CS3210 Tut 2

Programming Models & Performance of Parallel Systems

Slides yeeted from Sriram

Question 1: Task Parallelism

Question 1(a): Task Dependence Graphs

Fragment 1

```
parbegin
  do
    parbegin
      do
        parbegin
          do
           A
           C
          end
          parallel
          B
        parend
        F
      end
      parallel
      D
    parend
    G
  end
  parallel
  E
parend
H
```

What on earth is this about?

- `hx q1.c`
- `./q1`

Question 1(a): Task Dependence Graphs

Fragment 1

```
parbegin
  do
    parbegin
      do
        parbegin
          do
           A
           C
          end
          parallel
          B
        parend
        F
      end
      parallel
      D
    parend
    G
  end
  parallel
  E
parend
H
```

Let's find the dependencies!

Rules:

- **X**
  Y
  → X and Y are sequentially executed

- **X**
  parallel
  Y
  → X and Y are executed in parallel

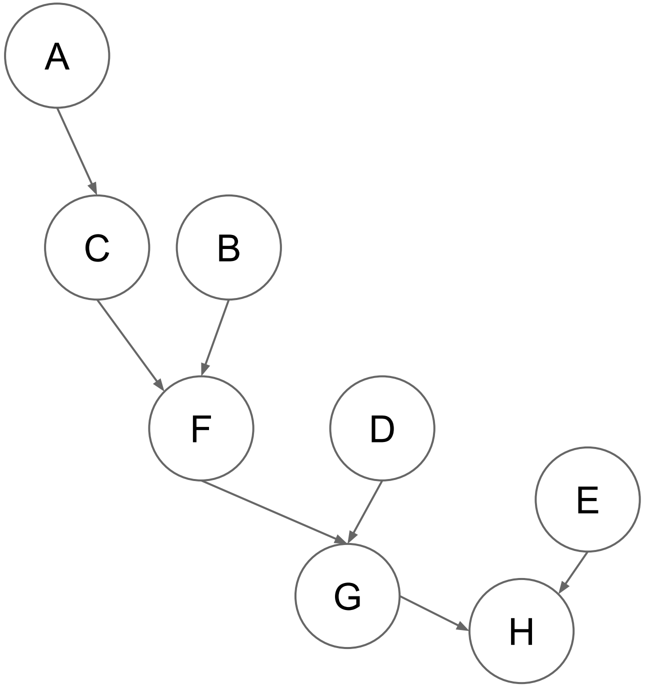
- **parend**
  → All tasks must complete before moving on

Question 1(a): Task Dependence Graphs

Fragment 1

```
parbegin
  do
    parbegin
      do
        parbegin
          do
           A
           C
          end
          parallel
          B
        parend
        F
      end
      parallel
      D
    parend
    G
  end
  parallel
  E
parend
H
```

Let's find the dependencies!

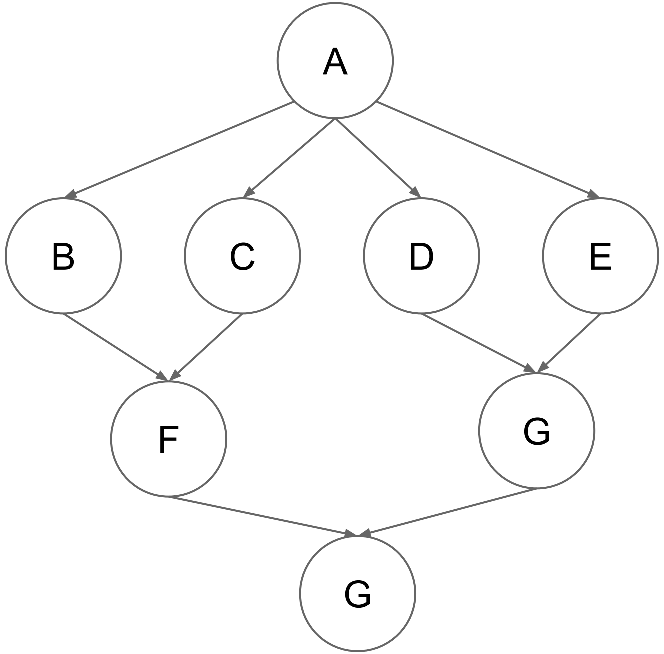


Question 1(a): Task Dependence Graphs

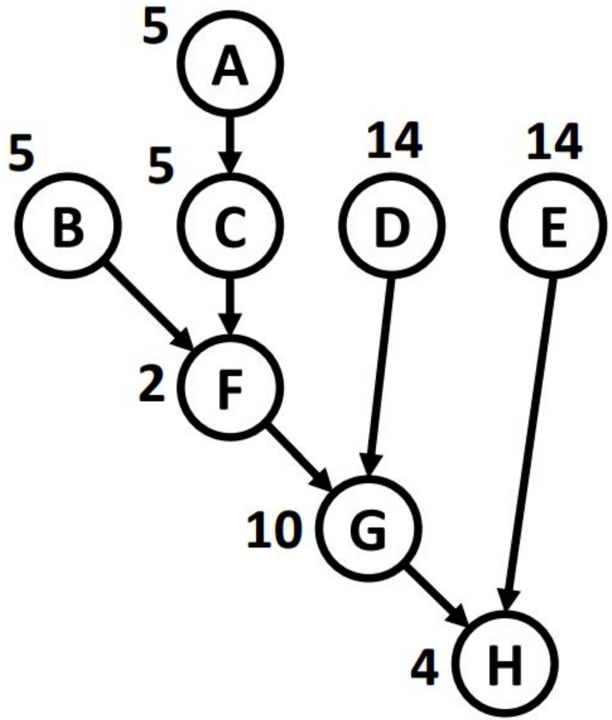
Fragment 2

```
A
parbegin
  do
    parbegin
      B
      parallel
      C
    parend
    F
  end
  parallel
  do
    parbegin
      D
      parallel
      E
    parend
    G
  end
parend
H
```

Fragment 2 Dependencies:

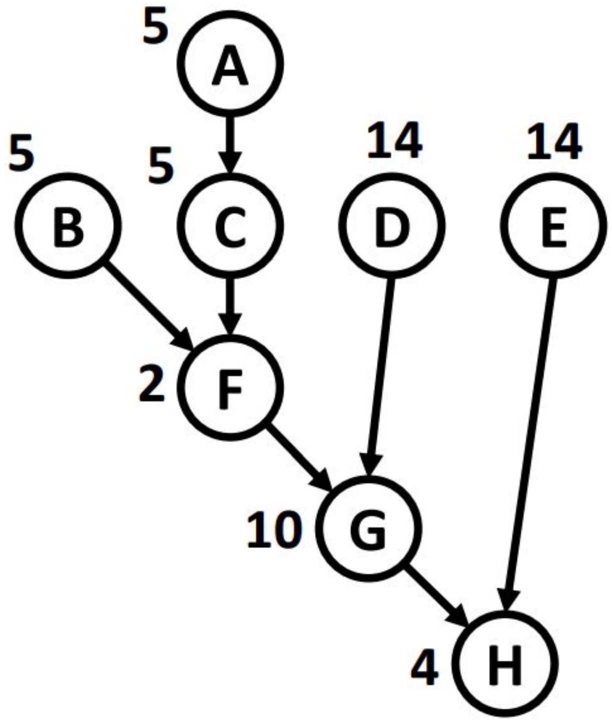


Q1 (b): Amount of Concurrency



Plot the concurrency for Fragment 1

Q1 (b): Amount of Concurrency

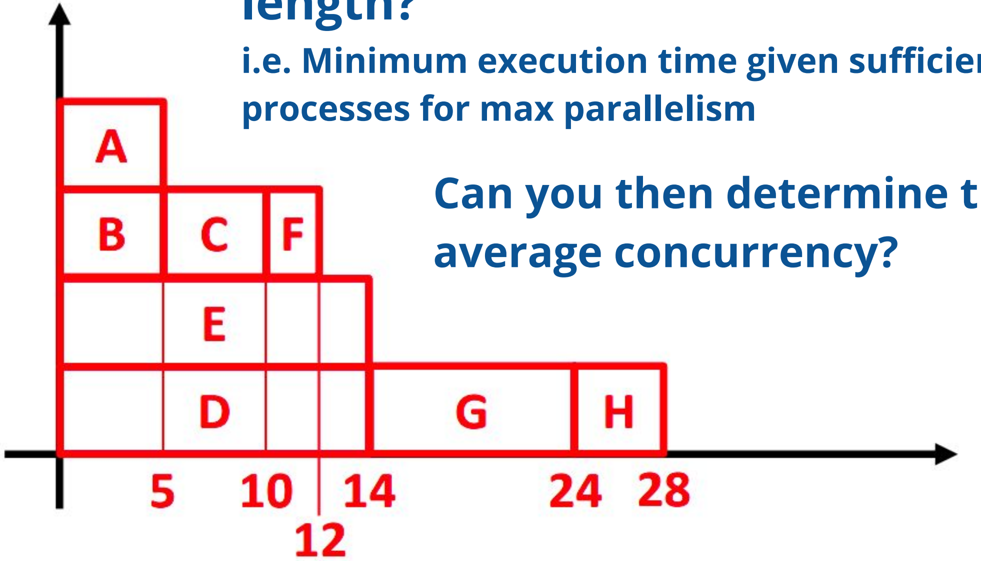


Plot the concurrency for Fragment 1

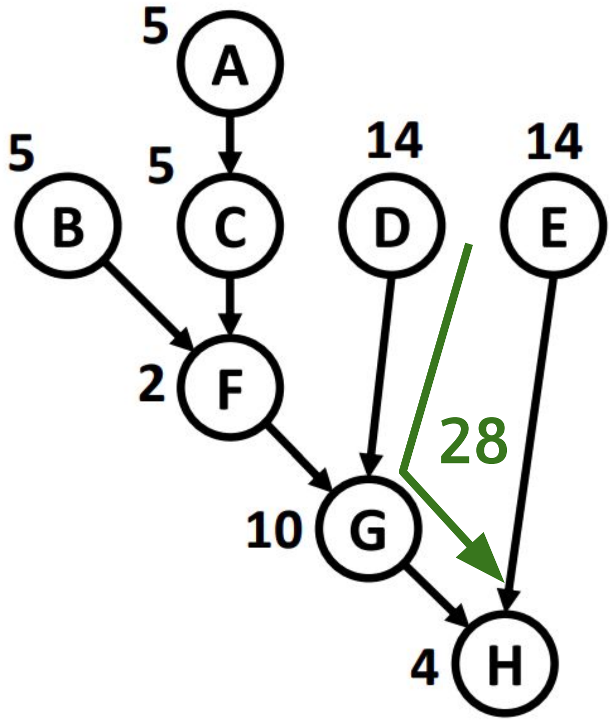
Can you determine the critical path length?

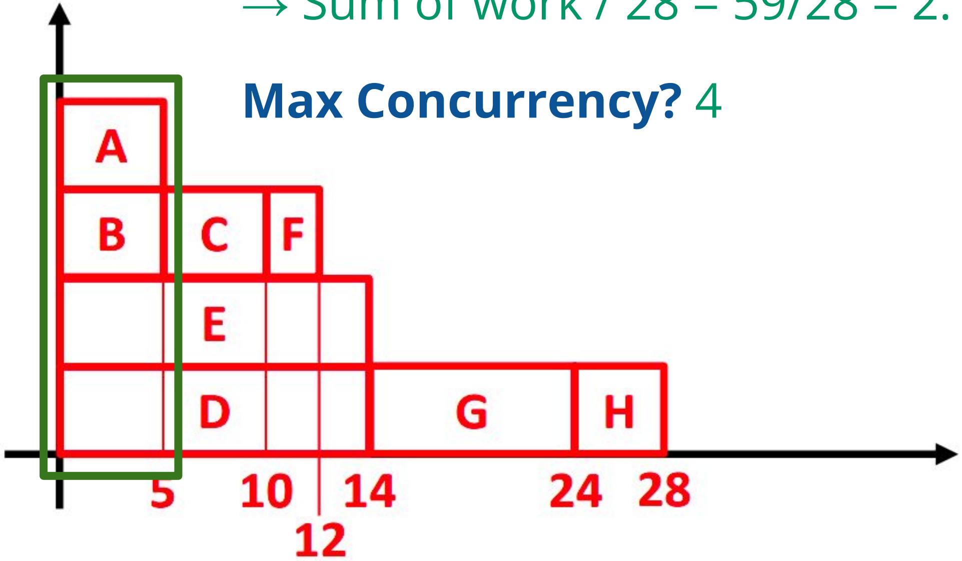
i.e. Minimum execution time given sufficient processes for max parallelism

Can you then determine the average concurrency?



Q1 (b): Amount of Concurrency





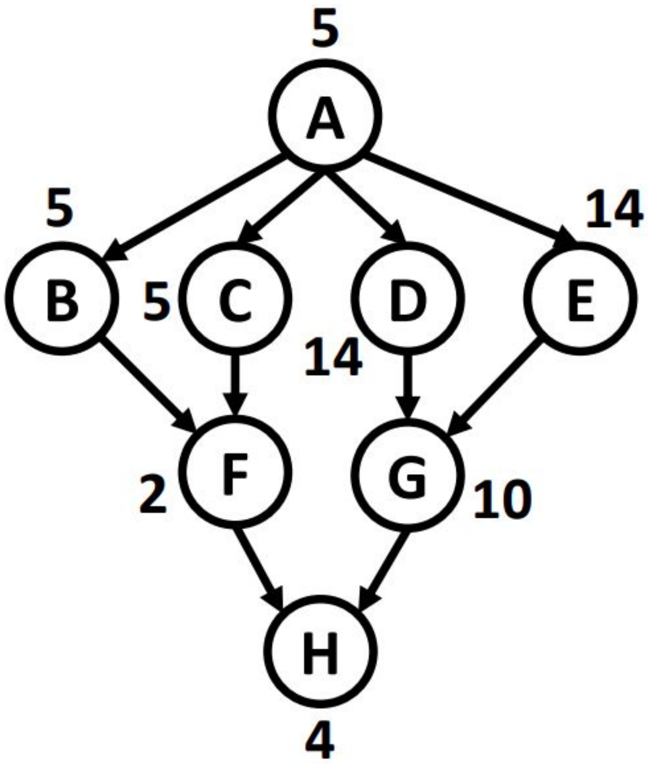
Critical path length? 28

Average Concurrency?

→ Sum of work / 28 = 59/28 = 2.10

Max Concurrency? 4

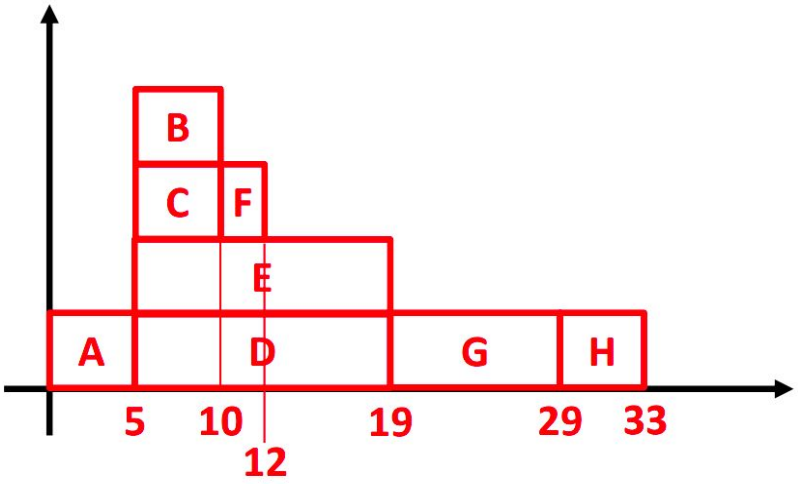
Q1 (b): Amount of Concurrency



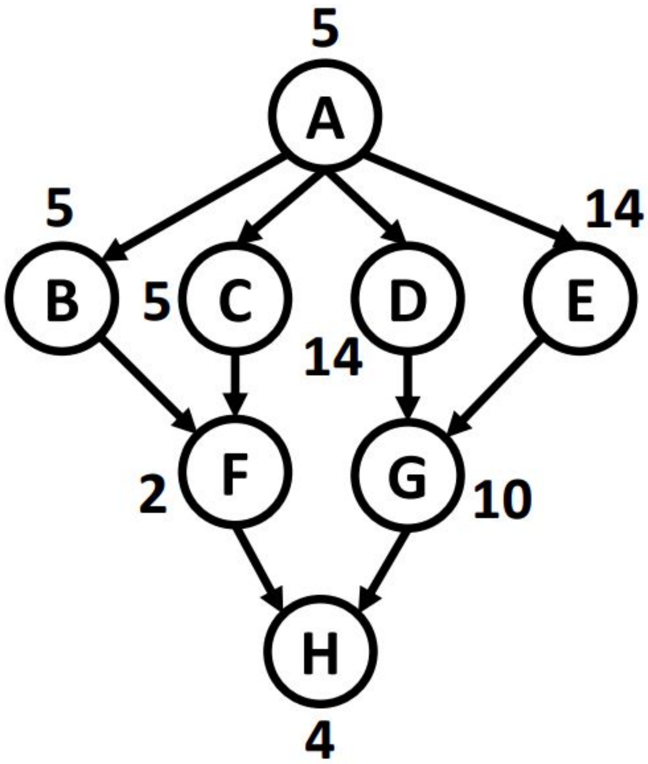
Critical path length?

Average Concurrency?

Max Concurrency?



Q1 (b): Amount of Concurrency

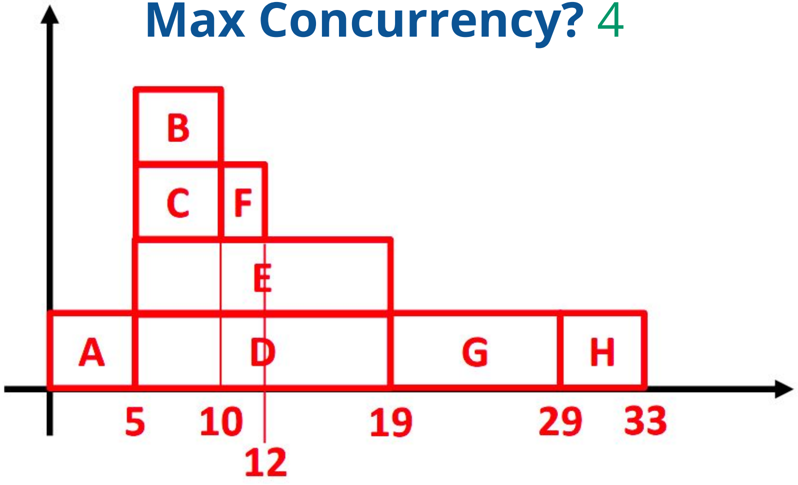


Critical path length? 33

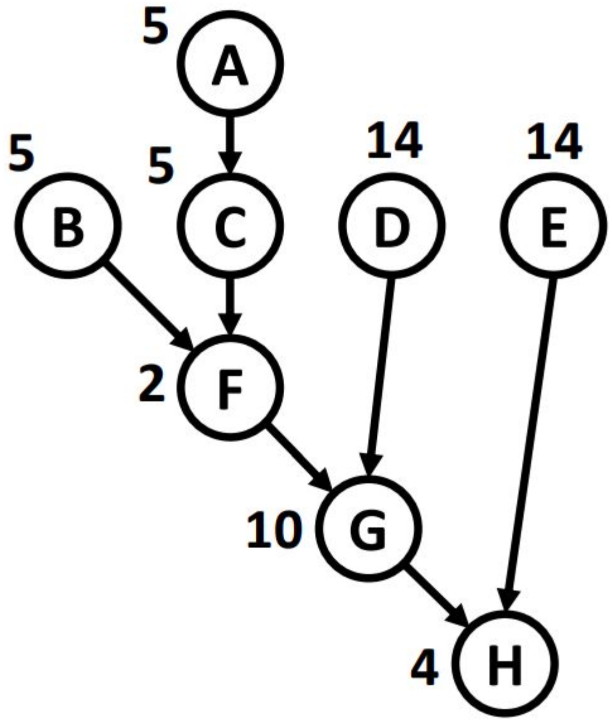
Average Concurrency?

→ Sum of work / 33 = 59/33 = 1.78

Max Concurrency? 4

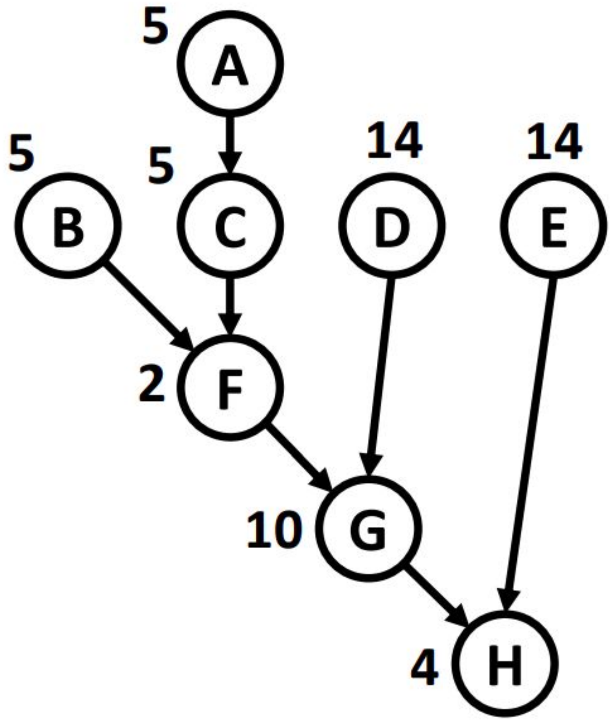


Q1 (c): Speedup



What is the speedup of this program given **infinite resources**?

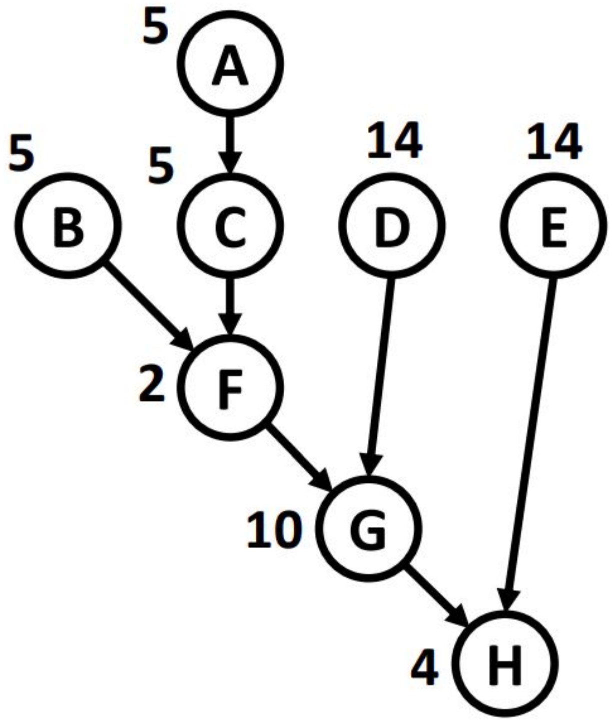
Q1 (c): Speedup



What is the speedup of this program given **infinite resources**?

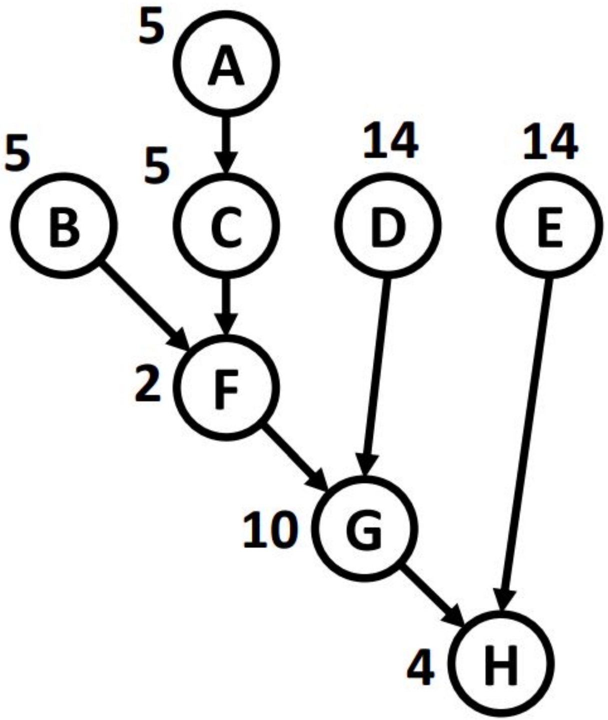
- Sequental implementation = 59 units
- Parallel: finishes in **28 time units**
    - **Length of the critical path!!**
- Speedup = 59/28 = **2.10**
    - (== avg deg of concurrency)
- Fragment 2's speedup is **1.78**
  == its avg deg of concurrency

Q1 (d): Speedup



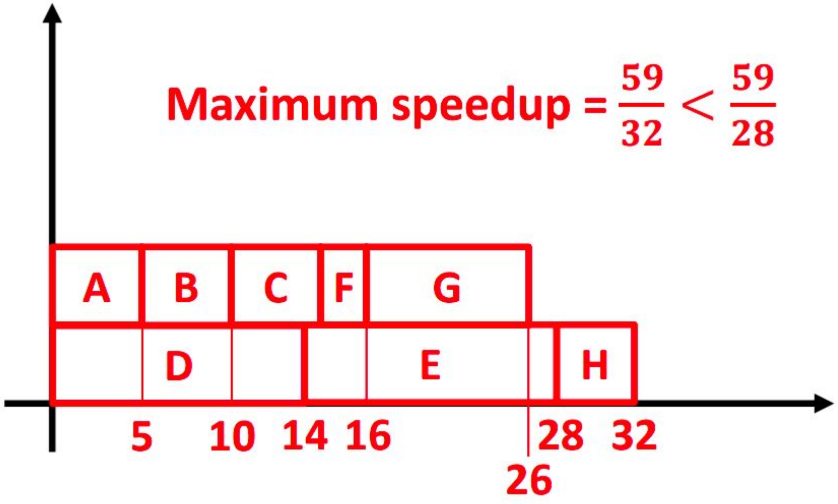
What if we have only 2 processing units? What is the speedup?

Q1 (d): Speedup

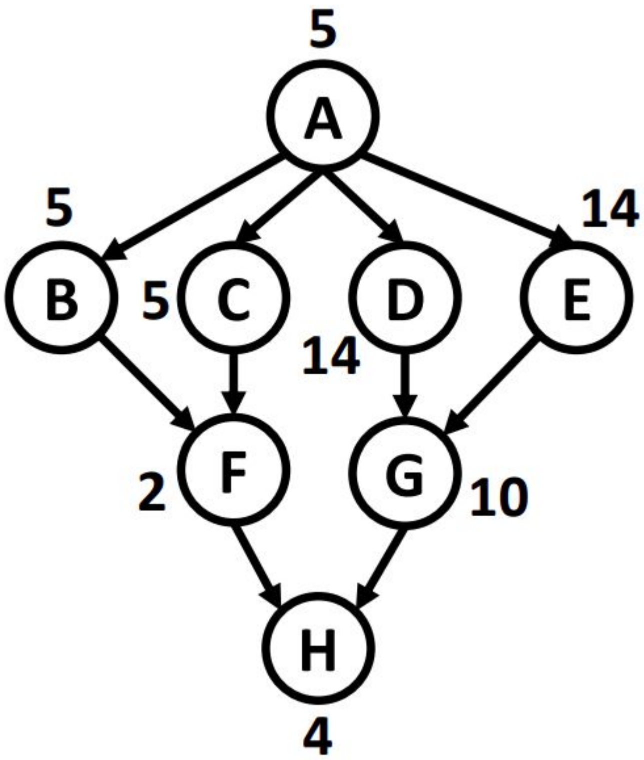


What if we have only 2 processing units? What is the speedup?

Have to draw it out, no easy solution

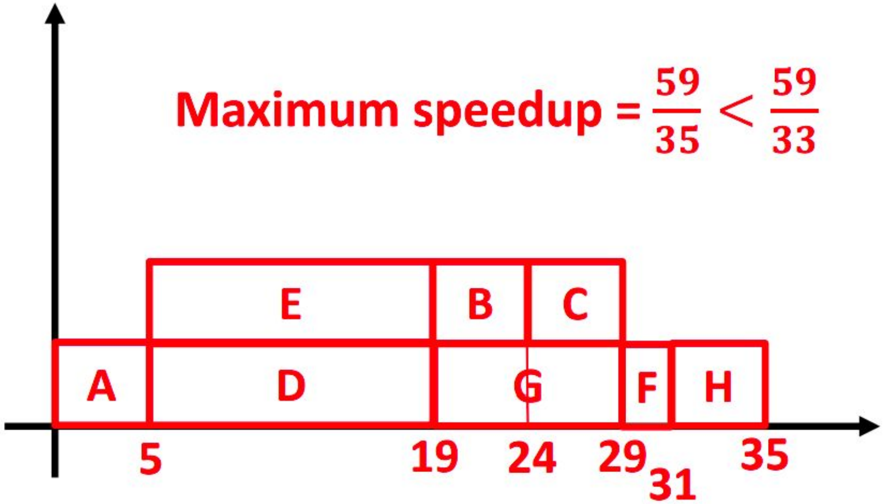


Q1 (d): Speedup



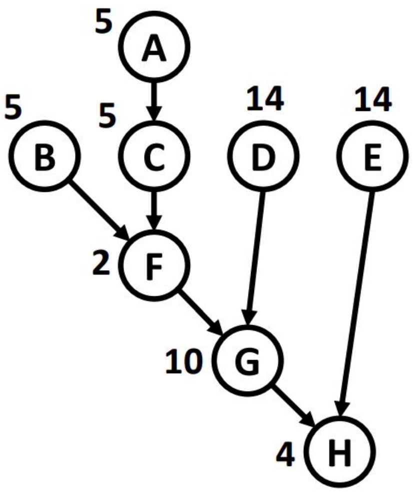
What if we have only 2 processing units? What is the speedup?

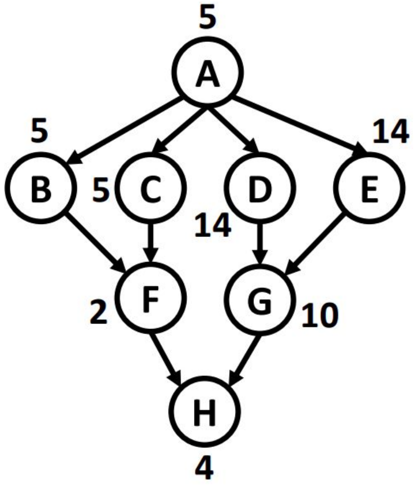
Have to draw it out, no easy solution



Why does this question matter?

- Helps you to understand **how to design your parallel programs!**
  - Your program is only as strong as its weakest link!
- Parallel tasks should be as **independent as possible**
- They should have the **shortest critical path possible** (dependency chain should be minimized)





Question 2: User CPU Time

Question 2: Cycles Per Instruction

- Cycles per instruction (CPI) for each instr: **I_1 = 1, I_2 = 2, I_3 = 3**
- What is the **average** CPI for the translation of both programs?

Translation	I_1	I_2	I_3	**Total instructions**	n_{cycles}
1	2	1	2	5	10
2	4	1	1	6	9

Question 2: Cycles Per Instruction

- Cycles per instruction (CPI) for each instr: $\mathbf{I_1 = 1, I_2 = 2, I_3 = 3}$
- What is the **average** CPI for the translation of both programs?

- Relatively trivial: no. of cycles / no. of instructions
  - 1st program: 10 / 5 = 2.0 (10 = 2*1 + 1*2 + 2*3)
  - 2nd program: 9 / 6 = 1.5

Translation	I_1	I_2	I_3	**Total instructions**	n_{cycles}
1	2	1	2	5	10
2	4	1	1	6	9

Why does this question matter?

- Not all instructions are created equal!
  - *i.e. no. of instructions is not a good comparative metric for time taken*

- Let's try...
  - `hx intadd.c`
  - `hx floatadd.c`
  - `perf stat -e cycles,instructions -- ./intadd`
  - `perf stat -e cycles,instructions -- ./floatadd`

- https://godbolt.org/z/3MobeMxbP

Question 3: MIPS

Question 3: MIPS

- Cycles per instruction (CPI) for each instr: **I_1 = 1, I_2 = 2, I_3 = 3**
- **2 GHz (2×10^9) clock rate**
- **Different composition of instructions in each program**
- What is the relationship between time taken (to complete the program) and MIPS in this qn?

Program	I_1	I_2	I_3
A_1	5×10^9	1×10^9	1×10^9
A_2	10×10^9	1×10^9	1×10^9

Question 3: MIPS

- Cycles per instruction (CPI) for each instr: **$I_1 = 1$, $I_2 = 2$, $I_3 = 3$**
- **2 GHz (2×10^9) clock rate**
- How long does each program take?
  - Time for A_1 = (Cycles / Clock speed) = $(5 + (1 \times 2) + (1 \times 3)) \times 10^9 / (2 \times 10^9)$ = 5s
  - Time for A_2 = (Cycles / Clock speed) = $(10 + (1 \times 2) + (1 \times 3)) \times 10^9 / (2 \times 10^9)$ = 7.5s
- What is the MIPS for each program?
  - MIPS for A_1 = (MillionInstrs / Time) = $((5 + 1 + 1) \times 10^9 / 106) / 5$ = 1400 MIPS
  - MIPS for A_2 = (MillionInstrs / Time) = $((10 + 1 + 1) \times 10^9 / 106) / 7.5$ = 1600 MIPS
- What can we conclude?

Program	I_1	I_2	I_3
A_1	5×10^9	1×10^9	1×10^9
A_2	10×10^9	1×10^9	1×10^9

“MIPS is like a real estate agent determining **how much a building is worth** by measuring the **weight of a rubber chicken.**”

(Brendan, StackOverflow)

Why does this question matter?

- **Don't be fooled by marketing!**

- You are now educated in parallel computing performance :)

Question 4: Speedup

Question 4: Speedup

- For these questions: we *could* use the laws directly
  (feel free in the exam, faster)

- But in this tutorial: let's **understand what we're doing from first principles!**

Sequential: N instructions	**Parallel:** N^2 instructions

Each instruction takes 2 cycles on a 1 GHz (10^9 Hz) processor

Question 4: Speedup

- For N = 100, what is the speedup for 10 and 100 processors?

- **Total number of cycles if no parallelism:** $(N + N^2)$ x 2 cycles/instr.

  $= \boxed{(100 + 100^2) \times 2}$

Sequential: N instructions	**Parallel:** N^2 instructions

Each instruction takes 2 cycles on a 1 GHz (10^9 Hz) processor

Question 4: Speedup

- For N = 100, what is the speedup for 10 and 100 processors?
- **Strategy (using basic logic)**: find sequential time, find parallel times
- **Sequential time:** $((100 + 100^2) \times 2) / 10^9$ = 20200 ns
- **Par time (p=10):** $((100 + 100^2/10) \times 2) / 10^9$ = 2200 ns (9.18x speedup)
- **Par time (p=100):** $((100 + 100^2/100) \times 2) / 10^9$ = 400 ns (50.6x speedup)
- If we have infinite resources, the parallel section can be approximated to 0 instructions running serially
- Par time (p=∞): $((100 + 0) \times 2) / 10^9$ = 200 ns (101x speedup)

Sequential: N instructions	**Parallel:** N^2 instructions

Each instruction takes 2 cycles on a 1 GHz (10^9 Hz) processor

Question 4: Speedup

Note: This is identical from direct application of Amhdal's law, but the basics are simpler to understand for now!

$$f = \frac{I_{seq}}{I_{total}} = \frac{N}{N + N^2} = \frac{1}{1 + N} = \frac{1}{101}$$

$$S_{10}(100) = \frac{1}{\frac{1}{101} + \frac{100}{101(10)}} = 9.181$$

$$S_{100}(100) = \frac{1}{\frac{1}{101} + \frac{100}{101(100)}} = 50.5$$

$$S_{\infty}(100) = \frac{1}{\frac{1}{101} + 0} = \frac{1}{f} = 101$$

Recap:
f = ratio of sequential execution time to total execution time
S_{10} = Speedup achievable with 10 processors

Sequential: N instructions	**Parallel:** N^2 instructions

Each instruction takes 2 cycles on a 1 GHz (10^9 Hz) processor

Question 4: Speedup

- Fixed time: N that can be solved with 10/100 processors?
- Sequential time (p=1): $((100 + 100^2) \times 2) / 109$ = 20200 ns
- For **10** processors, find N:
  - $((N + N^2/10) \times 2) / 10^9 = 20200$ ns $\Rightarrow N = 312$
  - “Gustafson speedup”: (Sequential time for N = 312 / Parallel time for N = 312)
- For **100** processors, find N:
  - $((N + N^2/100) \times 2) / 10^9 = 20200$ ns $\Rightarrow N = 956$
- **You don’t need to “stick to the law” to solve these problems!**

Sequential: N instructions	**Parallel:** N^2 instructions

Each instruction takes 2 cycles on a 1 GHz (10^9 Hz) processor

Why does this question matter?

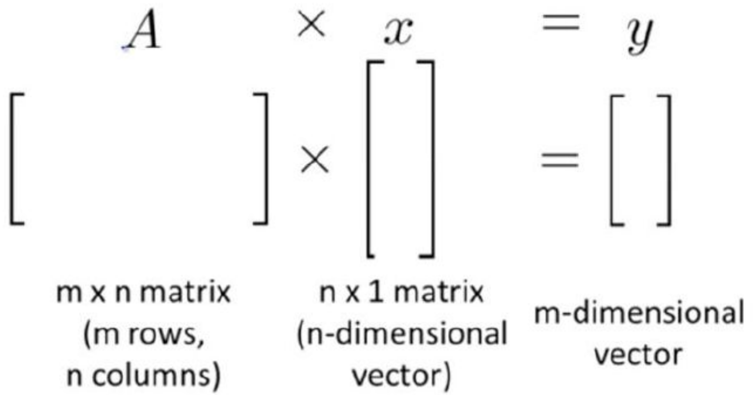
- If you have a fixed-sized problem to solve OR you have a constant sequential fraction with increasing problem size
    - **Amdahl's law applies**: speedup limited by the sequential fraction
- If you have a problem size that can be varied AND your sequential fraction does not scale as much with the problem
    - **Gustafson's law applies**: you can solve larger problems with more speedup!

- **Amdahl's Law — Strong Scaling**
    - Fixed Problem Size
    - How much does parallelism reduce the execution time of a problem?
- **Gustafson's Law — Weak Scaling**
    - Fixed Execution Time
    - How much longer does it take for the problem without parallelism?

Question 5: Parallel Programming Models

Question 5: Parallel Programming Models

Data or task parallelism?

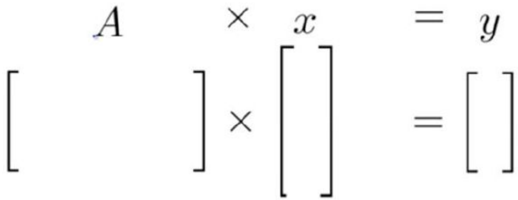


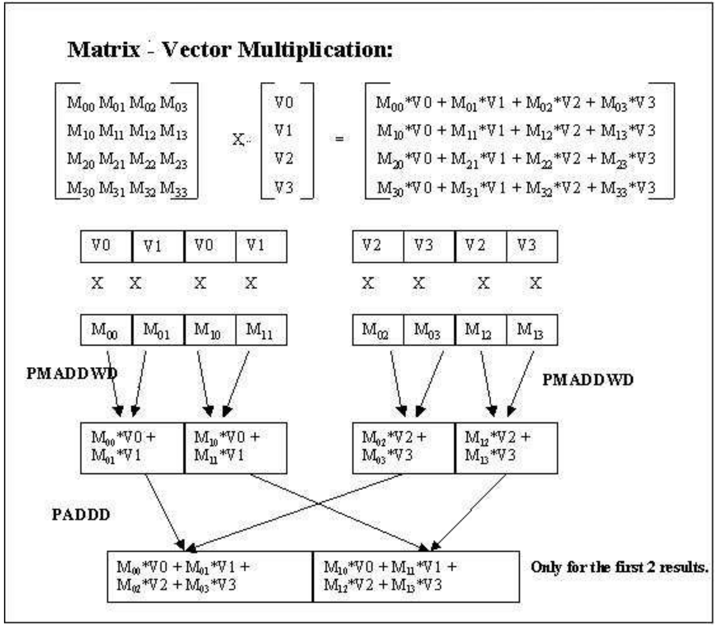
Question 5: Parallel Programming Models

- Data Parallelism

- We want to use SIMD (Flynn's Taxonomy) for this!

  - Yes, MIMD is superset of SIMD
  - Teaching point here is the idea of SIMD instructions

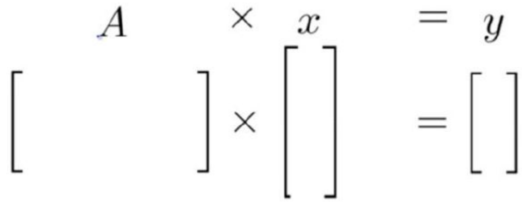


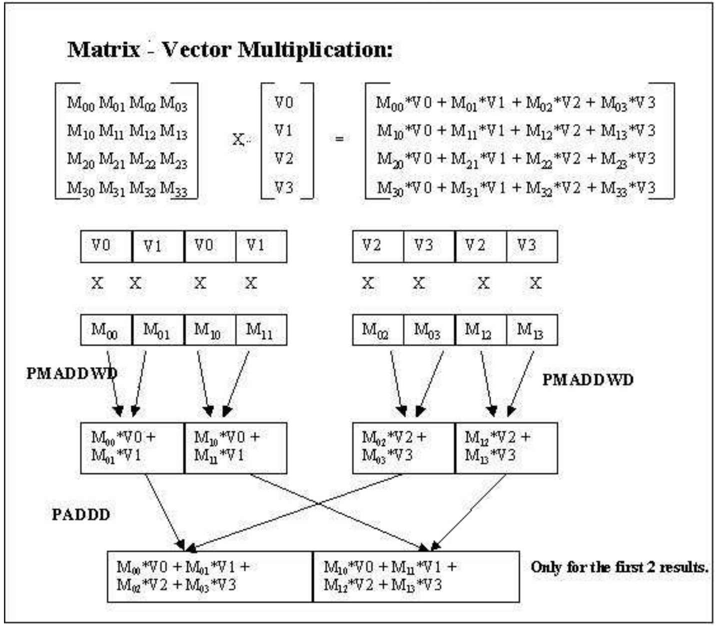


Question 5: Parallel Programming Models

What kind of parallel programming pattern (disregarding SIMD) would be best for this?

- **Fork-join**
- **Parbegin-parend**
- **Master-worker**
- **Task pool**
- **Pipelining**
- **Producer-consumer**





Question 5: Parallel Programming Models

- What kind of parallel programming pattern would be best for this?
- **Fork-join / Parbegin-parend**
  - We don't need the complexity of fork-join - leads to very spaghetti code
  - Parbegin/end is arguable since that is literally OpenMP
- **Master-worker**
  - Best here: we want relatively simple and homogeneous (same amount of work) worker threads, and a master thread to organize them
- **Task pool**
  - Not as good as master-worker here: tasks are usually for heterogeneous tasks or those that finish at very different times
- **Pipelining:** better for task parallelism, this is data parallel, single task type
- **Producer-consumer:** does not fit into this model as nothing is "produced"

Why does this question matter?

- Thinking of the right pattern allows you to use the **right tools**
- **Non-data-parallel-like problem:** Don't use GPGPU computation
- **Parbegin/end:** good for OpenMP
- Many more!

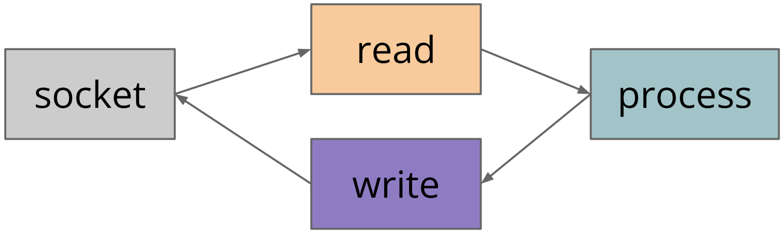
Question 6: 2020 Midterms Q1

Question 6: 2020 Midterms Q1

- You are parallelizing a backend web server
- It runs on a <u>shared memory</u> machine

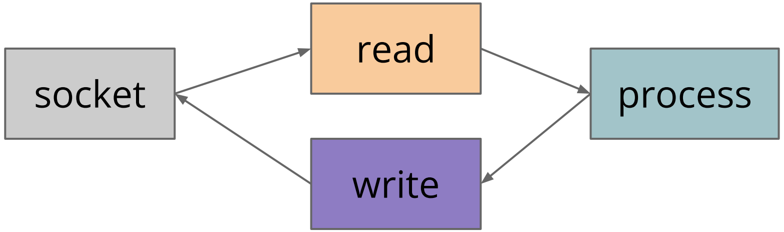
- **Discuss about**
  - **task vs data parallelism**
  - **what pattern to use**

- **Request for each client run in this order**



Question 6: 2020 Midterms Q1

What kind of parallelism?
[Task/Data parallelism]



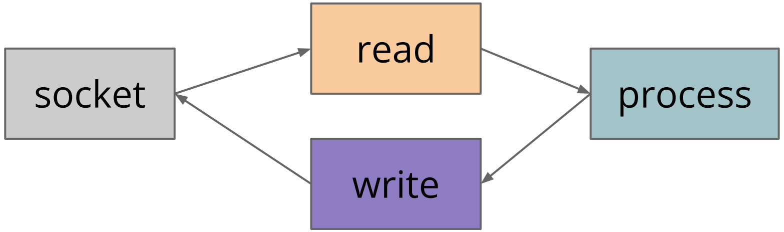
Assume that read/write/process time is *all very similar*

Question 6: 2020 Midterms Q1

What kind of parallelism?

- **Task parallelism: each stage is a task**
- Data parallelism may be accepted if request = task AND requests assumed to arrive at same time

What pattern to use?



Assume that read/write/process time is *all very similar*

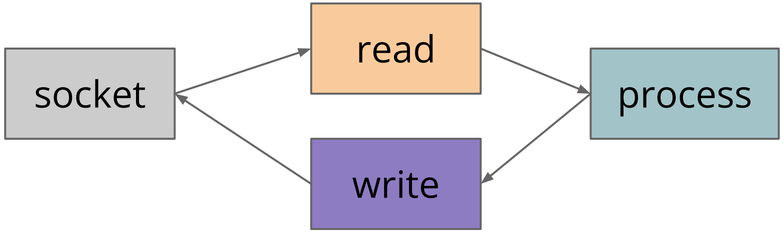
Question 6: 2020 Midterms Q1

What kind of parallelism?

- **Task parallelism: each stage is a task**
- Data parallelism may be accepted if request = task AND requests assumed to arrive at same time

What pattern to use?

- **Best:** pipelining - best in cases where **each stage** takes **similar time**



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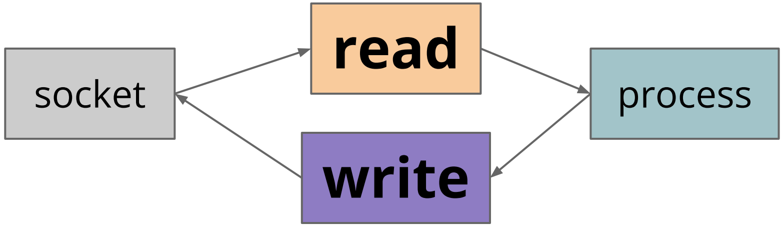
Question 6: 2020 Midterms Q1

What kind of parallelism?



Assume that read/write >> compute time

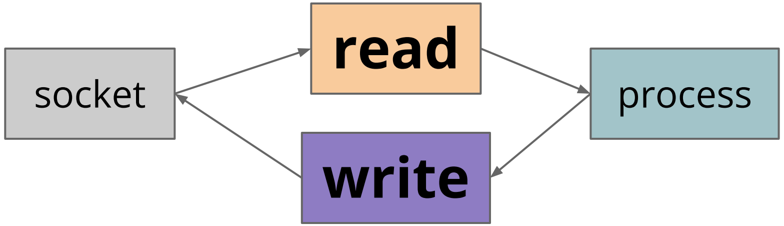
Question 6: 2020 Midterms Q1

What kind of parallelism?

- **Task parallelism: each stage is a task**

What pattern to use?

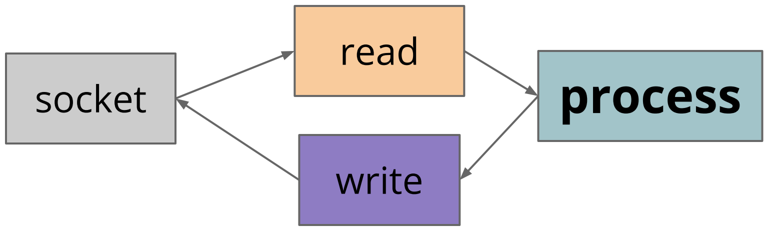
- **Producer-consumer:** producer **reads** from socket and **processes**, consumer **writes back** to the socket, **#producers == #consumers**
- **No pipelining: the stages are uneven!**



Assume that read/write >> compute time

Question 6: 2020 Midterms Q1

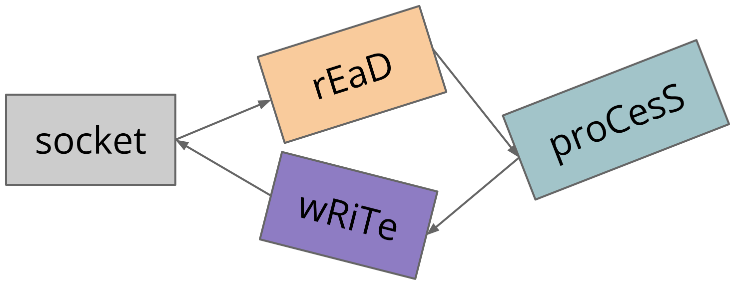
Similar to previous part: except for producer/consumer, we need **more producers than consumers**



Assume that compute time >> read/write

Question 6: 2020 Midterms Q1

- **Assume task parallelism**
- What pattern do we use?



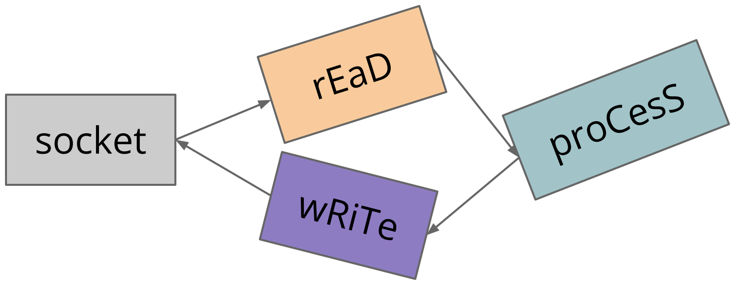
- **Task pool is perfect here:** pool of tasks are ready for jobs and are assigned as necessary
- **If distributed memory:** same answers, but need explicit communication.

What if we don't know how long anything takes? Or heavily varies?

Question 6: 2020 Midterms Q1

- **Distributed memory architecture?**

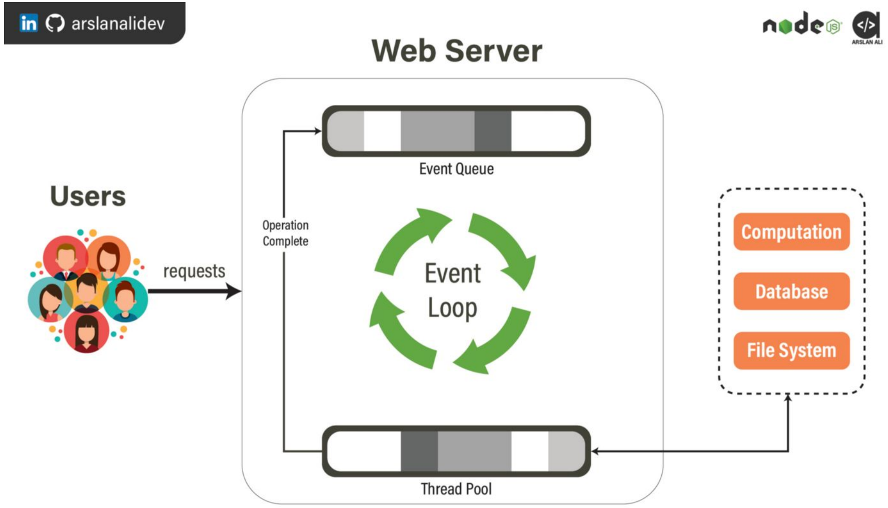
- Same answers, but need explicit communication.
- Pipelining not feasible



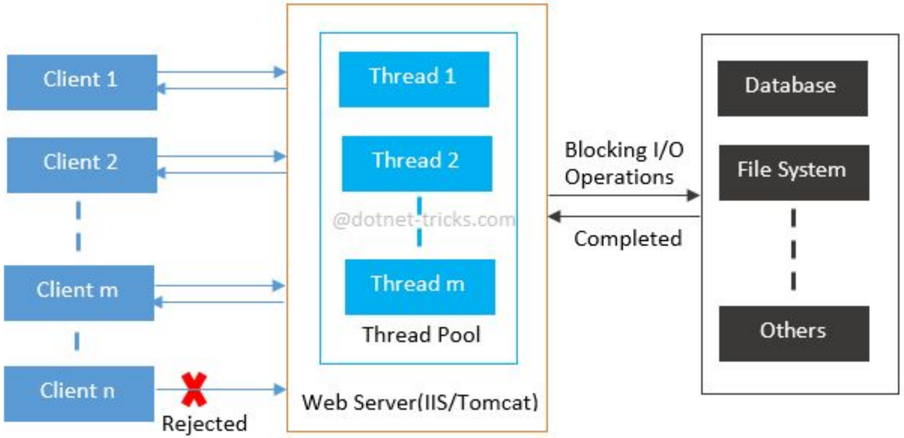
What if we don’t know how long anything takes? Or heavily varies?

Why does this question matter?

- Affects your entire system architecture and downstream programming patterns!



Node JS Architecture



Multi-Threaded Web Server request processing

End of Tut 2

Anonymous Feedback:
feedback.zhiheng.dev

Reminder: Submit your Lab 2 by Wednesday 2pm!

Attendance