Sol

Fast Distributed Computation Over Slow Networks

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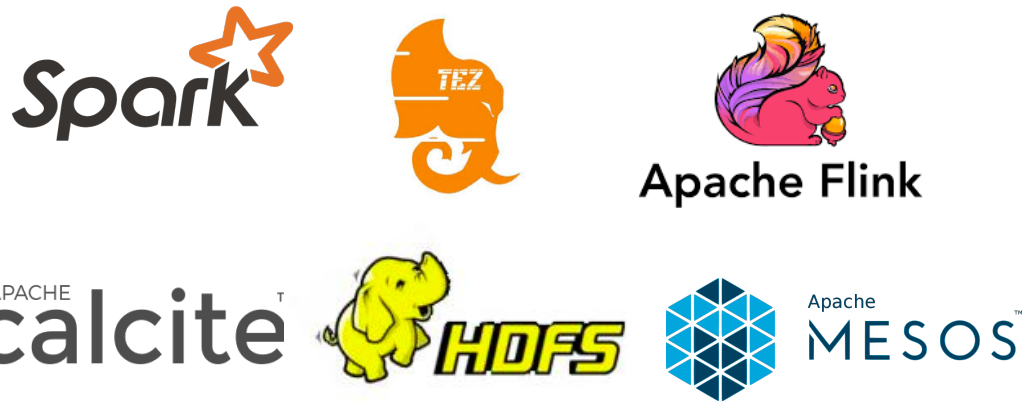
Harsha V. Madhyastha, Mosharaf Chowdhury

Distributed Data Processing is Ubiquitous

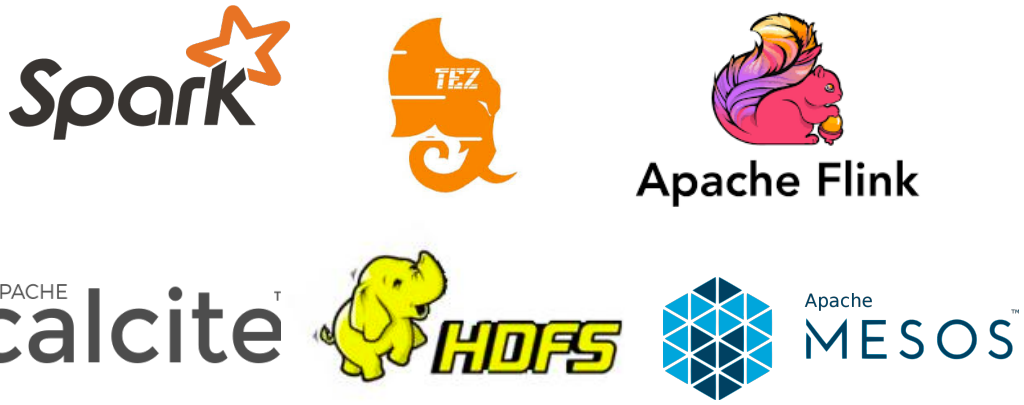
- **Distributed computation in Local-Area Networks (LAN)**
  - To accelerate executions within a single cluster



Efforts for Computation in LAN

Distributed Data Processing is Ubiquitous

- **Distributed computation in Local-Area Networks (LAN)**
  - To accelerate executions within a single cluster
- **Computation over Wide-Area Networks (WAN)**
  - To reduce data transfers, mitigate privacy risks



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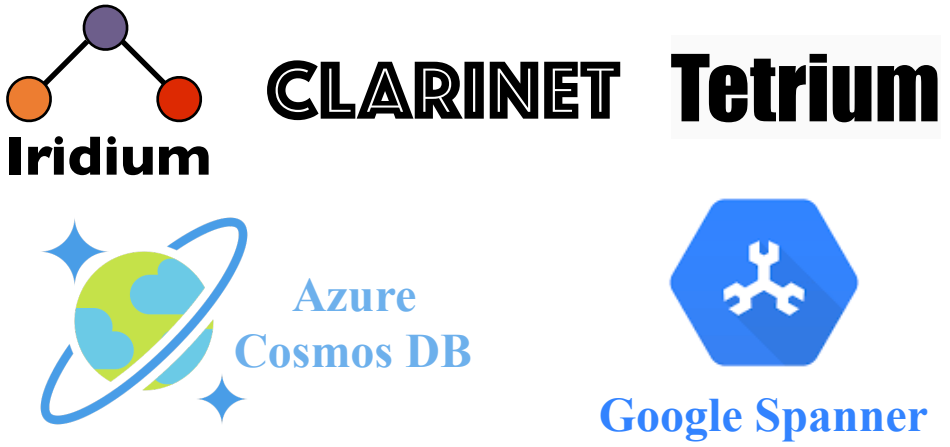
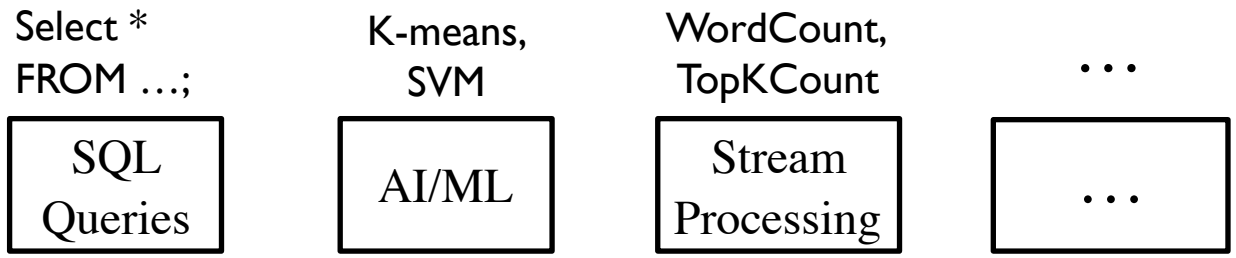


Efforts for Computation over WAN

Execution Engine: Core of Big Data Stack



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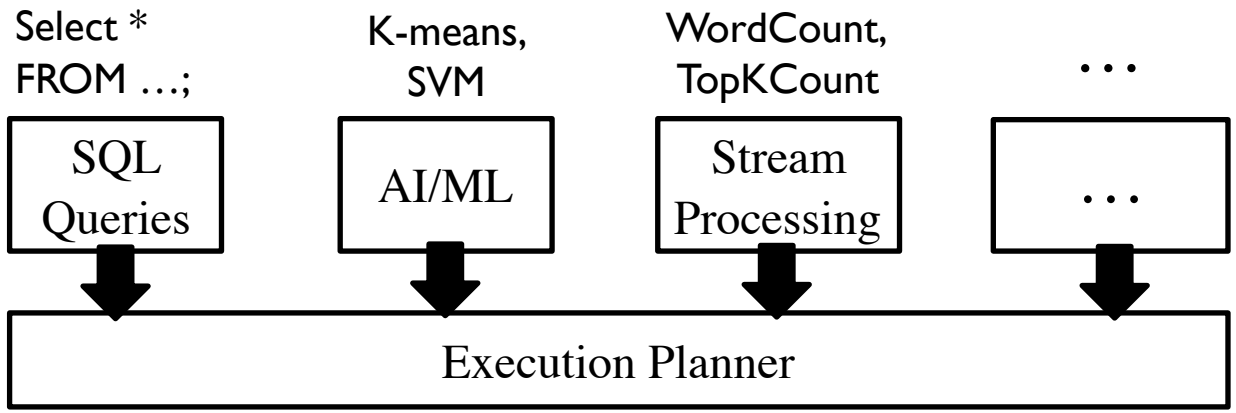

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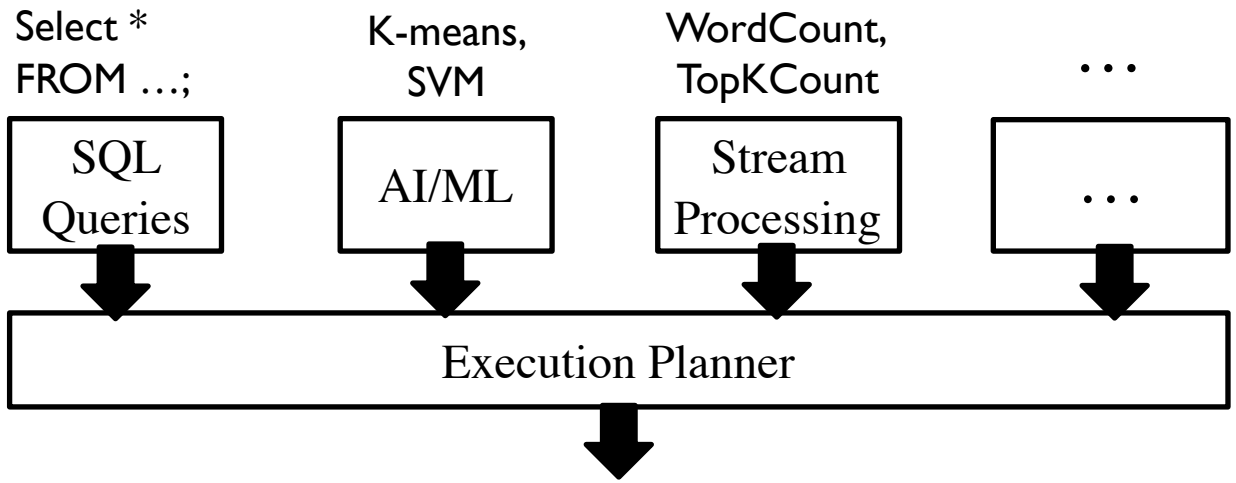
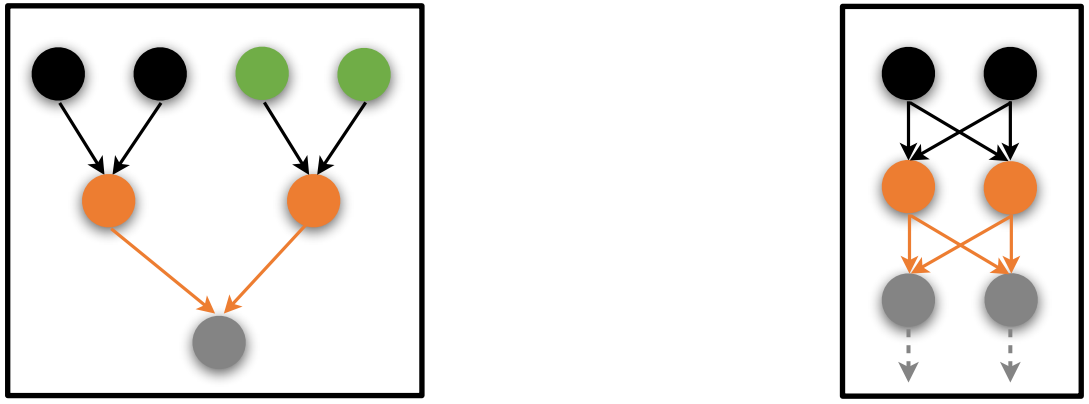


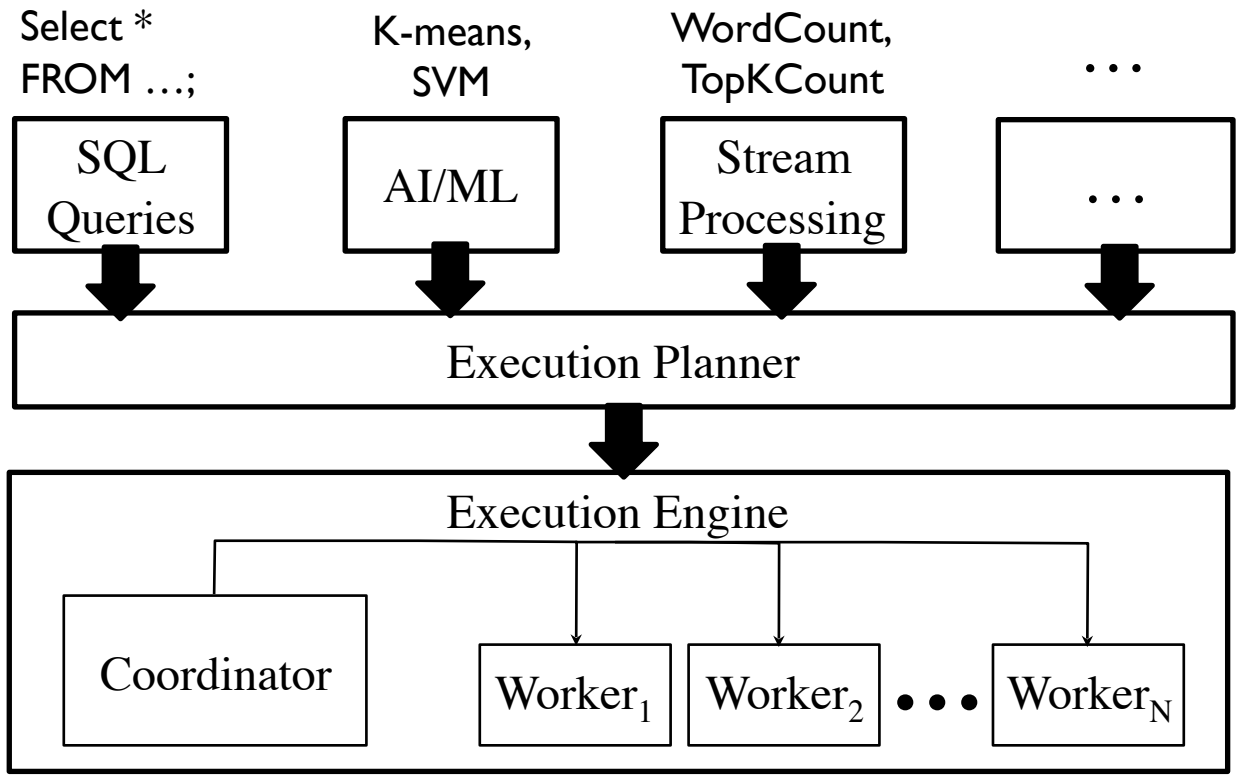


Job 1

Job 2

Typical job execution plans

Execution Engine: Core of Big Data Stack



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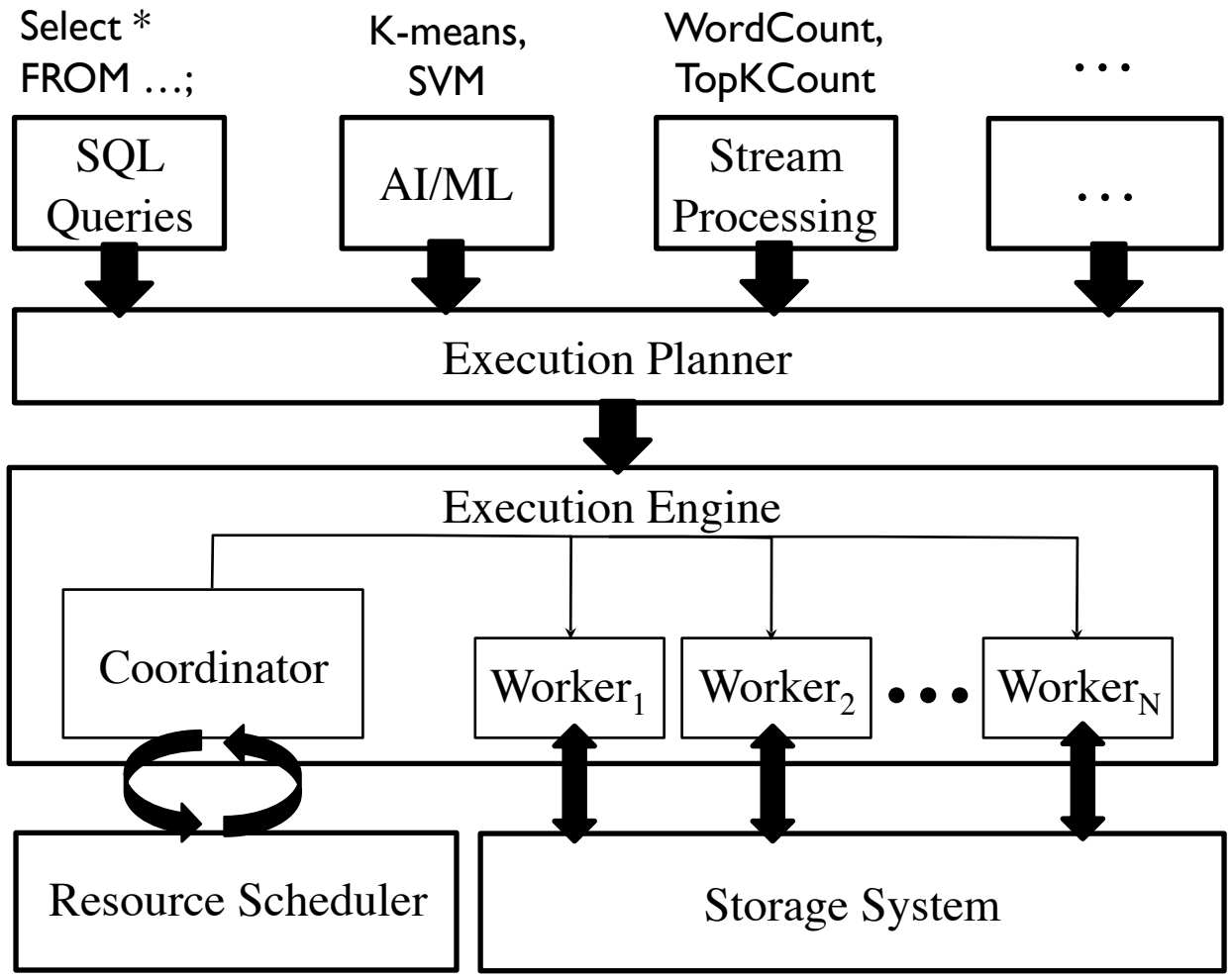

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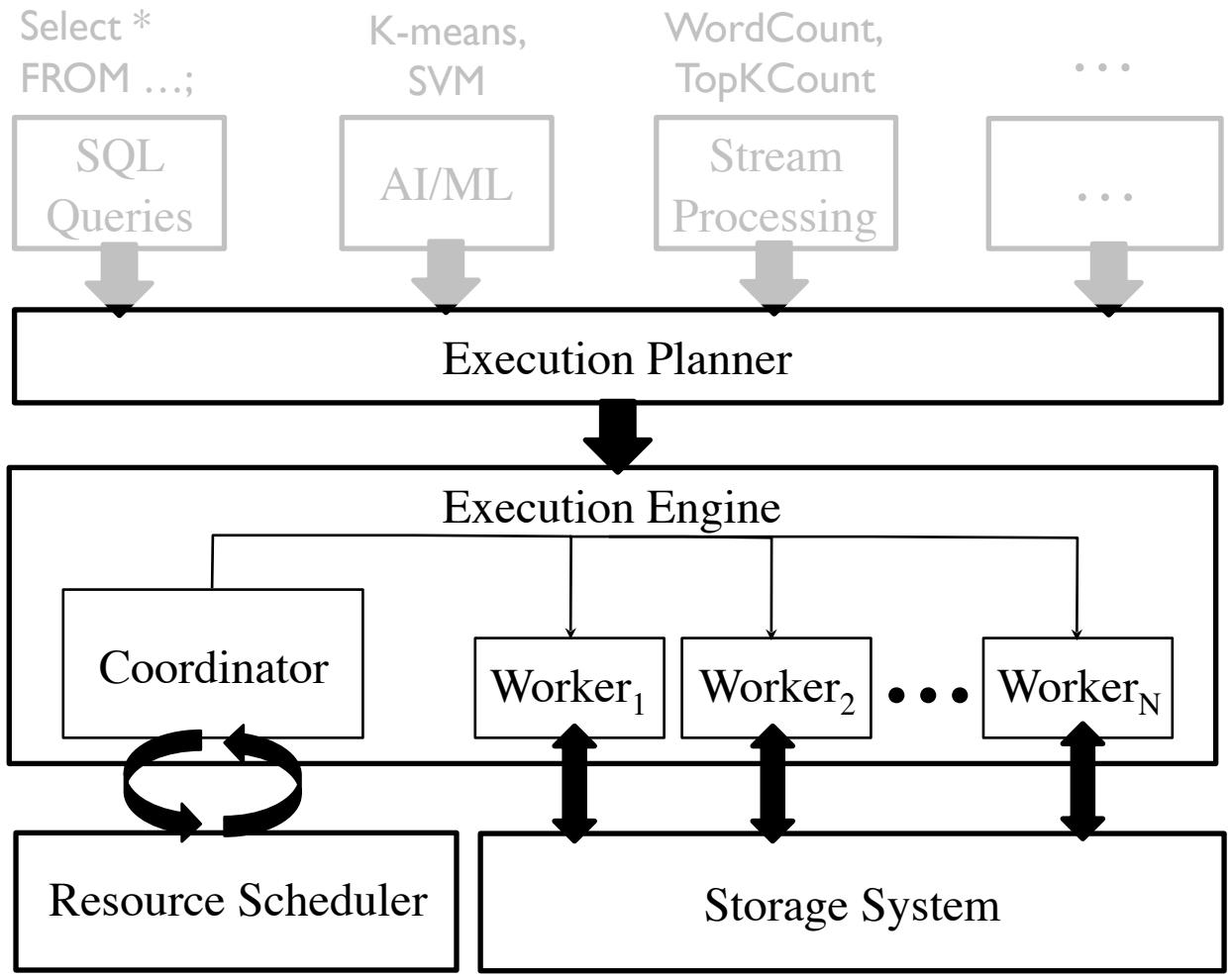


Spark TEZ Apache Flink

APACHE calcite HDFS Apache MESOS

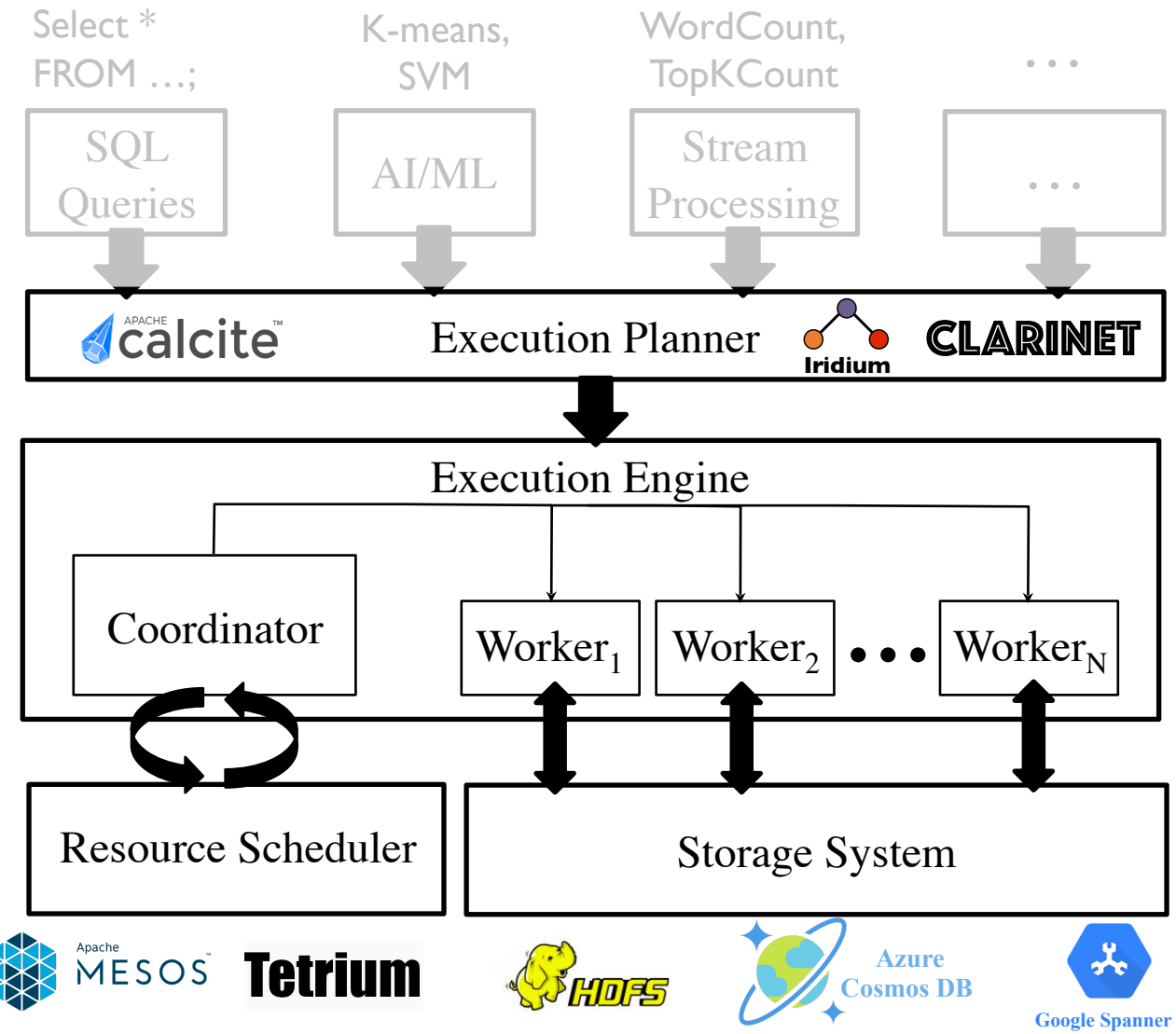
Efforts for Computation in LAN

Iridium CLARINET Tetrium

Azure Cosmos DB Google Spanner

Efforts for Computation over WAN

Execution Engine: Core of Big Data Stack



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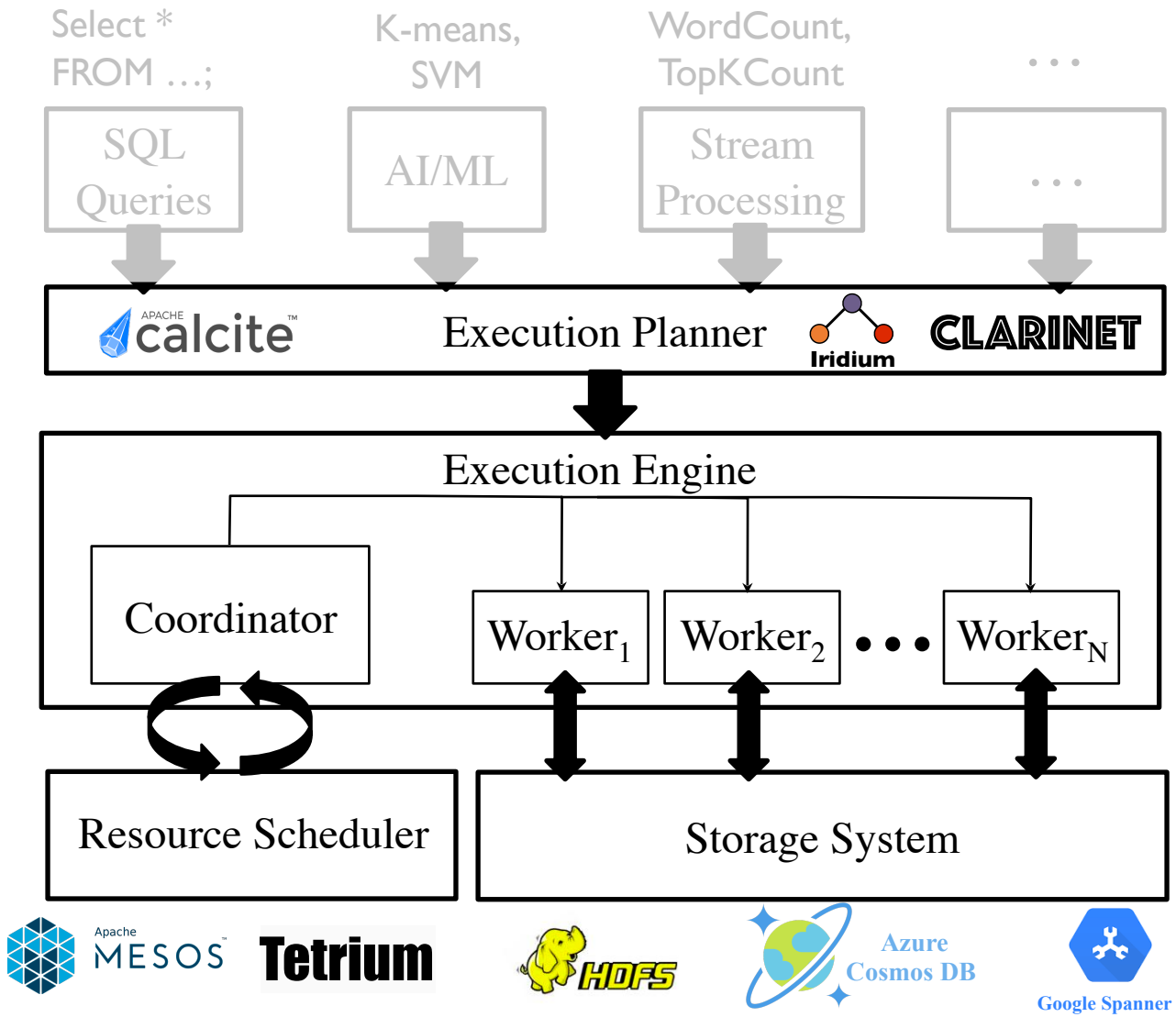
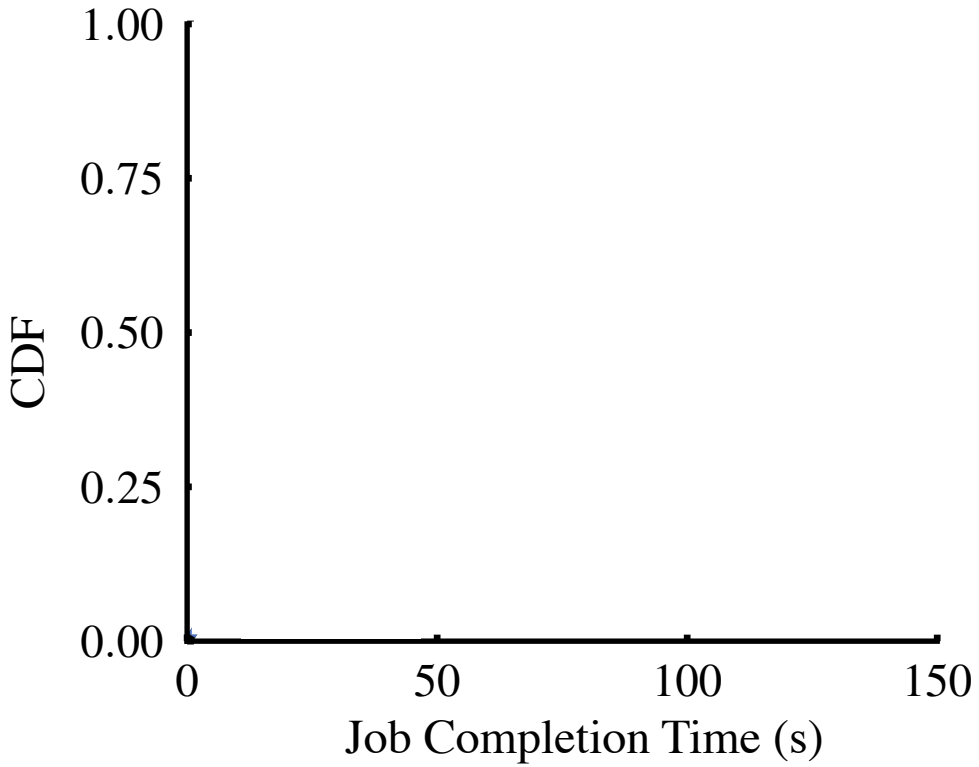


While network conditions are diverse in real, execution engines remain the same

Outline

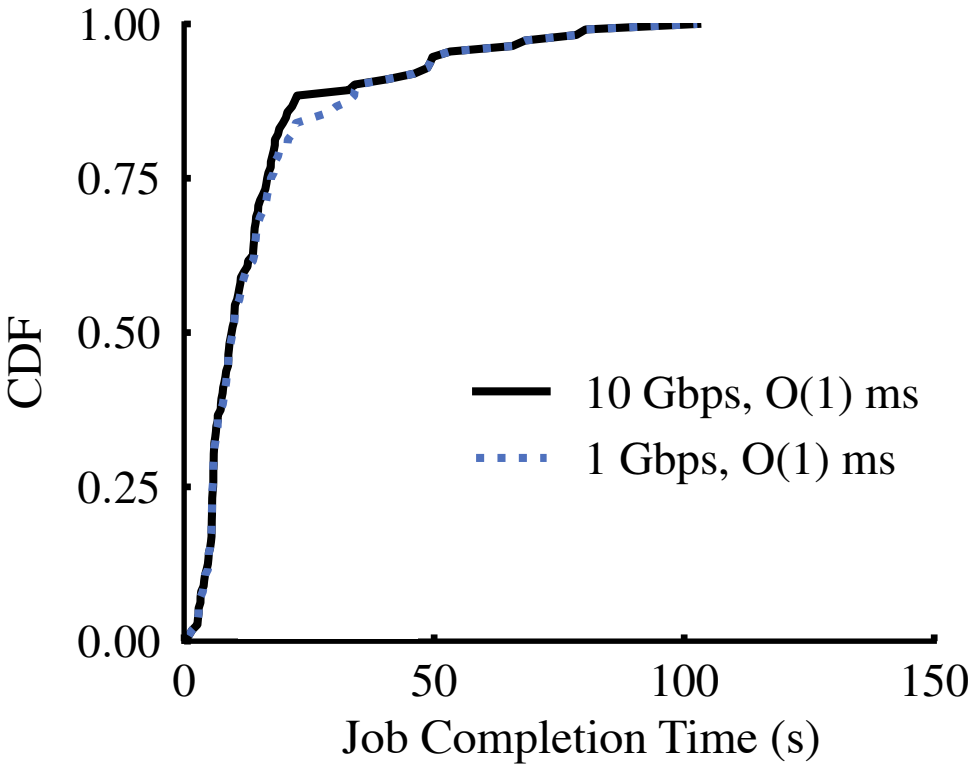
- Today's Execution Engines
- Sol Architecture
- Control Plane Design
- Data Plane Design
- Evaluation

Impact of Networks on Latency-sensitive Jobs



Queries from 100 GB TPC Benchmarks

Impact of Networks on Latency-sensitive Jobs



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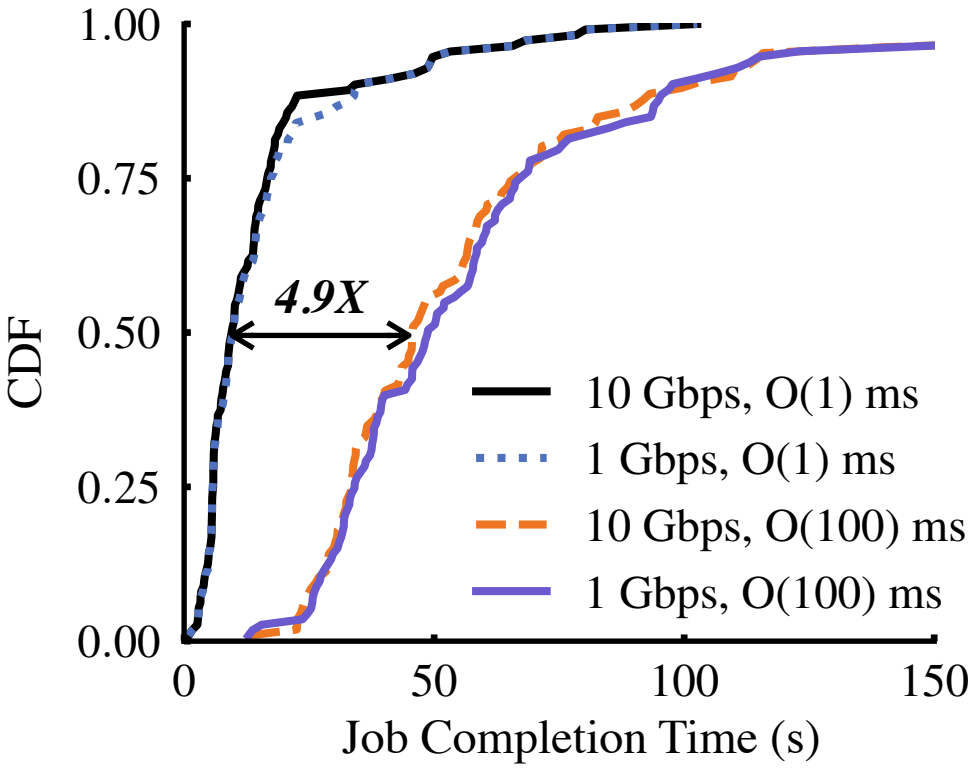

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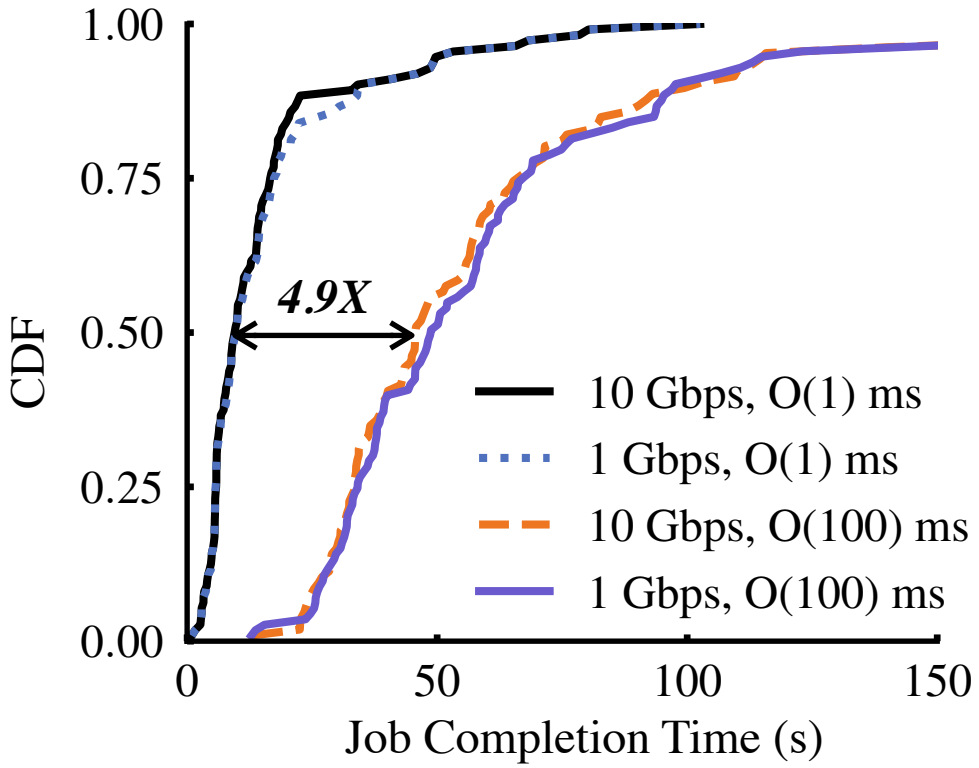

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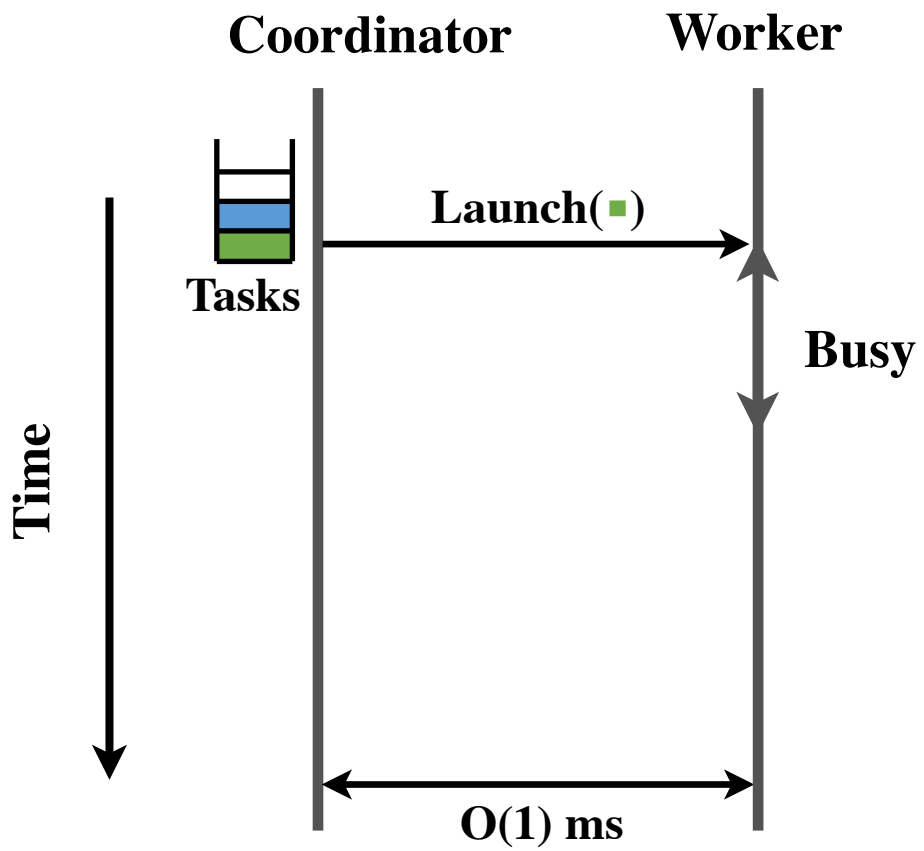
Problem #1

Slow job execution in *high-latency networks*

Control Plane Inefficiency Due to High Latency



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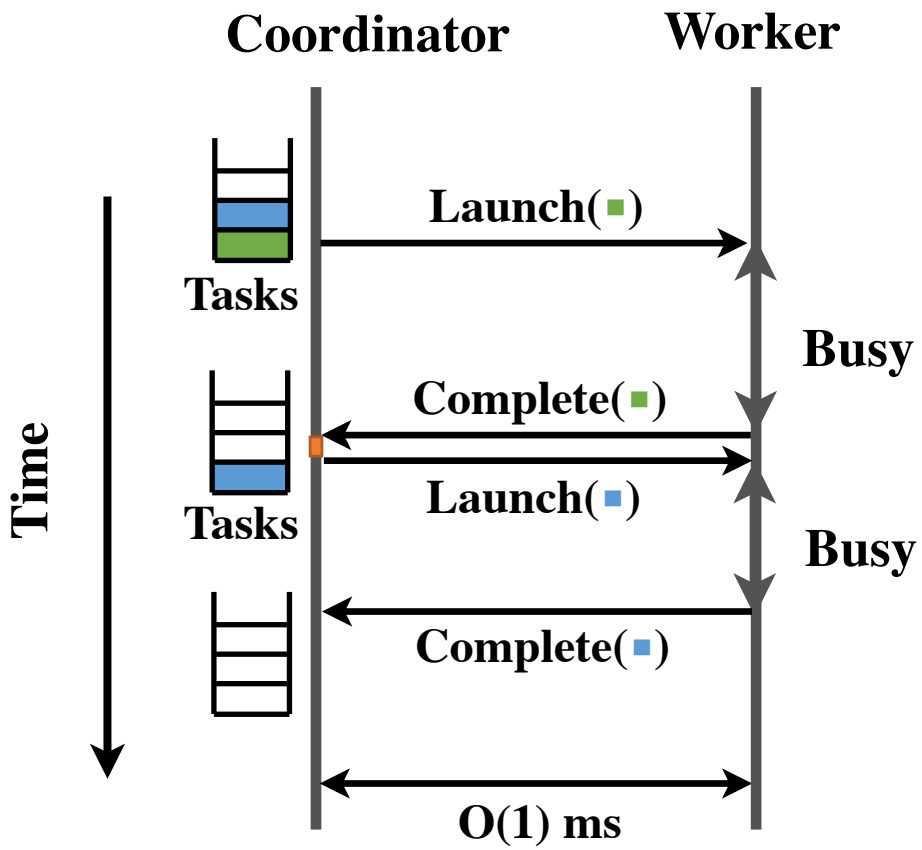

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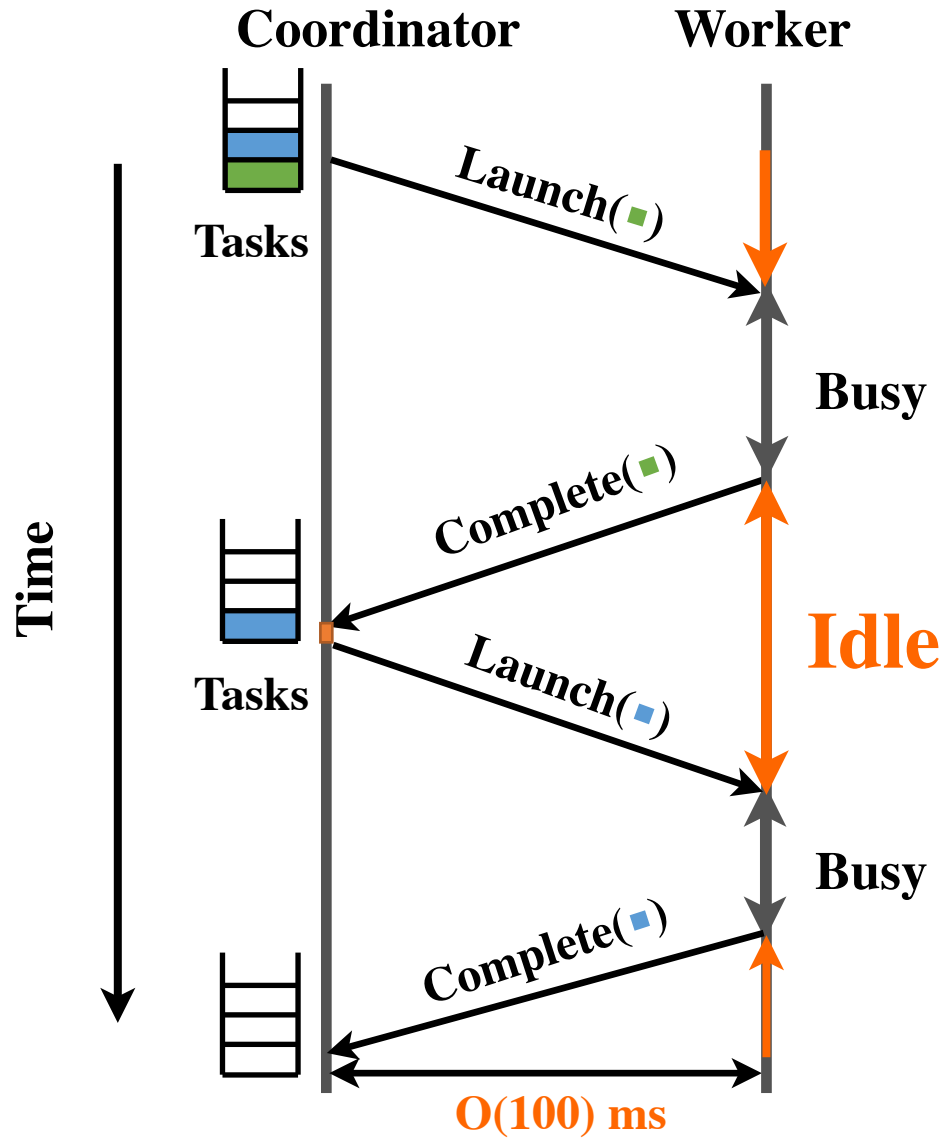

Late-binding of tasks postpones scheduling

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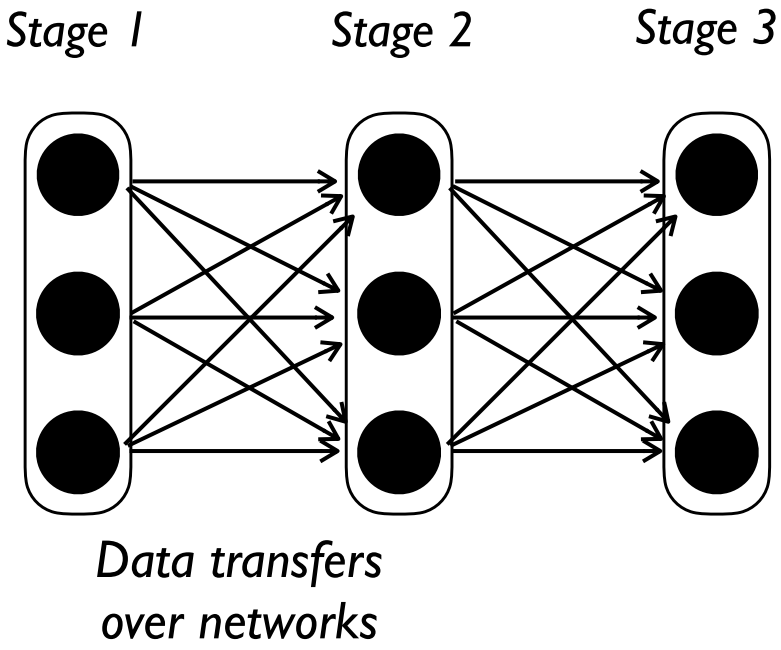
Impact of Networks on Bandwidth-intensive Jobs



Query25 on 1TB TPC benchmark

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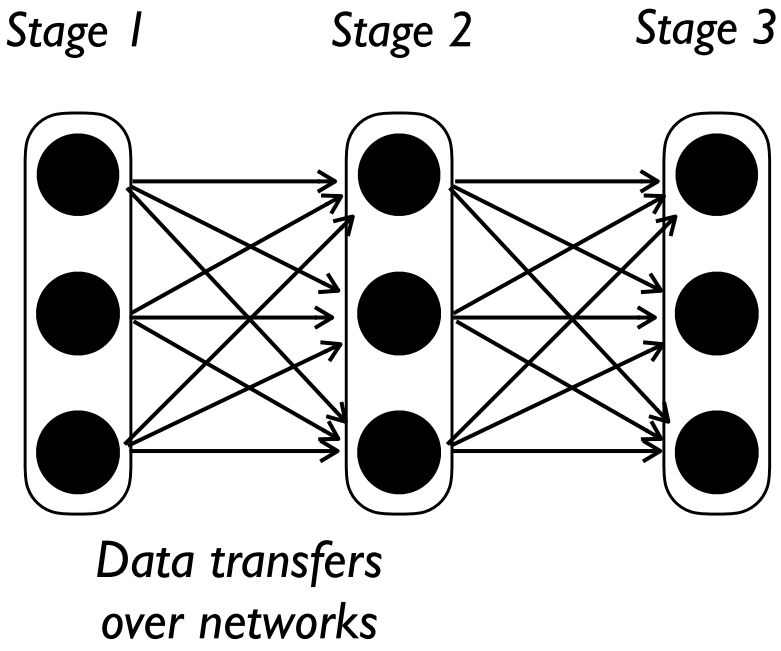

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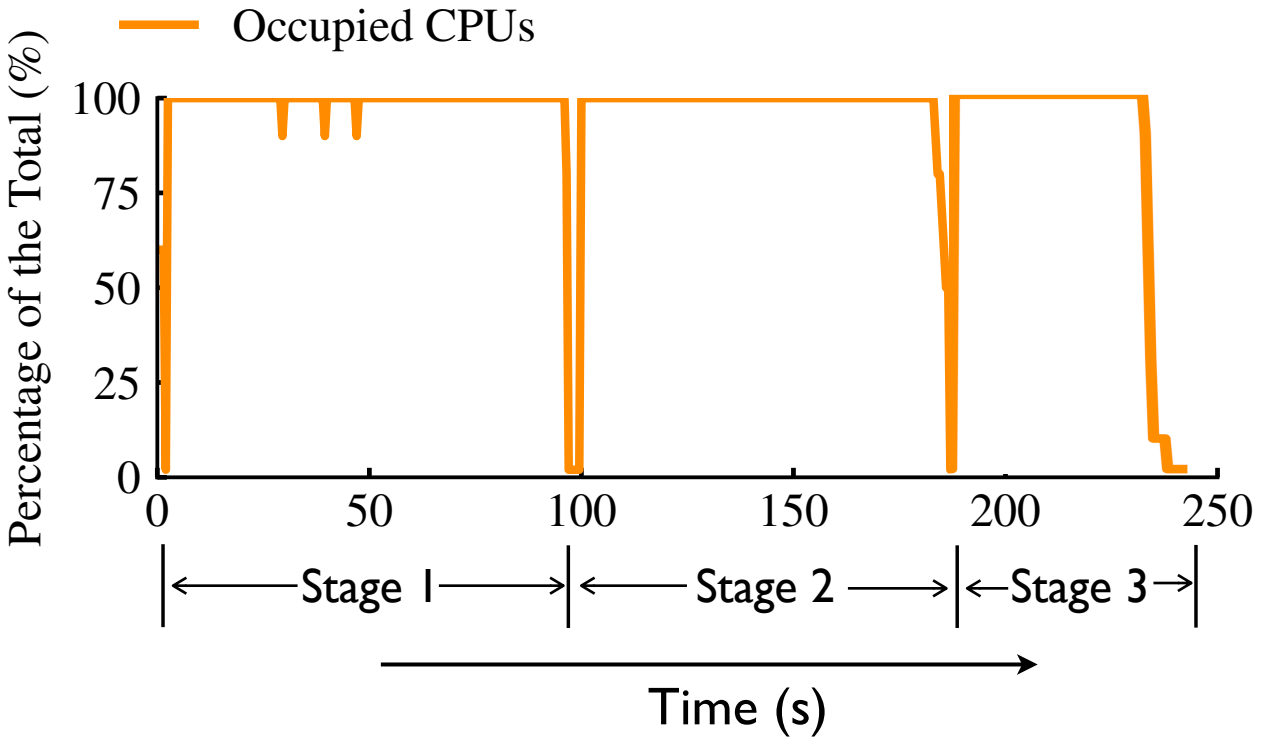

Resource utilization throughout the job

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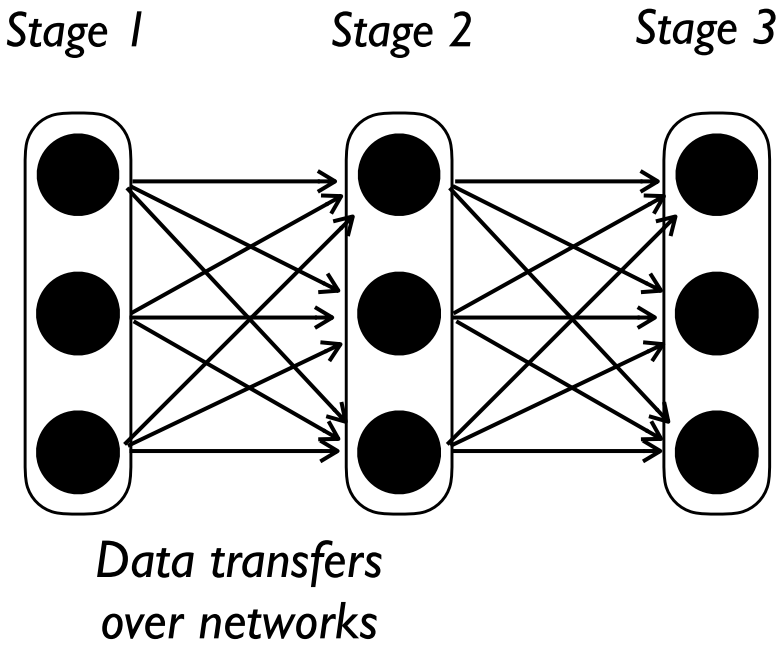

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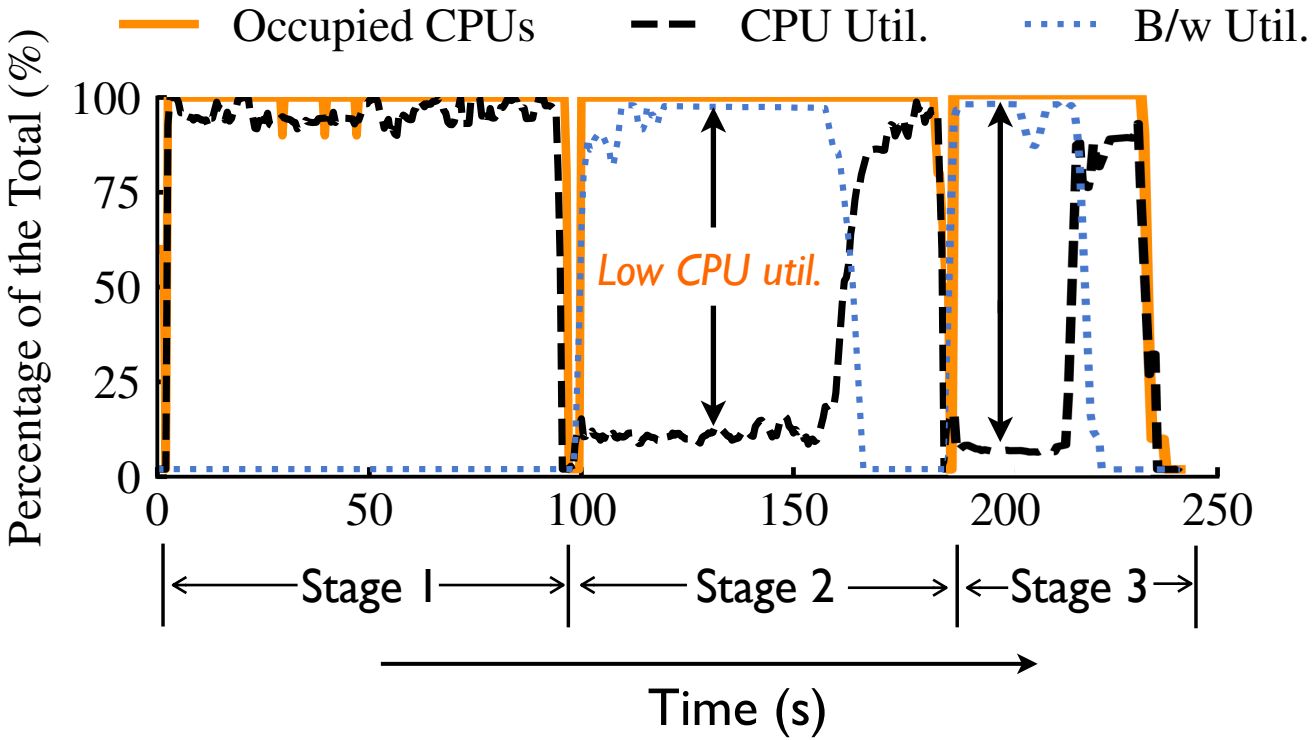
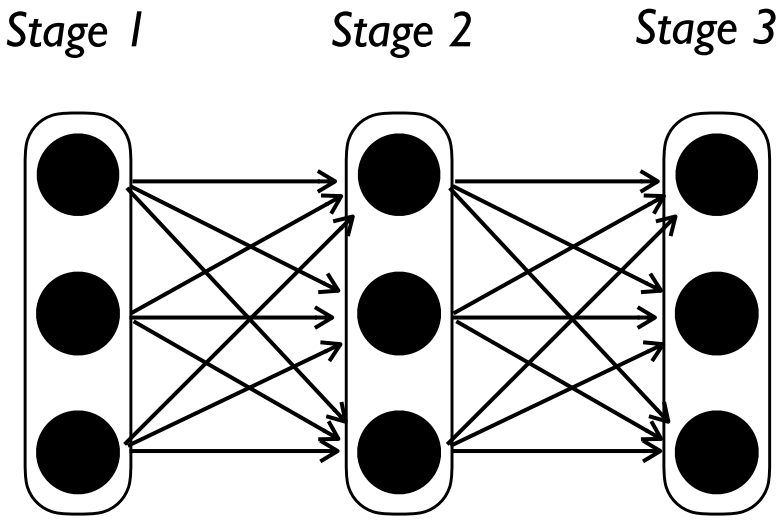


Resource utilization throughout the job

Data Plane Inefficiency Due to Low Bandwidth



Data transfers over networks

Query25 on 1TB TPC benchmark

Tasks hog CPUs throughout the lifespan

↓

Problem #2

CPU *underutilization* in *low-bandwidth networks*

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Problem #1

High latency → *Idleness of workers*

Problem #2

Low b/w → *CPU underutilization*

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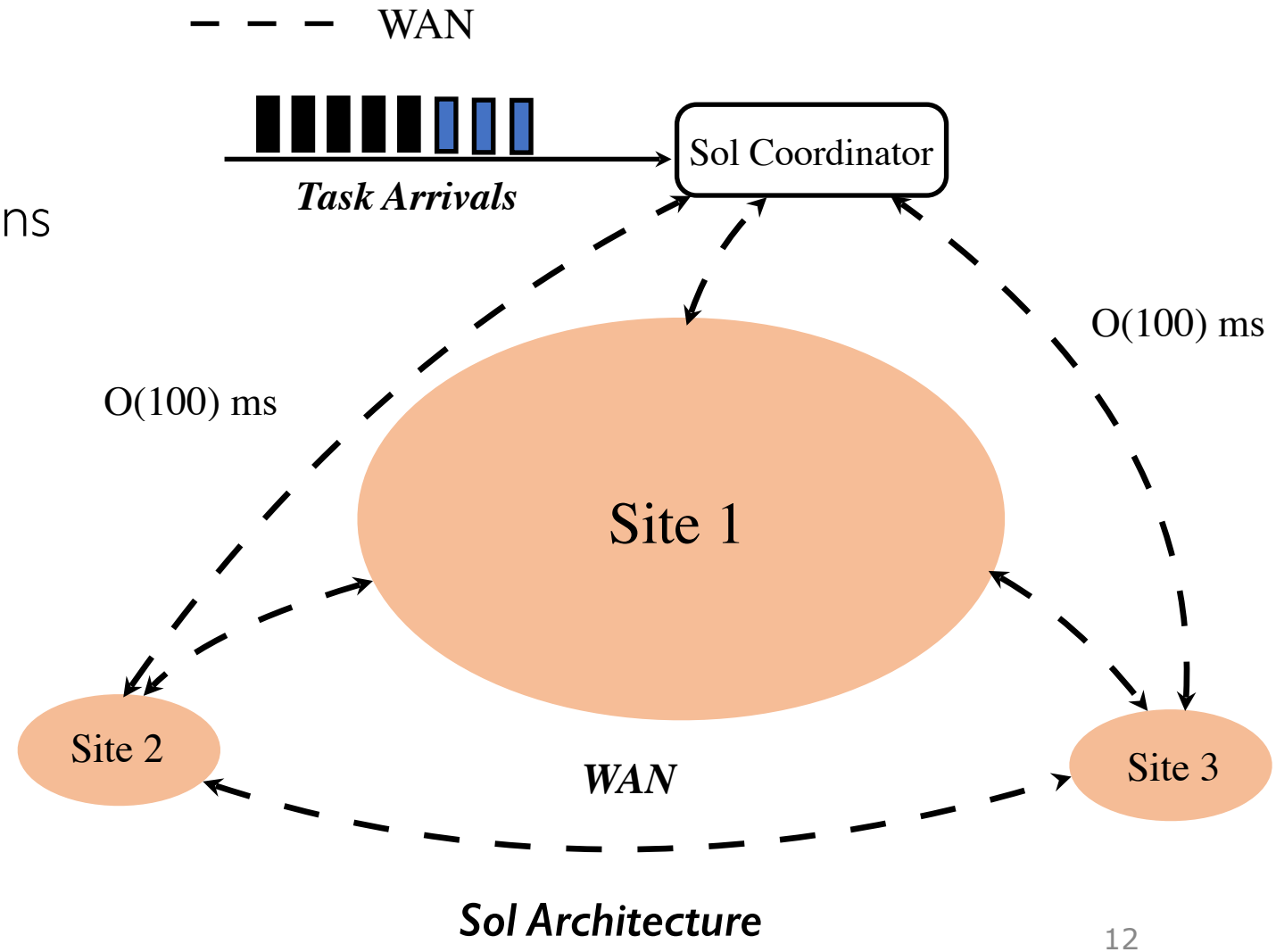
Sol

A *federated* execution engine for *diverse* network conditions w/

- faster job execution
- higher resource utilization

Sol: A Federated Execution Engine

- **Central Coordinator**
  - Coordinate inter-site executions



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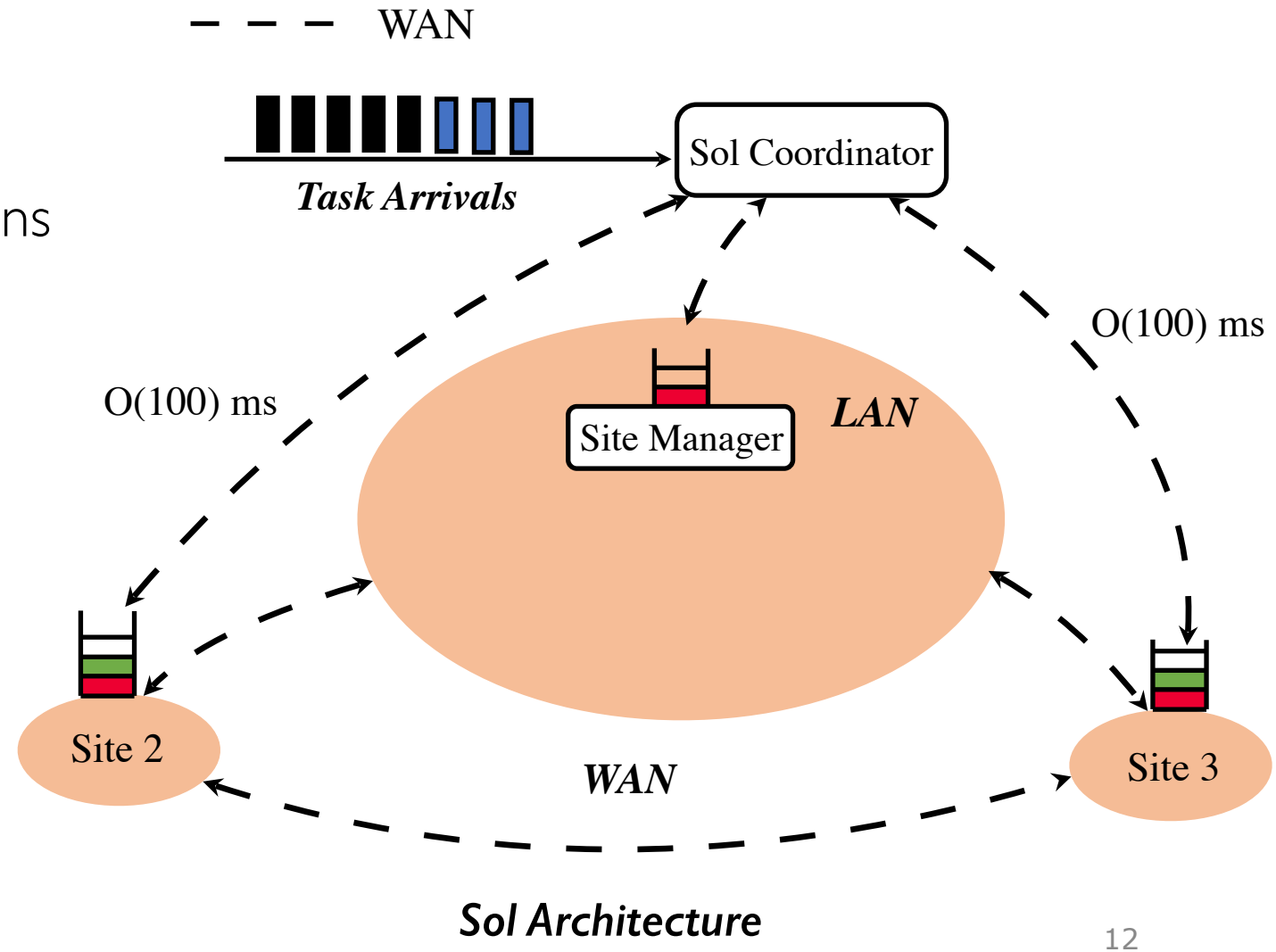
- **Site Manager**
  - Coordinate local workers
  - Manage queued tasks



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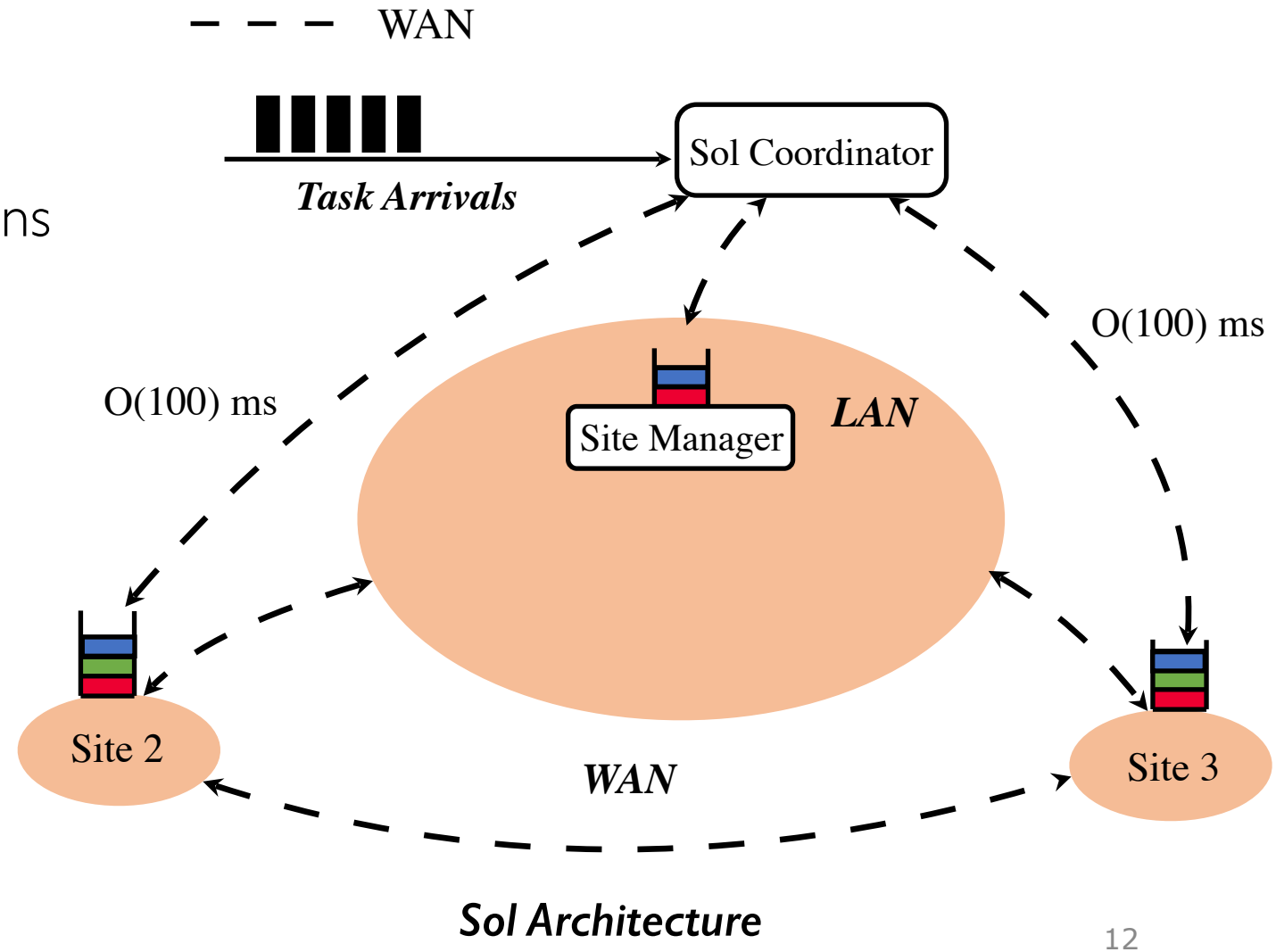

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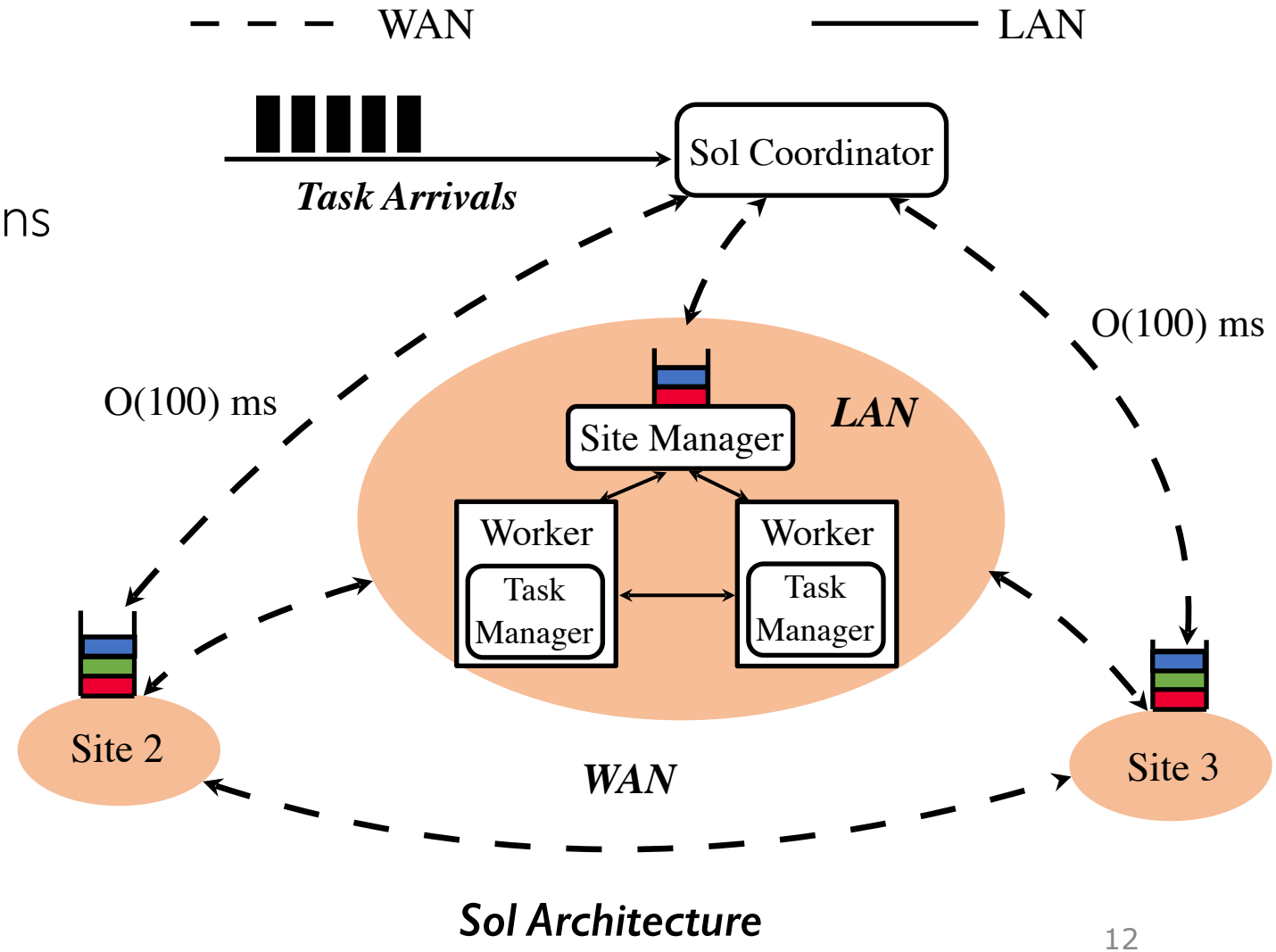
- **Task Manager**
  - Manage worker resource



Sol Architecture

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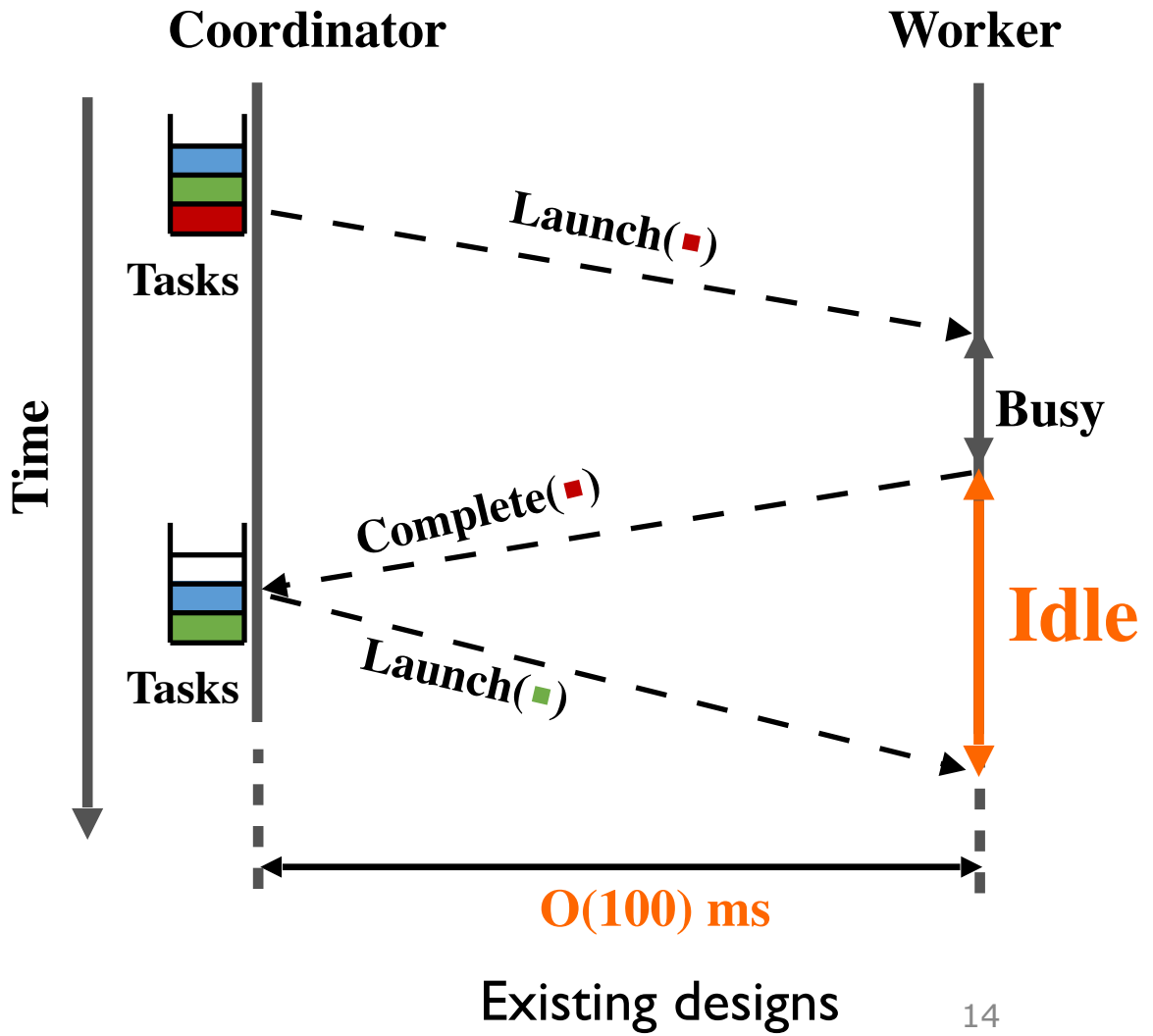
Problem #1

High latency → Idleness of workers

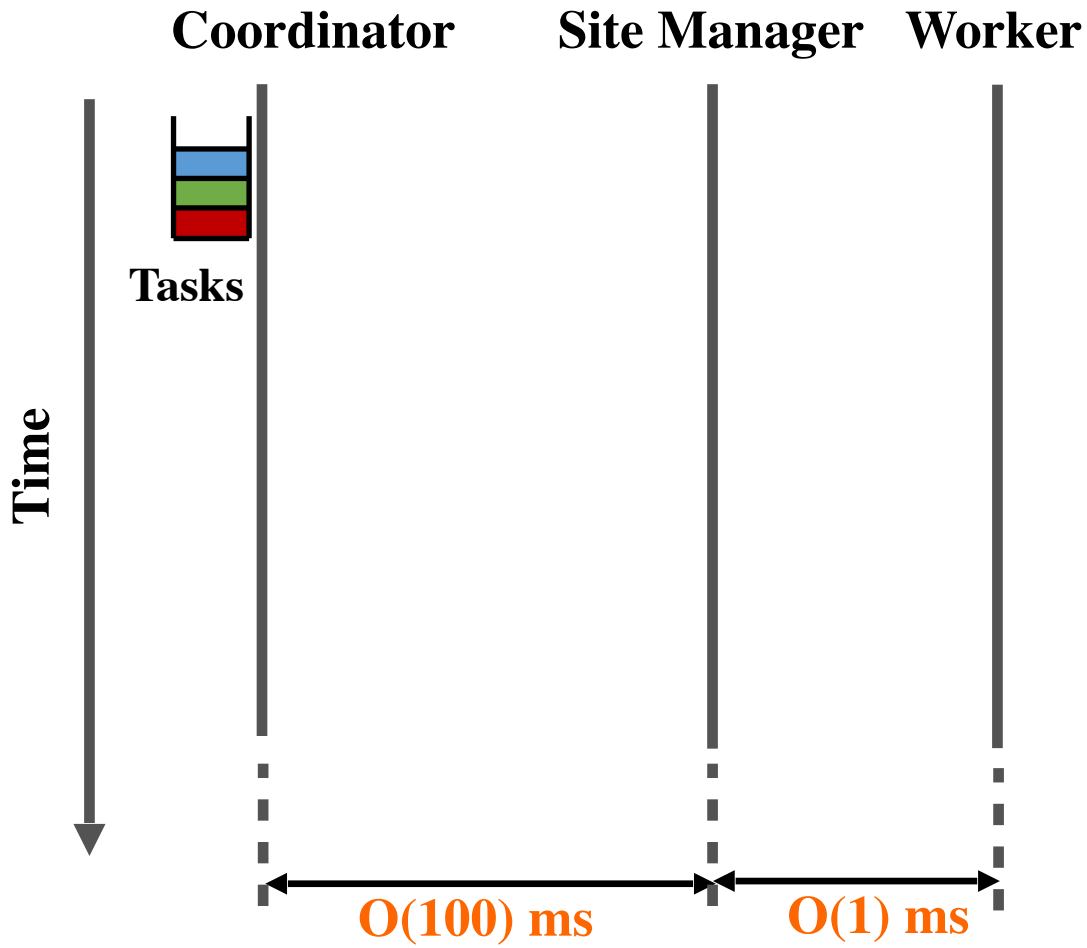
Push tasks proactively to reduce worker idle time

Task Early-binding in Control Plane



Existing designs

Task Early-binding in Control Plane



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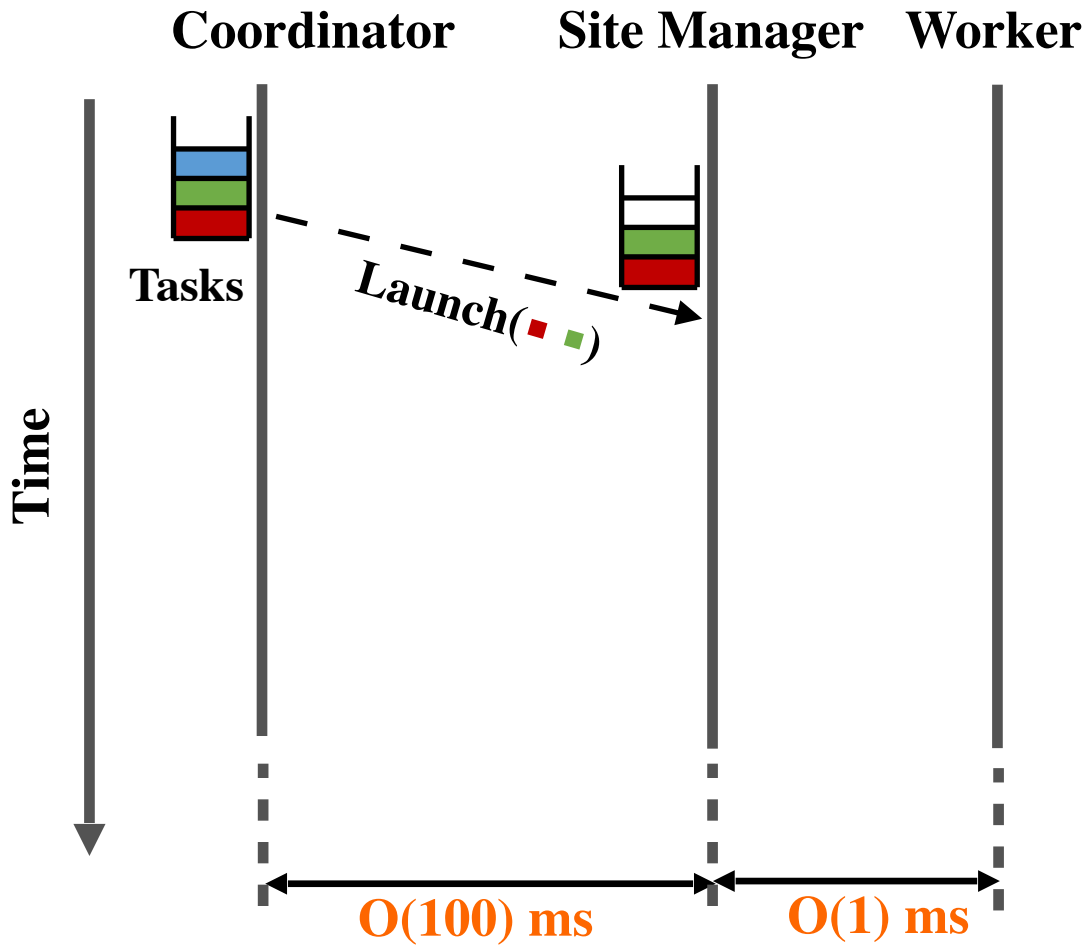

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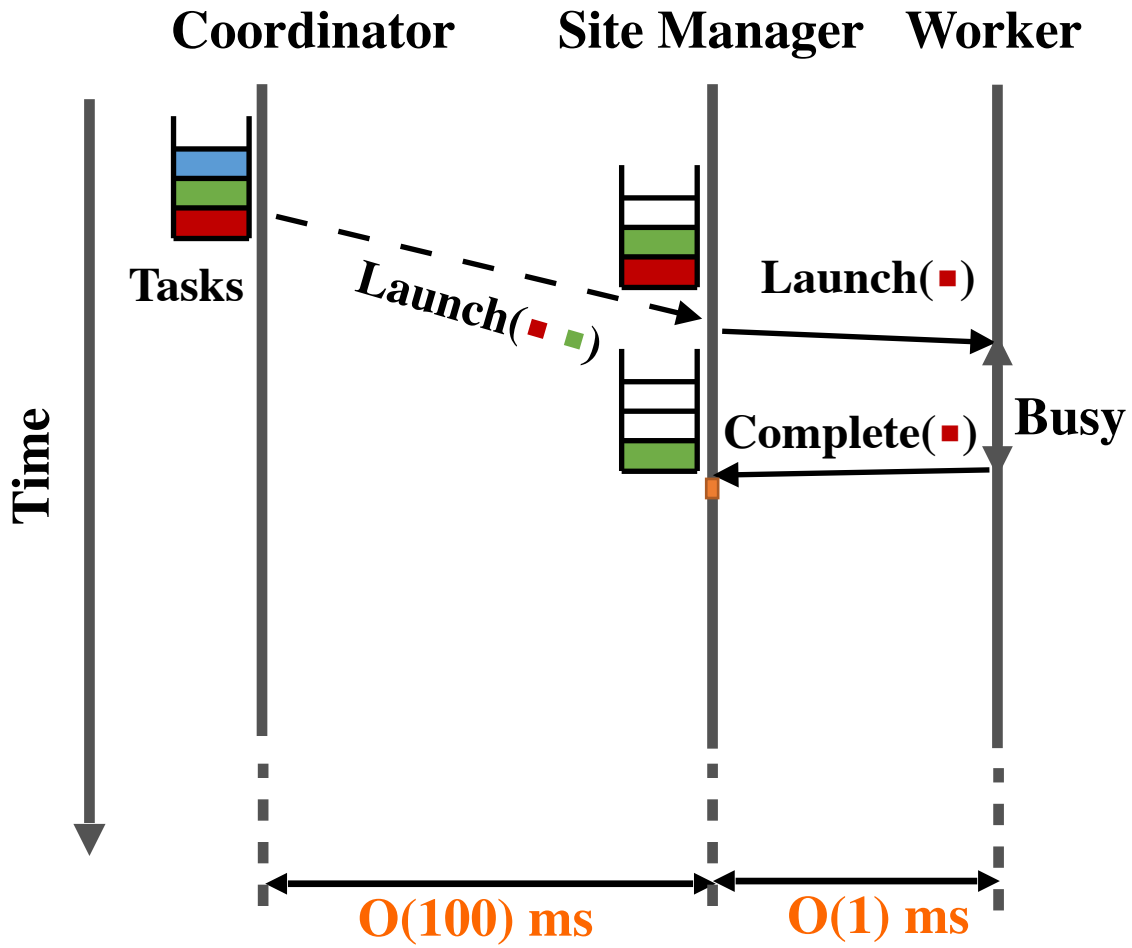
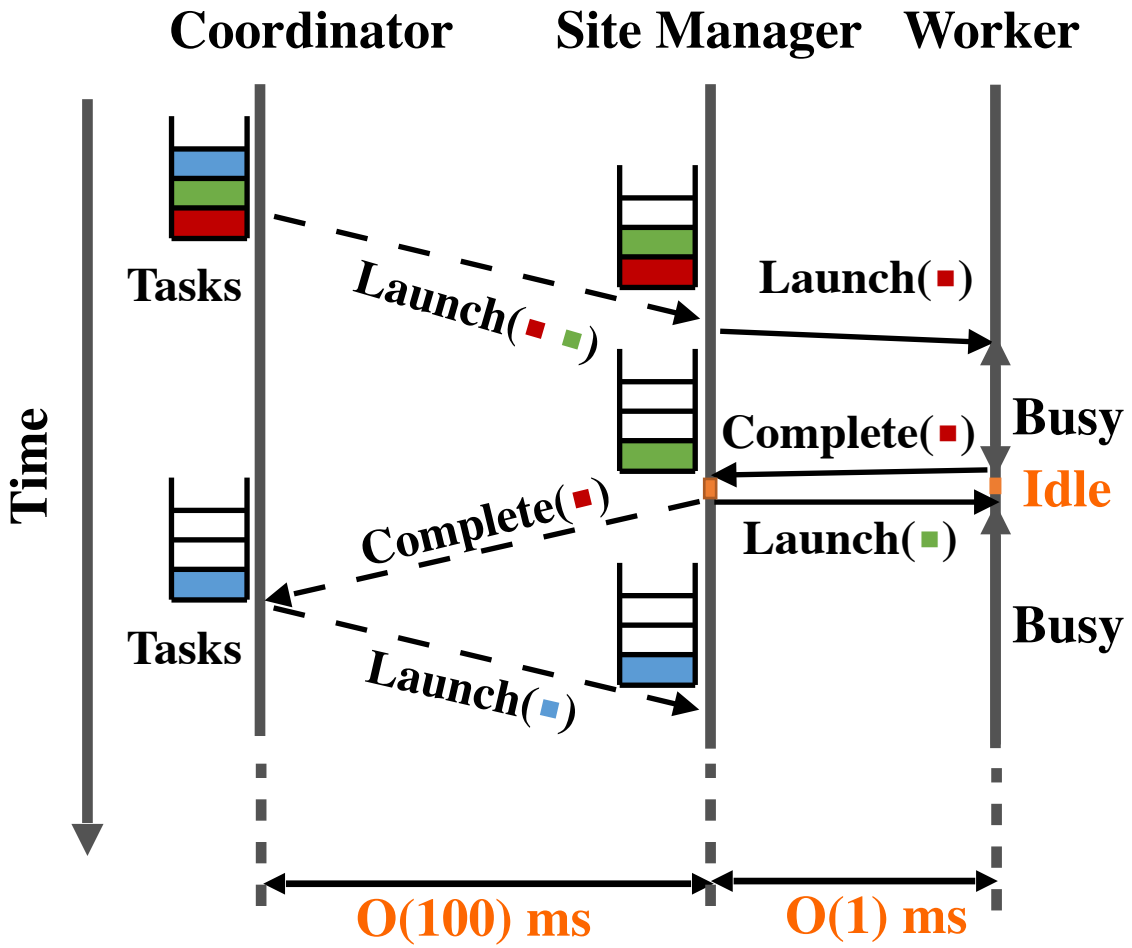


Task Early-binding in Control Plane

- **Coordinator ⟷ Site Manager**
  - Inter-site operations are *early-binding*

  → Guarantee high utilization



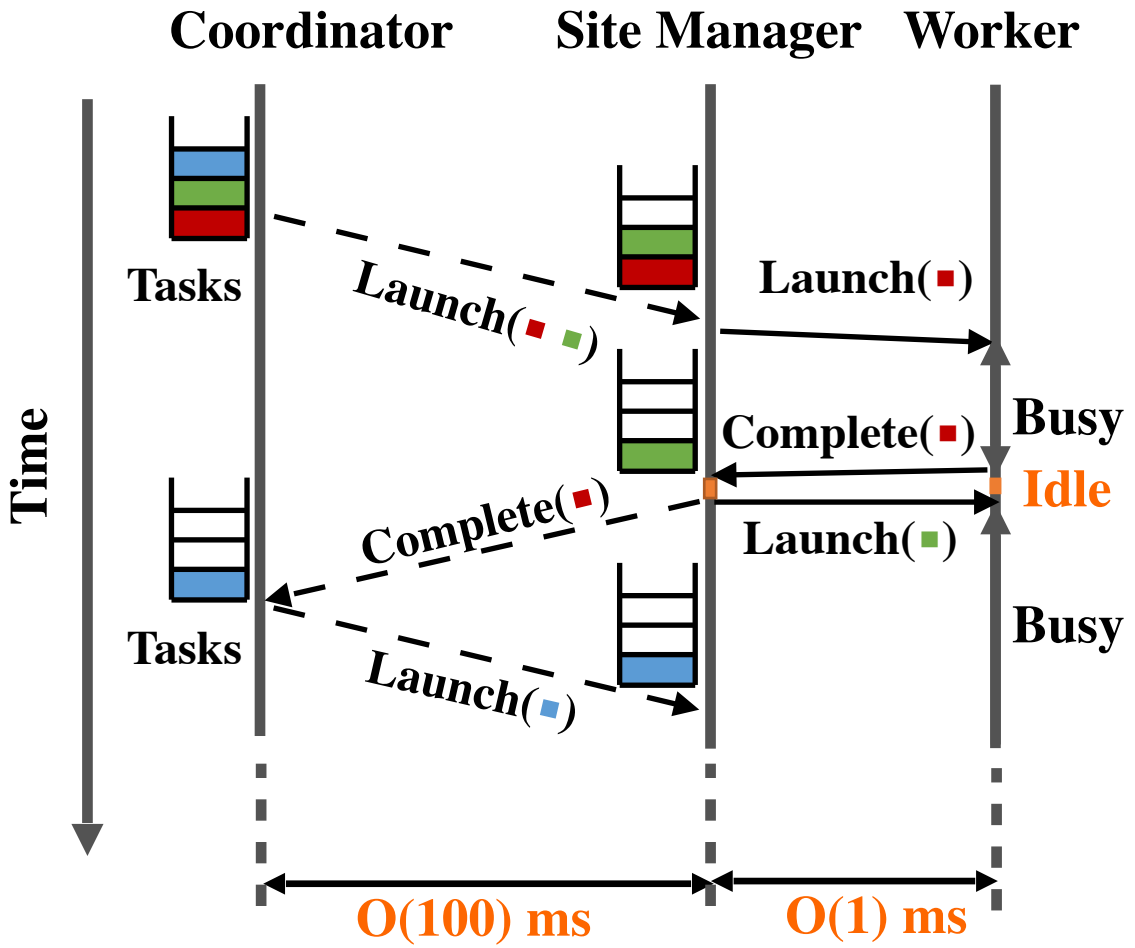
Task Early-binding in Control Plane

- **Coordinator ⟷ Site Manager**
  - Inter-site operations are *early-binding*

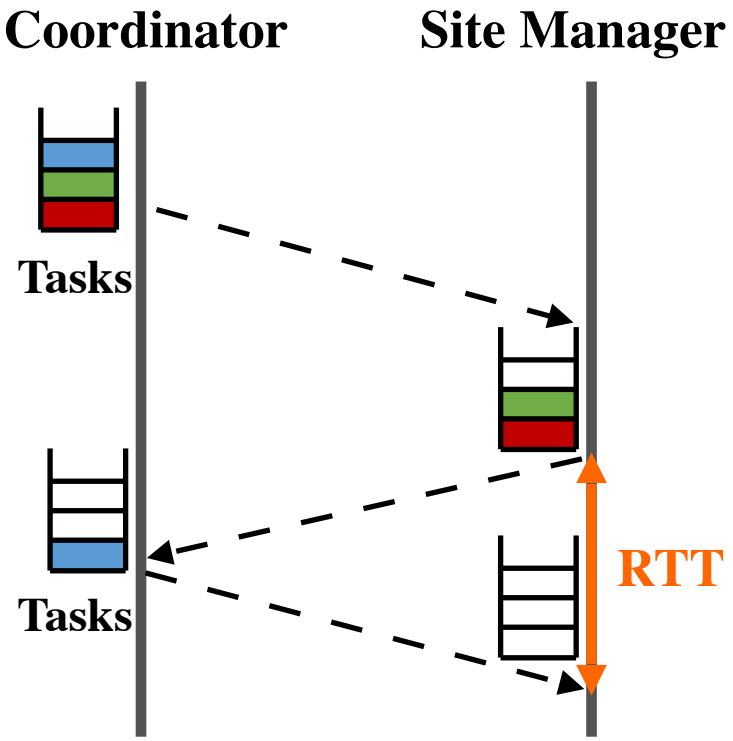
  → Guarantee high utilization

- **Site Manager ⟷ Worker**
  - Intra-site operations are *late-binding*

  → Retain precise views



Challenge 1.1: How Many Tasks to Push?



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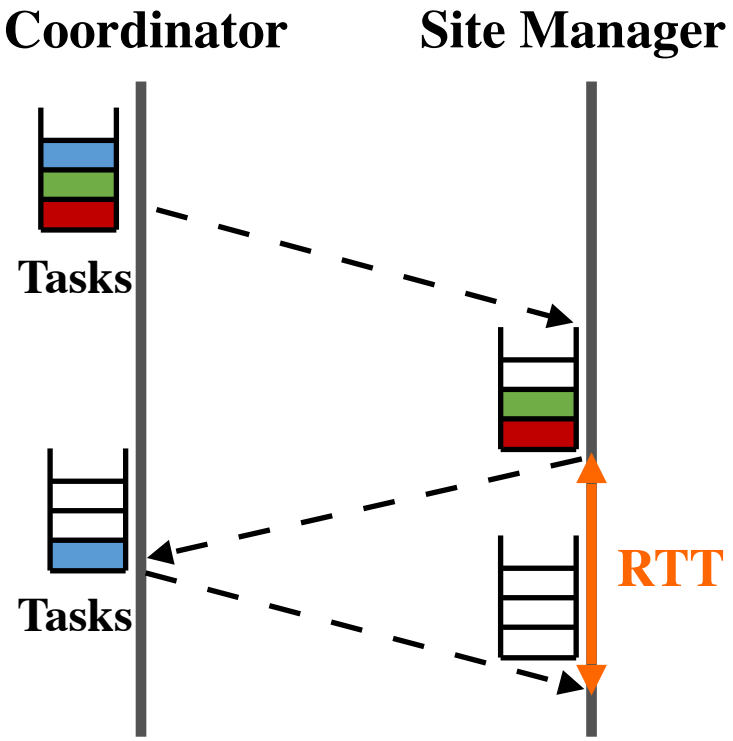
  - Not enough work → *Underutilization*
- **Queue up too many**
  - Scheduling too early → *Suboptimal placement*



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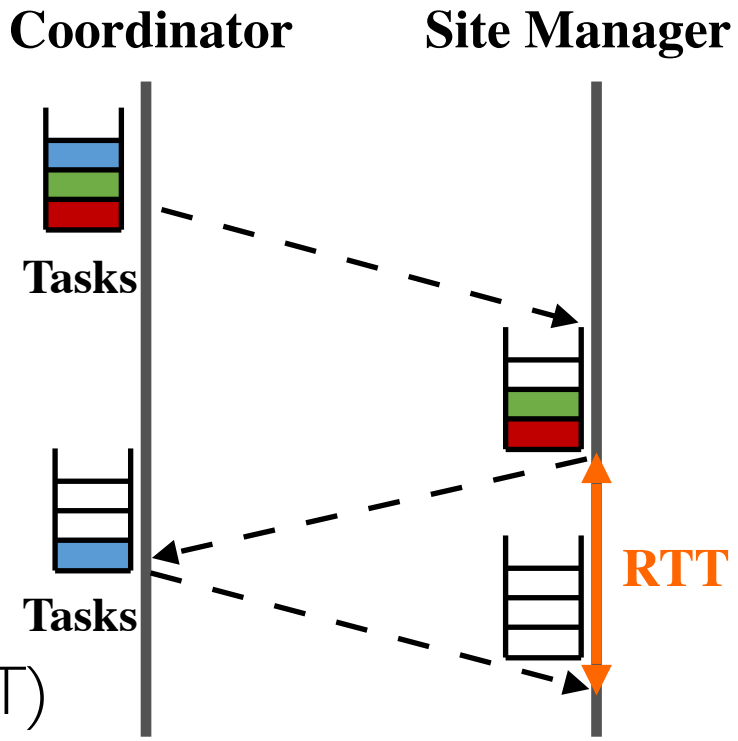

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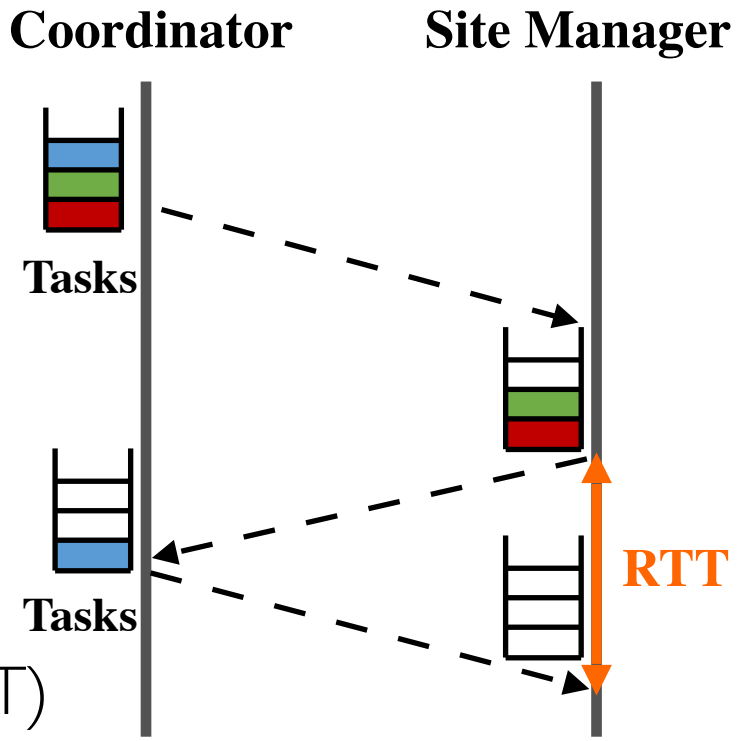
    - SoI works well *w/o* precise knowledge of task duration
      - Hoeffding-bound (details in paper)



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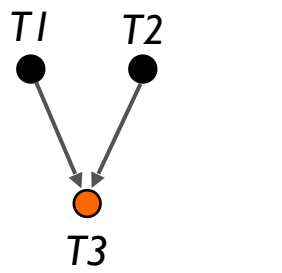

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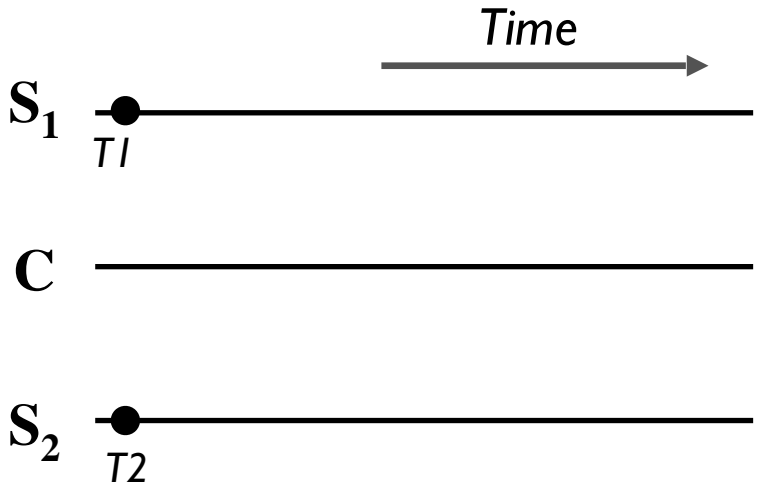

Design in Existing Engines

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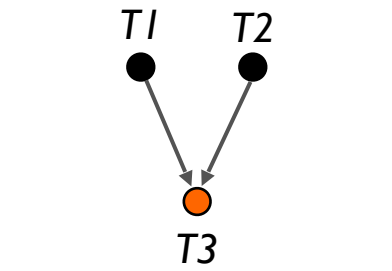

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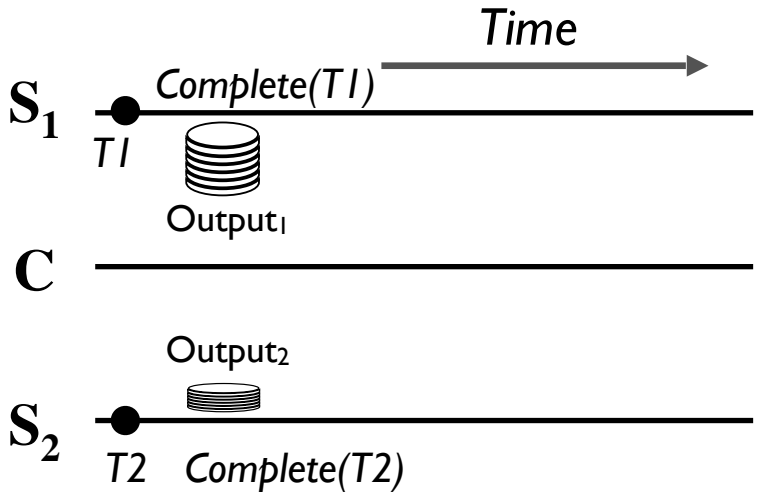

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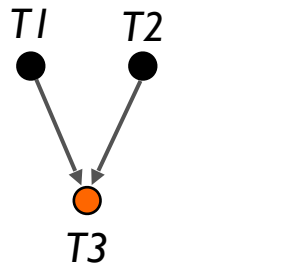

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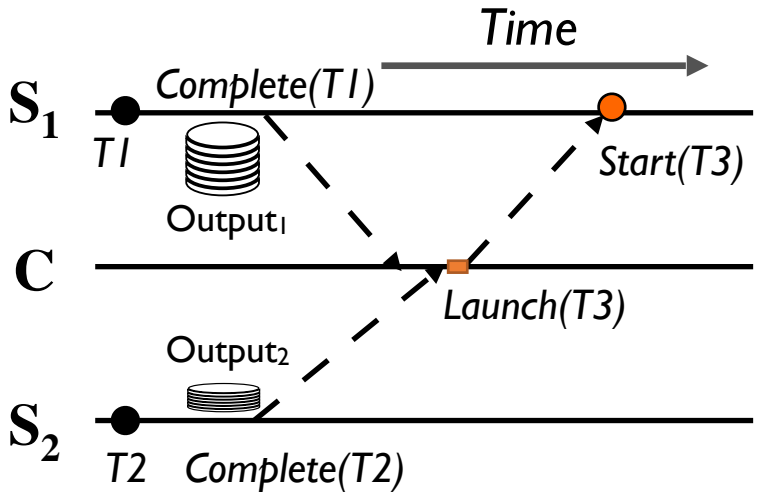

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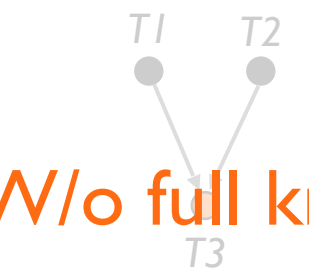

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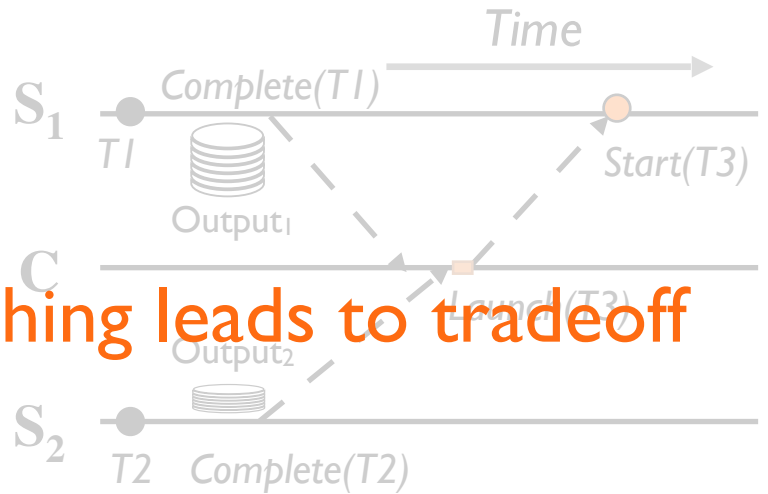
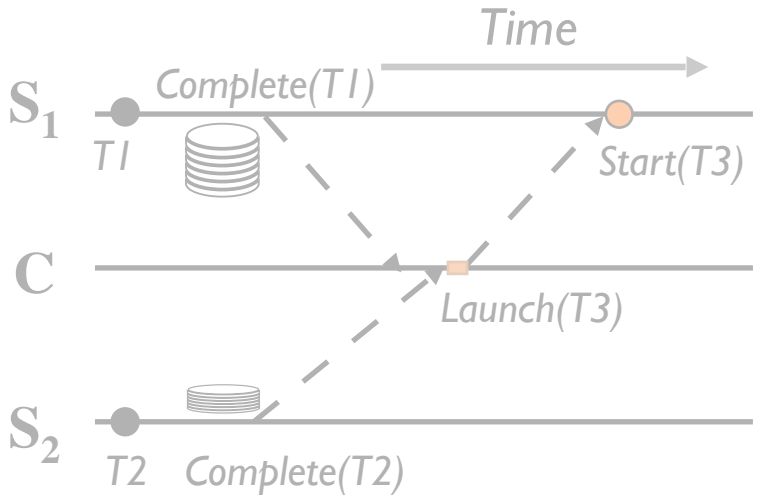


Design in Existing Engines

W/o full knowledge, pushing leads to tradeoff

Challenge 1.2: How to Push Tasks w/ Dependencies?

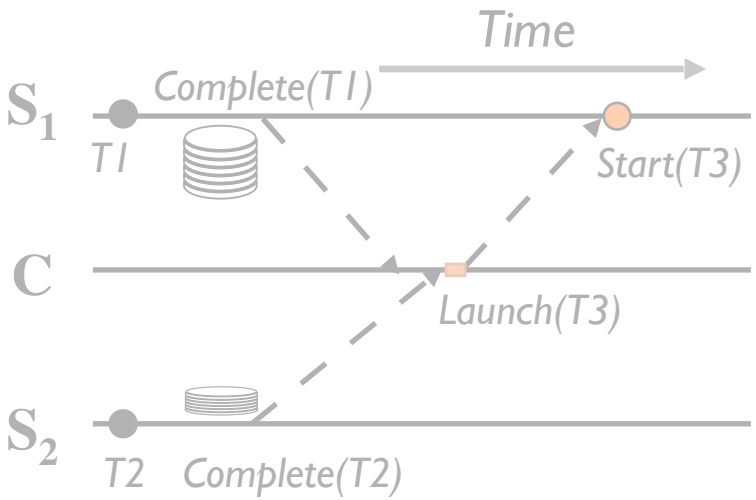
1. Sol improves utilization by pushing with speculation
   - E.g., historical information



Design in Existing Engines

Challenge 1.2: How to Push Tasks w/ Dependencies?

1. Sol improves utilization by pushing with speculation
   - E.g., historical information



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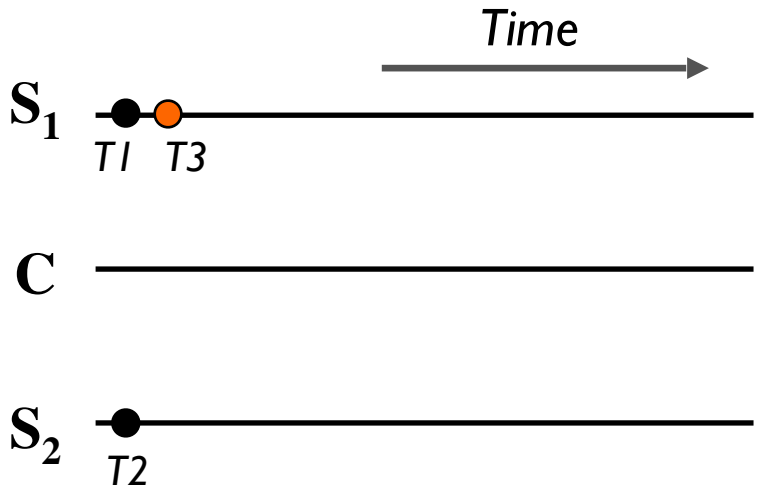

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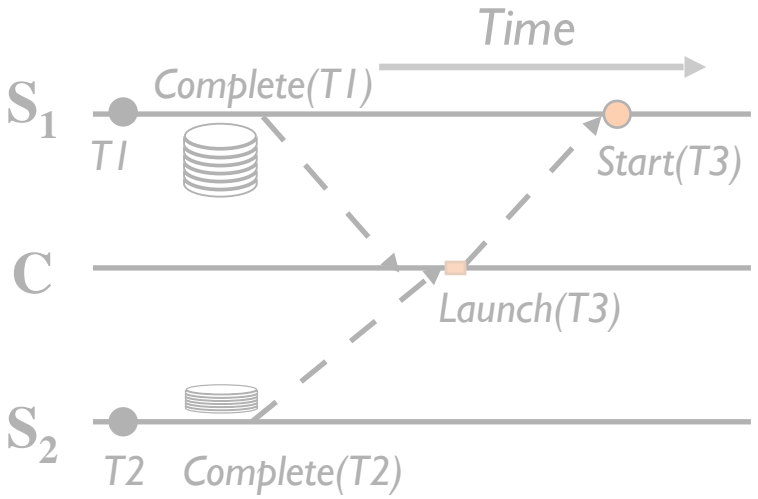

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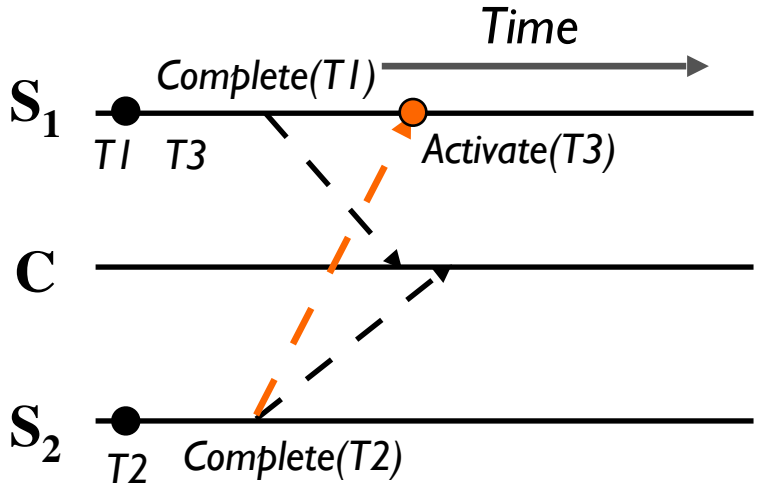
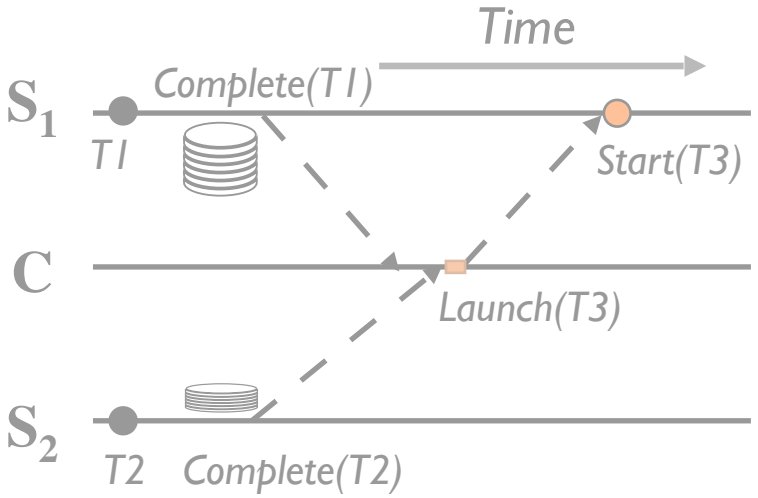


Push w/ Correct Speculations

Sol saves RTTs

Challenge 1.2: How to Push Tasks w/ Dependencies?

2. In case of mistakes, Sol retains good scheduling by recovering
   - With worker-initiated re-scheduling



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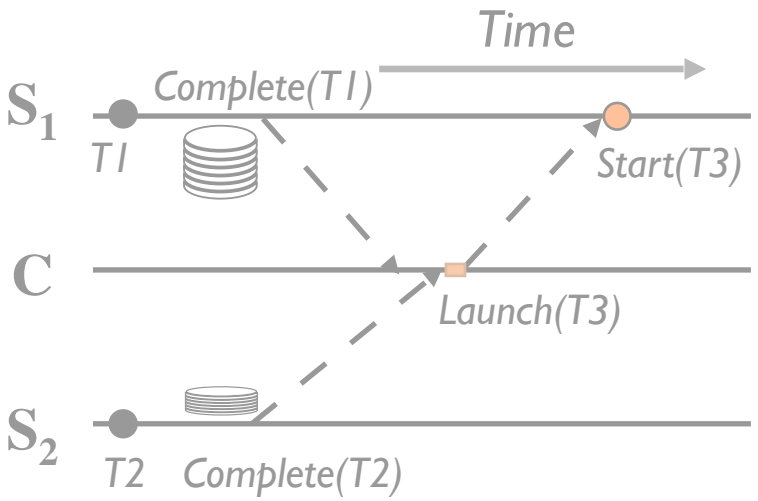

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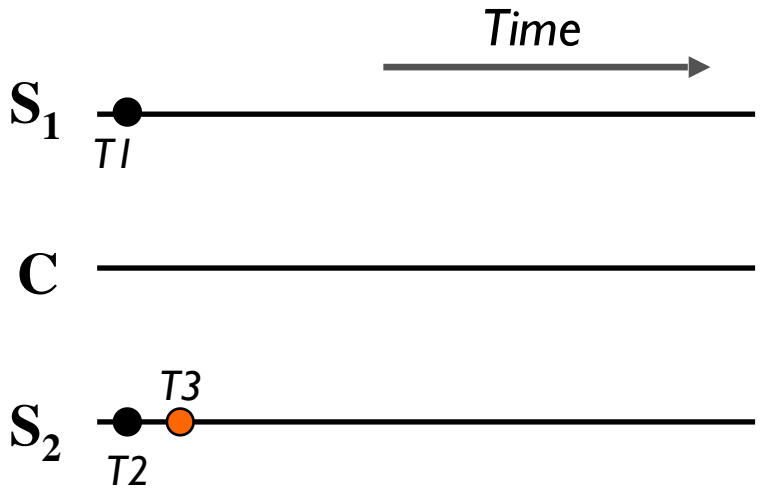

Push under Mispredictions

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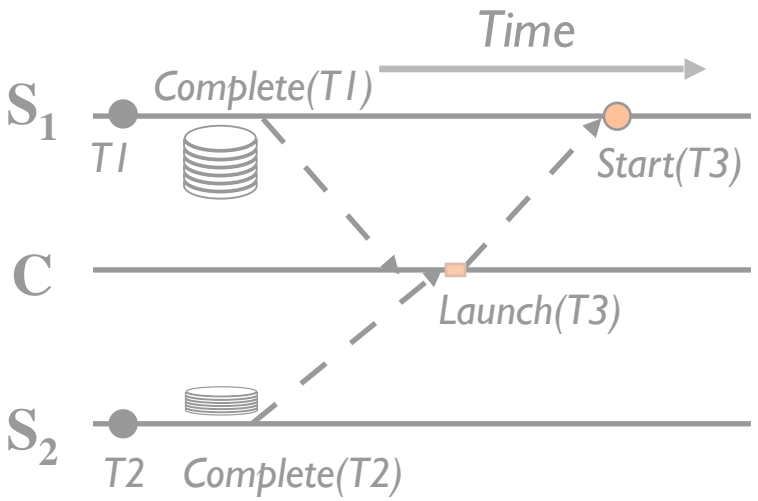

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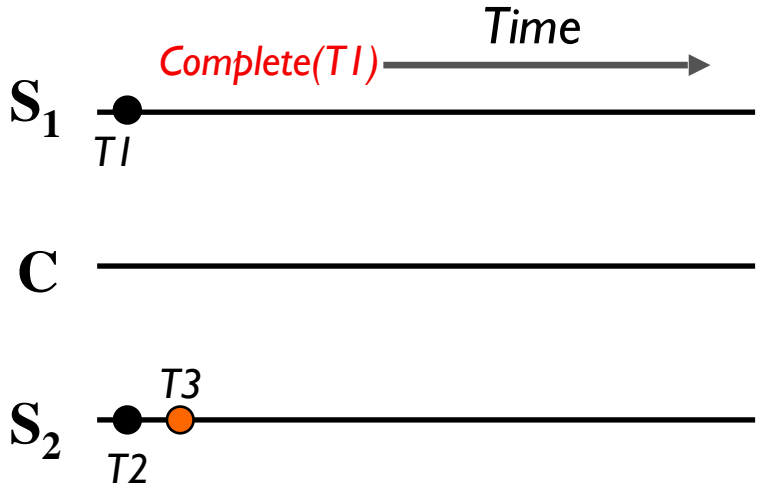

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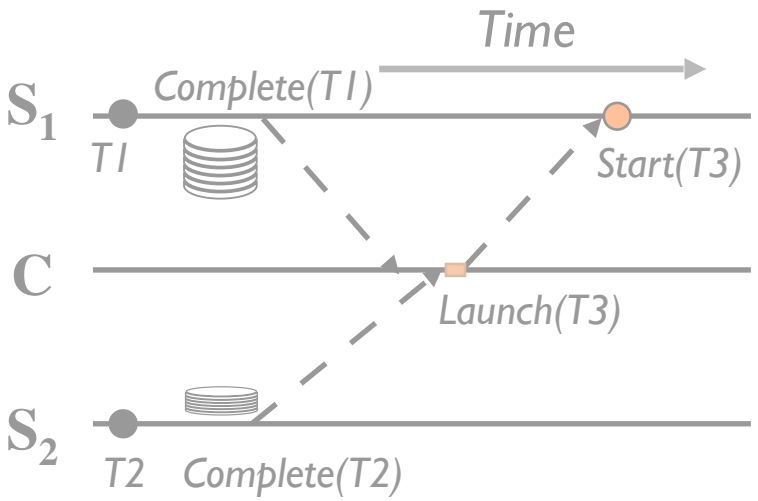

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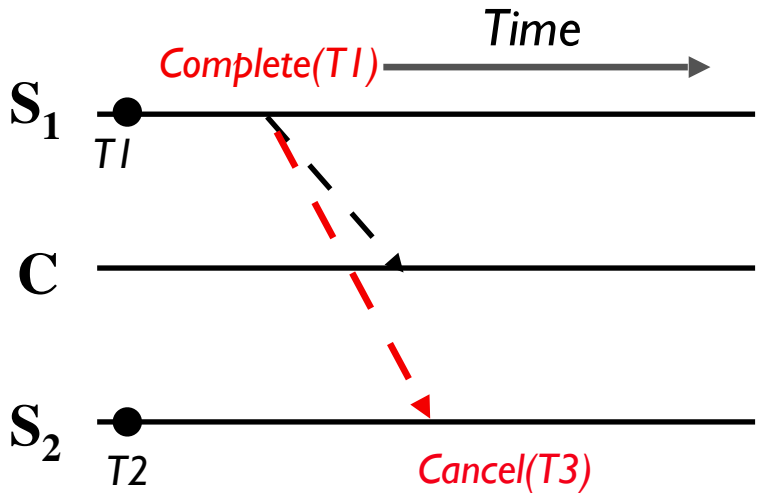

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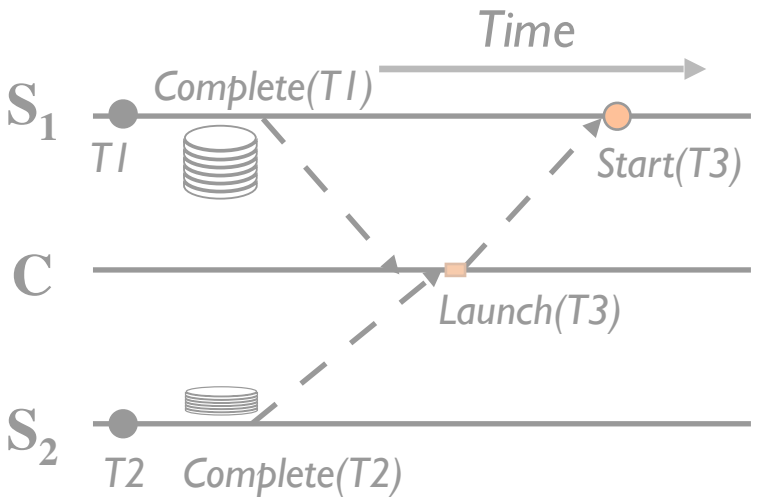

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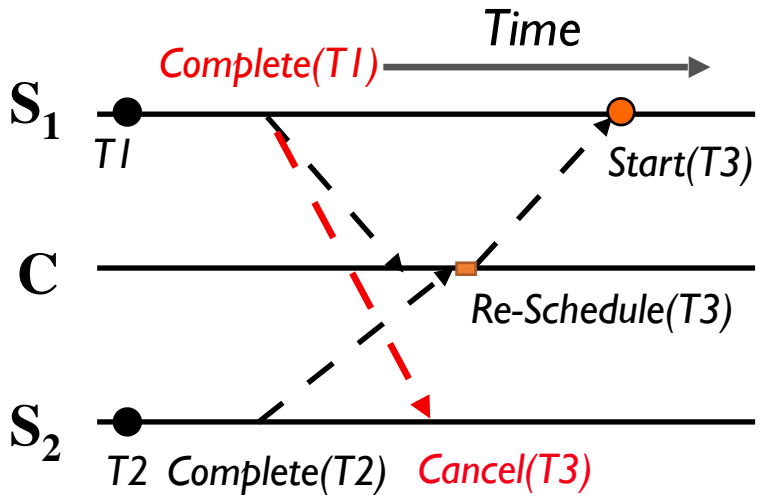
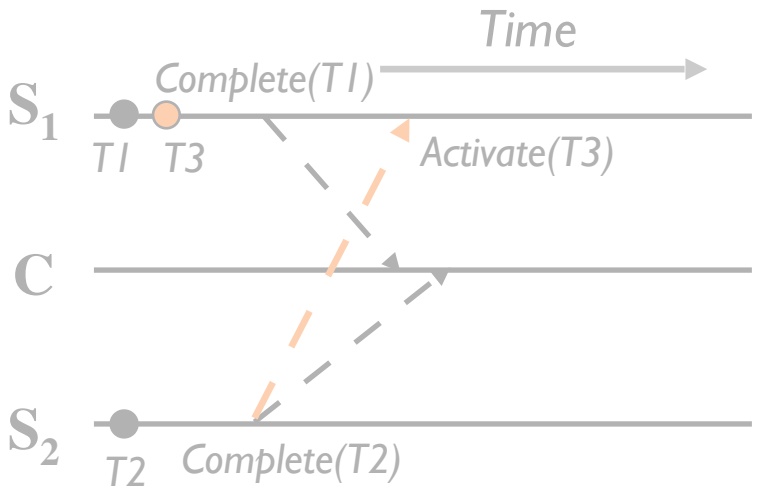


Push under Mispredictions

Sol does not make things worse

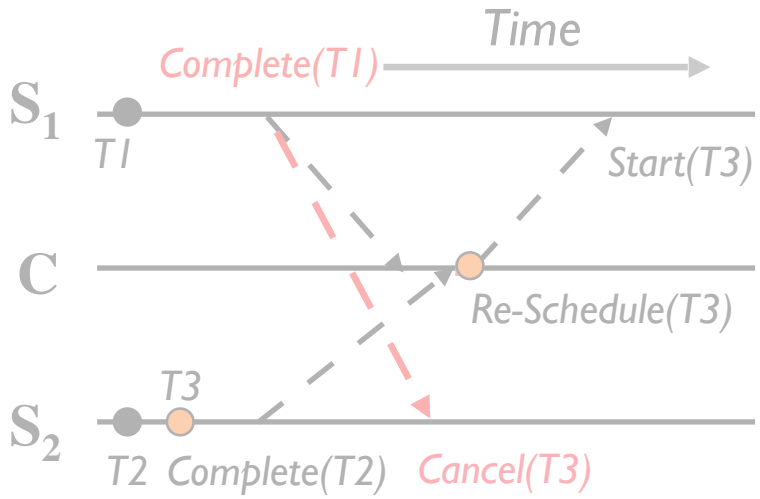
Task Early-binding in Control Plane

- Sol improves *utilization* while retaining good scheduling quality



Push w/ Correct Speculations

Sol improves utilization



Push under Mispredictions

Sol retains good scheduling quality

Outline

- Today's Execution Engines
- Sol Architecture
- Control Plane Design
- Data Plane Design
- Evaluation

Problem #2

Low b/w → CPU underutilization

Decouple resource provisioning to improve CPU utilization

Resource Decoupling in Data Plane

- **Decouple the resource provisioning *internally* with**
  - ***Communication task***: prepare data over networks

Resource Decoupling in Data Plane

- **Decouple the resource provisioning *internally* with**
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Sol scales down CPU requirements and reclaims unused CPUs

Challenge 2: How to Manage Jobs?

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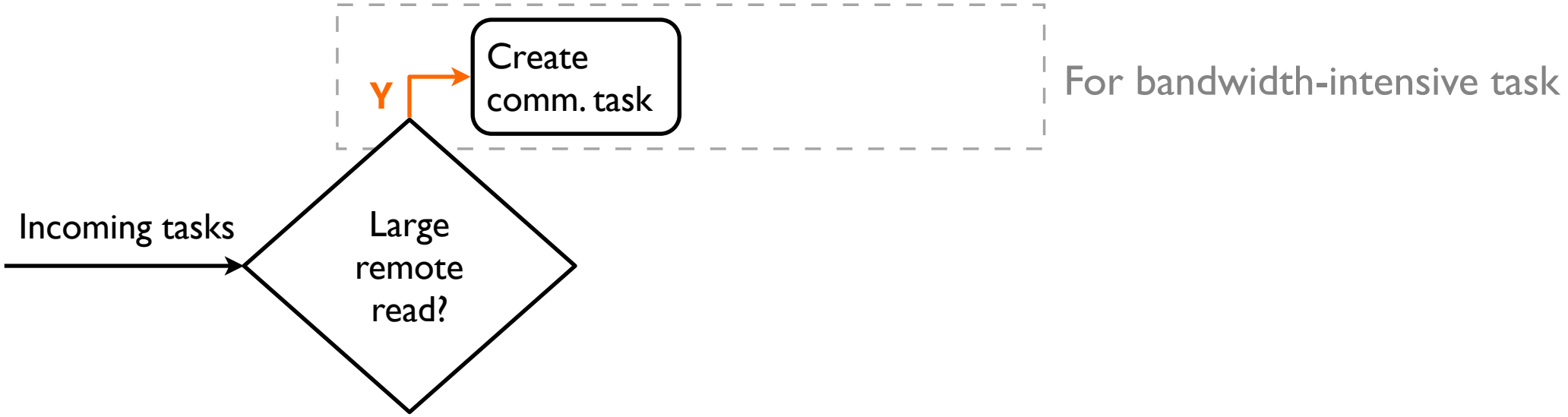
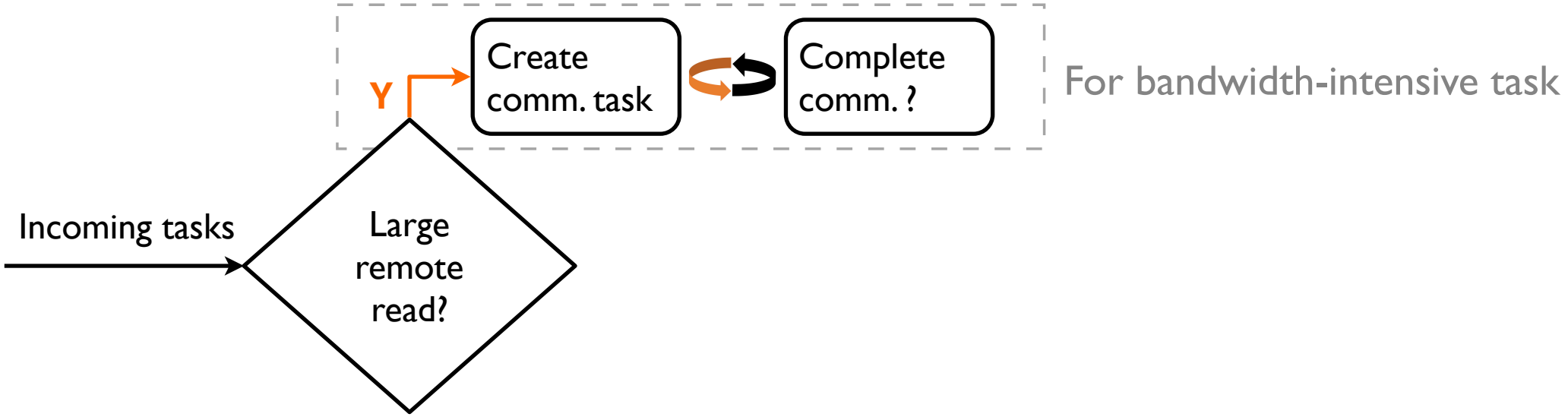


Control flow of decoupling

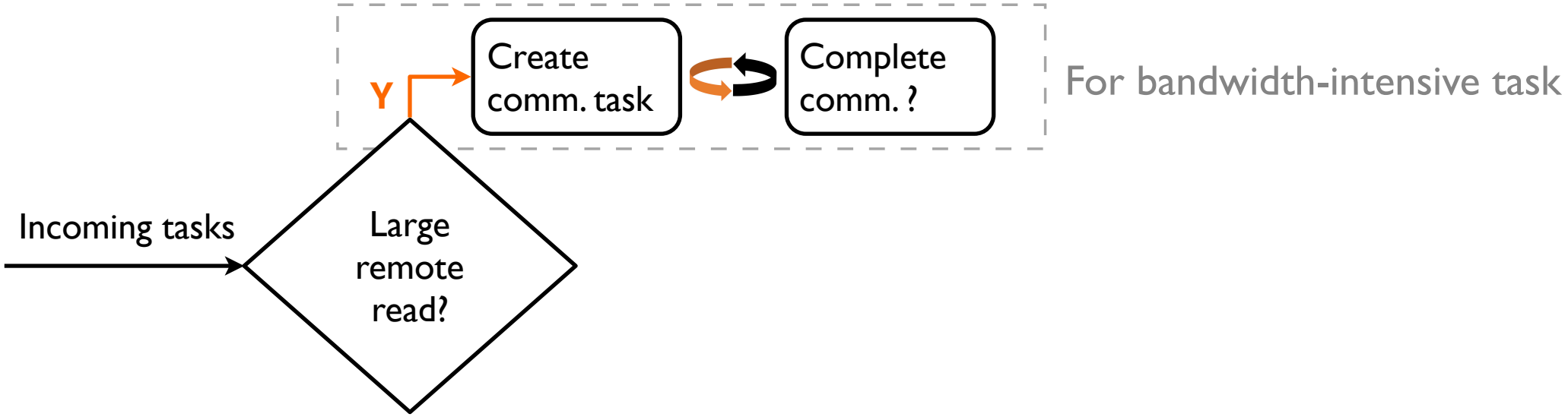
Challenge 2: How to Manage Jobs?



Control flow of decoupling

Challenge 2: How to Manage Jobs?

- **How many communication tasks to create?**
  - Too few → Network is not saturated
  - Too many → CPUs are not saturated



Control flow of decoupling

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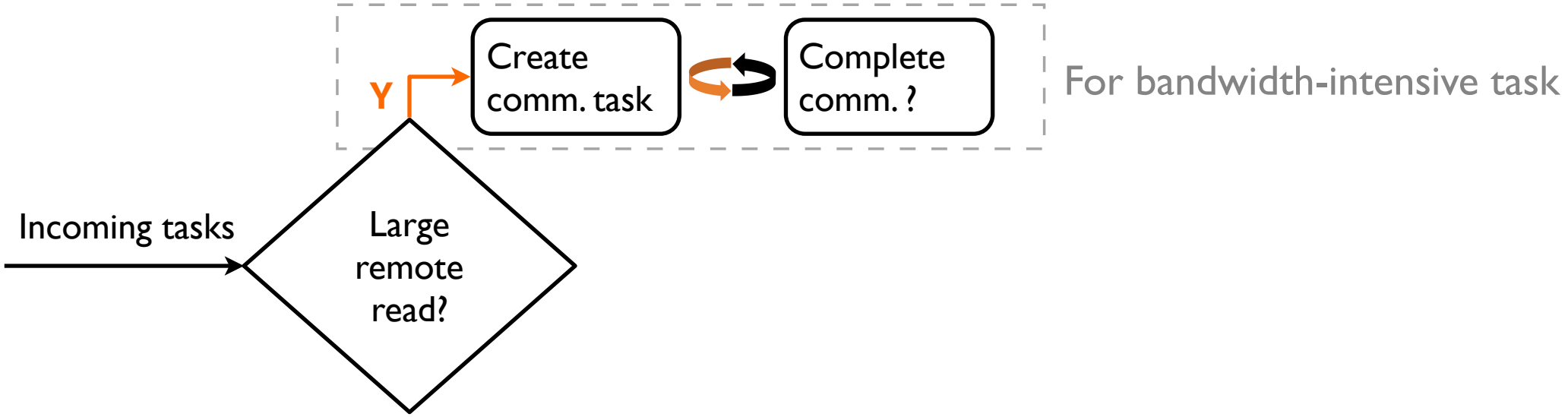
} *Adapt to available bandwidth*



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Challenge 2: How to Manage Jobs?

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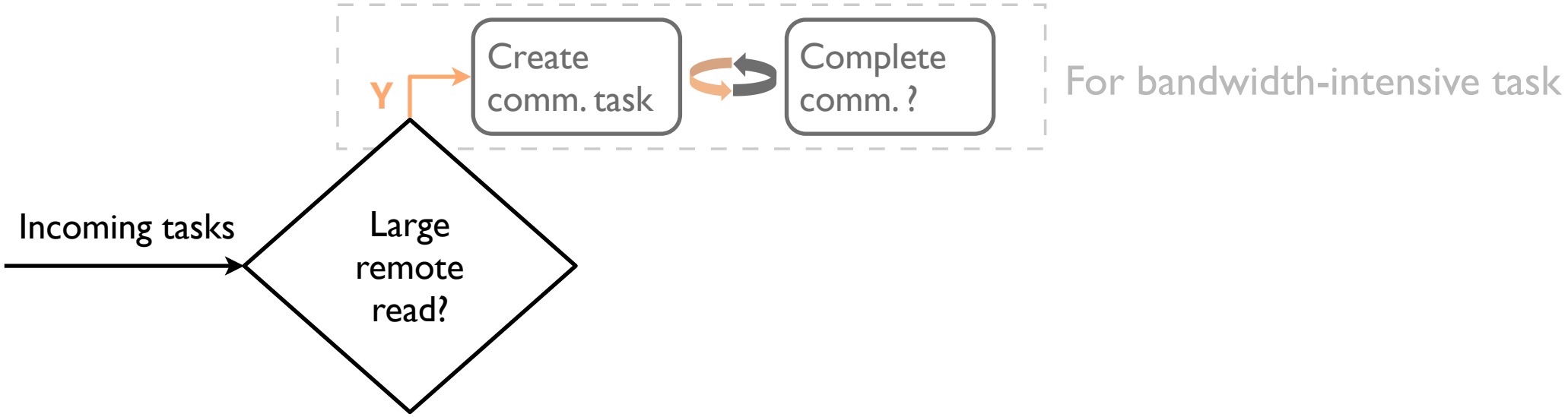

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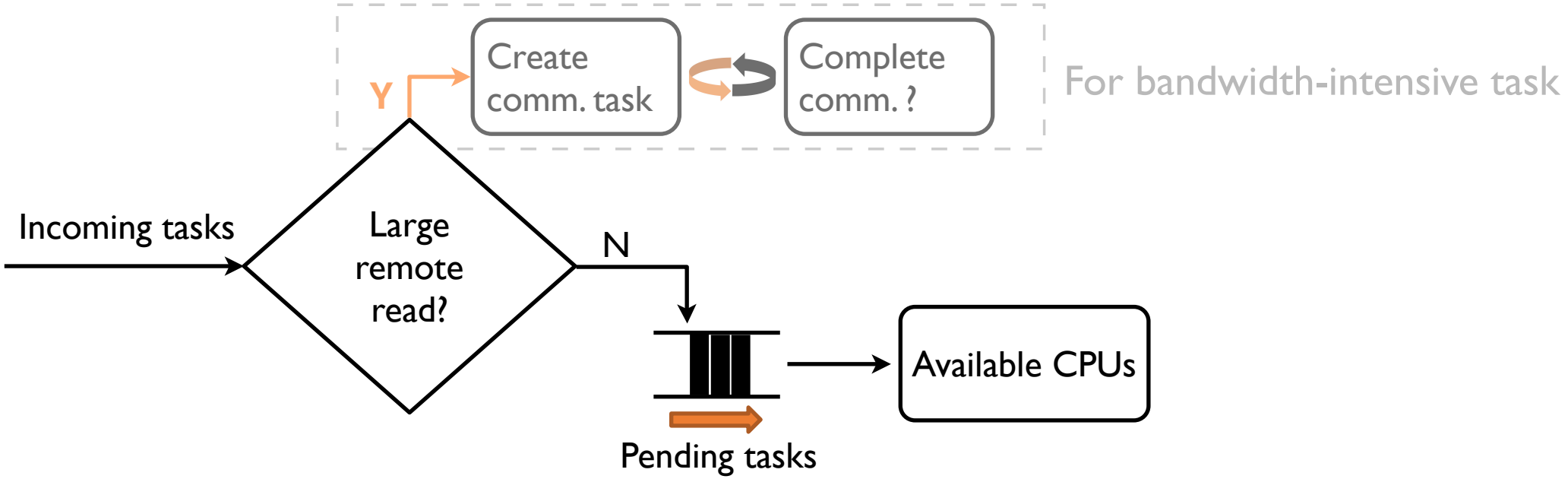

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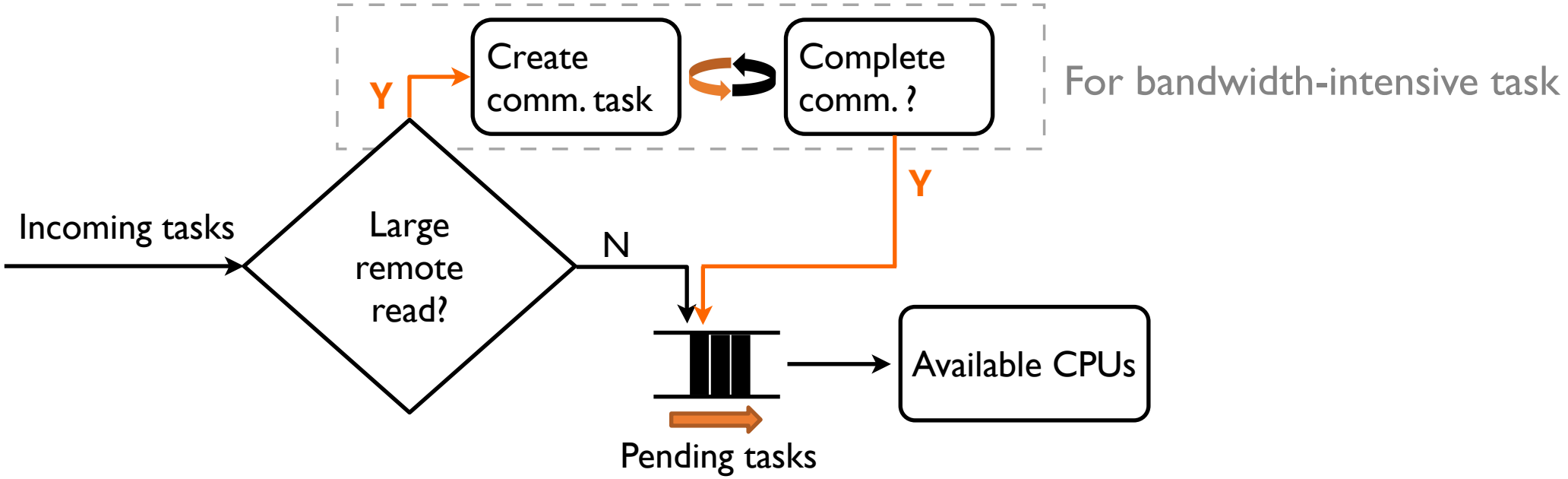
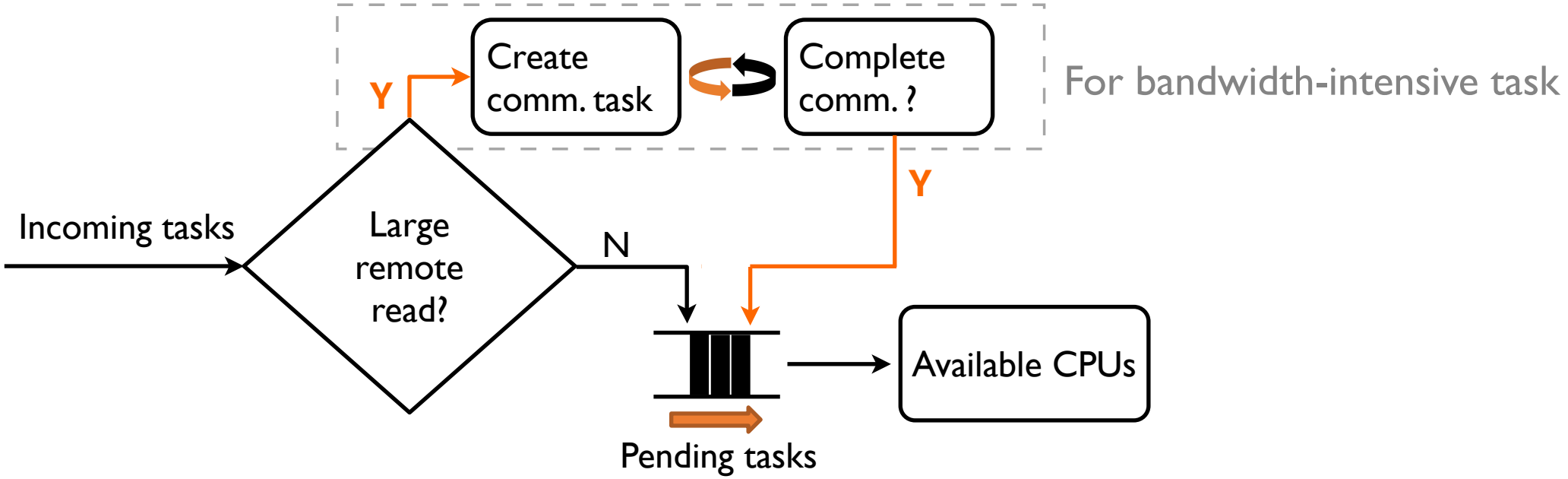


Control flow of decoupling

Challenge 2: How to Manage Jobs?

- **How to manage the computation tasks?**
  - ***Prioritize*** them when data is ready



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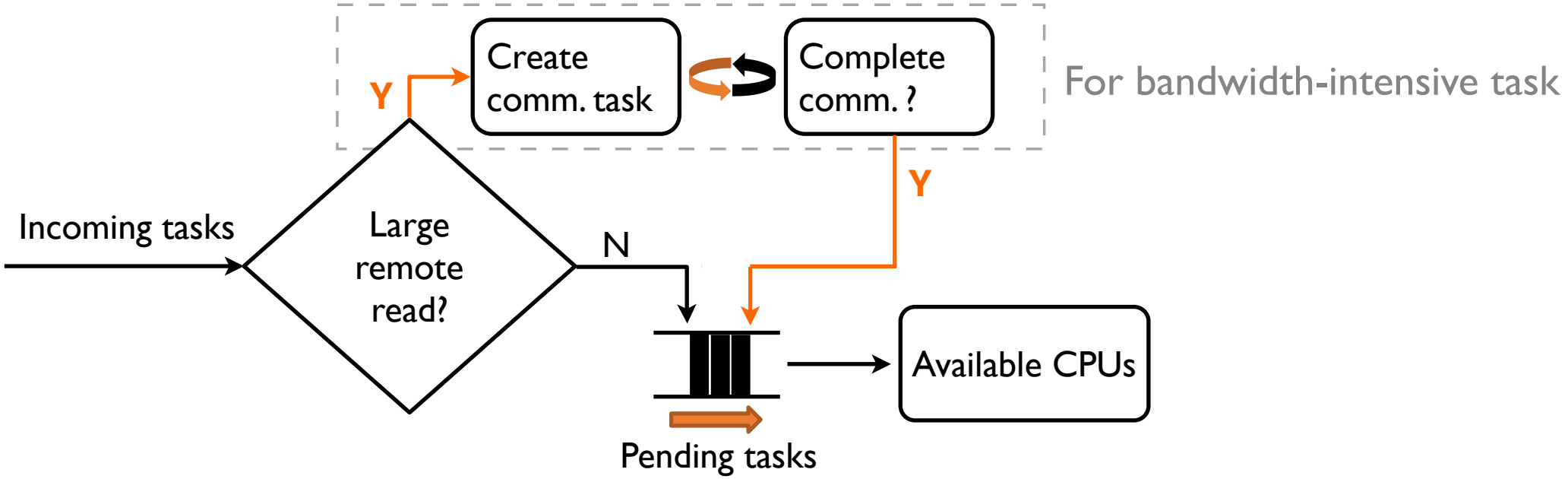

Control flow of decoupling

Evaluation

With a prototype supporting generic data processing

- **Environment**
  - 10-site deployment in EC2
  - 4 *m4.4xlarge* VMs in each site

Deployment over WAN

Evaluation

With a prototype supporting generic data processing

- **Environment**
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Deployment over WAN

How does Sol perform:

1. compared to existing engines?
2. across design space?
3. under uncertainties?

Sol Improves Job Performance and Resource Util. (WAN)

Benchmark — multi-job execution

- Latency-sensitive TPC queries
- Bandwidth-intensive TeraSort

Baseline

- Apache Spark

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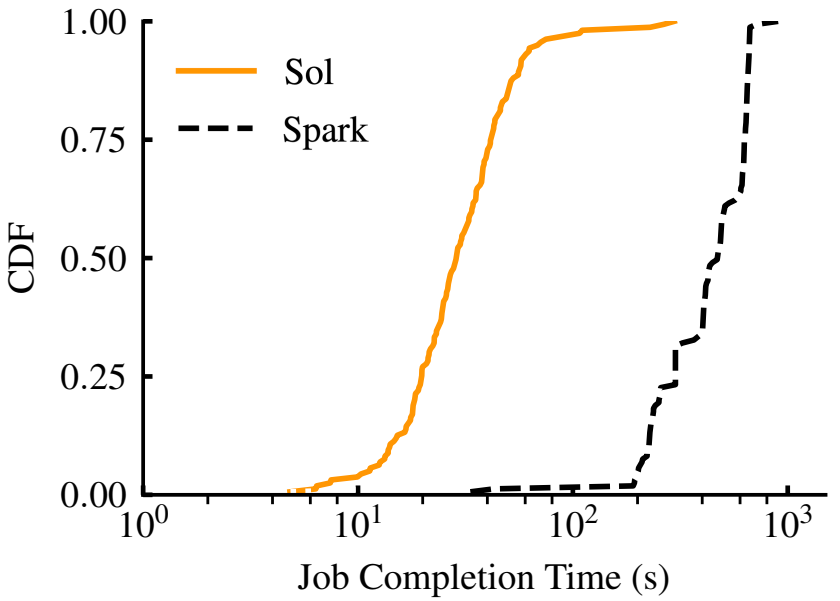
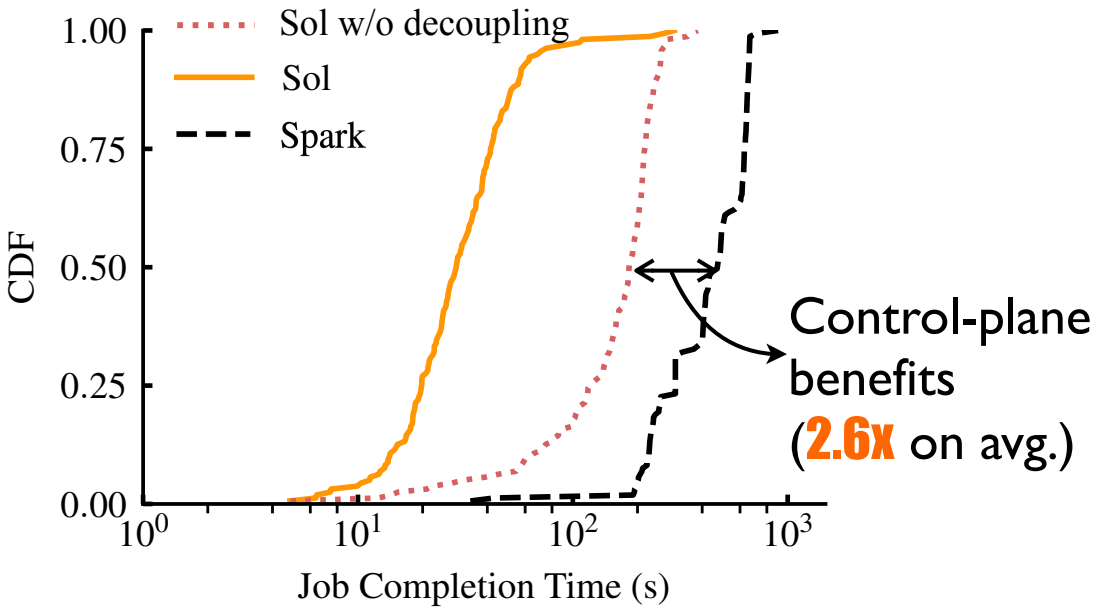


16.4x improvement on average

Sol Improves Job Performance and Resource Util. (WAN)

Control Plane:

Early-binding → Less idle time



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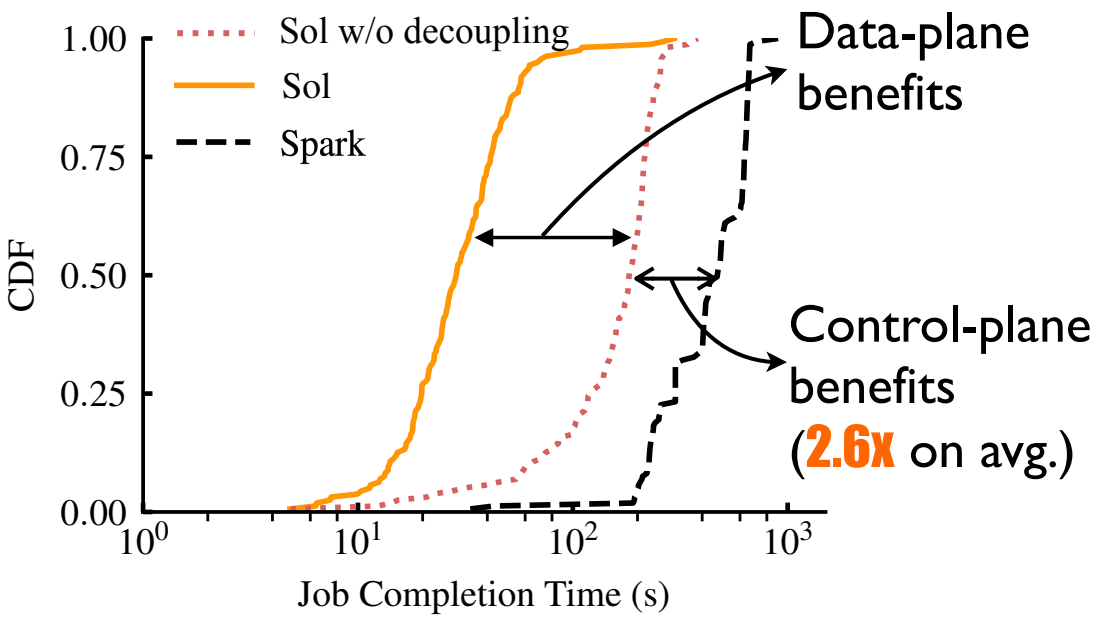
Control Plane:
Early-binding → Less idle time

Data Plane:
Decoupling → Less under-util.



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Sol Improves Job Performance and Resource Util. (WAN)

Control Plane:

Early-binding → Less idle time

+

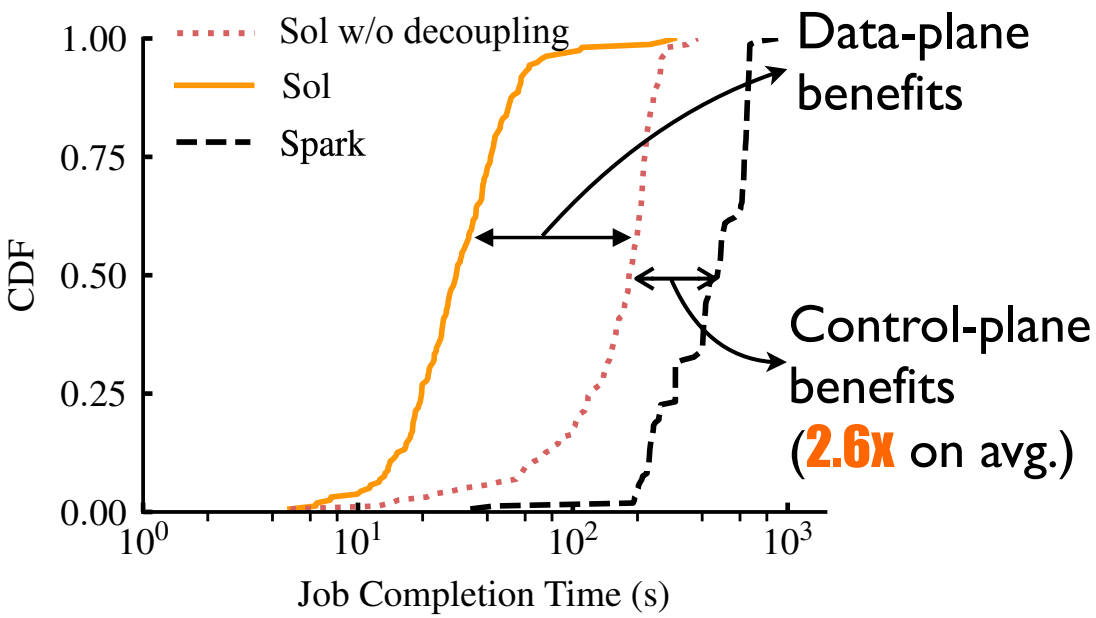
Data Plane:

Decoupling → Less under-util.

↓

16.4x *better job completion*

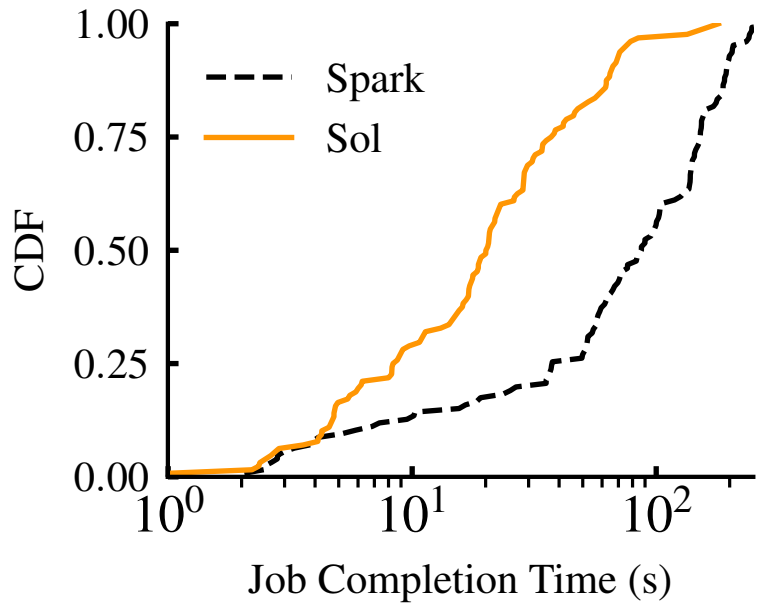
1.8x *better CPU util.*



16.4x improvement on average

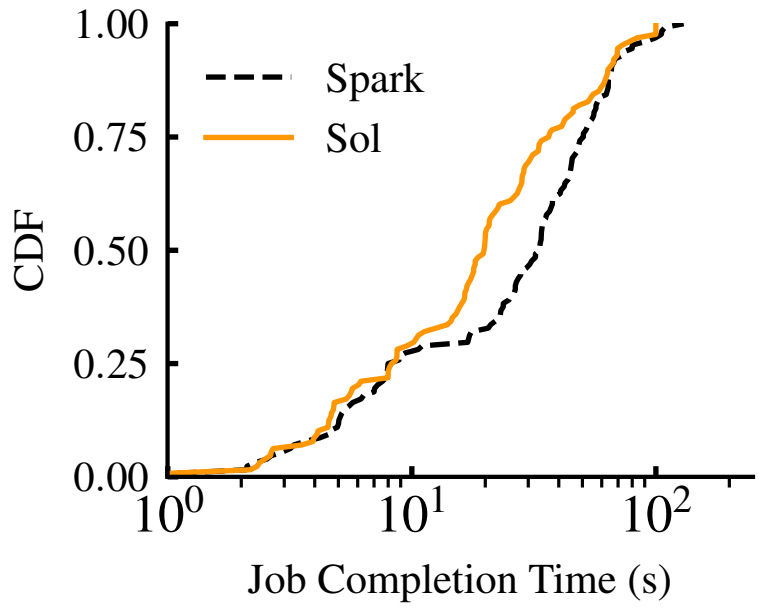
Sol Performs Well Across Design Space (LAN)

Low-bandwidth setting (1 Gbps)



3.9x improvement on average

High-bandwidth setting (10 Gbps)



1.3x improvement on average

Sol

https://github.com/SymbioticLab/Sol

A *federated* execution engine for ***diverse*** network conditions with

- *Faster job execution*
- *Higher resource utilization*

Improve CPU util. {
- *before* task executions → *Early-binding* of tasks
- *during* task executions → *Decoupling* of resource provisioning

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