CODA: Toward Automatically Identifying and Scheduling COflows in the DArk

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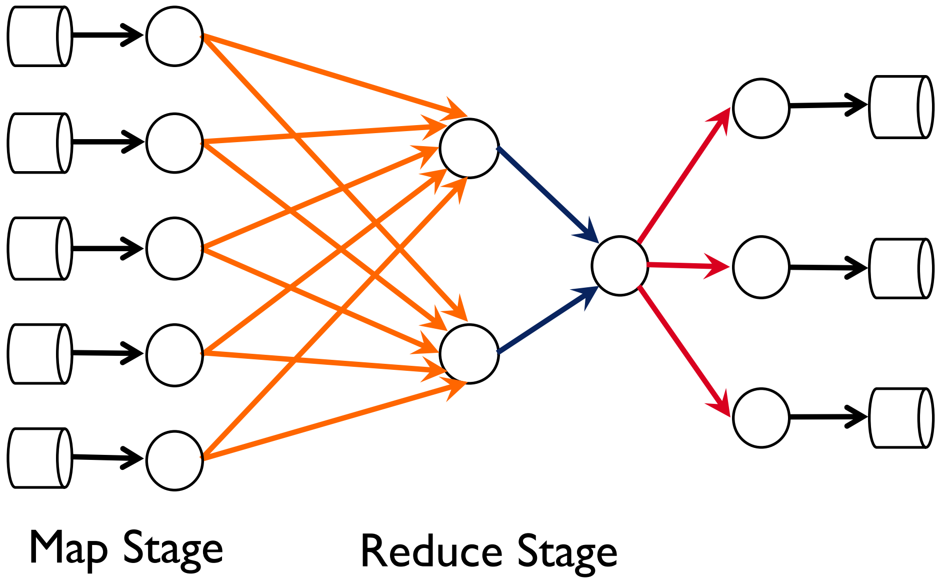
Communication is Crucial

- *Many distributed data-parallel applications involve a rich communication stage*

- *As SSD-based and in-memory systems proliferate, the network is more likely to become the bottleneck*

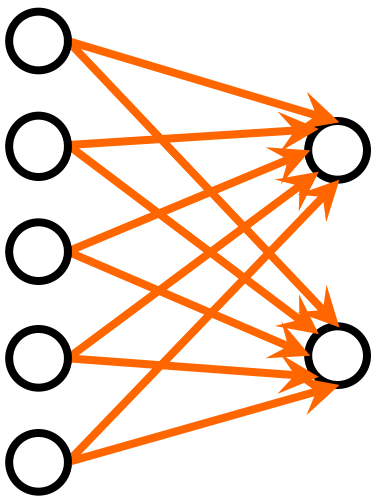


Improving the communication performance is crucial for these applications

Flow

- ***Application agnostic*** *--- schedule each flow independently*
- *Does not directly minimize the completion time of communication stages*

Coflow



- *A collection of parallel flows sharing a common application-level goal*
- *Minimizes the completion time of communication stages*

Coflow HotNets'12

Baraat SIGCOMM'14

Varys SIGCOMM'14

Rapier Infocom'14

Aalo SIGCOMM'15

Assumption: *all distributed data-parallel applications have to be modified to correctly use the same coflow API*

- **Difficulty 1:** Enable current Coflow API requires intrusive refactoring
- **Difficulty 2:** Hard to modify all applications and keep them up to date

Can we automatically identify and schedule coflows without manually modifying any data-parallel applications?

Varys

*Efficiently schedules coflows with **complete** application information*

Aalo

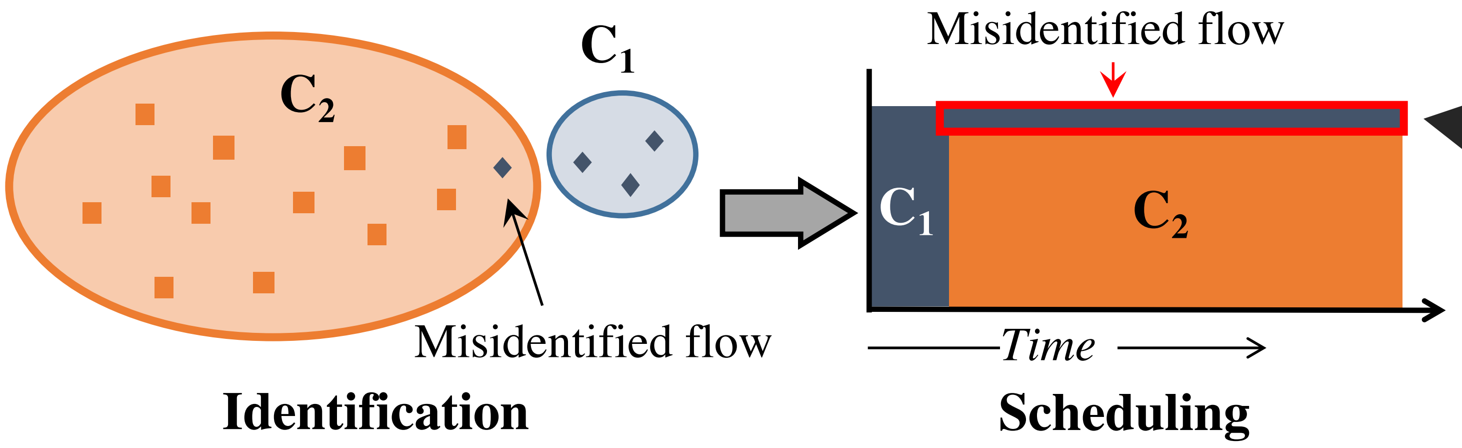
*Efficiently schedules coflows with **incomplete** application information*

CODA

*Efficiently **identifies** and schedules coflows with **no** information from application*

Challenge 1: *How to identify coflows without modifying applications?*

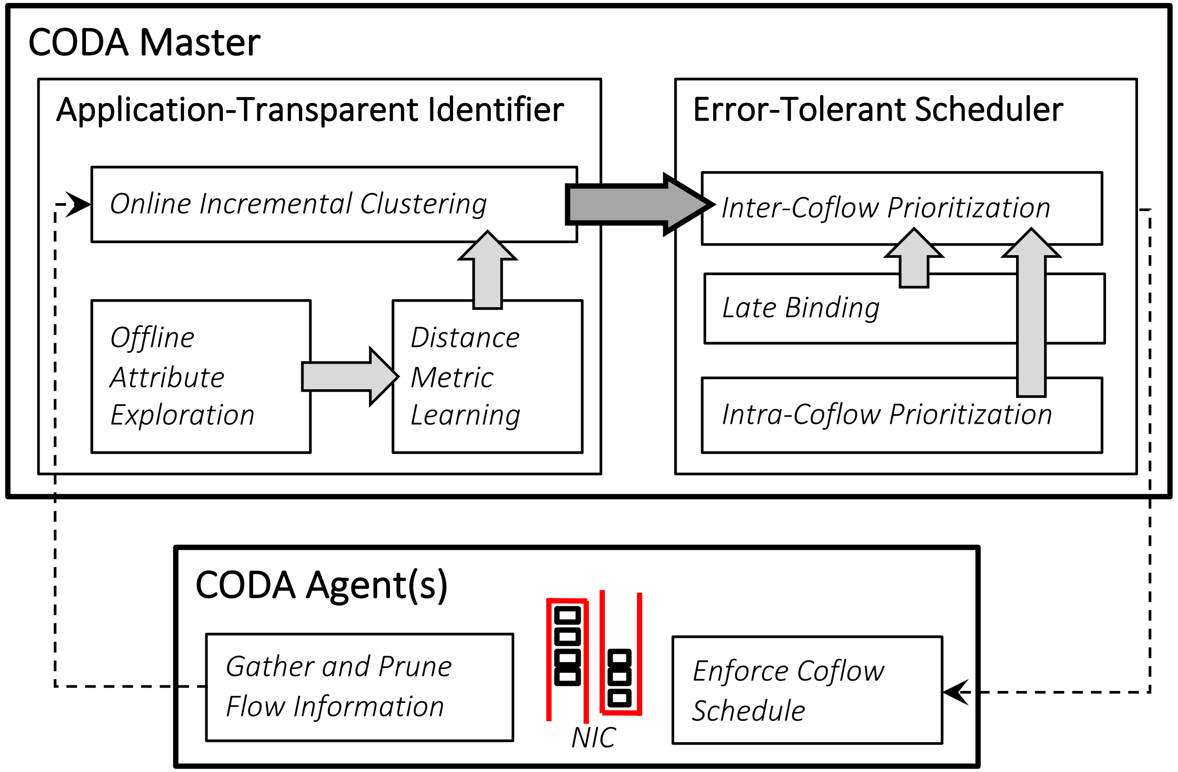
--- Transparent, accurate, fast



A mis-identified flow of C1 significantly affects the completion time of its parent Coflow C1.

Challenge 2: *How to schedule coflows with identification errors?*

CODA in One Slide



Application-Transparent Coflow Identification

Idea: a simple 3-step identification framework

Error-tolerant Coflow Scheduling

Idea: Combine inter-coflow scheduling with two novel heuristics

Application-Transparent Coflow Identification

Step 1 --- Attribute Exploration

---- *search for candidate attributes*

- *Flow start time, inter-packet arrival time, …*
- *Communication pattern*
- *Application-specific attributes (e.g., port assignment rules)*
- *….*

Step 2 --- Distance Calculation

---- *identify the importance of each attribute*

Input

- *Candidate attributes*
- *Training data*

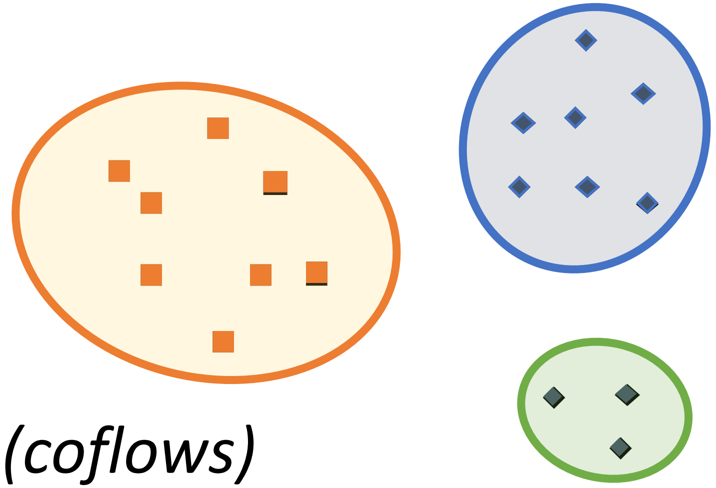
Distance Metric Learning

Output: distance function

Small/large distances between flows of same/different coflows;

Application-Transparent Coflow Identification

- **Step 3 --- Online Clustering**



- **Basic algorithm --- DBSCAN**
  - *Distance-based*
  - *Automatically determine the number of clusters (coflows)*
- **How to speed up?**
  - *Idea 1: sacrifice some accuracy for much faster speed*
  - *Idea 2: incremental identification*

----- Errors are inevitable

Error-tolerant Coflow Scheduling

D-CLAS (Aalo-SIGCOMM'15)

---inter-coflow scheduling to minimize average CCT

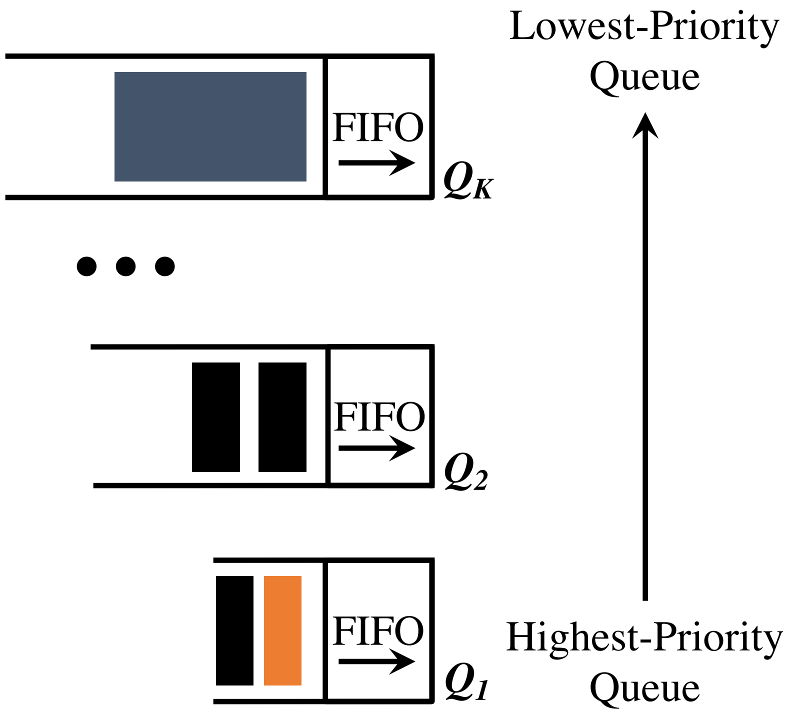
MLFQ with exponentially spaced thresholds

Priority discretization

- *Drop priority when total # of bytes sent exceeds predefined thresholds*

Scheduling policies

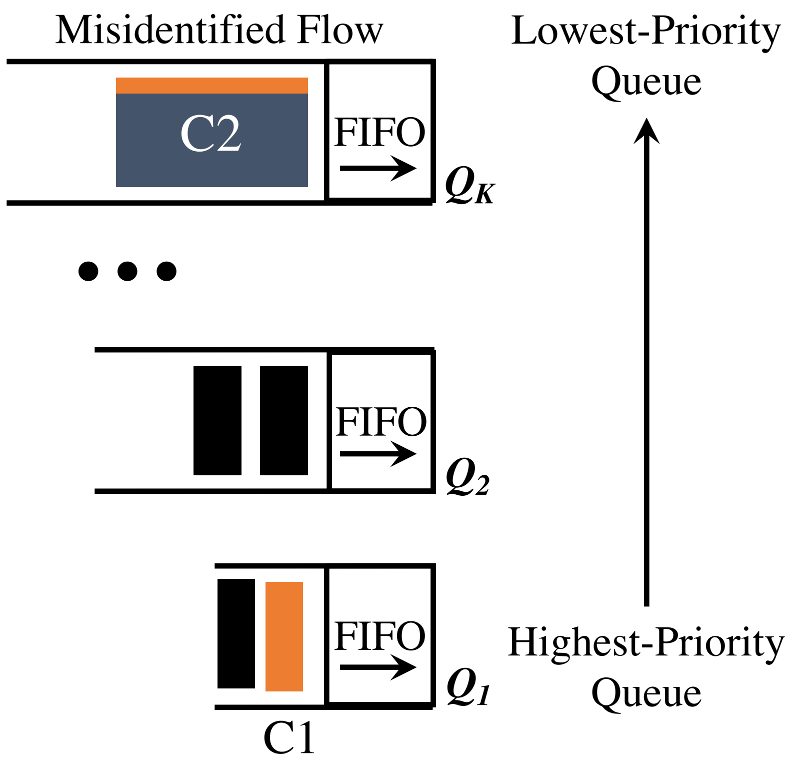
- *Prioritization across queues*
- *FIFO within the same queue*



Error-tolerant Coflow Scheduling

- **D-CLAS with identification errors**

  ---- Errors may significantly affect the performance of D-CLAS



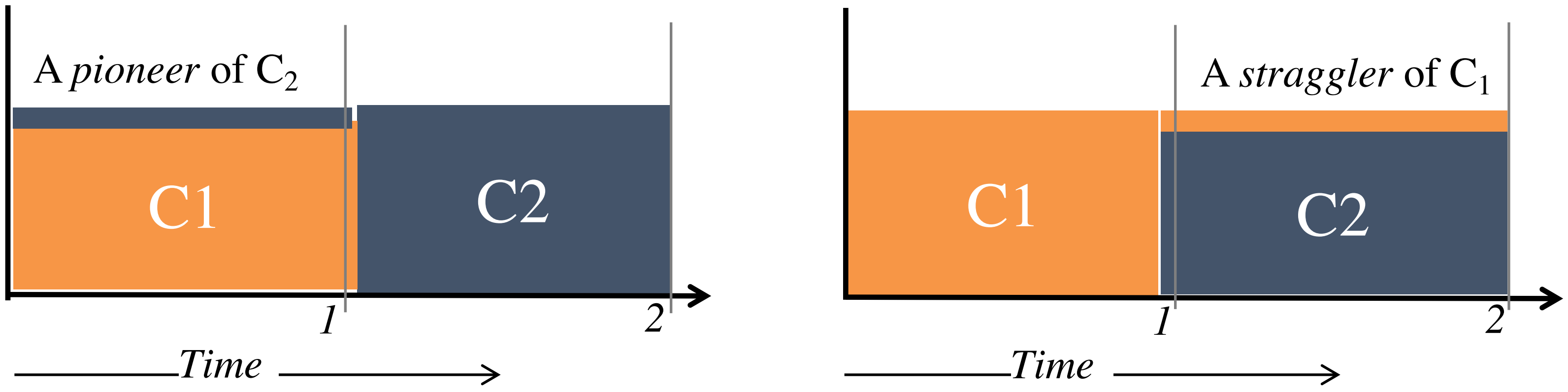
Error-tolerant Coflow Scheduling

- **Impact of different identification errors**
  - ***Pioneers***: *Flows that are misidentified into a coflow that is scheduled* ***earlier*** *than their parent coflow*

  - ***Stragglers***: *Flows that are misidentified into a coflow that is scheduled* ***later*** *than their parent coflow*

Error-tolerant Coflow Scheduling

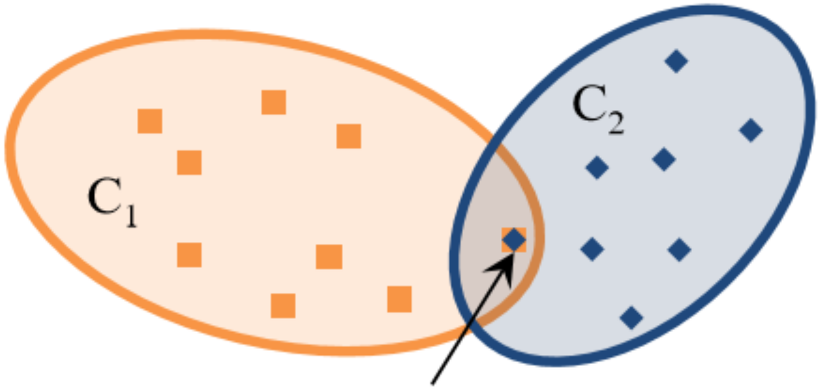
- **Impact of different identification errors**



Observation 1: *stragglers are likely to more negatively affect the average coflow completion time than pioneers*

Error-tolerant Coflow Scheduling

- **Design Principle 1: Late binding**
  ---- Reduce the number of stragglers



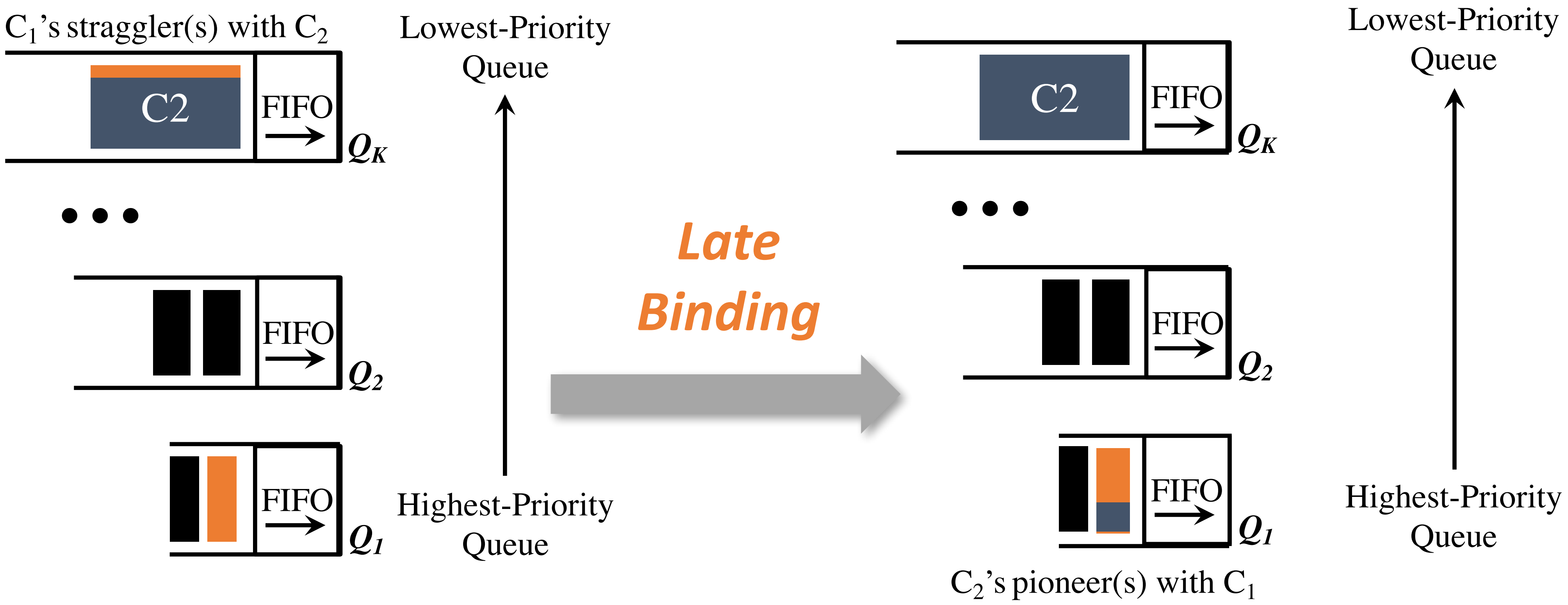
Potential source of misidentification

- *For a flow that can potentially belong to either C1 or C2*
- *Delay the decision and consider it to be in **both C1 and C2** at first*
- *Only during scheduling, assign it to the coflow with the **higher priority***

This flow does not become a straggler, no matter whether it belongs to C1 or C2!

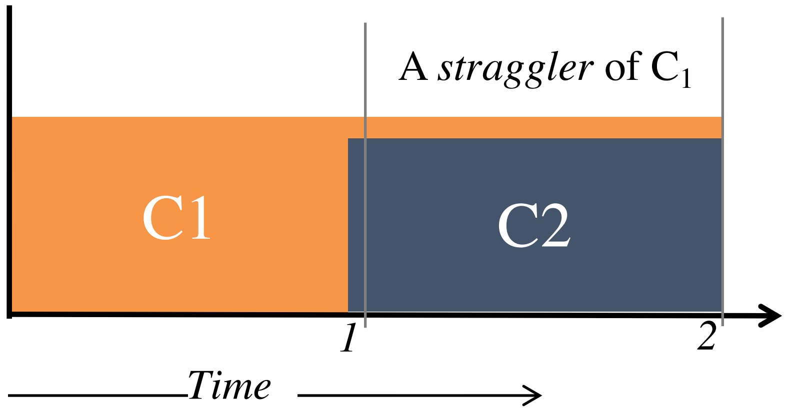
Error-tolerant Coflow Scheduling

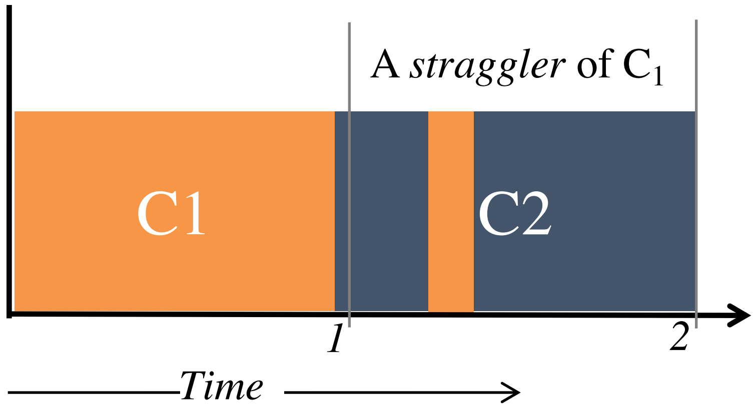
- ***Late binding**: Reduce the number of stragglers **at the cost of more pioneers***



Error-tolerant Coflow Scheduling

- ***Observation 2:*** *Intra-coflow prioritization matters*

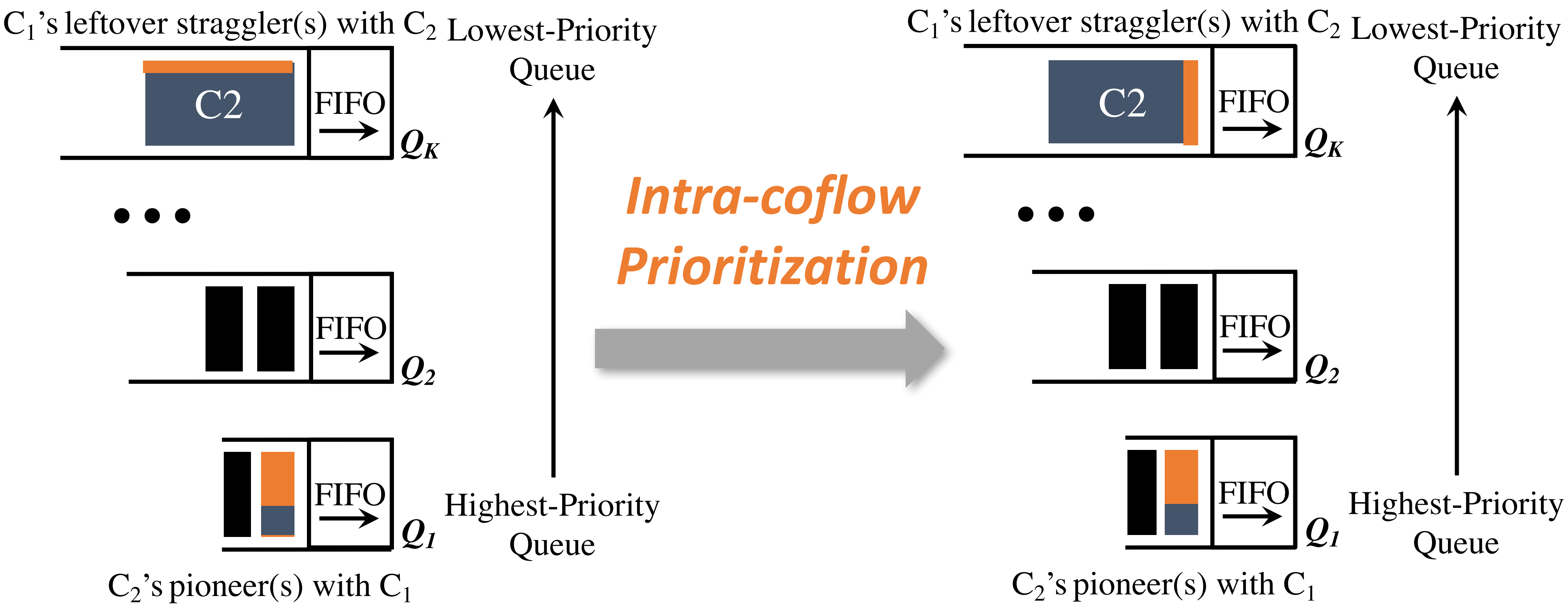




- **Design Principle 2: Intra-coflow prioritization**
  - *Idea: prioritize small flows within a coflow*

Error-tolerant Coflow Scheduling

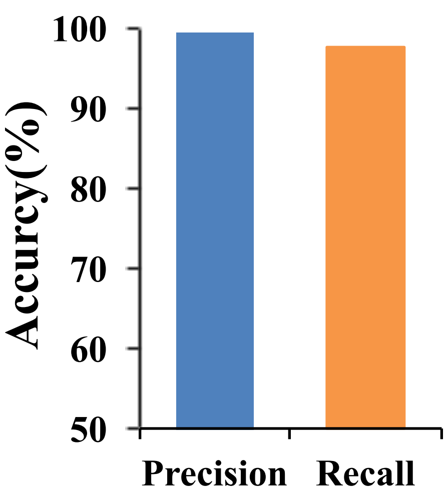
- ***Intra-coflow prioritization***: *Reduce the impact of leftover stragglers*

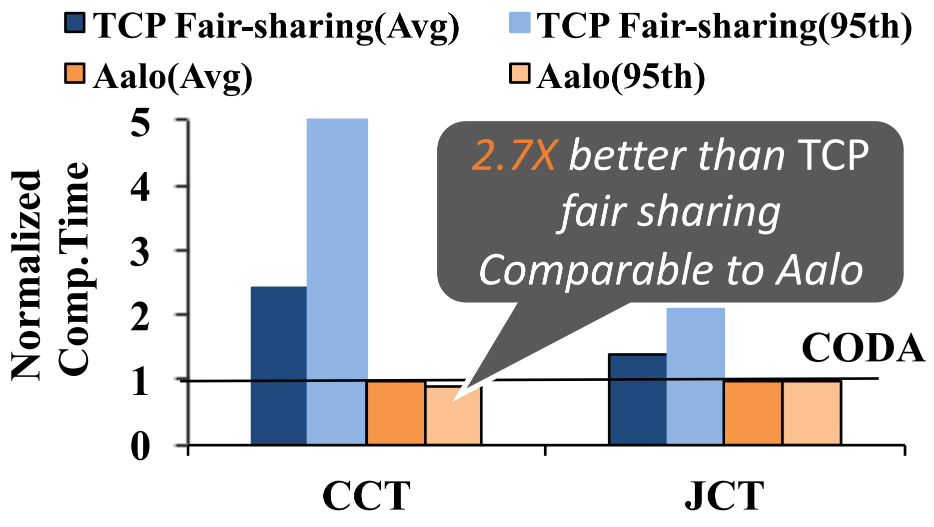


How does CODA Perform in Practice?

- **Workload**
  - *1-hour 3000-machine Mapreduce trace*
  - *500 coflows (7x10^5 flows)*
- **Settings**
  - *40-server testbed*
- **Performance Metric**
  - *Identification*
    - *Precision*
    - *Recall*
  - *Scheduling*
    - *TCP fair-sharing*
    - *Aalo (coflow-aware solution)*

Over 90% Identification accuracy





How Effective is CODA's Error-Tolerant Scheduling?

- *Creating more challenging cases*
  - *Batch arrival*
  - *Stretched arrival*

Up to 40% accuracy loss

- *CODA under more challenging cases*

	Stretched arrival	*Batch arrival*
Per-flow Fair	*2.03X*	*1.47X*
Aalo	*0.77X*	*0.56X*
CODA	***1X***	***1X***
CODA w.t. E.T.	***1.16X***	***1.04X***

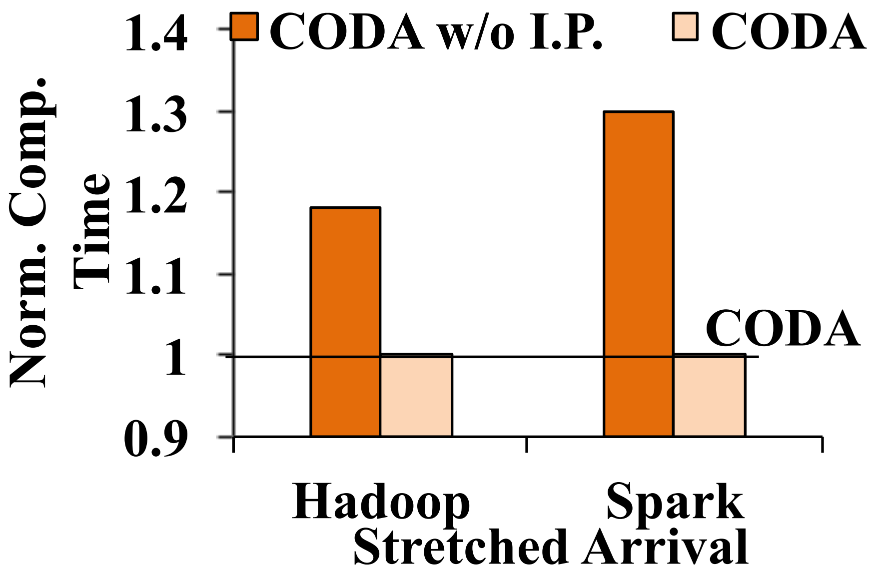
Reduce the impact of error by 40%

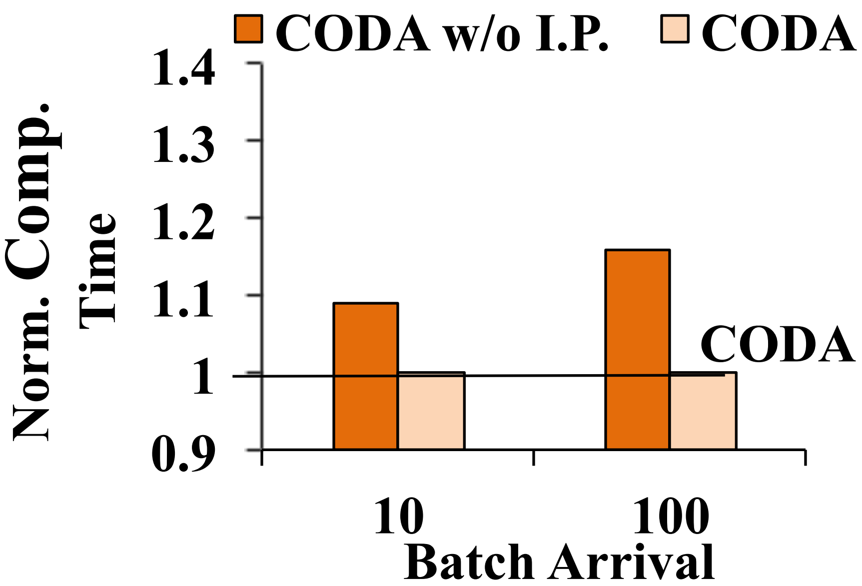
How Effective is CODA's Error-Tolerant Scheduling?

- *Benefit of Late Binding*
  - *Improve average coflow completion time by up to 10%*

Reduce the impact of error by 30%

- *Benefit of Intra-Coflow Prioritization*
  - *Improve average coflow completion time for small coflows by up to 30%*





CODA

Automatically identifies and schedules coflows ***without application modification***

Application-Transparent Coflow Identification:

-----Identify coflows without application modification

Error-Tolerant Coflow Scheduling:

-----Schedule coflows with minimal impact of identification errors

CODA, not coda

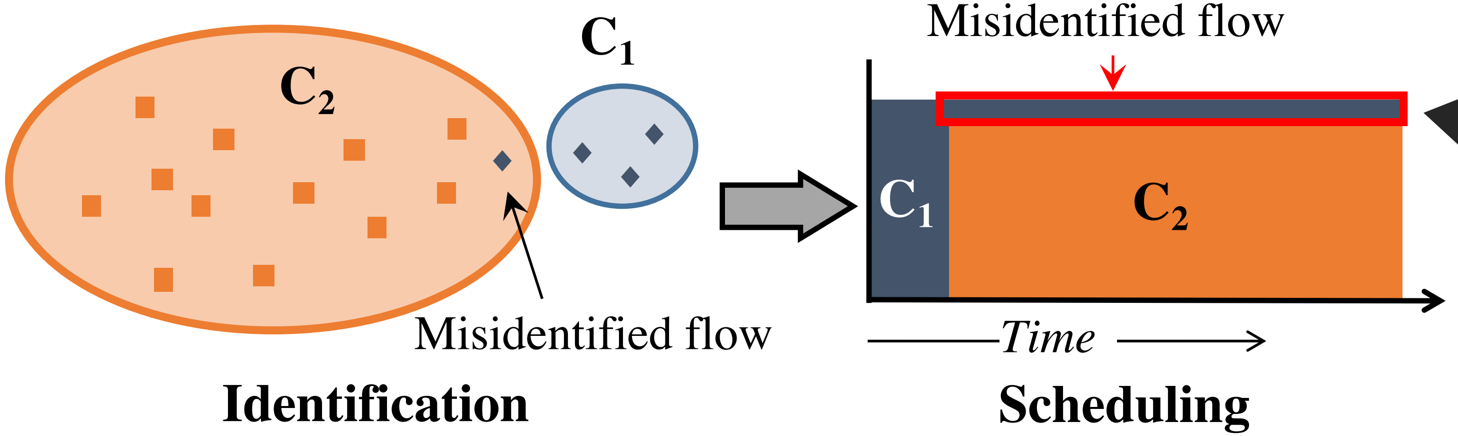
- *Apply CODA to more applications*
- *Extend CODA to coflow dependencies*
- *Perform error-tolerant ~~coflow~~ scheduling*

Thank You!

Application-Transparent Coflow Identification

Challenge 1: *How to accurately identify coflows without the help from applications in an online manner?*

Error-tolerant Coflow Scheduling



A mis-identified flow of Coflow C1 will significantly affects the CCT of its parent Coflow C1.

Challenge 2: *How to minimize the influence of identification errors?*

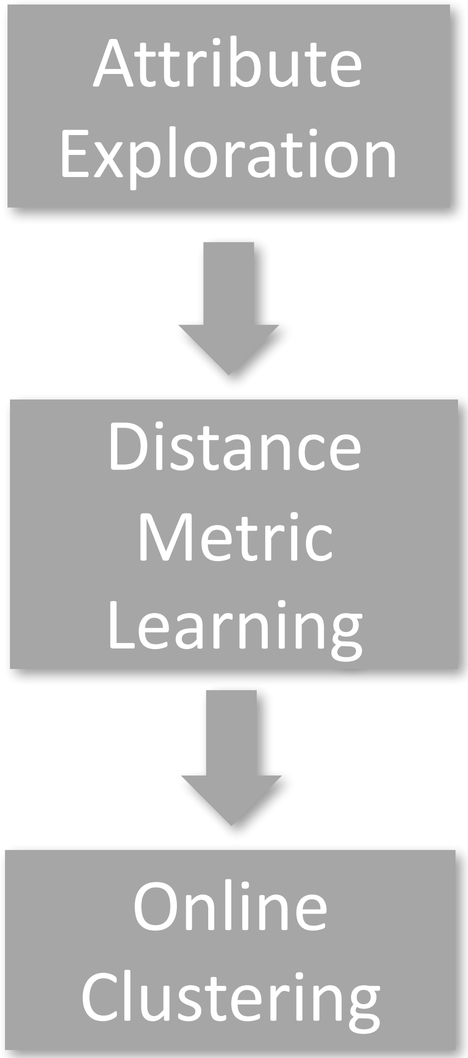
Application-Transparent Coflow Identification

Design Goals

- *Transparency: no modification to applications*
- *Accuracy: accurate for effective scheduling*
- *Speed: fast enough for timely scheduling*

3-step Learning Framework

- Attribute Exploration
  ---- *search for candidate attributes*
- Distance Calculation
  ---- *identify the importance of each attribute*
- Online Clustering
  ---- *group flows into coflows based on the distance metric*



Application-Transparent Coflow Identification

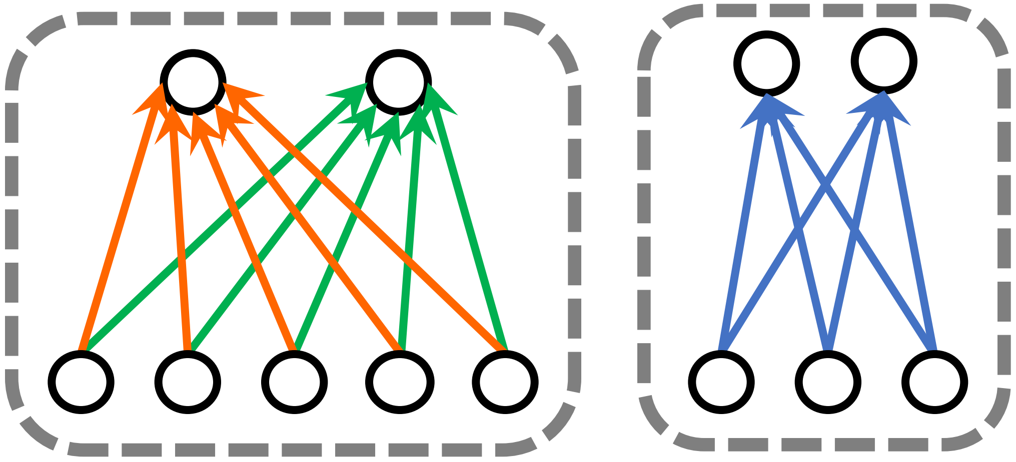
Step 1 --- Attribute Exploration

- Flow-level Attributes

Flow start time, inter-packet arrival time, …

Flow size …

- Community-Level Attributes
  - *Community Distance*
- Application-Level Attributes
  - *Port assignment of Spark*
  - *Port assignment of Hadoop*



Application-Transparent Coflow Identification

- **Step 2 --- Distance Calculation**
  - *Different attributes may have different importance*
  - *Thus need a good distance metric to reflect coflow relationships*

Input

- *Candidate Flow attributes*
- *Workloads with coflow information*

Distance Metric Learning →

Output: distance function

- *Small distances between flows within the same coflow;*
- *Large distances between flows belonging to different coflows;*

Flow arrival time and community attribute are most helpful

How Effective is CODA's Error-Tolerant Scheduling?

- *Benefit of Error-tolerant Scheduling*

	Stretched arrival	*Batch arrival*
Per-flow	*2.03X*	*1.47X*
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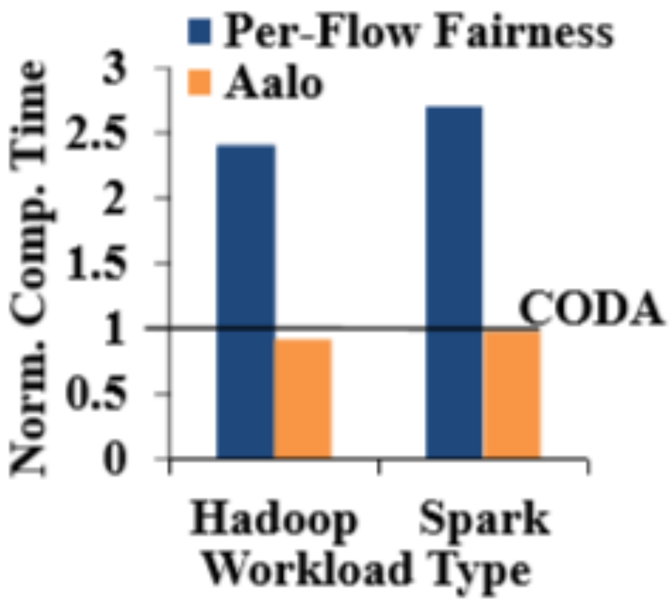
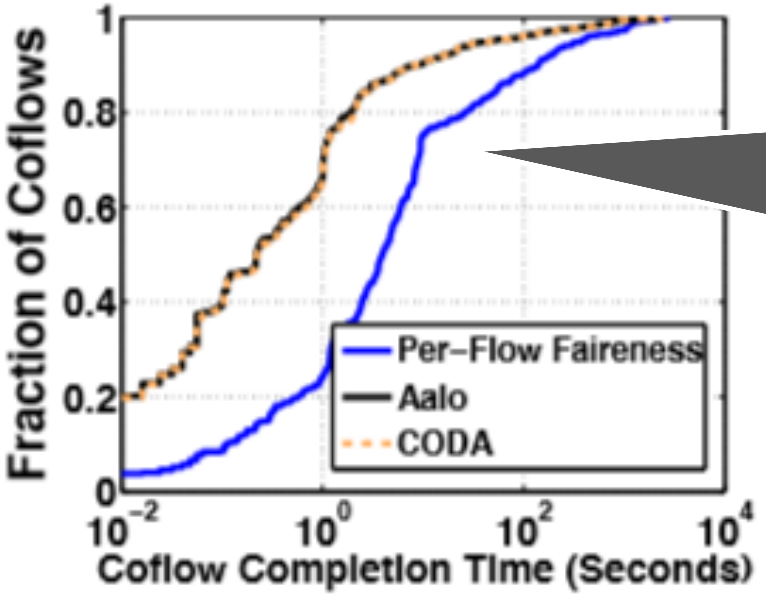
CODA	*1X*	*1X*
CODA w.t. ET	***1.16X***	***1.04X***

Reduce the impact of error by 40%

How Effective is CODA's Error-Tolerant Scheduling?

- *Performance under Normal cases*





Almost as good as Coflow-aware solutions

Application-Transparent Coflow Identification

- **Caveat**
  - *Xxxx*
  - *Xxxx*
  - *Xxxx*

Application-Transparent Coflow Identification

- **Discussion**
  - *More than Spark/Hadoop*
  - *The need of a training step*
  - *Sensitivity to workload*

Error-tolerant ~~Coflow~~ Scheduling

- **Error-tolerant scheduling design --- A new problem beyond coflow**
  - Most of existing scheduling problems take ground-truth information as input, thus no need to consider possible input errors.
  - However, with the wide adoption of machine learning algorithms, many of the scheduling inputs are predictions/estimations based on learning results.
  - As a result, error-tolerant scheduling can be an interesting yet important research topic, which may greatly improve the scheduling performance with erroneous inputs in many different scenarios.

CODA

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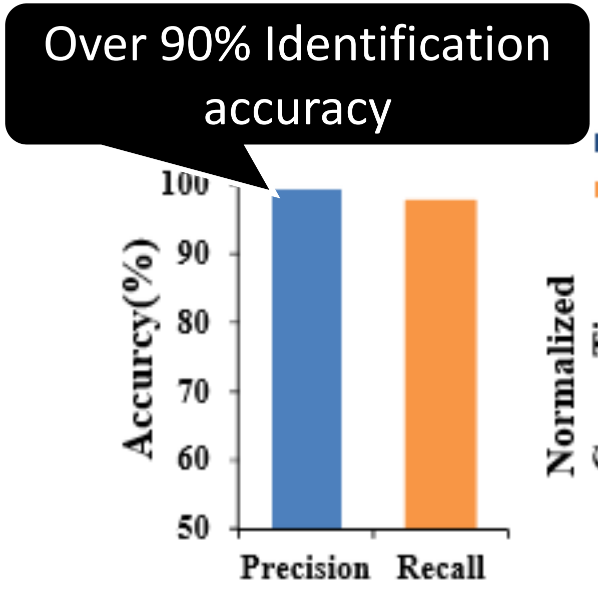
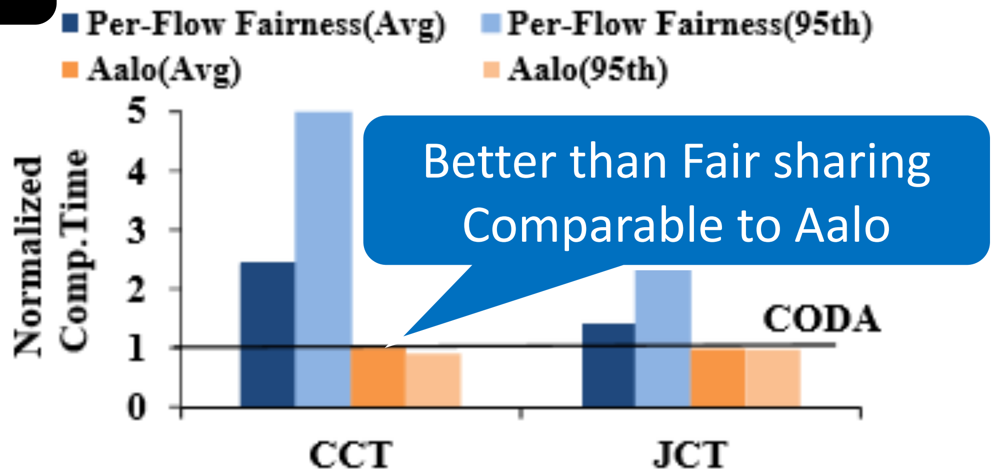
How does CODA perform in practice?

- **Can it approach xxx solutions?**

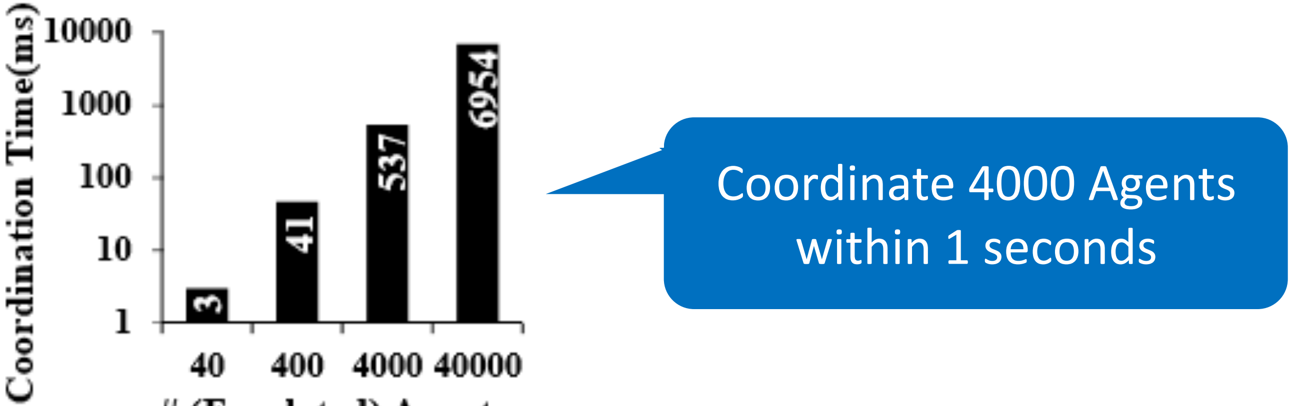


(a) Accuracy



(b) CCT and JCT

- **Can it scale gracefully?**



Application-Transparent Coflow Identification

- **Step 2 --- Distance Metric Learning**
  - Different attributes may have different importance
  - Thus need a good distance metric to reflect coflow relationships
    - Small distances between flows within the same coflow
    - Large distances between flows belonging to different coflows

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Formulation

- *Flow:*
- *Flow Distance:*

$$d(f_i, f_j) = ||f_i - f_j||_A = \sqrt{(f_i - f_j)^T A (f_i - f_j)}$$

$$\min_A \sum_{(f_i, f_j) \in S} ||f_i - f_j||_A^2$$

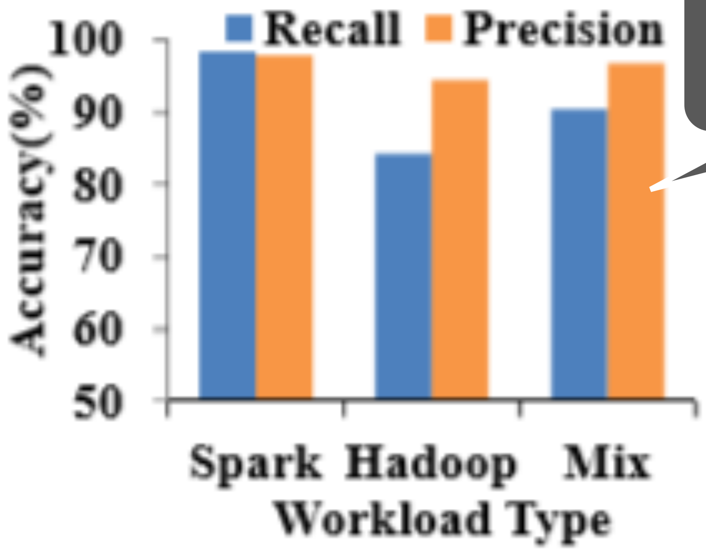
$$\text{s. t.} \sum_{(f_i, f_j) \in D} ||f_i - f_j||_A \geq 1, \quad A \succeq 0$$

Minimize the overall distance of flows within same coflows

Minimize the overall distance of flows within same coflows

How Effective is CODA's Identification?

- *How does CODA's identification perform overall?*



Over 90% accuracy

- *How does CODA's identification perform not work well?*

- *What is the speed up?*
  - *600X speed up with 2% accuracy loss*

How Effective is CODA's Error-Tolerant Scheduling?

- *Creating more challenging cases*
  - *Batch arrival*
  - *Stretch arrival*

→ *Around 40% accuracy loss*

- *CODA under more challenging cases*

	Stretched arrival	*Batch arrival*
Per-flow	*2.03X*	*1.47X*
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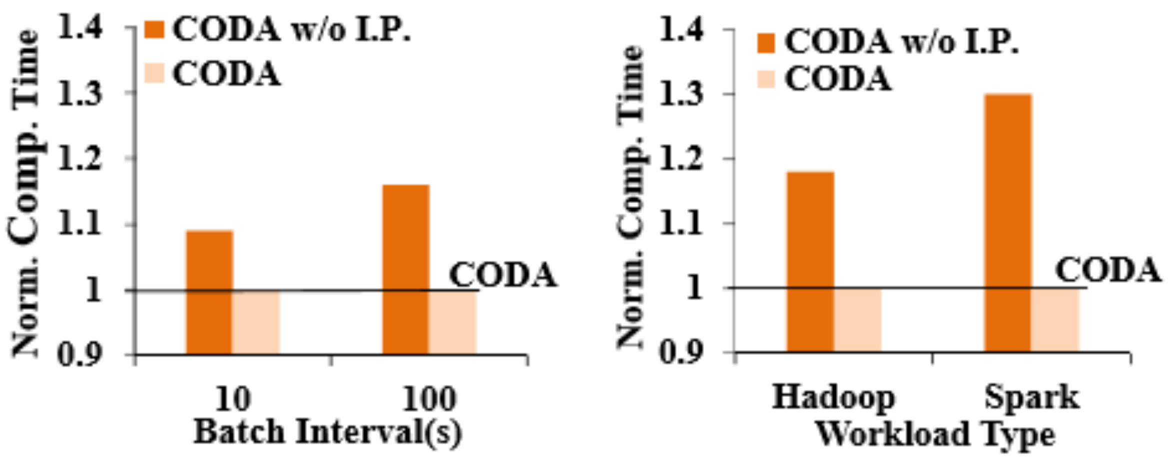
Reduce the impact of error by 30%

- *Benefit of Intra-Coflow Scheduling*
  - *Improve average coflow completion time for small flows for over 40%*



(a) Batch arrival case (Hadoop) (b) Stretched arrival case

Varys

Efficiently schedules coflows leveraging ***complete information***

- The size of each flow, the total number of flows

Not always achievable

Aalo

Efficiently schedules coflows ***without complete*** *information*

- ~~The size of each flow, and the total number of flows~~
- Which flow belongs to which coflow

Requires Application (e.g., Hadoop, Spark) Modification