in all at once, even if some showed up “after” other waiting writers

Mapping to Real Languages

```
Monitor ReadersNWriters {
  int x;
  Condition foo

 Void func()
  {
        while(x == 0)
        {
             foo.wait()
        }
        x = 1
  }
}
```

```
Class ReadersNWriters:
    def __init__(self):
        self.lock = Lock()
        self.foo = Condition(self.lock)

    def  func():
        with self.lock:
            while x == 0:
                self.foo.wait()
            x = 1
```

Condition Variables & Semaphores

- Condition Variables != semaphores
- Access to monitor is controlled by a lock
  - Wait: blocks thread and gives up the monitor lock
    - To call wait, thread has to be in monitor, hence the lock
    - Semaphore P() blocks thread only if value less than 0
  - Signal: causes waiting thread to wake up
    - If there is no waiting thread, the signal is lost
    - V() increments value, so future threads need not wait on P()
    - Condition variables have no history!

However they can be used to implement each other

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