COMP 322: Fundamentals of Parallel Programming

Lecture 2: Async-Finish Parallel Programming and Computation Graphs

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https://wiki.rice.edu/confluence/display/PARPROG/COMP322

Acknowledgments for Today's Lecture

- Cilk lectures, http://supertech.csail.mit.edu/cilk/
- PrimeSieve.java example
  - http://introcs.cs.princeton.edu/java/14array/PrimeSieve.java.html

Goals for Today's Lecture

- Discussion of Async and Finish constructs
- Understanding when two statements can run in parallel
- Understanding limits to ideal parallelism (critical path length)

Async and Finish Statements for Task Creation and Termination (Recap)

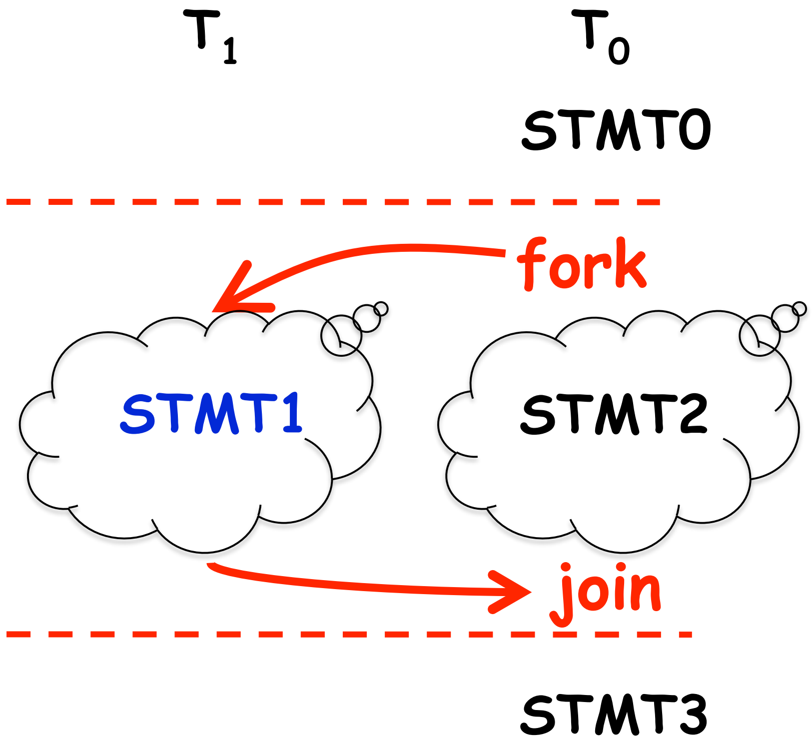
async S

- Creates a new child task that executes statement S

finish S

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

```
// T0(Parent task)
STMT0;
finish {     //Begin finish
  async {
    STMT1; //T1(Child task)
  }
  STMT2;     //Continue in T0
             //Wait for T1
}            //End finish
STMT3;       //Continue in T0
```



Some Properties of Async & Finish constructs

1. Scope of async/finish can be any arbitrary statement
   - async/finish constructs can be arbitrarily nested e.g.,
   - `finish { async S1; finish { async S2; S3; } S4; } S5;`
2. A method may return before all its async's have terminated
   - Enclose method body in a finish if you don't want this to happen
   - main() method is enclosed in an implicit finish e.g.,
   - `main(){ foo();}  void foo() {async S1; S2; return;}`
3. Each dynamic async task will have a unique Immediately Enclosing Finish (IEF) at runtime
4. Async/finish constructs cannot "deadlock"
   - Cannot have a situation where both task A waits for task B to finish, and task B waits for task A to finish
5. Async tasks can read/write shared data via objects and arrays
   - Local variables have special restrictions (next slide)

Local Variables

Three rules for accessing local variables across tasks in HJ:

1) *An async may read the value of any final outer local var*

```
final int i1 = 1; async { ... = i1; /* i1=1 */ }
```

2) *An async may read the value of any non-final outer local var (copied on entry to async like method parameters)*

```
int i2 = 2; // i2=2 is  copied on entry to the async
async { ... = i2; /* i2=2*/}
i2 = 3; // This assignment is not seen by the above async
```

3) *An async is not permitted to modify an outer local var*

```
int[] A; async { A = ...; /*ERROR*/  A[i] = ...; /*OK*/ }
```

Converting sequential Java programs to parallel Async-Finish HJ programs

One possible approach:

1. Create "ideal" parallel version

— Insert async's at all points where parallelism can logically be exploited

— Insert finish's to ensure that the parallel version produces the same results as the sequential version

2. Transform ideal parallelism to useful parallelism

— Merge or remove async's to amortize overhead

— Replace finish by more efficient synchronization constructs (to be covered later in course)

Java Example: Sieve of Eratosthenes

```
1.  // initially assume all integers are prime
2.  boolean[] isPrime = new boolean[N + 1];
3.  for (int i = 2; i <= N; i++) isPrime[i] = true;
4.  // mark non-primes <= N using Sieve of Eratosthenes
5.  for (int i = 2; i*i <= N; i++)
6.    // if i is prime, then mark multiples of i as nonprime
7.    if (isPrime[i])
8.        for (int j = i; i*j <= N; j++)
9.            isPrime[i*j] = false;
10.  // count primes
11. int primes = 0;
12. for (int i = 2; i <= N; i++) if (isPrime[i]) primes++;
```

How should we parallelize the sieve computation in lines 5-9?

Ideal Parallelization of Sieve Computation

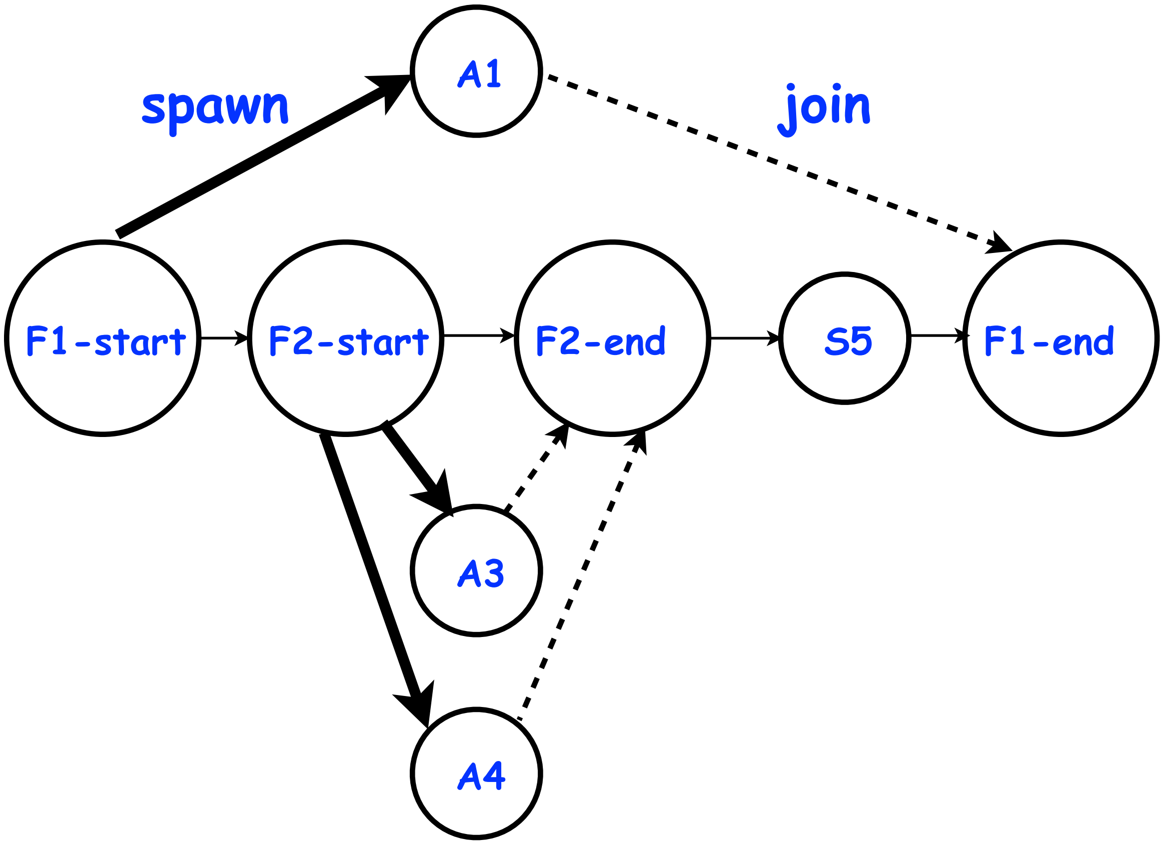
```
// initially assume all integers are prime
boolean[] isPrime = new boolean[N + 1];
for (int i = 2; i <= N; i++) isPrime[i] = true;
// mark non-primes <= N using Sieve of Eratosthenes
for (int i = 2; i*i <= N; i++)
  // if i is prime, then mark multiples of i as nonprime
  if (isPrime[i])
      finish for (int j = i; i*j <= N; j++)
          async isPrime[i*j] = false;
// count primes
int primes = 0;
for (int i = 2; i <= N; i++) if (isPrime[i]) primes++;
```

Is this approach correct? Is it efficient?

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

```
finish { // F1
  async A1;
    finish { // F2
      async A3;
      async A4;
    } // F2
  S5;
} // F1
```

Computation Graph



Computation Graphs for HJ Programs

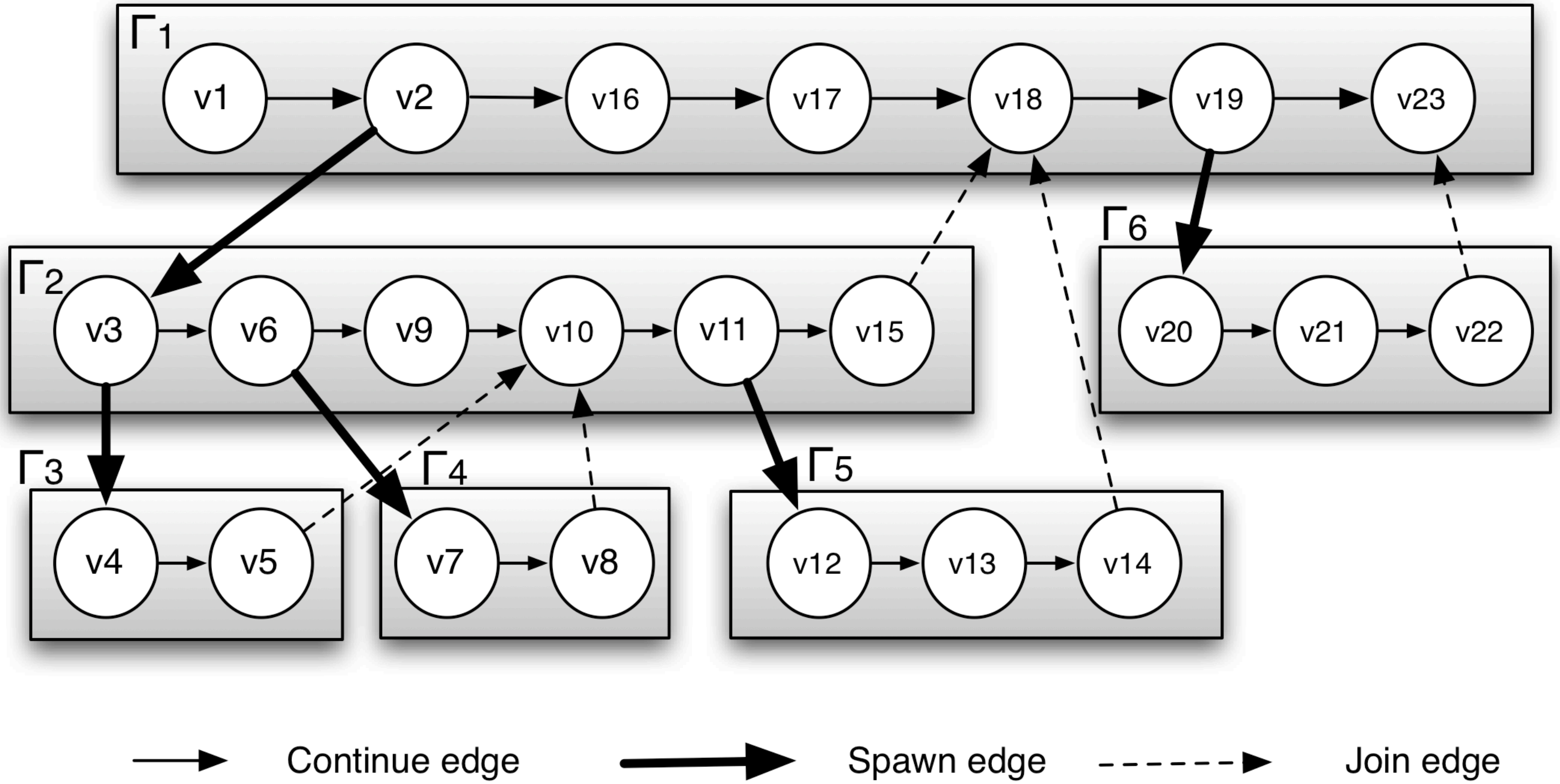
- A Computation Graph (CG) captures the dynamic execution of an HJ program, for a specific input
- CG nodes are "steps" in the program's execution
  - A step is a sequential subcomputation without any async, begin-finish and end-finish operations
- CG edges represent ordering constraints
  - "Continue" edges define sequencing of steps within a task
  - "Spawn" edges connect parent tasks to child async tasks
  - "Join" edges connect the end of each async task to its IEF's end-finish operations

Example HJ Program with statements v1 … v23

```
// Task T1
v1; v2;
finish {
  async {
    // Task T2
    v3;
    finish {
      async { v4; v5; } // Task T3
      v6;
      async { v7; v8; } // Task T4
      v9;
    } // finish
    v10; v11;
```

```
// Task T2 (contd)
    async { v12; v13;
            v14; } // Task T5
    v15;
  } // end of task T2
  v16; v17; // back in Task T1
} // finish
v18; v19;
finish {
  async {
    // Task T6
    v20; v21; v22; }
}
v23;
```

Computation Graph for previous HJ Example



Example: Step v16 can potentially execute in parallel with steps v3 … v15

Complexity Measures for Computation Graphs

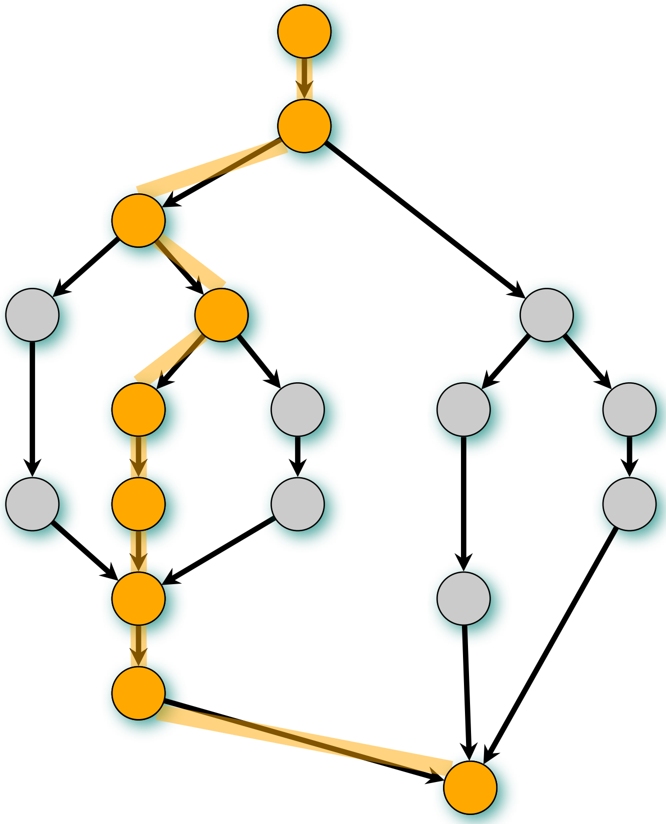
Define

- TIME(N) = execution time of node N
- WORK(G) = sum of TIME(N), for all nodes N in CG G
  - WORK(G) is the total work to be performed in G
- CPL(G) = length of a longest path in CG G, when adding up execution times of all nodes in the path
  - Such paths are called critical paths
  - CPL(G) is the length of these paths (critical path length)

Ideal Speedup

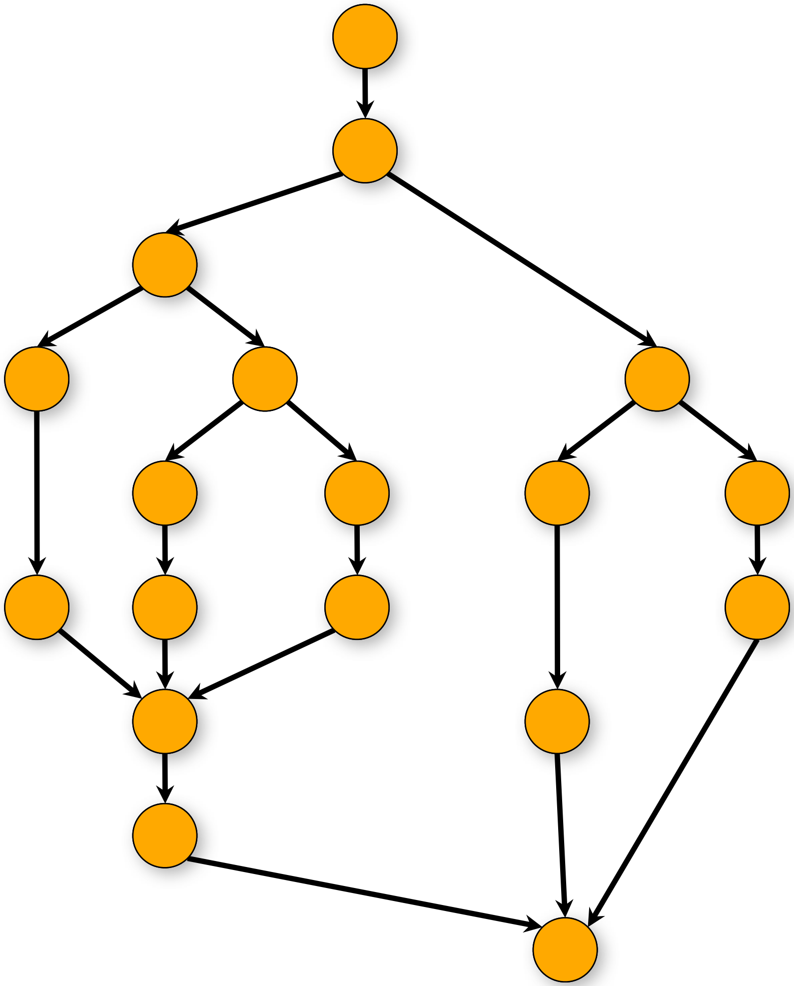
Define ideal speedup of Computation G Graph as the ratio, WORK(G)/CPL(G)

Ideal Speedup is independent of the number of processors that the program executes on, and only depends on the computation graph



Example

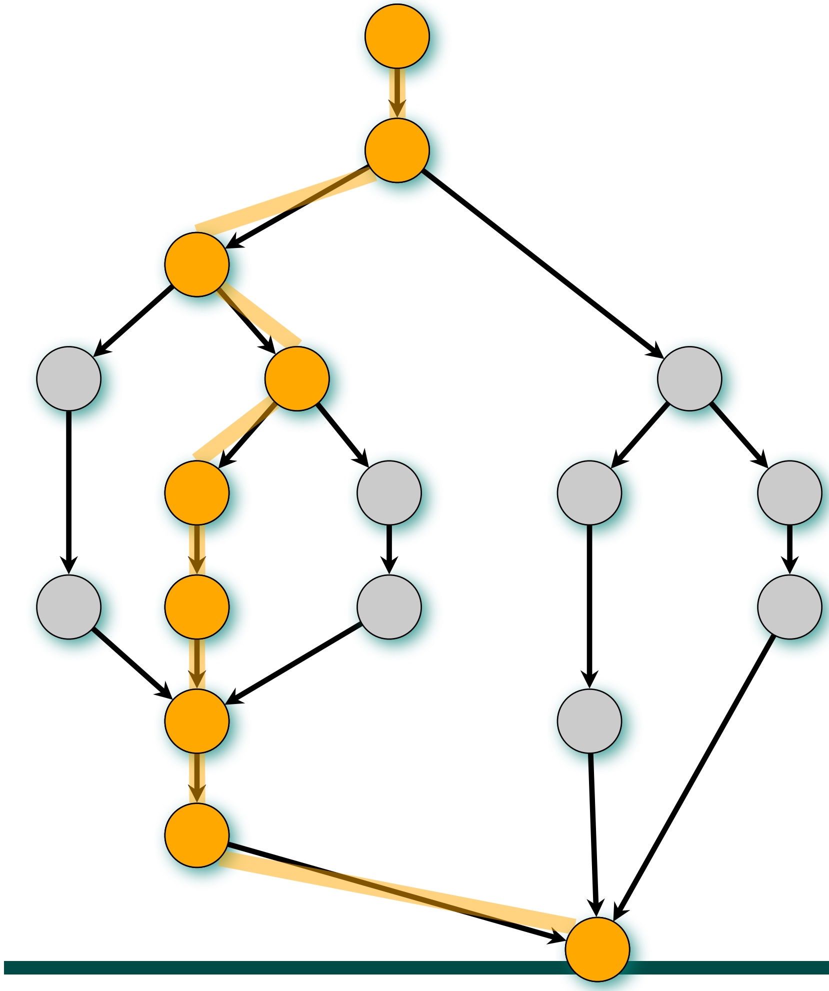
- Assume time(N) = 1 for all nodes in this graph



WORK(G) = 18

Example (contd)

- Assume time(N) = 1 for all nodes in this graph



CPL(G) = 9

Ideal speedup

= WORK(G)/CPL(G)

= 2

Homework 1 Reminder

- Written assignment, due by Friday, Jan 13th
- Submit a softcopy of your solution in Word, PDF, or plain text format
  - Try and use turn-in script for submission, if possible
  - Otherwise, email your homework to comp322-staff at mailman.rice.edu
- See course web site for penalties for late submissions
  - Send me email if you have an extenuating circumstance for delay