Concurrent Programming Issues & Readers/Writers

Summary of Our Discussions

- Developing and debugging concurrent programs is hard
  - Non-deterministic interleaving of instructions
- Safety: isolation and atomicity
- Scheduling: busy-waiting and blocking
- Synchronization constructs
  - Locks: mutual exclusion
  - Condition variables: wait while holding a lock
  - Semaphores: Mutual exclusion (binary) and condition synchronization (counting)
- How can you use these constructs effectively?
  - Develop and follow strict programming style/strategy

Programming Strategy

- Decompose the problem into objects
- Object-oriented style of programming
  - Identify shared chunk of state
  - Encapsulate shared state and synchronization variables inside objects
- Don't manipulate shared variables or synchronization variables along with the logic associated with a thread
- Programs with race conditions always fail.
  - A. True, B. False

General Programming Strategy

- Two step process
- Threads:
  - Identify units of concurrency – these are your threads
  - Identify chunks of shared state – make each shared "thing" an object; identify methods for these objects (how will the thread access the objects?)
  - Write down the main loop for the thread
- Shared objects:
  - Identify synchronization constructs
    - Mutual exclusion vs. conditional synchronization
  - Create a lock/condition variable for each constraint
  - Develop the methods –using locks and condition variables – for coordination

Coding Style and Standards

- Always do things the same way
- Always use locks and condition variables
- Always hold locks while operating on condition variables
- Always acquire lock at the beginning of a procedure and release it at the end
  - If it does not make sense to do this → split your procedures further
- Always use while to check conditions, not if

```
while (predicate on state variable) {
      conditionVariable→wait(&lock);
      };
```

- (Almost) never sleep(), yield(), or isLocked() in your code
  - Use condition variables to synchronize
- Note that printf() internally uses locks, and may hide race conditions

Readers/Writers: A Complete Example

- Motivation
  - Shared databases accesses
    - Examples: bank accounts, airline seats, …
- Two types of users
  - Readers: Never modify data
  - Writers: read and modify data
- Problem constraints
  - Using a single lock is too restrictive
    - Allow multiple readers at the same time
    - …but only one writer at any time
  - Specific constraints
    - Readers can access database when there are no writers
    - Writers can access database when there are no readers/writers
    - Only one thread can manipulate shared variables at any time

Readers/Writer: Solution Structure

- Basic structure: two methods

```
Database::Read() {
    Wait until no writers;
    Block any writers;
    Access database;
    Let in one writer or reader;
}
```

```
Database::Write() {
    Wait until no readers/writers;
    Write database;
    Let all readers/writers in;
}
```


Solution Details

```
Lock dbLock;
Condition dbAvail;
int reader = 0;
bool writer = false;
```

```
Public Database::Read() {
  dbLock.lock();
  while(writer) {
    dbAvail.wait();
  }
  reader++;
  dbLock.unlock();
  Read database;
  dbLock.lock();
  reader--;
  if(reader == 0) {
    dbAvail.singal();}
  dbLock.unlock();
}
```

```
Public Database::Write() {
  dbLock.lock();
  while(reader > 0 || writer){
    dbAvail.wait();}
  writer = true;
  dbLock.unlock();
  Write database;
  dbLock.lock();
  writer = false;
  dbAvail.signalAll();
  dbLock.unlock();
}
```

This solution favors
1. Readers
2. Writers
3. Neither, it is fair

Self-criticism can lead to self-understanding

- Our solution works, but it favors readers over writers.
  - Any reader blocks all writers
  - All readers must finish before a writer can start
  - Last reader will wake any writer, but a writer will wake readers and writers (statistically which is more likely?)
  - If a writer exits and a reader goes next, then all readers that are waiting will get through
- Are threads guaranteed to make progress?
  - A. Yes B. No

Readers/Writer: Using Monitors

- Basic structure: two methods

```
Database::Read() {
    Wait until no writers;
    Access database;
    Wake up waiting writers;
}
```

```
Database::Write() {
    Wait until no readers/writers;
    Access database;
    Wake up waiting readers/writers;
}
```

- State variables

```
Class RWFairLock {
  AR = 0; // # of active readers
  AW = false; // is there an active writer
  public bool iRead;
  Condition okToRead;
  Condition okToWrite;
  LinkedList<RWFairLock> q;
  Lock lock;
```


Solution Details: Readers

```
Class RWFairLock {
  AR = 0; // # of active readers
  AW = false; // is there an active writer
  public bool iRead;
  Condition okToRead;
  Condition okToWrite;
  LinkedList<RWFairLock> q;
  Lock lock;
```

```
Private Database::StartRead() {
    lock.Acquire();
    iRead = true;
    q.add(this);
    while (AW || !q.peek().iRead) {
        okToRead.wait(&lock);
    }
    AR++;
    lock.Release();
}
```

```
Private Database::DoneRead() {
    lock.Acquire();
    AR--;
    q.remove(this);
    if(q.size() > 0) {
      if (q.peek().iRead == false) {
          okToWrite.notify();
      }
    }
    lock.Release();
}
```

```
Public Database::Read() {
    StartRead();
    Access database;
    DoneRead();
}
```


Solution Details: Writers

```
Class RWFairLock {
  AR = 0; // # of active readers
  AW = false; // is there an active writer
  public bool iRead;
  Condition okToRead;
  Condition okToWrite;
  LinkedList<RWFairLock> q;
  Lock lock;
```

```
Private Database::StartWrite() {
    lock.Acquire();
    iRead = false;
    q.add(this);
    while (AW || AR > 0
        || q.peek().isRead) {
          okToWrite.wait(&lock);
    }
    AW = true;
    lock.Release();
}
```

```
Database::Write() {
    StartWrite();
    Access database;
    DoneWrite();
}
```

```
Private Database::DoneWrite() {
    lock.Acquire();
    AW = false;
    q.remove(this);
    if(q.size() > 0) {
      if (q.peek().isRead) {
        okToRead.notifyAll();
      } else {
        okToWrite.notify();
      }
    }
    lock.Release();
}
```

Summary

- Allowing concurrent reader execution is a common concurrent programming pattern
- Naïve implementations can starve writers
- Bookkeeping to ensure fair queuing is tricky, but not impossible
  - A lot of effort to reason about all possible interleavings of operations