COMP 322: Fundamentals of Parallel Programming

Lecture 21: Read-Write Isolation, Review of Phasers

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Worksheet #20 solution: Parallel Spanning Tree Algorithm

1. Insert finish, async, and isolated constructs (pseudocode is fine) to convert the sequential spanning tree algorithm below into a parallel algorithm

   See slide 3, as well as the isolatedWithReturn() API in slide 4 for convenience in implementing the pseudocode.

2. Is it better to use a global isolated or an object-based isolated construct for the parallelization in question 1? If object-based is better, which object(s) should be included in the isolated list?

   Object-based isolation should be better with a singleton object list containing the "this" object for the makeParent() method.

Parallel Spanning Tree Algorithm using object-based isolated construct

```
class V  {
  V [] neighbors; // adjacency list for input graph
  V parent; // output value of parent in spanning tree
  boolean makeParent(final V n) {
    return isolatedWithReturn(this, () -> {
      if (parent == null) { parent = n; return true; }
      else return false; // return true if n became parent
    });
  } // makeParent
  void compute() {
    for (int i=0; i<neighbors.length; i++) {
      final V child = neighbors[i];
      if (child.makeParent(this))
        async(() -> { child.compute(); });
     }
  } // compute
} // class V
. . .
root.parent = root; // Use self-cycle to identify root
finish(() -> { root.compute(); });
. . .
```

HJ isolatedWithReturn construct

```
// <body> must contain return statement
isolatedWithReturn (obj1, obj2, …, () -> <body> );
```

Motivation: isolated() construct cannot modify local variables due to restrictions imposed by Java 8 lambdas

- Workaround 1: use isolated() and modify objects rather than local variables
  - Pro: code can be easier to understand than modifying local variables
  - Con: source of errors if multiple tasks read/write same object
- Workaround 2: use isolatedWithReturn()
  - Pro: cleaner than modifying local variables
  - Con: can only return one value

java.util.concurrent.AtomicInteger methods and their equivalent object-based isolated constructs (Lecture 20)

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() // init = 0	int j = v.**getAndSet**(newVal);	int j; isolated (v) { j = v.val; v.val = newVal; }
	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.

Atomic Variables represent a special (and more efficient) case of Object-based isolation

```
class V  {
  V [] neighbors; // adjacency list for input graph
  AtomicReference<V> parent; // output value of parent in spanning tree
  boolean makeParent(final V n) {
    // compareAndSet() is a more efficient implementation of
    // object-based isolation
    return parent.compareAndSet(null, n);
  } // makeParent
  void compute() {
    for (int i=0; i<neighbors.length; i++) {
      final V child = neighbors[i];
      if (child.makeParent(this))
        async(() -> { child.compute(); }); // escaping async
     }
  } // compute
} // class V
. . .
root.parent = root; // Use self-cycle to identify root
finish(() -> { root.compute(); });
. . .
```

Motivation for Read-Write Object-based isolation

<u>Sorted List example</u>

```
public boolean contains(Object object) {
    // Observation: multiple calls to contains() should not
    // interfere with each other
    return isolatedWithReturn(this, () -> {
      Entry pred, curr;
      ...
      return (key == curr.key);
  });
}

 public int add(Object object) {
  return isolatedWithReturn(this, () -> {
    Entry pred, curr;
    ...
    if (...) return 1; else return 0;
  });
}
```

Read-Write Object-based isolation in HJ

```
isolated(readMode(obj1),writeMode(obj2), …, () -> <body> );
```

- Programmer specifies list of objects as well as their read-write modes for which isolation is required
- Not specifying a mode is the same as specifying a write mode (default mode = read + write)
- Mutual exclusion is only guaranteed for instances of isolated statements that have a non-empty intersection in their object lists such that one of the accesses is in writeMode
- <u>Sorted List example</u>

```
public boolean contains(Object object) {
   return isolatedWithReturn( readMode(this), () -> {
     Entry pred, curr;
     ...
     return (key == curr.key);
  });
}

 public int add(Object object) {
   return isolatedWithReturn( writeMode(this), () -> {
     Entry pred, curr;
     ...
     if (...) return 1; else return 0;
   });
 }
```

The world according to Module 1 without & with Phasers

- **All the non-phaser parallel constructs that we learned focused on task creation and termination**
  - —async creates a task
    - – forasync creates a set of tasks specified by an iteration region
  - —finish waits for a set of tasks to terminate
    - – forall (like "finish forasync") creates and waits for a set of tasks specified by an iteration region
  - —future get() waits for a specific task to terminate
  - —asyncAwait() waits for a set of DataDrivenFuture values before starting
- **Motivation for phasers**
  - —Deterministic directed synchronization within tasks for barriers, point-to-point synchronization, pipelining
  - —Separate from synchronization associated with task creation and termination
  - —next operations are much more efficient than task creation/termination (async/finish), but they *only help reduce overhead if you perform multiple next operations in a task*

Pipeline Parallelism: Another Example of Point-to-point Synchronization (Recap)

DENOISE → REGISTER → SEGMENT

- **Medical imaging pipeline with three stages**
  1. **Denoising stage generates a sequence of results, one per image.**
  2. **Registration stage's input is Denoising stage's output.**
  3. **Segmentation stage's input is Registration stage's output.**
- **Even though the processing is sequential for a single image, *pipeline parallelism* can be exploited via point-to-point synchronization between neighboring stages**

Implementation of Medical Imaging Pipeline

```
final List<PhaserPair> phList1 = Arrays.asList(ph0.inMode(PhaserMode.SIG));
final List<PhaserPair> phList2 = Arrays.asList(ph0.inMode(PhaserMode.WAIT), ph1.inMode(PhaserMode.SIG));
final List<PhaserPair> phList3 = Arrays.asList(ph1.inMode(PhaserMode.WAIT));

asyncPhased(phList1, () -> { // DENOISE stage
    for (int i = 0; i < n; i++) {
        doWork(1);
        signal(); // same as ph0.signal(); as only ph0 is registered in this async
    }
});

asyncPhased(phList2, () -> { // REGISTER stage
    for (int i = 0; i < n; i++) {
        ph0.doWait();  // WARNING: Explicit calls to doWait() can lead to deadlock in general
        doWork(1);
        ph1.signal();
    }
});

asyncPhased(phList3, () -> { // SEGMENT stage
    for (int i = 0; i < n; i++) {
        ph1.doWait();
        doWork(1);
    }
});
```

Announcements

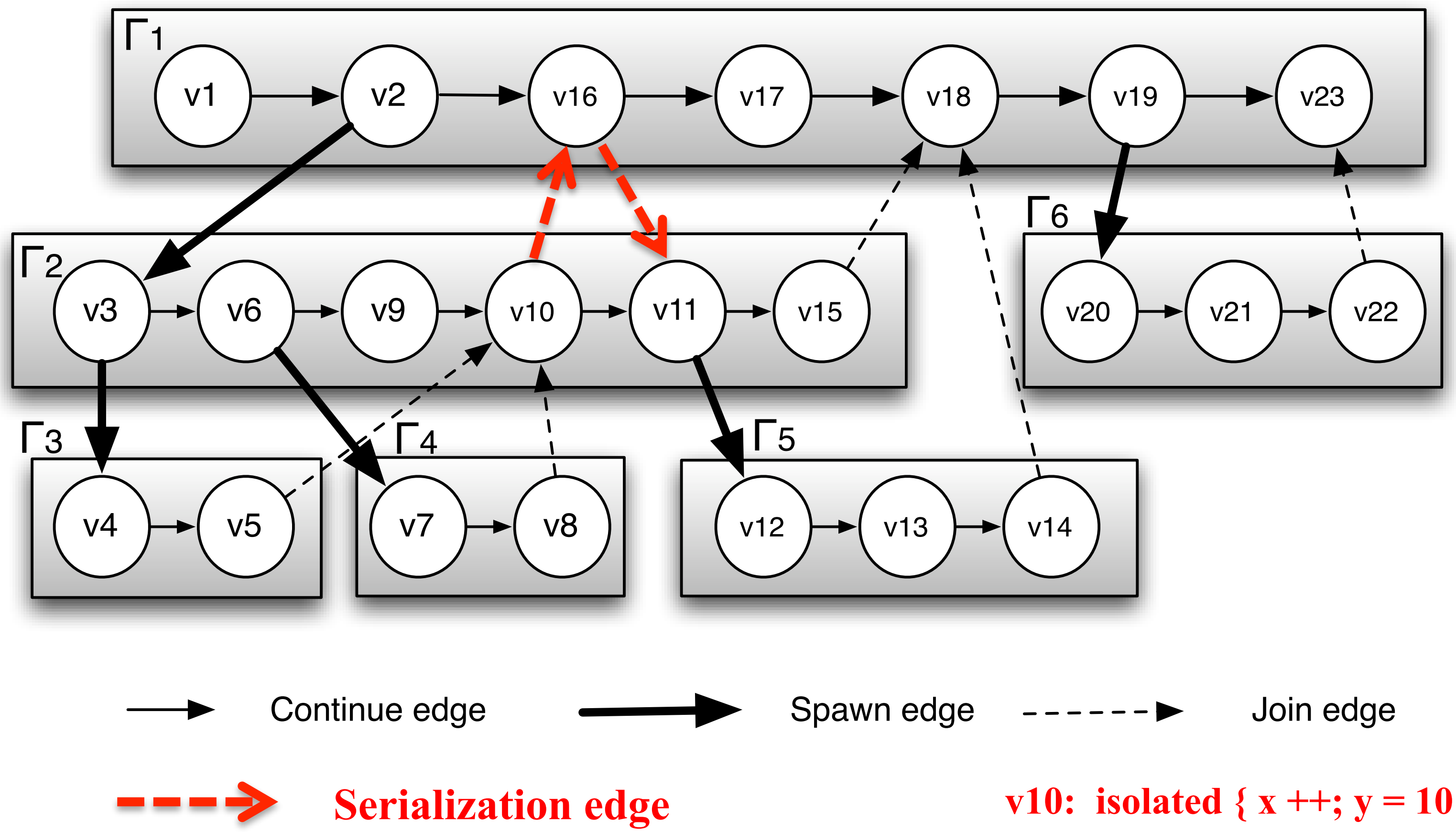
- Reminder: Quiz for Unit 4 is due today
- Reminder: Checkpoint #2 for Homework 3 is due by Wednesday, March 8th, and the entire homework is due by March 22nd
- The registrar has announced the schedule for the COMP 322 final exam:
  - 2-MAY-2017
  - 9:00AM - 12:00PM
  - Location TBD
- Scope of final exam (Exam 2) will be limited to Lectures 19 - 38

Serialized Computation Graph for Isolated Constructs (Recap)

- Model each instance of an isolated construct as a distinct step (node) in the CG.
- Need to reason about the *order* in which interfering isolated constructs are executed
  - Complicated because the order of isolated constructs may vary from execution to execution
- Introduce Serialized Computation Graph (SCG) that includes a specific ordering of all interfering isolated constructs.
  - SCG consists of a CG with additional serialization edges.
  - Each time an isolated step, S', is executed, we add a serialization edge from S to S' for each prior "interfering" isolated step, S
    - Two isolated constructs always interfere with each other
    - Interference of "object-based isolated" constructs depends on intersection of object sets
    - Serialization edge is not needed if S and S' are already ordered in CG
  - An SCG represents a set of schedules in which all interfering isolated constructs execute in the same order.

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

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; }

— **Need to consider all possible orderings of interfering isolated constructs to establish data race freedom**