A Scalable Architecture for Ordered Parallelism

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Massachusetts Institute of Technology

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Multicores Target Easy Parallelism

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Regular: known tasks and data

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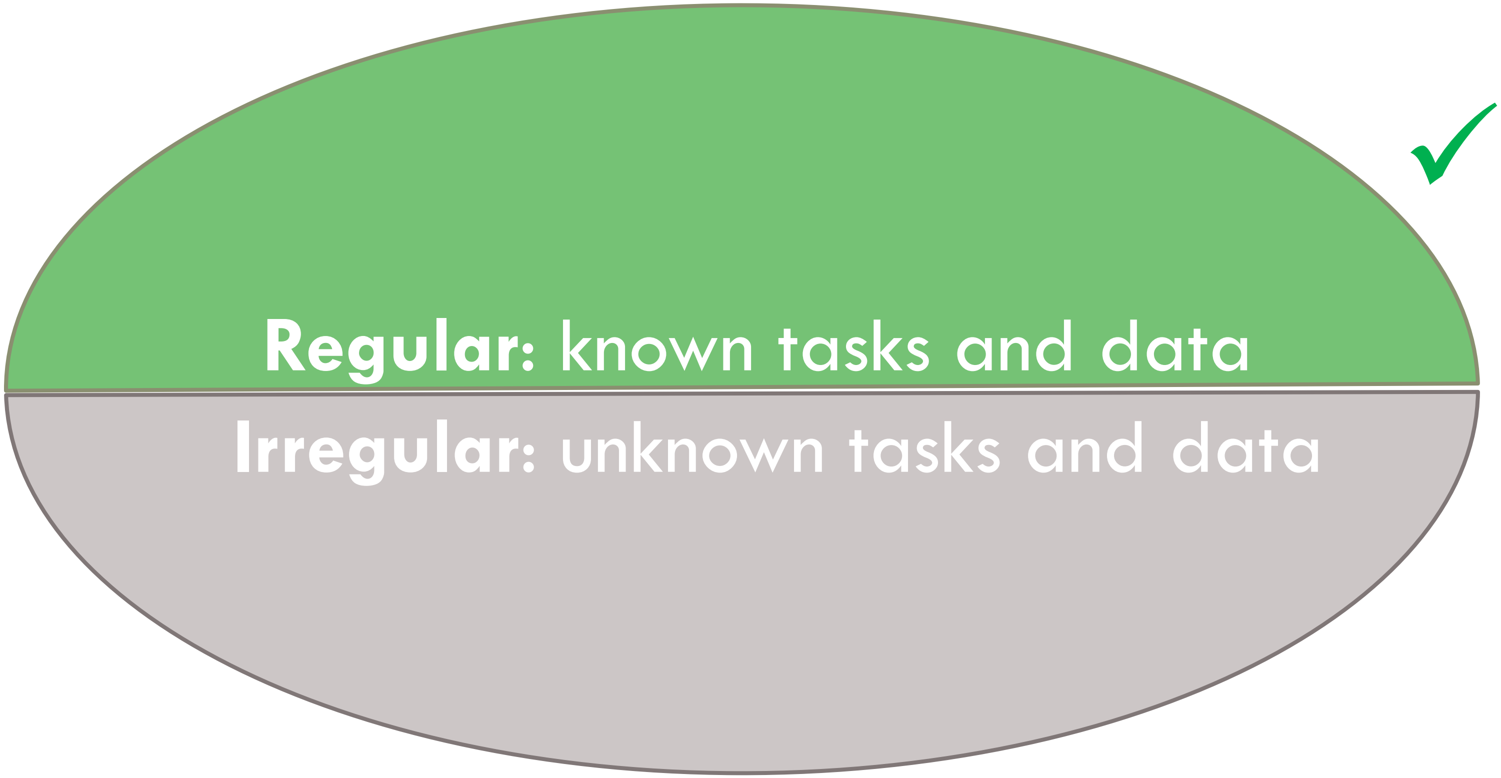

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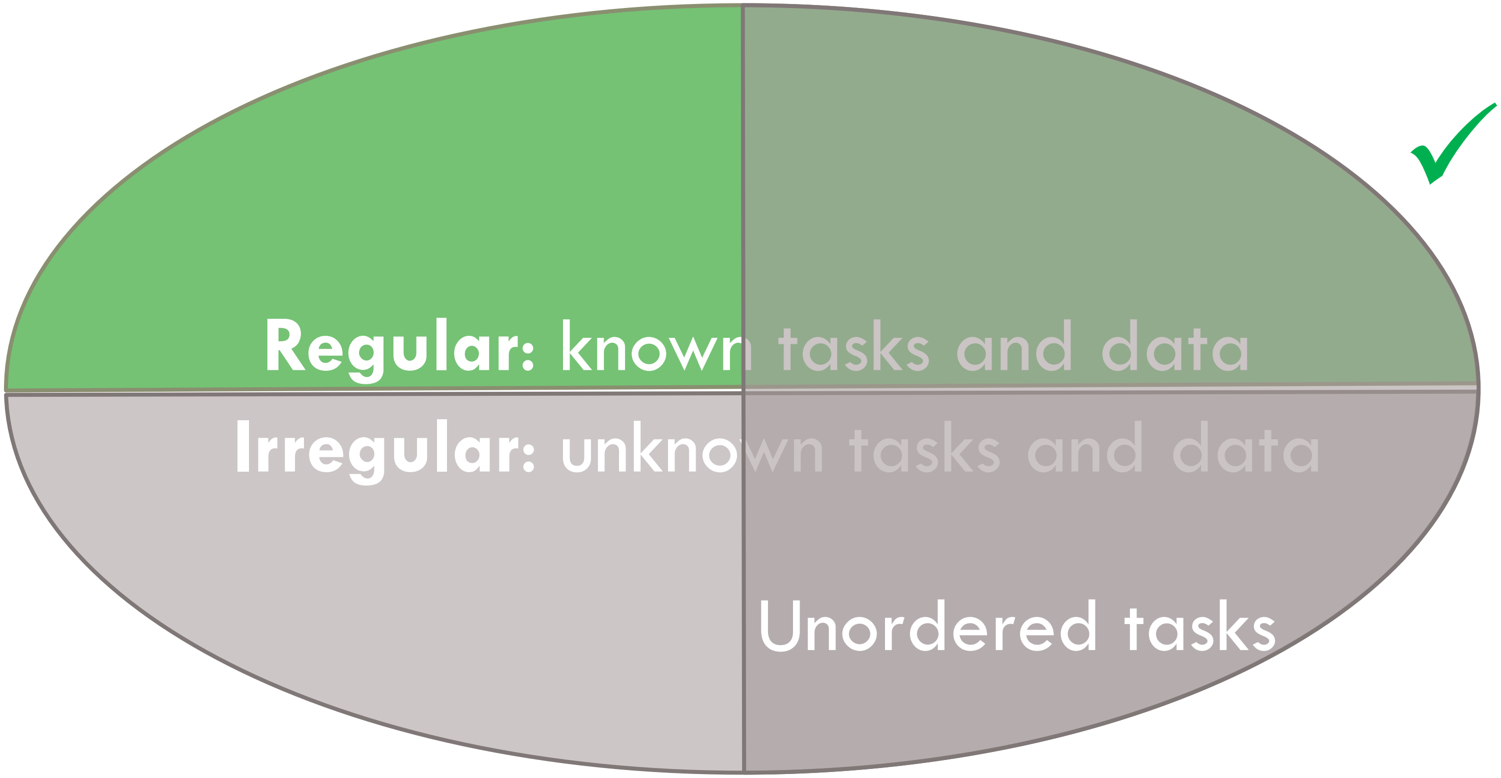

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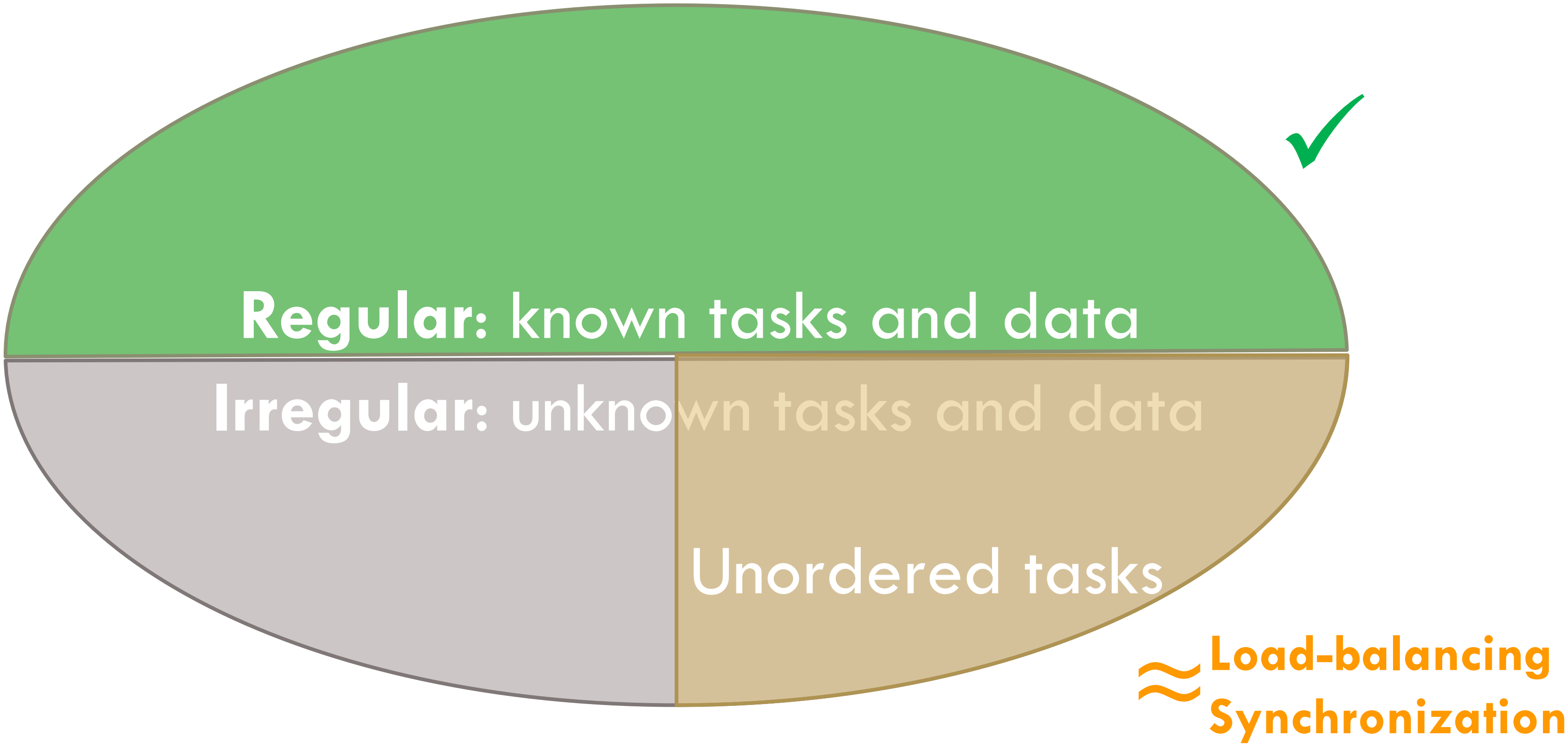

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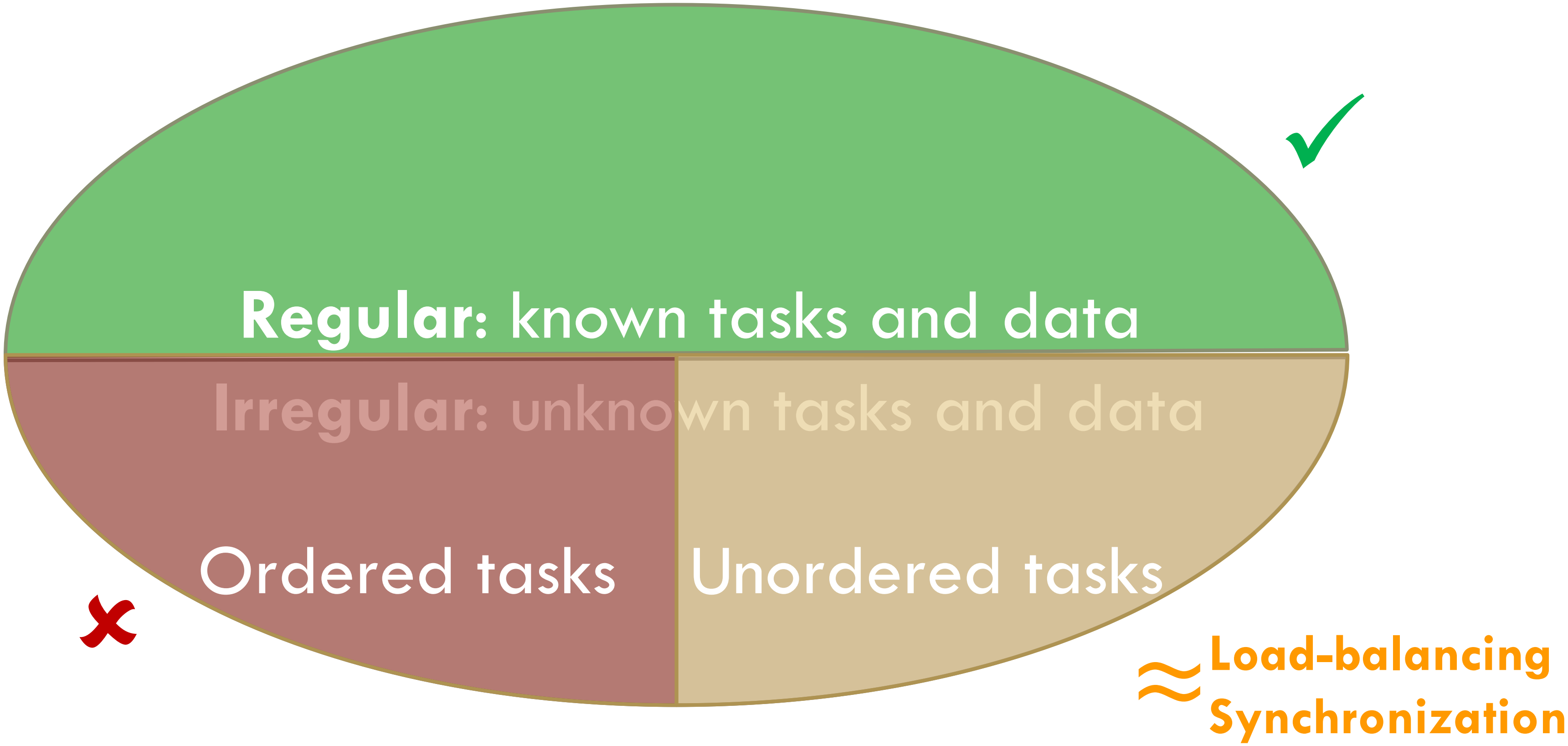

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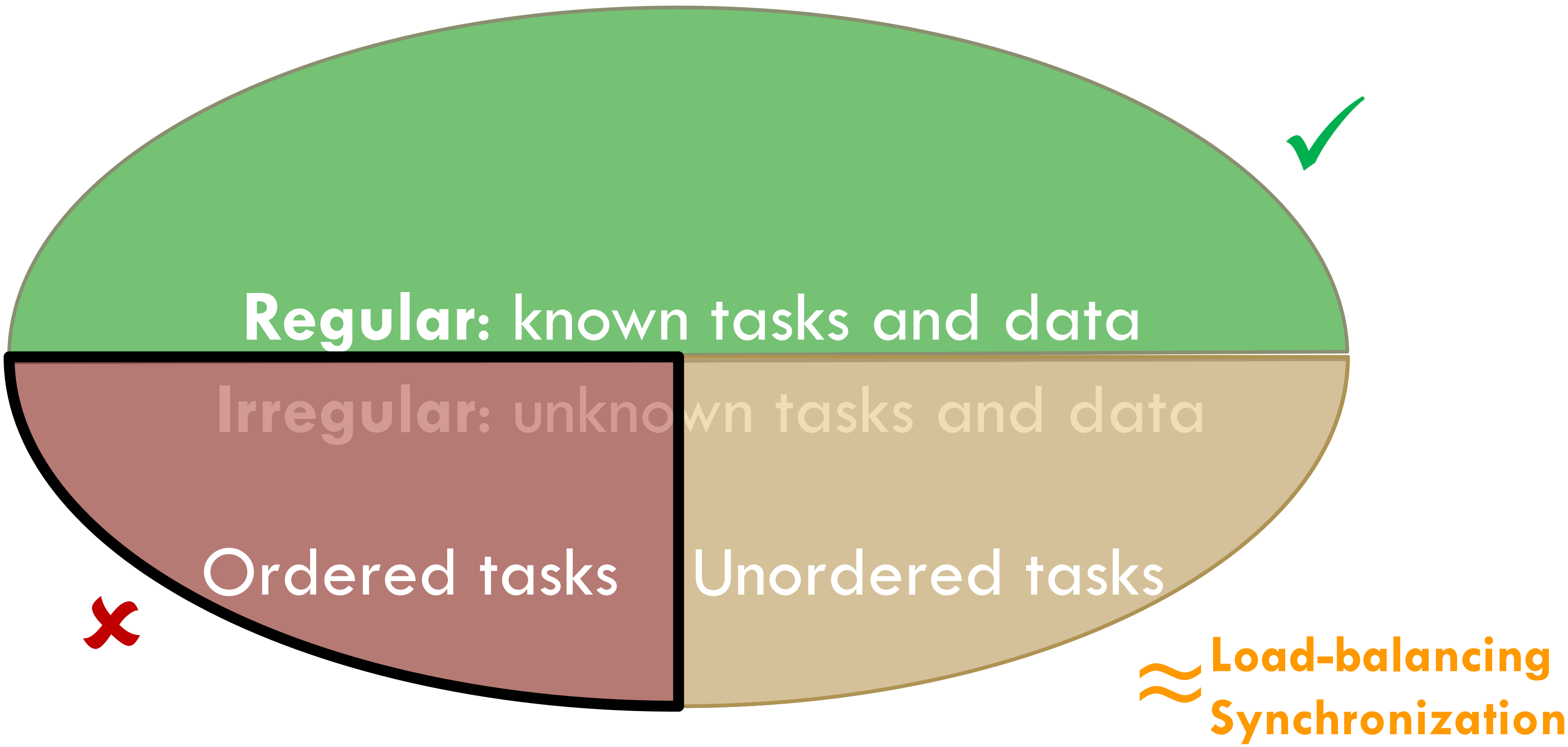

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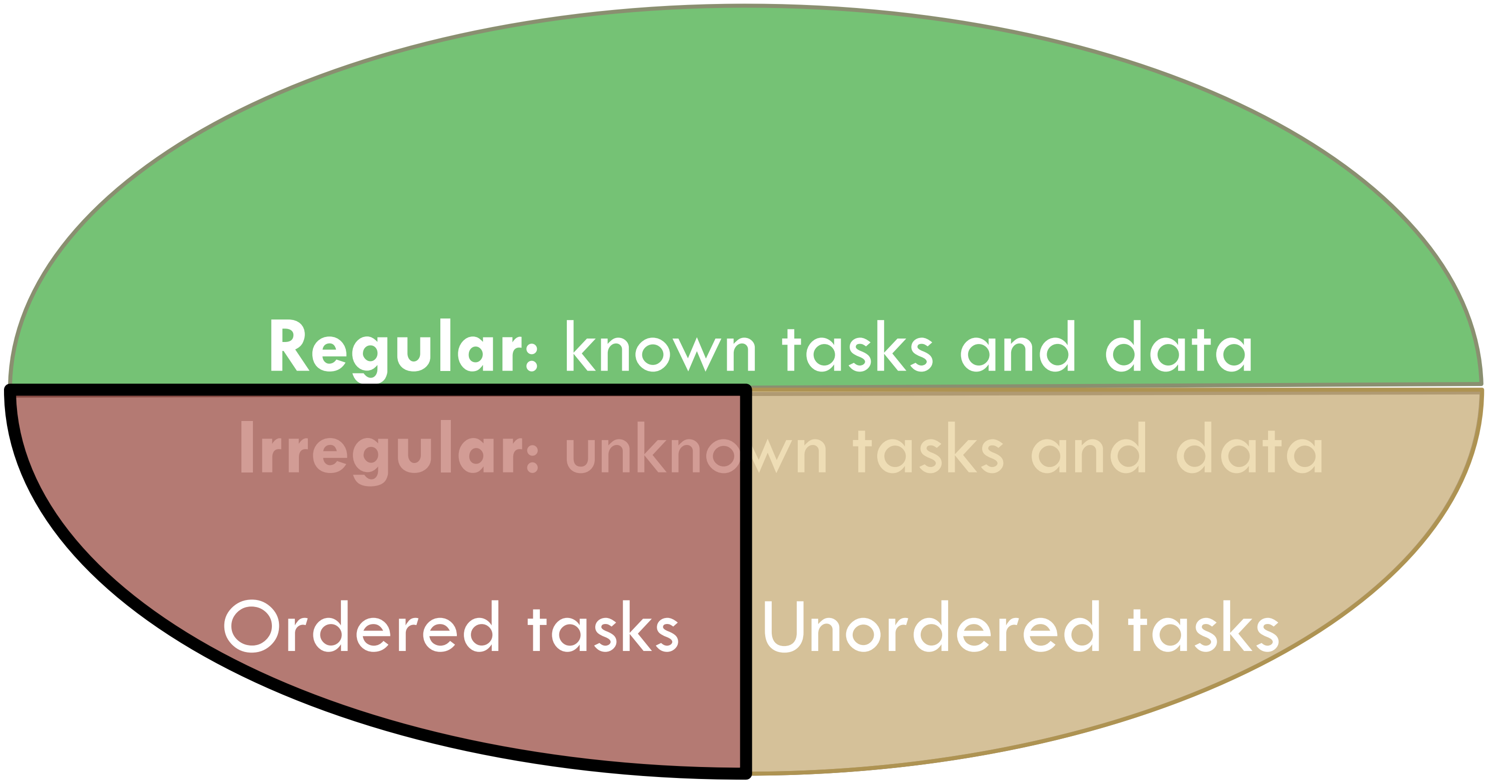
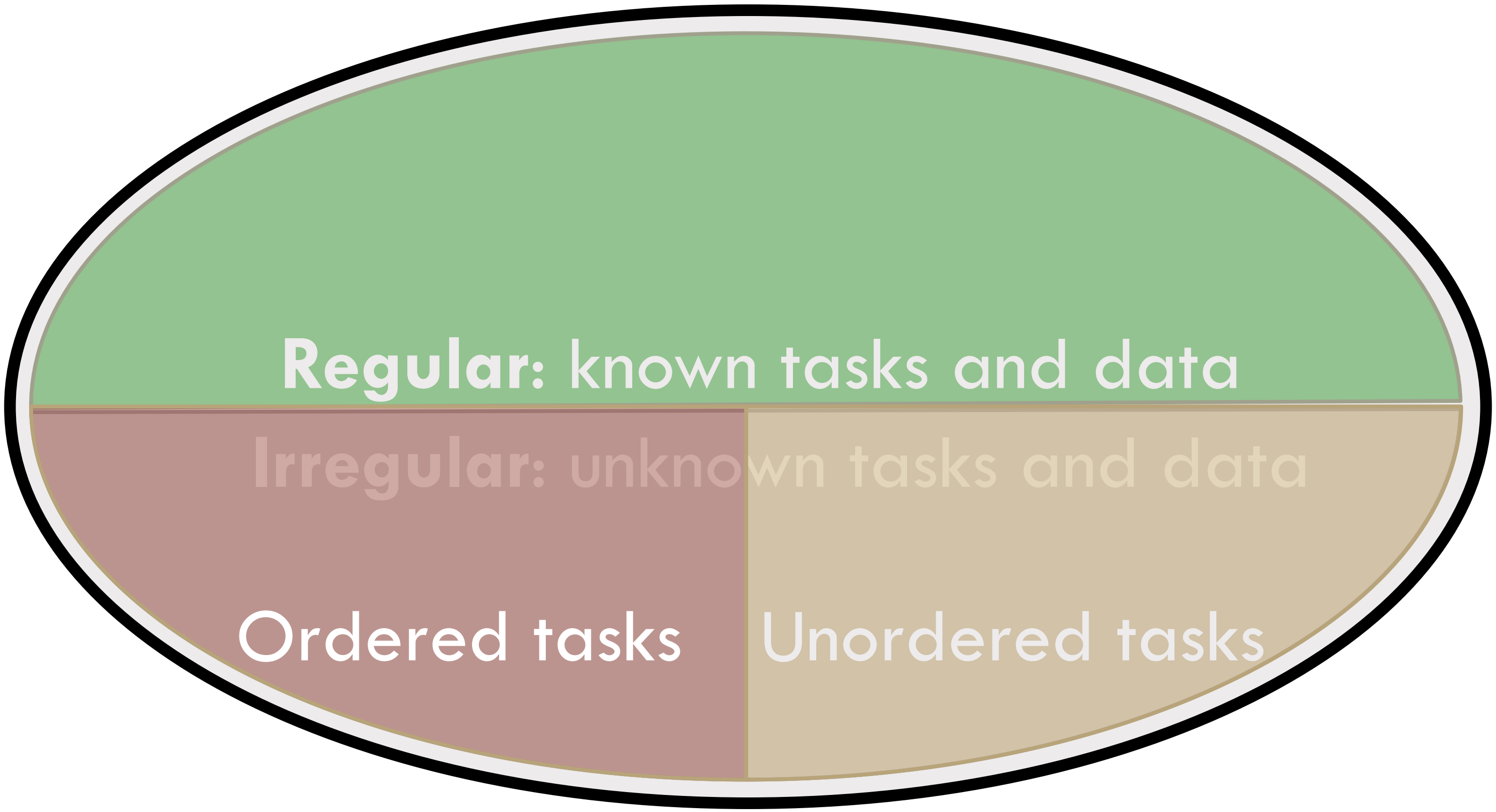


Ordering is a simple and general form of synchronization

Multicores Target Easy Parallelism



Ordering is a simple and general form of synchronization

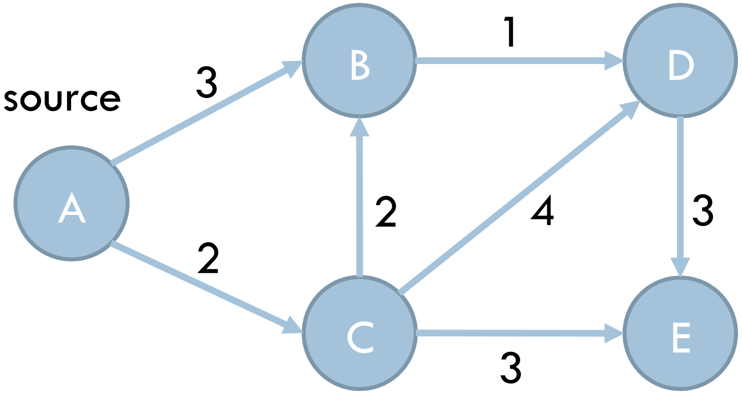
Support for **order** enables widespread parallelism

Outline

- Understanding Ordered Parallelism
- Swarm
- Evaluation

Example: Parallelism in Dijkstra's Algorithm

Finds shortest-path tree on a graph with weighted edges



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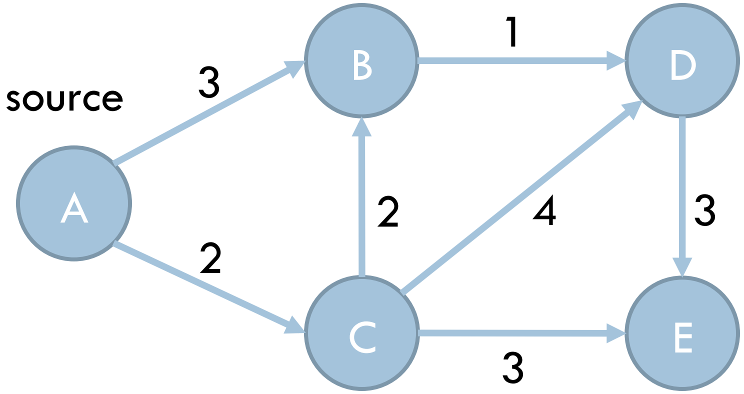

Tasks

A

0 1 2 3 4 5 6 7 8

Order = Distance from source node

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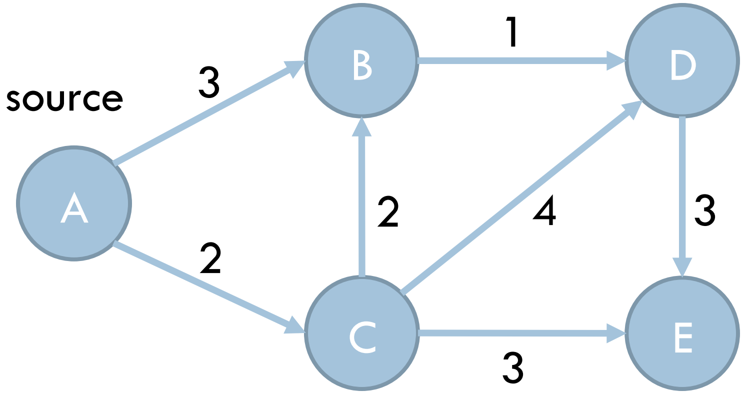

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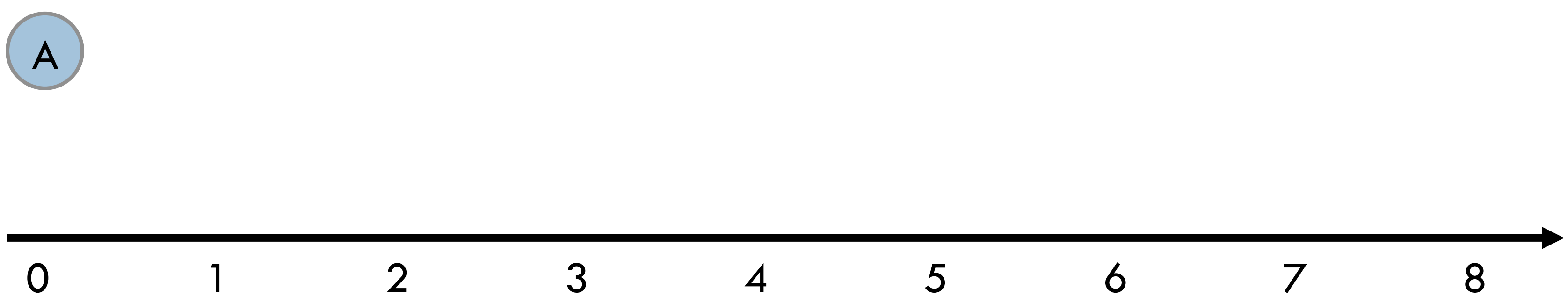

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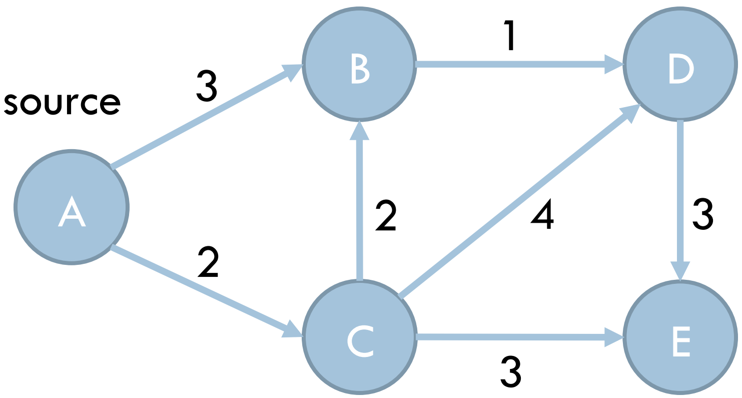

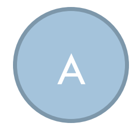

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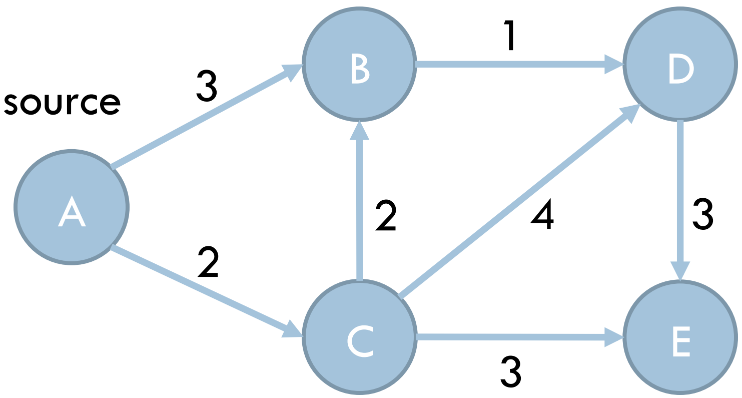

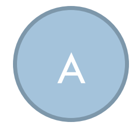

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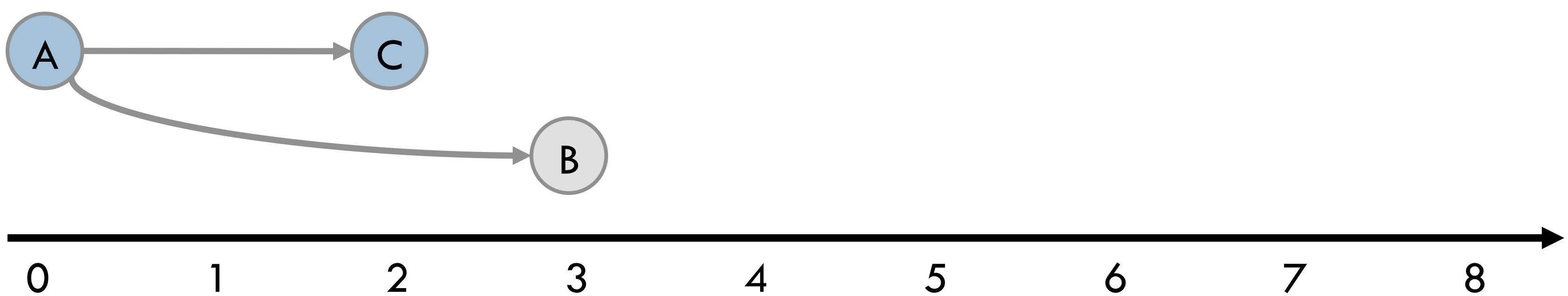

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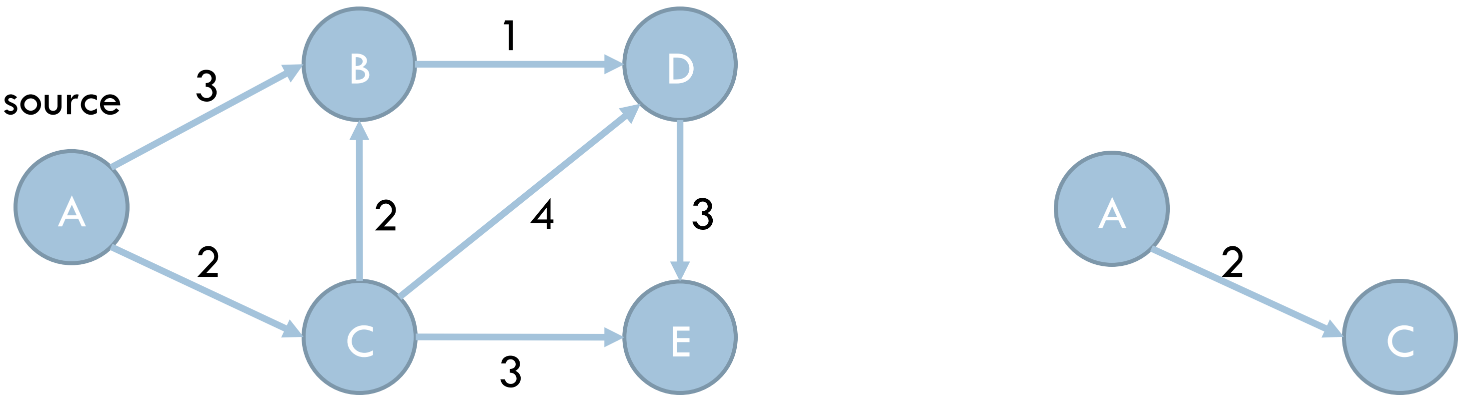

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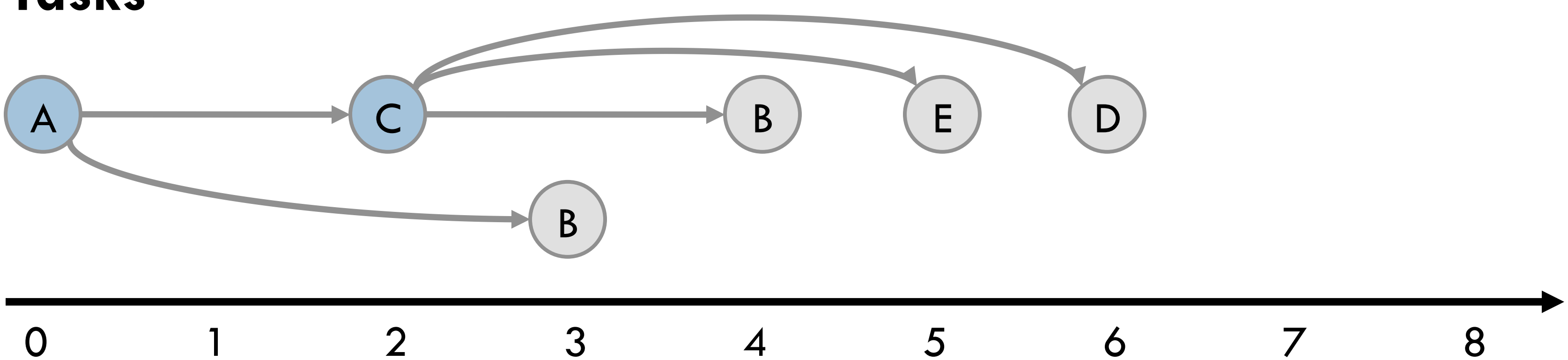

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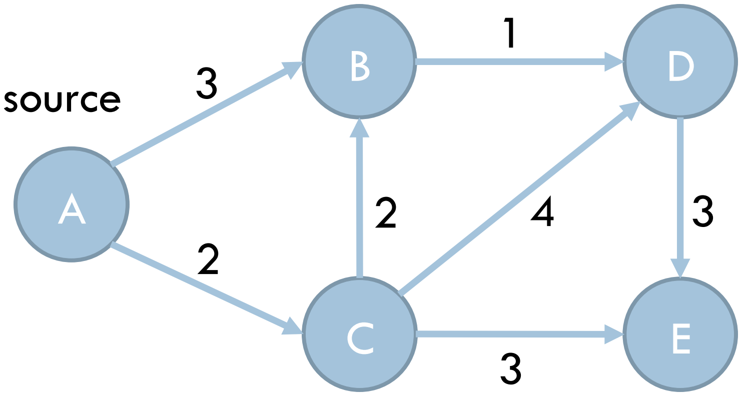

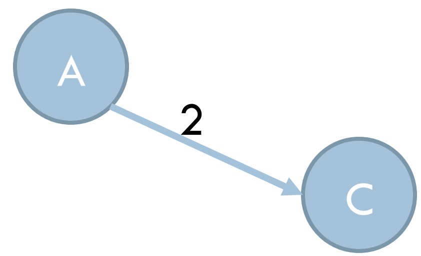

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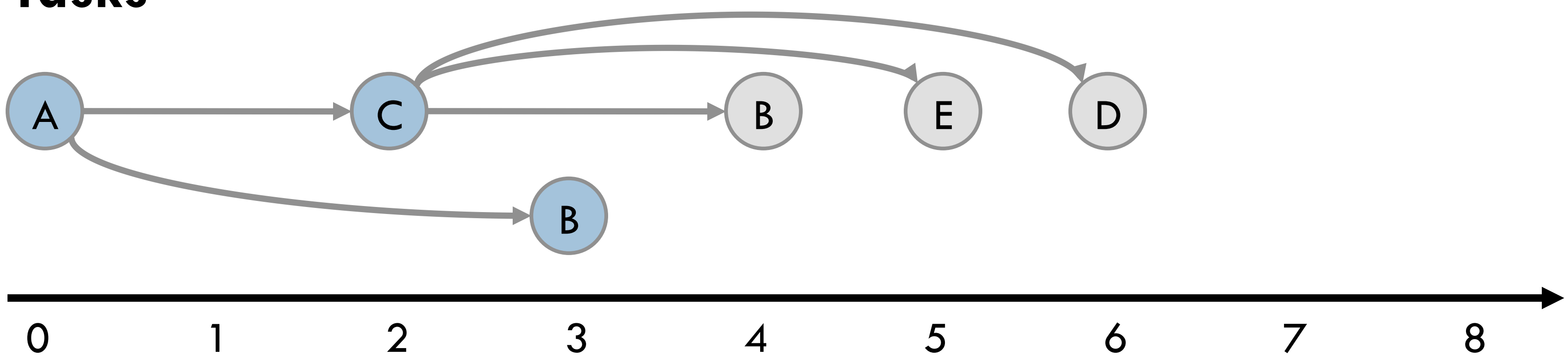

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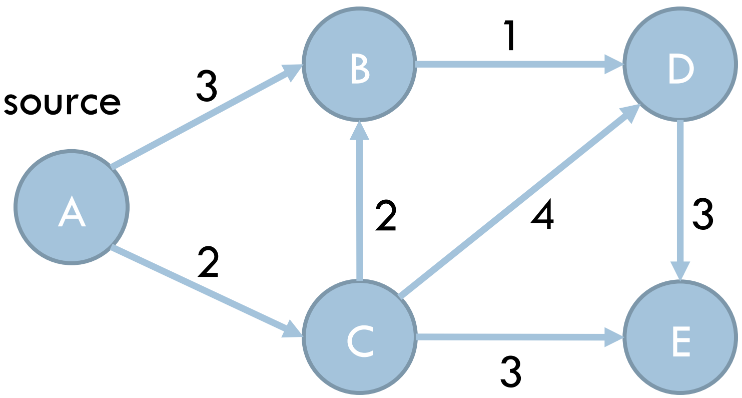

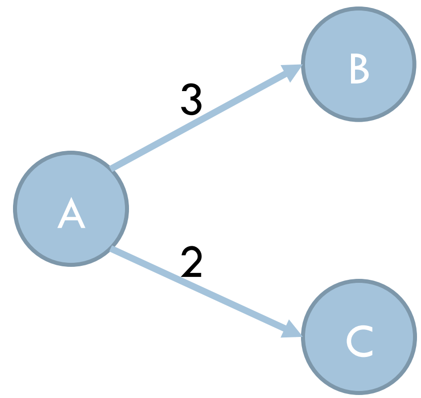

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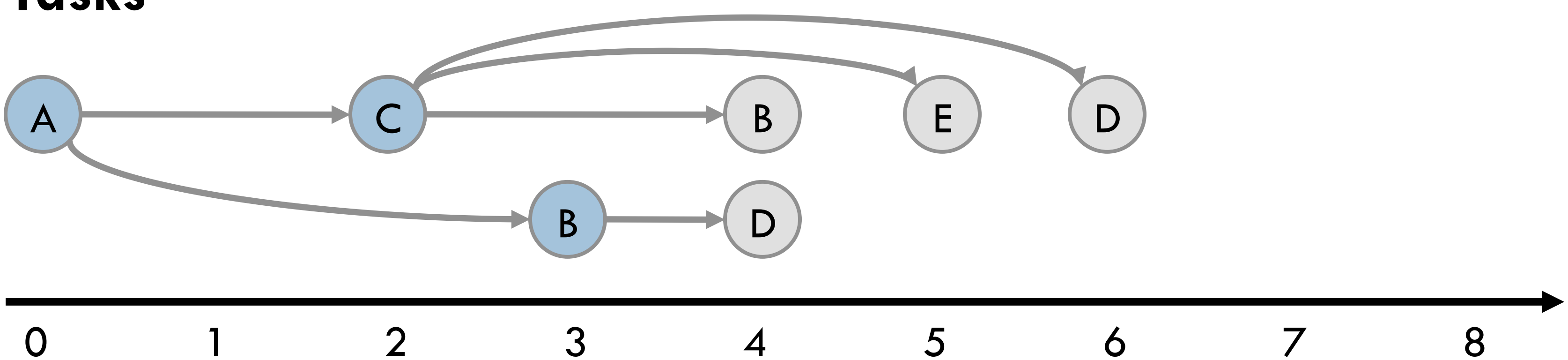

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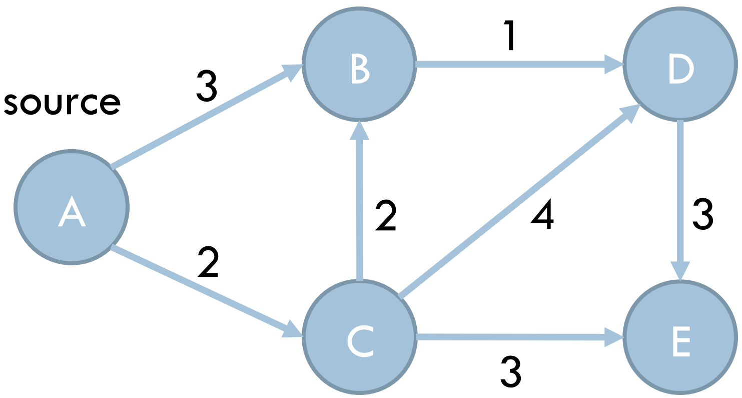

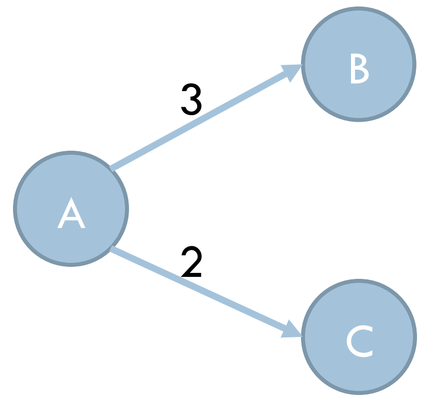

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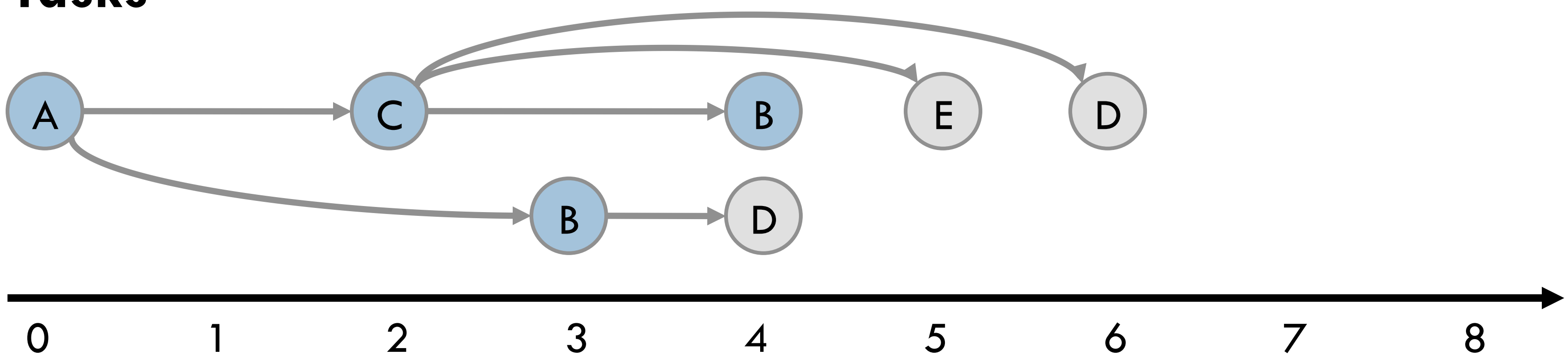

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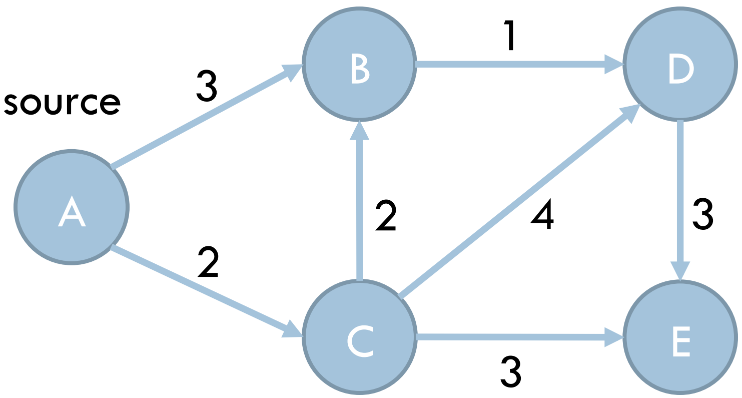

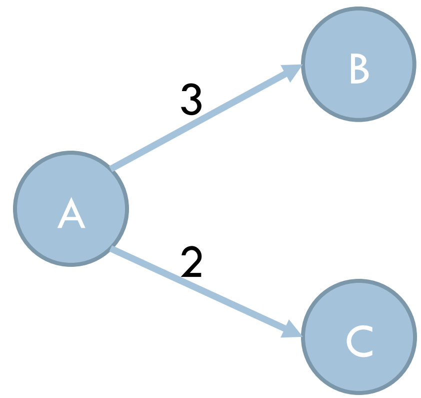

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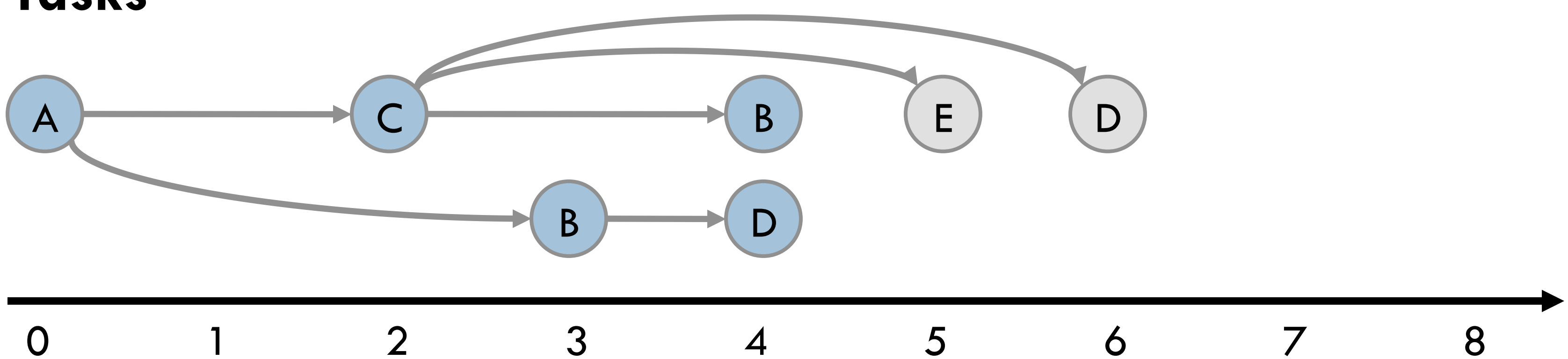

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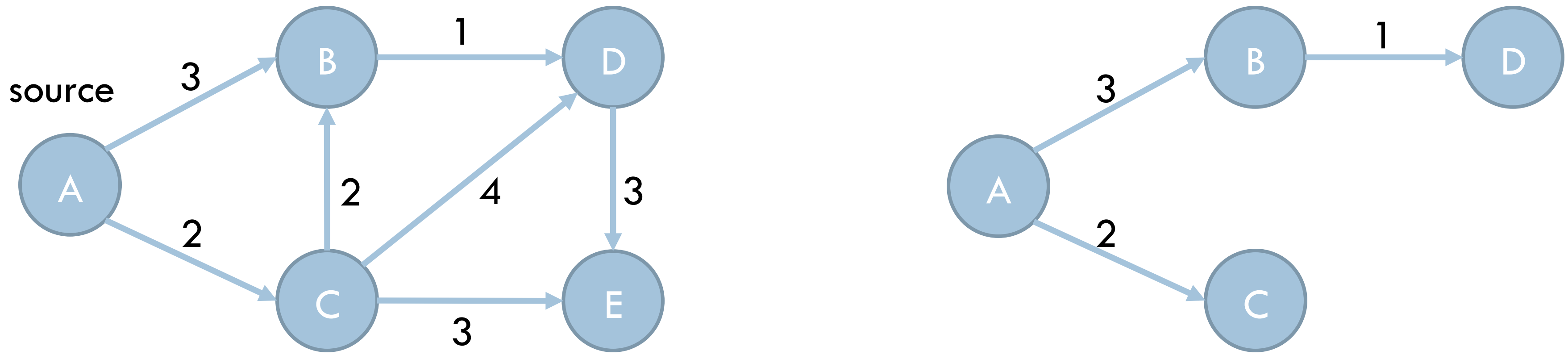

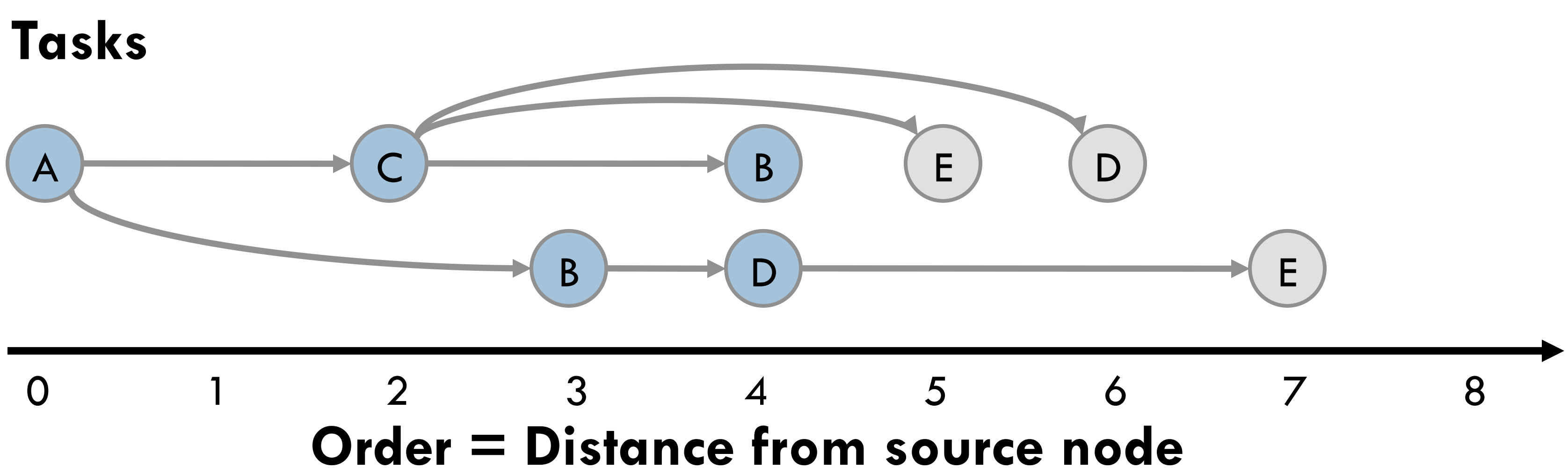

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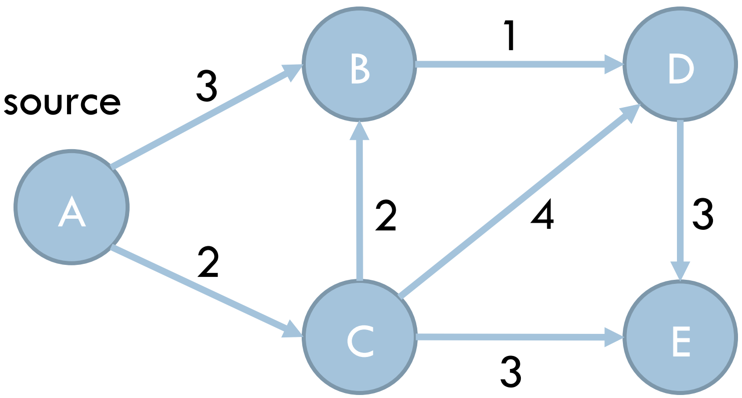

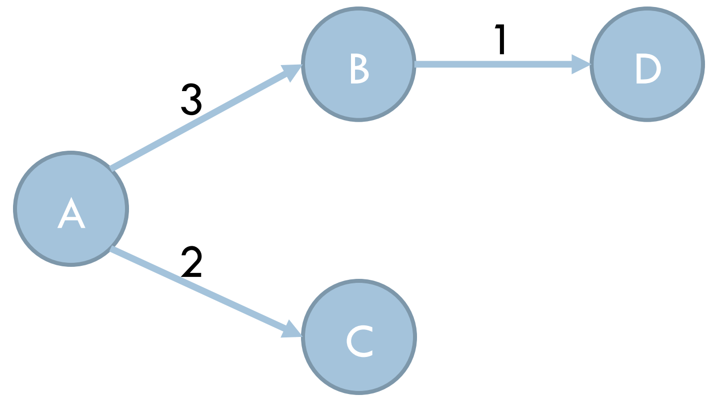

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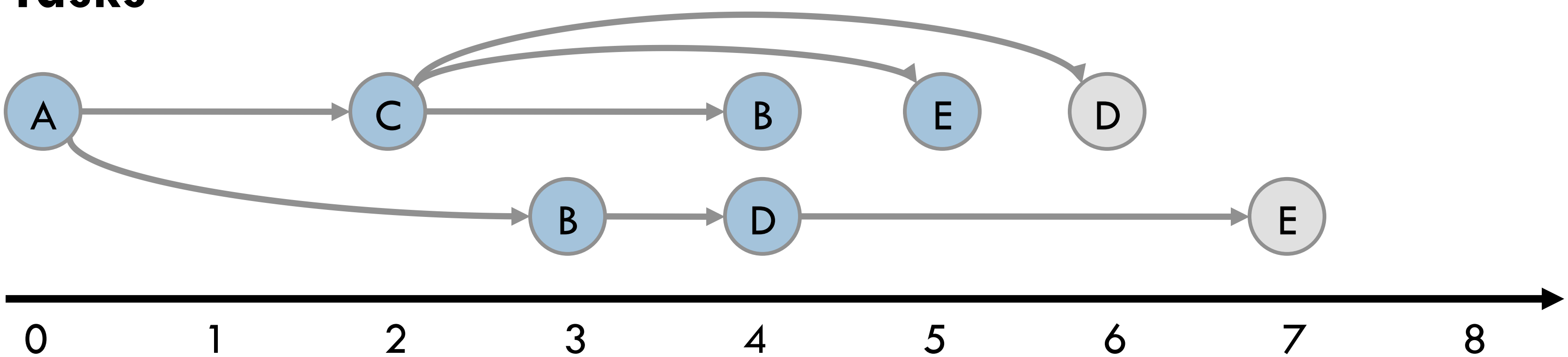

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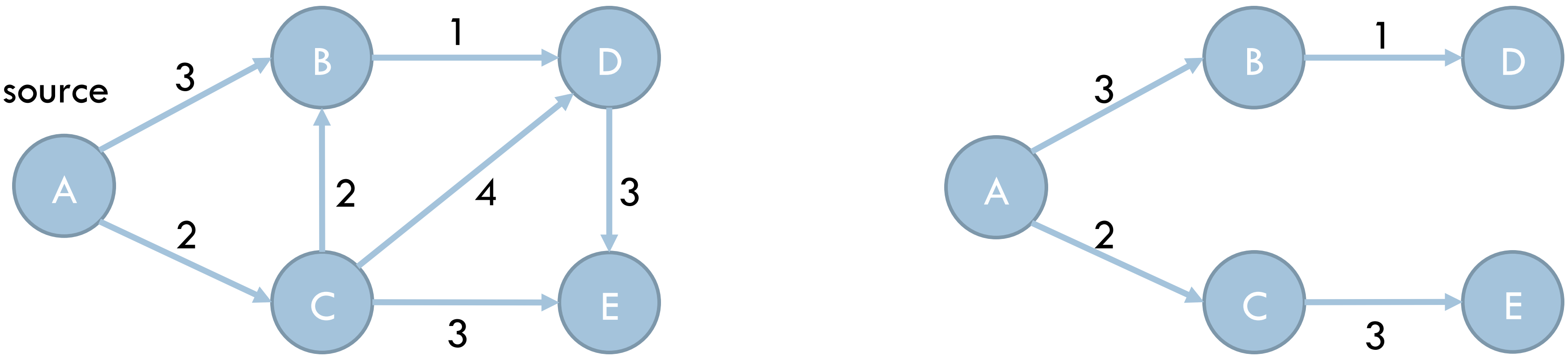

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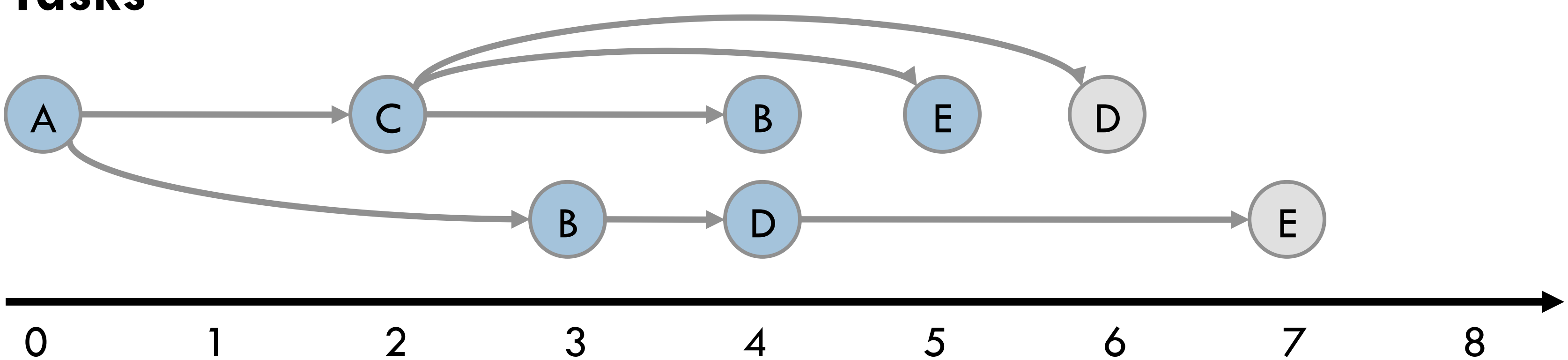

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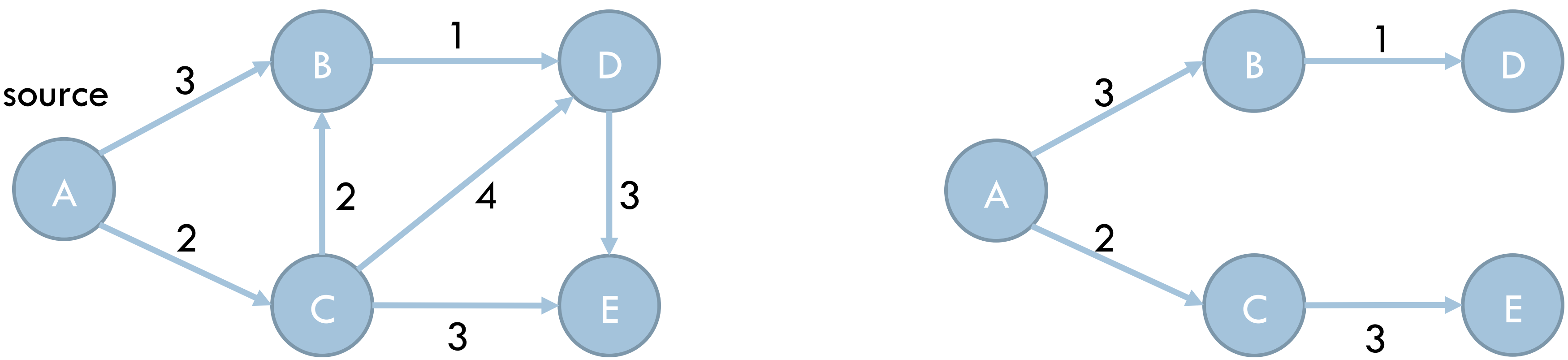

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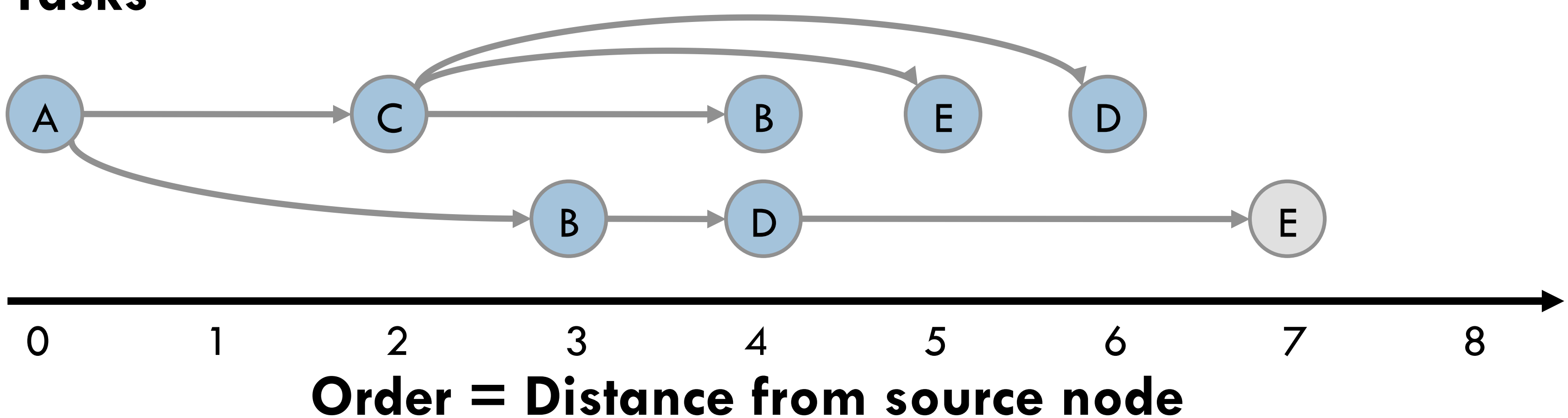

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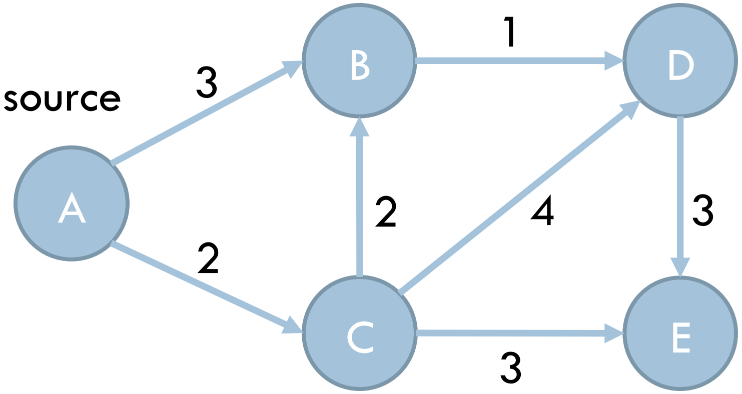

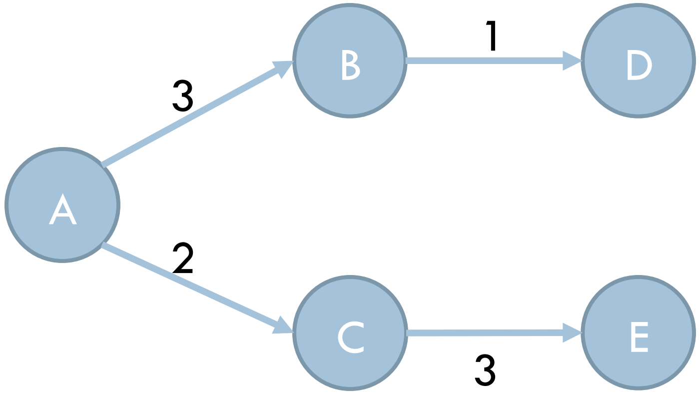

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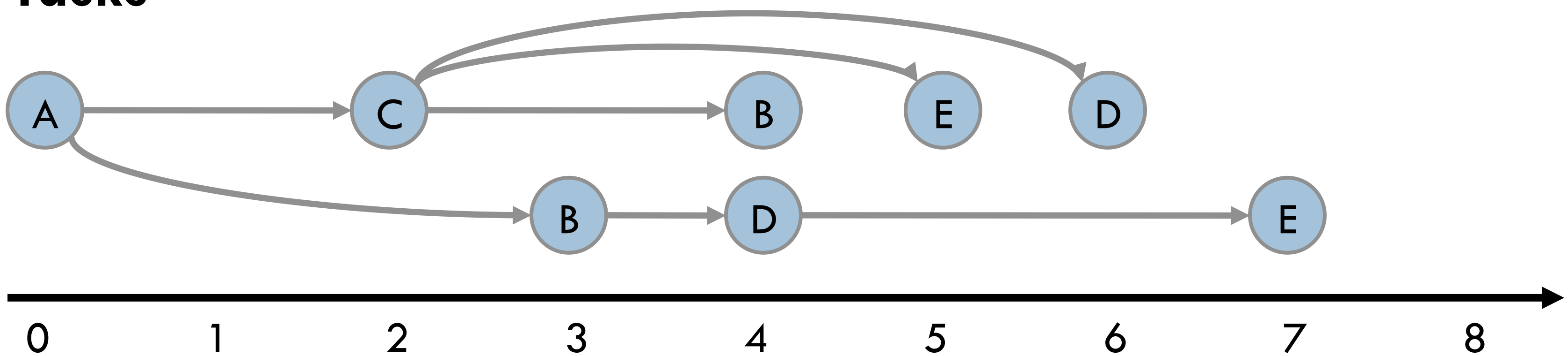

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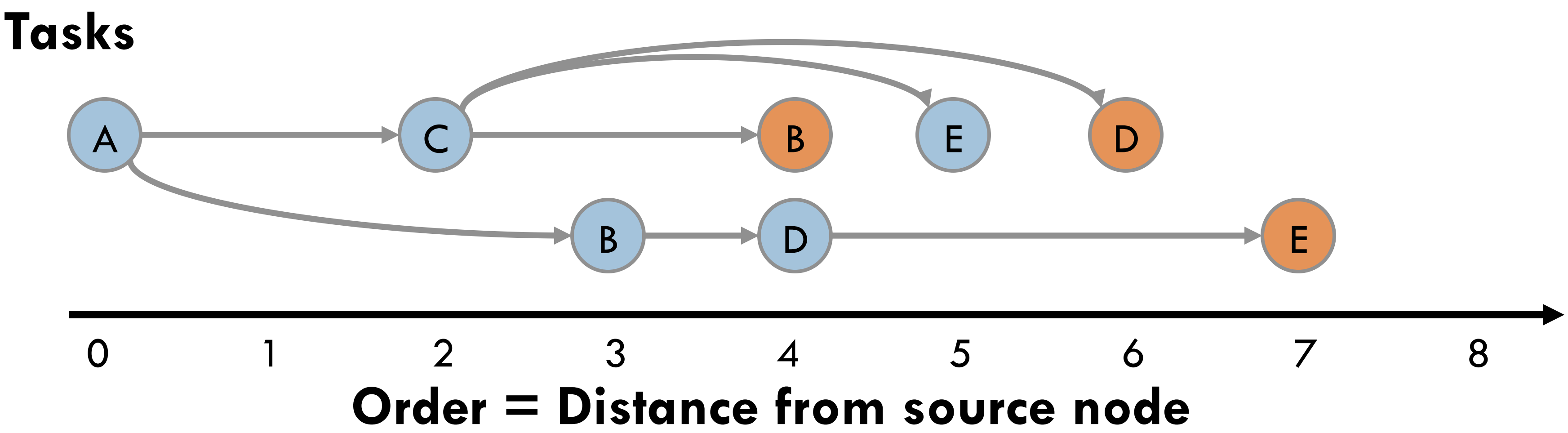
Parallelism in Dijkstra's Algorithm

Can execute independent tasks out of order



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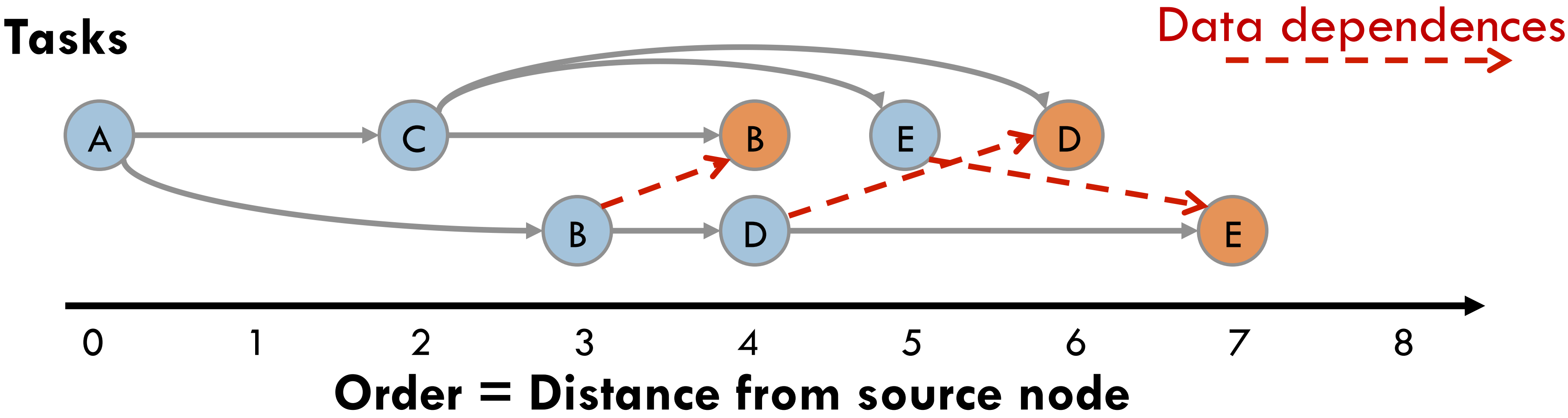

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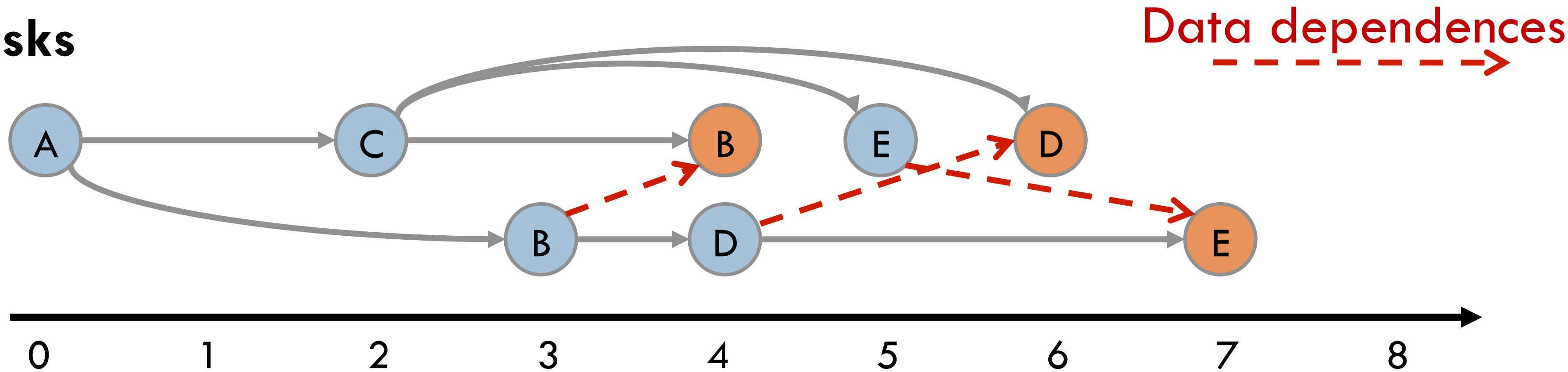
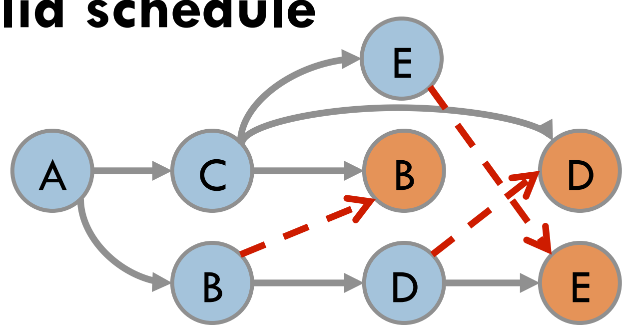


Order = Distance from source node

Valid schedule



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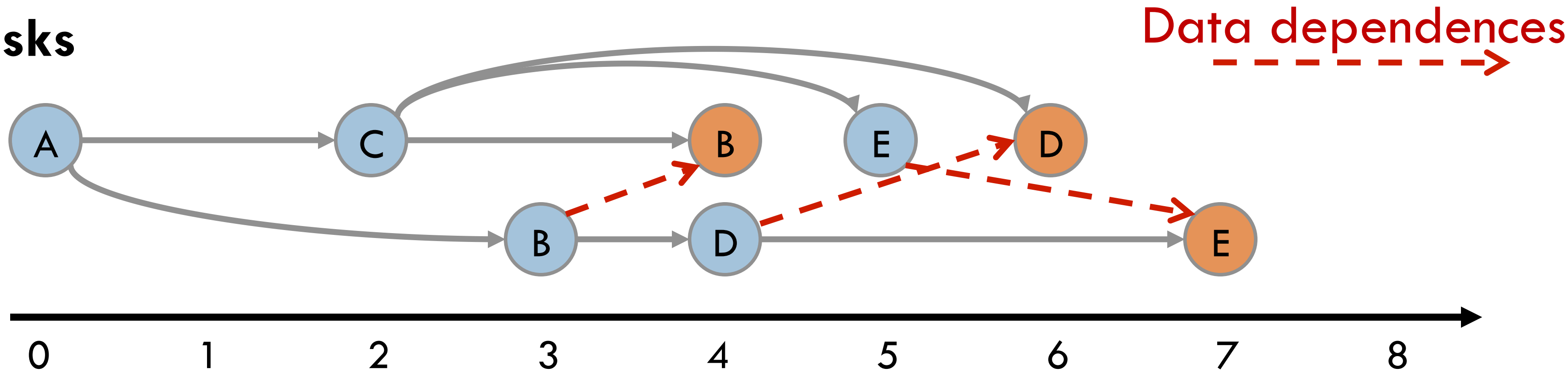

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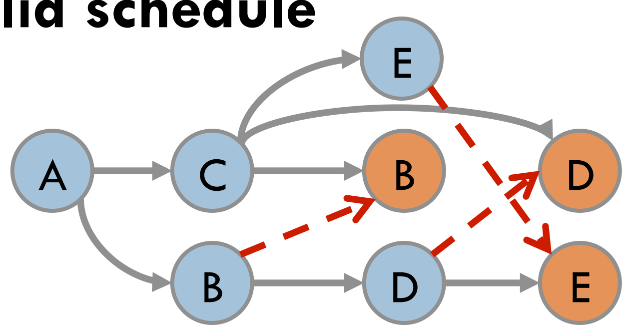

2x parallelism
(more in larger graphs)

Tasks and dependences unknown in advance

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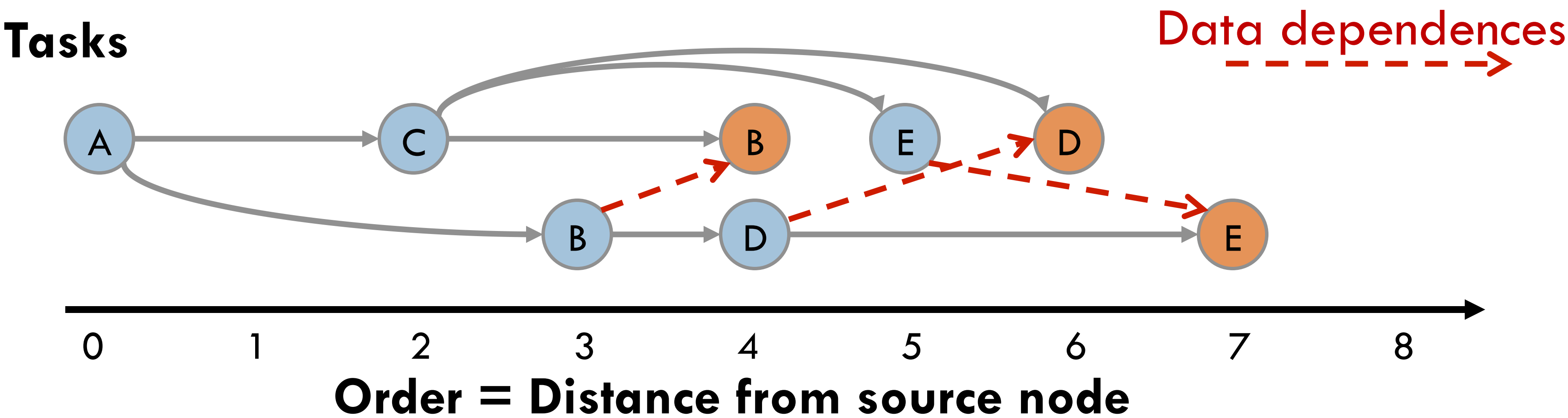

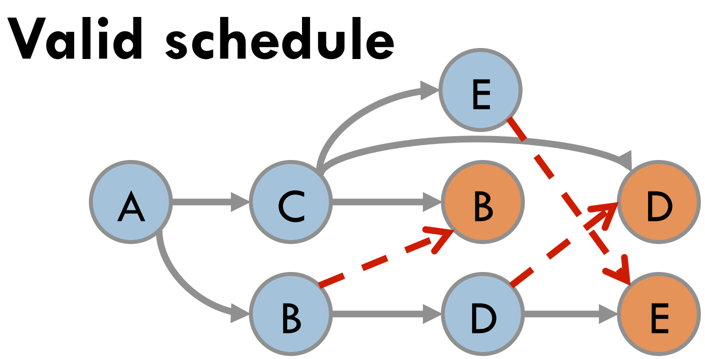

2x parallelism (more in larger graphs)

Tasks and dependences unknown in advance

Need speculative execution to elide order constraints

Insights about Ordered Parallelism

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1. With perfect speculation, parallelism is plentiful

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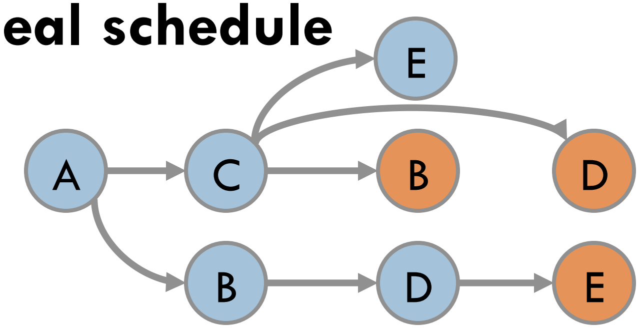
Ideal schedule



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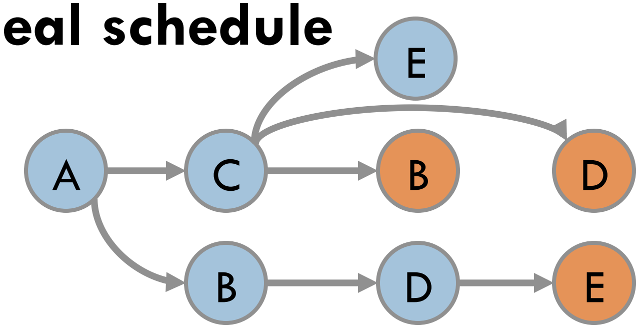

Parallelism	
max	800x

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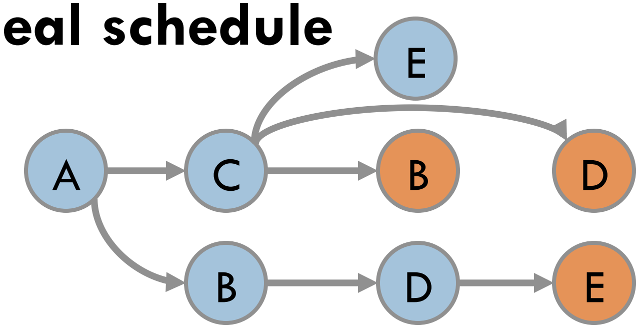

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2. Tasks are tiny: 32 instructions on average

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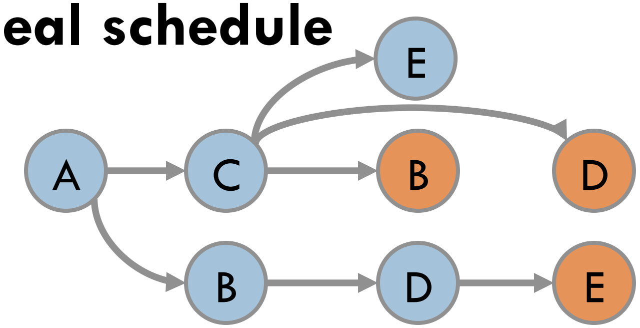

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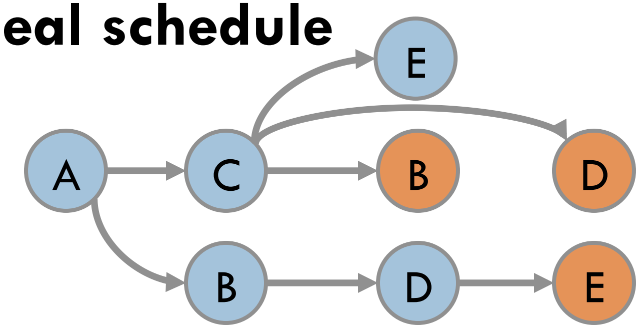

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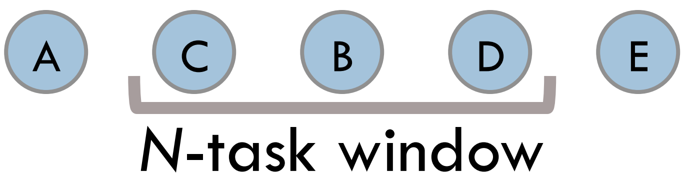

Can execute *N* tasks ahead of the earliest active task

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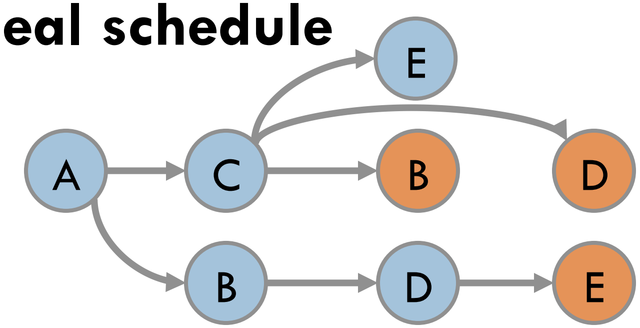

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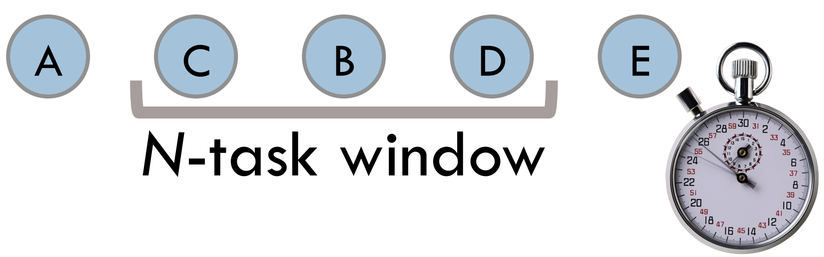

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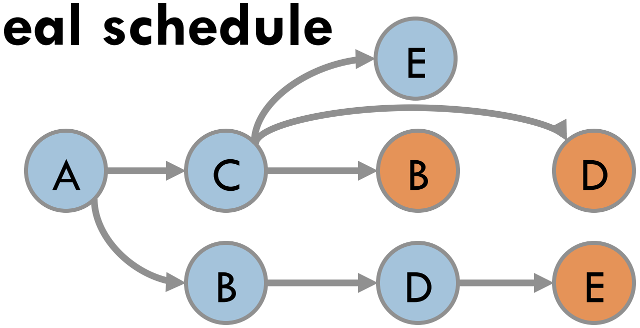

Parallelism	
max	800x
window=64	26x

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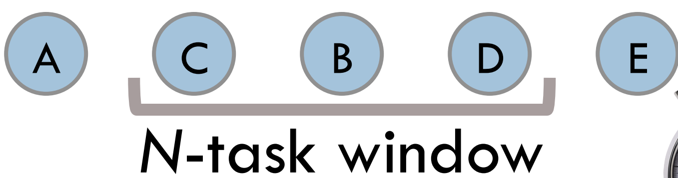

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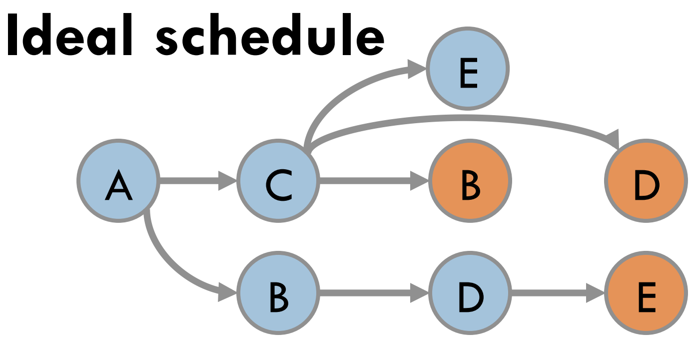

Parallelism	
max	800x
window=64	26x
window=1k	180x

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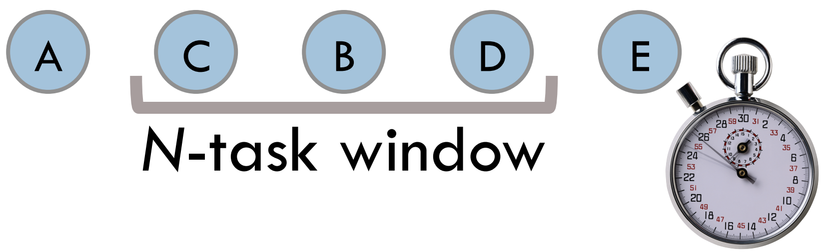

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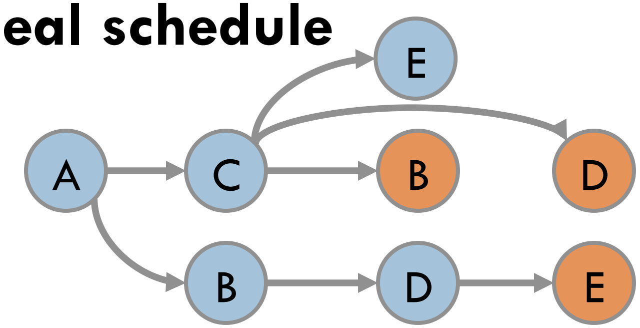

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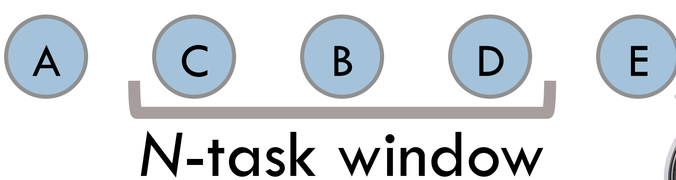

Can execute *N* tasks ahead of the earliest active task

Need a large window of speculation

Prior Work Can't Mine Ordered Parallelism

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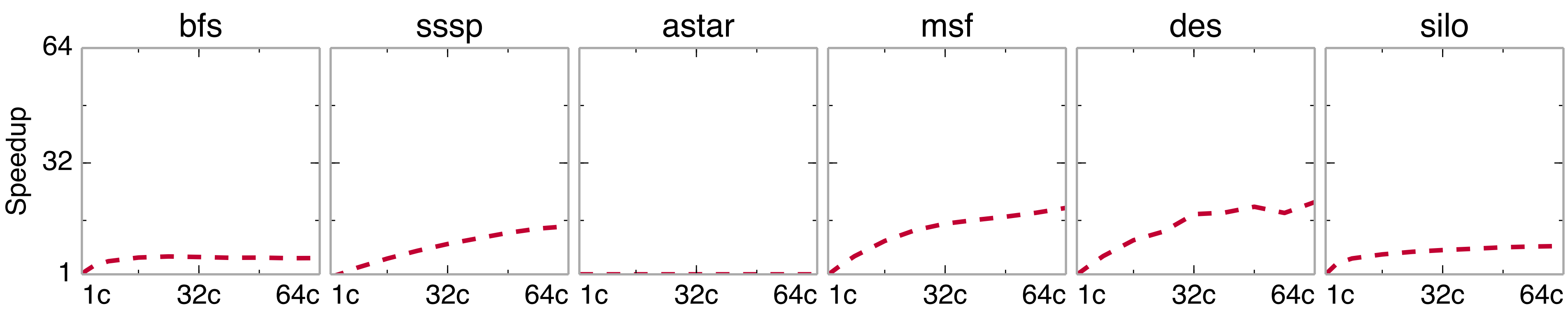
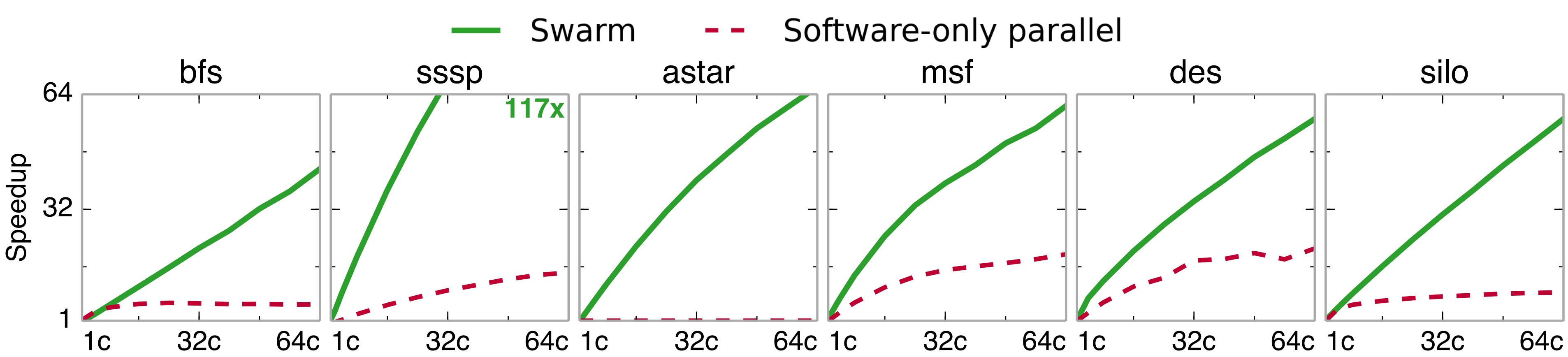


Swarm Mines Ordered Parallelism



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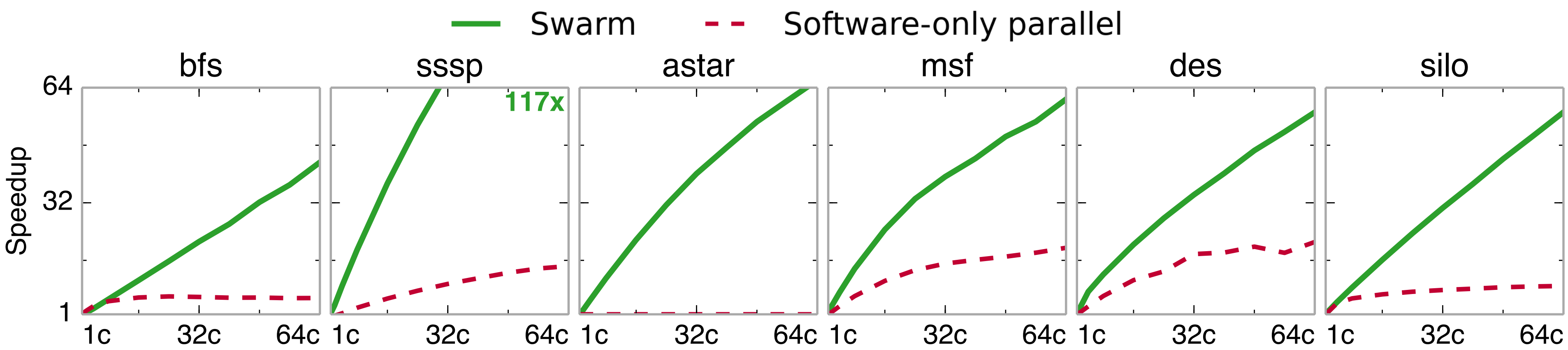

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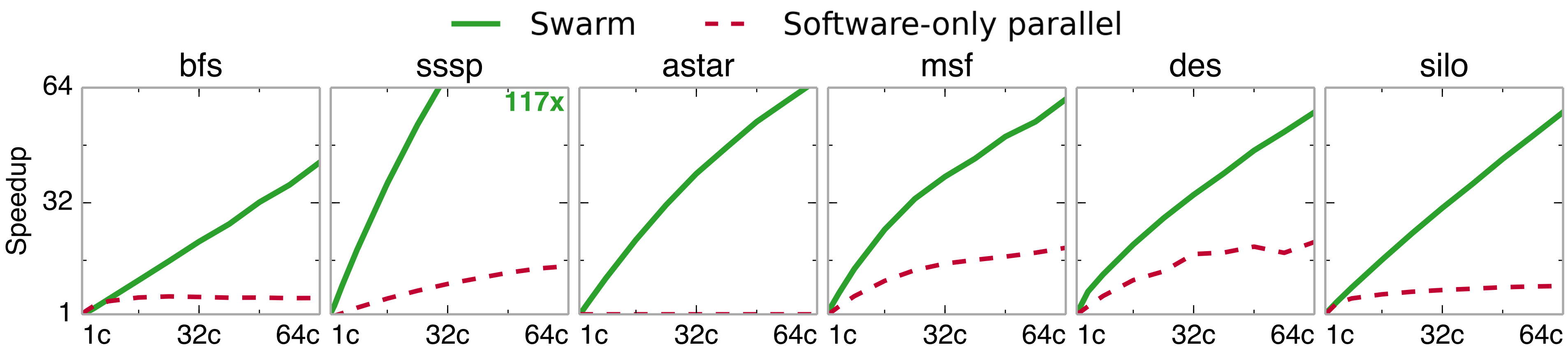

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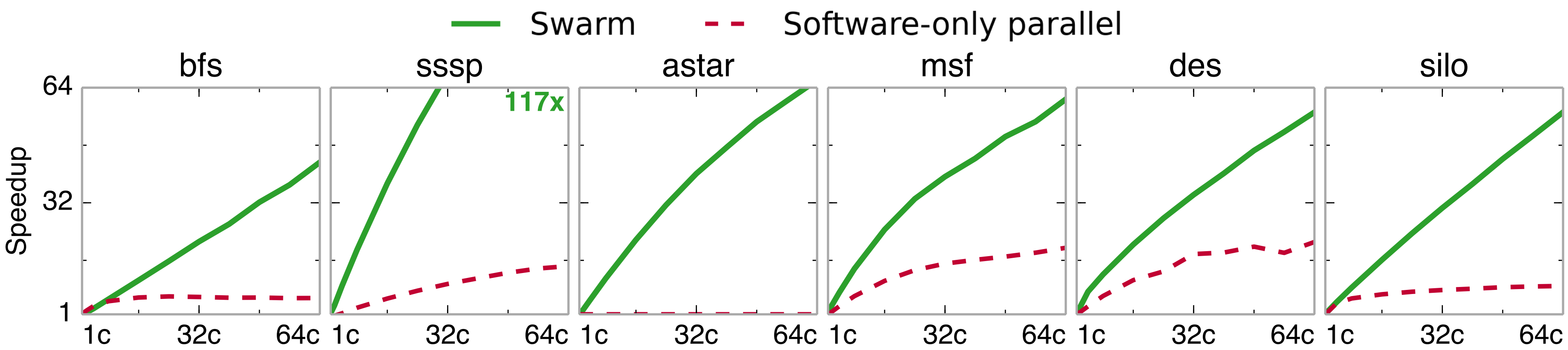

- Execution model based on timestamped tasks
- Architecture executes tasks speculatively out of order
  - Leverages execution model to scale

Outline

- Understanding Ordered Parallelism
- Swarm
- Evaluation

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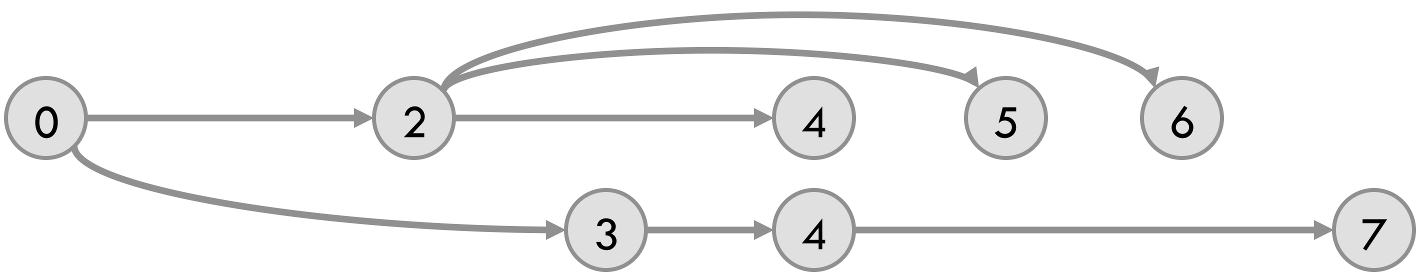

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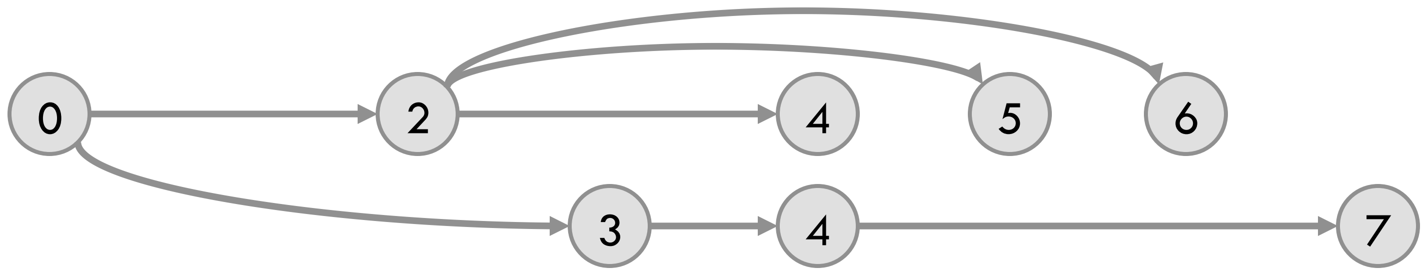

Conveys new work to hardware as soon as possible

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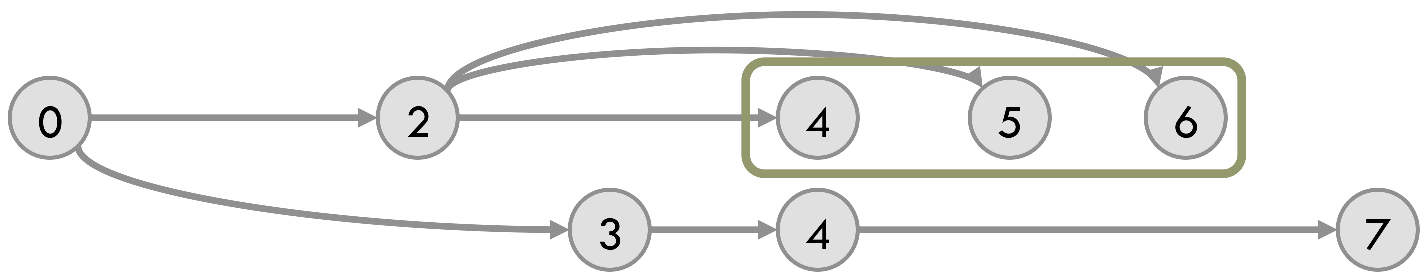

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Swarm Task Example: Dijkstra


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  if (!v.isVisited()) {
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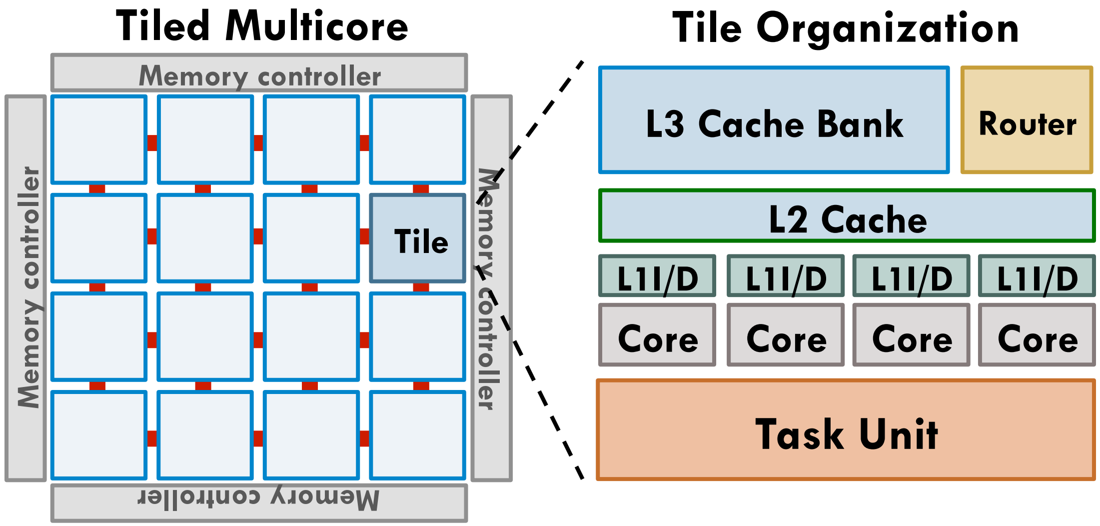
swarm::enqueue(ssspTask, 0, sourceVertex);
swarm::run();
```

Timestamp

Swarm Architecture Overview



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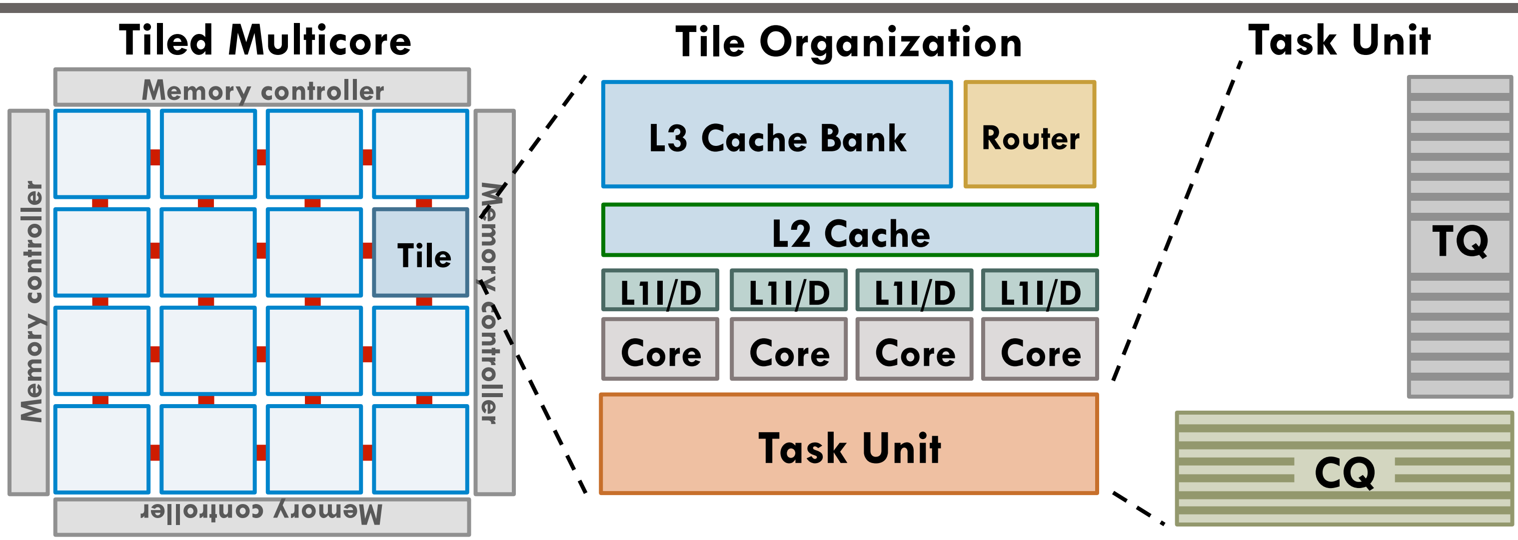

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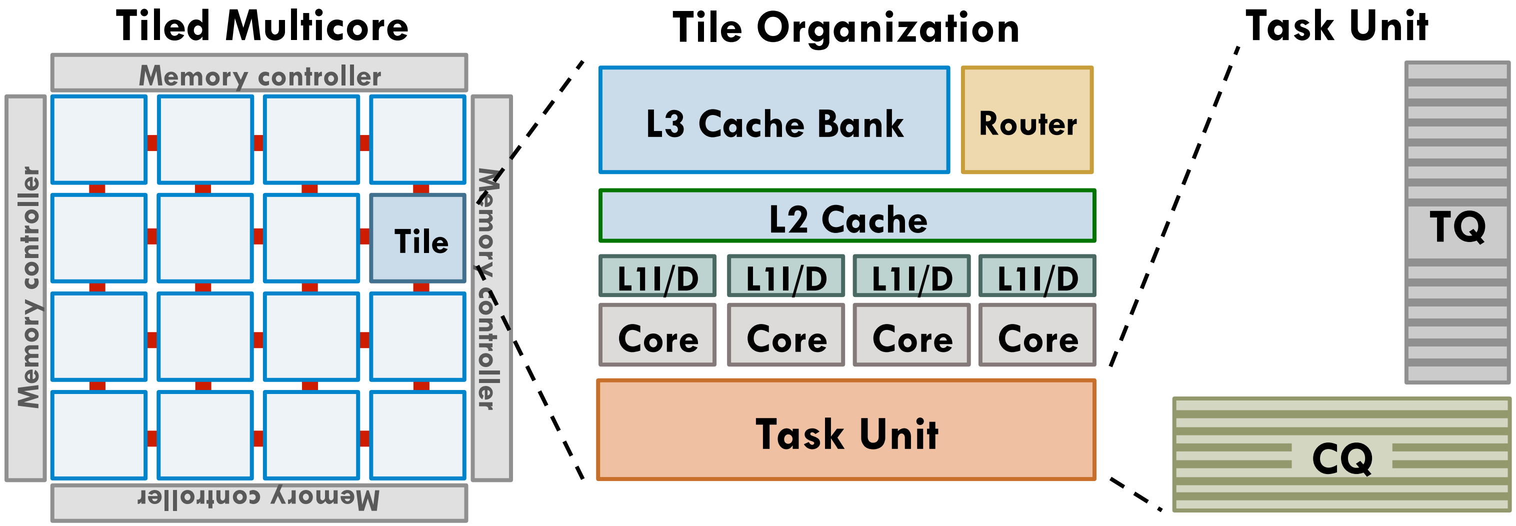

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Commit queues provide the window of speculation

Task Unit Queues

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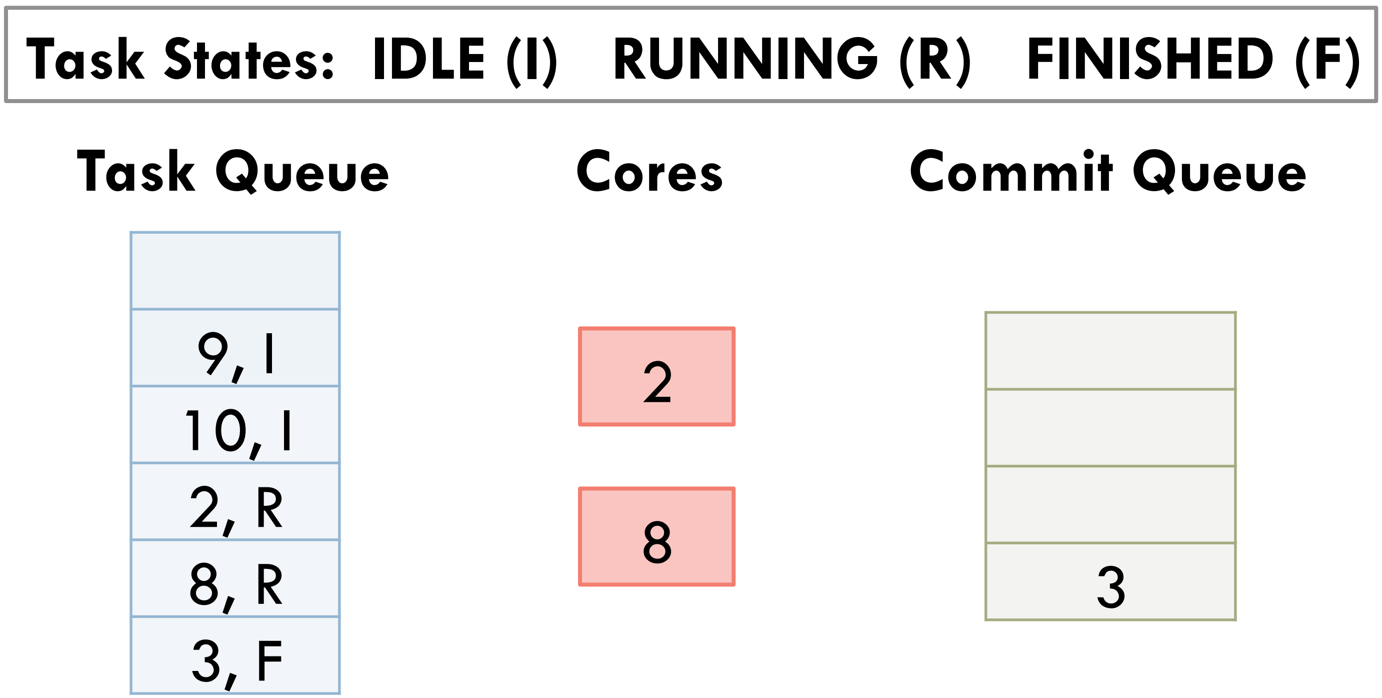

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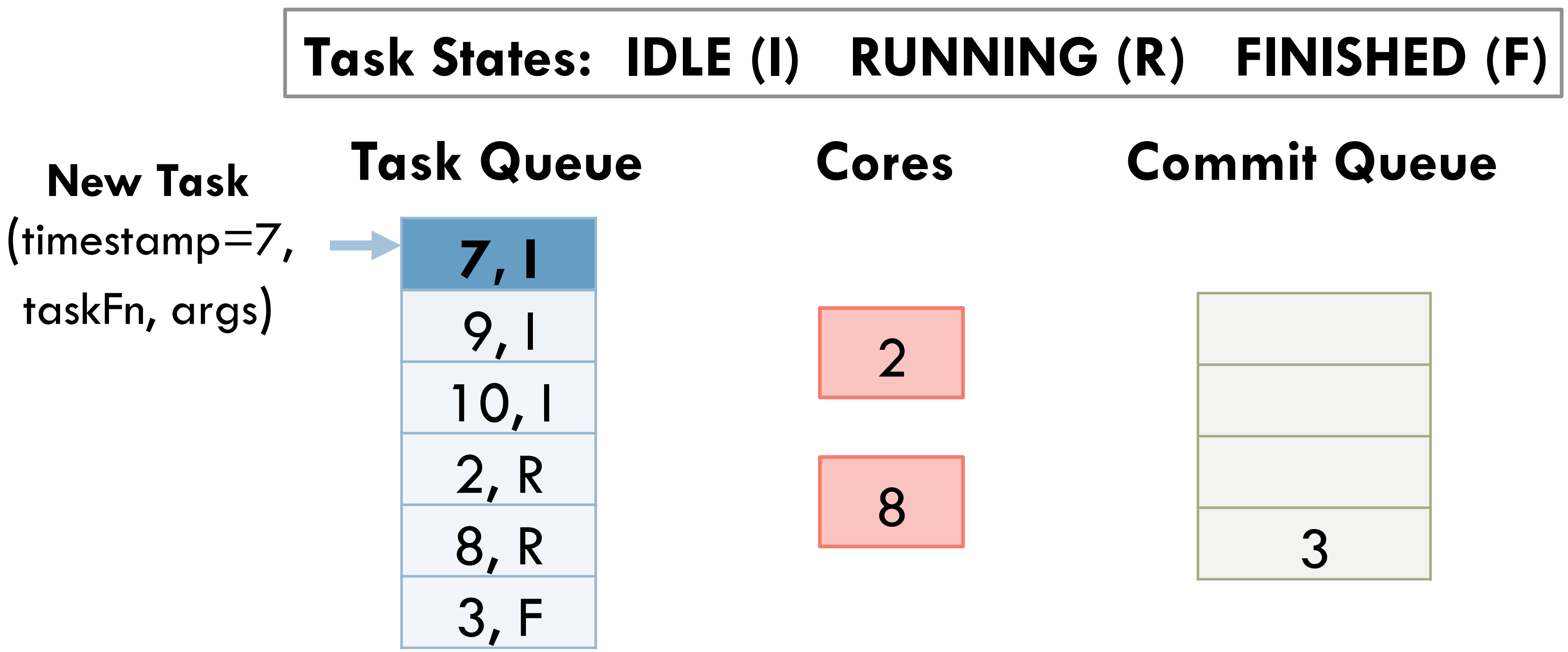

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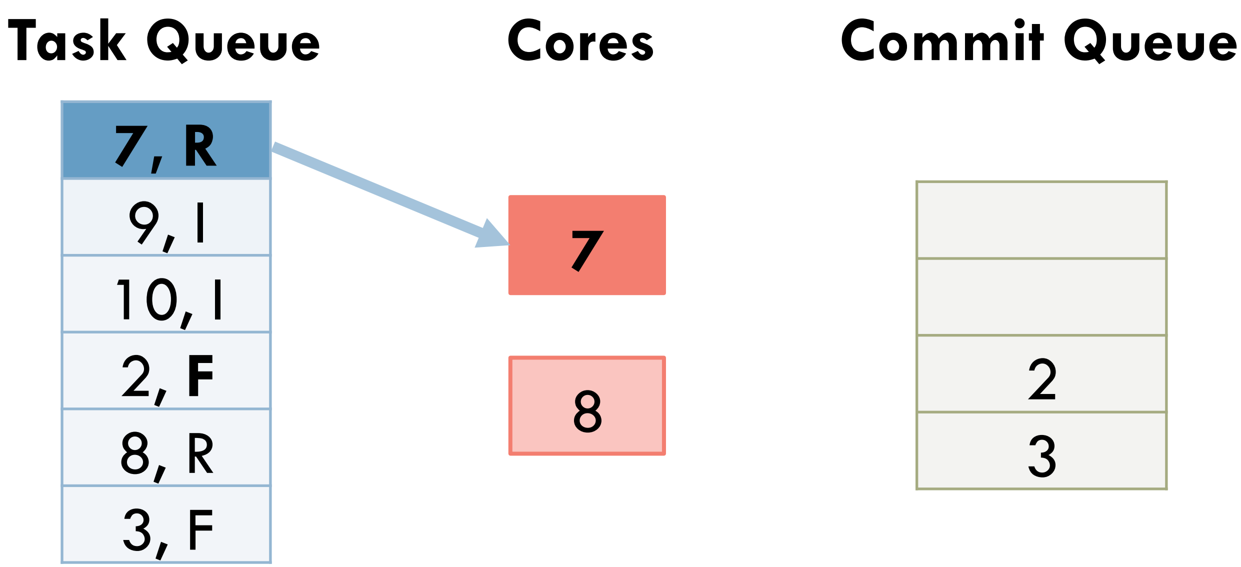

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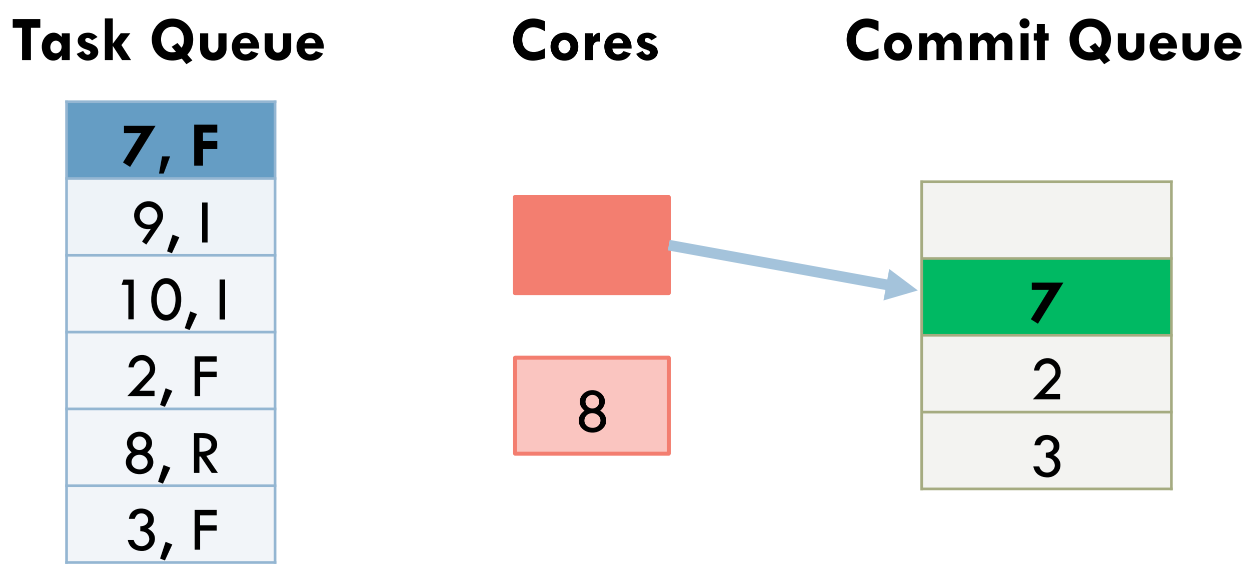

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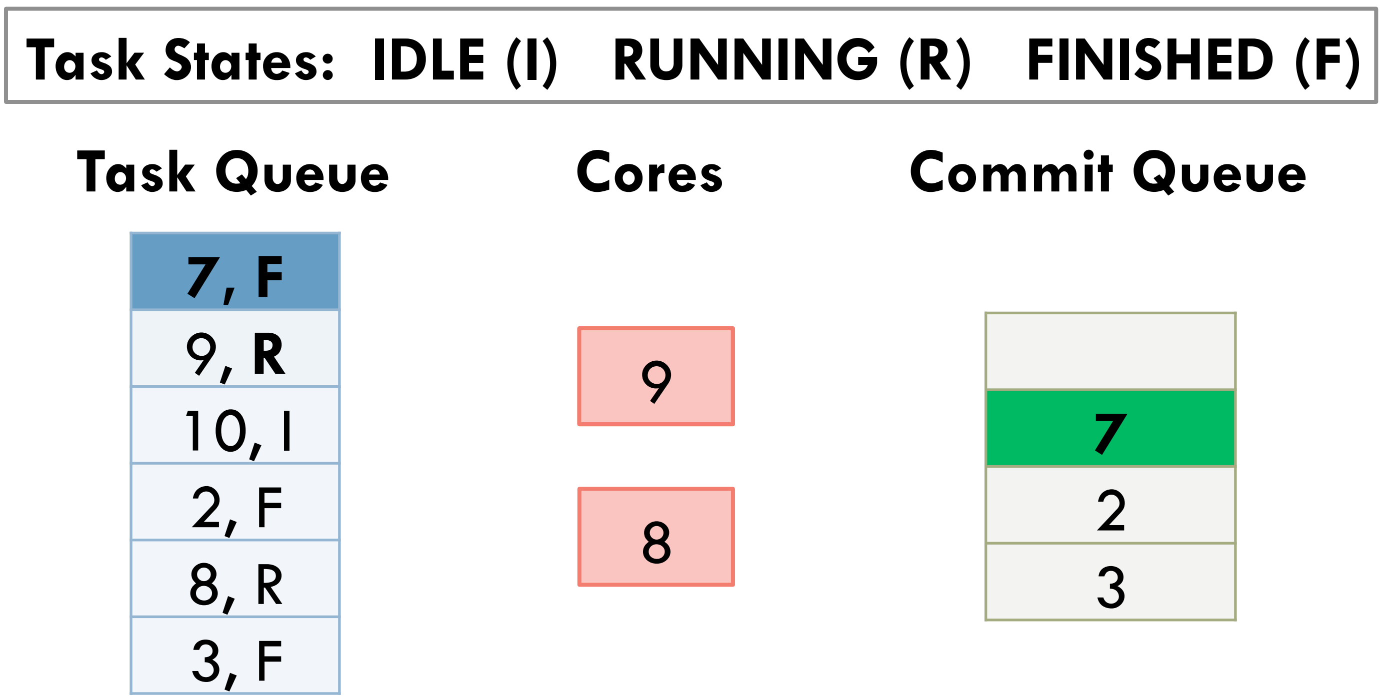

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Task Queue	Cores	Commit Queue
7, F		
9, **R**	9	
10, I		**7**
2, F	8	2
8, R		3
3, F		

Similar to a reorder buffer, but at the task level

High-Throughput Ordered Commits

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  - **1 task commit/cycle** to scale
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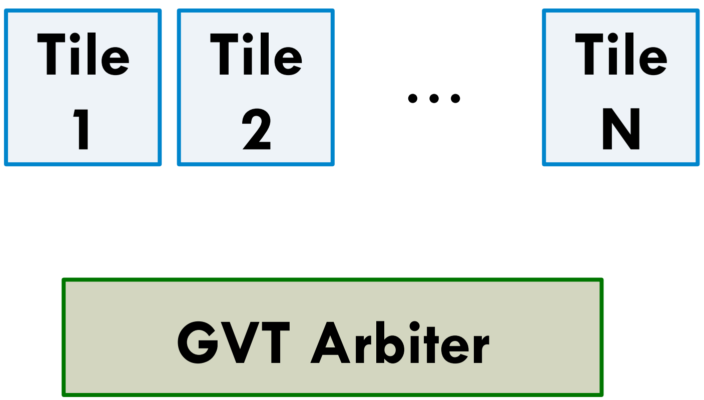

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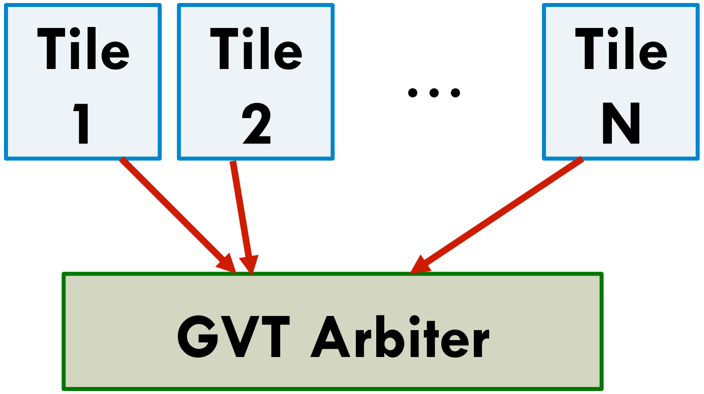

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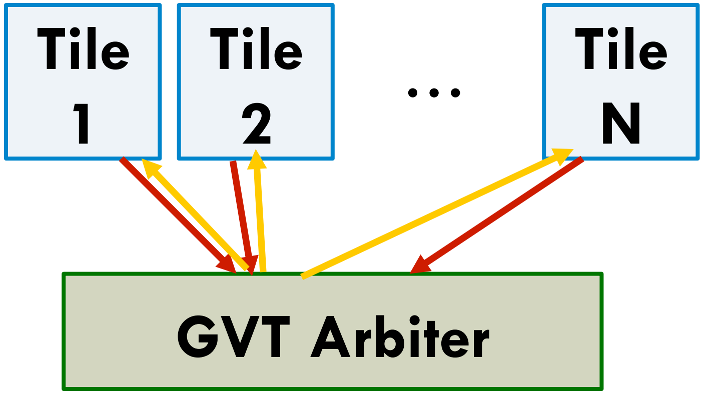

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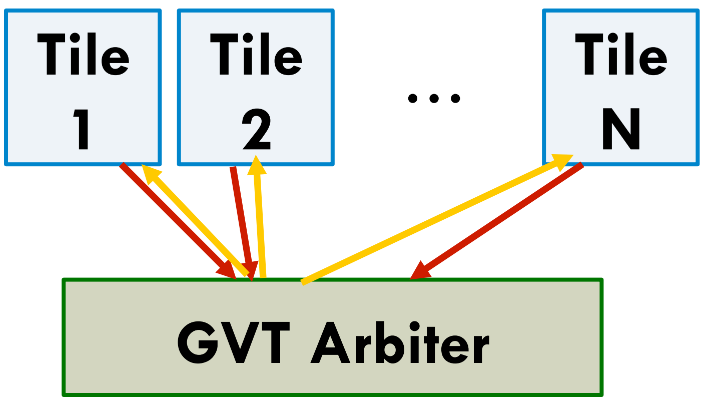

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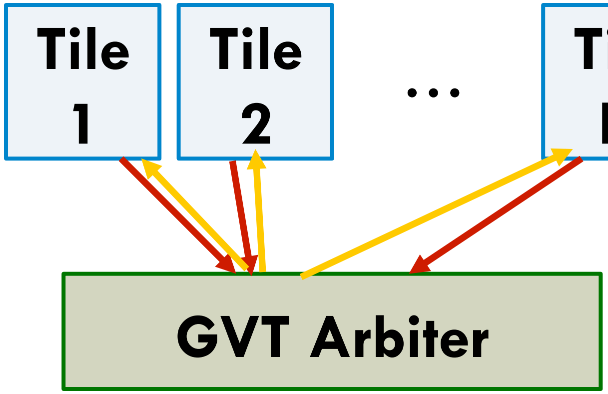

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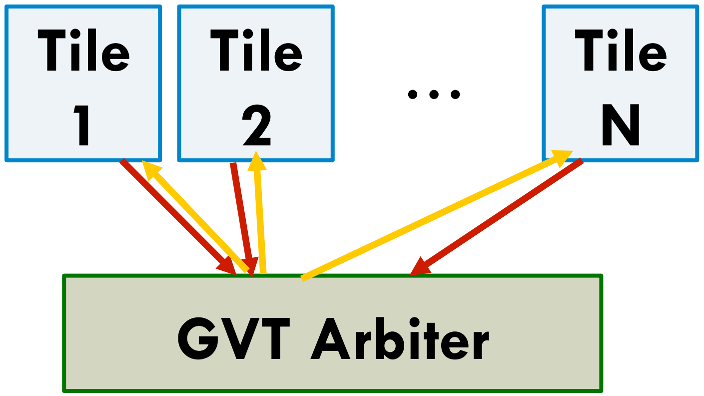

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Amortizes commit costs among many tasks

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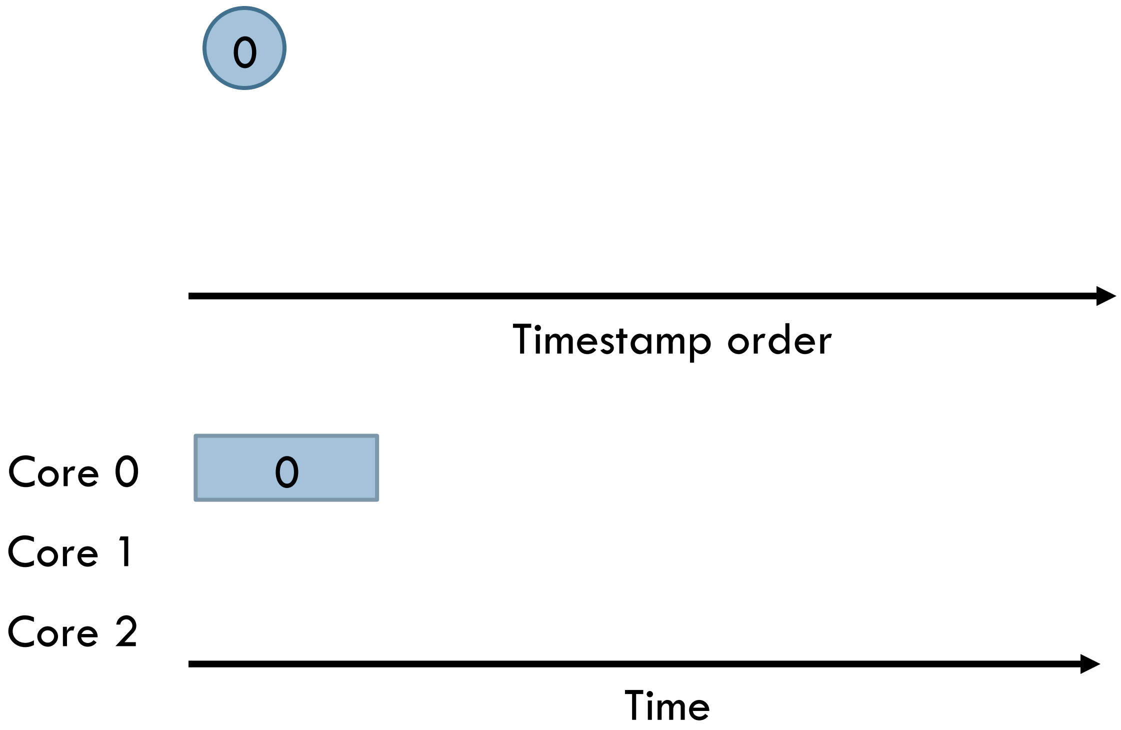

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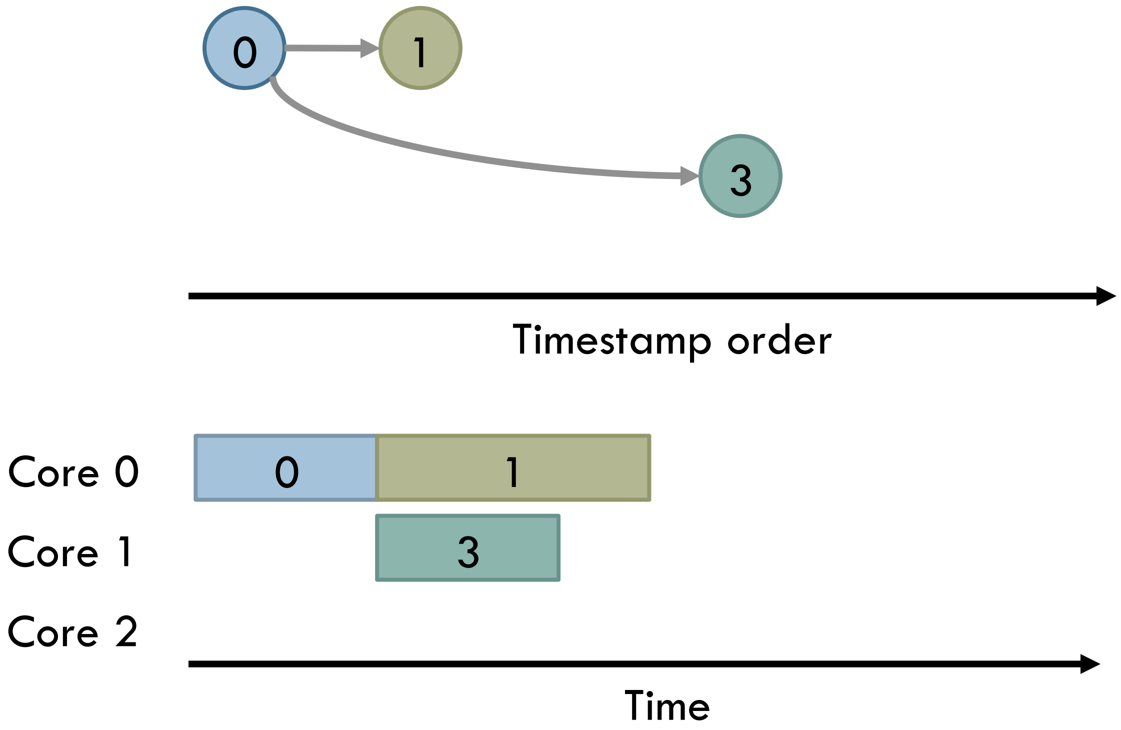

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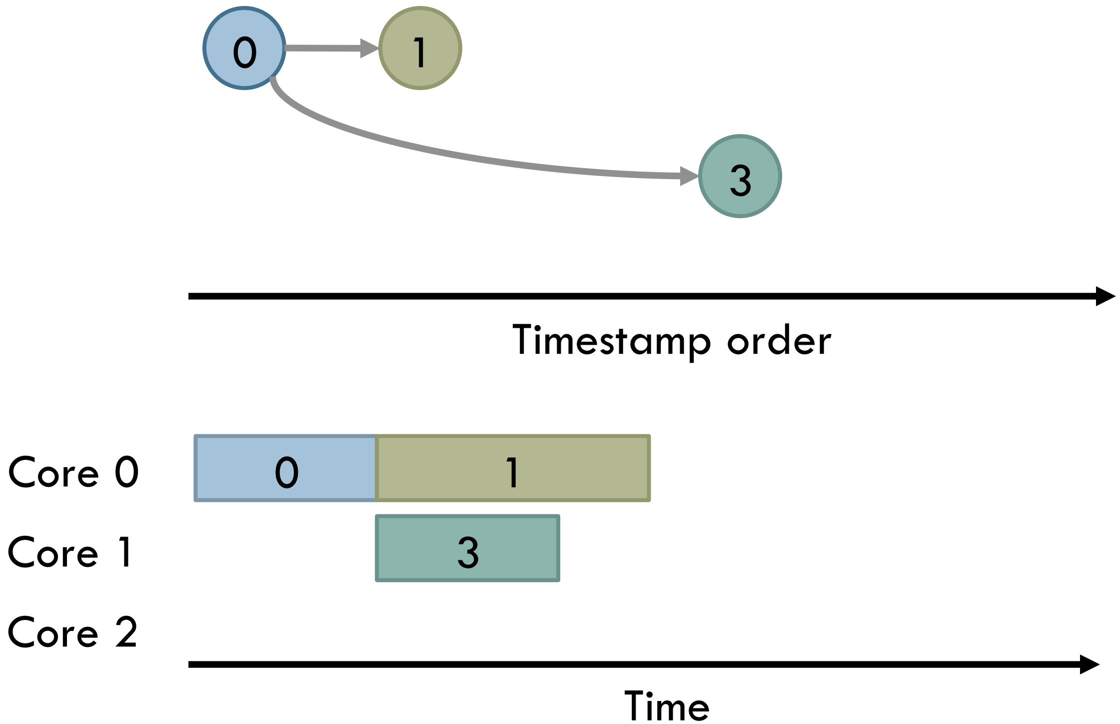

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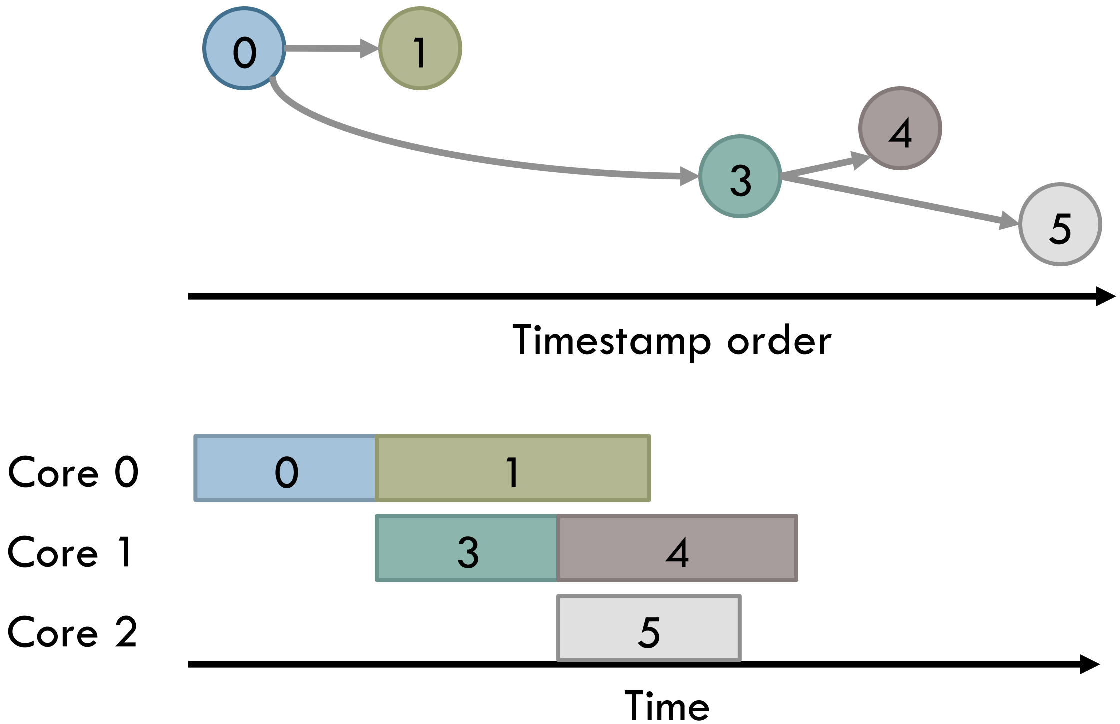

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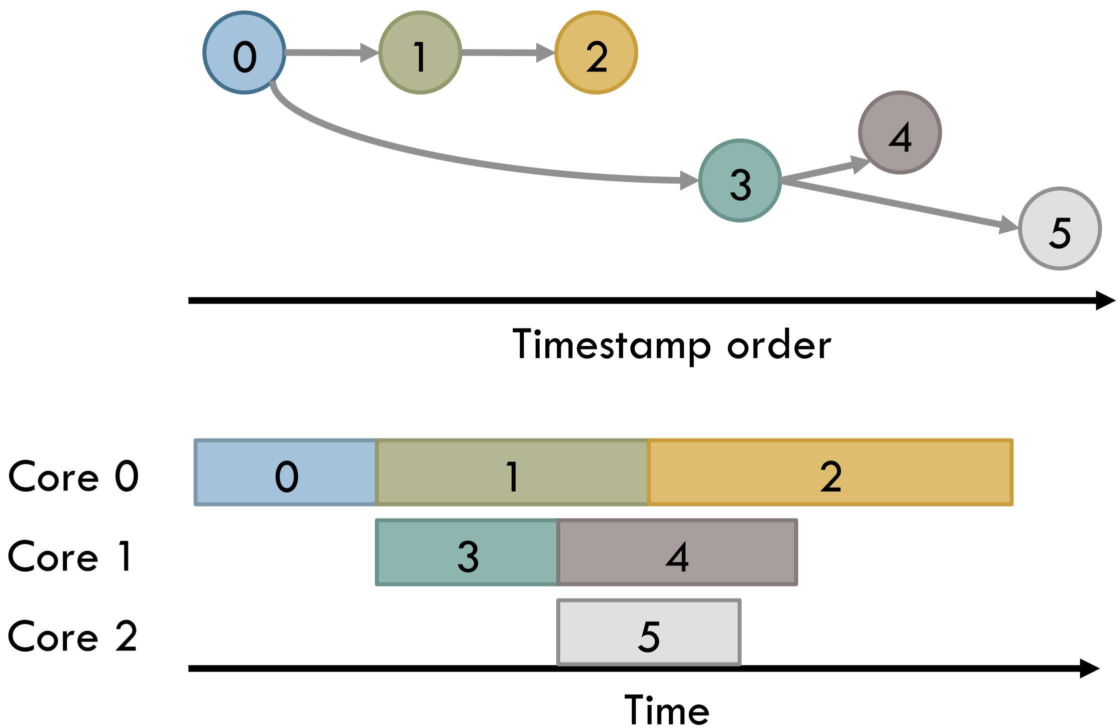

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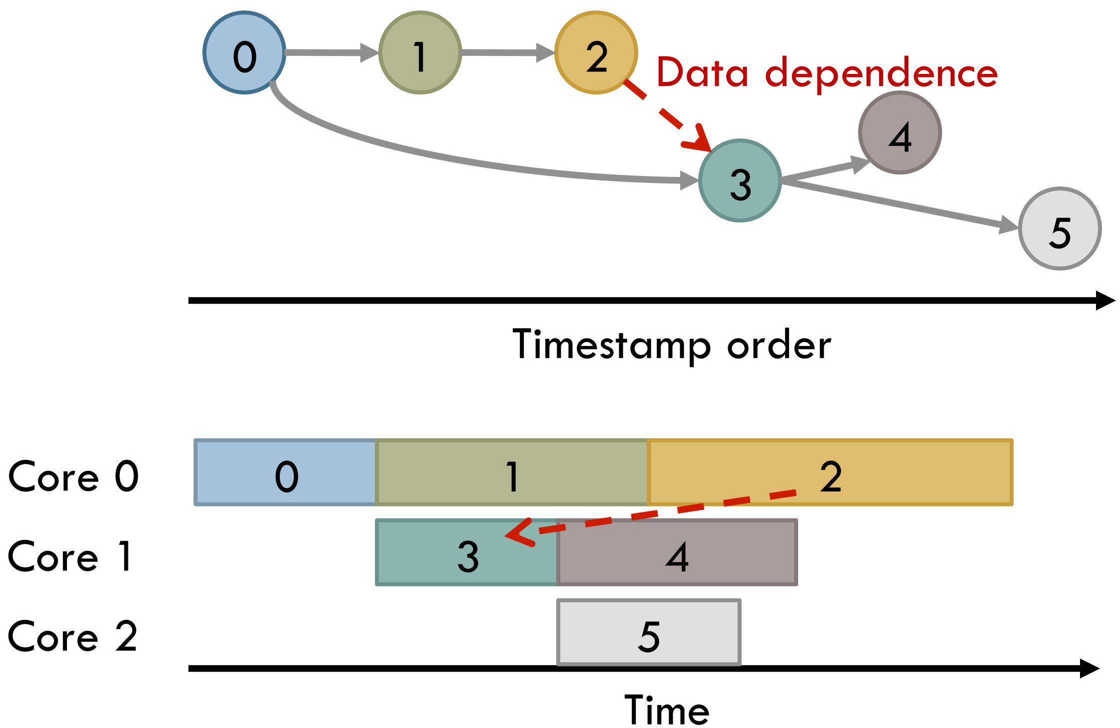

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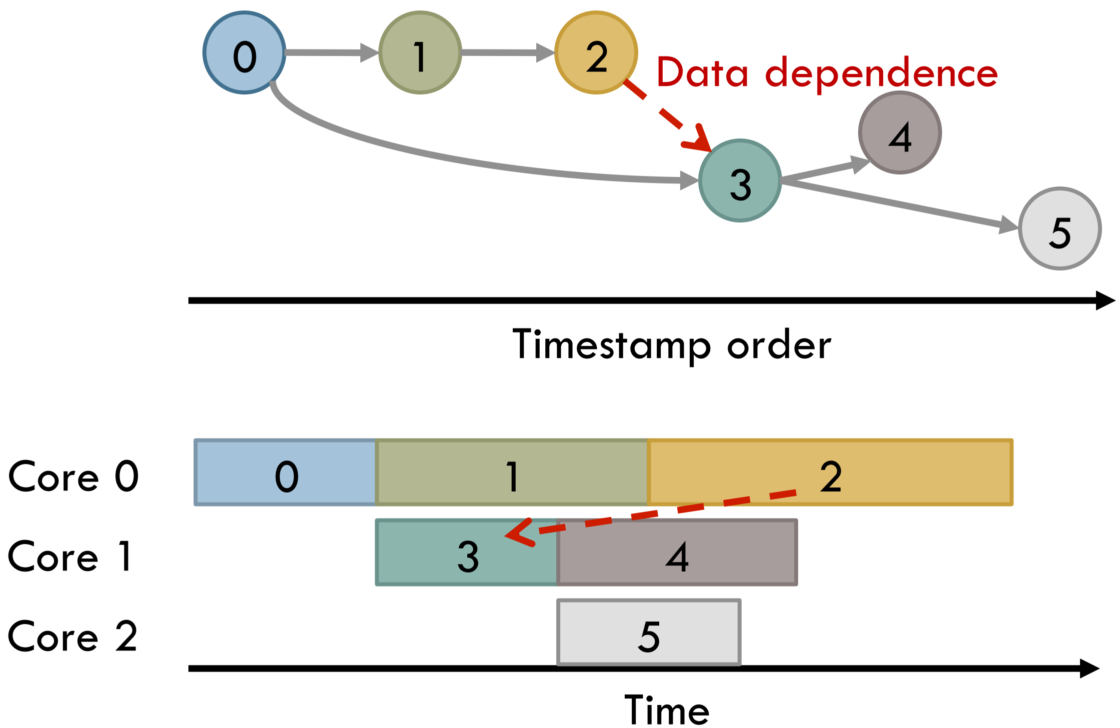

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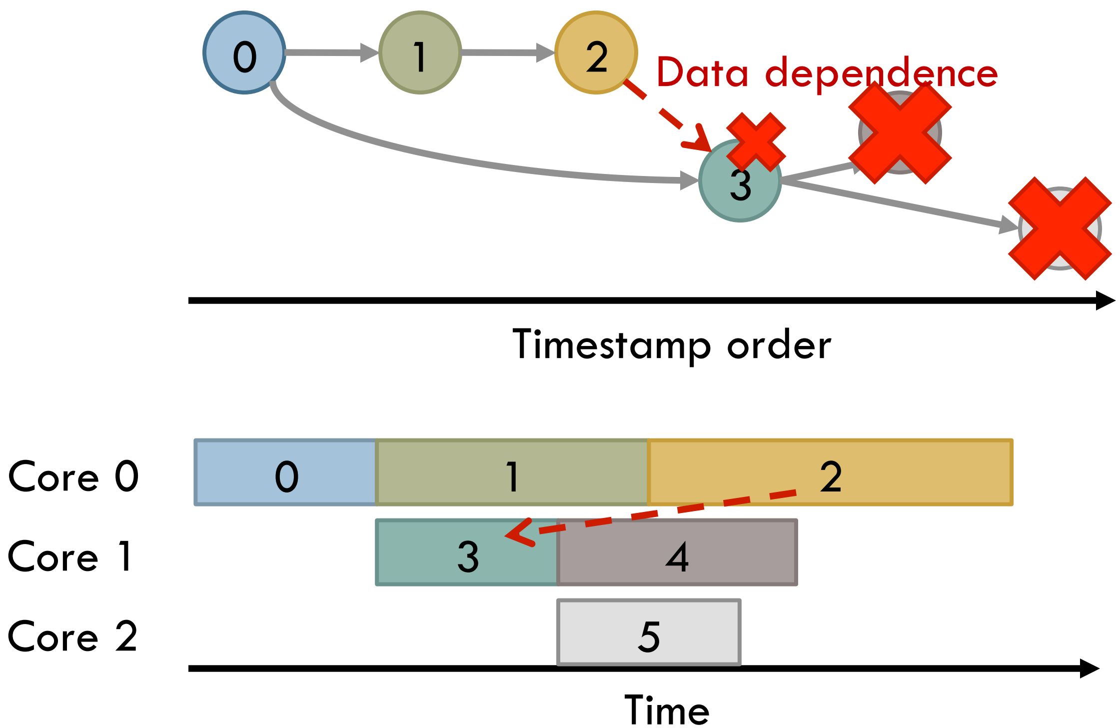

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  - Bloom filters for cheap read/write sets [Yen, HPCA 2007]
  - Uses hierarchical memory system to filter conflict checks
- Enables two helpful properties
  1. **Forwarding** of still-speculative data
  2. On rollback, corrective writes **abort dependent tasks only**

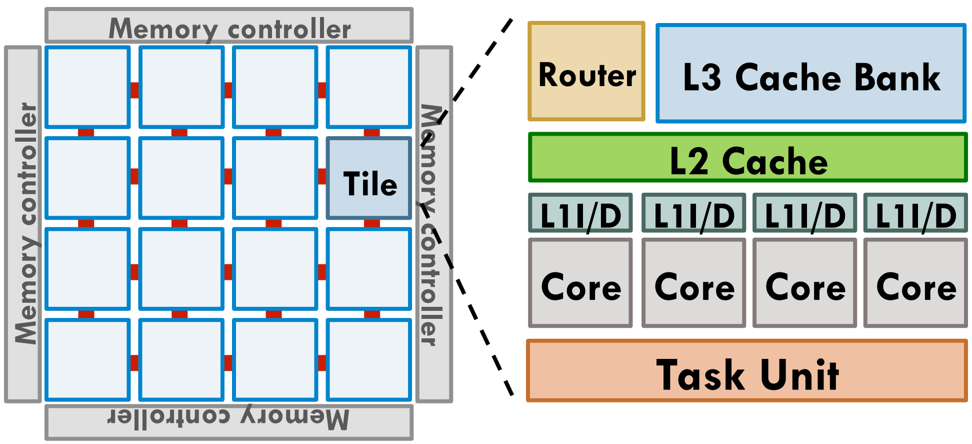
Outline

- Understanding Ordered Parallelism
- Swarm
- Evaluation

Evaluation Methodology

- Event-driven, sequential, Pin-based simulator

- Target system: 64-core, 16-tile chip



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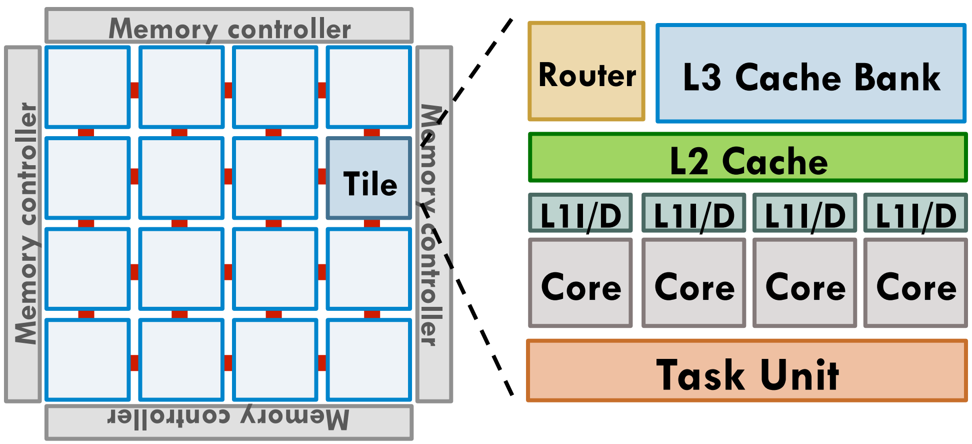

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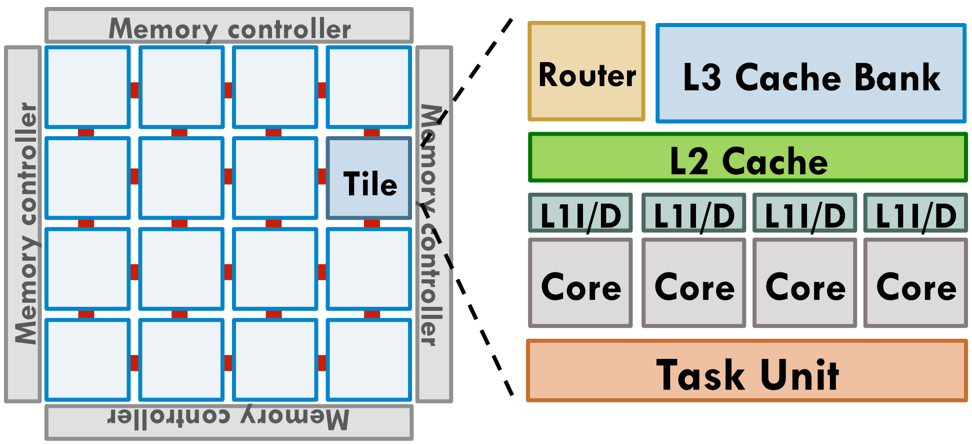

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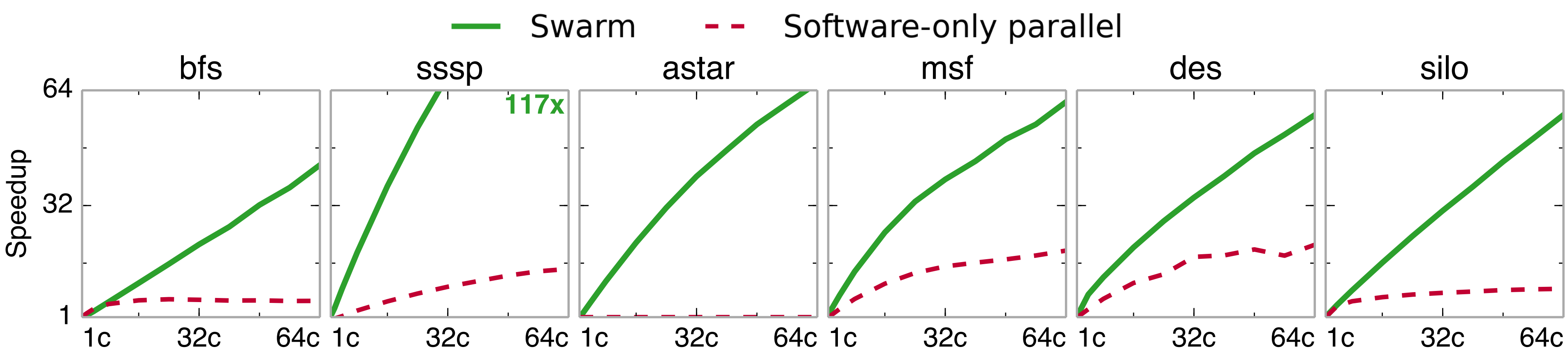
- Scalability experiments from 1-64 cores
  - Scaled-down systems have fewer tiles

Swarm vs. Software Versions



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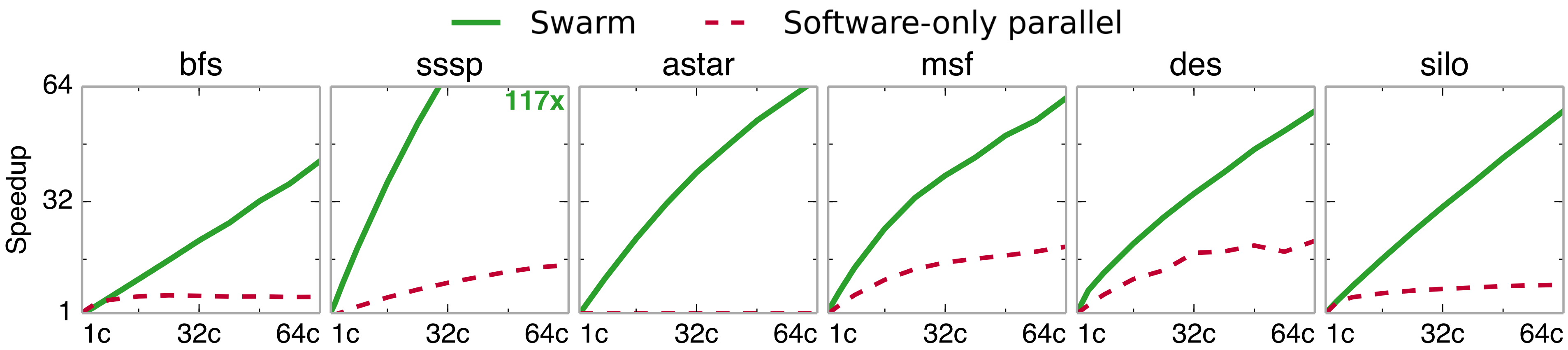

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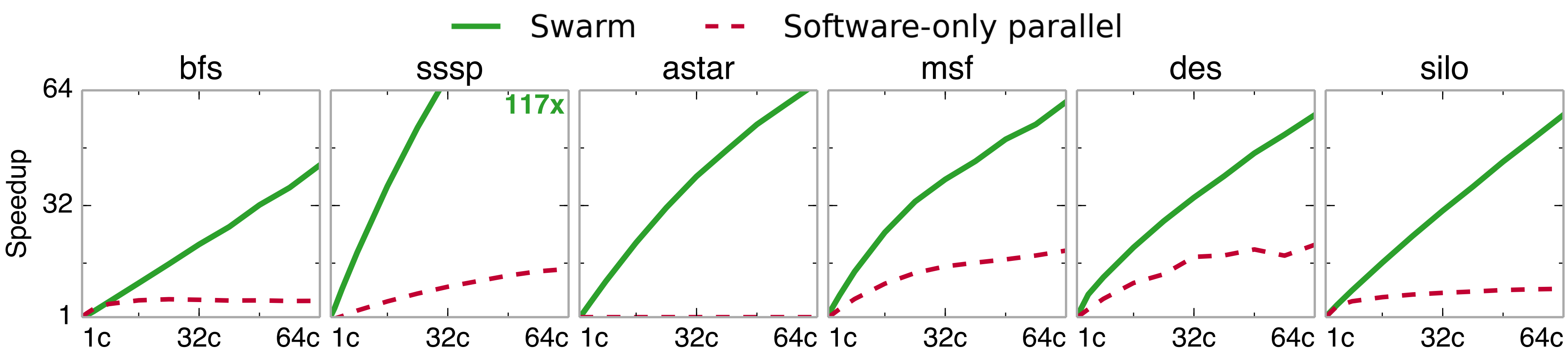

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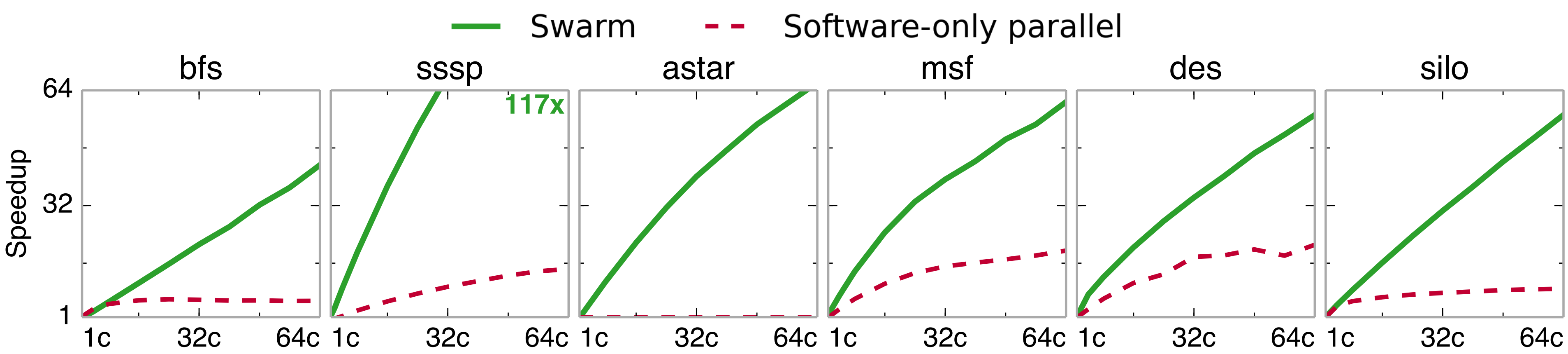

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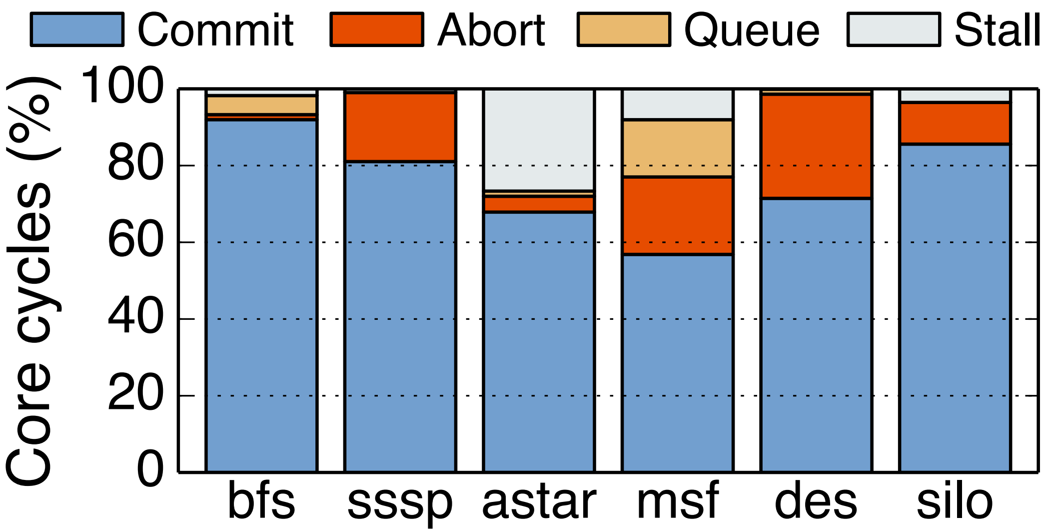
Simple implicitly-parallel code

Swarm Uses Resources Efficiently



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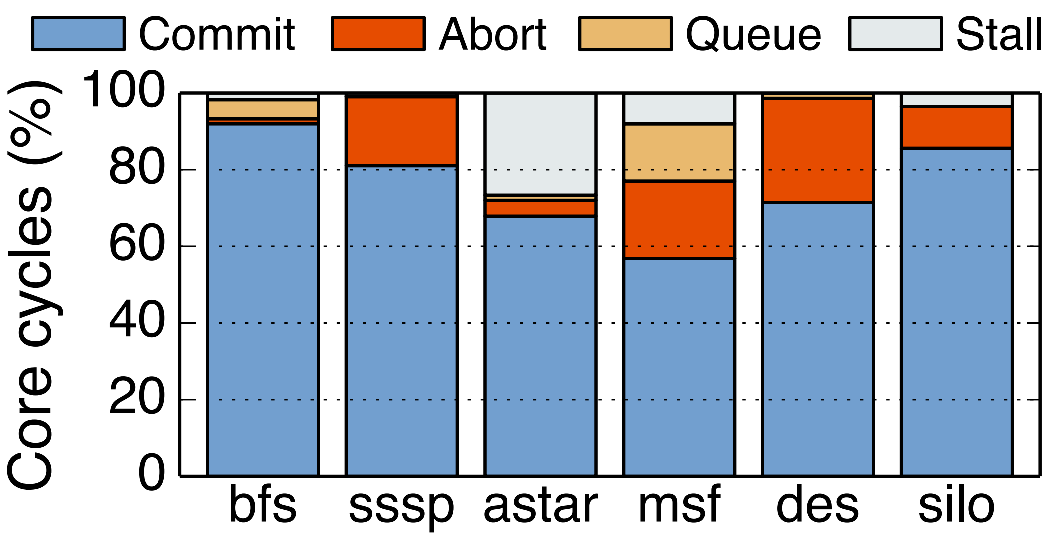

Most time spent executing tasks that commit

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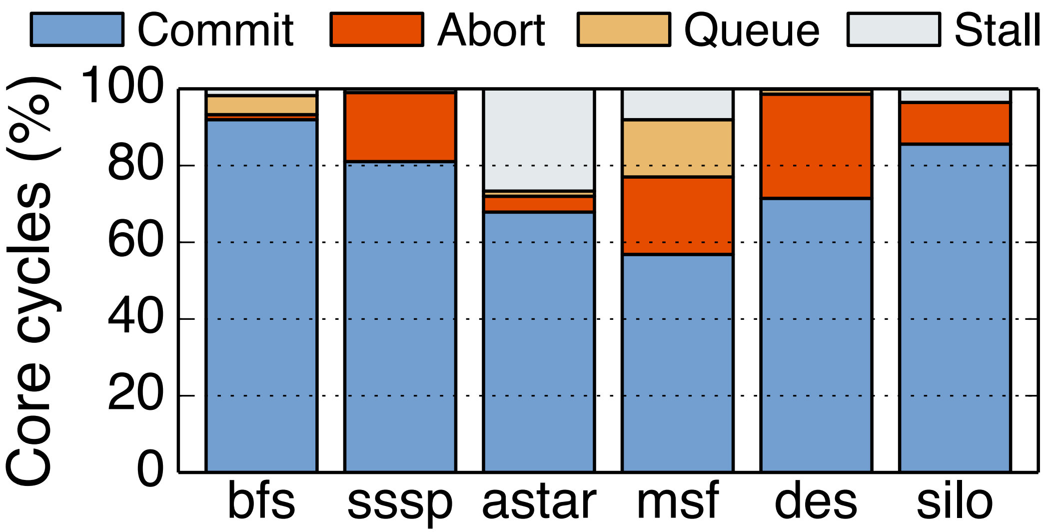

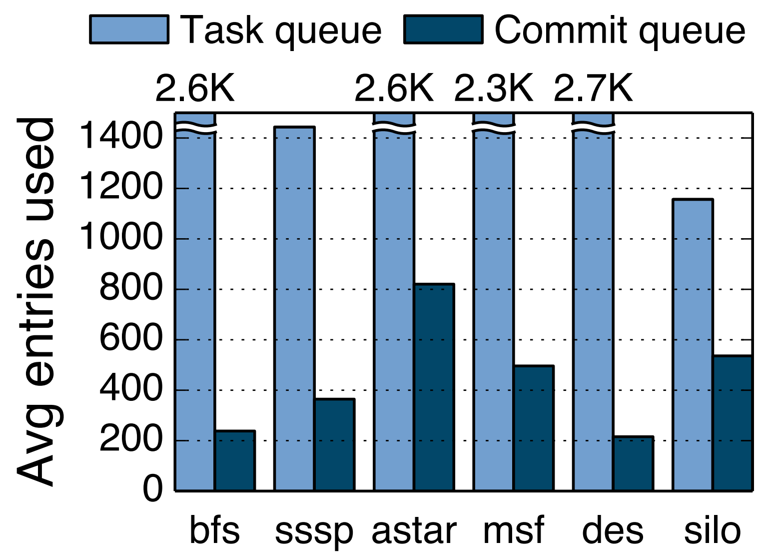

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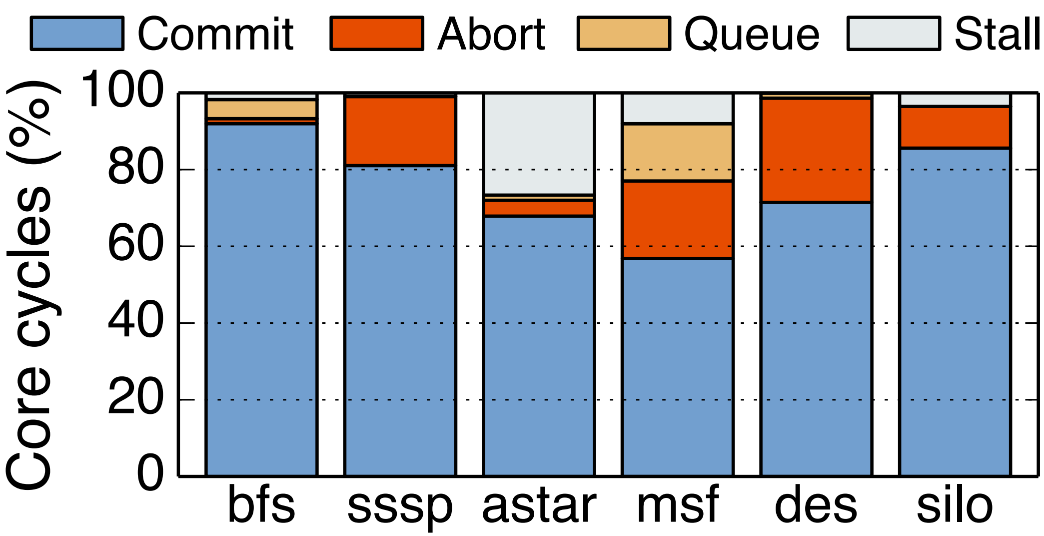

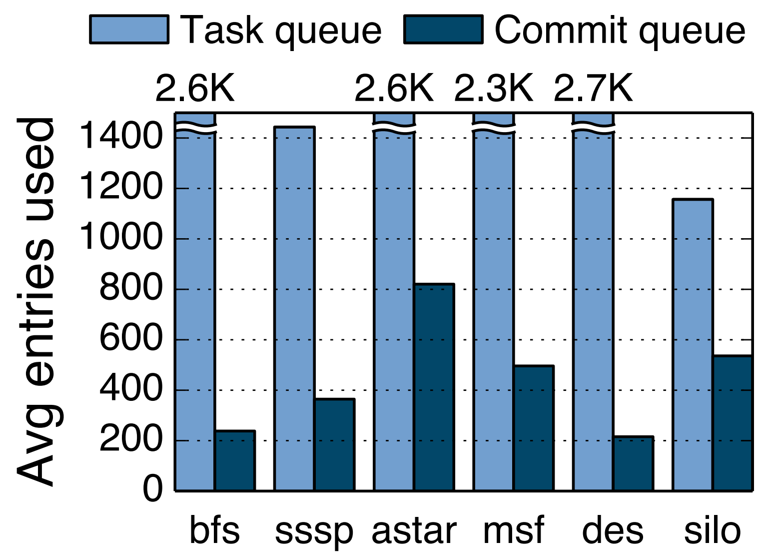

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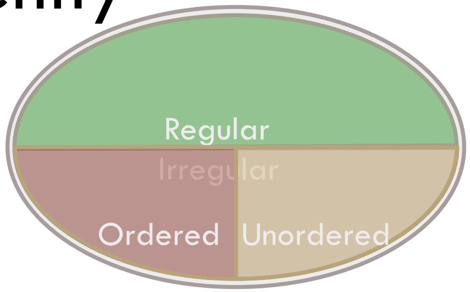
Swarm speculates 200-800 tasks ahead on average

- Speculation adds moderate energy overheads:
  - 15% extra network traffic
  - Conflict check logic triggered in 9-16% of cycles

Conclusions

- Swarm exploits ordered parallelism efficiently
  - **Necessary** to parallelize many key algorithms
  - **Simplifies** parallel programming in general



Conclusions

- Swarm exploits ordered parallelism efficiently
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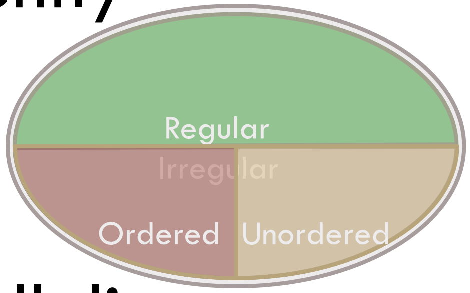

- Conventional wisdom: Ordering limits parallelism

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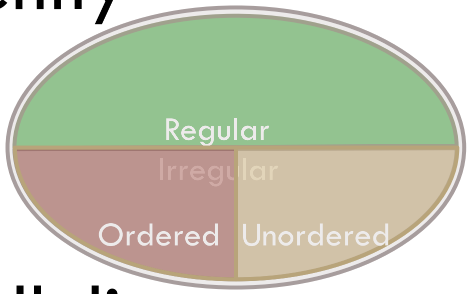

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Expressive execution model + large window =
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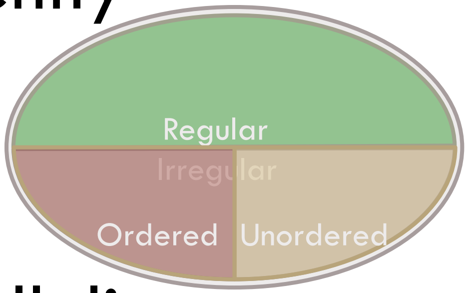

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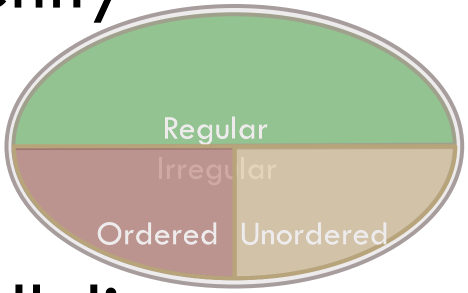

- ~~Conventional wisdom: Ordering limits parallelism~~

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  Speculation unlocks plentiful ordered parallelism

  Can trade parallelism for efficiency (e.g., simpler cores)

Thanks for your attention!
Questions?

A Scalable Architecture for Ordered Parallelism

Mark Jeffrey, Suvinay Subramanian, Cong Yan,
Joel Emer, Daniel Sanchez