Caerus: NIMBLE Task Scheduling for Serverless Analytics

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Serverless computing

AWS Lambda Google Cloud Functions Azure Functions IBM Cloud Functions

Fast Scaling

30 ~ 120 Seconds → < 1 Second

Fine-grained billing

Per second → Per millisecond

Serverless analytics

ExCamera (NSDI'17) Sprocket(SoCC'18)
Video processing

gg compiler (ATC'19)
Distributed compiling

Locus (NSDI'19)
Mapreduce & SQL-like queries

Web severing

IoT applications

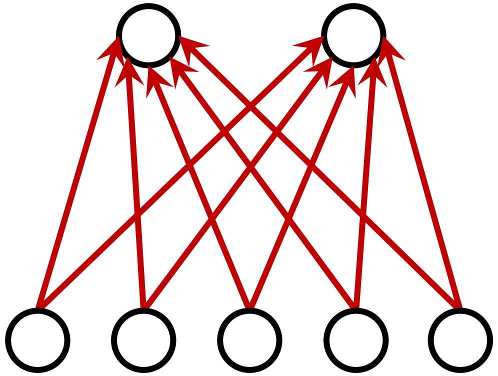
PyWren (SoCC'17)
Scaling python functions

NumPyWren
Matrix computation

Cloudburst (VLDB'20)
Stateful functions

Starling (Sigmod'20)
SQL query engine

2014 **Single-stage functions** 2017 **General data analytics** 2021

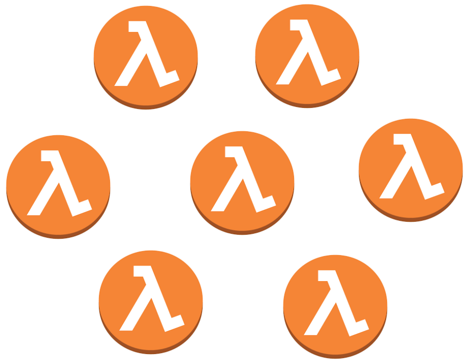


Job Execution plan

Job completion time (JCT)

Deploy

Cost (total duration of all workers)



A pool of (infinite) serverless workers

Serverless scheduling: a new problem

Server-centric users

Inter-job scheduling
Optimization Metrics: average JCT, cluster utilization, fairness *across jobs*

Now handled by the serverless platform

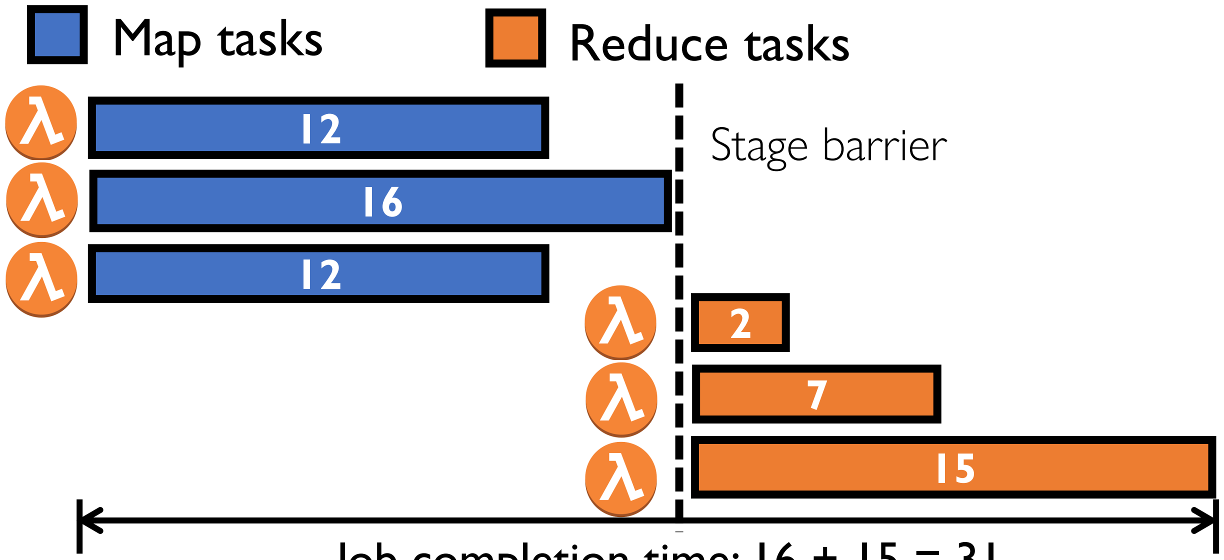
Serverless users

Intra-job scheduling across tasks
Optimization Metrics: *Both JCT and cost* for *each individual job*

Can existing server-centric intra-job scheduling policies optimize both JCT and cost in serverless settings?

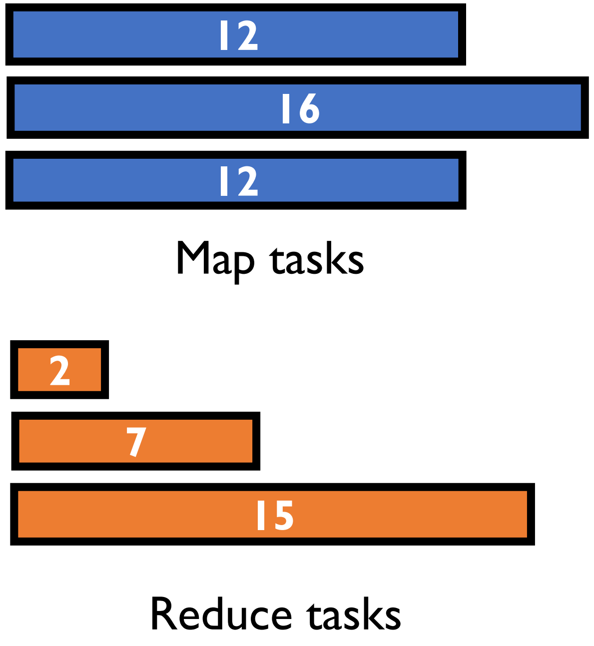
Trade-off: Lazy *vs.* Eager

Lazy: start a task after ALL tasks in its upstream stages have finished (Spark)



Job completion time: 16 + 15 = 31
Cost (total duration): (12*2+16)+(2+7+15) = 64

A MapReduce job with 3 map tasks and 3 reduce tasks



Trade-off: Lazy *vs.* Eager

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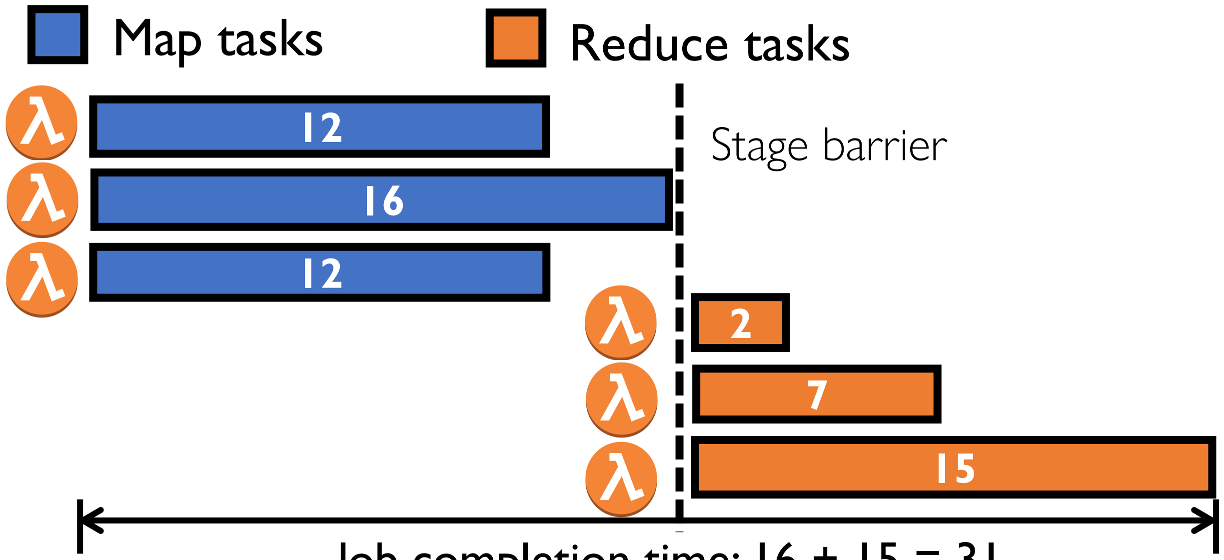
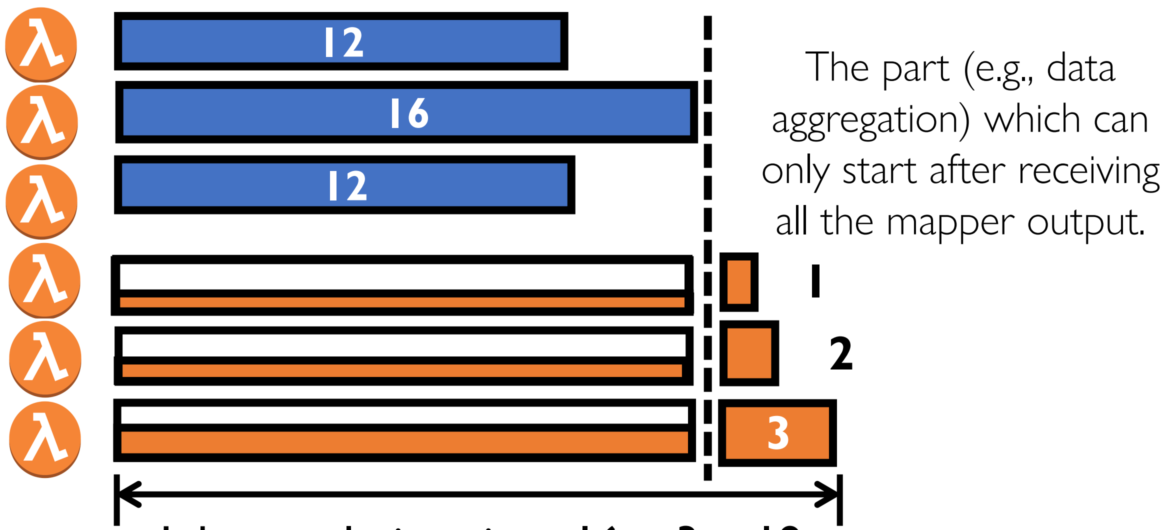


Job completion time: 16 + 15 = 31
Cost (total duration): (12*2+16)+(2+7+15) = 64

Minimizes cost (duration)
Much longer job completion time (1.63X) ☹

Trade-off

Eager: start a task when ANY output from its upstream stages is ready (Mapreduce Online)

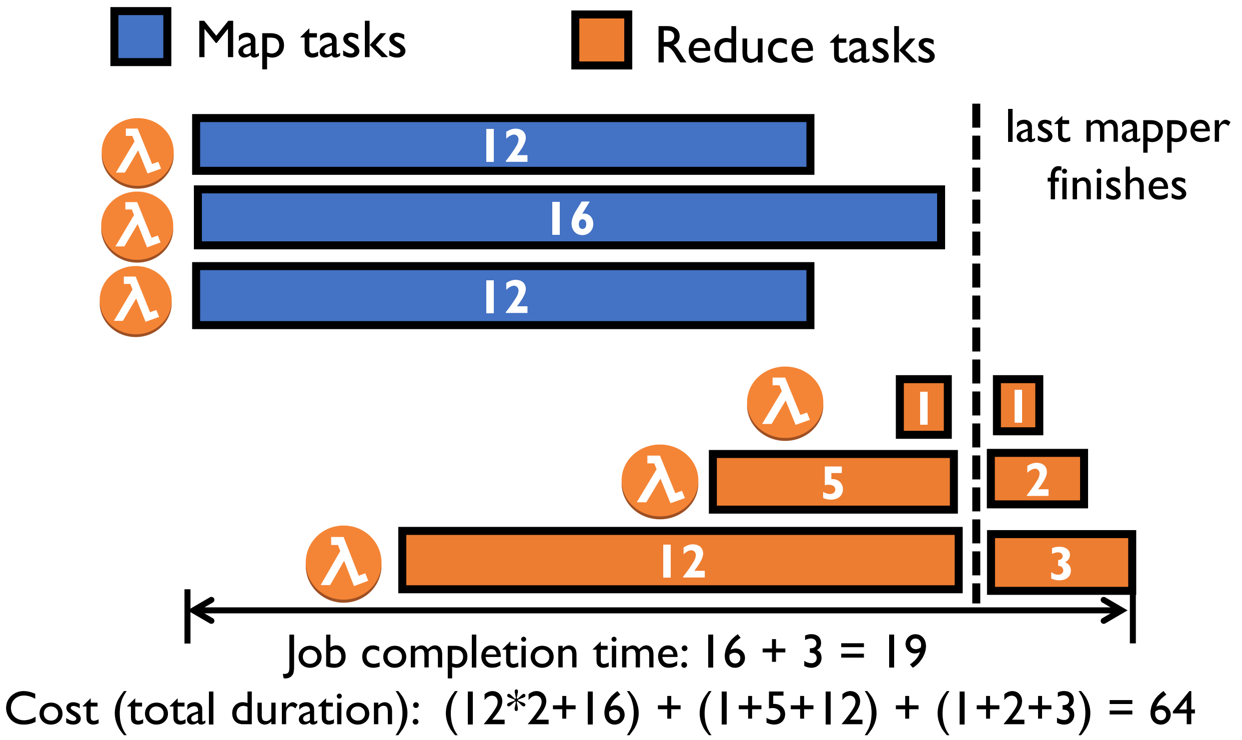


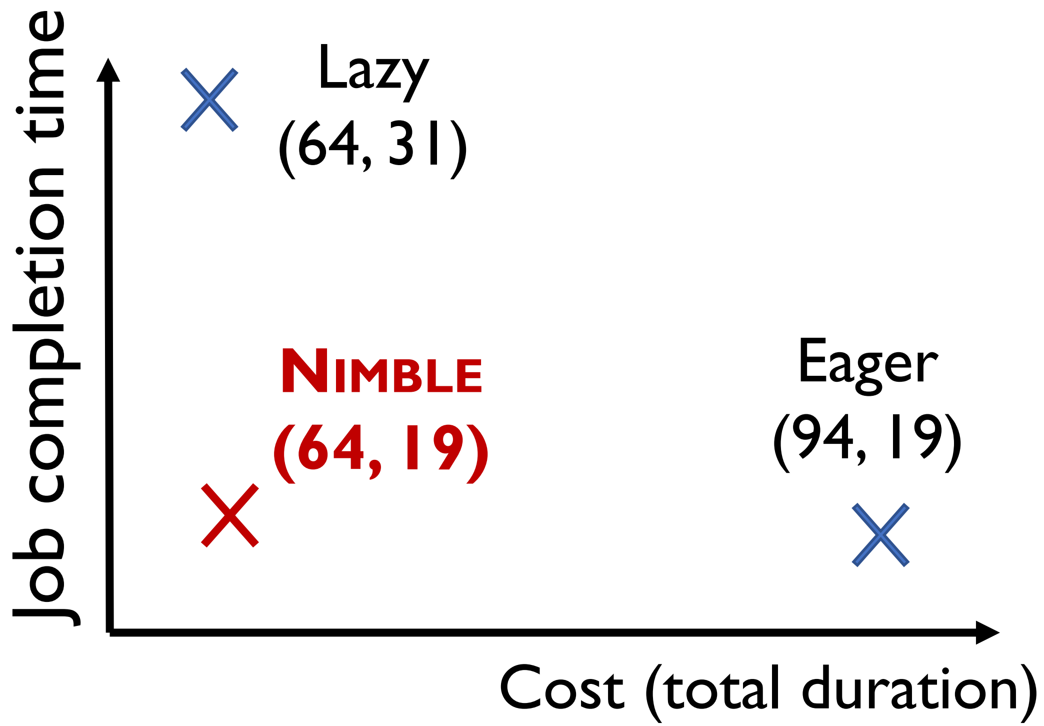
Job completion time: 16 + 3 = 19
Cost: (12*2+16)+ 16*3 + (1+2+3) = 94

Minimizes job completion time
Much higher cost (1.47X) ☹

NIMBLE scheduling: main idea

Main idea:
- Fully exploit the *flexible resource scaling* of serverless computing
- Calculate and enforce the *best launch time* for *each individual task*

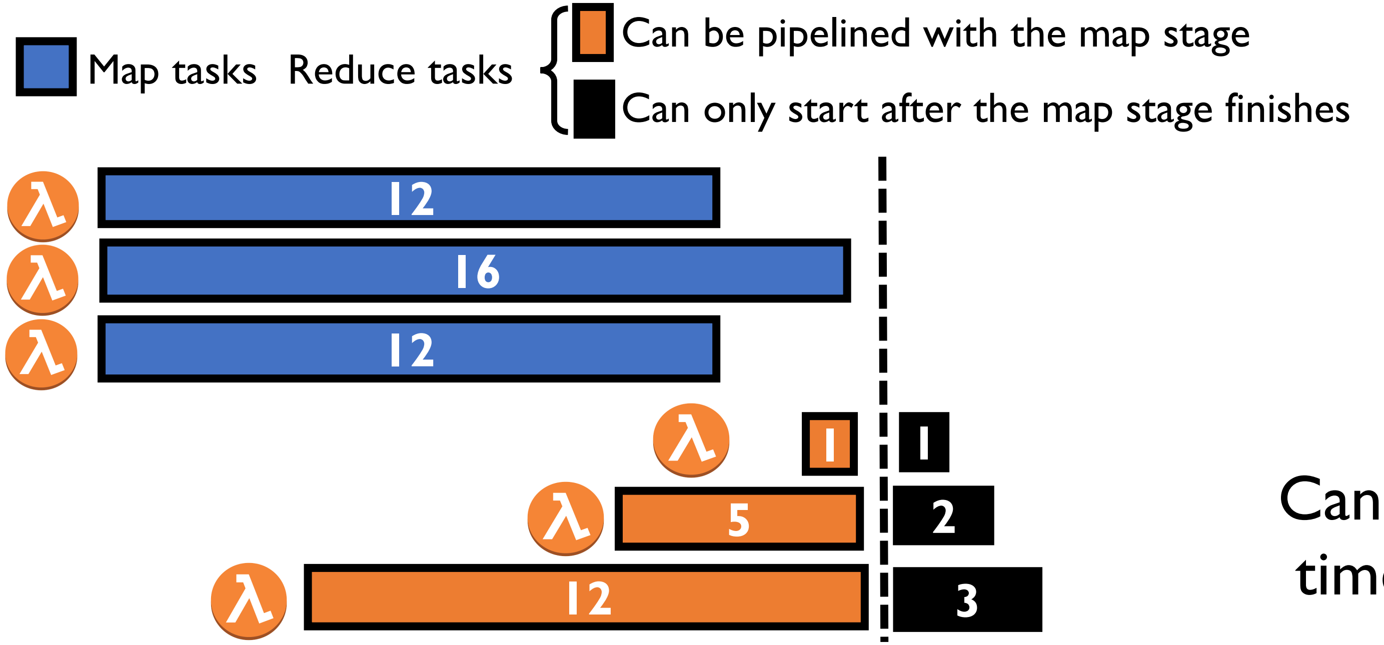


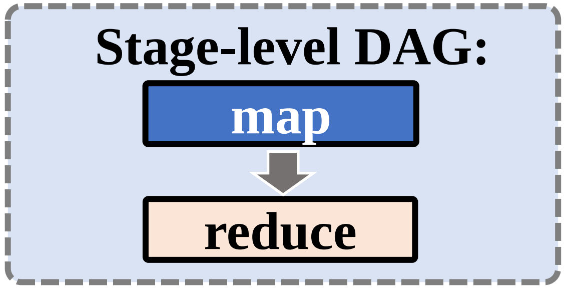


How to calculate the optimal launch time for each task?

Challenge 1: Describe pipelinablity

- NIMBLE scheduling requires a precise description of the pipelinablity across different job stages



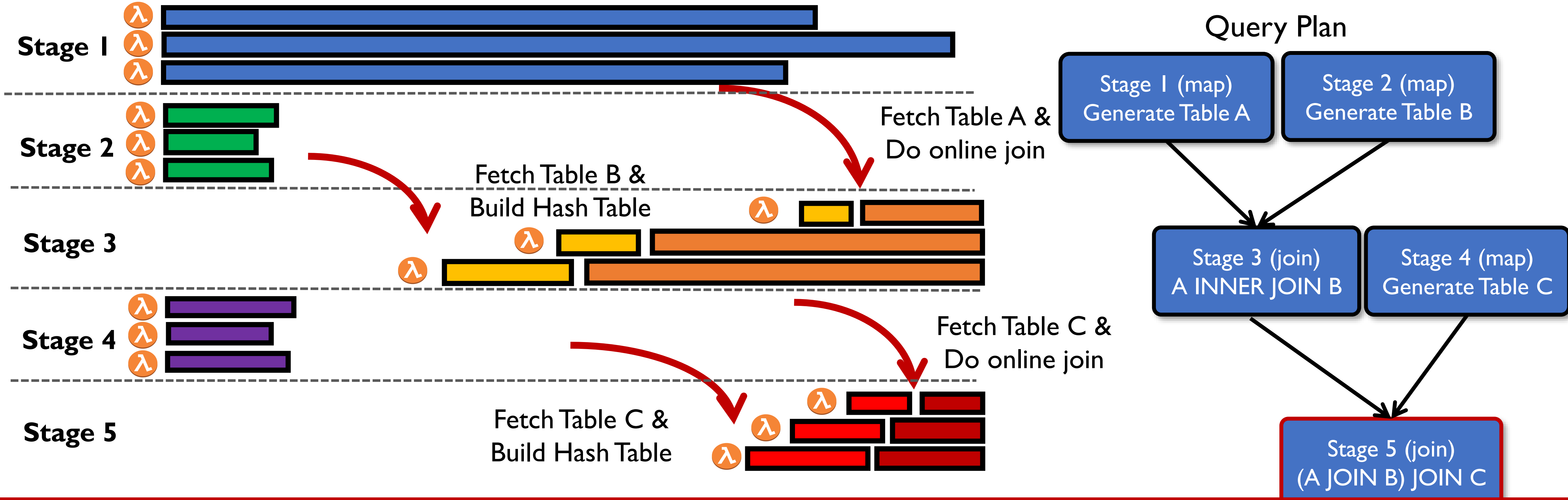


Cannot calculate the optimal task launch time without *sub-stage level* information

How to describe pipelinability at *sub-stage level*?

Challenge 2: Arbitrary DAGs

- General analytics workloads can have complicated DAGs.
  - **Within a stage:** tasks can consume data from multiple upstream stages
  - **Across stages:** tasks can have cascading dependencies



How to calculate the optimal task launch time for arbitrary DAGs?

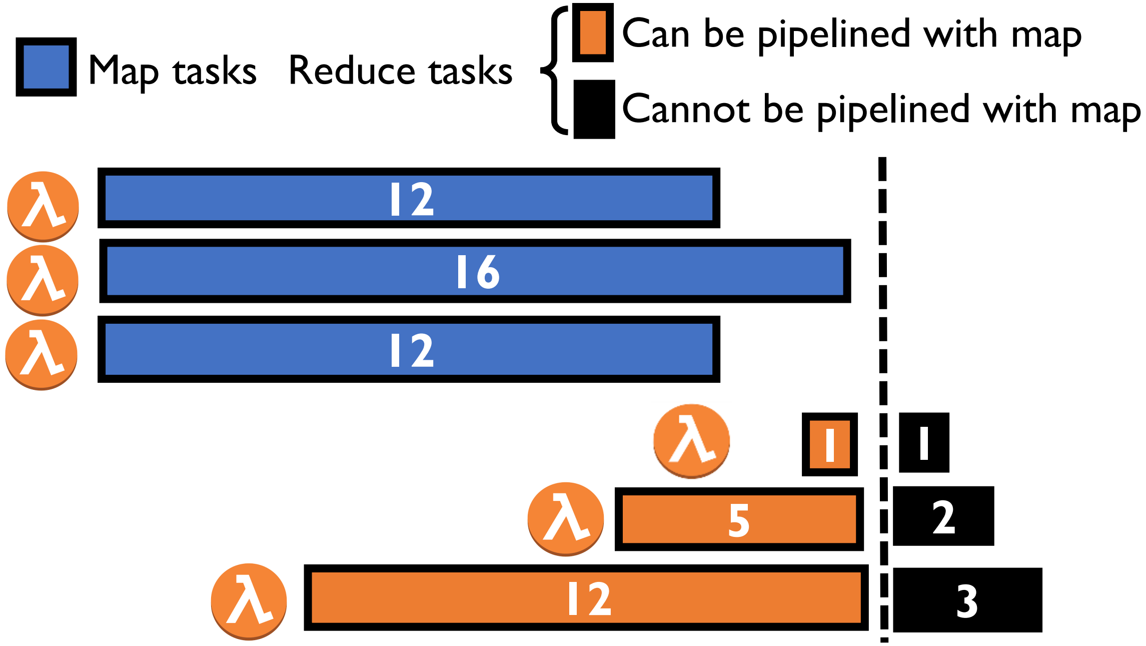
NIMBLE design outline

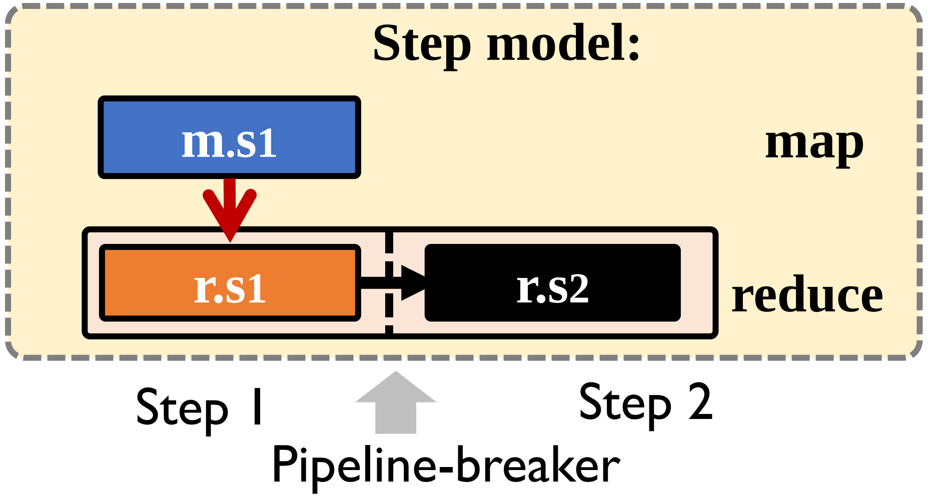
- **Challenge 1:** How to describe pipelinability at sub-stage level?
- Develop a ***step model*** to precisely capture the sub-stage level pipelinablity

- **Challenge 2:** How to calculate the optimal task launch time for arbitrary DAGs?
- Develop a scheduling algorithm which guarantees ***optimal cost*** while being ***Pareto-optimal*** between cost and JCT for arbitrary DAGs

Step model

- **Idea:** Break stages into steps
  - Step: largest pipeline-able component within a stage
  - Separated by pipeline breakers[1] (e.g., MIN, MAX, SUM)





1. A pipeline breaker is an operator that produces the first output only after all its input has been processed

Step model

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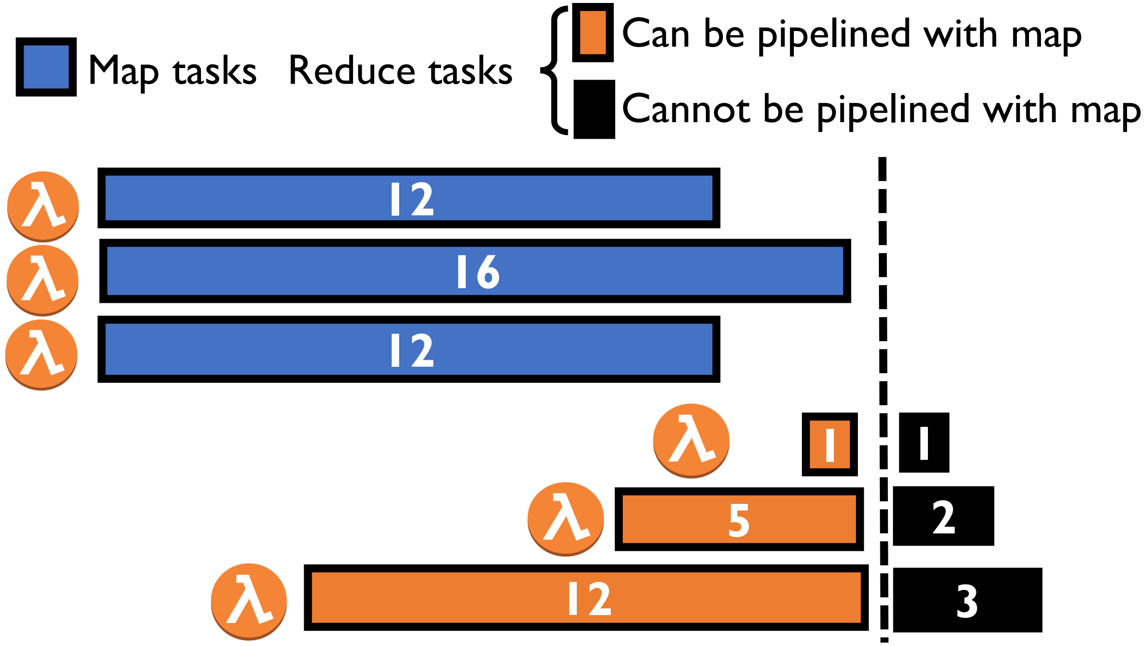
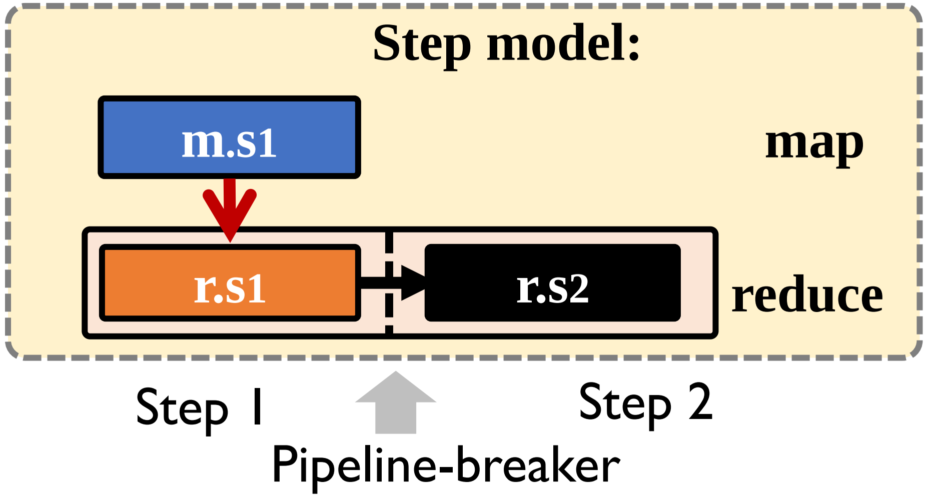




Data dependency within a stage:
- Must be executed *sequentially*

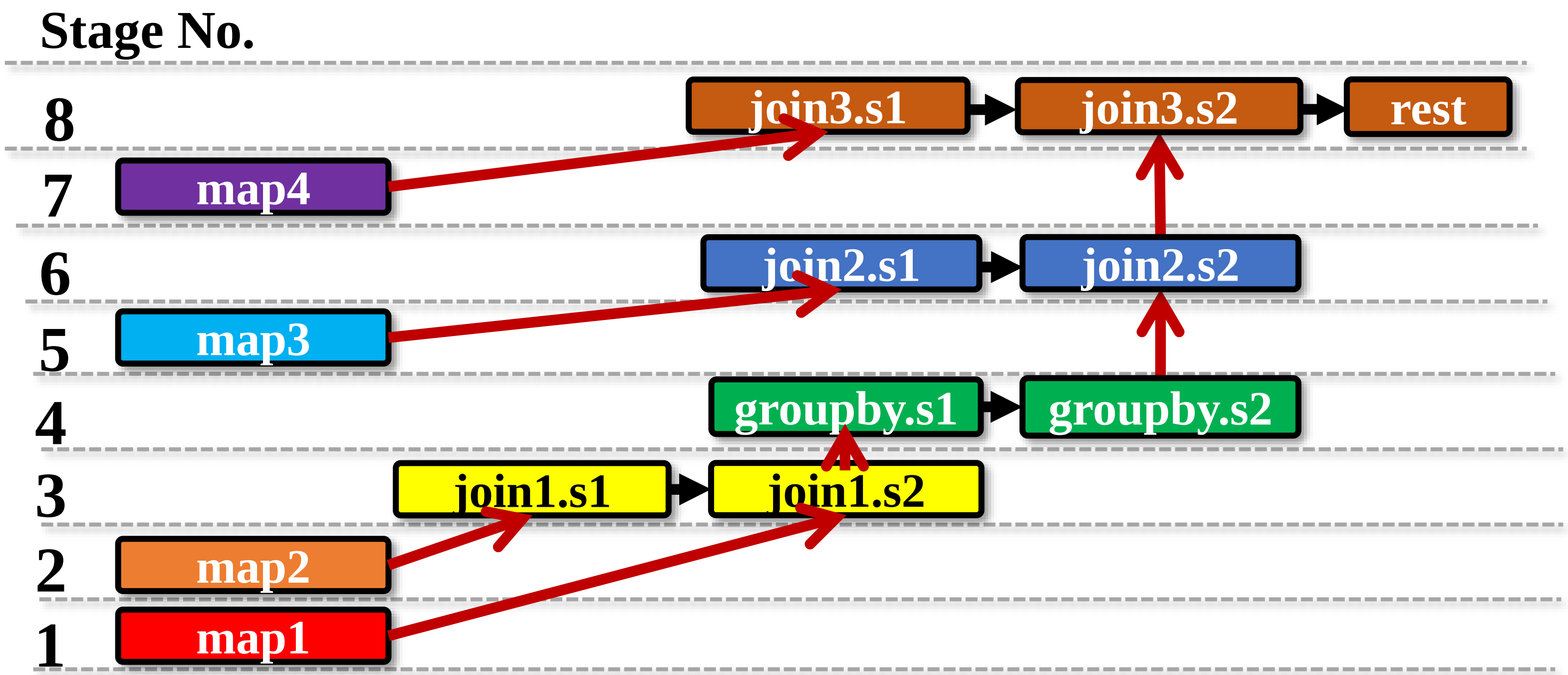
Data dependency across stages:
- Can be *pipelined*
- Referred as *parent-child step pairs*

1. A pipeline breaker is an operator that produces the first output only after all its input has been processed

Step model

- Example: the step model for a complicated SQL query in TPC-DS benchmark

```
WITH customer_total_return AS (
    SELECT
        sr_customer_sk AS ctr_customer_sk,
        sr_store_sk AS ctr_store_sk,
        sum(sr_return_amt) AS ctr_total_return
    FROM
        store_returns,
        date_dim
    WHERE
        sr_returned_date_sk = d_date_sk
        AND d_year = 2000
    GROUP BY
        sr_customer_sk,
        sr_store_sk
)
SELECT
    c_customer_id
FROM
    customer_total_return ctr1,
    store,
    customer
WHERE
    ctr1.ctr_total_return > (
        SELECT
            avg(ctr_total_return) * 1.2
        FROM
            customer_total_return ctr2
        WHERE
            ctr1.ctr_store_sk = ctr2.ctr_store_sk)
    AND s_store_sk = ctr1.ctr_store_sk
    AND s_state = 'TN'
    AND ctr1.ctr_customer_sk = c_customer_sk
ORDER BY
    c_customer_id
LIMIT 100;
```

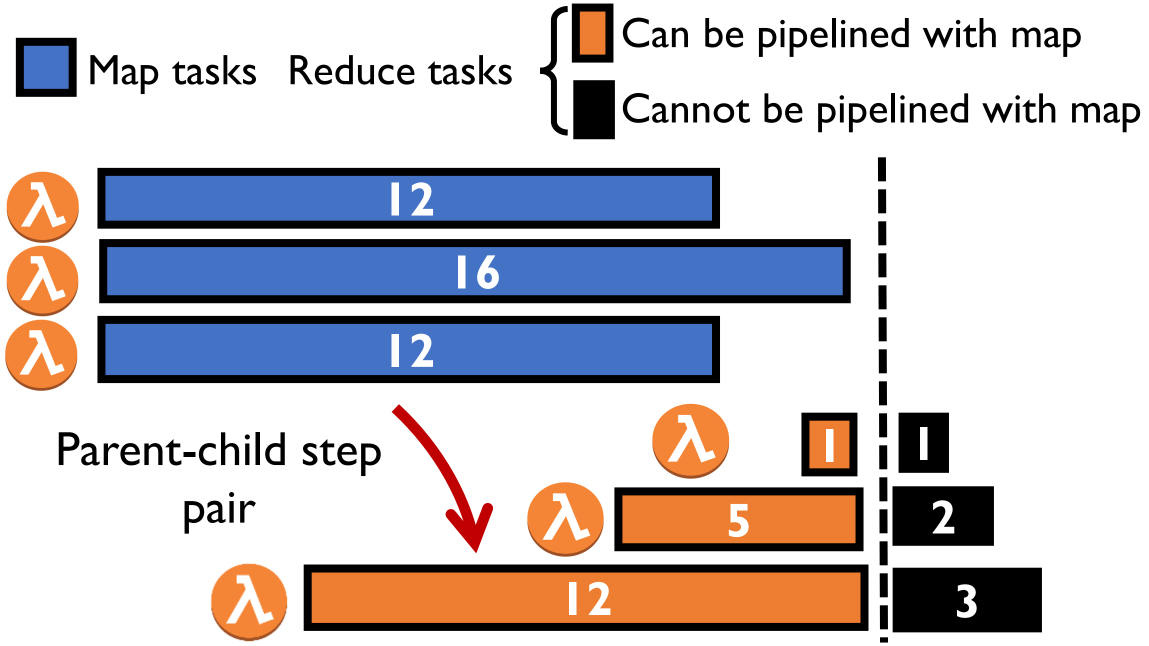


Step model can efficiently describe pipelinability across a wide range of applications

Basic algorithm for 2-stage map-reduce

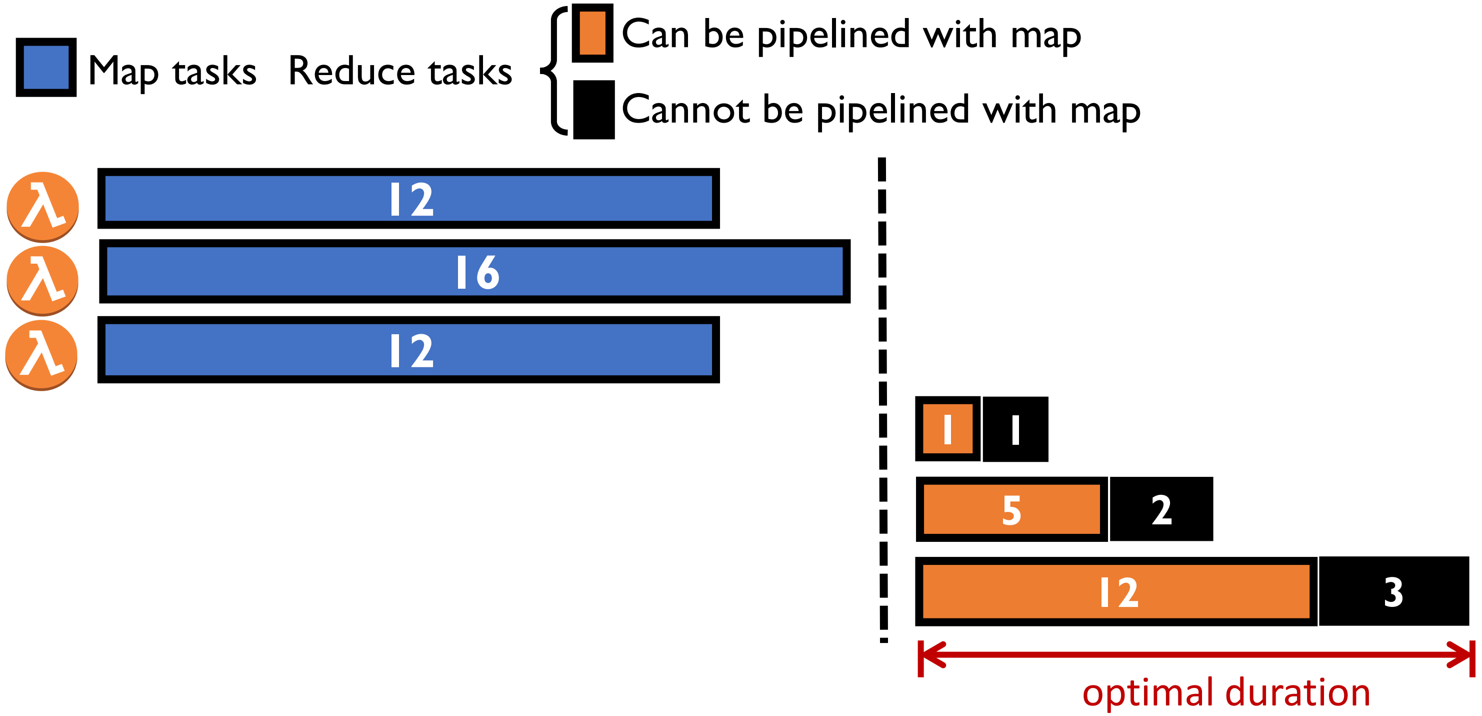
- Intuition to calculate the launch time:
  - Optimally overlap the *parent-child step pair* based on the *data produce and data consume rate*

Historical
+ online job information



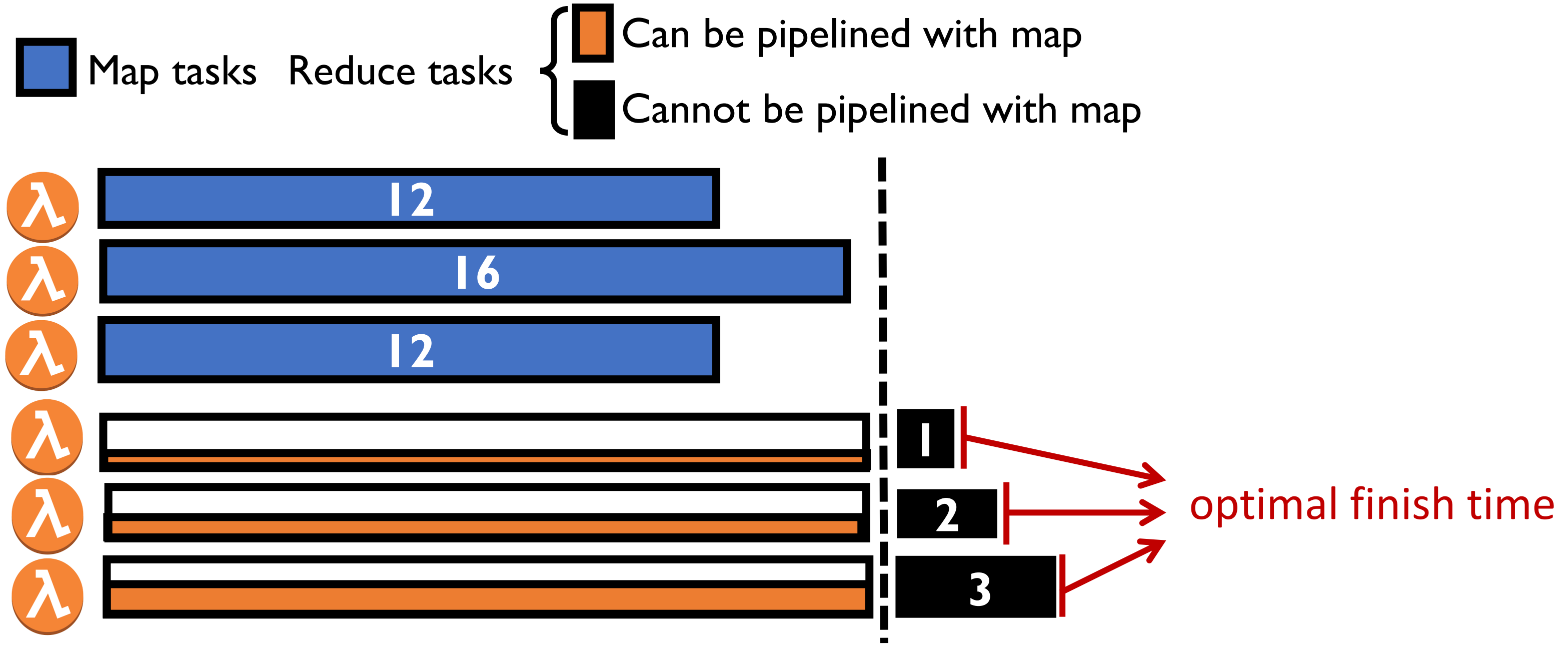
Basic algorithm for 2-stage map-reduce

- **Optimal launch time in three simple steps**
  - Step 1: Calculate *optimal task duration* based on *Lazy* solution



Basic algorithm for 2-stage map-reduce

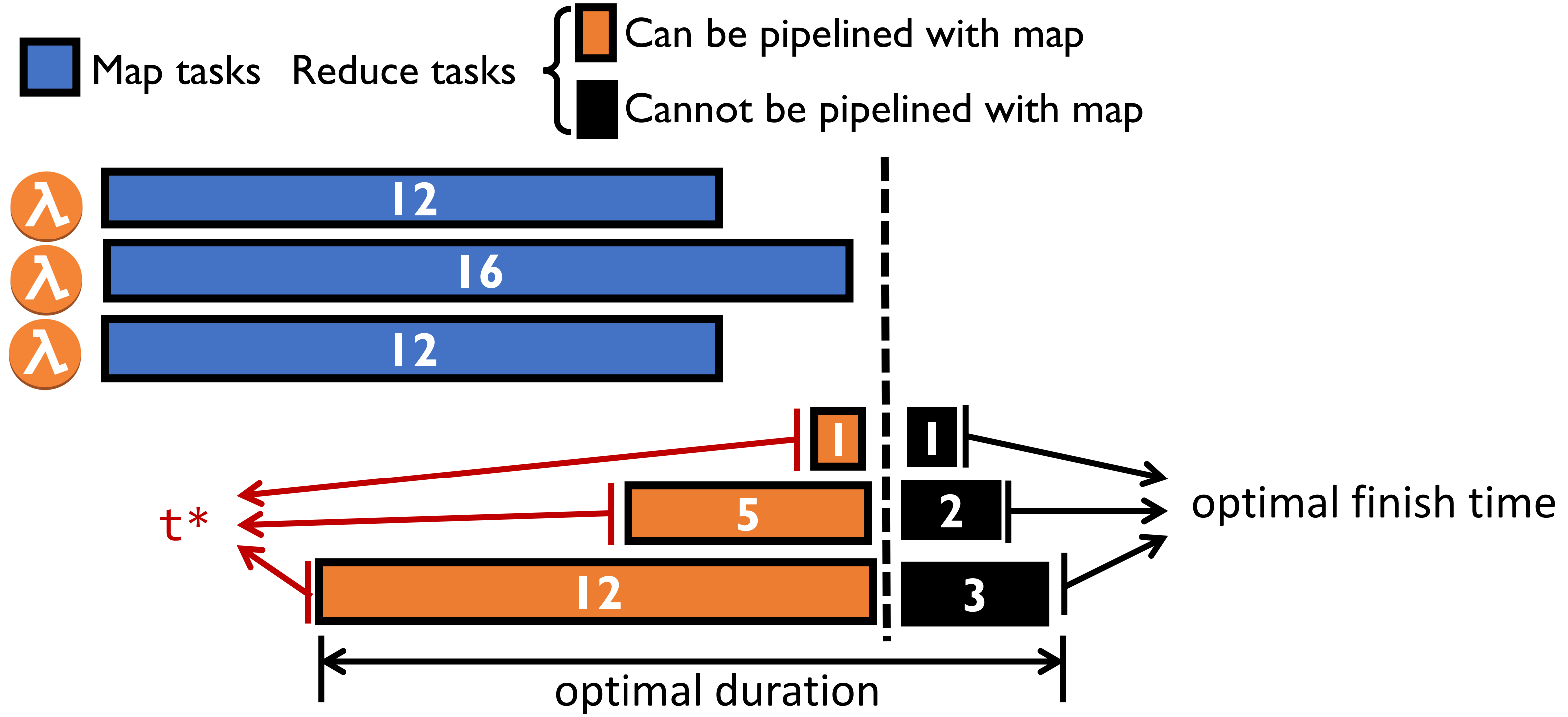
- **Optimal launch time in three simple steps**
  - Step 2: Calculate *optimal task finish time* based on *Eager* solution



Basic algorithm for 2-stage map-reduce

- **Optimal launch time in three simple steps**
  - Step 3: Calculate the task launch time ***t**** as:

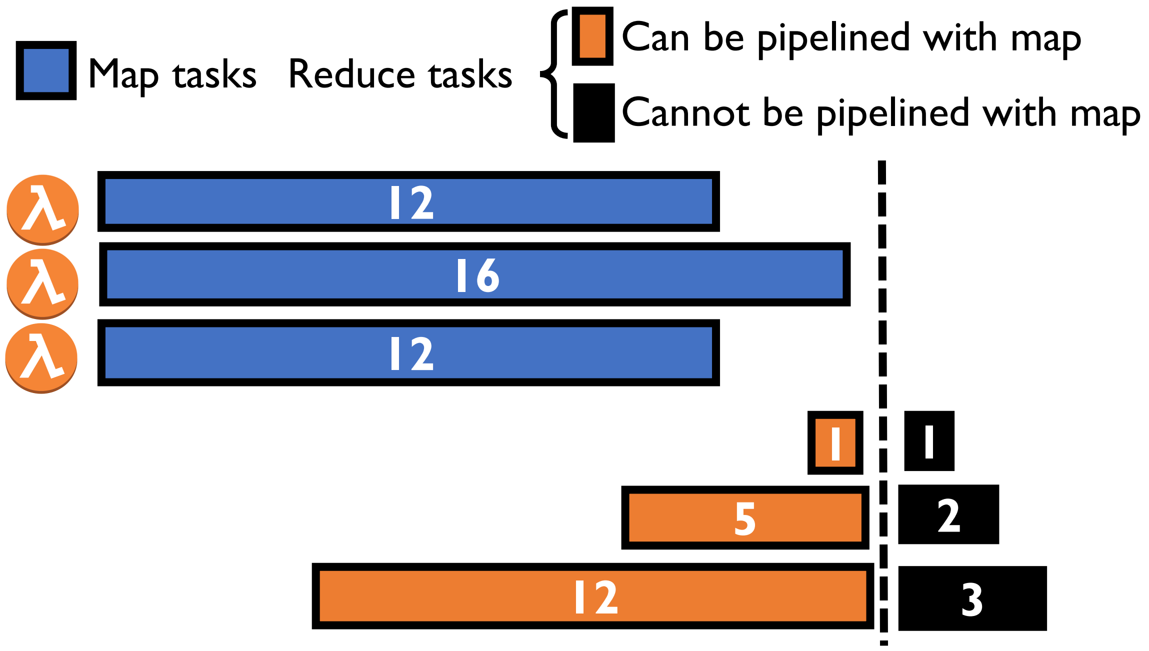
    optimal task finish time - optimal task duration



Basic algorithm for 2-stage map-reduce

- **Optimal launch time in three simple steps**

Theorem 1: ***t* ensures optimal cost and finish time*** for each reduce task.



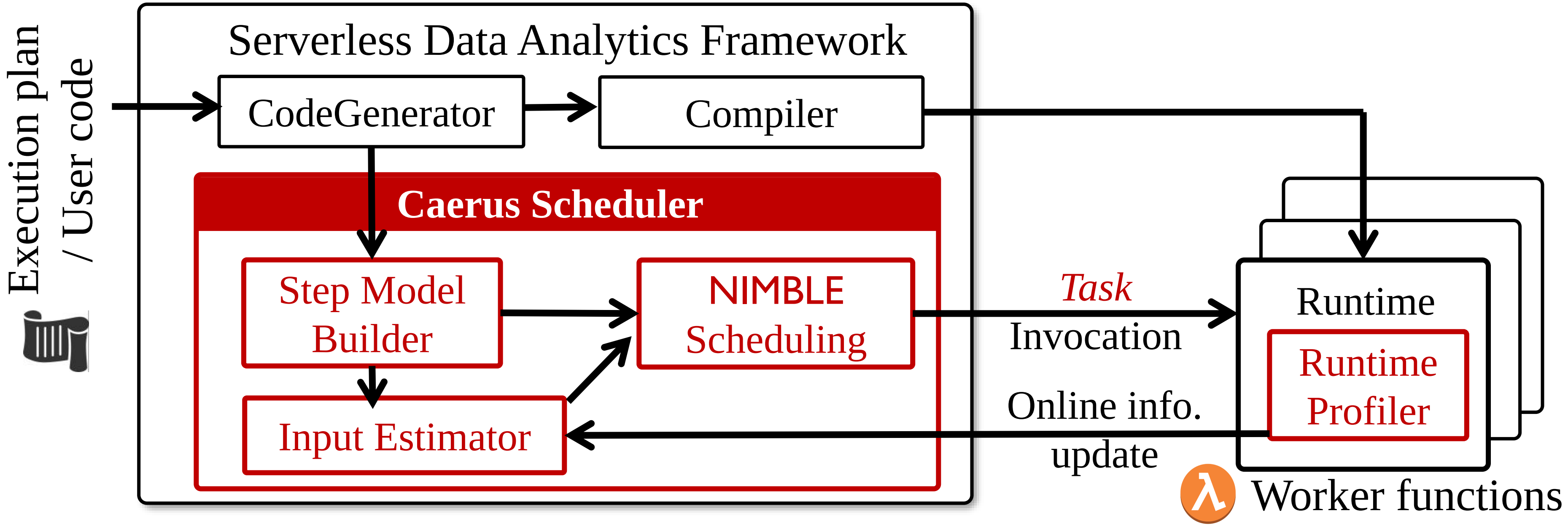
From map-reduce to arbitrary DAGs

- **Challenges for arbitrary DAGs :**
  - Within a stage: tasks can consume data from multiple upstream stages
  - Across stages: tasks can have cascading dependencies

- **Takeaways:**
  - **Bad news**: ***Impossible*** to design an algorithm that can achieve optimal cost and JCT ***simultaneously*** for arbitrary DAGs
  - **Good news:** Extend the basic algorithm to guarantee ***optimal cost*** while being ***Pareto-optimal*** between cost and JCT

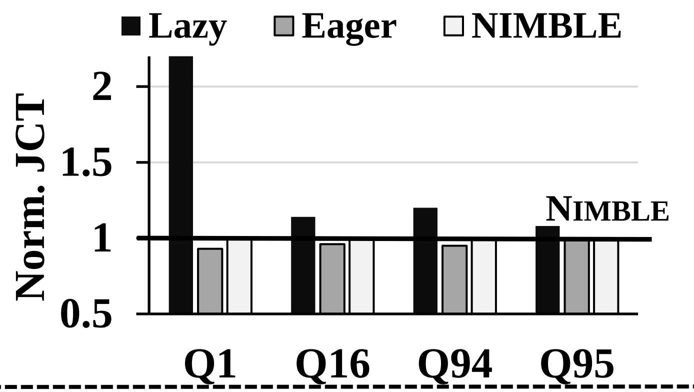
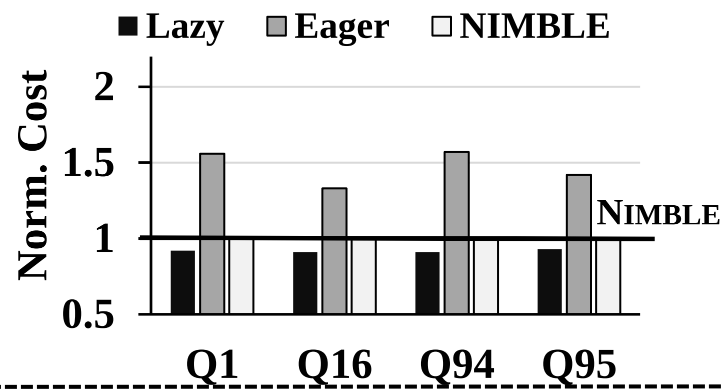
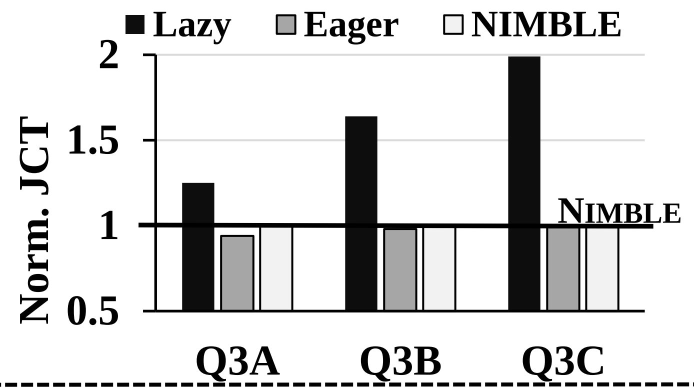
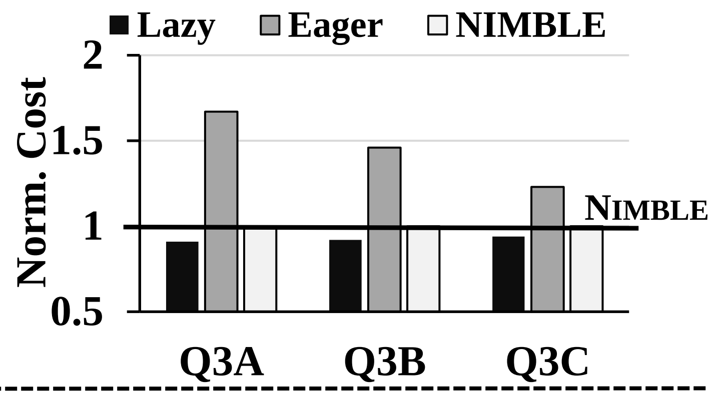
Caerus System

- Caerus: a task-level scheduler for serverless analytics which enables NIMBLE scheduling



Data Analytics Framework with **Caerus**

Evaluation results on AWS

	JCT (1.1-2.2X improvement)	Cost (1.2-1.6X improvement)
TPC-DS (4 queries)		
BigData (3 queries)		

NIMBLE scheduling can effectively optimize both JCT and cost across all these workloads

Takeaways

- **Serverless analytics introduces a new intra-job scheduling problem to optimize both JCT and cost**
  - Existing solutions expose a hard tradeoff between these two metrics
- **NIMBLE scheduling with a simple idea: to launch each task at *its right time***
  - Step model to capture sub-stage level pipelinablity and data dependencies
  - Achieves cost optimality while being Pareto-optimal between cost and JCT
- **Caerus: a task-level scheduler for serverless analytics which enables NIMBLE scheduling in practice**

Thank you!

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