Synchronization Part 2

CSE 410 - Computer Systems
November 28, 2001

Readings and References

- Reading
  - Chapter 7, Sections 7.4 through 7.7, *Operating System Concepts*, Silberschatz, Galvin, and Gagne
- Other References

Shared Stack

```
void Stack::Push(Item *item) {
    item->next = top;
    top = item;
}
```

- Suppose two threads, red and blue, share this code and a Stack `s`
- The two threads both operate on `s`
  - each calls `s->Push(…)`
- Execution is interleaved by context switches

Stack Example

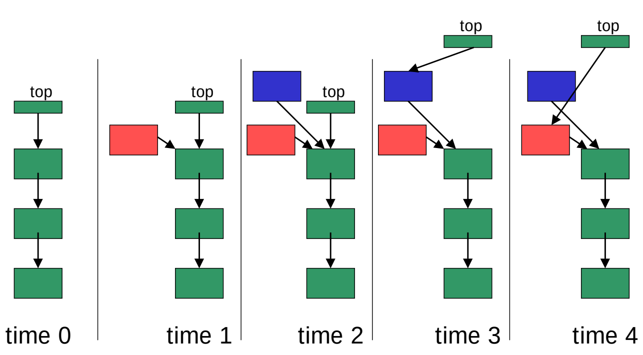
- Now suppose that a context switch occurs at an "inconvenient" time, so that the actual execution order is

context switch from red to blue

```
1  item->next = top;
2                          item->next = top;
3                          top = item;
4  top = item;
```

context switch from blue to red

Disaster Strikes



Shared Stack Solution

- How do we fix this using locks?

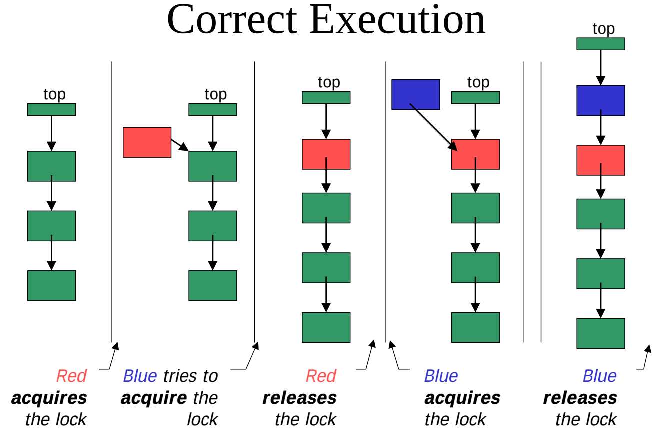
```
void Stack::Push(Item *item) {
    lock->Acquire();
    item->next = top;
    top = item;
    lock->Release();
}
```

Correct Execution

- Only one thread can hold the lock

```
lock->Acquire();
item->next = top;
                                  lock->Acquire();
                                  | wait for lock acquisition
top = item;                       |
lock->Release();                  v
                                  item->next = top;
                                  top = item;
                                  lock->Release();
```


Correct Execution



How can Pop wait for a Stack item?

- Synchronized stack using locks

```
Stack::Push(Item * item) {          Item * Stack::Pop() {
  lock->Acquire();                    lock->Acquire();
  push item on stack                  pop item from stack
  lock->Release();                    lock->Release();
}                                     return item;
                                    }
```

- › want to go to sleep inside the critical section
- › other threads won't be able to run because Pop holds the lock
- › **condition variables** make it possible to go to sleep inside a critical section, by **atomically** releasing the lock and going to sleep

Monitors

- **Monitor**: a **lock** and **condition variables**
- Key addition is the ability to inexpensively and reliably wait for a condition change
- Often implemented as a separate class
  - › The class contains code and private data
  - › Since the data is private, only monitor code can access it
  - › Only one thread is allowed to run in the monitor at a time
- Can also implement directly in other classes using locks and condition variables

Condition Variables

- A condition variable is a queue of threads waiting for something inside a critical section
- There are three operations
  - › **Wait()**--release lock & go to sleep (atomic); reacquire lock upon awakening
  - › **Signal()**--wake up a waiting thread, if any
  - › **Broadcast()**--wake up all waiting threads
- A thread must hold the lock when doing condition variable operations

Stack with Condition Variables

- Pop can now wait for something to be pushed onto the stack

```
Stack::Push(Item *item) {          Item *Stack::Pop() {
  lock->Acquire();                   lock->Acquire();
  push item on stack                 while( nothing on stack ) {
  condition->signal( lock );           condition->wait( lock );
  lock->Release();                   }
}                                    pop item from stack
                                     lock->Release();
                                     return item;
                                   }
```

Database Readers and Writers

- Many threads may read the database at the same time
- If any thread is writing the database, then no other thread may read or write
  - › when a reader enters, it must wait if there is a writer inside
  - › when a writer enters, it must wait if there is a reader or writer inside
  - › writers have priority over readers

Constraints

- Reader can access the database when no writers are active
  - › condition okToRead
- Writer can access the database when no readers or writers are active
  - › condition okToWrite
- Only one thread of any type can manipulate the shared state variables at a time
  - › lock

Basic Algorithm

```
Database::read()
  wait until no writers
  access database
  checkout -- wake up waiting writer (if any)

Database::write()
   wait until no readers or writers
   access database
   checkout -- wake up waiting readers or writers
```


State Variables

```
Condition okToRead = TRUE;  // "signaled"
Condition okToWrite = TRUE; // "signaled"
Lock lock = FREE;           // "signaled"

AR=0;  // number of active readers
AW=0;  // number of active writers
WR=0;  // number of waiting readers
WW=0;  // number of waiting writers
```



```
Database::read() {
  StartRead();              // wait until it is okay to read
  access database           // read
  DoneRead();               // checkout -- wakeup a waiting writer
}
Database::StartRead() {
  lock->Acquire();          // acquire lock when accessing shared variables
  while( AW + WW > 0 ) {    // while there are waiting or active writers
    WR++;                   // I am a waiting reader
    okToRead->Wait( lock ); // wait until it is okay to read
    WR--;                   // I am no longer a waiting reader
  }
  AR++;                     // it is now okay to read.  I am an active reader
  lock->Release();          // release lock after accessing shared variables
}
Database::DoneRead() {
  lock->Acquire();          // acquire lock when accessing shared variables
  AR--;                     // I am no longer an active reader
  if( AR==0 && WW > 0 ) {   // if no one else is reading & someone wants to write
    okToWrite->Signal(lock); // signal that it's okay to write
  }
  lock->Release();          // release lock after accessing shared variables
}
```

```
Database::write() {
  StartWrite();             // wait until it is okay to write
  access database           // read
  DoneWrite();              // checkout -- wakeup a waiting writer or readers
}
Database::StartWrite() {
  lock->Acquire();          // acquire lock when accessing shared variables
  while( AW + AR > 0 ) {    // while there are active writers or readers
    WW++;                   // I am a waiting writer
    okToWrite->Wait( lock ); // wait until it is okay to write
    WW--;                   // I am no longer a waiting writer
  }
  AW++;                     // it is now okay to write.  I am an active writer
  lock->Release();          // release lock after accessing shared variables
}
Database::DoneWrite() {
  lock->Acquire();           // acquire lock when accessing shared variables
  AW--;                      // I am no longer an active writer
  if( WW > 0 ) {             // give priority to waiting writers
    okToWrite->Signal(lock); // signal that it's okay to write
  } else if ( WR > 0 ) {     // otherwise, if there are any waiting readers
    okToRead->Broadcast(lock);// signal that it's okay to read
  }
  lock->Release();           // release lock after accessing shared variables
}
```

Semaphores

- Semaphores were first synchronization mechanism
  - › Don't use semaphores, use condition variables instead
- The semaphore is an integer variable that has two **atomic** operations:
  - › P() (the entry procedure) wait for semaphore to become positive and then decrement it by 1
  - › V() (the exit procedure) increment semaphore by 1, wake up a waiting P if any
  - › P and V are from the Dutch for *probieren* (to try) and *verhogen* (to increment) - named by Dijkstra

Synchronization in NT

- NT has locks (known as mutexes)
  - › `CreateMutex`--returns a handle to a new mutex
  - › `WaitForSingleObject`--acquires the mutex
  - › `ReleaseMutex`--releases the mutex
- NT has **events** instead of condition variables
  - › `CreateEvent`--returns a handle to a new event
  - › `WaitForSingleObject`--waits for the event to happen
  - › `SetEvent`--signals the event, waking up one waiting thread

Advice for Threads Programming #1

- Always do things the same way
  - › you can focus on the core problem because the standard approach becomes a habit
  - › makes it easier for other people to read (modify and debug) your code
  - › you might be able to cut corners occasionally and save a line or two of code
    - spend time convincing yourself it works
    - spend time convincing others that it works with your comments
    - NOT WORTH IT!

Advice for Threads Programming #2

- Always use **monitors** (locks + condition variables) or **events**
  - › 99% monitor/event code is more clear than semaphore code because monitor code is "self-documenting"
  - › occasionally a semaphore might fit what you are doing perfectly
  - › what if the code needs to change, is it still a perfect fit?

Advice for Threads Programming #3

- Always acquire the lock at the beginning of a procedure and release it before returning
  - › if there is a logical chunk of code that requires holding a lock, then it should probably be its own procedure
  - › we are sometimes lazy about creating new procedures when we should (don't be lazy)
  - › always do things the same way (rule #1)

Advice for Threads Programming #4

- Always use `while` instead of `if` when checking a synchronization condition
- Many implementations allow for a thread to be waked up even though the condition is not true. Must wait again.

```
Item * Stack::Pop() {
  lock->Acquire();
  while( nothing on stack ) {
    condition->wait( lock );
  }
  pop item from stack
  lock->Release();
  return item;
}
```

```
Item * Stack::Pop() {
  lock->Acquire();
  if( nothing on stack ) {
    condition->wait( lock );
  }
  pop item from stack
  lock->Release();
  return item;
}
```