Condition Variables

Don Porter

Portions courtesy Emmett Witchel

Synchronization

- Now that you have seen locks, is that all there is?
- No, but what is the "right" way to build a parallel program?
  - People are still trying to figure that out.
- Compromises:
  - between making it easy to modify shared variables AND
  - restricting when you can modify shared variables.
  - between really flexible primitives AND
  - simple primitives that are easy to reason about.

Moving Beyond Locks

- Synchronizing on a condition.
  - When you start working on a synchronization problem, first define the mutual exclusion constraints, then ask "when does a thread wait", and create a separate synchronization variable representing each constraint.
- Bounded Buffer problem – producer puts things in a fixed sized buffer, consumer takes them out.
  - What are the constraints for bounded buffer?
  - 1) only one thread can manipulate buffer queue at a time (*mutual exclusion)*
  - 2) consumer must wait for producer to fill buffers if none full (*scheduling constraint)*
  - 3) producer must wait for consumer to empty buffers if all full (*scheduling constraint)*

Beyond Locking

- Locks ensure mutual exclusion
- Bounded Buffer problem – producer puts things in a fixed sized buffer, consumer takes them out.
  - Synchronizing on a condition.

```
Class BoundedBuffer{
    …
    void* buffer[];
    Lock lock;
    int count = 0;
}
```

What is wrong with this?

```
BoundedBuffer::Deposit(c){
    lock→acquire();
    while (count == n); //spin
    Add c to the buffer;
    count++;
    lock→release();
}
```

```
BoundedBuffer::Remove(c){
    lock→acquire();
    while (count == 0); // spin
    Remove c from buffer;
    count--;
    lock→release();
}
```

Beyond Locks

```
Class BoundedBuffer{
    …
    void* buffer[];
    Lock lock;
    int count = 0;
}
```

What is wrong with this?

```
BoundedBuffer::Deposit(c){
    while (count == n); //spin
    lock→acquire();
    Add c to the buffer;
    count++;
    lock→release();
}
```

```
BoundedBuffer::Remove(c){
    while (count == 0); // spin
    lock→acquire();
    Remove c from buffer;
    count--;
    lock→release();
}
```

Beyond Locks

```
Class BoundedBuffer{
    …
    void* buffer[];
    Lock lock;
    int count = 0;
}
```

What is wrong with this?

```
BoundedBuffer::Deposit(c){
    if (count == n) sleep();
    lock->acquire();
    Add c to the buffer;
    count++;
    lock->release();
    if(count == 1) wakeup(remove);
}
```

```
BoundedBuffer::Remove(c){
    if (count == 0) sleep();
    lock->acquire();
    Remove c from buffer;
    count--;
    lock->release();
    if(count==n-1) wakeup(deposit);
}
```

Beyond Locks

```
Class BoundedBuffer{
    …
    void* buffer[];
    Lock lock;
    int count = 0;
}
```

What is wrong with this?

```
BoundedBuffer::Deposit(c){
    lock→acquire();
    if (count == n) sleep();
    Add c to the buffer;
    count++;
    if(count == 1) wakeup(remove);
    lock→release();
}
```

```
BoundedBuffer::Remove(c){
    lock→acquire();
    if (count == 0) sleep();
    Remove c from buffer;
    count--;
    if(count==n-1) wakeup(deposit);
    lock→release();
}
```

Beyond Locks

```
Class BoundedBuffer{
    …
    void* buffer[];
    Lock lock;
    int count = 0;
}
```

What is wrong with this?

```
BoundedBuffer::Deposit(c){
    while(1) {
      lock→acquire();
      if(count == n) {
          lock->release();
          continue;}
      Add c to the buffer;
      count++;
      lock→release();
      break;
}}
```

```
BoundedBuffer::Remove(c){
    while(1) {
      lock→acquire();
      if (count == 0) {
         lock->release();
         continue;
      }
      Remove c from buffer;
      count--;
      lock→release();
      break;
}}
```

Introducing Condition Variables

- Correctness requirements for bounded buffer producer-consumer problem
  - Only one thread manipulates the buffer at any time (mutual exclusion)
  - Consumer must wait for producer when the buffer is empty (scheduling/synchronization constraint)
  - Producer must wait for the consumer when the buffer is full (scheduling/synchronization constraint)

- Solution: condition variables
  - An abstraction that supports conditional synchronization
  - Condition variables are associated with a monitor lock
  - Enable threads to wait inside a critical section by releasing the monitor lock.

Condition Variables: Operation

- Three operations
  - Wait()
    - Release lock
    - Go to sleep
    - Reacquire lock upon return
    - Java Condition interface await() and awaitUninterruptably()
  - Notify() (historically called Signal())
    - Wake up a waiter, if any
    - Condition interface signal()
  - NotifyAll() (historically called Broadcast())
    - Wake up all the waiters
    - Condition interface signalAll()

Wait() usually specified a lock to be released as a parameter

- Implementation
  - Requires a per-condition variable queue to be maintained
  - Threads waiting for the condition wait for a notify()

Coke Machine Example

```
Class CokeMachine{
    …
    Storge for cokes (buffer)
    Lock lock;
    int count = 0;
    Condition notFull, notEmpty;
}
```

```
CokeMachine::Deposit(){
    lock→acquire();
    while (count == n) {
            notFull.wait(&lock); }
    Add coke to the machine;
    count++;
    notEmpty.notify();
    lock→release();
}
```

```
CokeMachine::Remove(){
    lock→acquire();
    while (count == 0) {
            notEmpty.wait(&lock); }
    Remove coke from to the machine;
    count--;
    notFull.notify();
    lock→release();
}
```

Implementing Wait and Notify

```
Condition::Notify(lock){
    schedLock->acquire();
    if (lock->numWaiting > 0) {
        Move a TCB from waiting queue to ready queue;
        lock->numWaiting--;
    }
    schedLock->release();
}
```

```
Condition::Wait(lock){
    schedLock->acquire();
    lock->numWaiting++;
    lock→release();
    Put TCB on the waiting queue for the CV;
    schedLock->release()
    switch();
    lock→acquire();
}
```

Why do we need schedLock?

Using Condition Variables: An Example

- Coke machine as a shared buffer

- Two types of users
  - Producer: Restocks the coke machine
  - Consumer: Removes coke from the machine

- Requirements
  - Only a single person can access the machine at any time
  - If the machine is out of coke, wait until coke is restocked
  - If machine is full, wait for consumers to drink coke prior to restocking

- How will we implement this?
  - What is the class definition?
  - How many lock and condition variables do we need?

Word to the Wise…

- Always wait and notify condition variables with the mutex held.
- Period.
  - Fine print: There are cases where notification outside of a lock can be safe, but the code tends to be fragile, error-prone, and easy for another developer to break.
  - In many cases you can lose notifications and hang (liveness)
  - Moreover there is no clear advantage to breaking this convention. So just don't do it.

Summary

- Non-deterministic order of thread execution ➔ concurrency problems
  - Multiprocessing
    - A system may contain multiple processors ➔ cooperating threads/processes can execute simultaneously
  - Multi-programming
    - Thread/process execution can be interleaved because of time-slicing

- Goal: Ensure that your concurrent program works under ALL possible interleaving

- Define synchronization constructs and programming style for developing concurrent programs
    - Locks → provide mutual exclusion
    - Condition variables → provide conditional synchronization