COMP 322: Fundamentals of Parallel Programming

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Lecture 17: Advanced Phaser Topics

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Announcements

- Feb 23rd lecture will be a Midterm Review
- No COMP 322 labs this week
- No lecture on Friday, Feb 25th since midterm exam is due that day
  - Midterm will be a 2-hour take-home written exam
    - Closed-book, closed-notes, closed-computer
  - Will be given out at lecture on Wed, Feb 23rd
  - Must be handed in by 5pm on Friday, Feb 25th
  - Scope of midterm exam will be Lectures 1-15 and Lecture 17
    - Lecture 16 (Bitonic Sort) will not be included in midterm exam

Acknowledgments for Today's Lecture

- Phasers: a unified deadlock-free construct for collective and point-to-point synchronization. Jun Shirako et al. ICS '08
- The fuzzy barrier: a mechanism for high speed synchronization of processors. Rajiv Gupta. In Proceedings of the third international conference on Architectural support for programming languages and operating systems, ASPLOS-III, pages 54–63, New York, NY, USA, 1989. ACM.
- Handout for Lectures 17

Adding Phaser Operations to the Computation Graph

CG node = step

Step boundaries are induced by continuation points

- async: source of a spawn edge
- end-finish: destination of join edges
- future.get(): destination of a join edge
- isolated-start: destination of serialization edges
- isolated-end: source of serialization edges
- signal, drop: source of signal edges
- wait: destination of wait edges
- next: modeled as signal + wait

CG also includes an unbounded set of pairs of phase transition nodes for each phaser ph allocated during program execution

- ph.next-start(i→i+1) and ph.next-end(i→i+1)

Adding Phaser Operations to the Computation Graph (contd)

CG edges enforce ordering constraints among the nodes

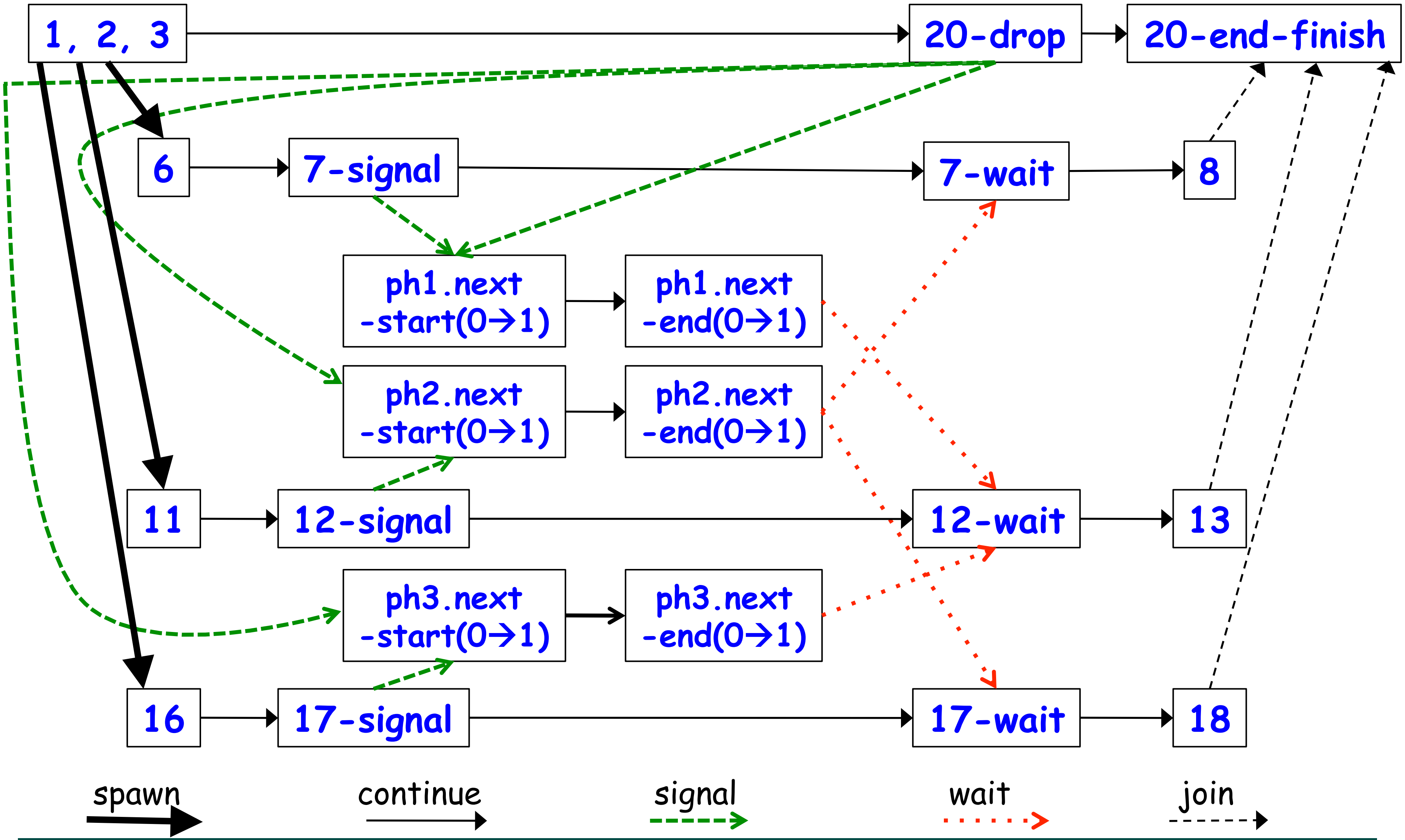
- *continue* edges capture sequencing of steps within a task
- *spawn* edges connect parent tasks to child async tasks
- *join* edges connect descendant tasks to their Immediately Enclosing Finish (IEF) operations and to get() operations for future tasks
- *signal* edges connect each signal or drop operation to the corresponding phase transition node, ph.next-start(i→i+1)
- *wait* edges connect each phase transition node, ph.next-end(i→i+1) to corresponding wait or next operations
- *single* edges connect each phase transition node, ph.next-start (i→i+1) to the start of a single statement instance, and from the end of that single statement to the phase transition node, ph.next-end(i→i+1)

Left-Right Neighbor Synchronization Example for m=3 (Listing 1)

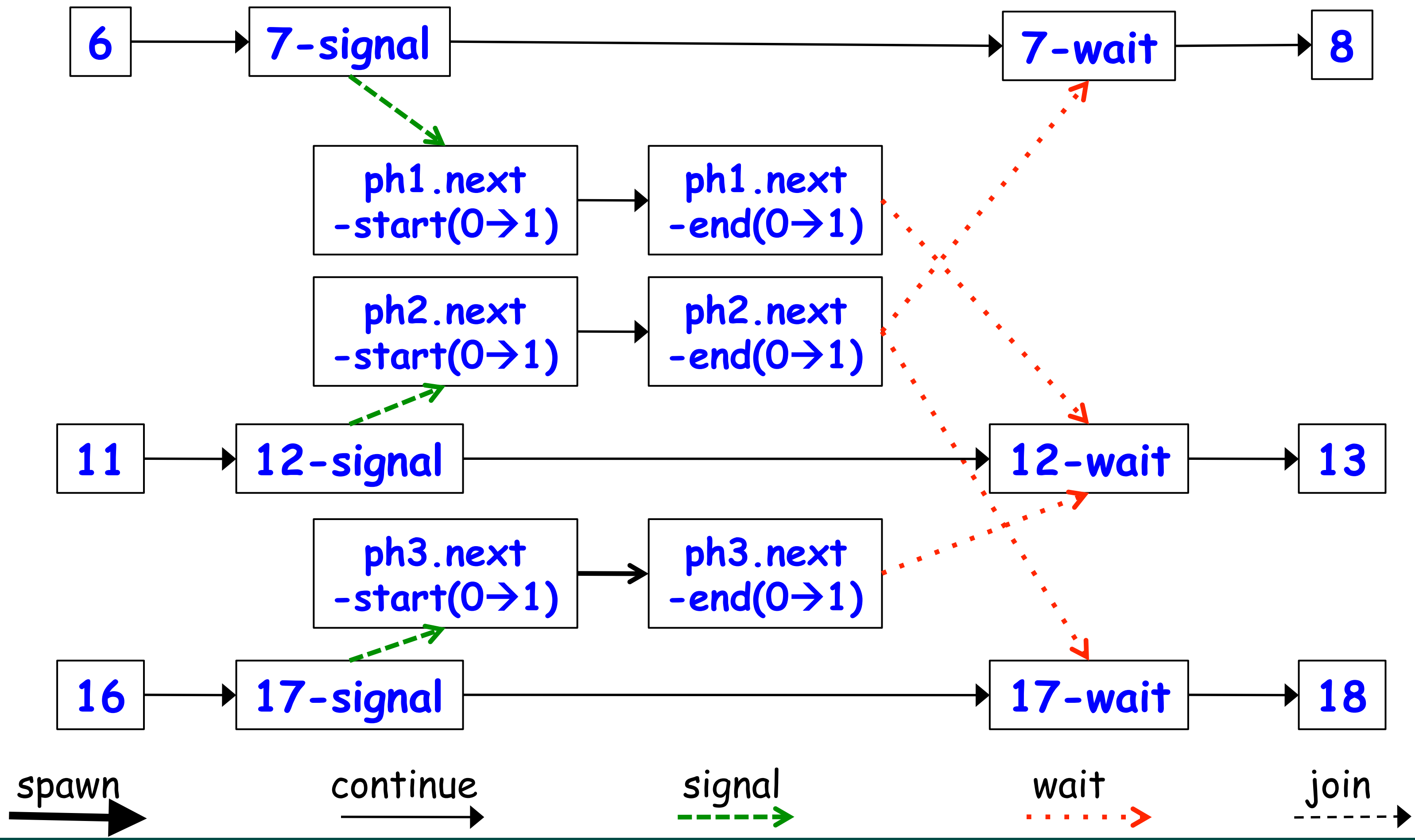
```
finish {
 phaser ph1 = new phaser(phaserMode.SIG_WAIT);
 phaser ph2 = new phaser(phaserMode.SIG_WAIT);
 phaser ph3 = new phaser(phaserMode.SIG_WAIT);
 async phased(ph1<phaserMode.SIG>, ph2<phaserMode.WAIT>)
 { doPhase1(1); // Task T1
   next; // Signals ph1, and waits on ph2
   doPhase2(1);
 }
 async phased(ph2<phaserMode.SIG>,ph1<phaserMode.WAIT>,ph3<phaserMode.WAIT>)
 { doPhase1(2); // Task T2
   next; // Signals ph2, and waits on ph1 and ph3
   doPhase2(2);
 }
 async phased(ph3<phaserMode.SIG>, ph2<phaserMode.WAIT>)
 { doPhase1(3); // Task T3
   next; // Signals ph3, and waits on ph2
   doPhase2(3);
 }
} // finish
```

Listing 1: Example of left-right neighbor synchronization for $m = 3$ case

Computation Graph for m=3 example



Computation Graph for m=3 example (without async/finish nodes and edges)



Translation of Barrier to Phaser Version

```
rank.count = 0; // rank object contains an int field, count
forall (point[i] : [0:m-1]) {
  // Start of phase 0
  int r;
  isolated {r = rank.count++;}
  System.out.println("Hello from task ranked " + r);
  next; // Acts as barrier between phases 0 and 1
  // Start of phase 1
  System.out.println("Goodbye from task ranked " + r);
}
```

Listing 2: Hello-Goodbye forall loop with barrier (next) statement

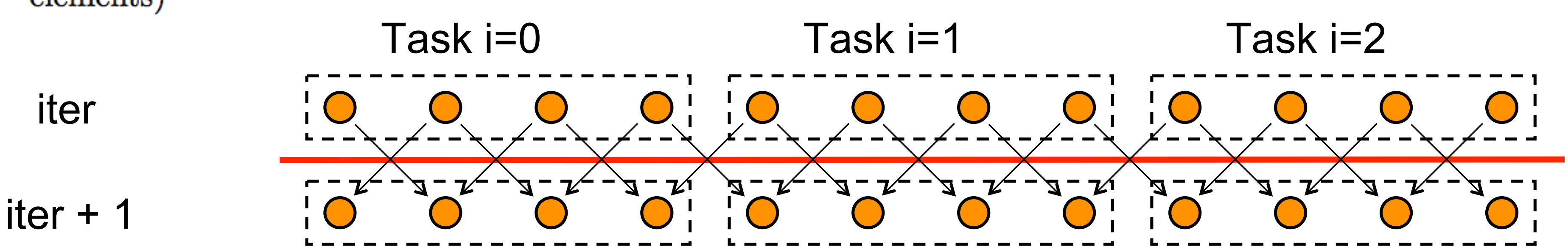
```
rank.count = 0; // rank object contains an int field, count
finish {
  phaser ph = new phaser(phaserMode.SIG_WAIT);
  for (point[i] : [0:m-1]) async phased {
    // Start of phase 0
    int r;
    isolated {r = rank.count++;}
    System.out.println("Hello from task ranked " + r);
    next; // Acts as barrier between phases 0 and 1
    // Start of phase 1
    System.out.println("Goodbye from task ranked " + r);
  } // for async phased
} // finish
```

Listing 3: Translation of Listing 2 to a finish-for-async-phased code structure (phaser version)

Optimized One-Dimensional Iterative Averaging with Barrier Synchronization

```
double[] val1 = new double[n]; val[0] = 0; val[n+1] = 1;
double[] val2 = new double[n];
int batchSize = CeilDiv(n,t); // Number of elements per task
forall (point [i] : [0:t-1]) { // Create t tasks
  double[] myVal = val1; double myNew = val2; double[] temp = null;
  int start=i*batchSize+1; int end=Math.min(start+batchSize-1,n);
  for (point [iter] : [0:iterations-1]) {
    for (point[j] : [start:end])
      myNew[j] = (myVal[j-1] + myVal[j+1])/2.0;
    next; // barrier
    temp = myNew; myNew = myVal; myVal = temp; // swap(myNew, myVal)
  } // for
} // forall
```

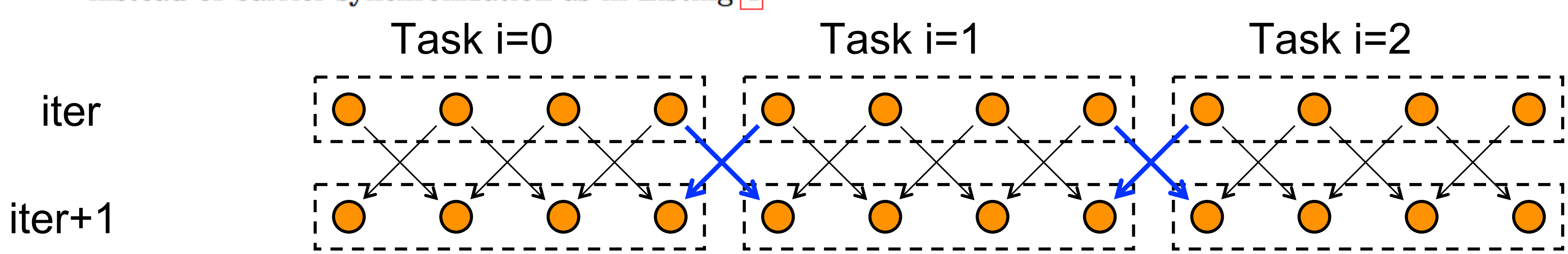
Listing 4: Optimized One-Dimensional Iterative Averaging Example using forall-for-next computation structure with t parallel tasks working on an array with $n + 2$ elements (each task processes a batch of array elements)



Optimized One-Dimensional Iterative Averaging with Point-to-Point Synchronization

```
double[] val1 = new double[n]; val[0] = 0; val[n+1] = 1;
double[] val2 = new double[n];
int batchSize = CeilDiv(n,t); // Number of elements per task
finish {
  phaser ph = new phaser[t+2];
  forall(point [i]:[0:t+1]) ph[i]=new phaser(phaserMode.SIG_WAIT);
  for (point [i] : [1:t])
    async phased(ph[i]<SIG>, ph[i-1]<WAIT>, ph[i+1]<WAIT>) {
      double[] myVal = val1; double myNew = val2; double[] temp = null;
      int start = (i-1)*batchSize + 1; int end = Math.min(start+batchSize-1,n);
      for (point [iter] : [0:iterations-1]) {
        for (point[j] : [start:end])
          myNew[j] = (myVal[j-1] + myVal[j+1])/2.0;
        next; // signal ph[i] and wait on ph[i-1] and ph[i+1]
        temp = myNew; myNew = myVal; myVal = temp; // swap(myNew, myVal)
      } // for
  } // for-async
} // finish
```

Listing 5: Optimized One-Dimensional Iterative Averaging Example using point-to-point synchronization, instead of barrier synchronization as in Listing 4



Signal statement

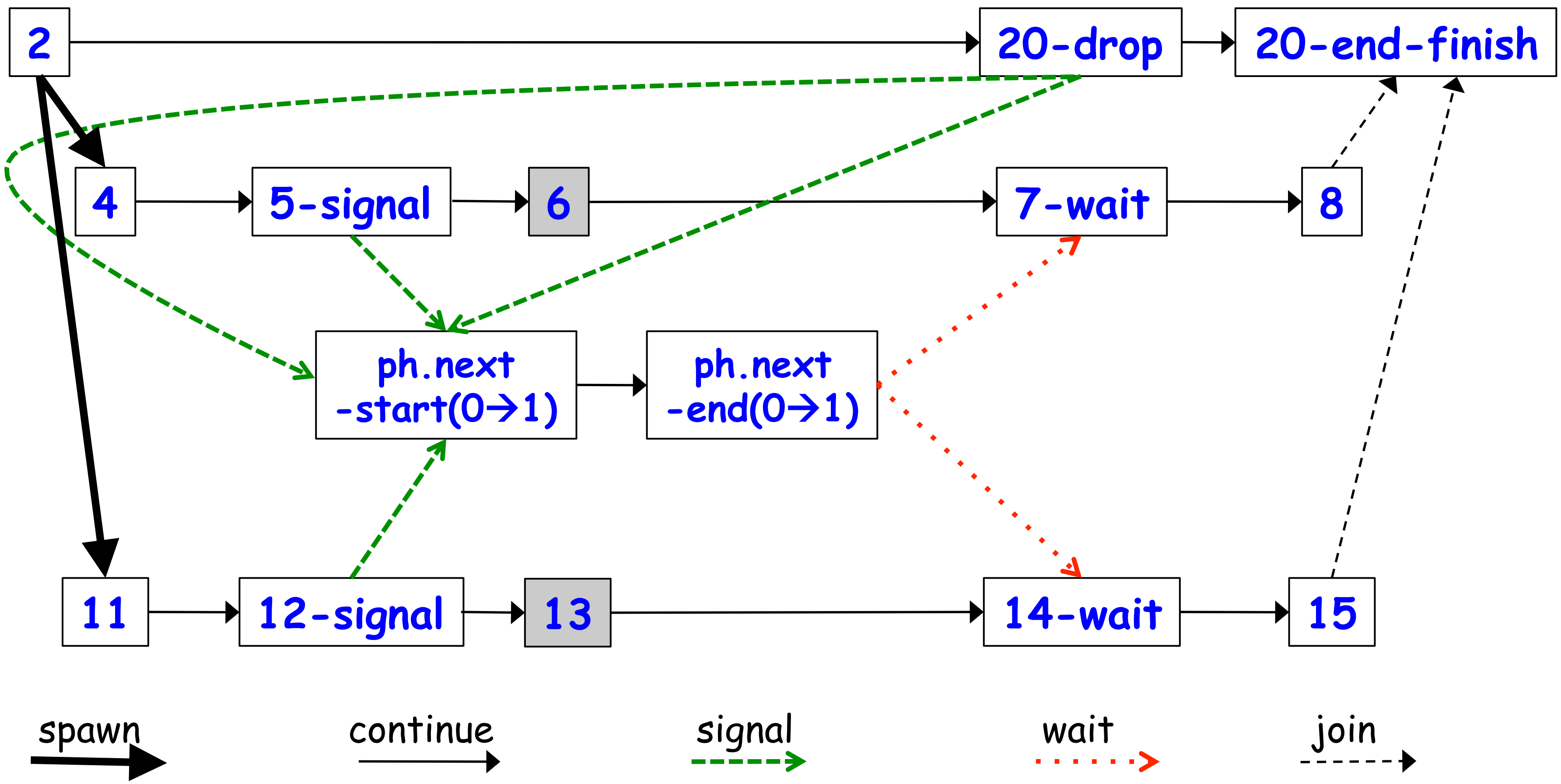
- When a task T performs a signal operation, it notifies all the phasers it is registered on that it has completed all the work expected by other tasks in the current phase ("shared" work).
  - Since signal is a non-blocking operation, an early execution of signal cannot create a deadlock.
- Later, when T performs a next operation, the next degenerates to a wait since a signal has already been performed in the current phase.
- The execution of "local work" between signal and next is performed during phase transition
  - Referred to as a "split-phase barrier" or "fuzzy barrier"

Example of Split-Phase Barrier

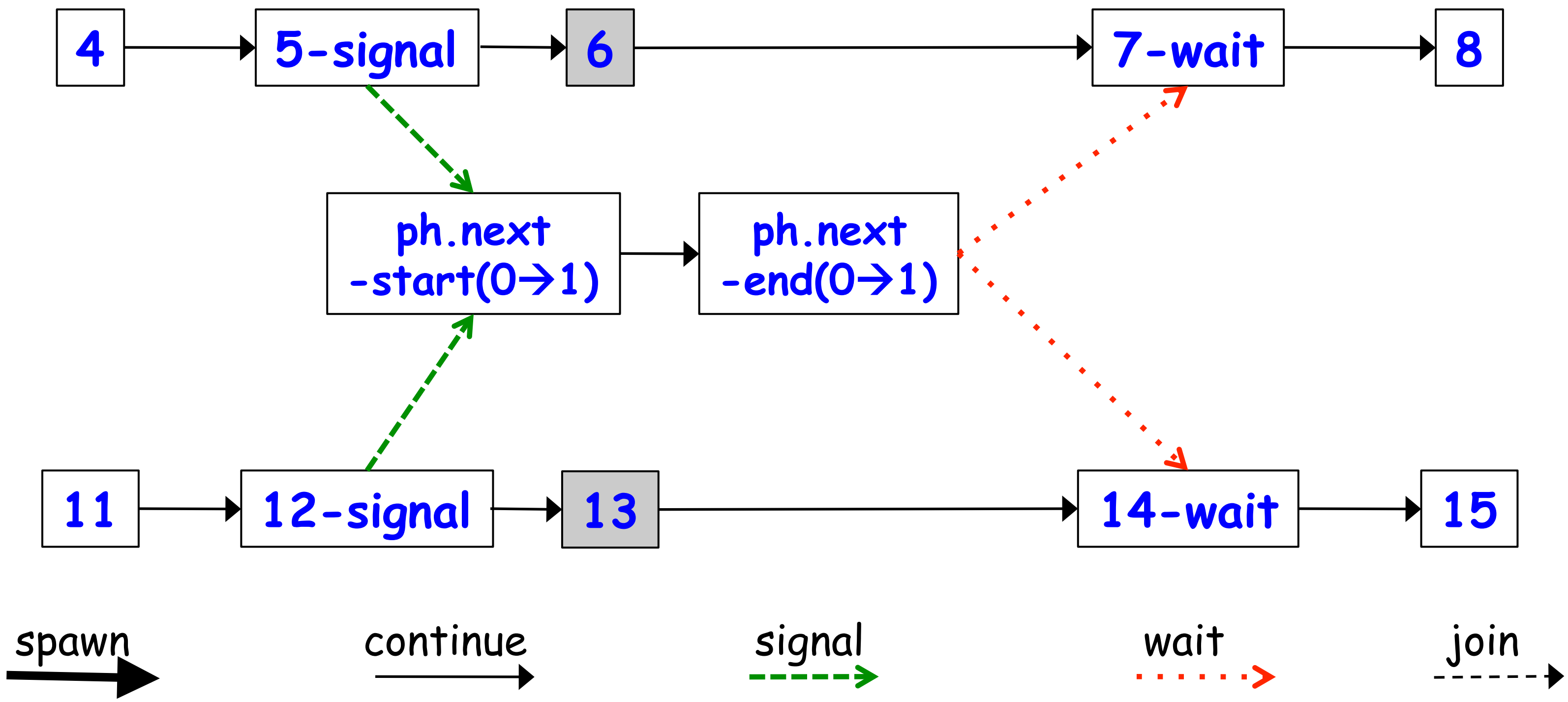
```
finish {
  phaser ph = new phaser(phaserMode.SIG_WAIT);
  async phased { // Task T1
    a = ... ;    // Shared work in phase 0
    signal;      // Signal completion of a's computation
    b = ... ;    // Local work in phase 0
    next;        // Barrier -- wait for T2 to compute x
    b = f(b,x); // Use x computed by T2 in phase 0
  }
  async phased { // Task T2
    x = ... ;    // Shared work in phase 0
    signal;      // Signal completion of x's computation
    y = ... ;    // Local work in phase 0
    next;        // Barrier -- wait for T1 to compute a
    y = f(y,a); // Use a computed by T1 in phase 0
  }
} // finish
```

Listing 6: Example of split-phase barrier

Computation Graph for Split-Phase Barrier Example



Computation Graph for Split-Phase Barrier Example (without async and finish nodes and edges)



Optimized One-Dimensional Iterative Averaging with Split-Phase Point-to-Point Synchronization

```
double[] val1 = new double[n]; val[0] = 0; val[n+1] = 1;
double[] val2 = new double[n];
int batchSize = CeilDiv(n,t); // Number of elements per task
finish {
  phaser ph = new phaser[t+2];
  forall(point [i]:[0:t+1]) ph[i]=new phaser(phaserMode.SIG_WAIT);
  for (point [i] : [1:t])
    async phased(ph[i]<SIG>, ph[i-1]<WAIT>, ph[i+1]<WAIT>) {
      double[] myVal = val1; double myNew = val2; double[] temp = null;
      int start=(i-1)*batchSize+1; int end=Math.min(start+batchSize-1,n);
      for (point [iter] : [0:iterations-1]) {
        myNew[start] = (myVal[start-1] + myVal[start+1])/2.0;
        myNew[end] = (myVal[end-1] + myVal[end+1])/2.0;
        signal; // signal ph[i]
        for (point[j] : [start+1:end-1])
          myNew[j] = (myVal[j-1] + myVal[j+1])/2.0;
        next; // wait on ph[i-1] and ph[i+1]
        temp = myNew; myNew = myVal; myVal = temp; // swap(myNew, myVal)
      } // for
  } // for-async
} // finish
```

Listing 7: Optimized One-Dimensional Iterative Averaging Example using signal statements for split-phase point-to-point synchronization