Exploiting Inter-Flow Relationship for Coflow Placement in Datacenters

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Introduction

- **Coflow**
- Represents a collection of independent flows that share a common performance goal.
- Coflow's performance depends on its slowest flow.
- Coflow aware scheduling benefits distributed data processing applications.

- **State-of-arts**
  - Most of current work focus on optimizing the network scheduling algorithm to improve coflows' performance.
  - They assume predetermined coflow placement, i.e. the endpoint locations of a Coflow are preset.
  - But Coflow's placement can be more flexible in practice.

Coflow placement challenge

- **Challenge for inter-flow relationship in a Coflow**
  - E.g., in a one-to-many Coflow, all constituent flows share the same sender location.
  - In many-to-many Coflow, the relationship is even more complex. Because any member flow shares its two ends points with two different groups of flows.
  - Thus, we need to take care of such inter-flow relationship for placement decisions.

2D Placement for Coflow

- **Network Model**
  - Topology designs such as Fat-tree or Clos enable full bisection bandwidth in datacenters.
  - Assume non-blocking N-port switch with link bandwidth B.
  - Switch ports are connected to nodes, which can be host machines or ToR switches.
  - Only edge links are congested and core is congestion free.
- **Scheduling objective**
  - Minimize Coflow completion time (CCT). It is the duration to finish all flows in a Coflow to speed up application level performance.
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2D Placement for Coflow

- **Problem Statement**
  - K Coflows arrive at various time . We want to decide the placement for each new-arrived Coflow.
  - The placement of a Coflow can be represented by mapping functions

$$P_k^s : \{s_i\} \rightarrow \{in.1, ..., in.N\} \text{ for senders}$$
$$P_k^r : \{r_j\} \rightarrow \{out.1, ..., out.N\} \text{ for receivers.}$$

  - We assume when a Coflow arrives, its traffic demand D is available.
  - Thus, we need to decide the placement of a new Coflow given the existing previous Coflows, so that the sum of all Coflows' CCTs is minimized.

2D Placement for Coflow

- **Problem Analysis**
  - The sum of CCTs is jointly determined by Coflow's placement and the network scheduling during runtime.
  - First, Coflows' placement decides the optimal sum of CCTs achievable by any network scheduling policy.
  - Second, after Coflows are placed, the sum of CCts will be further determined by the network scheduling poicy, which arbitrates bandwidth allocation for each Coflow.
  - This paper focus on finding Coflow placement that minimizes the sum of CCTs under optimal network scheduling.
  - Given specific placement, finding the optimal scheduling policy to minimize the total CCTs is NP-hard.

Motivation Example 1

Exploiting Inter-Flow Relationship for Coflow Placement in Datacenters

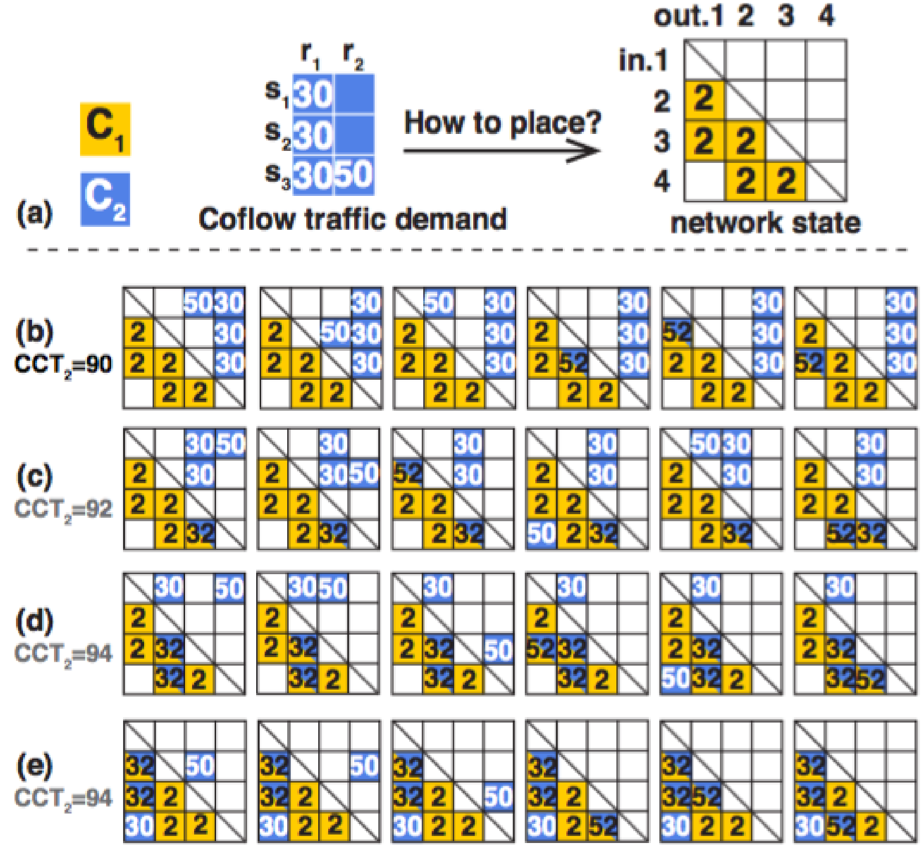

Figure 1: Coflow placement should avoid delaying bottleneck endpoint. (a) Placing 3-by-2 C_2 onto a 4-by-4 network with active flows from 3-by-3 C_1. (b-e) All possible placements of C_2. Cells with two colors indicate links shared by two Coflows. Cell numbers are the aggregated traffic size on the link. The optimal priority order is C_1, C_2. Thus CCT_1 is insensitive to C_2 placement, so only CCT_2 is considered. (b) Optimal placement with C_2's bottleneck r_1 on the least congested *out*.4. (c) Suboptimal placement due to delay of C_2's bottleneck r_1 on *out*.3 (d) Suboptimal placement due to delay of C_2's bottleneck r_1 on *out*.2 (e) Suboptimal placement due to delay of C_2's bottleneck r_1 on *out*.1. For fair comparison, we assume all Coflow traffic should traverse the network.

2D Placement for Coflow

- **Observations**

Hence, we have *Observation 1: When only the CCT of the Coflow to be placed is concerned, the Coflow's placement should avoid delaying the bottleneck.* To achieve this goal, bottleneck endpoint(s) should be placed at ports with sufficient bandwidth resource.

It is interesting to note that, without considering a Coflow's bottleneck, flow-level placement strategy may be suboptimal for Coflow placement. For example, prior work proposes to place a Coflow's constituent flows sequentially in the decreasing order of their flow sizes using a flow-level placement algorithm, because "large flows are more likely to be the critical flows to determine CCT" [14]. However, such strategy would yield suboptimal solutions, as shown in the first column of Figure 1c and Figure 1d. Under this flow-level strategy, the non-critical $f_{3,2}$, despite its largest flow size, takes over $out.4$, leaving suboptimal ports of $out.2$ or $out.3$ for the bottleneck receiver r_2 of C_2.

Motivation Example 2

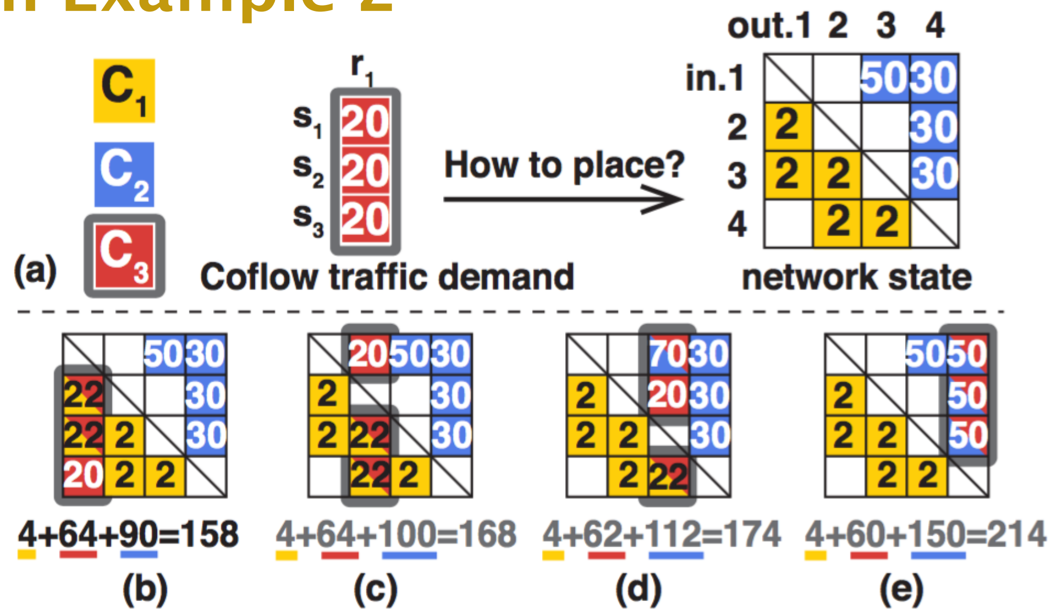

Figure 2: Coflow placement should avoid contentions among critical endpoints with heavy traffic load. (a) Placing incast C_3 onto a 4-by-4 network with active flows from C_1 and C_2. Optimal priority order is C_1, C_3, C_2. (b-e) All possible placements of C_3. CCTs are presented in $CCT_1+CCT_3+CCT_2$. (b) Optimal placement, placing C_3 on *out*.1. (c) Suboptimal placement, delaying C_2 on *in*.1. (d) Suboptimal placement, delaying C_2 on *out*.3. (e) Suboptimal placement, delaying C_2 on *out*.4. Legends and assumptions follow Figure 1.

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2D Placement for Coflow

- **First step**
  - Calculate the traffic demand requested on each endpoints for Coflow to place.
- **Second step**
  - 2D-Placement considers each sender (or receiver) in the descending order of their requested demand, and place the sender (or receiver) onto the input (or output) port with the minimum traffic load.
- **Complexity**
  - O(n^2).

Algorithm 1 2D-Placement

Input: Coflow to place C_{new}, remaining load $E^s[.]$ and $E^r[.]$

Output: Placement of all senders $P^s(.)$ and receivers $P^r(.)$

for all $(s_i, r_j, d_{i,j})$ in C_{new} **do** ▷ Requested load

  Load on sender $L^s[s_i] \mathrel{+}= d_{i,j}$

  Load on receiver $L^r[r_j] \mathrel{+}= d_{i,j}$

end for

for all s_i in the descending order of $L^s[.]$ **do**

  $P^s(s_i) = \operatorname{argmin} E^s[.]$ ▷ Place sender

  $E^s[P^s(s_i)] \mathrel{+}= L^s[s_i]$ ▷ Update load on port

end for

for all r_j in the descending order of $L^r[.]$ **do**

  $P^r(r_j) = \operatorname{argmin} E^r[.]$ ▷ Place receiver

  $E^r[P^r(r_j)] \mathrel{+}= L^r[r_j]$

end for

Simulation

- **Apply two network schedulers**
  - Varys assume accurate Coflow traffic request.
  - Aalo tries to approximate Varys with unknown sizes so as to tolerate error in the requested demand.

Scale factor	×0.5	×0.75	×1	×1.25	×1.5
Aalo	0.87	0.82	0.77	0.77	0.87
Varys	1.00	0.96	0.79	0.74	0.78

Table 1: 2D-Placement's average CCT normalized on Neat's average CCT. Normalized average CCT less than 1 means 2D-Placement is better.

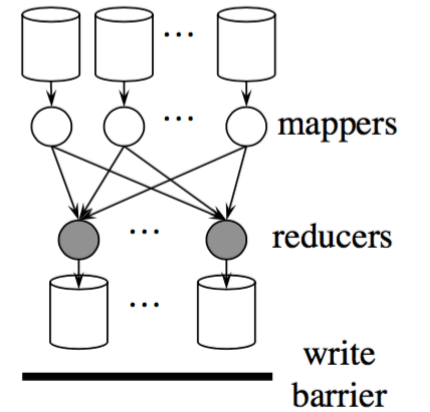
Communications in Cluster Applications

- **Dataflow pipelines**
  - MapReduce

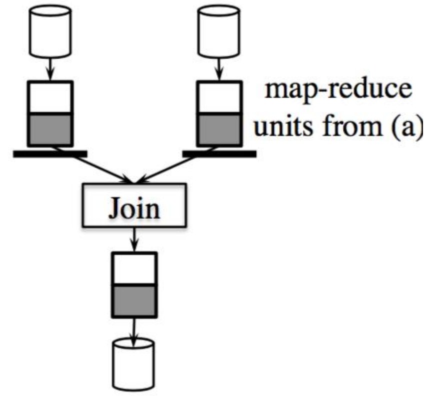
  Each mapper reads its input from the distributed file system (DFS), performs user-defined computations, and writes intermediate data to the disk; each reducer pulls intermediate data from different mappers, merges them, and writes its output to the DFS, which then replicates it to multiple destinations.

  - Dataflow with Barriers

  A dataflow pipeline with multiple stages uses MapReduce as its building block. Consequently, there are barriers at the end of each building block, and this paradigm is no different than MapReduce in terms of communication.



(a) MapReduce

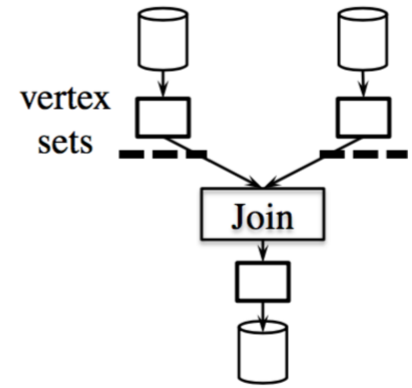


(b) Dataflow with barriers

Communications in Cluster Applications

- **Dataflow pipelines**
  - Dataflow without Explicit Barriers.

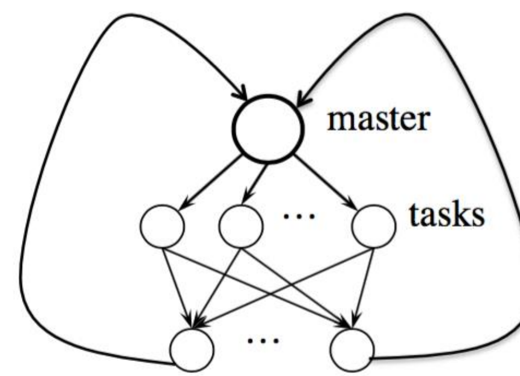
  Some data flow pipelines do not have explicit barriers and enable higher-level optimizations of the operators. A stage can start as soon as some input is available. Because there is no explicit barrier, barrier-synchronized optimization techniques are not useful.



(c) Dataflow without explicit barriers

  - Dataflow with Cycles

  Traditional dataflow pipelines unroll loops to support iterative computation requirements. However, implicit barriers at the end of each iteration allow MapReduce-like communication optimizations in cyclic dataflows. These frameworks also provide communication primitives like broadcast and many- to-one aggregation that, unlike shuffle, push data to a set of already known destinations.



(d) Dataflow with cycles

Communications in Cluster Applications

- **Dataflow pipelines**
  - Bulk Synchronous Parallel

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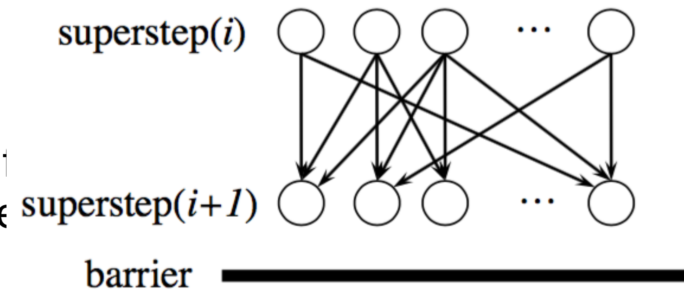
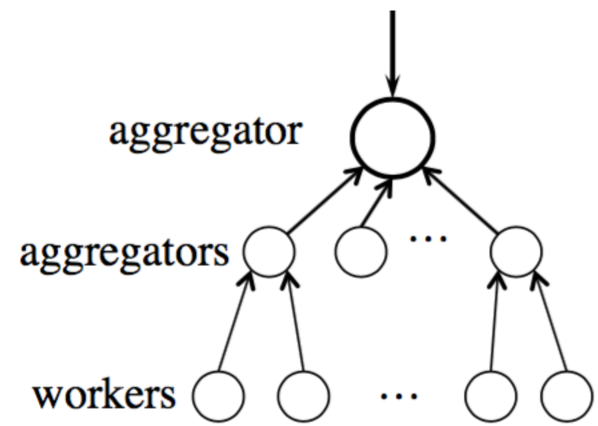


(e) Bulk Synchronous Parallel (BSP)

  - Partition-Aggregate

  User-facing online services (e.g., search results in Google or feeds in Facebook) receive requests from users and send it downward to the workers using an aggregation tree. At each level of the tree, individual requests generate activities in different partitions. Ultimately, worker responses are aggregated and sent back to the user within strict deadlines. Responses that cannot make it within the dead- line are either left behind [26] or sent later asynchronously



(f) Partition-aggregate

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