CMSC 433 Fall 2013
Michael Hicks
(Some slides due to Rance Cleaveland)

UNIVERSITY OF MARYLAND

Lecture 4
Issues in Synchronization

Synchronization?

- Synchronization: the maintenance of constraints on the order in which in different threads operations occur
- Another term: concurrency control
- Locks are used to enforce synchronization among threads accessing a shared object
- We will see other aspects of synchronization as well

Locks and Performance

- Suppose a class is correct (i.e. it satisfies its specification from a sequential perspective)
- One way to make it thread-safe: make all methods synchronized
  - E.g. from BoundedCounter example:
    - `public void reset () { value = 0; }` becomes
    - `public` **`synchronized`** `void reset () { value = 0; }`
  - This makes every method atomic and locks every field during a method call
  - If there are no public fields, then no threads can see data violating invariants!

Locks and Performance (2)

- Problem: performance!
  - If every method is synchronized, only one method at a time can execute
  - Some methods can run in parallel however: for example (BoundedCounter)
    - `current()`
    - `isMaxed()`
  - If every method is synchronized, then this is not possible
  - On the other hand, both of the above methods should only access consistent data
- BoundedCounter methods are small, so aggressive locking is not so problematic
- For classes with large, time-consuming methods, this creates performance bottlenecks

Designing Locking Protocols

- Locking protocol: how you do locking in order to balance thread-safety, performance
- Making every method synchronized is one example
  - Each data value is "guarded by" `this`
  - Each method must acquire implicit lock on `this` to execute
- Another approach
  - Associate same lock with all fields mentioned in an invariant
  - Lock on these, rather than using `this`
  - Idea
    - Accessing a field should only be done when values are consistent with invariants
    - Using same variable to lock accesses to variables mentioned in same invariants enforces this
    - Fields that are not involved in the invariant can be accessed without disturbing the invariant

Example: ColoredMutableLine

```
public class ColoredMutableLine {

  //@Invariant:  p1 and p2 must be different points.

  Object InvLockP1P2 = new Object ();
  private Point p1;  // Guarded by lock LockP1P2Inv
  private Point p2;  // Guarded by lock LockP1P2Inv

  //@Invariant:  none

  Object InvLockColor = new Object ();
  private int color; // Guarded by lock LockColor

  public Point getP1() { synchronized (InvLockP1P2) { return p1; } }

  public void setP1(Point p1) {
    synchronized (InvLockP1P2) {
      if (!p2.equals(p1)) this.p1 = p1;
      else throw new IllegalArgumentException (
        "Illegal argument to setP1 : " + p1.toString() + " same as second point");
  }

  public int getColor() { synchronized (InvLockColor) { return color; } }

  public void setColor(int color) {
    synchronized (InvLockColor) { this.color = color; }
  }
}
```

Locks and Overlapping Invariants

- What if invariants are:
  - Invariant 1: left ≤ middle
  - Invariant 2: middle ≤ right
- One lock for left and middle, another for middle and right?
  - Not advisable
    - Rule of thumb: each variable should be guarded by one lock
    - This approach would have two locks for middle
  - Better approach: one lock for left, middle and right
    - Methods accessing any of these variables must first acquire this lock
    - This ensures preservation of invariants

A Peril of Locking

What can following code do?

- RunnableAB.java

```
public class RunnableAB implements Runnable {

  private Object firstLock; private Object secondLock;

  public RunnableAB (Object a, Object b) { firstLock = a; secondLock = b; }

  public void run () {
    synchronized (firstLock) { synchronized (secondLock) {
      System.out.println ("AB succeeds");
     }}
  }
}
```

- RunnableBA.java same, except that first, second locks switched
- DeadlockPossible.java

```
public class DeadlockPossible {

  public static void main(String[] args) {
    Object lockA = new Object ();  Object lockB = new Object ();

    Thread t1 = new Thread (new RunnableAB (lockA, lockB));
    Thread t2 = new Thread (new RunnableBA (lockA, lockB));

    t1.start ();
    t2.start ();
  }
}
```

Answer: It Can Deadlock

- Consider this sequence
  - AB thread acquires lockA
  - BA thread acquires lockB
  - AB then tries to acquire lockB
  - BA tries to acquire lockA
- Neither thread can acquire the second lock it needs
- The threads both block, and the system "freezes"!

Defining Deadlock

- A set of threads is deadlocked if each thread is waiting for a resource (lock) that is held by some other thread in the set
- In the preceding example, the sequence of events leads to Thread AB and Thread B deadlocking
  - Thread AB is waiting for lockB, which is held by BA
  - Thread BA is waiting for lockA, which is held by AB
- Note: a system can sometimes deadlock and sometimes not!
  - Example system has this property
  - Deadlocking behavior is scheduler-dependent

Detecting Deadlock

- Difficult!
  - When threads are deadlocked, nothing is happening
  - When threads are not scheduled, nothing is also happening
  - How can you tell the difference?
- There is an approach based on graphs that can be used

Conditions Necessary for Deadlock

1. Mutual exclusion

   There is at least one non-sharable resource (e.g. lock)
2. Hold-and-wait

   Threads already holding resources may request other resources held by other threads
3. Non-preemptability

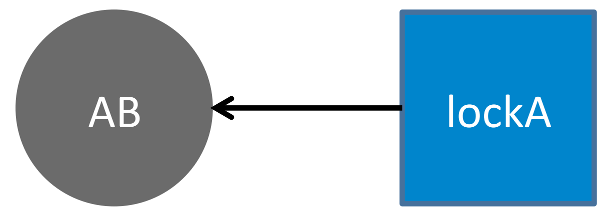
   No resource held by a thread may be forcibly removed from its control
4. Circular waiting

   There is a circular chain of dependencies consisting of one thread waiting for a resource held by another thread

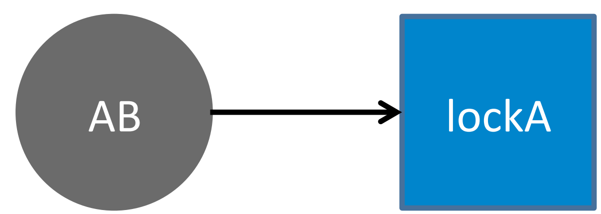
Circular Waiting and Waits-For Graphs

- Circular waiting can be depicted using graphs (i.e. diagrams)
  - Circles: threads
  - Boxes: locks
- There is an arrow from a lock to a thread if the thread holds the lock
- There is an arrow from a thread to a lock if the thread is waiting for the lock

"Thread AB holds lockA"

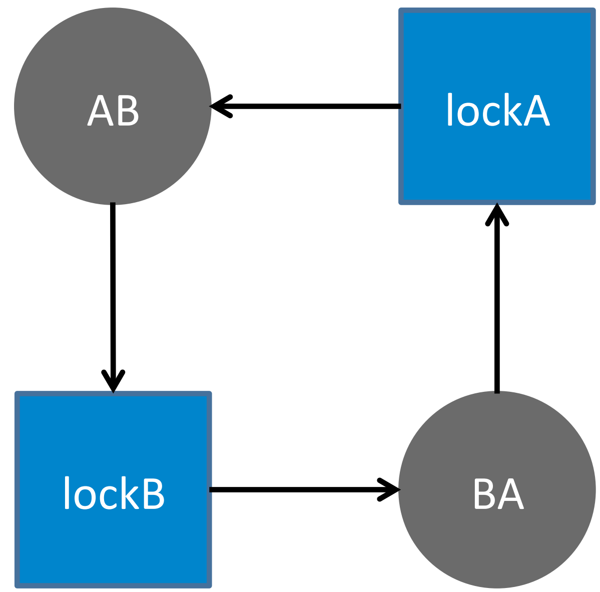


"Thread AB is waiting for lockA"



Waits-For Graph: Cycle = Deadlock!

- Thread AB has lockA
- Thread AB is waiting for lockB
- Thread BA has lockB
- Thread BA is waiting for lock A



Preventing Deadlock

- Impose an order on the locks
- Every thread that needs multiple locks must acquire them in the order specified
- Example revisited
  - Order could be lockA < lockB, meaning that if you need lockA and lockB, you must acquire lockA first, then lockB
  - Currently, AB follows this order, but BA does not
  - If BA did follow this order, deadlock could not occur, because thread that acquires A first would be guaranteed to acquire B!