Gaia: Geo-Distributed Machine Learning Approaching LAN Speeds

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[NSDI'17]

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Machine Learning and Big Data

- Machine learning is widely used to derive useful information from large-scale data

Big Data is Geo-Distributed

- A large amount of data is generated rapidly, all over the world
- Virginia, Ohio, California, Oregon, Mumbai, Seoul, Singapore, Sydney, Tokyo, Central Canada, Beijing, Frankfurt, Ireland, London, Sao Paulo…

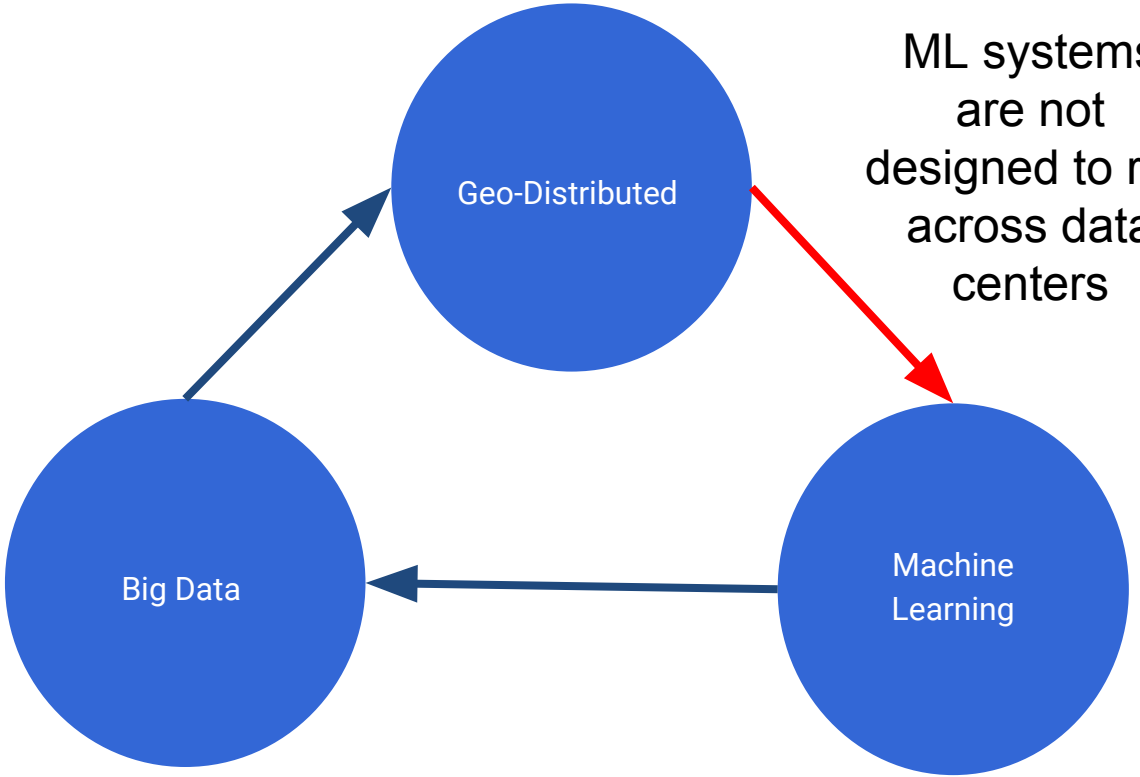
Big Data is Geo-Distributed

Centralizing Data is Infeasible

- Moving data over wide-area networks can be extremely slow
- It is also subject to data sovereignty laws

1. Vulimiri et al., NSDI'15
2. Pu et al., SIGCOMM'15
3. Viswanathan et al., OSDI'16

Central Problem

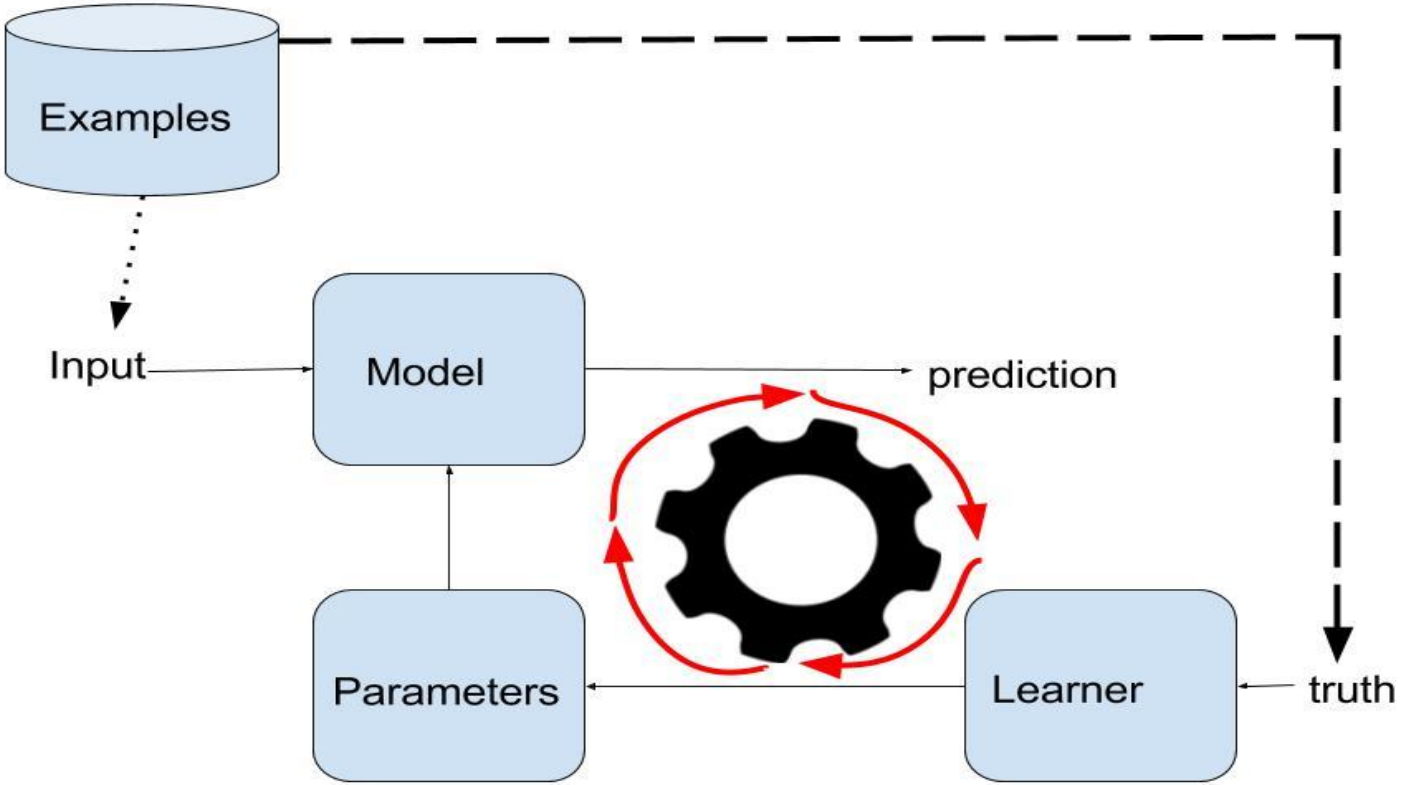


ML systems are not designed to run across data centers

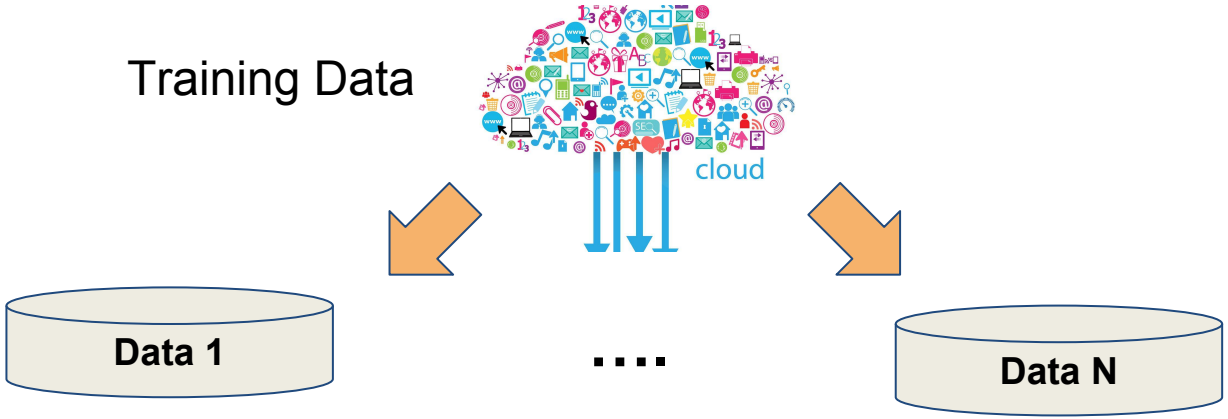
Gaia

- A geo-distributed ML system
- Goals
  - Minimize communication over WAN
  - Retain accuracy and correctness of ML algorithms
  - No changes to current algorithms

Who Does What?



Parameter Server Architecture



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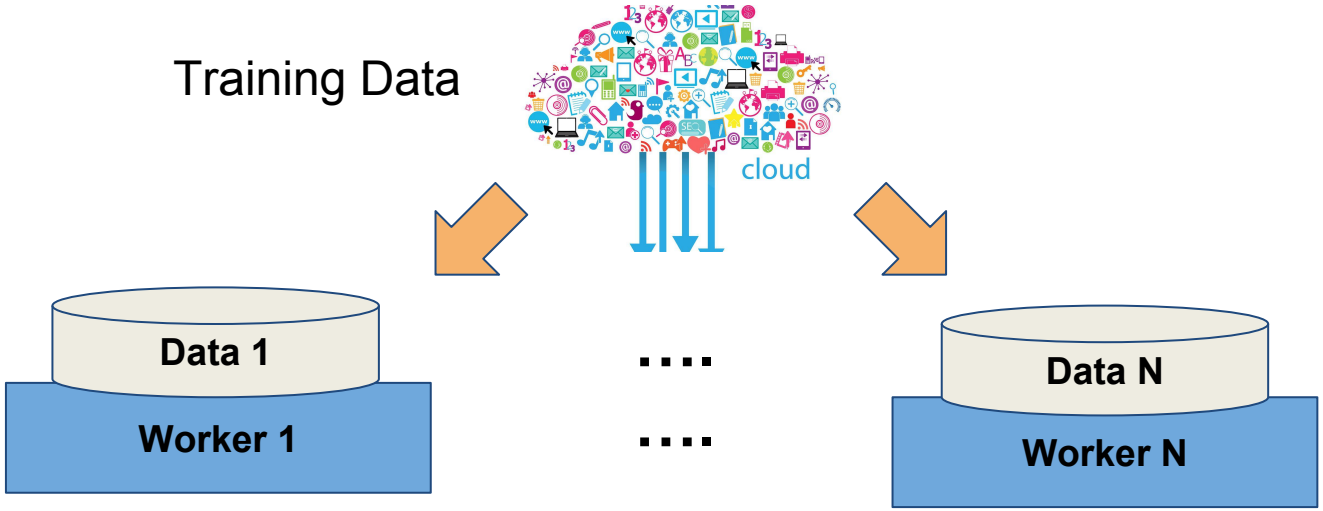

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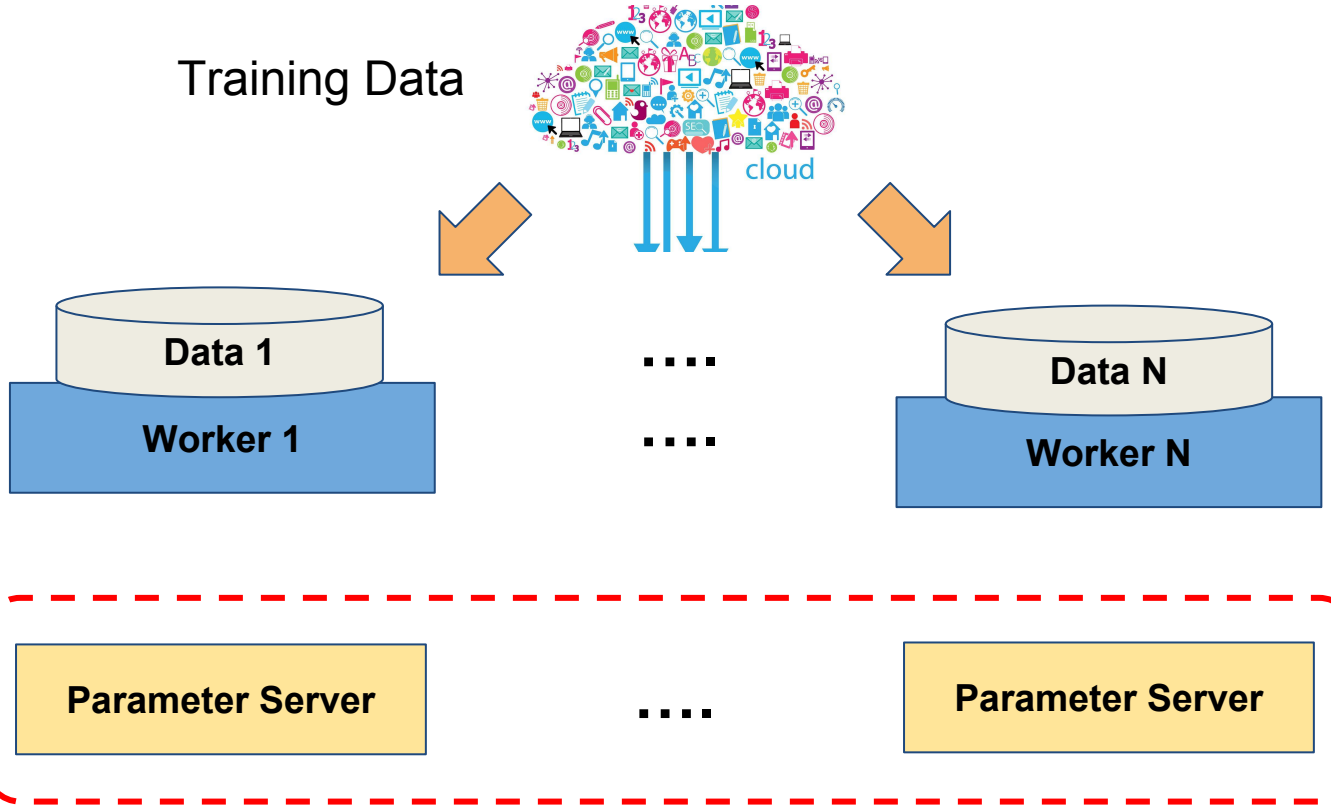

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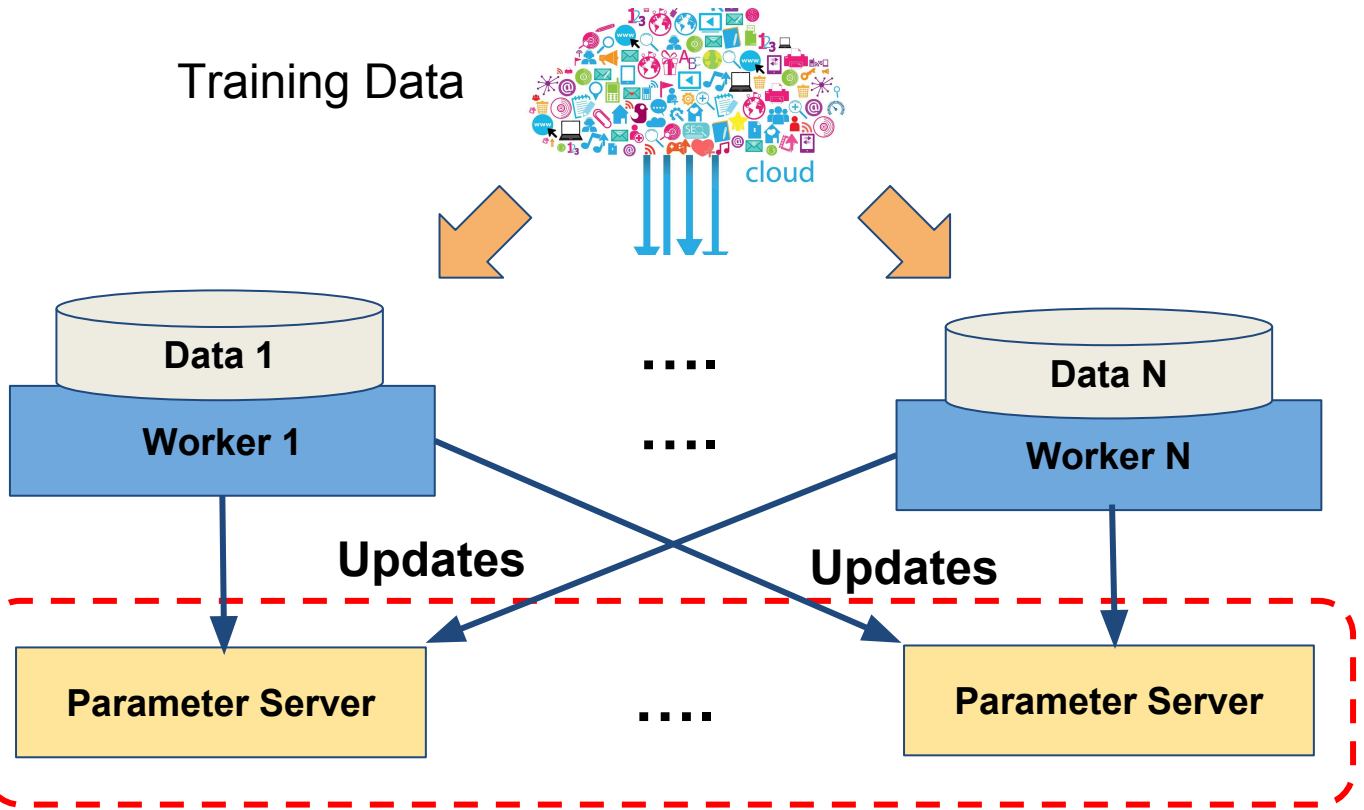

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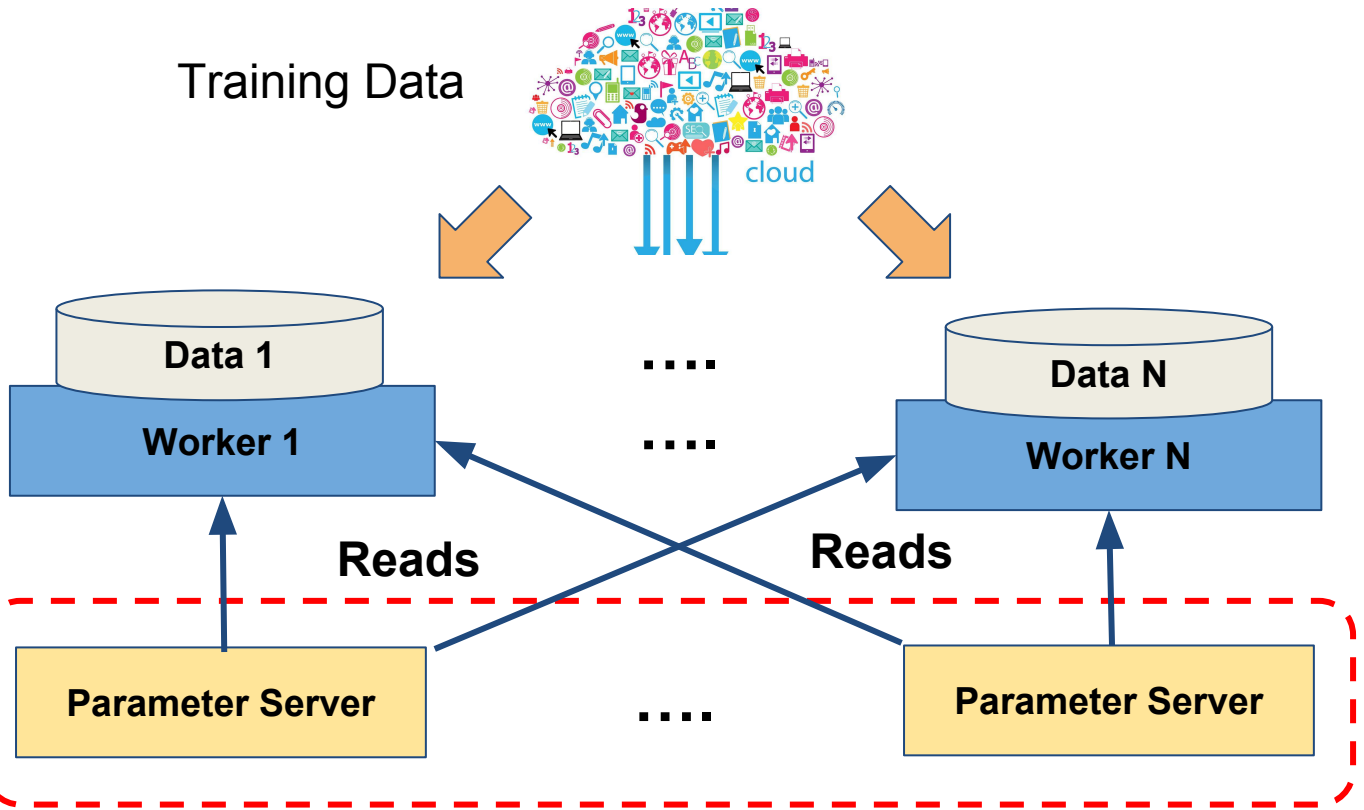
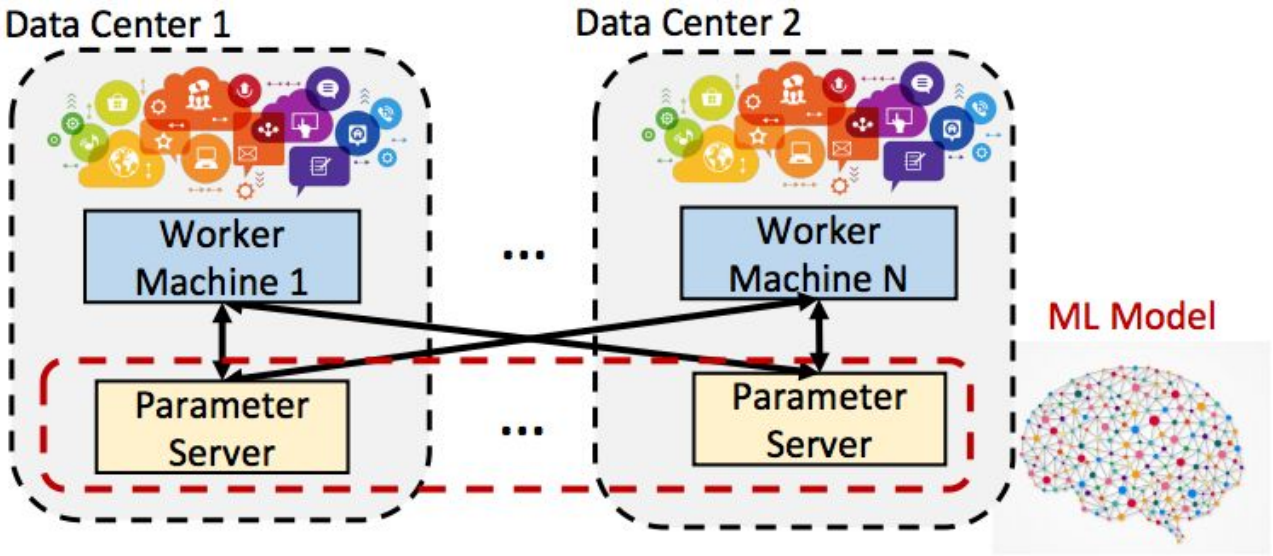


Parameter Servers on WANs

- Synchronization requires lots of communication over WAN



Slide from Kevin Hsieh, NSDI 17

WAN: Low Bandwidth and High Cost

- WAN bandwidth is 15X smaller than LAN bandwidth on average, and up to **60X** smaller!
- In Amazon EC2, the monetary cost of WAN communication is up to 38X the cost of renting machines

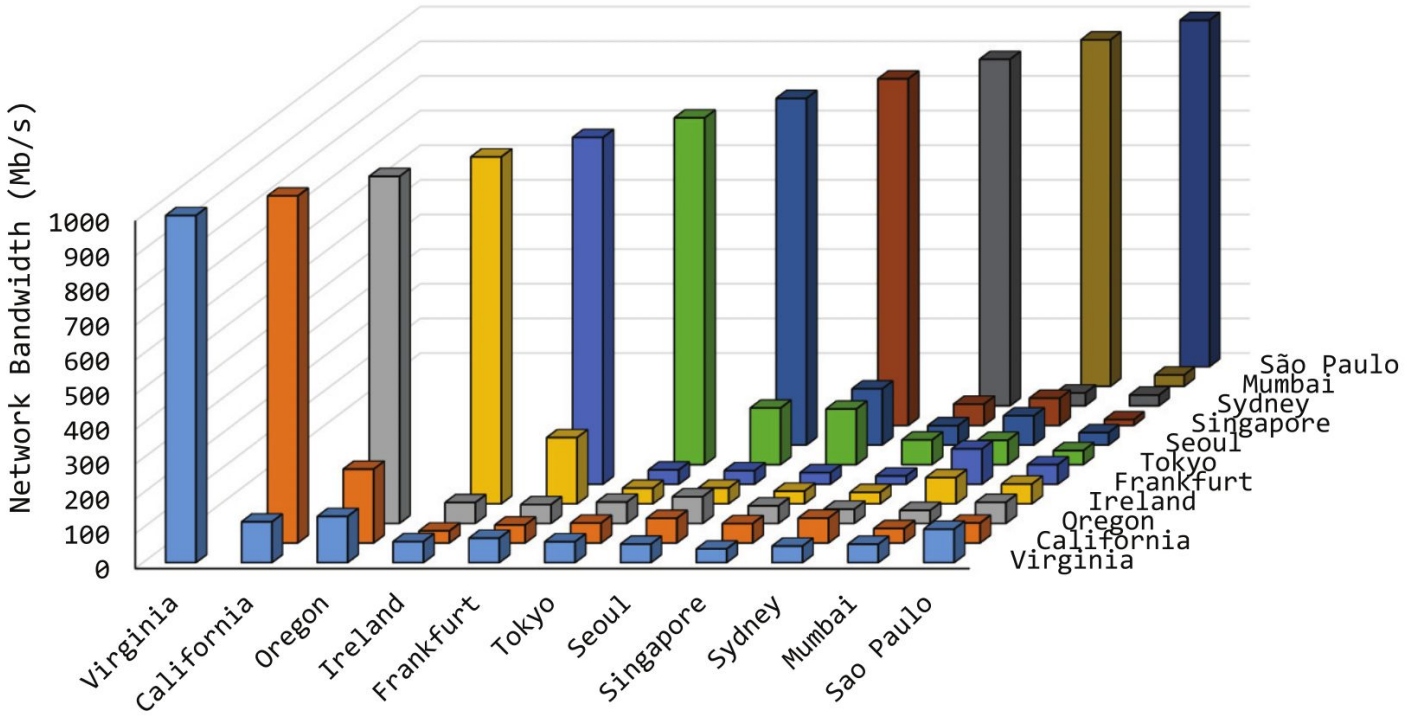
Slide adapted from Kevin Hsieh, NSDI 17

WAN: Low Bandwidth and High Cost

- WAN bandwidth is 15X smaller than LAN bandwidth on average, and up to **60X** smaller!
- In Amazon EC2, the monetary cost of WAN communication is up to 38X the cost of renting machines
  - How did they get this number?

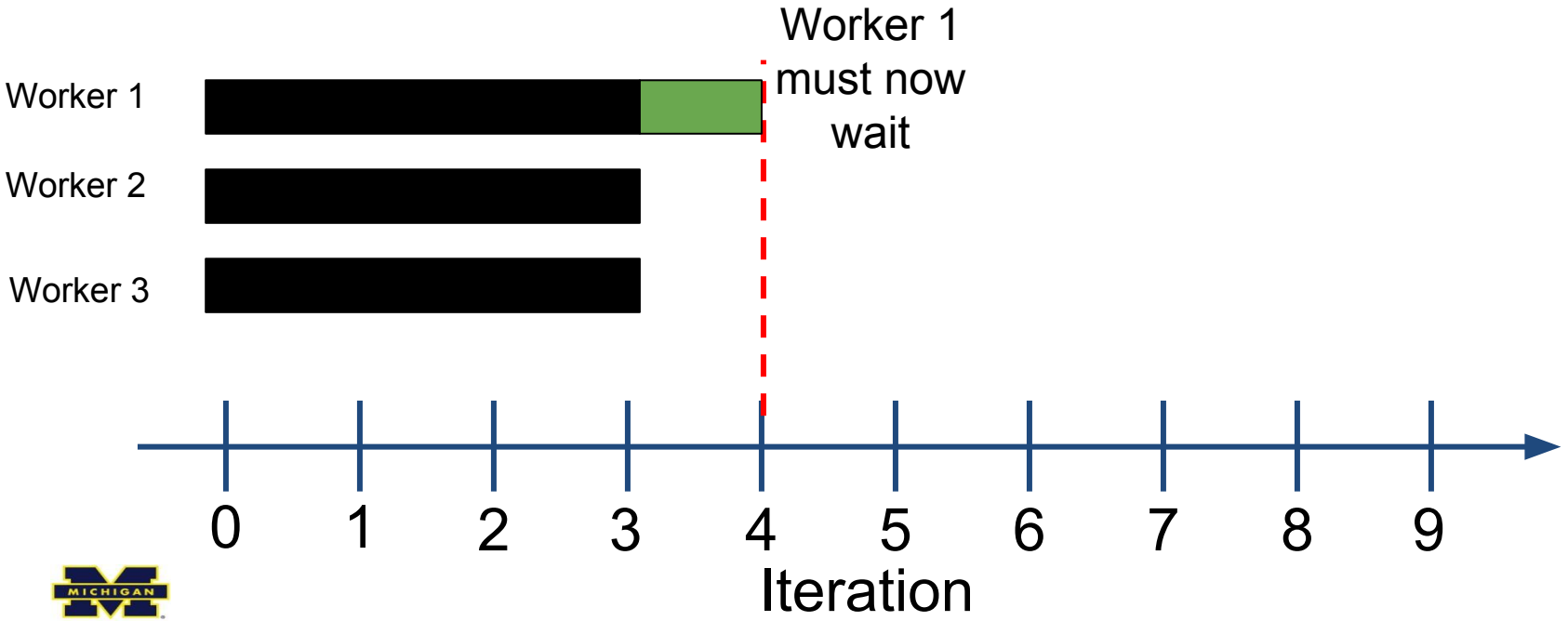
Slide adapted from Kevin Hsieh, NSDI 17

WAN: Low Bandwidth



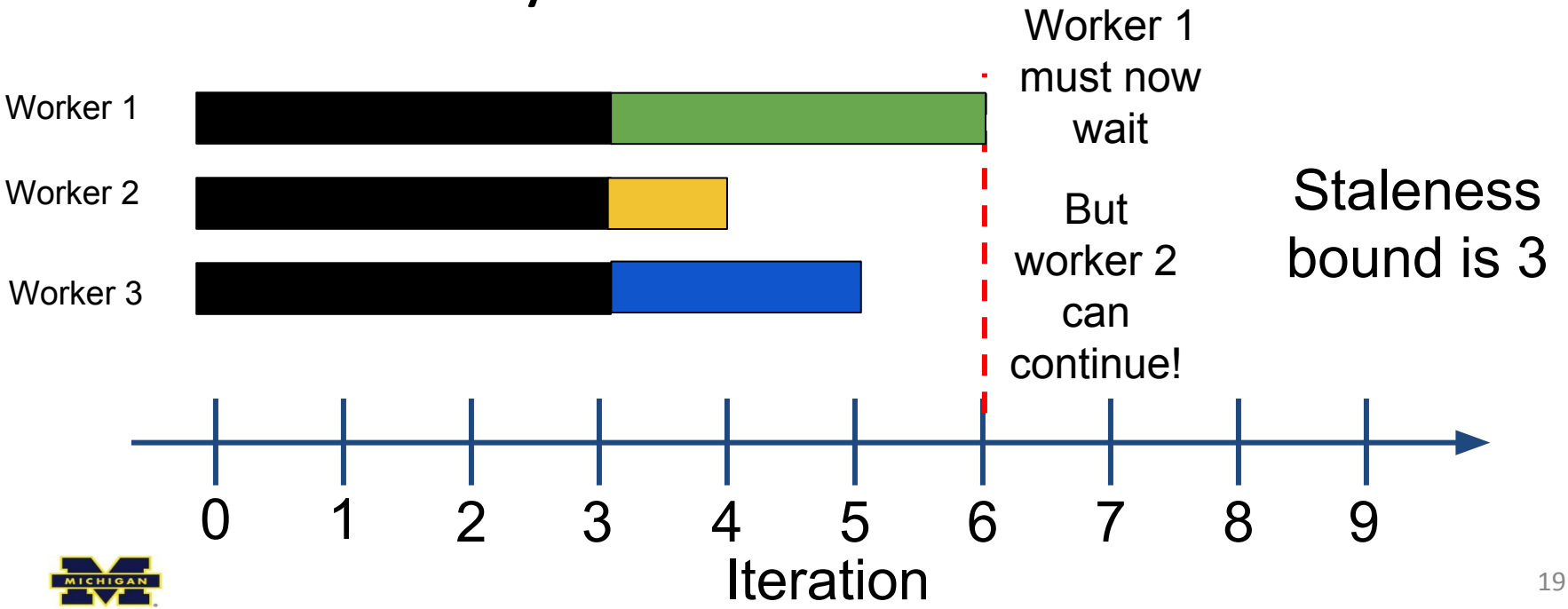
Previous Synchronization Algorithms

- BSP - Bulk Synchronous Parallel



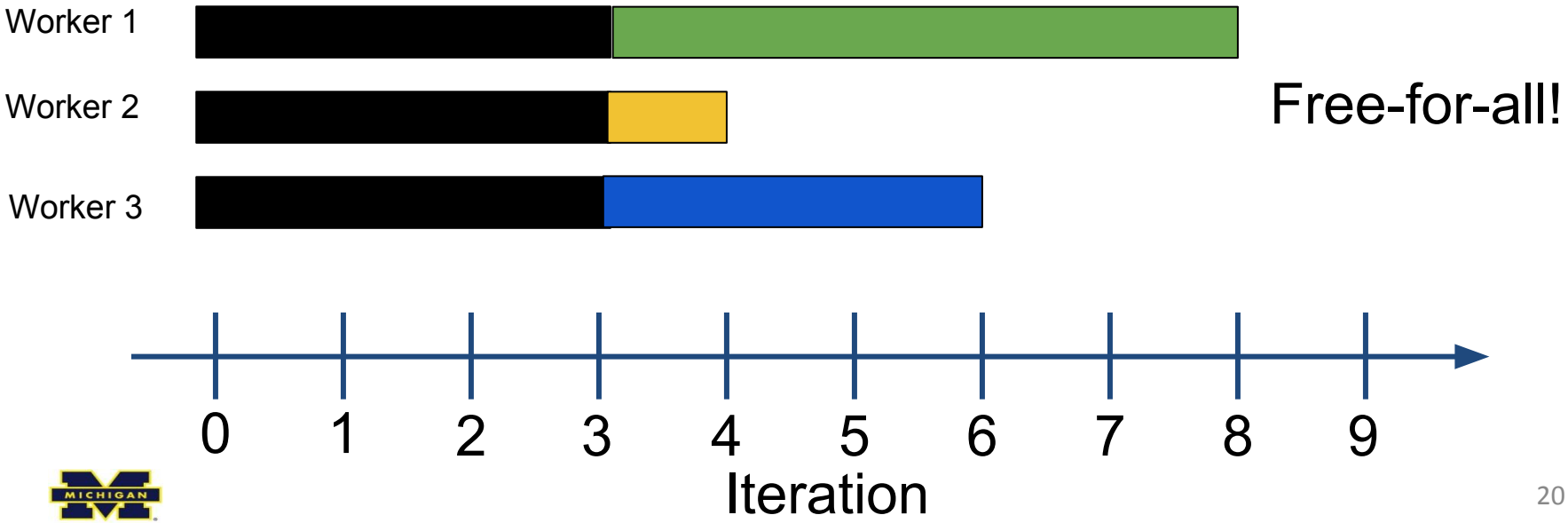
Previous Synchronization Algorithms

- SSP - Stale Synchronous Parallel

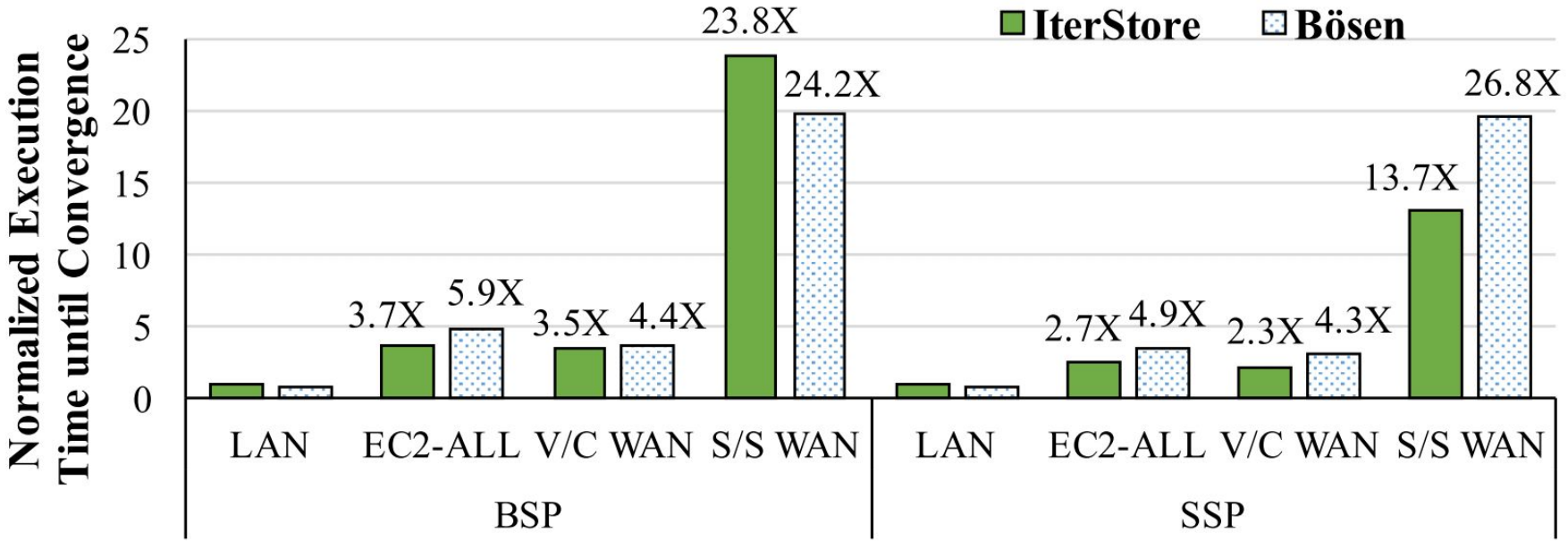


Previous Synchronization Algorithms

- TAP - Total Asynchronous Parallel



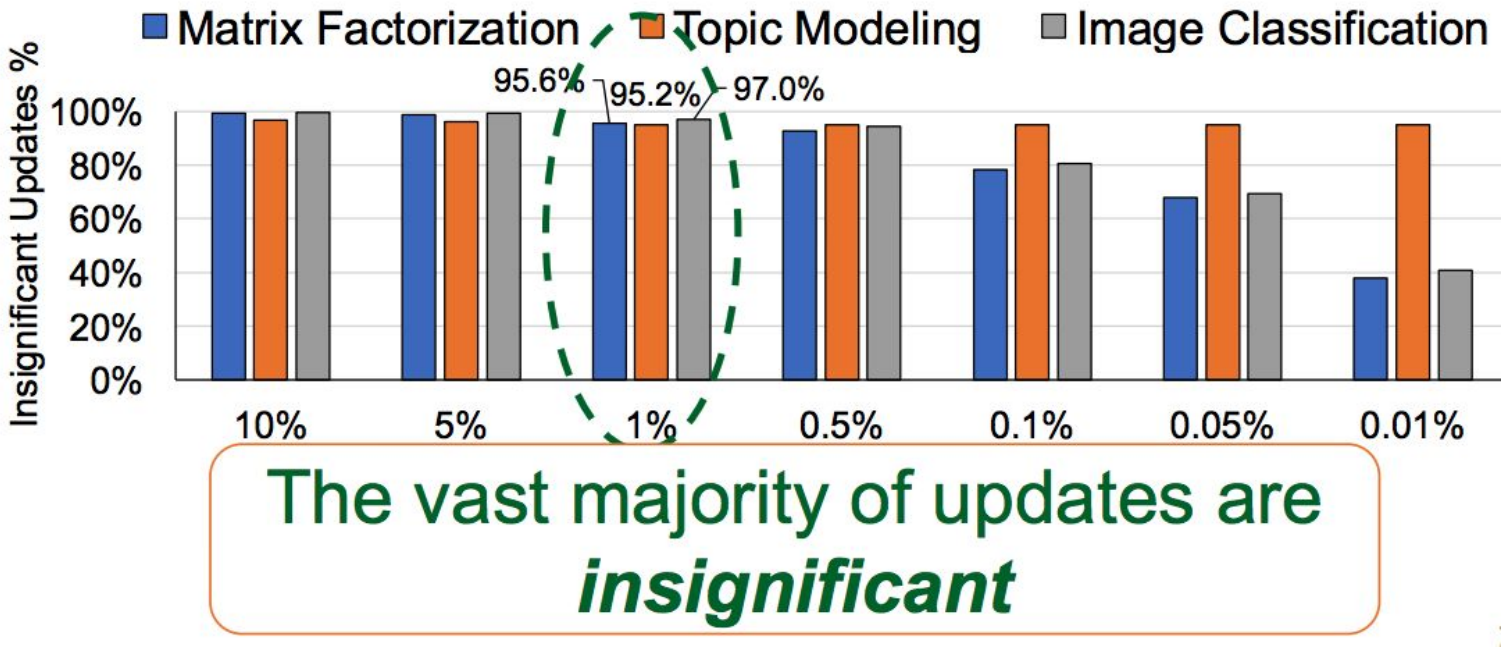
ML System Performance on WANs



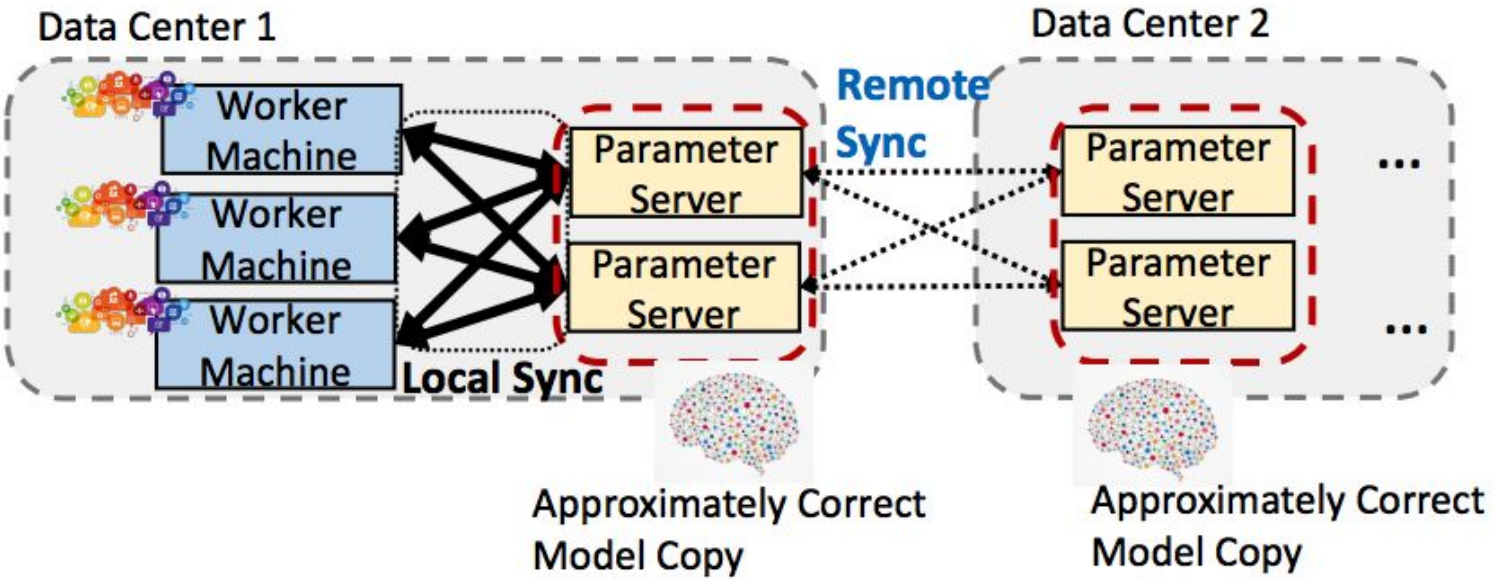
Gaia System Overview

Key Idea: Decouple the synchronisation model between the data centers from the synchronisation model within a data center.

Key Finding: Study of update significance



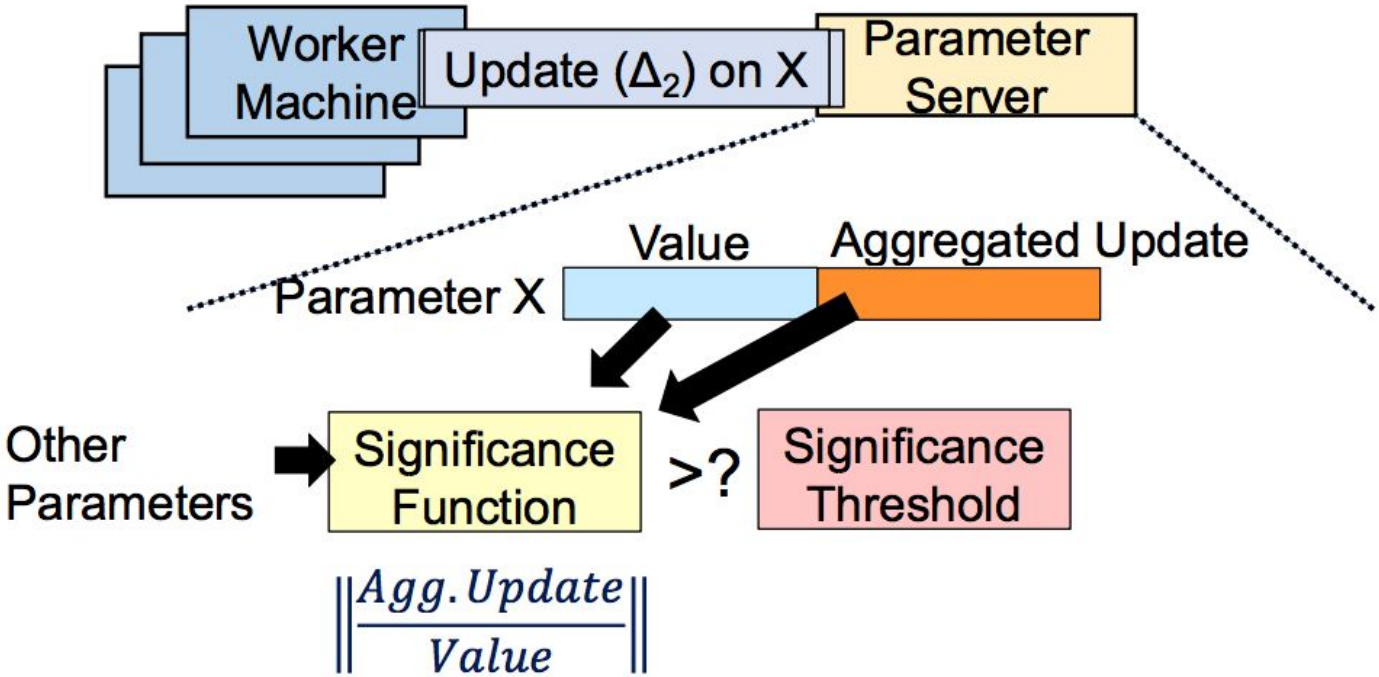
Gaia Synchronization



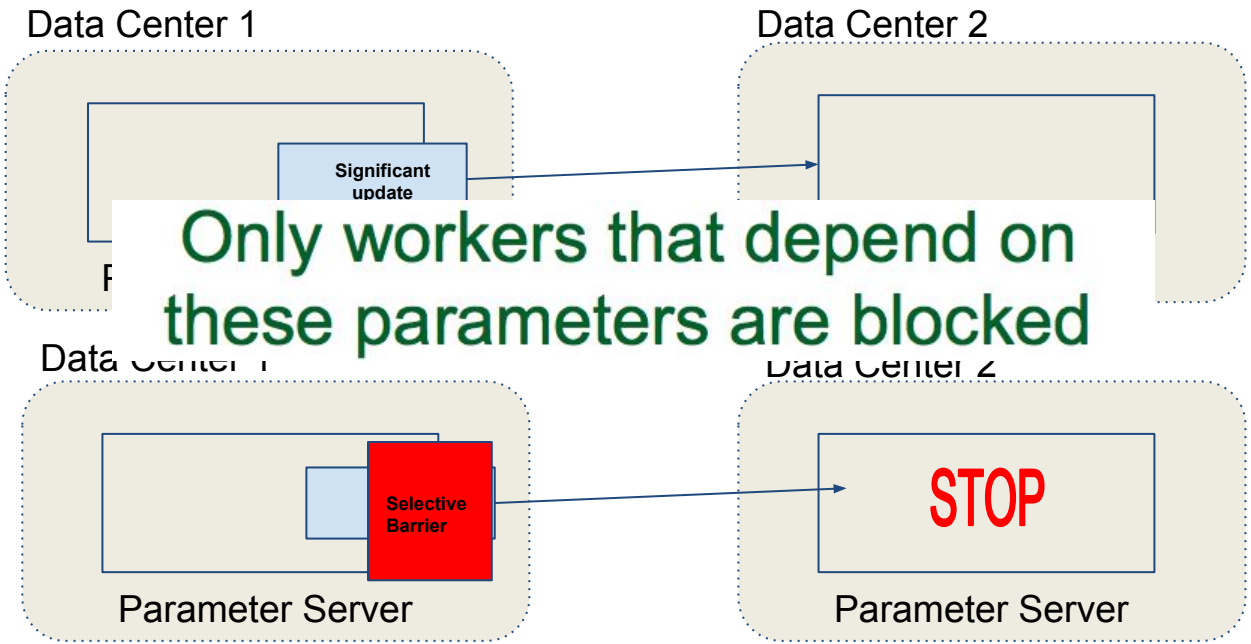
Approximate Synchronous Parallel

- The significance filter
  - Filter updates based on their significance
- ASP Selective barrier
  - Ensure significant updates are read in time
- Mirror clock
  - Safeguard for pathological cases

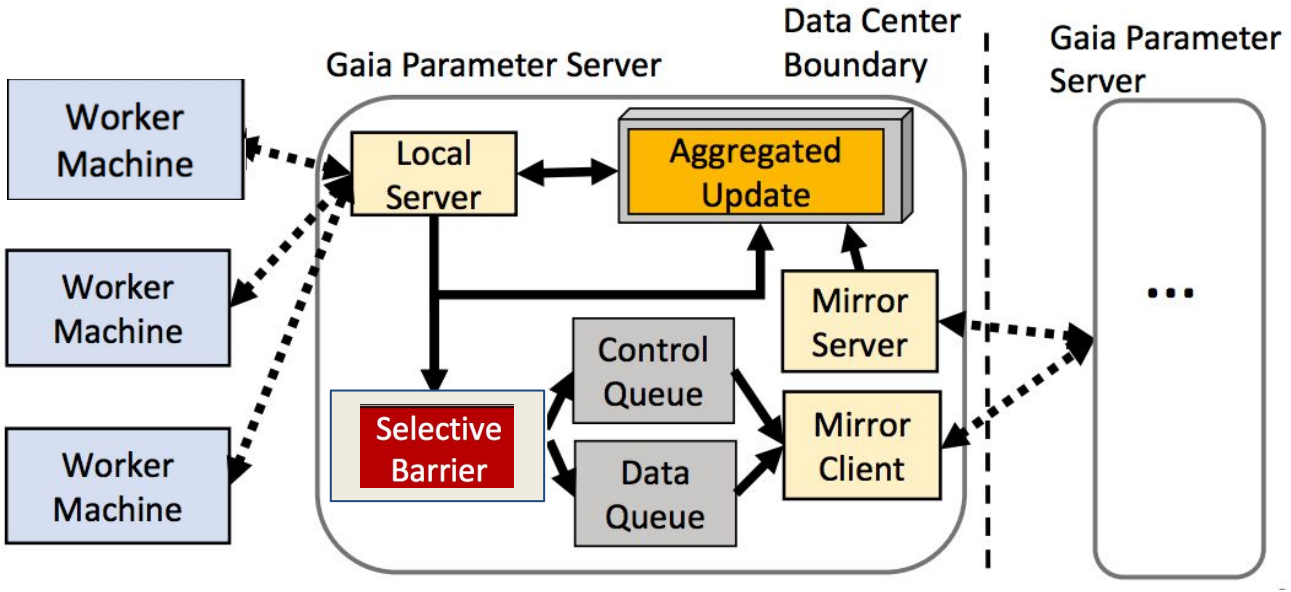
The Significance Filter



ASP Selective Barrier



System Implementation: Putting it all together



Problem: Broadcast Significant updates

Communication overhead is proportional to the number of data centers

Mitigation: Overlay Networks and Hubs

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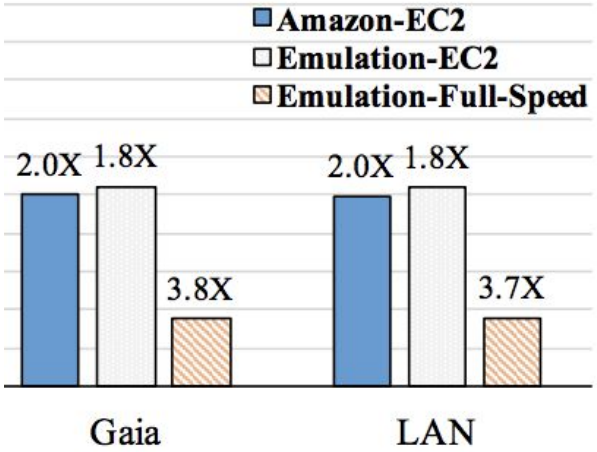
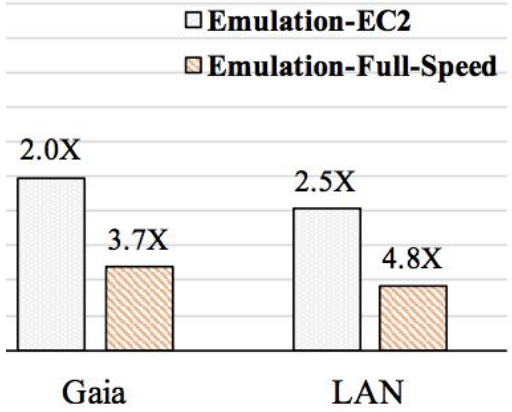
Evaluation: 11 EC2 Data Centers



Matrix Factorization



Topic Modeling

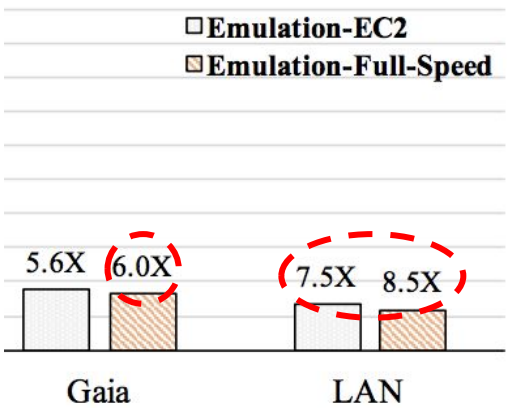
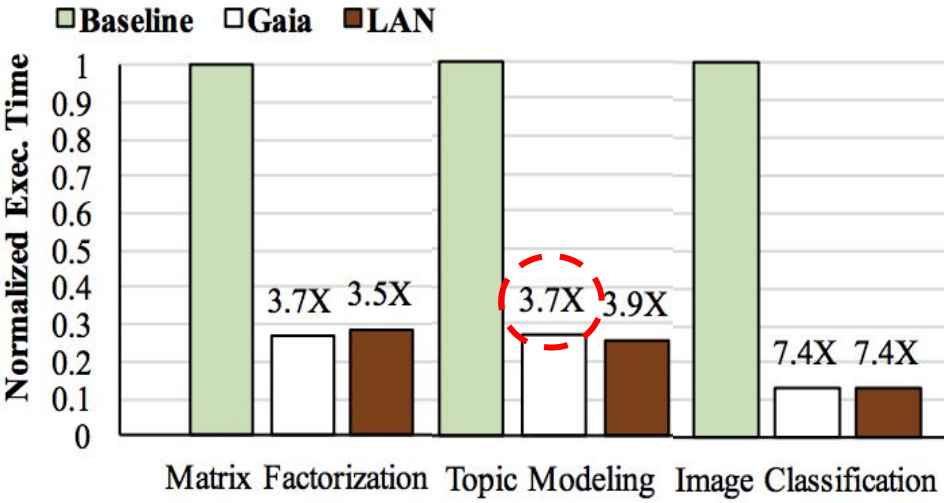
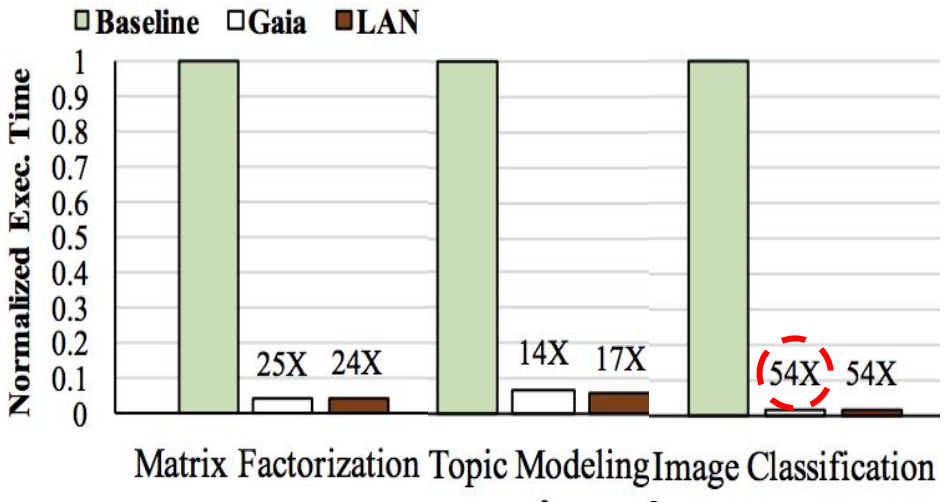


Image Classification

Gaia achieves up to 6x performance!

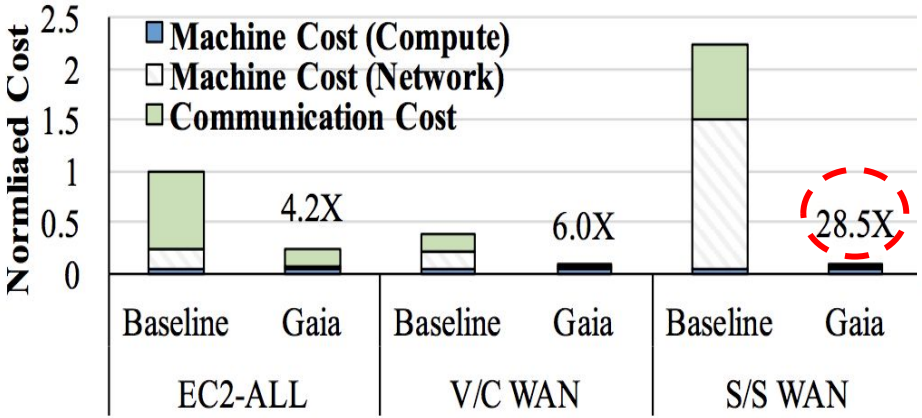
Evaluation contin.



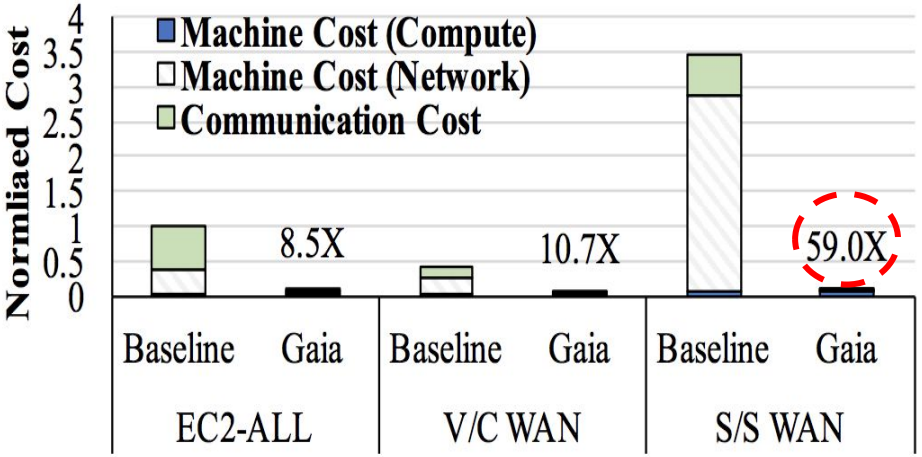


Gaia achieves up to 54x performance!

Evaluation: cost



(a) *Matrix Factorization (MF)*



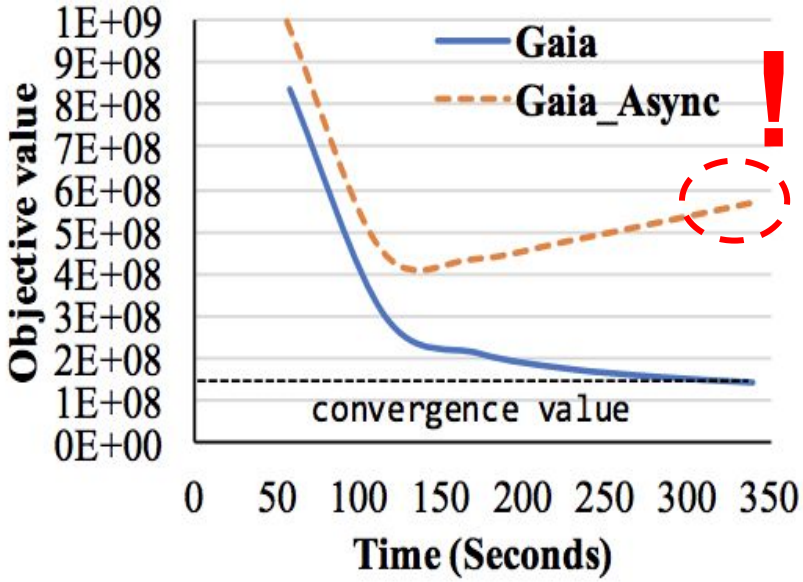
(c) *Image Classification (IC)*

Evaluation: Centralized vs. Gaia

Table 1: Comparison between Gaia and Centralized

Application	Setting	Gaia Speedup over Centralized	Gaia cost / Centralized cost
MF	EC2-ALL	1.11	3.54
	V/C WAN	1.22	1.00
	S/S WAN	2.13	1.17
TM	EC2-ALL	0.80	6.14
	V/C WAN	1.02	1.26
	S/S WAN	1.25	1.92
IC	EC2-ALL	0.76	3.33
	V/C WAN	1.12	1.07
	S/S WAN	1.86	1.08

Evaluation: Synchronization



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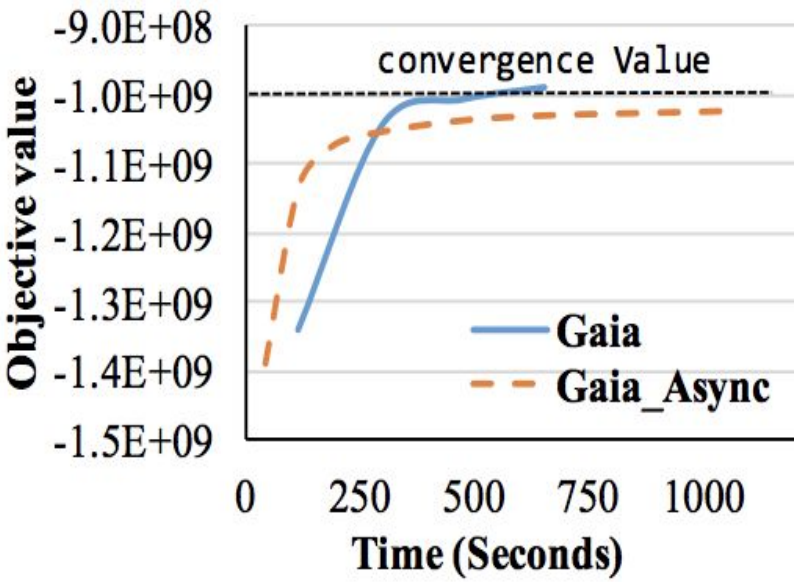

(b) *Topic Modeling (TM)*

Conclusion

Gaia: ML on geo-distributed data

⇒ Eliminate insignificant updates over WANs

⇒ Retain correctness & accuracy of ML algs.

⇒ New Synchronization model: *ASP*

1.8 to 53.5x speedup!

Comparison With Other ML Algorithms

- Apples to oranges comparison
- Works atop current ML algorithms
- Currently supports PS architecture
  - Can be extended to support other ML algorithms (Mapreduce, graph algorithms)

Comparison With Other Geo-Distributed Systems

Thoughts?

Questions