COMP 322: Fundamentals of Parallel Programming

Lecture 21: Atomics, Java Synchronized Statements

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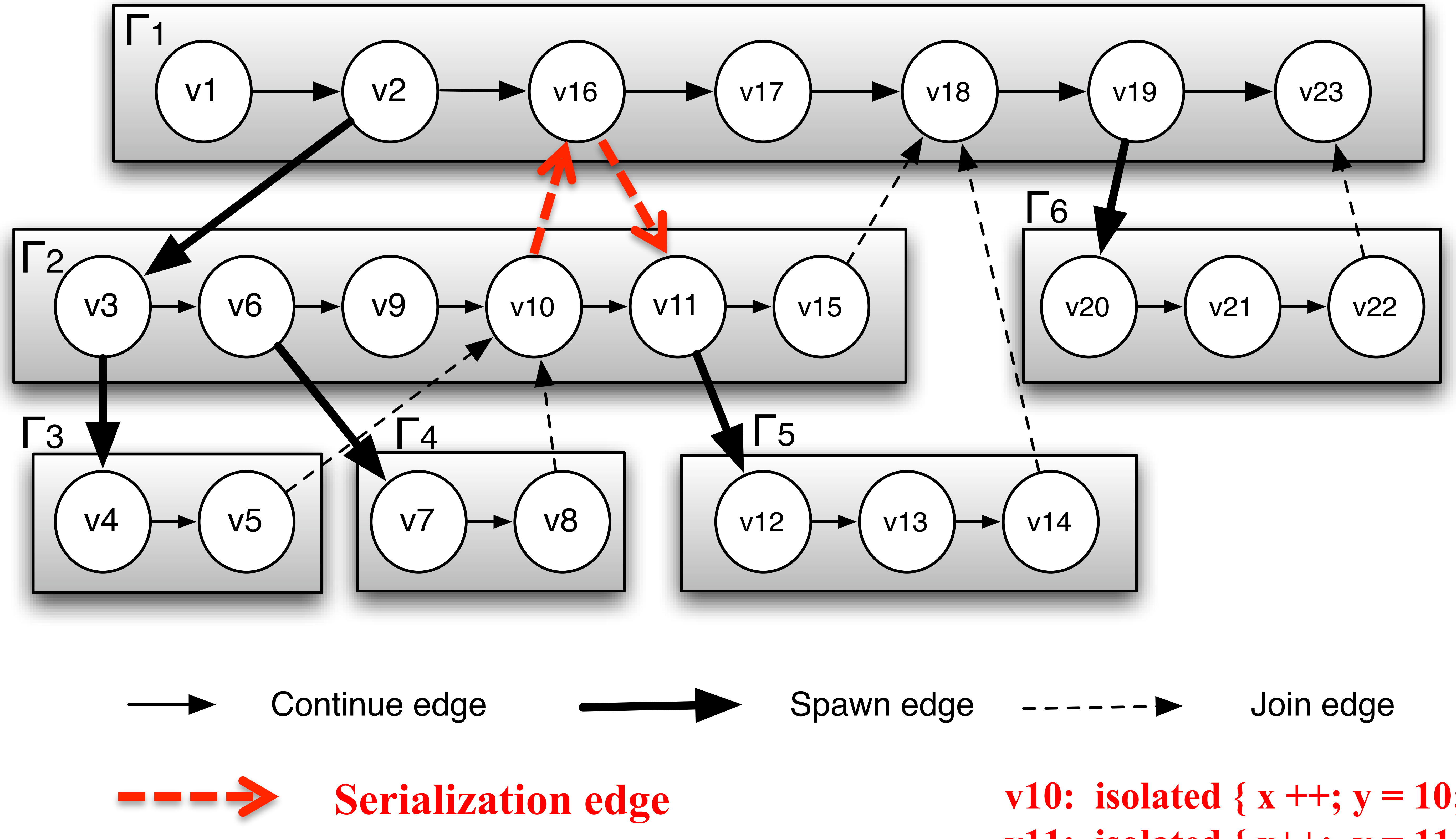
How to enforce mutual exclusion?

- The predominant approach to ensure mutual exclusion proposed many years ago is to enclose the code region in a critical section.
  - "In concurrent programming a critical section is a piece of code that accesses a shared resource (data structure or device) that must not be concurrently accessed by more than one thread of execution. A critical section will usually terminate in fixed time, and a thread, task or process will have to wait a fixed time to enter it (aka bounded waiting). Some synchronization mechanism is required at the entry and exit of the critical section to ensure exclusive use, for example a semaphore."
  - Source: http://en.wikipedia.org/wiki/Critical_section

Example of Serialized Computation Graph with Serialization Edges for v10-v16-v11 order

Data race definition can be applied to Serialized Computation Graphs (SCGs) just like regular CGs



v10: isolated { x ++; y = 10; }
v11: isolated { x++; y = 11; }
v16: isolated { x++; y = 16; }

- ***Have to consider all possible orderings of interfering isolated constructs to establish data race freedom!***

java.util.concurrent.atomic.AtomicInteger

- Constructors
  - new AtomicInteger()
    - Creates a new AtomicInteger with initial value 0
  - new AtomicInteger(int initialValue)
    - Creates a new AtomicInteger with the given initial value
- Selected methods
  - int addAndGet(int delta)
    - Atomically adds delta to the current value of the atomic variable, and returns the new value
  - int getAndAdd(int delta)
    - Atomically returns the current value of the atomic variable, and adds delta to the current value
- Similar interfaces available for LongInteger

java.util.concurrent.AtomicInteger methods and their equivalent isolated constructs (pseudocode)

j.u.c.atomic Class and Constructors	j.u.c.atomic Methods	Equivalent HJ isolated statements
AtomicInteger	int j = v.**get**();	int j; `isolated` (v) j = v.val;
	v.**set**(newVal);	`isolated` (v) v.val = newVal;
AtomicInteger()	int j = v.**getAndSet**(newVal);	int j; `isolated` (v) { j = v.val; v.val = newVal; }
// init = 0	int j = v.**addAndGet**(delta);	`isolated` (v) { v.val += delta; j = v.val; }
	int j = v.**getAndAdd**(delta);	`isolated` (v) { j = v.val; v.val += delta; }
AtomicInteger(init)	boolean b = v.**compareAndSet** (expect,update);	boolean b; `isolated` (v) if (v.val==expect) {v.val=update; b=true;} else b = false;

Methods in java.util.concurrent.AtomicInteger class and their equivalent HJ isolated statements. Variable v refers to an AtomicInteger object in column 2 and to a standard non-atomic Java object in column 3. val refers to a field of type int.

Work-Sharing Pattern using AtomicInteger

```
import java.util.concurrent.atomic.AtomicInteger;
. . .
String[] X = ... ; int numTasks = ...; int j;
int[] taskId = new int[X.length];
. . .
finish(() -> {
  for (int i=0; i<numTasks; i++ )
    async(() -> {
    do {
       j = j + 1;
       // check if at end of X
       if (j >= X.length) break;
       taskId[j] = i; // Task i processes string X[j]
       . . .
     } while (true);
   });
}); // finish-for-async
```

Work-Sharing Pattern using AtomicInteger

```
import java.util.concurrent.atomic.AtomicInteger;
. . .
String[] X = ... ; int numTasks = …; int j;
int[] taskId = new int[X.length];
AtomicInteger a = new AtomicInteger();
. . .
finish(() -> {
  for (int i=0; i<numTasks; i++ )
    async(() -> {
    do {
       j = a.getAndAdd(1);
       // can also use a.getAndIncrement()
       if (j >= X.length) break;
       taskId[j] = i; // Task i processes string X[j]
       . . .
     } while (true);
   });
}); // finish-for-async
```

Work-Sharing Pattern using AtomicInteger

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import java.util.concurrent.atomic.AtomicInteger;
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String[] X = ... ; int numTasks = ...;
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      // can also use a.getAndIncrement()
      if (j >= X.length) break;
      taskId[j] = i; // Task i processes string X[j]
      . . .
    } while (true);
  });
}); // finish-for-async
```

Objects and Locks in Java — synchronized statements and methods

- Every Java object has an associated lock acquired via:
  - synchronized statements
    - synchronized(foo) { // acquire foo's lock
      // execute code while holding foo's lock
      } // release foo's lock
  - synchronized methods
    - public synchronized void op1() { // acquire 'this' lock
      // execute method while holding 'this' lock
      } // release 'this' lock
- Java language does not enforce any relationship between the object used for locking and objects accessed in isolated code
  - If same object is used for locking and data access, then the object behaves like a monitor
- Locking and unlocking are automatic
  - Locks are released when a synchronized block exits
    - By normal means: end of block reached, return, break
    - When an exception is thrown and not caught

Locking guarantees in Java

- It is preferable to use java.util.concurrent.atomic or HJlib isolated constructs, since they cannot deadlock
- Locks are needed for more general cases. Basic idea is for JVM to implement synchronized(a) <stmt> as follows:
  1. Acquire lock for object a
  2. Execute <stmt>
  3. Release lock for object a
- The responsibility for ensuring that the choice of locks correctly implements the semantics of isolation lies with the programmer.
- The main guarantee provided by locks is that only one thread can hold a given lock at a time, and the thread is blocked when acquiring a lock if the lock is unavailable.

Java’s Object Locks are Reentrant

- Locks are granted on a per-thread basis
  - Called reentrant or recursive locks
  - Promotes object-oriented concurrent code
- A synchronized block means execution of this code requires the current thread to hold this lock
  - If it does — fine
  - If it doesn’t — then acquire the lock
- Reentrancy means that recursive methods, invocation of super methods, or local callbacks, don’t deadlock

```
public class Widget {
  public synchronized void doSomething() { ... }
}
public class LoggingWidget extends Widget {
  public synchronized void doSomething() {
    Logger.log(this + ": calling doSomething()");
    …
    doSomething(); // Doesn't deadlock!
  }
}
```

Deadlock example with Java synchronized statement

- The code below can deadlock if leftHand() and rightHand() are called concurrently from different threads
  - Because the locks are not acquired in the same order

```
public class ObviousDeadlock {
   . . .
   public void leftHand() {
     synchronized(lock1) {
       synchronized(lock2) {
         for (int i=0; i<10000; i++)
            sum += random.nextInt(100);
       }
     }
   }
```

```
   public void rightHand() {
     synchronized(lock2) {
       synchronized(lock1) {
         for (int i=0; i<10000; i++)
           sum += random.nextInt(100);
       }
     }
   }
}
```

Deadlock avoidance in HJ with object-based isolation

- HJ implementation ensures that all locks are acquired in the same order
- ==> no deadlock

```
public class ObviousDeadlock {
    . . .
    public void leftHand() {
      isolated(lock1,lock2) {
        for (int i=0; i<10000; i++)
            sum += random.nextInt(100);
      }
    }
}
```

```
    public void rightHand() {
      isolated(lock2, lock1) {
        for (int i=0; i<10000; i++)
          sum += random.nextInt(100);
      }
    }
}
```

Announcements & Reminders

- Hw #3 is due Friday, Mar. 4th at 11:59pm
- Quiz #5 is due Wednesday, Mar. 9th at 11:59pm
- Module 2 (concurrency) handout available