RAGraph: A Region-Aware Framework for Geo-Distributed Graph Processing

Feng Yao, Qian Tao, Wenyuan Yu, Yanfeng Zhang, Shufeng Gong,
Qiange Wang, Ge Yu, Jingren Zhou
Northeastern University, Alibaba Group

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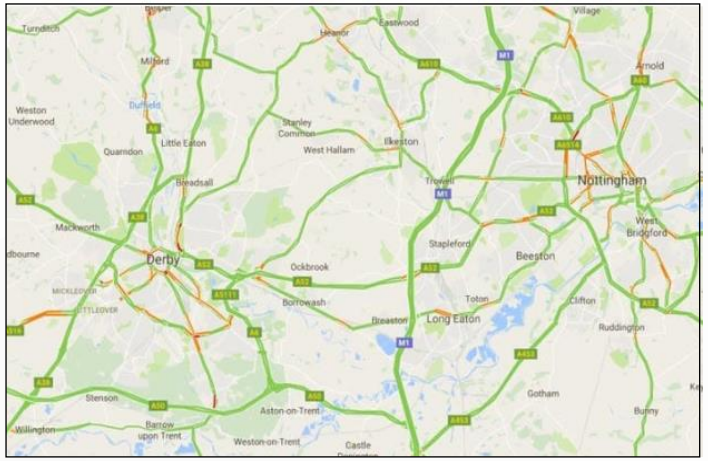
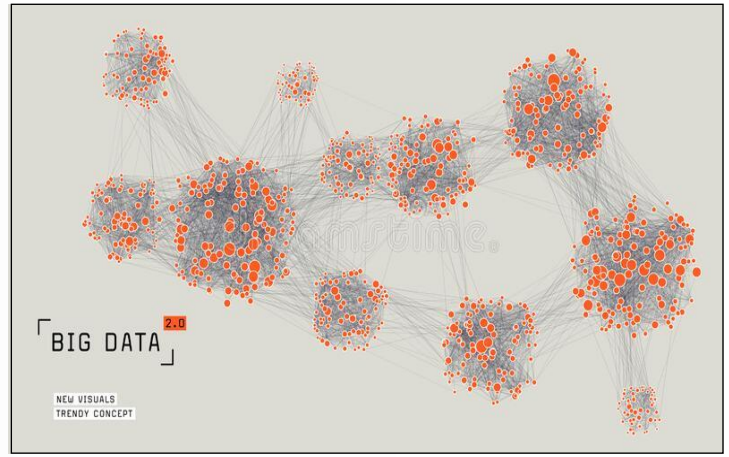
GUANGZHOU

Graphs

Social network



Road network



Biological networks

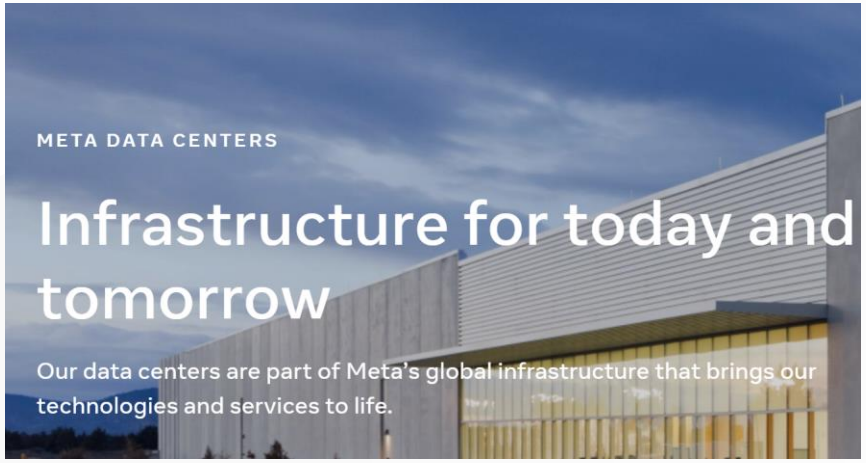
Geo-distributed Graphs

In many real-world application scenarios, graph data is geographically distributed.

Geo-distributed Graphs

In many real-world application scenarios, graph data is geographically distributed.

META has constructed over 20 data centers for global social networking operations.



Europe



Asia

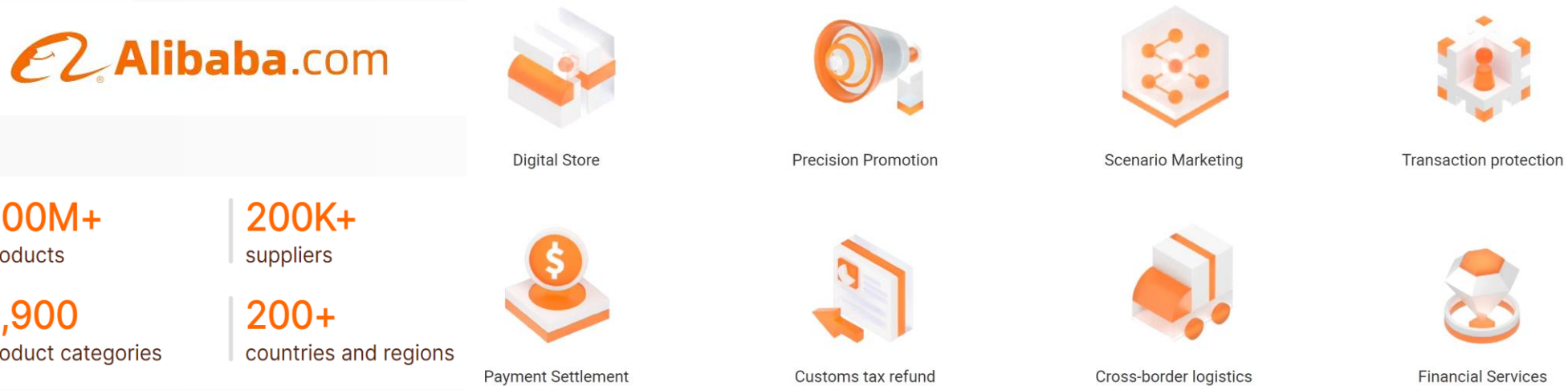
United States



Geo-distributed Graphs

In many real-world application scenarios, graph data is geographically distributed.

E-commerce platform for global trade network and cross-border logistics.

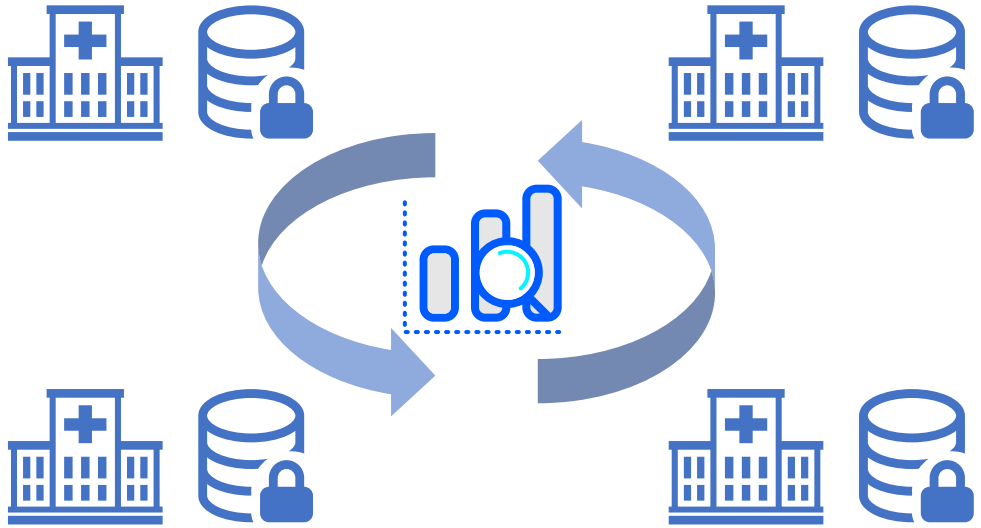


Geo-distributed Graphs

In many real-world application scenarios, graph data is geographically distributed.

Federated graph computing

- Healthcare organizations provide personalized healthcare services by integrating medical data.



Geo-distributed Graphs

Geo-distributed graph data have significant value for data mining.

Geo-distributed Graphs

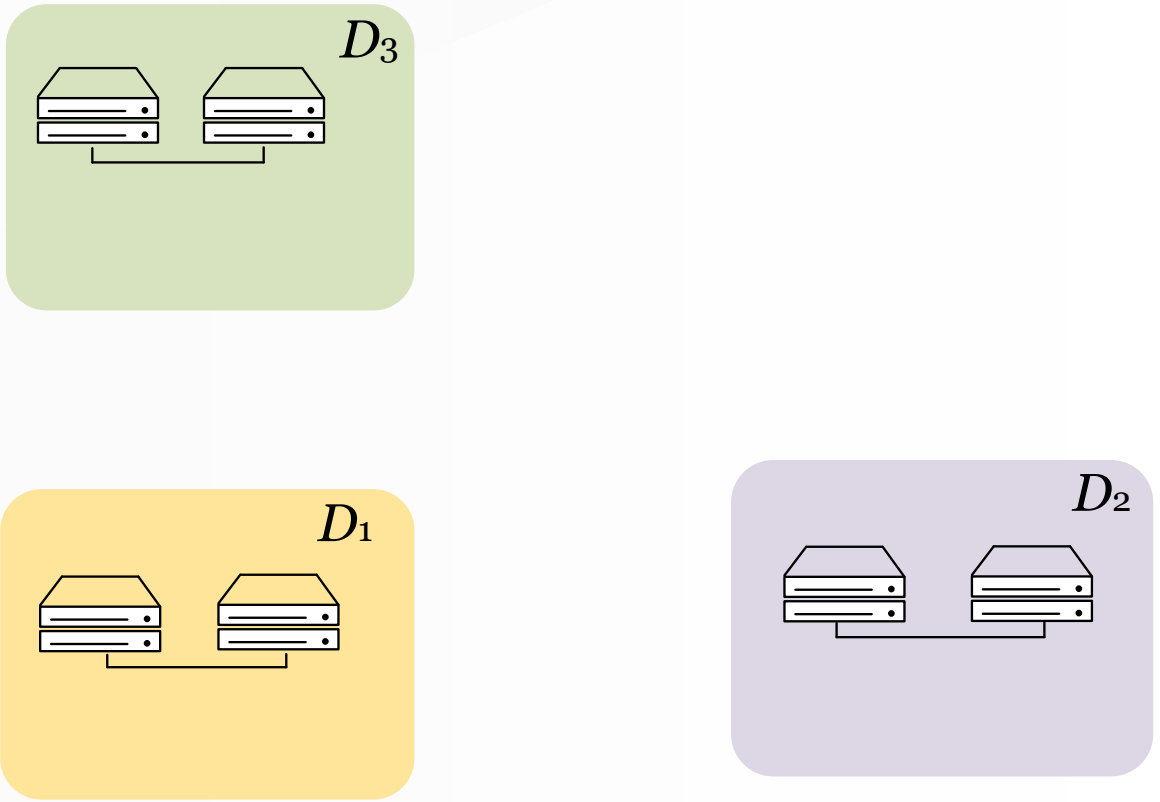
Geo-distributed graph data have significant value for data mining.

- Large-scale **data migration centralized processing** graph is expensive due to high network transmission costs.

- The increasing **data protection** requirements also make redistributing data among data centers impossible.

Geo-distributed Cluster

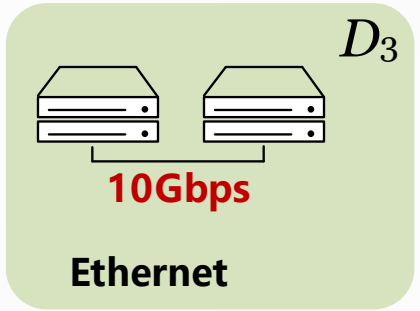
Real-world geo-distributed cluster configuration (AliCloud ECS cluster):

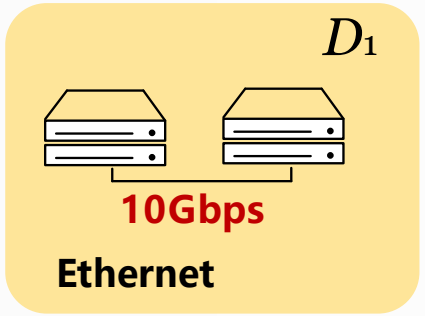


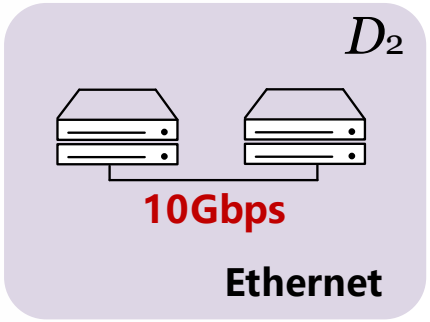
Geo-distributed Cluster

Real-world geo-distributed cluster configuration (AliCloud ECS cluster):

- **High bandwidth within data centers**
- Scarce and heterogeneous bandwidth between data centers
- Network fluctuations







10 Gbps Ethernet connection within the data center.

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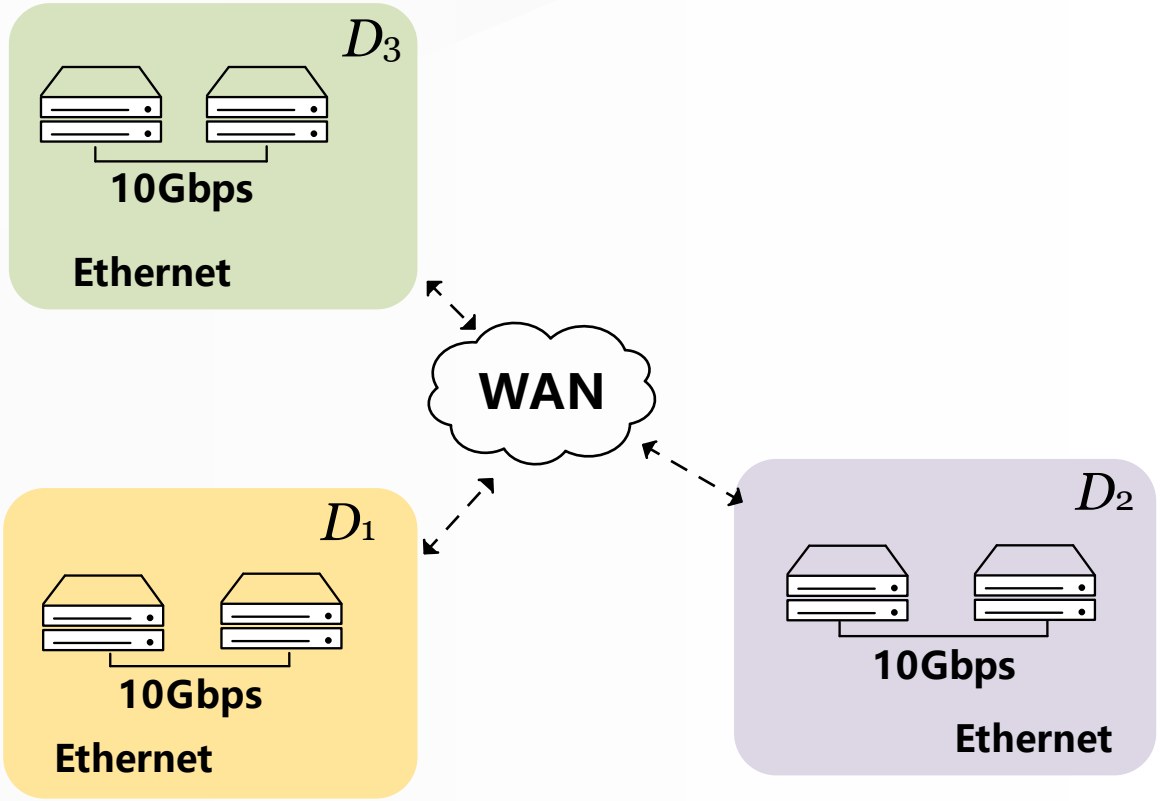

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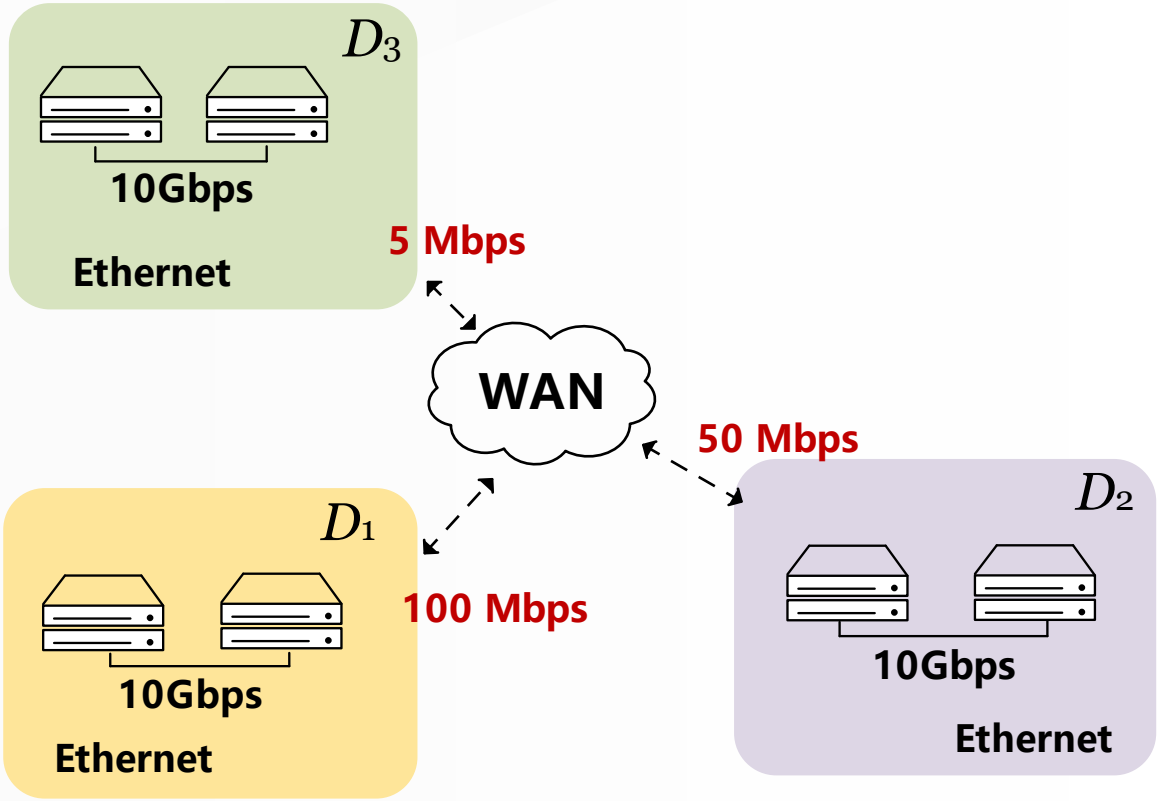

Up to 100 Mbps between data centers.

Geo-distributed Cluster

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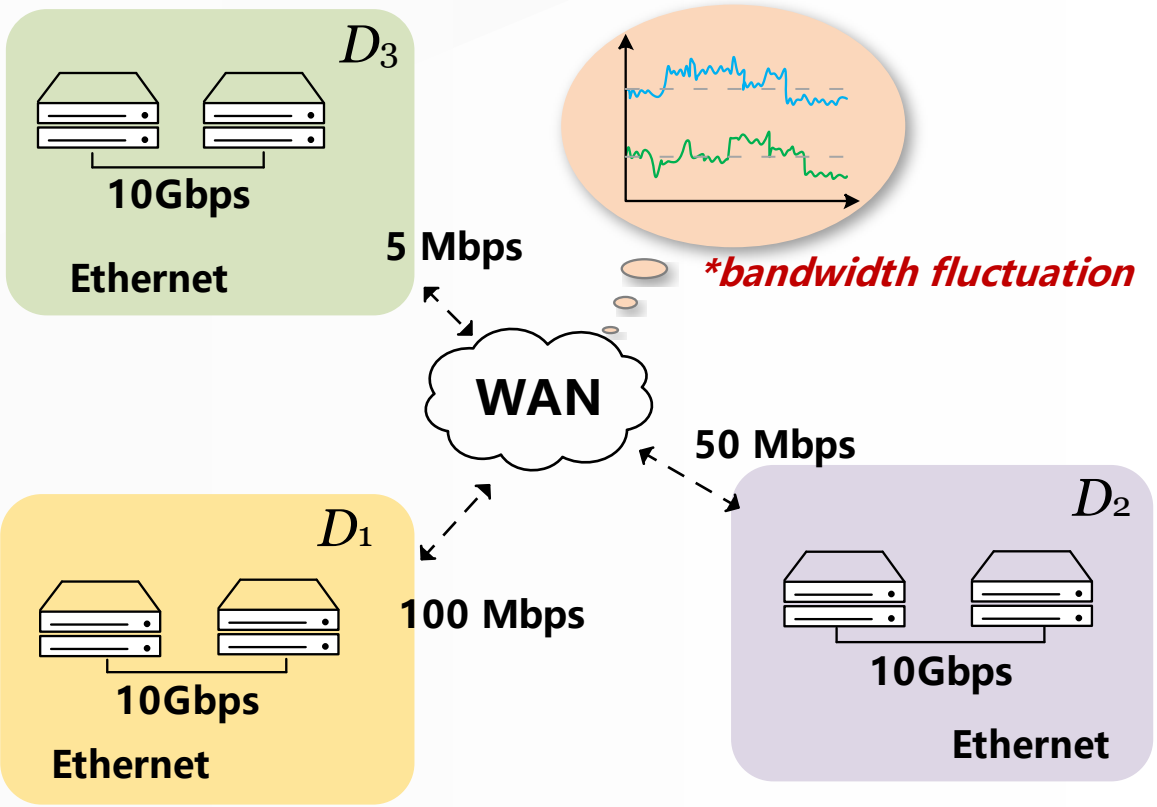
- **Network fluctuations**

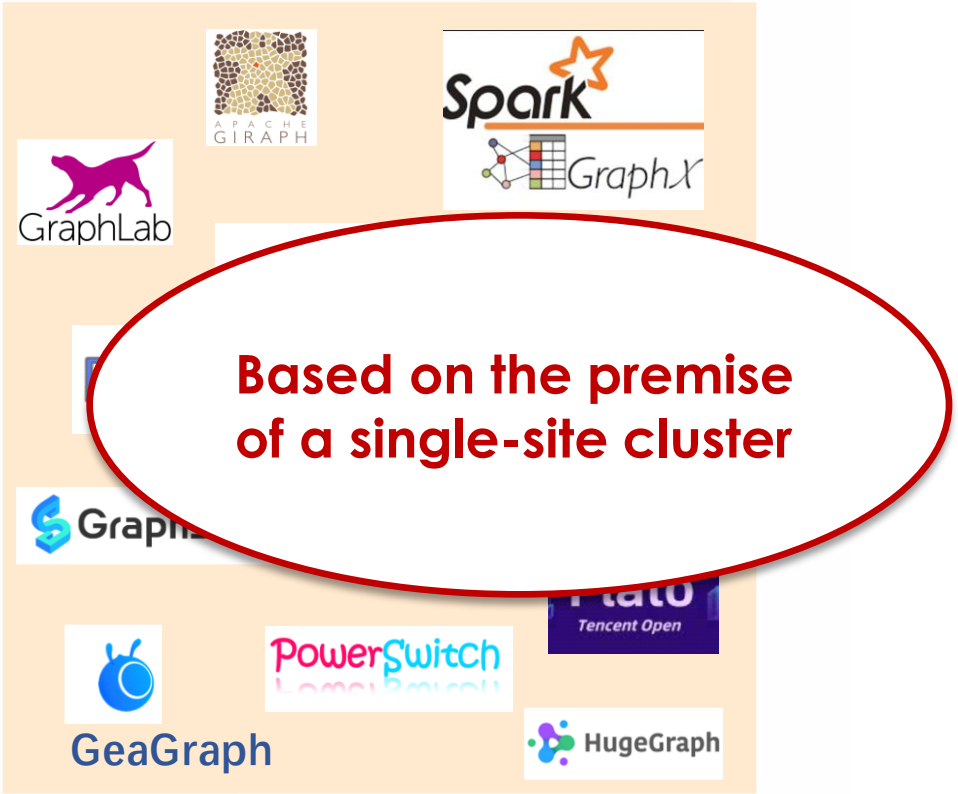


Due to **network fluctuations**, WAN links are unstable.

Graph Processing Systems

Distributed Systems

Graph Processing Systems

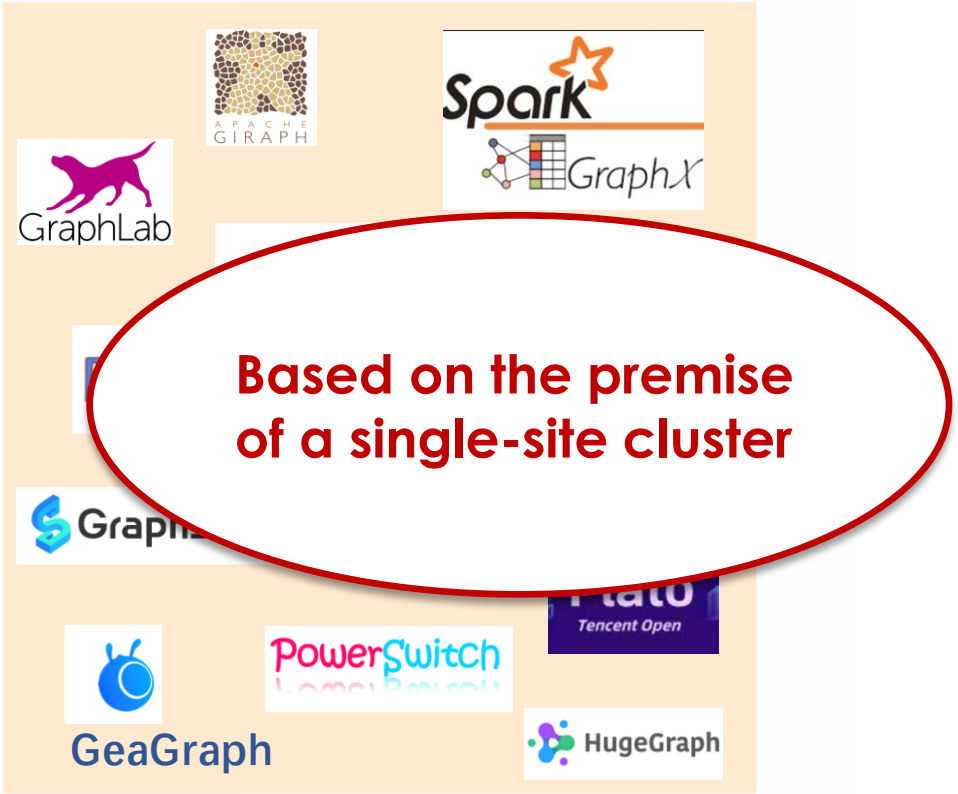


Distributed Systems

Graph Processing Systems

high bandwidth

homogeneous links



Distributed Systems

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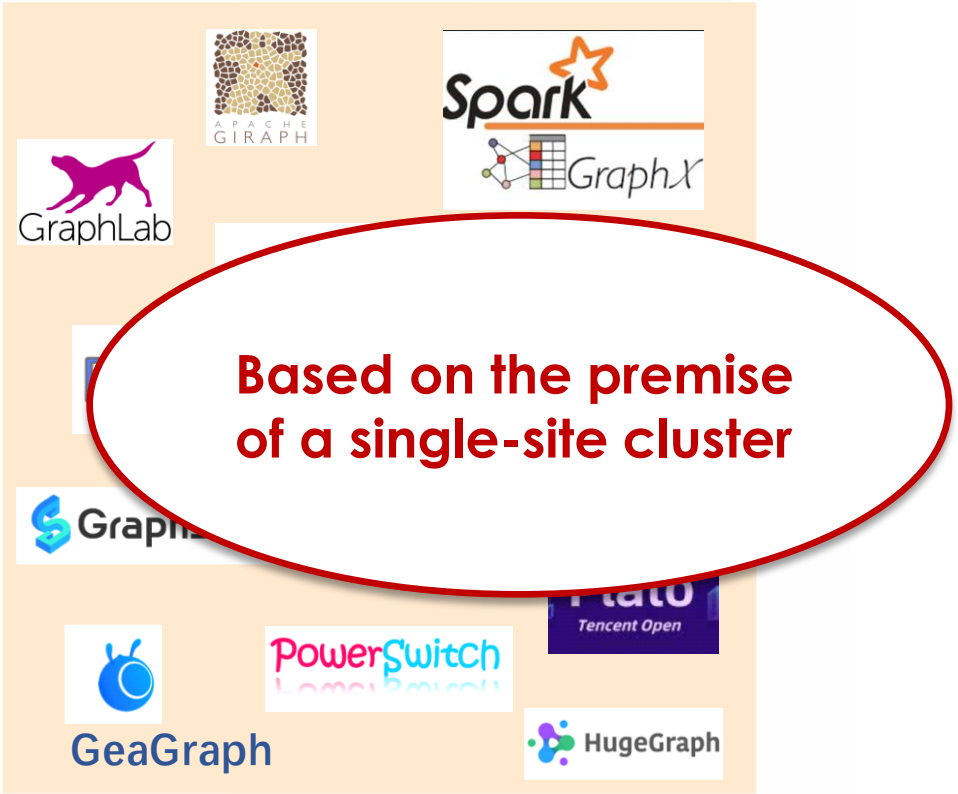

Distributed Systems

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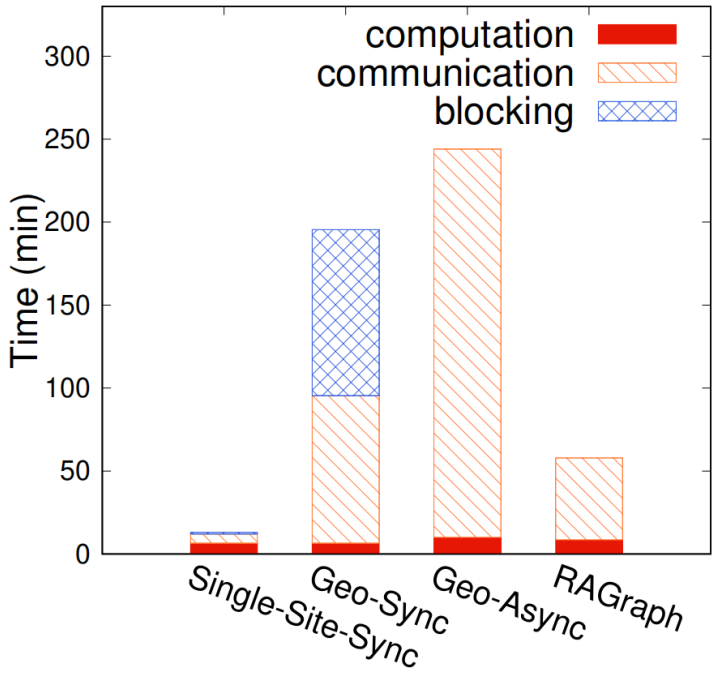
A challenge to the **traditional assumptions** underlying the design of distributed systems.

Geo-distributed Cluster

Tested SOTA traditional system GRAPE (Sync) /Maiter (Async) on single-site cluster and geo-distributed cluster



Single-site VS. geo-distributed cluster.

Geo-distributed Cluster

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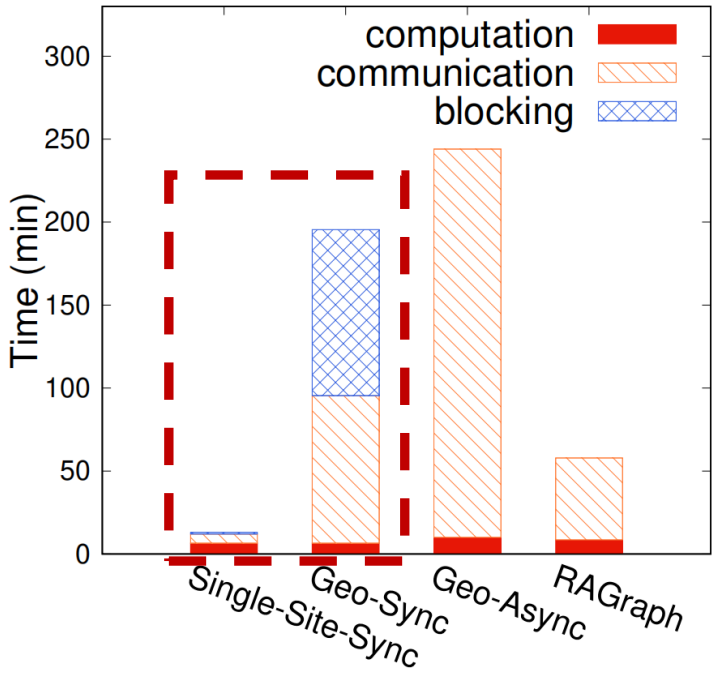
- **Network bandwidth differences**
- Scarce and heterogeneous bandwidth between data centers



Single-site VS. geo-distributed cluster.

running time **significantly increases** under geo-distributed cluster.

Geo-distributed Cluster

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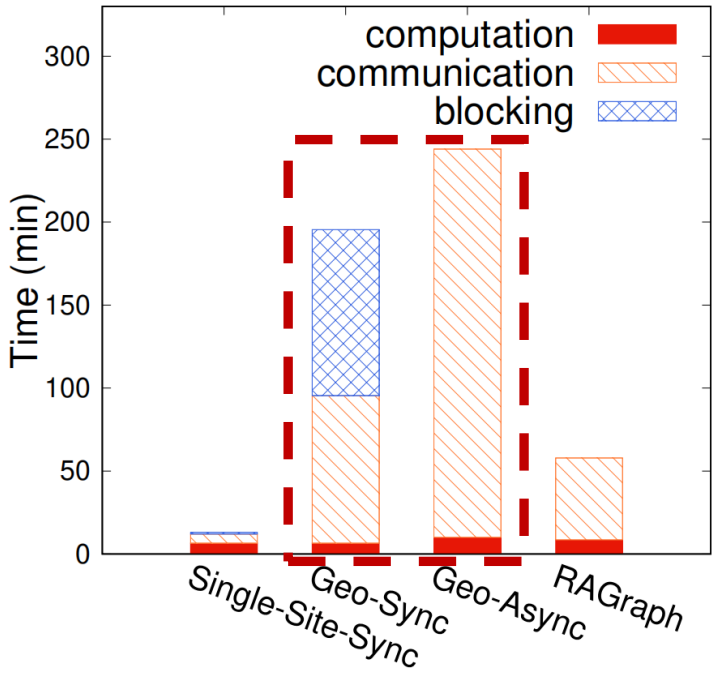


Single-site VS. geo-distributed cluster.

overhead comes from **communication time** and **blocking wait time**.

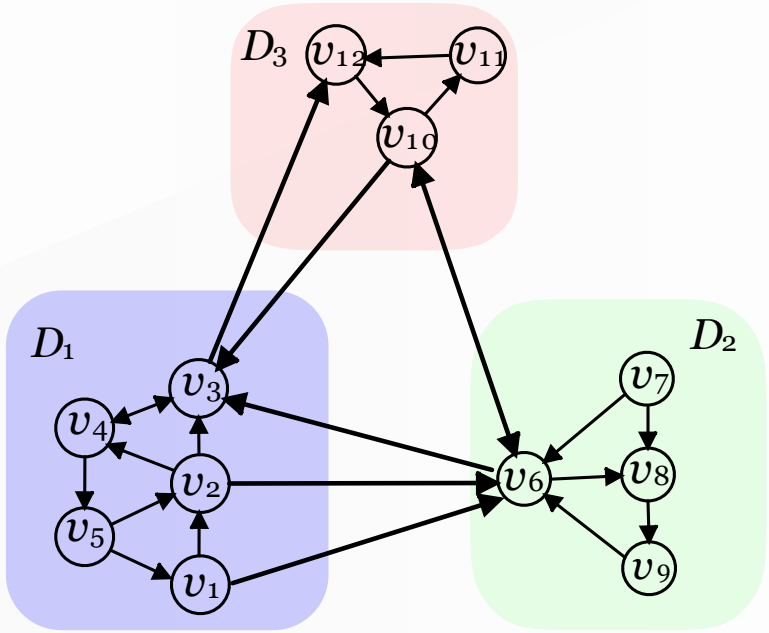
Challenges

- ***Imbalance of Message Transmission***
  - Message transmission time between data centers **is much longer** than that within a data center.
  - Heterogeneous networks cause **imbalanced message transmission** between data centers.
- ***Inefficiency of Graph Processing Model***
  - Synchronous Parallel model (**blocking wait time**)
  - Asynchronous Parallel model (**communication time**)

Observations

1 Imbalanced local-global interaction

Input graph:

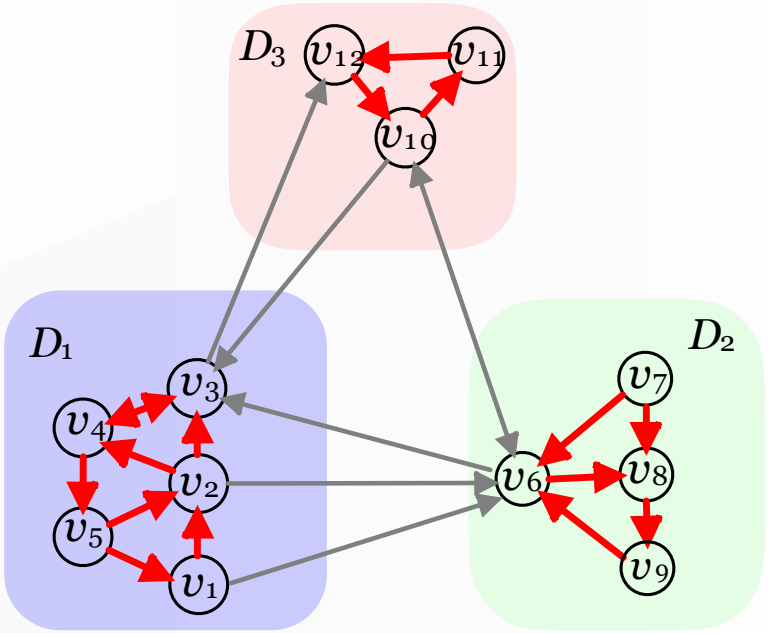


Observations

1 Imbalanced local-global interaction

Observation: Traditional interaction pattern.

- **Local execution**
- Global execution



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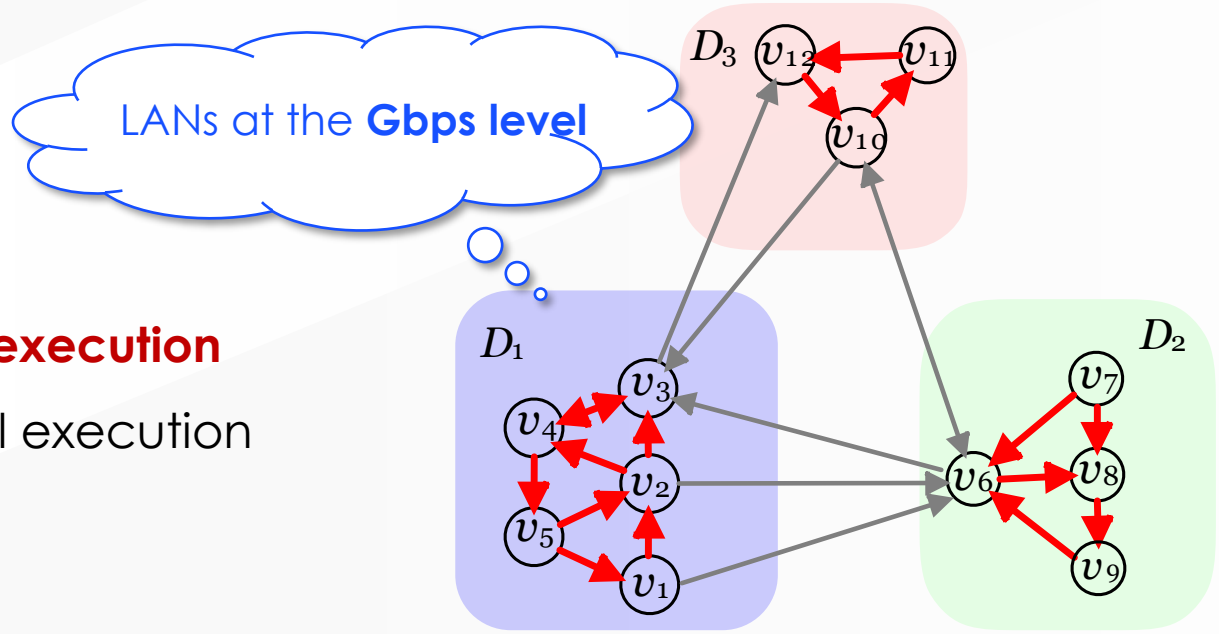

- **Local execution**
- Global execution

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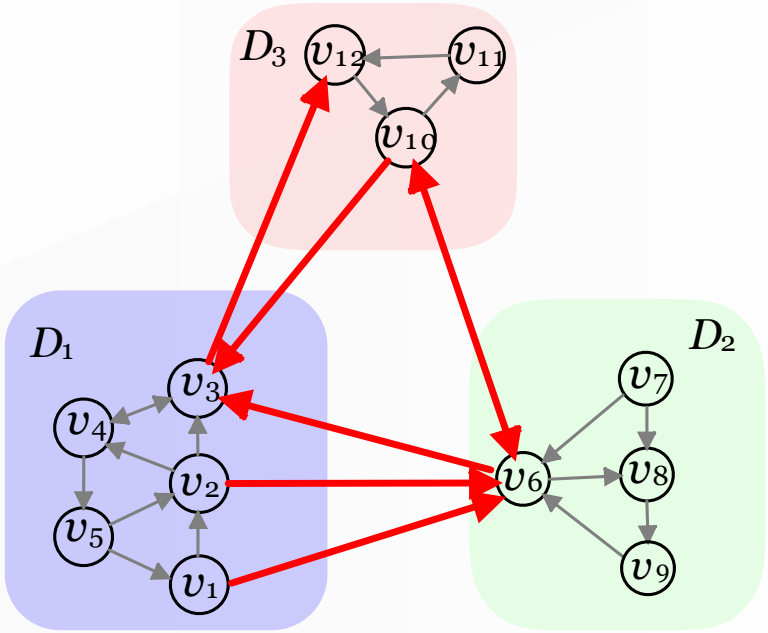

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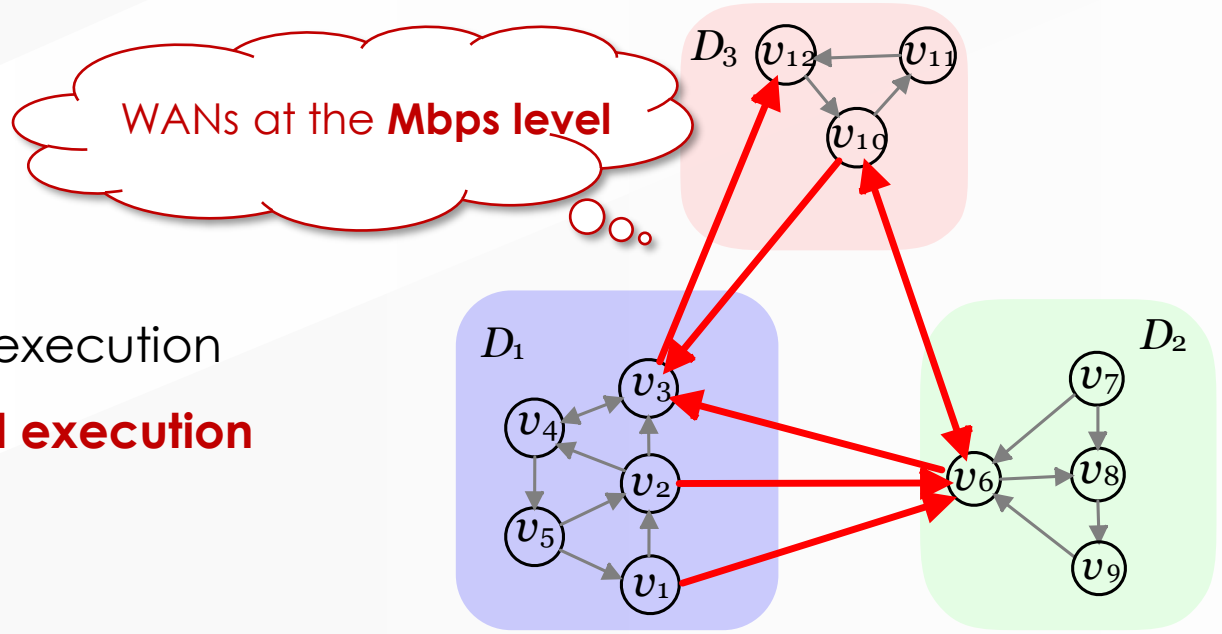

- Local execution
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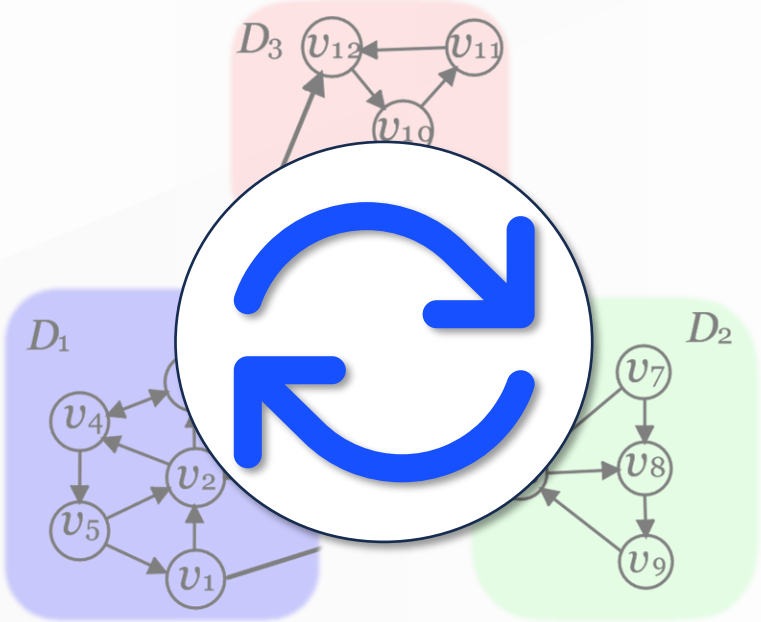
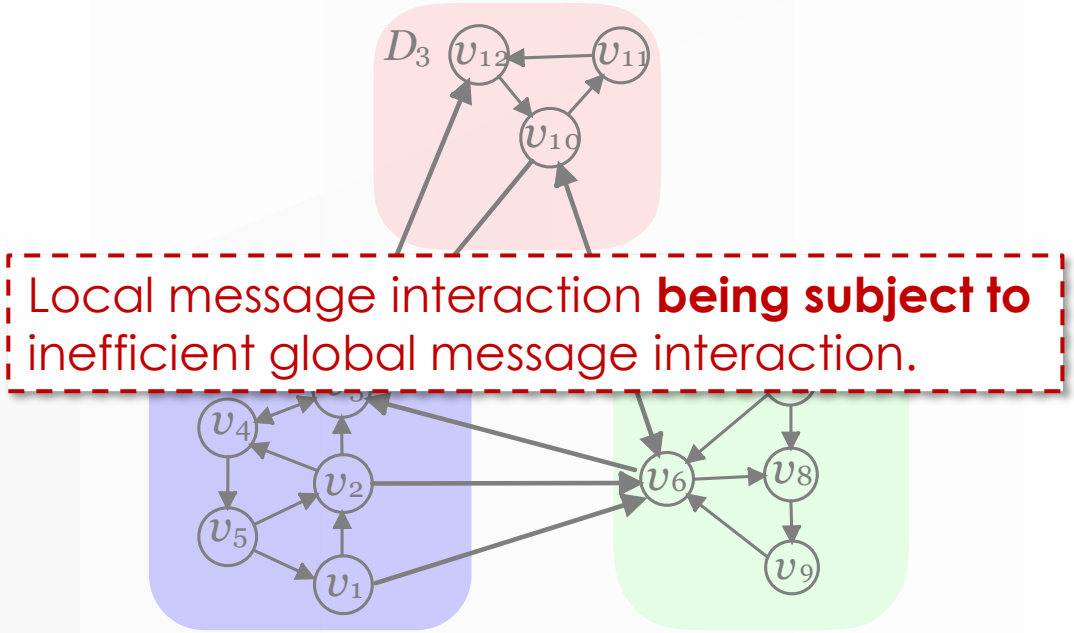


Local-global **alternate** execution

Observations

1 Imbalanced local-global interaction

Issues arising:

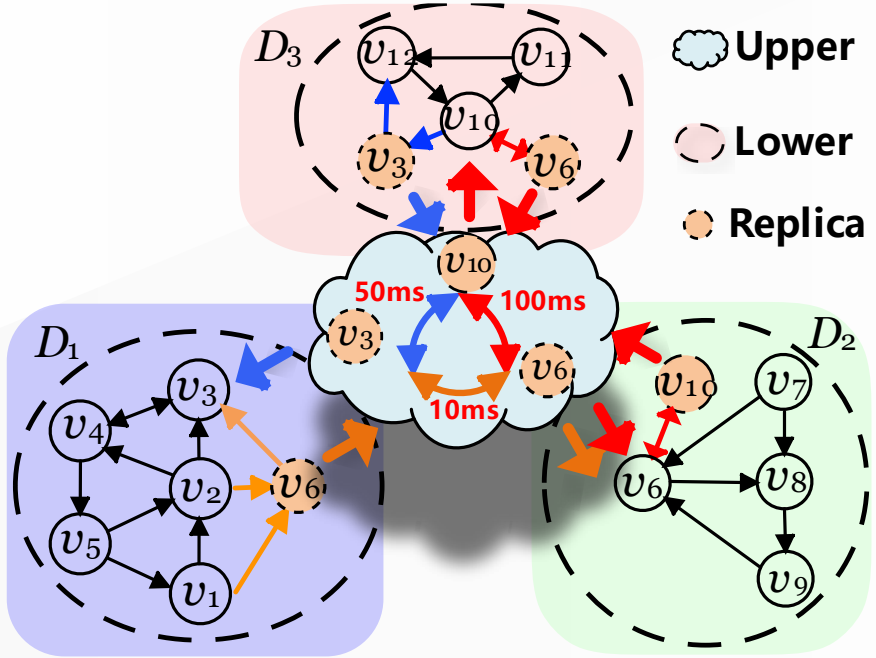


Local message interaction **being subject to** inefficient global message interaction.

Observations

1 Imbalanced local-global interaction

Solution: Two-layer interaction view.

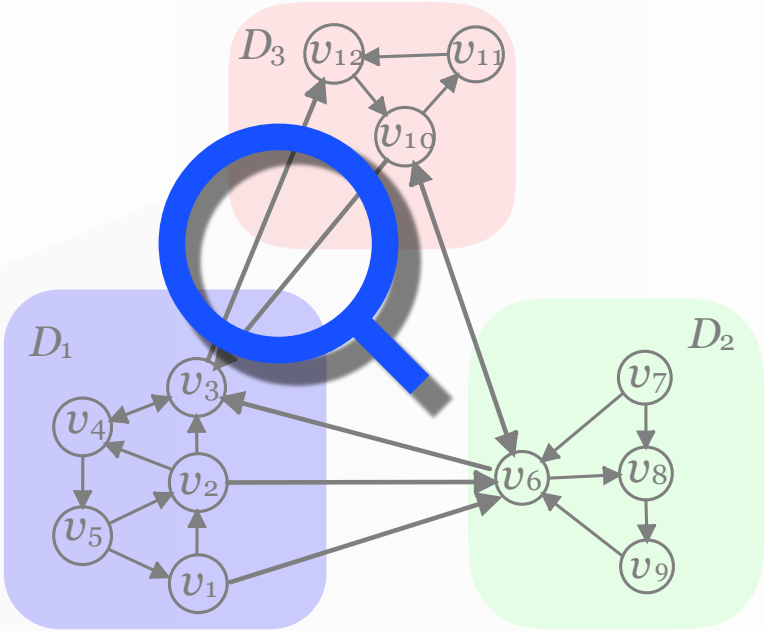


Decouple local-global interactions.

Observations

2 Ping-Pong Effect

Observation: Message interaction on the boundary.

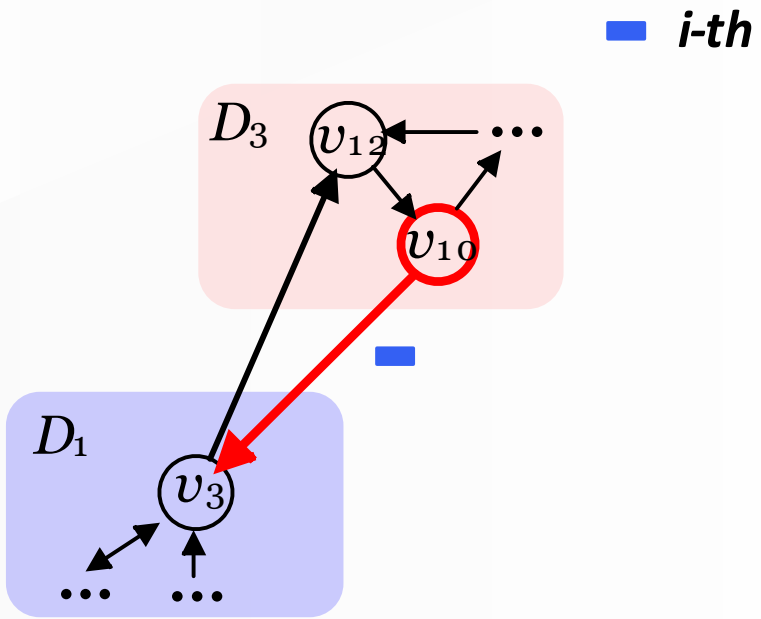


Observations

2 Ping-Pong Effect

Observation: Message interaction on the boundary.

- **V_{10} sends a message to V_3 in D_1**
- V_3 generates a new message
- V_3 sends this message to V_{12}



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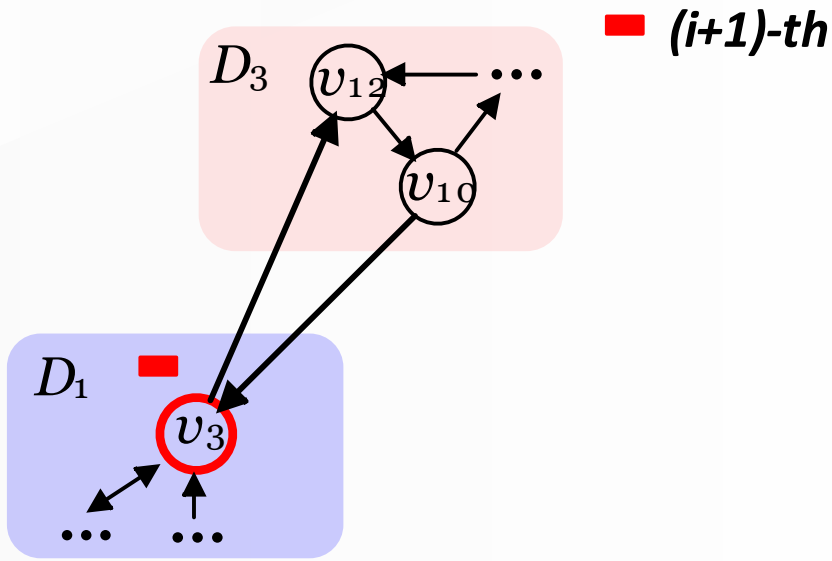

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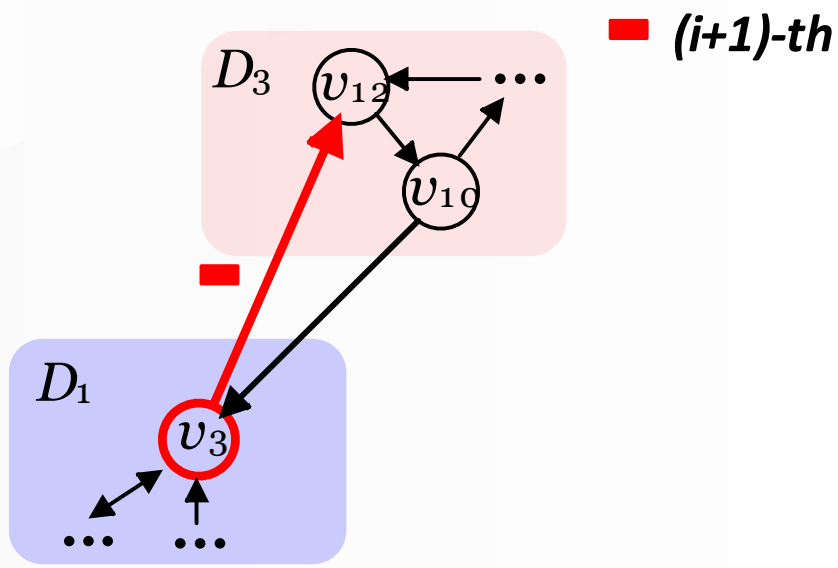

Observations

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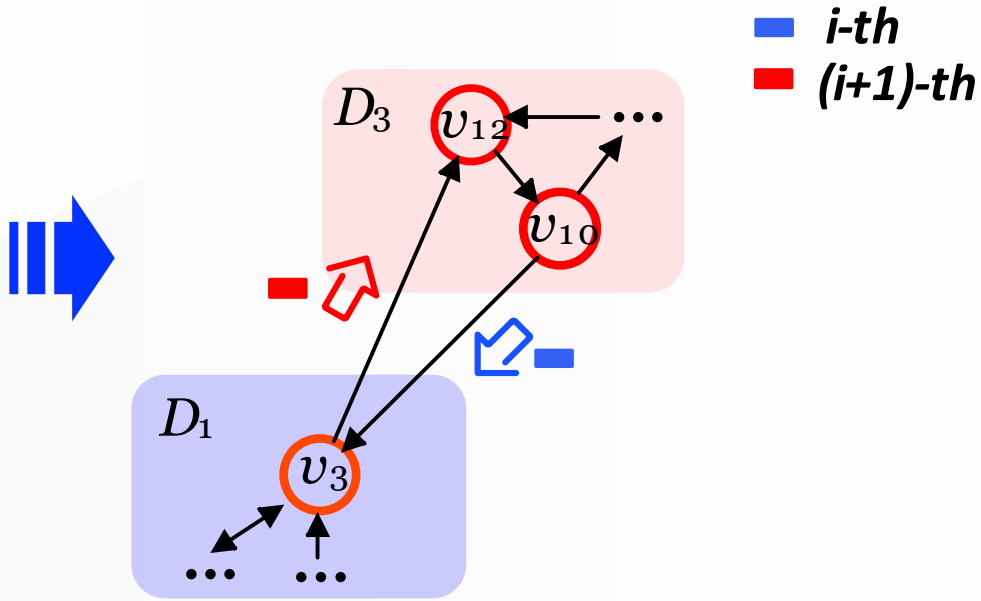
Called **Ping-Pong Effect**



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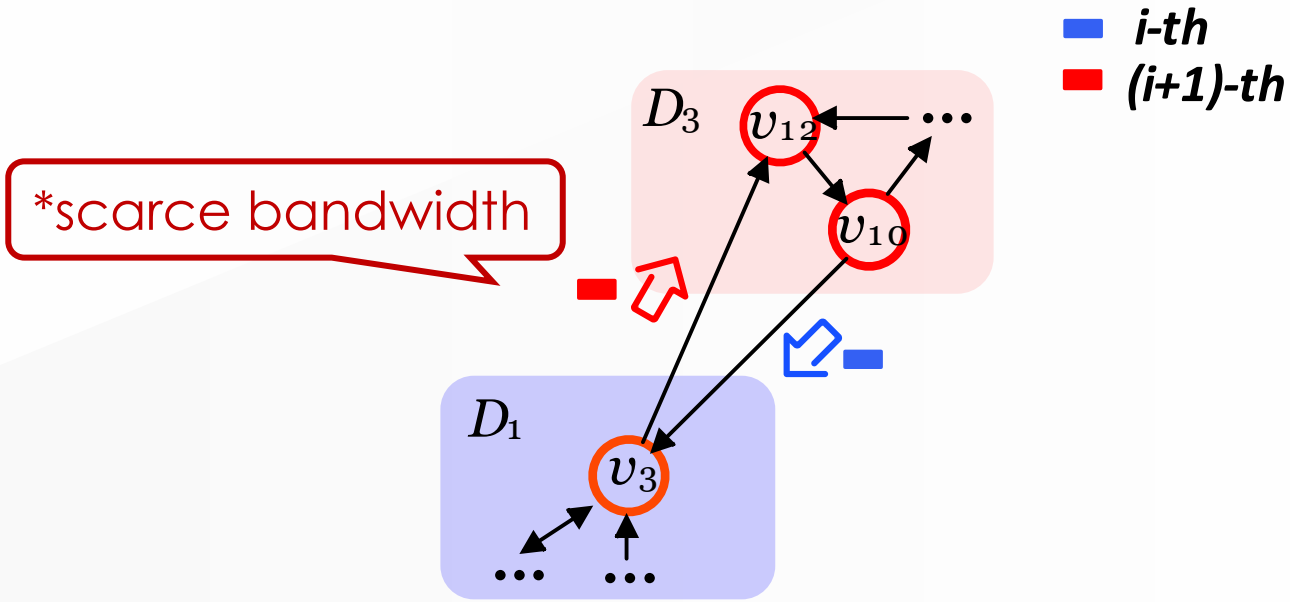


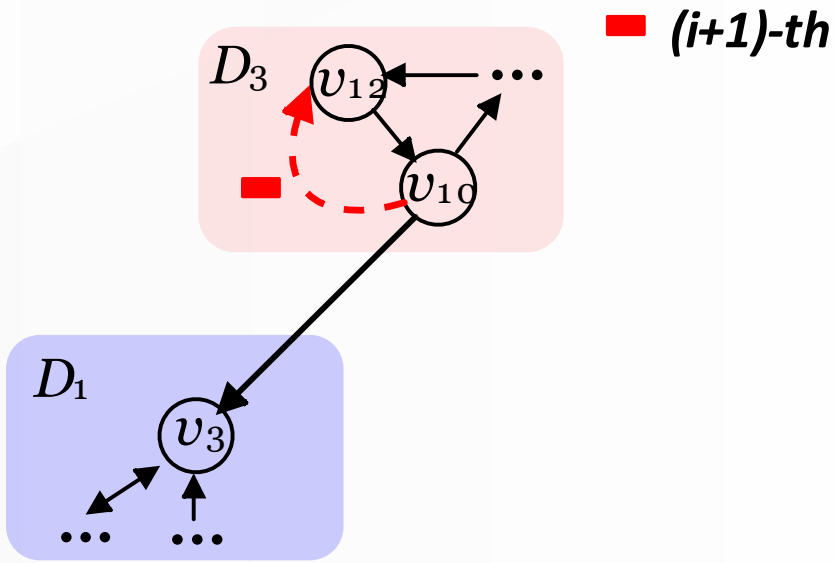
round-trip transmission waiting.

Observations

2 Ping-Pong Effect

Solution: Remote message internal execution.

- **The message from V_{10} is updated and sent directly to V_{12}**
- Boost the message passing



Advance inefficient global updates to local computation.

Observations

2 Ping-Pong Effect

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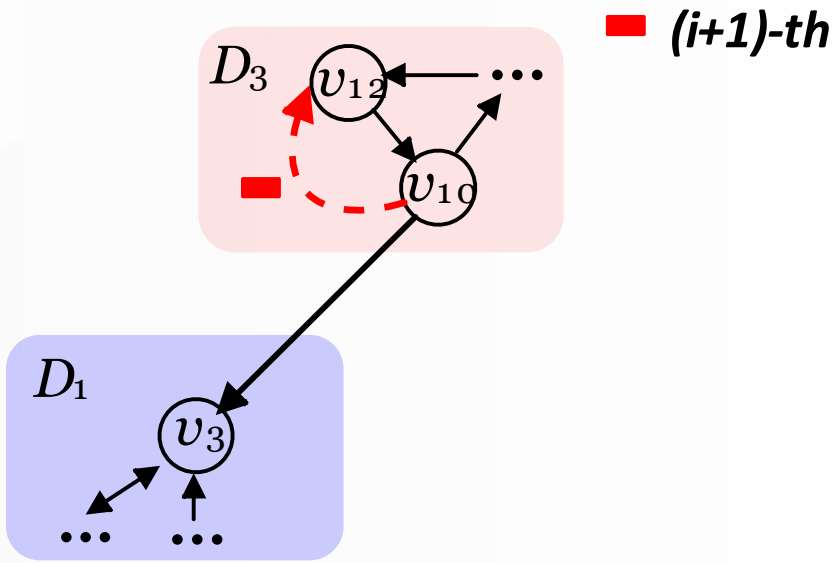


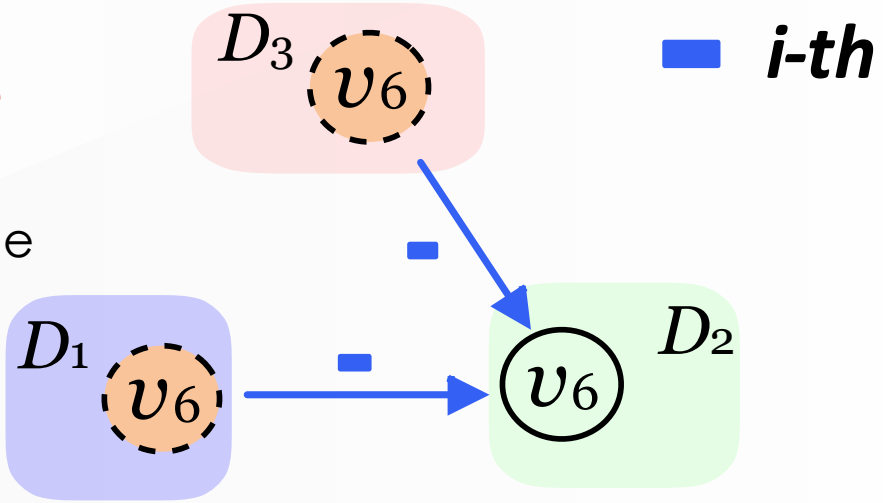
Advance inefficient global updates to local computation.

Observations

3 Intolerable network congestion

Observation: Typical communication pattern.

- **Replicas send messages to the master**
- Master sends updated message to replicas



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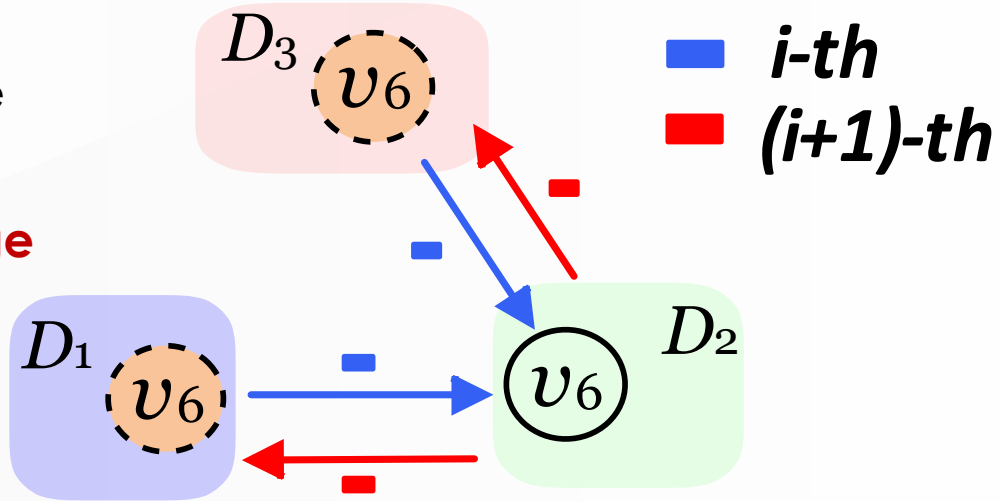

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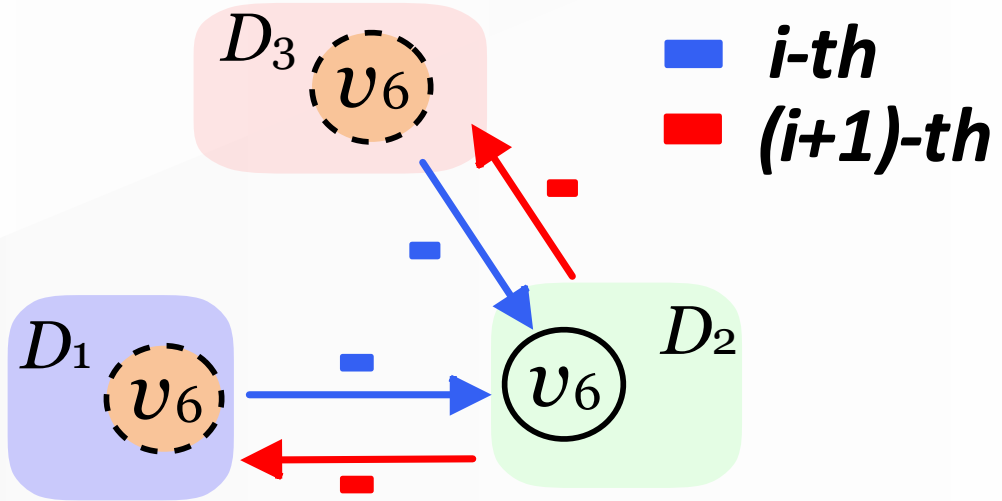
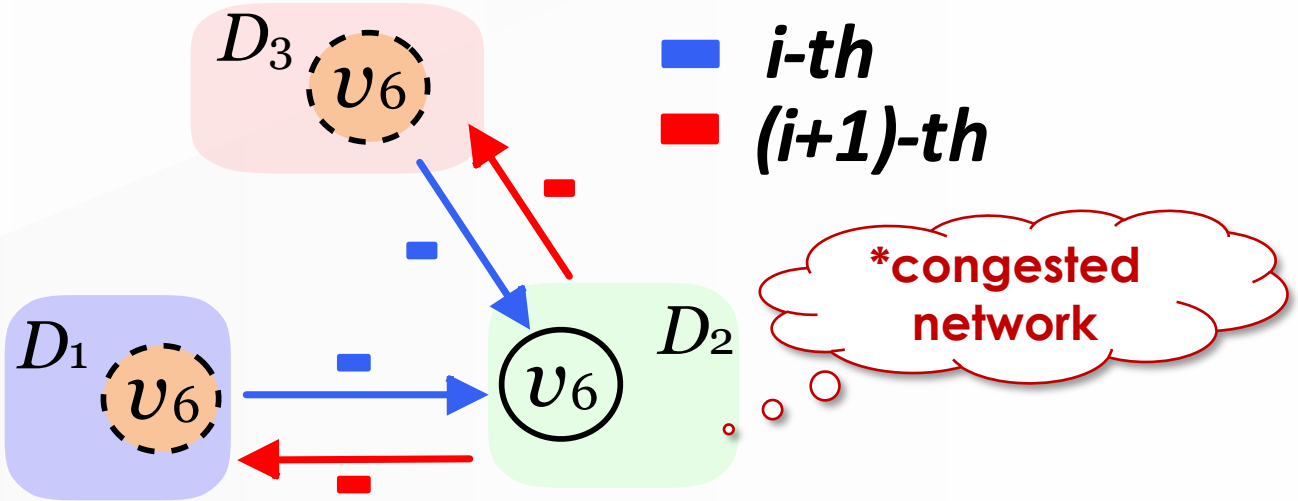


One-to-many pattern result in a large inflow/outflow of messages on the "one" side.

Observations

3 Intolerable network congestion

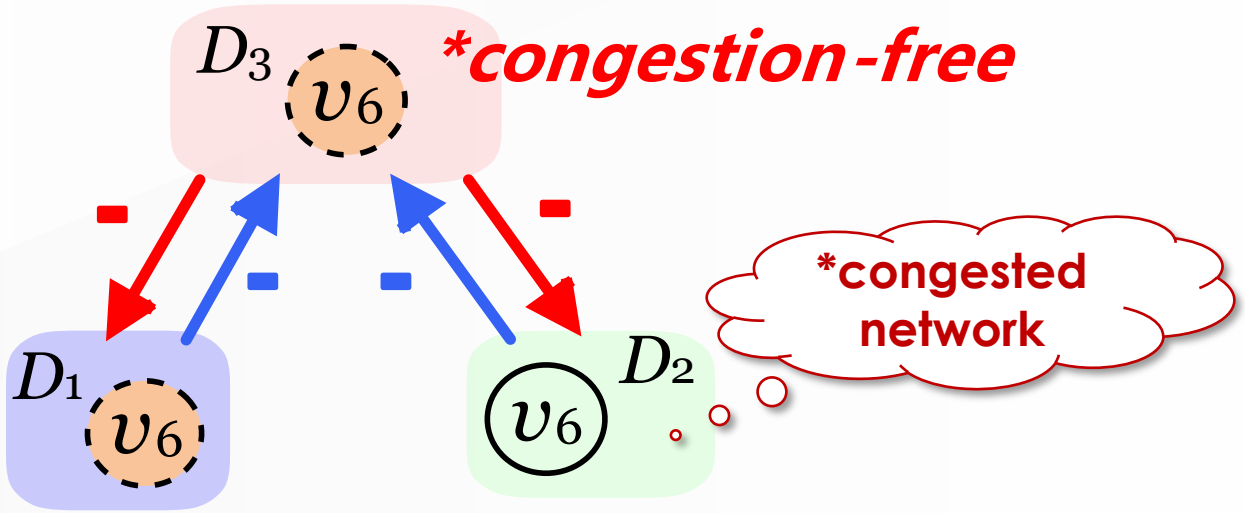
Issues arising:



Observations

3 Intolerable network congestion

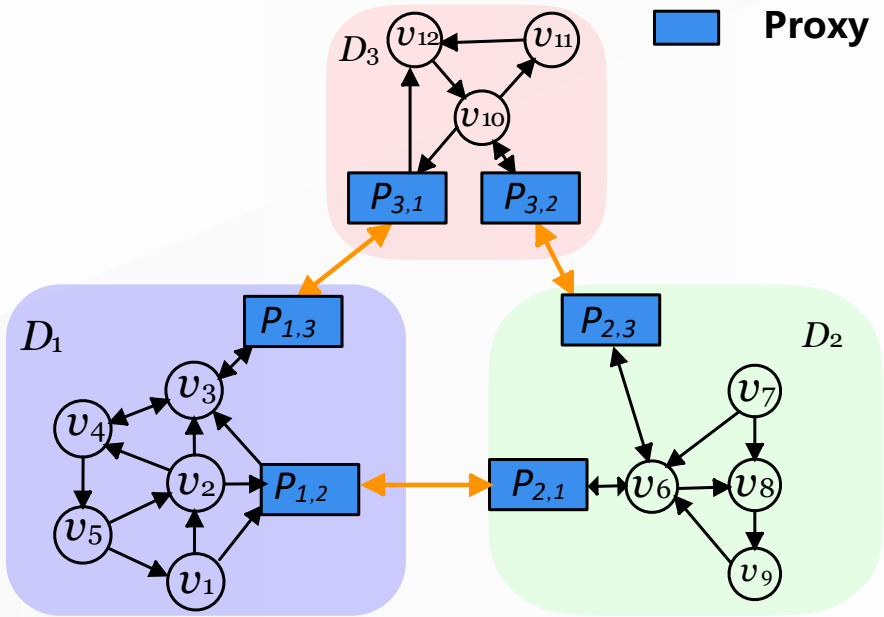
Solution: Replaceable communication pattern.



Replace the master role in a **congestion-free data center.**

Region-Aware Framework

Setting up proxy



Region-Aware Framework

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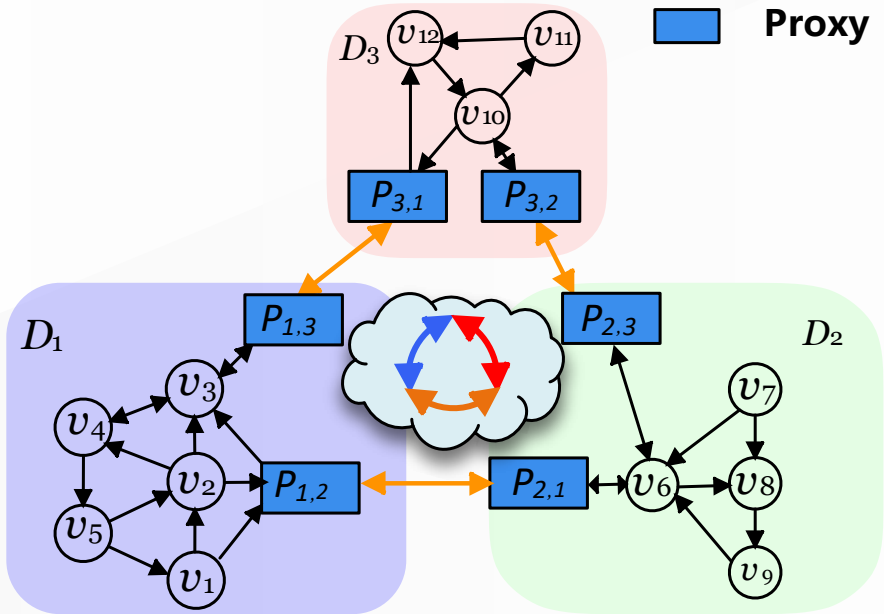
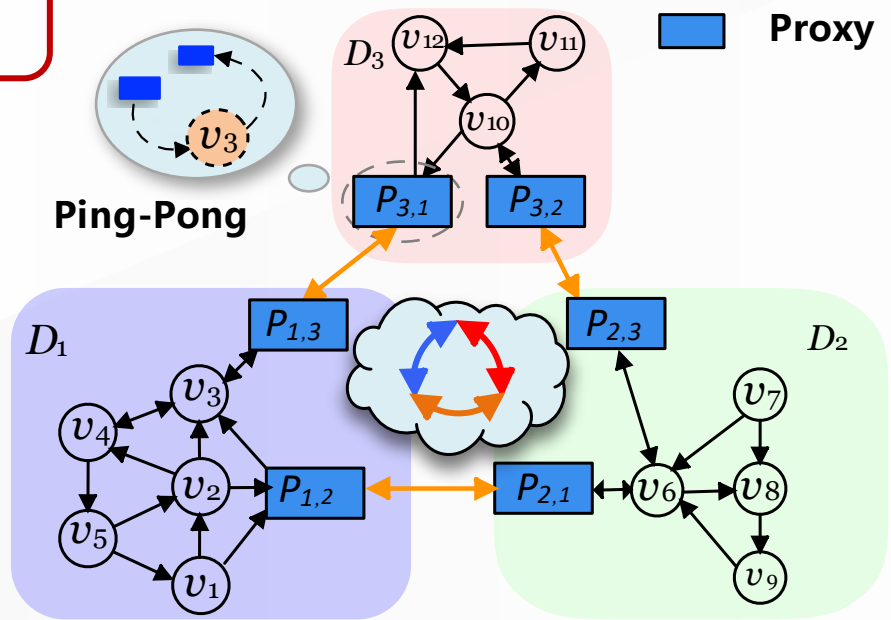


❖ decoupled local/global layers

Region-Aware Framework

Setting up proxy

- Local computation of the ping-pong effect



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Region-Aware Framework

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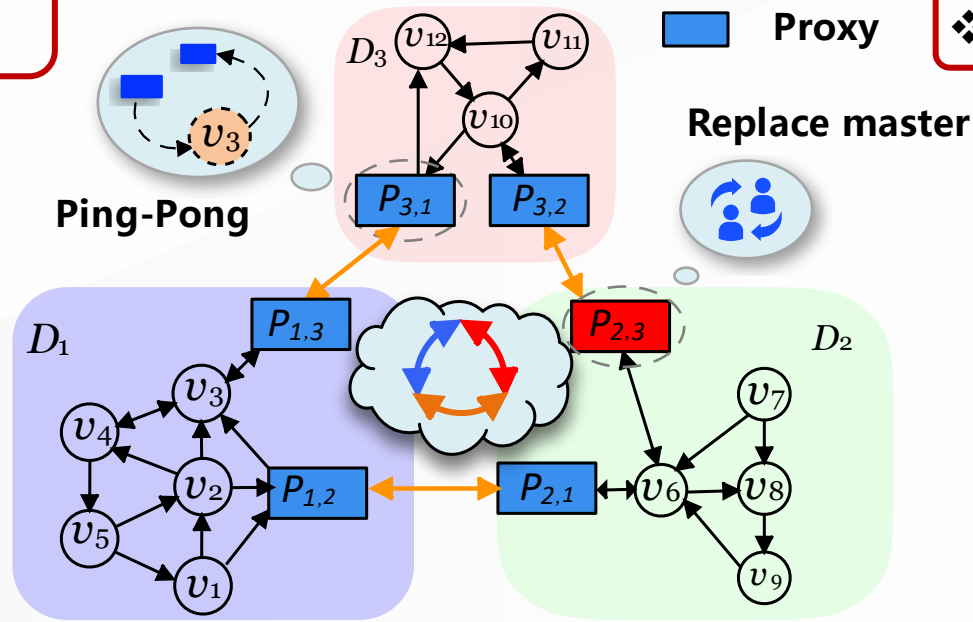


- Replaceable communications
- decoupled local/global layers

System correctness guarantee

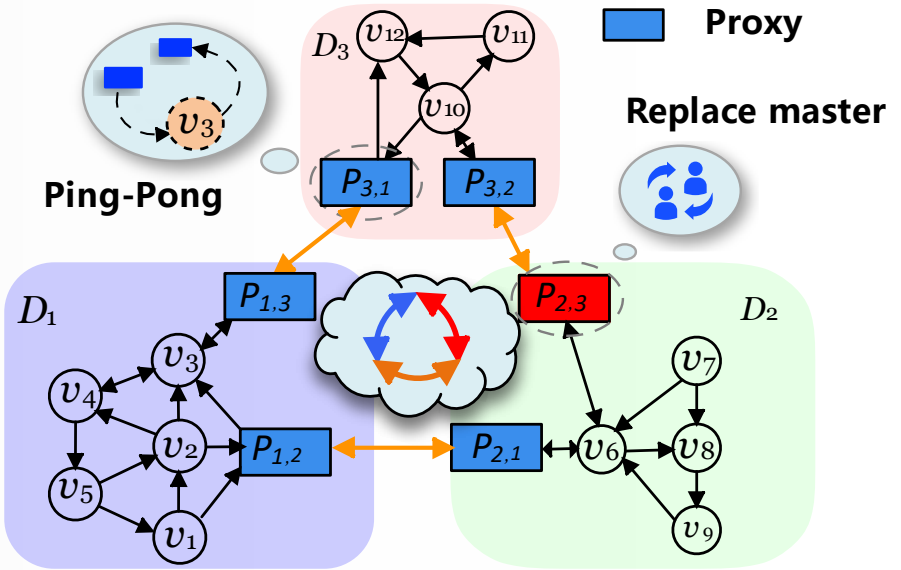
The Delta State Conflict-free Replicated Data Type (CRDT) [1] theory guarantees *Strong Eventual Consistency* between proxies.

Given algorithmic constraints, the aggregation function A and message interaction function I satisfy the monotonic condition:

Monotonic Conditions. $\mathcal{A}$ and $\mathcal{I}$ satisfy monotonic conditions if:

(C1) $\mathcal{A}(X \cup Y) = \mathcal{A}(Y \cup X)$ and $\mathcal{A}(\mathcal{A}(X) \cup Y) = \mathcal{A}(X \cup Y)$

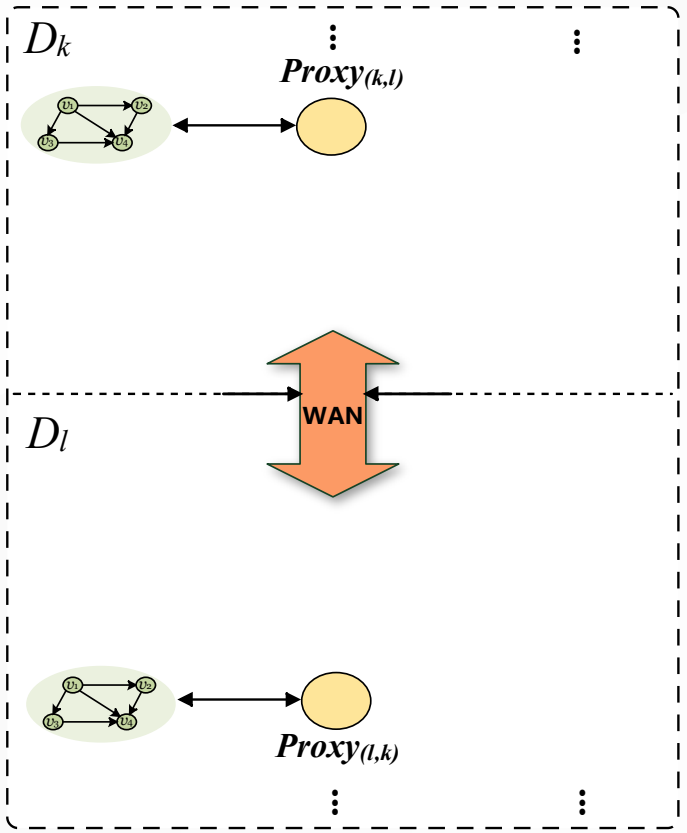
(C2) $\mathcal{I}(\mathcal{A}(X \cup Y)) = \mathcal{A}(\mathcal{I}(X) \cup \mathcal{I}(Y))$



[1] Marc Shapiro, Nuno Preguiça, Carlos Baquero, and Marek Zawirski. 2011. Conflict-free replicated data types. In SSS. 386–

Two Runtime Optimization

1 Adaptive hierarchical interaction engine

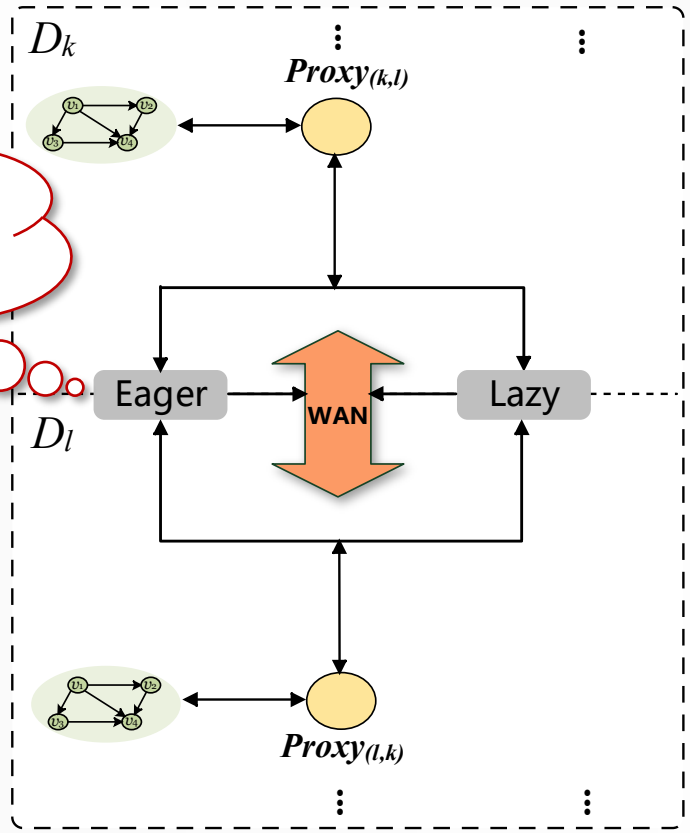


two modes for **heterogeneous networks**

Two Runtime Optimization

1 Adaptive hierarchical interaction engine

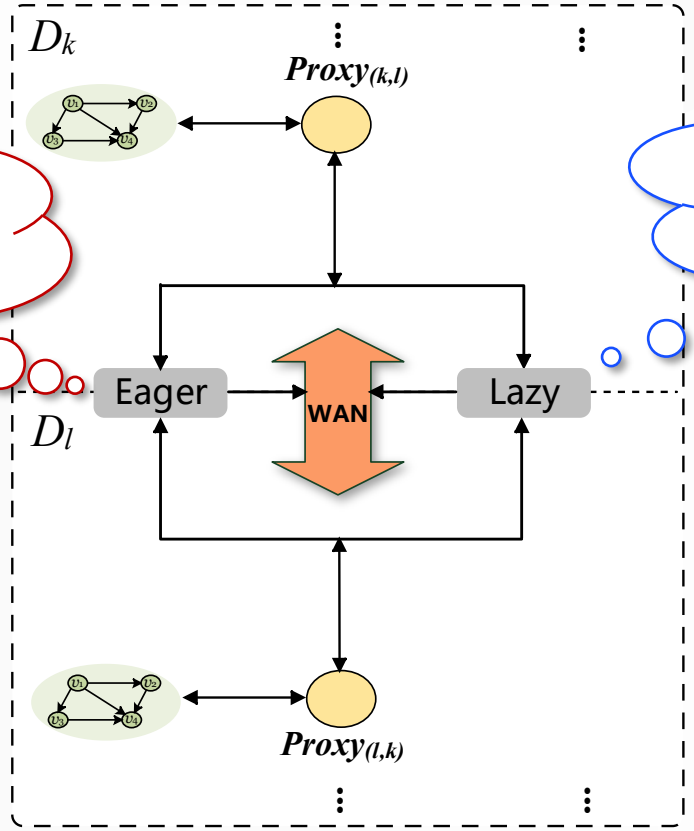
Eager mode for **timely messages** whenever possible.



two modes for **heterogeneous networks**

Two Runtime Optimization

1 Adaptive hierarchical interaction engine



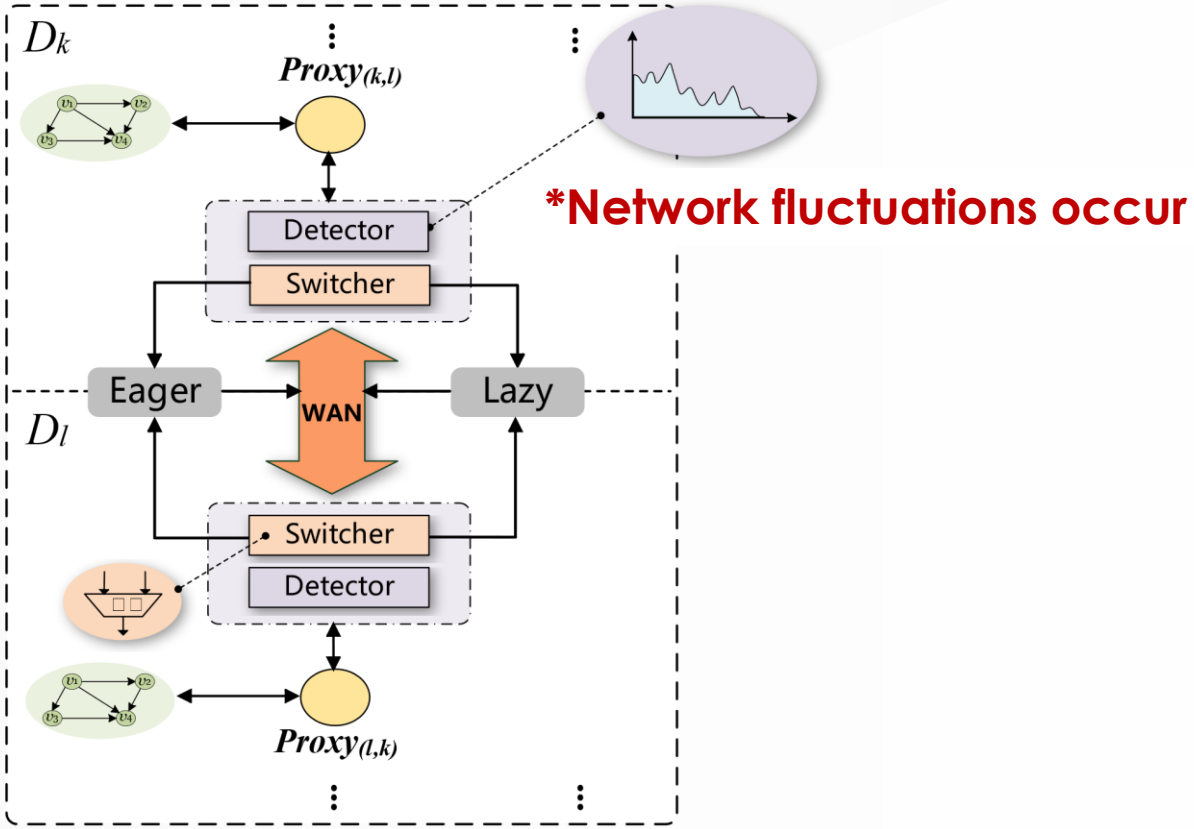
Eager mode for **timely messages** whenever possible.

lazy mode **fetches significant messages** only when necessary.

two modes for **heterogeneous networks**

Two Runtime Optimization

1 Adaptive hierarchical interaction engine

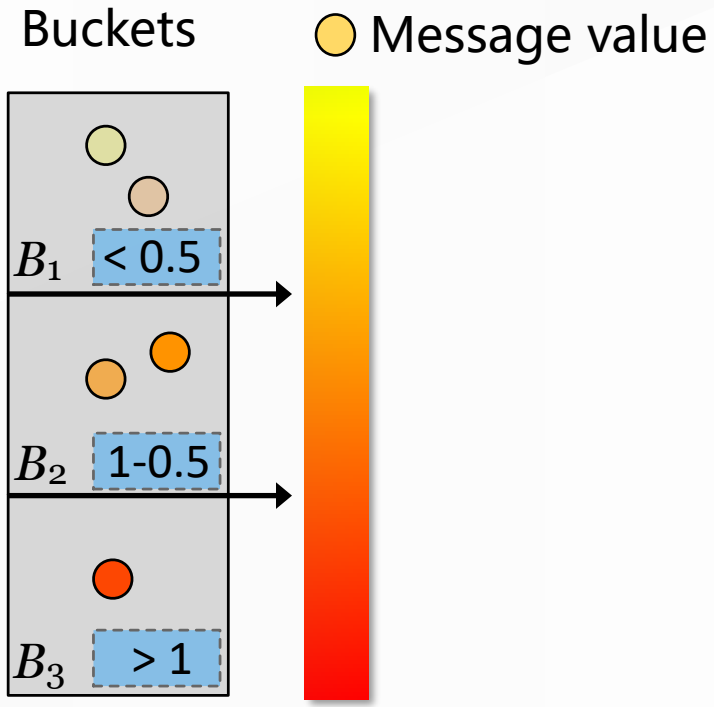


*Network fluctuations occur

proxy **dynamically switches** between the two modes

Two Runtime Optimization

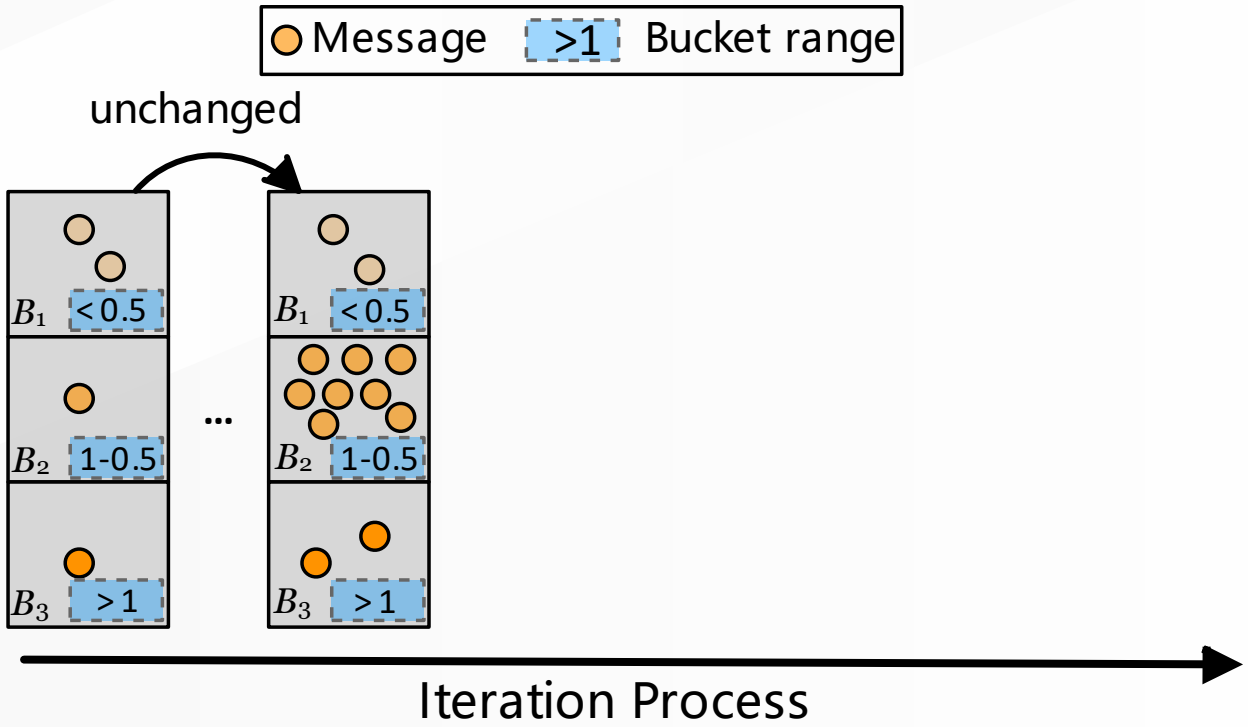
2 Adaptive buckets for message filtering



Messages **fall into different buckets** according to their values

Two Runtime Optimization

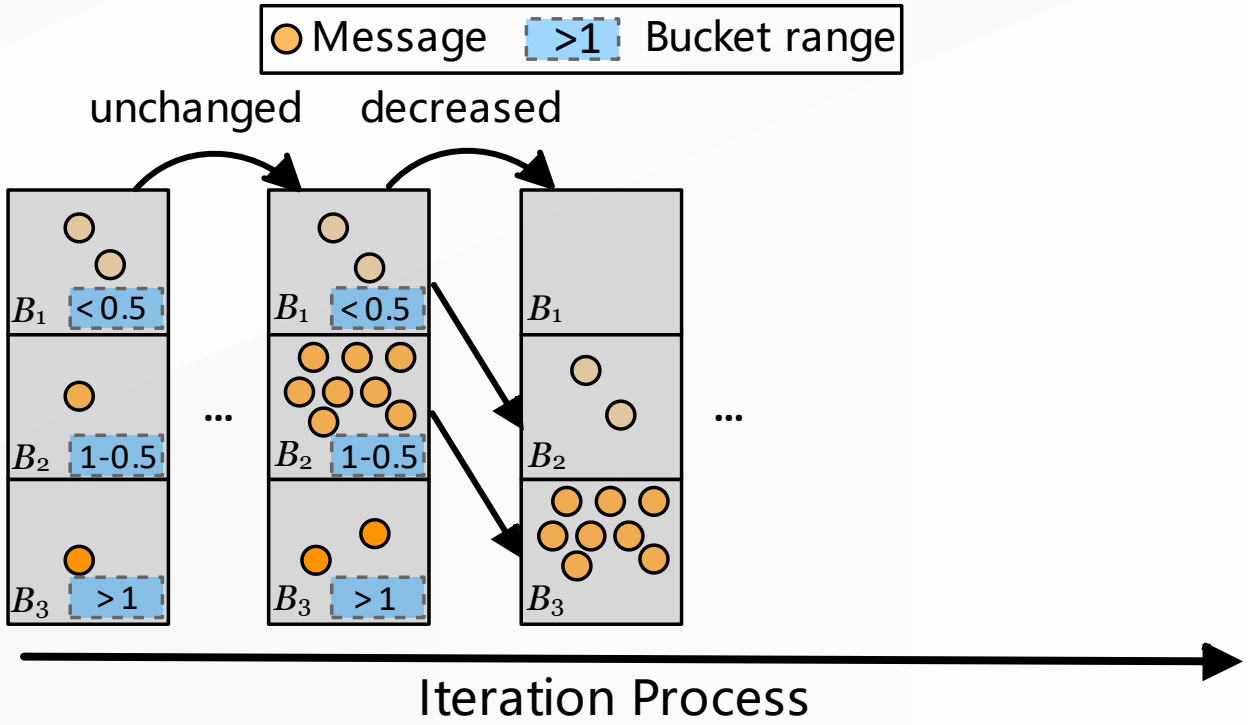
2 Adaptive buckets for message filtering



Dynamically change the range of buckets as the iterative progresses

Two Runtime Optimization

2 Adaptive buckets for message filtering



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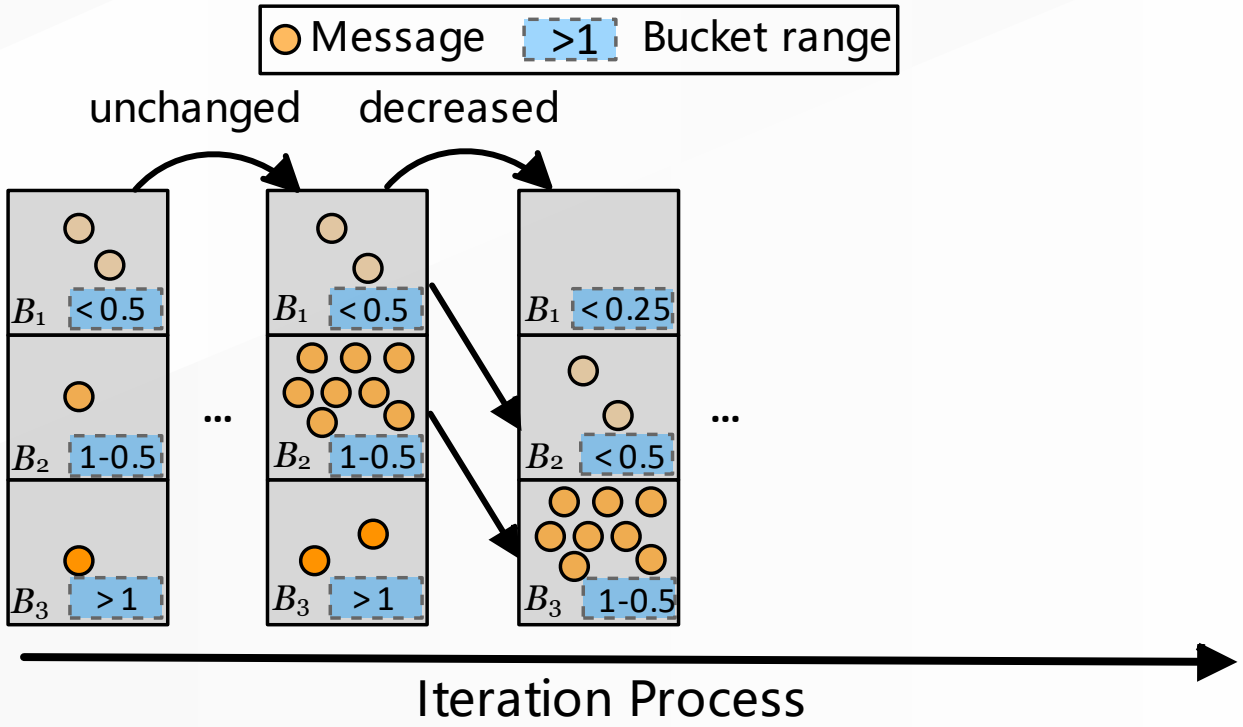

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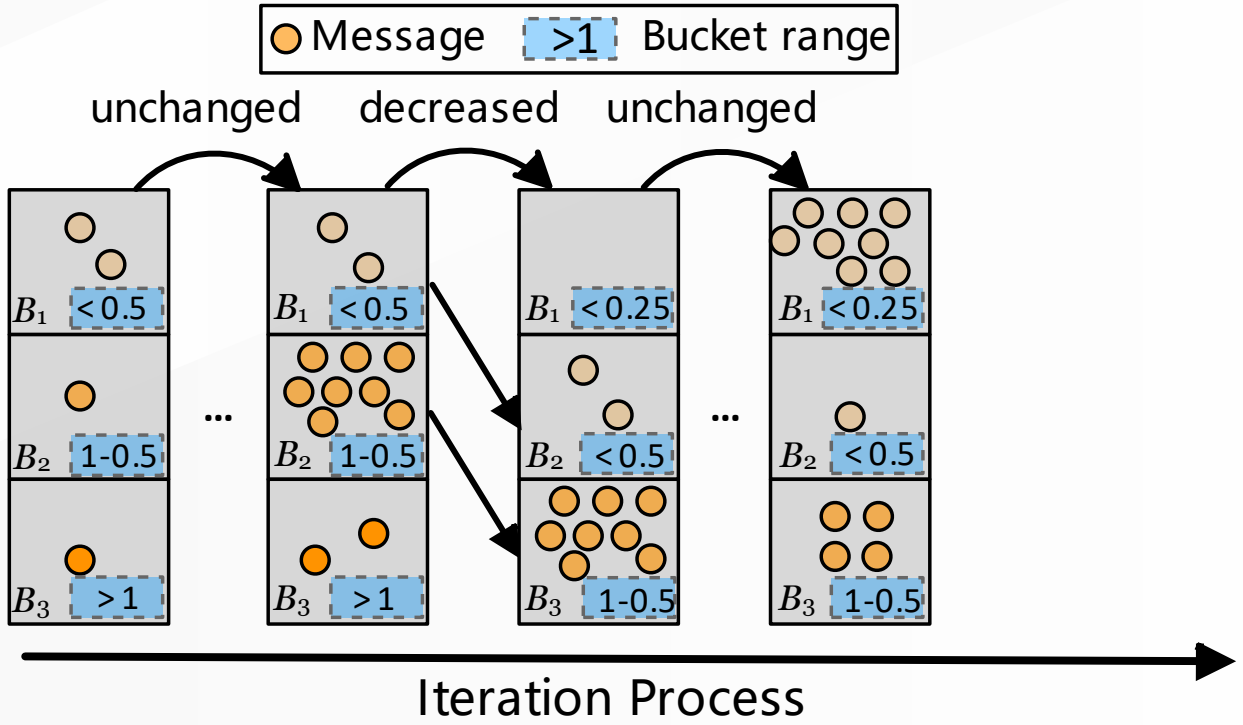

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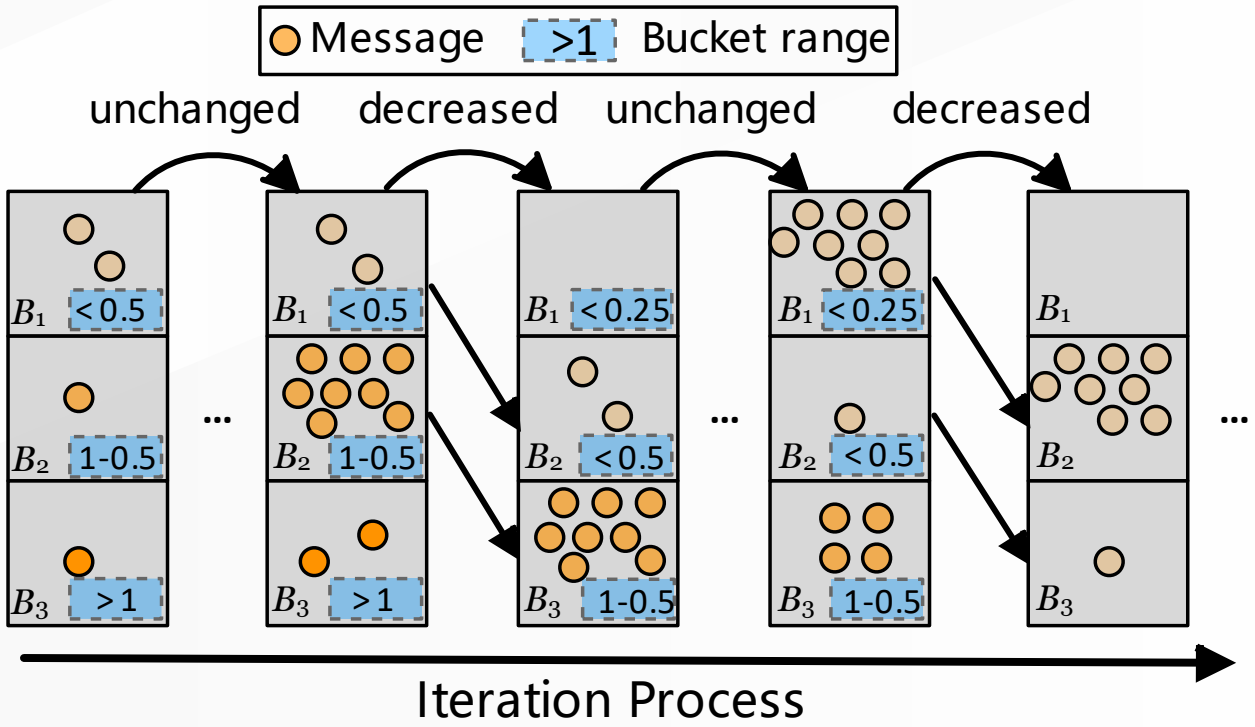

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Two Runtime Optimization

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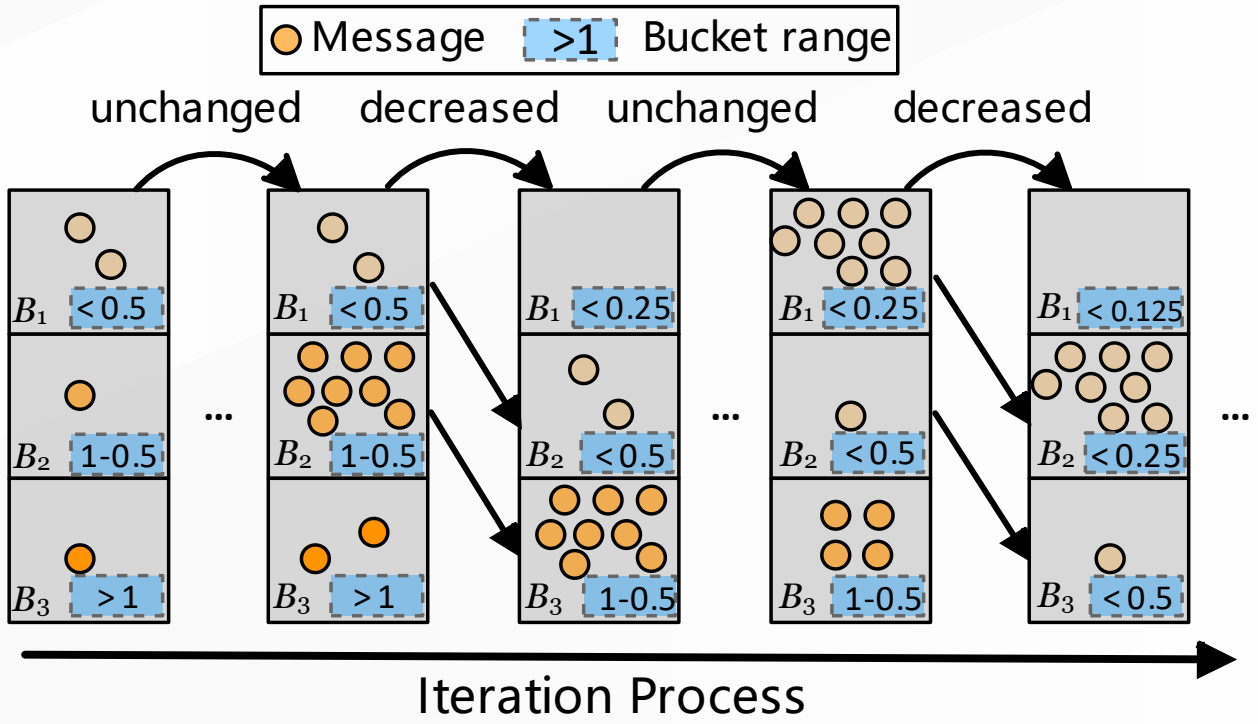


Dynamically change the range of buckets as the iterative progresses

Experiments

- Competitors

  GRAPE, Monarch, GeoGraph,

- Workloads

  PageRank, SSSP, BFS, PHP

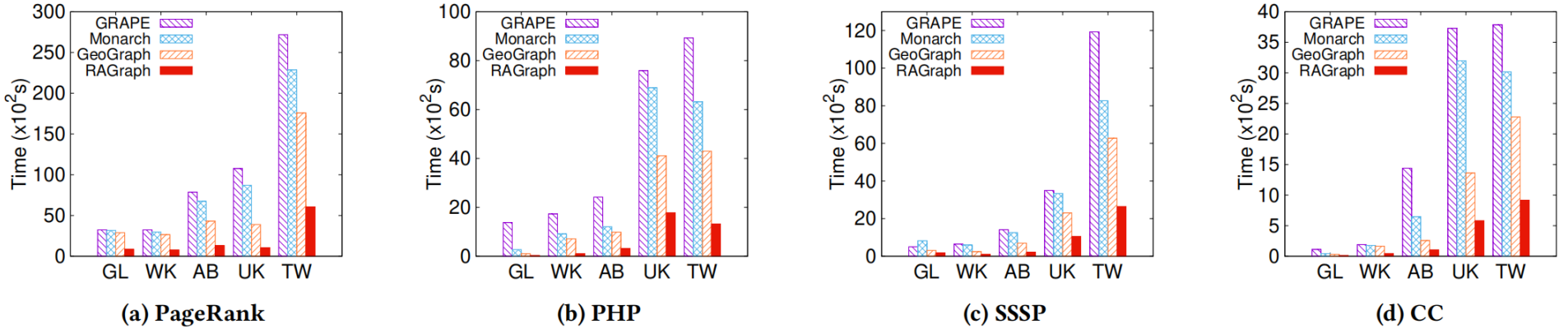
- Environment

  AliCloud ECS clusters from five regions are chosen as geo-distributed data centers, including Qingdao, China; Singapore; Sydney, Australia; Frankfurt, Germany; Virginia, USA.

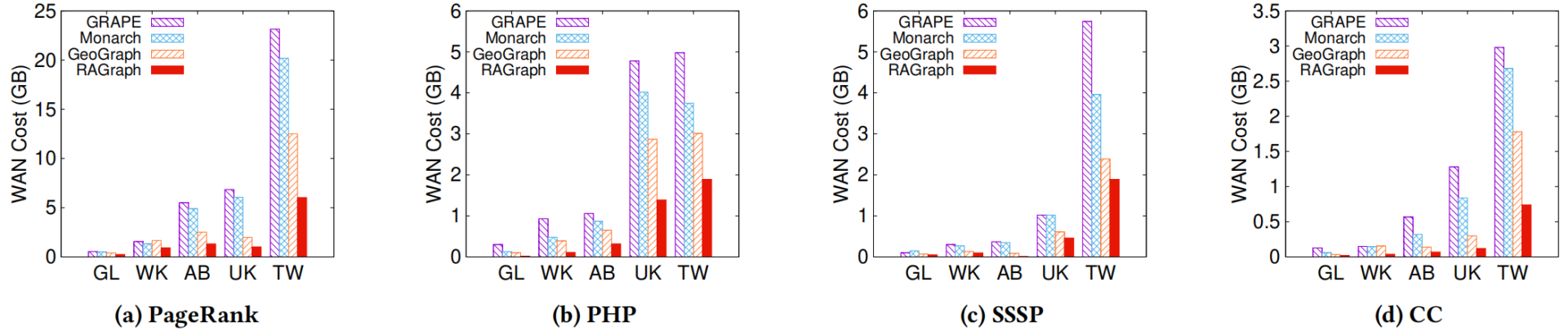
- Datasets

Graph	Vertices	Edges	Abbreviation
Web-Google [1]	916,428	6,078,250	GL
Enwiki-2013 [13]	4,203,323	101,311,614	WK
Arabic-2005 [2]	22,744,080	639,999,458	AB
UK-2005 [3]	39,459,925	936,364,282	UK
Twitter-2010 [12]	41,652,230	1,468,364,884	TW

Overall performance



Running time comparison.



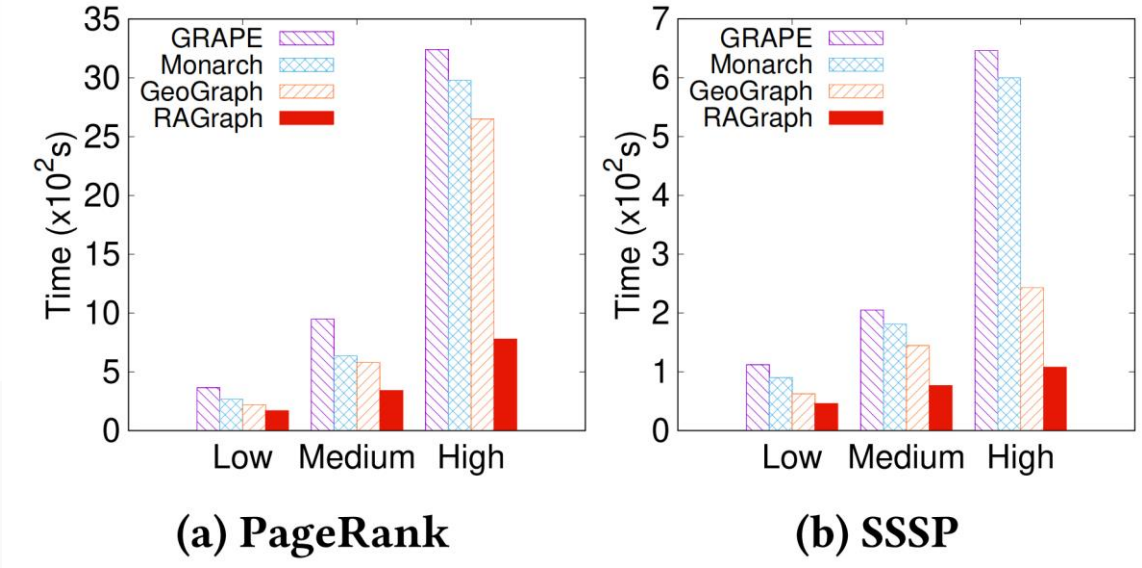
WAN cost comparison.

Achieve a **1.69x - 40.53x** speedup and a **20.9% - 97%** reduction in WAN cost

VLDB2024
GUANGZHOU

Sensitivity to Network Heterogeneity

We use different data center locations around the world to build low/medium/high-heterogeneity networks

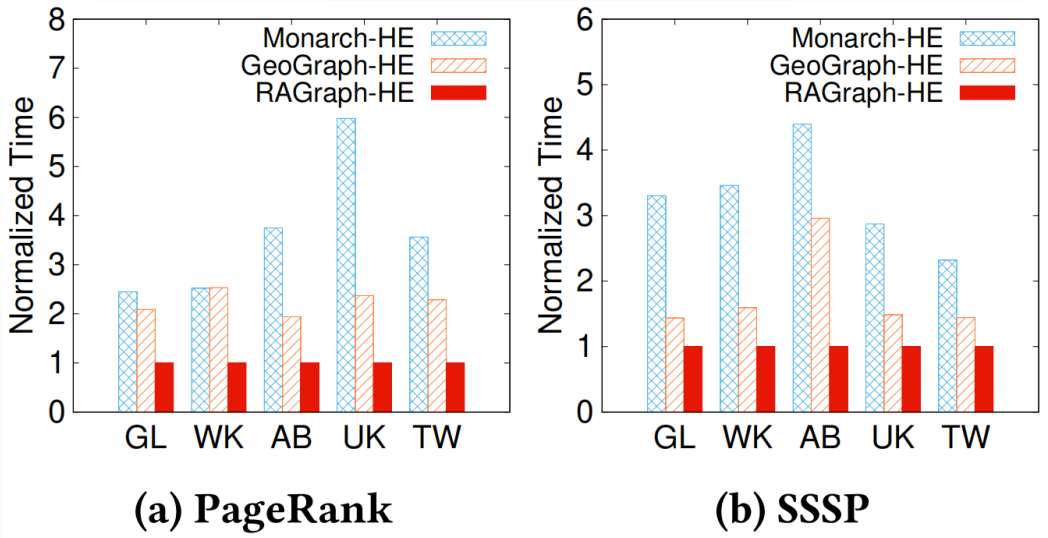


Sensitivity to network status.

RAGraph shows substantial superiority on the high-heterogeneity network.

Performance on Homomorphic Encryption

RAGraph provides homomorphic encryption (HE) interfaces to protect the users' data from other parties.



Performance on HE.

RAGraph requires a shorter running time on the HE module

Summary

RAGraph: A Region-Aware Framework for Geo-Distributed Graph Processing.

- **Providing three observations under geo-distributed environments.**

  We (1) allow advancing inefficient global updates to local computation, (2) design a two-layer coordination-free interaction view to, and (3) mitigates the impact of network congestion by replacing communication roles.

Summary

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  We conduct an adaptive hierarchical interaction engine to adapt to heterogeneous networks and a discrepancy-aware message filtering strategy to dynamically filter unimportant messages.

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- **Proposing two runtime optimizations.**

  We conduct an adaptive hierarchical interaction engine to adapt to heterogeneous networks and a discrepancy-aware message filtering strategy to dynamically filter unimportant messages.

- **Delivering a fast Geo-Distributed Graph Processing system**

  We design and implement RAGraph, a region-aware geo-distributed graph processing system that achieves 1.69x – 40.53x speedup and 20.9% - 97% WAN cost reduction.

  - **The codes are publicly available on github**

    https://www.github.com/farisyao/RAGraph.

Thank you for listening!