COMP 322: Fundamentals of Parallel Programming

Lecture 8: Finish, Async, Computation Graphs

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Homework #1 Hints

- sorted operation on streams results in ascending order. To sort in descending order, use sorted(Comparator.reverseOrder()).

- groupingBy, convert elements of stream into type you want by passing Collectors.mapping(map-function, downstream-collector) as an additional argument. For parallel streams use groupingByConcurrent.

```
Create a mapping between customer IDs and their order IDs whose status is "PENDING"
orderRepo.findAll().stream()
 .filter(order -> order.getStatus().equals("PENDING"))
 .collect(Collectors.groupingBy(order -> order.getCustomer().getId(), Collectors.mapping(
         Order::getId,
         Collectors.toSet()
 )));
```

Acknowledgement: Chase Hartsell

Async and Finish Statements for Task Creation and Termination

async S

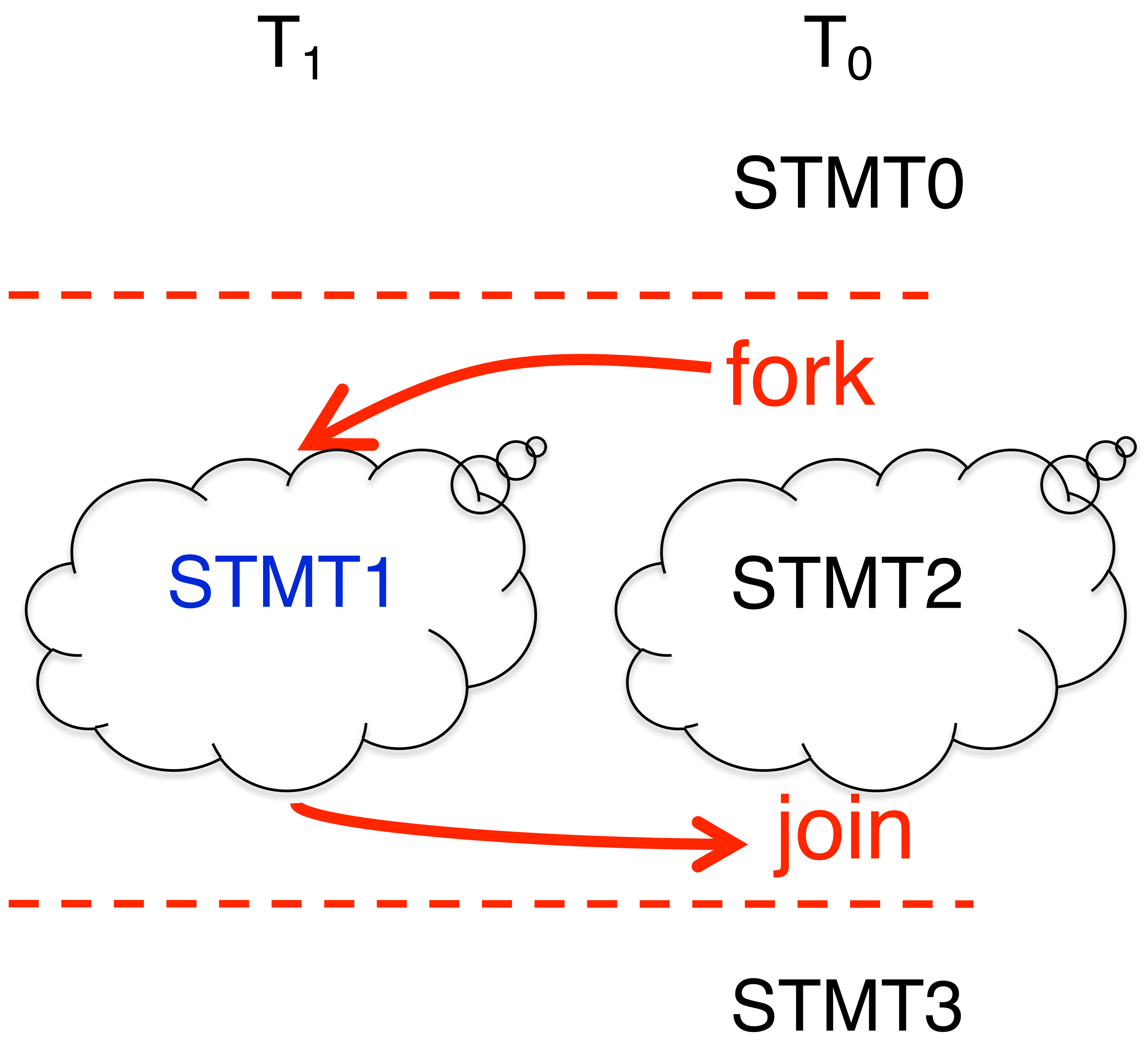
- Creates a new child task that executes statement S

```
// T0(Parent task)
STMT0;
finish {   //Begin finish
  async {
    STMT1; //T1(Child task)
  }
  STMT2;   //Continue in T0

}          //End finish (wait for T1)
STMT3;     //Continue in T0
```

finish S

- Execute S, but wait until *all* asyncs in S's scope have terminated.

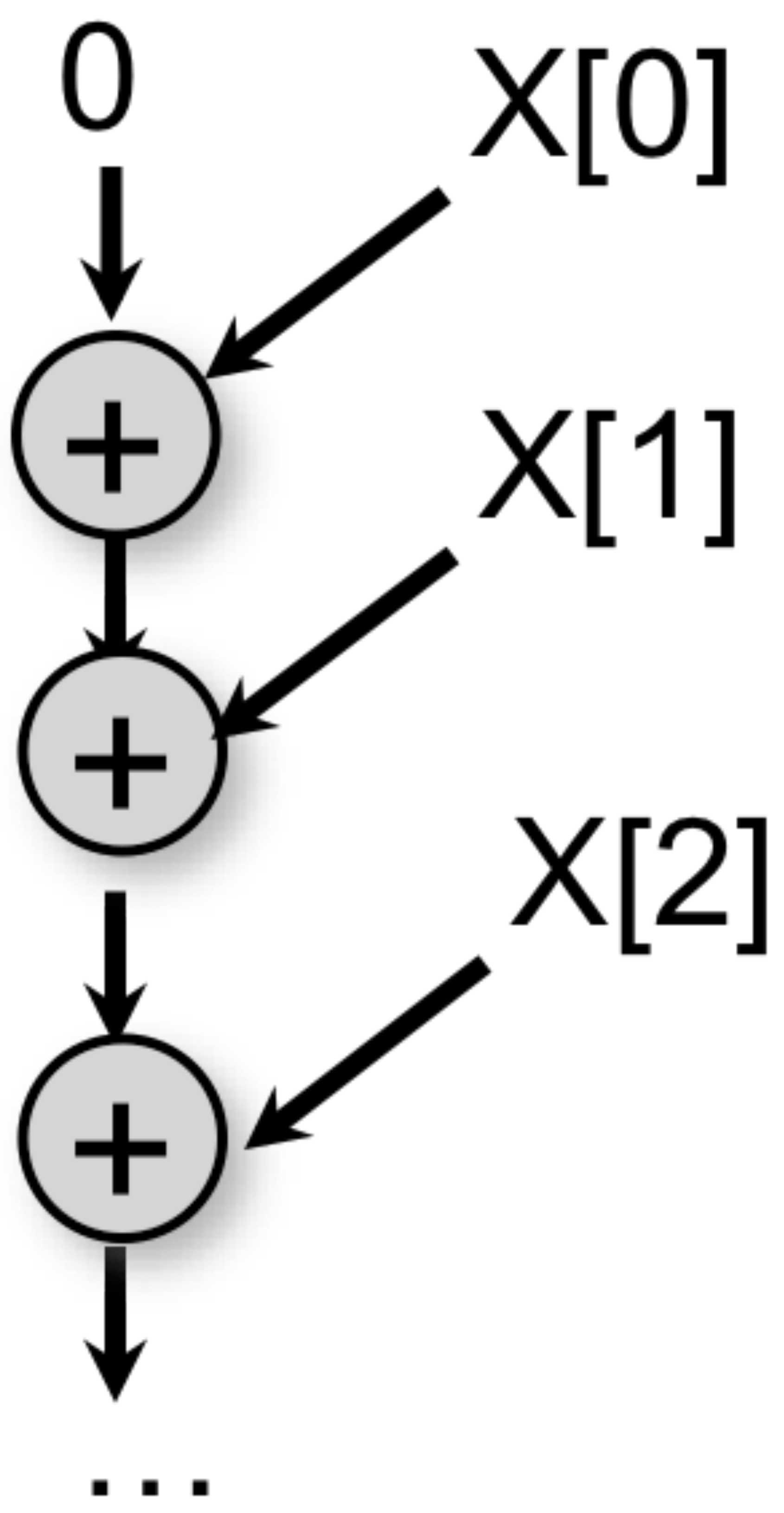


Example of a Sequential Program: Computing sum of array elements

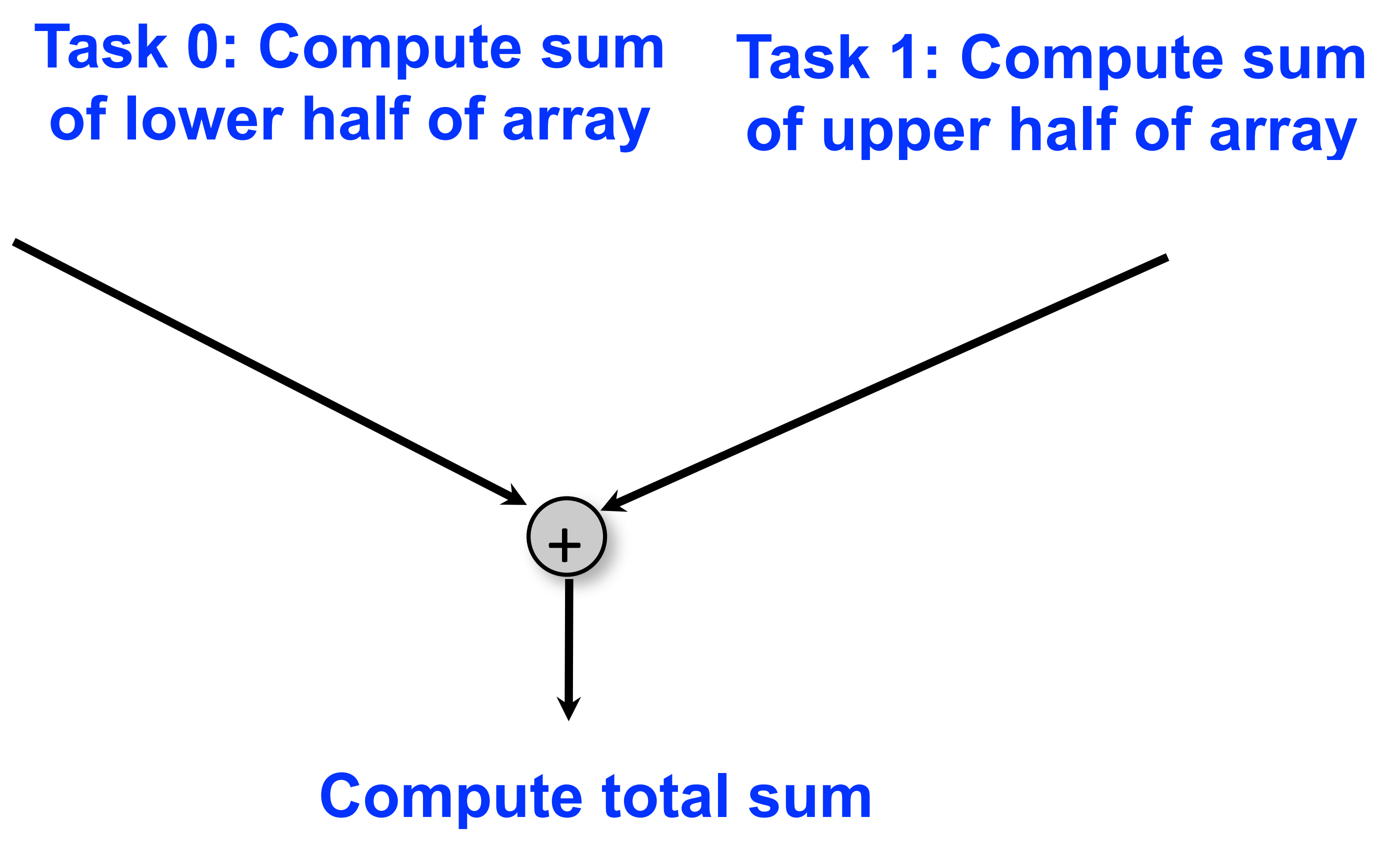
Algorithm 1: Sequential ArraySum

Input: Array of numbers, X.
Output: sum = sum of elements in array X.

$sum \leftarrow 0$;
for $i \leftarrow 0$ **to** $X.length - 1$ **do**
  $sum \leftarrow sum + X[i]$;
return sum;



Parallelization Strategy for 2 cores (Two-way Parallel Array Sum)



Basic idea:

- Decompose problem into two tasks for partial sums
- Combine results to obtain final answer
- Parallel divide-and-conquer pattern

Two-way Parallel Array Sum using async & finish constructs

Algorithm 2: Two-way Parallel ArraySum

Input: Array of numbers, X.
Output: sum = sum of elements in array X.

```
// Start of Task T1 (main program)
sum1 ← 0; sum2 ← 0;
// Compute sum1 (lower half) and sum2 (upper half) in parallel.
finish{
    async{
        // Task T2
        for i ← 0 to X.length/2 − 1 do
            sum1 ← sum1 + X[i];
    };
    async{
        // Task T3
        for i ← X.length/2 to X.length − 1 do
            sum2 ← sum2 + X[i];
    };
};
// Task T1 waits for Tasks T2 and T3 to complete
// Continuation of Task T1
sum ← sum1 + sum2;
return sum;
```

Two-way Parallel Array Sum using async & finish constructs

Algorithm 2: Two-way Parallel ArraySum

Input: Array of numbers, X.
Output: sum = sum of elements in array X.

```
// Start of Task T1 (main program)
sum1 ← 0; sum2 ← 0;
// Compute sum1 (lower half) and sum2 (upper half) in parallel.
finish{
    async{
        // Task T2
        for i ← 0 to X.length/2 − 1 do
            sum1 ← sum1 + X[i];
    };
    async{
        // Task T3
        for i ← X.length/2 to X.length − 1 do
            sum2 ← sum2 + X[i];
    };
};
```

…more work…

```
sum ← sum1 + sum2;
return sum;
```

Two-way Parallel Array Sum using futures

```
// Parent Task T1 (main program)
// Compute sum1 (lower half) & sum2 (upper half) in parallel
var sum1 = future(() -> { // Future Task T2
    int sum = 0;
    for (int i = 0; i < X.length / 2; i++) sum += X[i];
    return sum;
});
var sum2 = future(() -> { // Future Task T3
    int sum = 0;
    for (int i = X.length / 2; i < X.length; i++) sum += X[i];
    return sum;
});
…more work…
int total = sum1.get() + sum2.get();
```

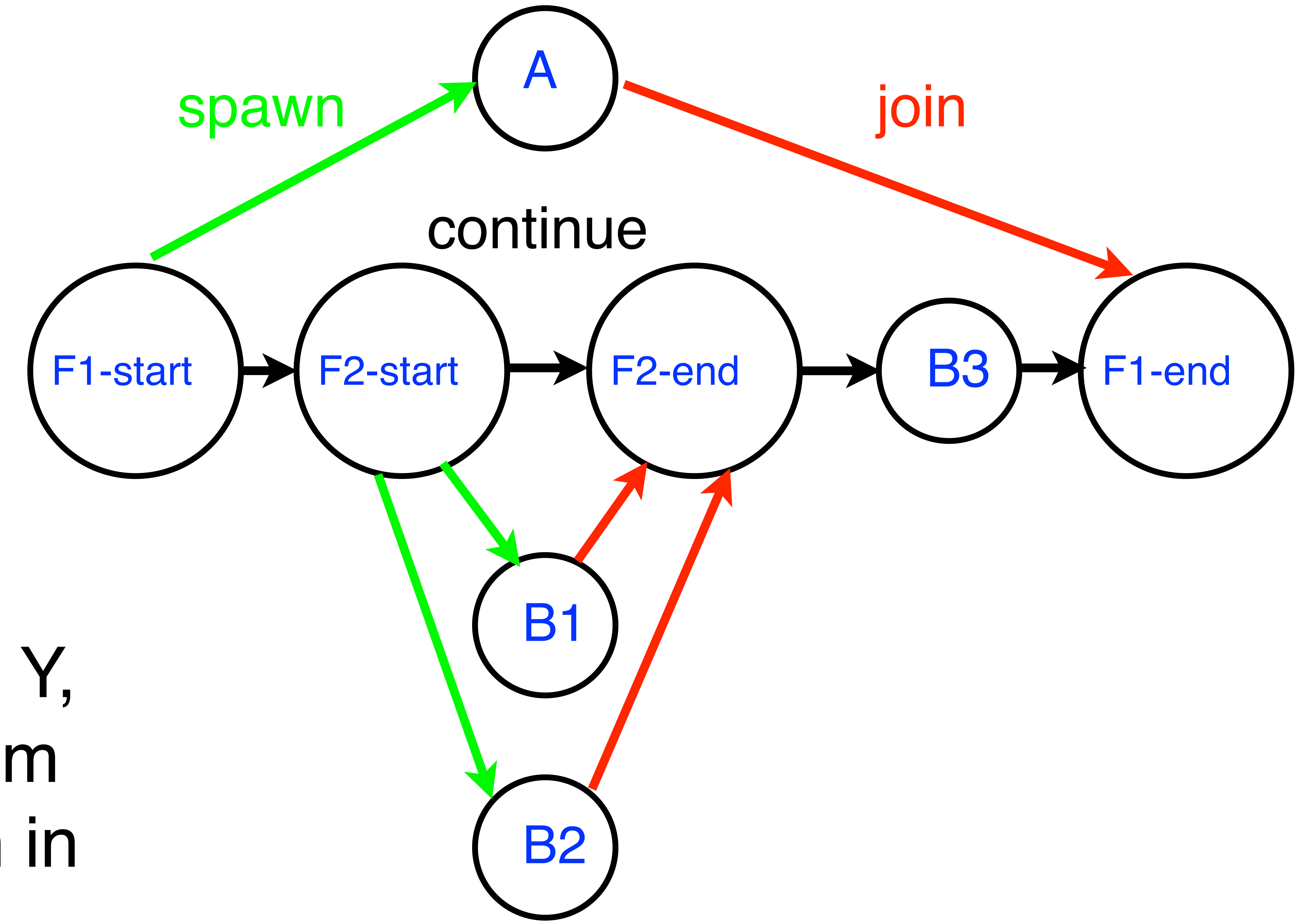
Computation Graphs

- A Computation Graph (CG) captures the dynamic execution of a parallel program, for a specific input
- CG nodes are "steps" in the program's execution
  - A step is a sequential subcomputation without any spawned, begin-finish or end-finish operations
- CG edges represent ordering constraints
  - "Continue" edges define sequencing of steps within a task
  - "Spawn" edges connect parent tasks to child spawned tasks
  - "Join" edges connect the end of each spawned task to its IEF's end-must finish operations
- All computation graphs must be acyclic
  - It is not possible for a node to depend on itself
- Computation graphs are examples of "directed acyclic graphs" (DAGs)

Which statements can potentially be executed in parallel with each other?

```
1. finish { // F1
2.     async { A; }
3.     finish { // F2
4.         async { B1; }
5.         async { B2; }
6.     } // F2
7.     B3;
8. } // F1
```

Computation Graph



Key idea: If two statements, X and Y, have *no path of directed edges* from one to the other, then they can run in parallel with each other.

Parallelize Tasks

Assume you have 2 washers and 2 dryers. Assume there's 0 cost to spawn a task.

Place "finish" and "async" blocks around the following tasks:

1. Run load 1 in washer (LW1)
2. Run load 2 in washer (LW2)
3. Run load 1 in dryer (LD1)
4. Run load 2 in dryer (LD2)

Parallelize Tasks (Solution #1)

Assume you have 2 washers and 2 dryers. Assume there's 0 cost to spawn a task.

Place "finish" and "async" blocks around the following tasks:

1. finish { // F1
2. async { Run load 1 in washer (LW1) }
3. async { Run load 2 in washer (LW2) }
4. } // F1
5. async { Run load 1 in dryer (LD1) }
6. async { Run load 2 in dryer (LD2) }

Parallelize Tasks (Solution #2)

Assume you have 2 washers and 2 dryers. Assume there's 0 cost to spawn a task.

Place "finish" and "async" blocks around the following tasks:

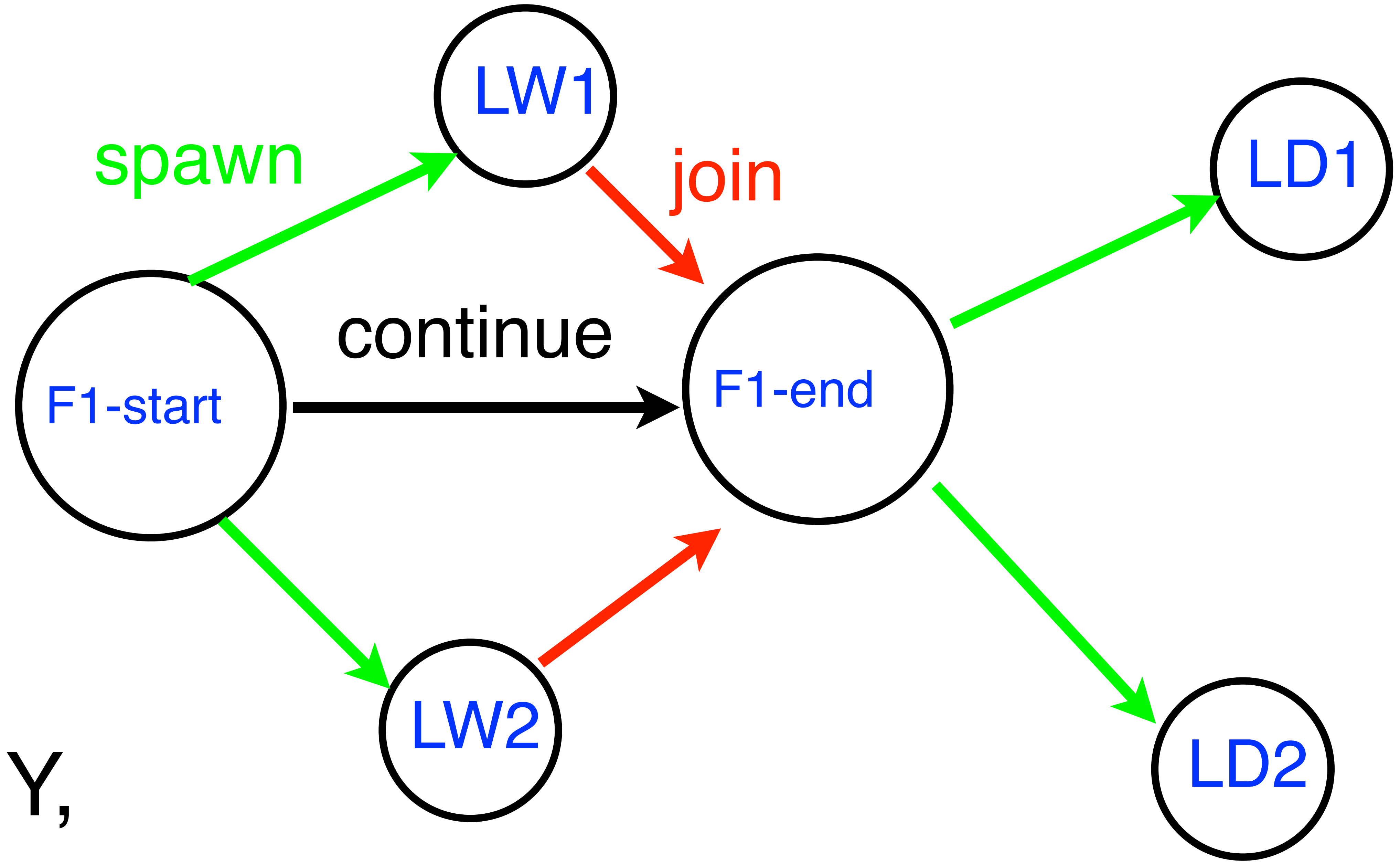
1. finish { // F1
2.   async { Run load 1 in washer (LW1); Run load 1 in dryer (LD1) }
3.   async { Run load 2 in washer (LW2); Run load 2 in dryer (LD2) }
4. } // F1

Draw Computation Graph for Solution

Draw Computation Graph for Solution #1

```
1. finish { // F1
2.     async LW1;
3.     async LW2;
4.} // F1
5. async LD1;
6. async LD2;
```

Computation Graph

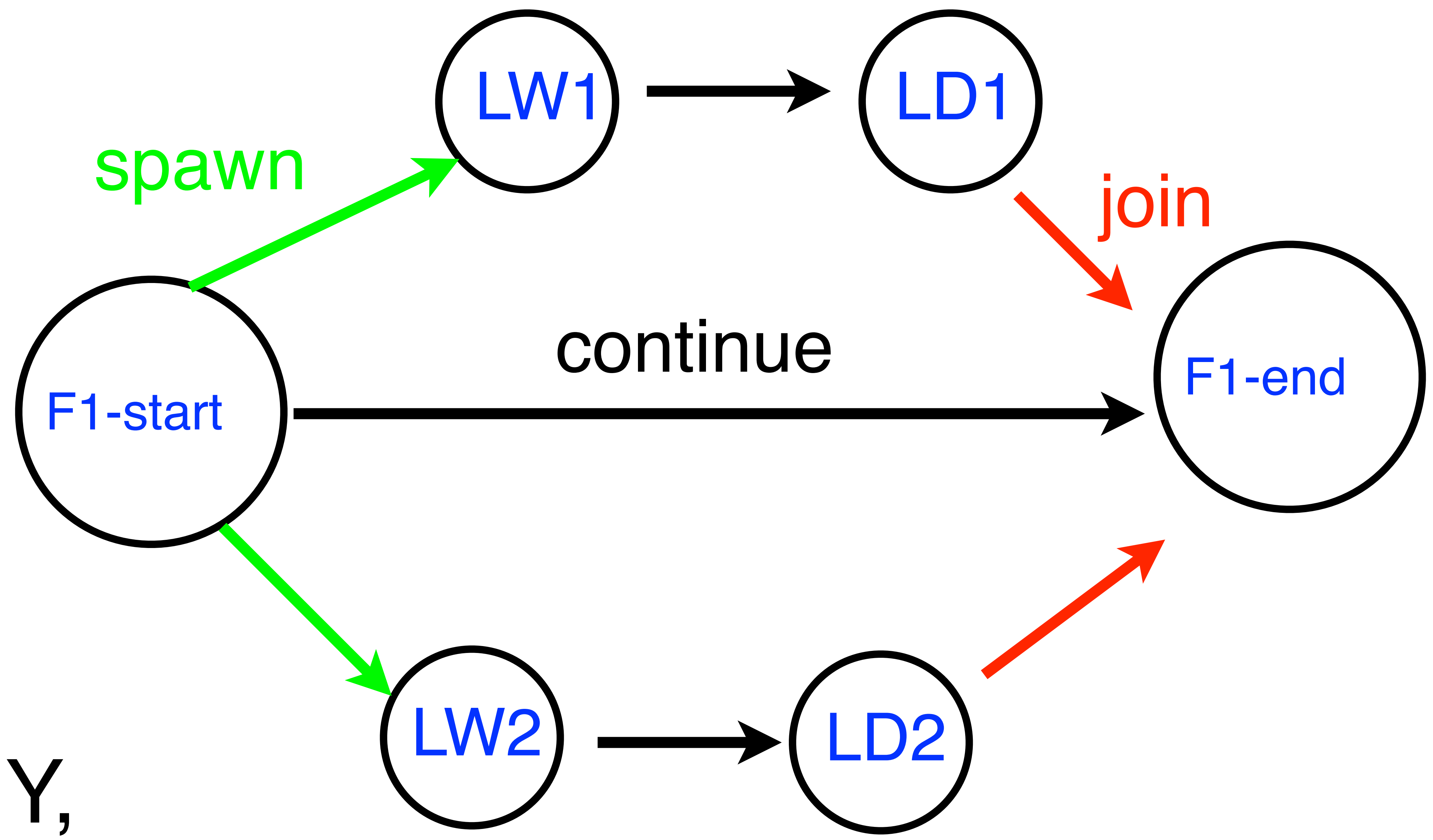


<u>Key idea</u>: If two statements, X and Y, have *no path of directed edges* from one to the other, then they can run in parallel with each other.

Draw Computation Graph for Solution #2

1. finish { // F1
2. async { LW1; LD1 }
3. async { LW2; LD2 }
4. } // F1

Computation Graph



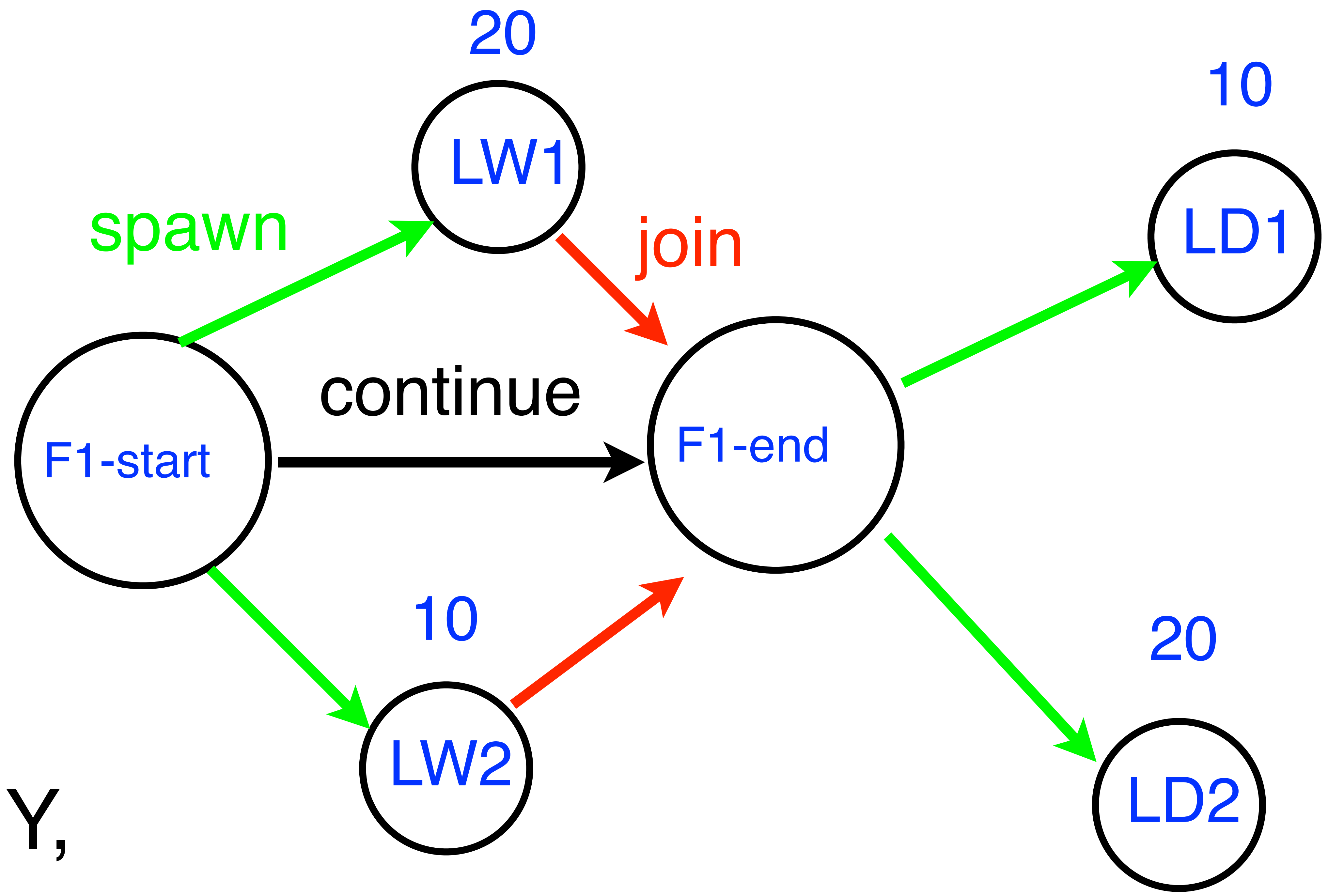
Key idea: If two statements, X and Y, have *no path of directed edges* from one to the other, then they can run in parallel with each other.

Which solution is better?

Draw Computation Graph for Solution #1

```
1. finish { // F1
2.     async LW1;
3.     async LW2;
4.} // F1
5. async LD1;
6. async LD2;
```

Computation Graph

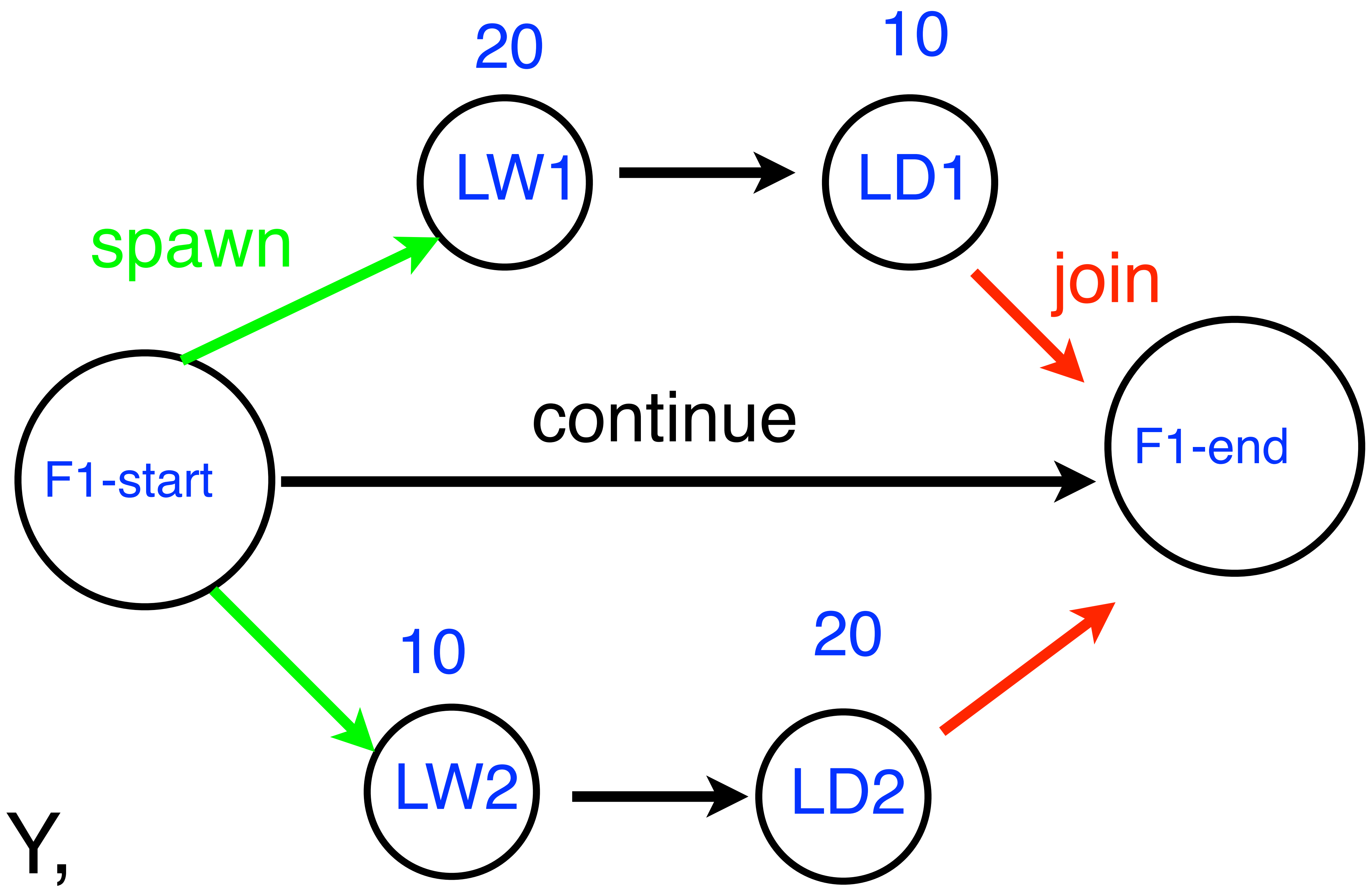


<u>Key idea</u>: If two statements, X and Y, have *no path of directed edges* from one to the other, then they can run in parallel with each other.

Draw Computation Graph for Solution #2

```
1. finish { // F1
2.     async { LW1; LD1 }
3.     async { LW2; LD2 }
4.} // F1
```

Computation Graph



<u>Key idea</u>: If two statements, X and Y, have *no path of directed edges* from one to the other, then they can run in parallel with each other.

Announcements & Reminders

- IMPORTANT:
  - —Watch videos for topics 1.3, 4.5 for next lecture
- HW 1 is due on Wednesday, Jan 31st
- Quiz 2 is due on Monday, Feb 5th
- Module 1 handout is available
- See course web site for syllabus, work assignments, due dates, …
  - http://comp322.rice.edu