COMP 322: Fundamentals of Parallel Programming

Lecture 3: Computation Graphs, Ideal Parallelism

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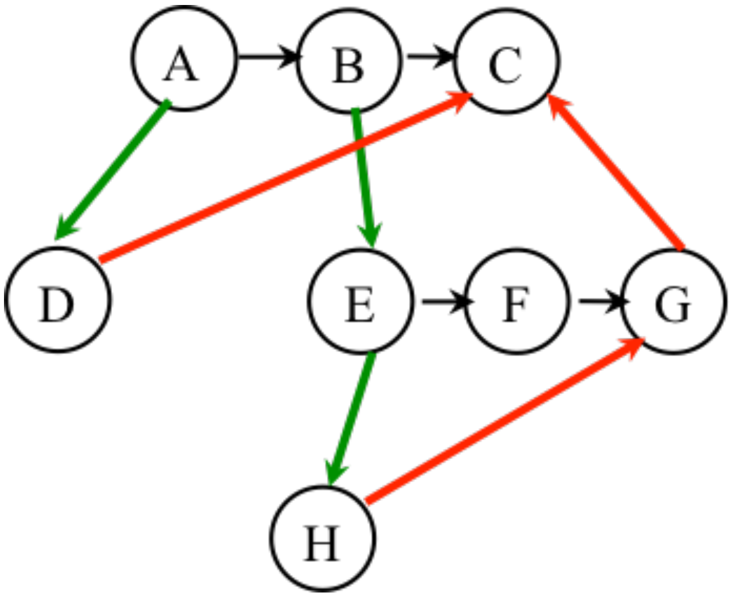
One Possible Solution to Worksheet 2 (Reverse Engineering a Computation Graph)



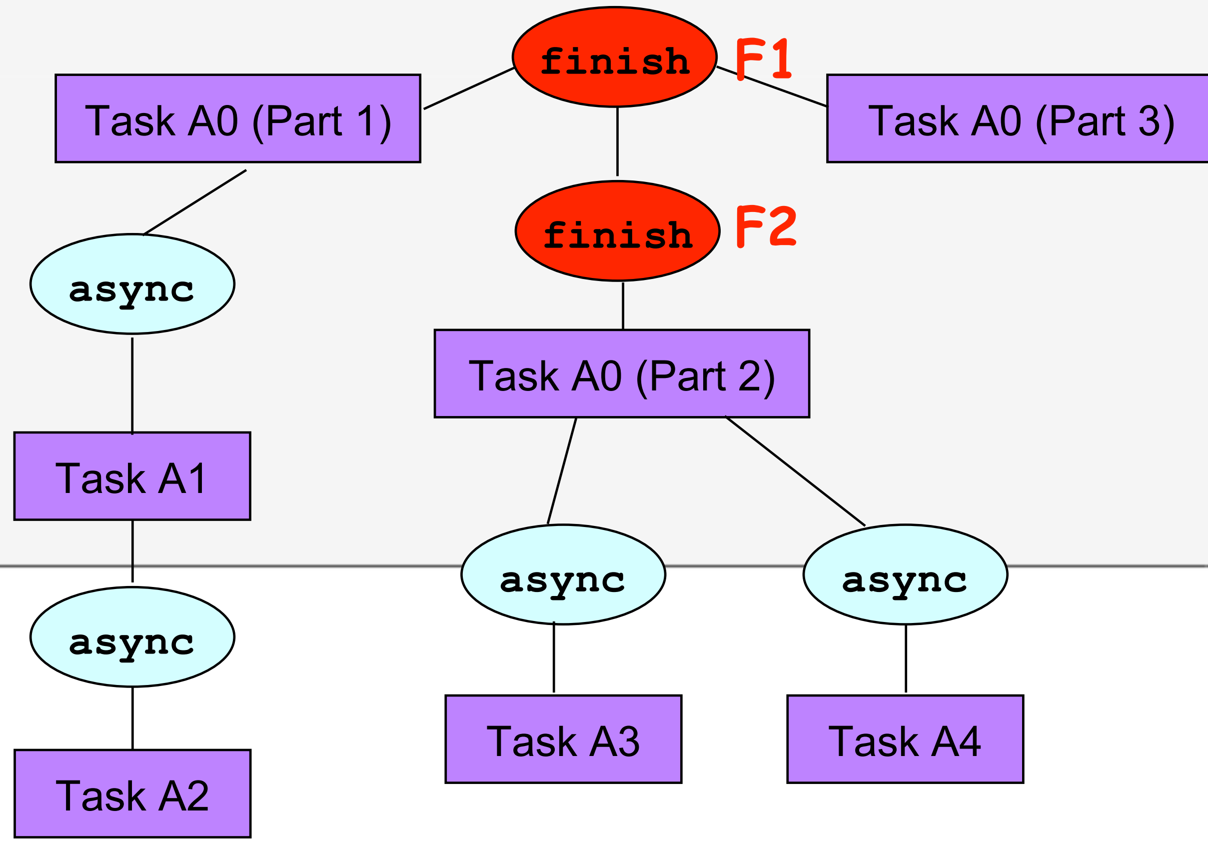

```
A();
finish { // F1
  async D();
  B();
  async {
    E();
    finish { // F2
      async H();
      F();
    } // F2
    G();
  }
} // F1
C();
```

Observations:

- Any node with out-degree > 1 must be an async (must have an outgoing spawn edge)
- Any node with in-degree > 1 must be an end-finish (must have an incoming join edge
- Adding or removing transitive edges does not impact ordering constraints

Dynamic Finish-Async nesting structure and Immediately Enclosing Finish (IEF)

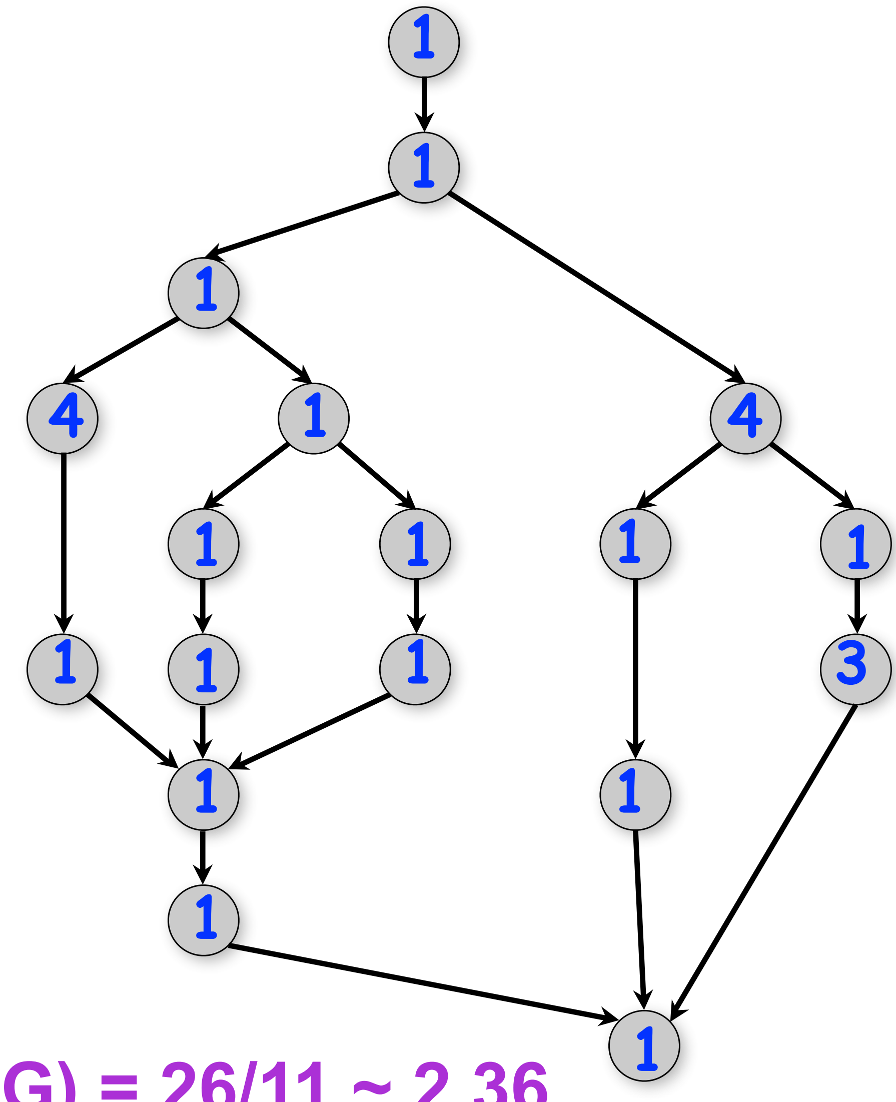
```
finish { // F1
  // Part 1 of Task A0
  async {A1; async A2;}
  finish { // F2
    // Part 2 of Task A0
    async A3;
    async A4;
  }
  // Part 3 of Task A0
}
```



- IEF(A3) = IEF(A4) = F2
- IEF(A1) = IEF(A2) = F1
- Module 1 handout: Listing 4 & Figure 6 (Section 1.1)

Ideal Parallelism (Recap)

- Define ideal parallelism of Computation G Graph as the ratio, WORK(G)/CPL(G)
- Ideal Parallelism is independent of the number of processors that the program executes on, and only depends on the computation graph



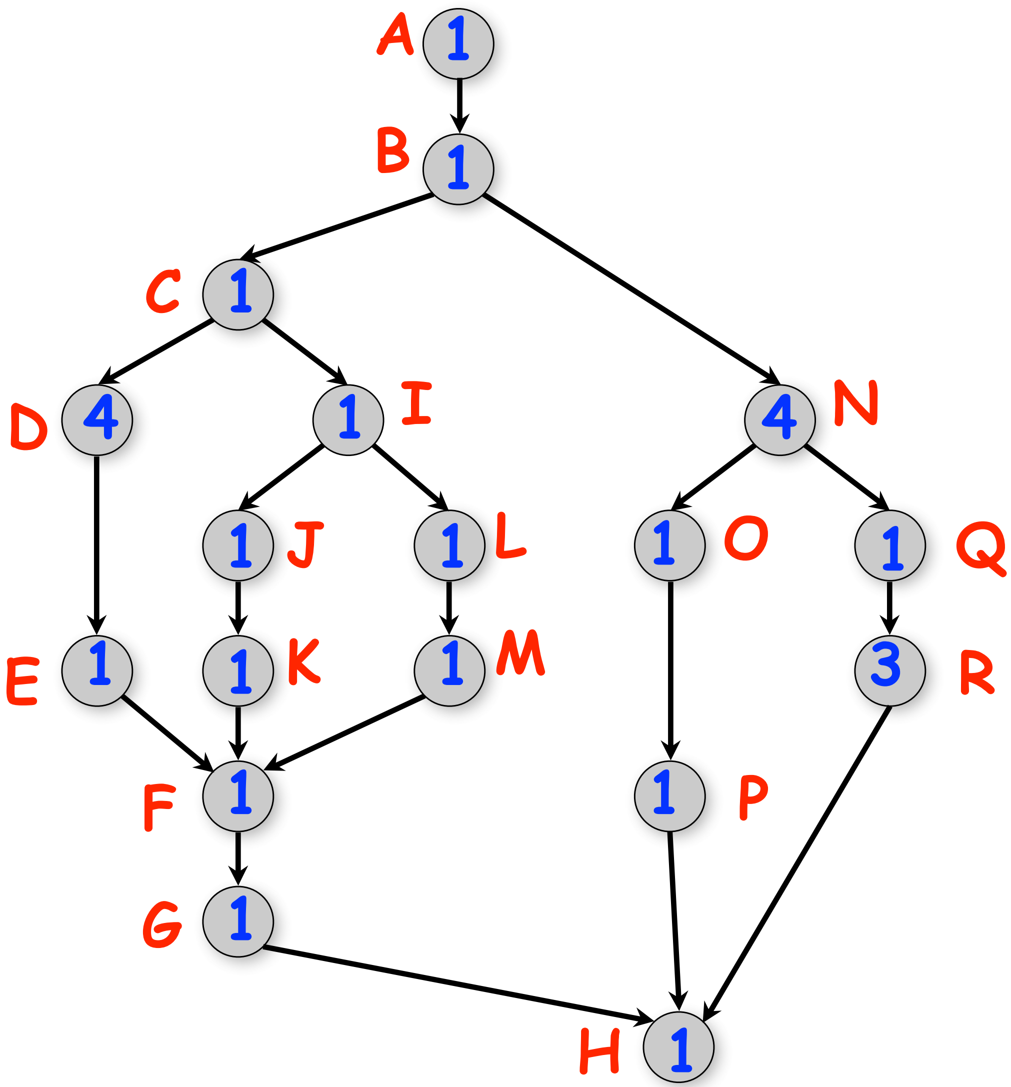
Example:

WORK(G) = 26

CPL(G) = 11

Ideal Parallelism = WORK(G)/CPL(G) = 26/11 ~ 2.36

Scheduling of a Computation Graph on a fixed number of processors: Example



Start time	Proc 1	Proc 2	Proc 3
0	A		
1	B		
2	C	N	
3	D	N	I
4	D	N	J
5	D	N	K
6	D	Q	L
7	E	R	M
8	F	R	O
9	G	R	P
10	H		
11	Completion time = 11		

NOTE: this schedule achieved a completion time of 11, which is the same as the CPL. Can we do better?

Scheduling of a Computation Graph on a fixed number of processors, P

- Assume that node N takes TIME(N) regardless of which processor it executes on, and that there is no overhead for creating parallel tasks
- A schedule specifies the following for each node
  - START(N) = start time
  - PROC(N) = index of processor in range 1...P

  such that
  - START(i) + TIME(i) <= START(j), for all CG edges from i to j (Precedence constraint)
  - A node occupies consecutive time slots in a processor (Non-preemption constraint)
  - All nodes assigned to the same processor occupy distinct time slots (Resource constraint)

Greedy Schedule

- A greedy schedule is one that never forces a processor to be idle when one or more nodes are ready for execution
- A node is ready for execution if all its predecessors have been executed
- Observations
  - T_1 = WORK(G), for all greedy schedules
  - T_∞ = CPL(G), for all greedy schedules
- where T_P = execution time of a schedule for computation graph G on P processors

Lower Bounds on Execution Time of Schedules

- Let T_P = execution time of a schedule for computation graph G on P processors
  - Can be different for different schedules
- Lower bounds for all greedy schedules
  - Capacity bound: $T_P \geq WORK(G)/P$
  - Critical path bound: $T_P \geq CPL(G)$
- Putting them together
  - $T_P \geq \max(WORK(G)/P, CPL(G))$

Upper Bound on Execution Time of Greedy Schedules

Theorem [Graham '66]. Any greedy scheduler achieves

$$T_P \leq WORK(G)/P + CPL(G)$$

<u>Proof sketch</u>:

Define a time step to be complete if $\geq P$ nodes are ready at that time, or incomplete otherwise

complete time steps $\leq$ WORK(G)/P

incomplete time steps $\leq$ CPL(G)

Start time	Proc 1	Proc 2	Proc 3
0	A		
1	B		
2	C	N	
3	D	N	I
4	D	N	J
5	D	N	K
6	D	Q	L
7	E	R	M
8	F	R	O
9	G	R	P
10	H		
11			

Bounding the performance of Greedy Schedulers

Combine lower and upper bounds to get

$\max(WORK(G)/P,\ CPL(G)) \le T_P \le WORK(G)/P + CPL(G)$

Corollary 1: Any greedy scheduler achieves execution time T_P that is within a factor of 2 of the optimal time (since max(a,b) and (a+b) are within a factor of 2 of each other, for any $a \ge 0, b \ge 0$).

Corollary 2: Lower and upper bounds approach the same value whenever

- There's lots of parallelism, $WORK(G)/CPL(G) >> P$
- Or there's little parallelism, $WORK(G)/CPL(G) << P$

Abstract Performance Metrics

- Basic Idea
  - Count operations of interest, as in big-O analysis
  - Abstraction ignores many overheads that occur on real systems
- Calls to doWork()
  - Programmer inserts calls of the form, doWork(N), within a step to indicate abstraction execution of N application-specific abstract operation
    - e.g., adds, compares, stencil ops, data structure ops
  - Multiple calls dynamically add to the execution time of current step in computation graph
- Abstract metrics are enabled by calling
  - HjSystemProperty.abstractMetrics.set(true);
- If an HJ program is executed with this option, abstract metrics are printed at end of program execution with WORK(G), CPL(G), Ideal Parallelism = WORK(G) / CPL(G)

Reminders

- Send email to comp322-staff@mailman.rice.edu if you did NOT receive a welcome email from us, or if you don't have svn access
- A Lab 1 help session will be held today, immediately after class
- Watch videos and read handout for topic 1.5 for next lecture on Wednesday, Jan 21st
- Complete this week's assigned quizzes on edX by 11:59pm today (all quizzes for topics 1.1, 1.2, 1.3, 1.4 including last quiz titled "Multiprocessor Scheduling")
- HW1 will be assigned today, and is due on Jan 28th
- See course web site for all work assignments and due dates
  - https://wiki.rice.edu/confluence/display/PARPROG/COMP322