COMPSAC 2016
June 2016

Causal Consistency
for Distributed Data Stores and Applications
as They are

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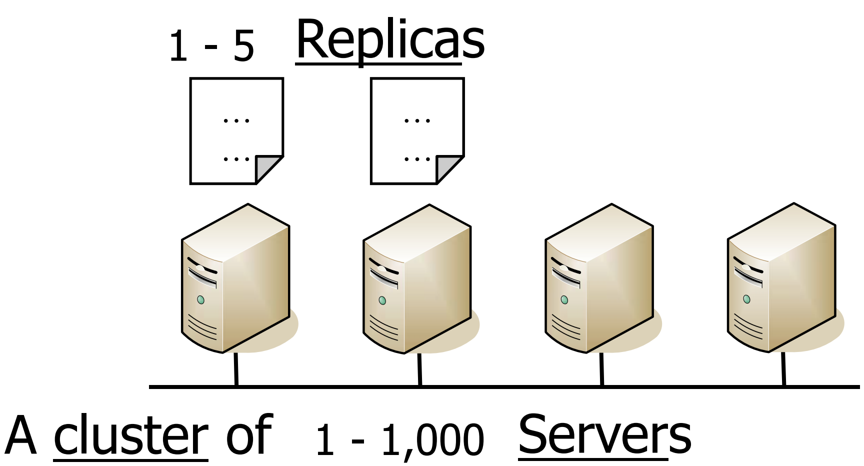
Background:
Distributed data store

- Database management system (DBMS) that consists of multiple servers.
  - For performance, capacity, and fault tolerance
  - Cf. NoSQL
- A data item is replicated.



NoSQL:

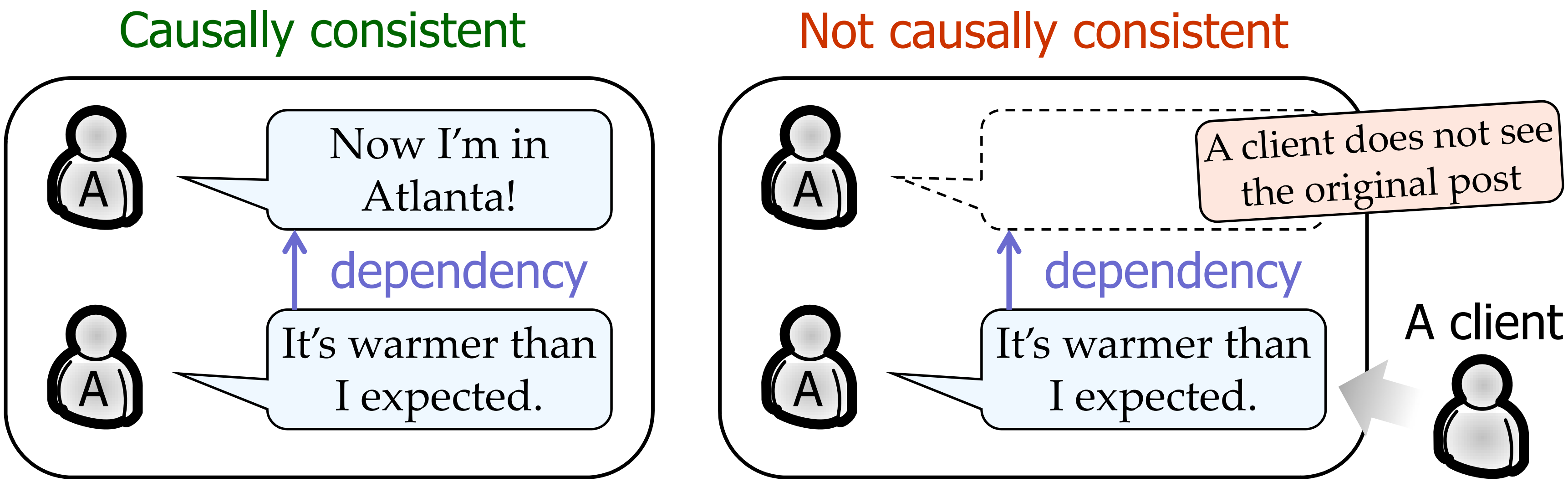
The base of our implementation

Background:
Causal consistency

- One of consistency models.
- A consistency model is a contract between DBMS and a client
  - of what a client observes.
  - It is related to **replicas** closely. If a client see an old replica, …
- Consistency models related to this research:
  - **Eventual** consistency
    - All **replicas** converge to the same value eventually.
    - Most NoSQLs adopt this model.
  - **Causal** consistency
    - All writes and reads of **replicas** obey causality relationships between them.

Background:
Causal consistency

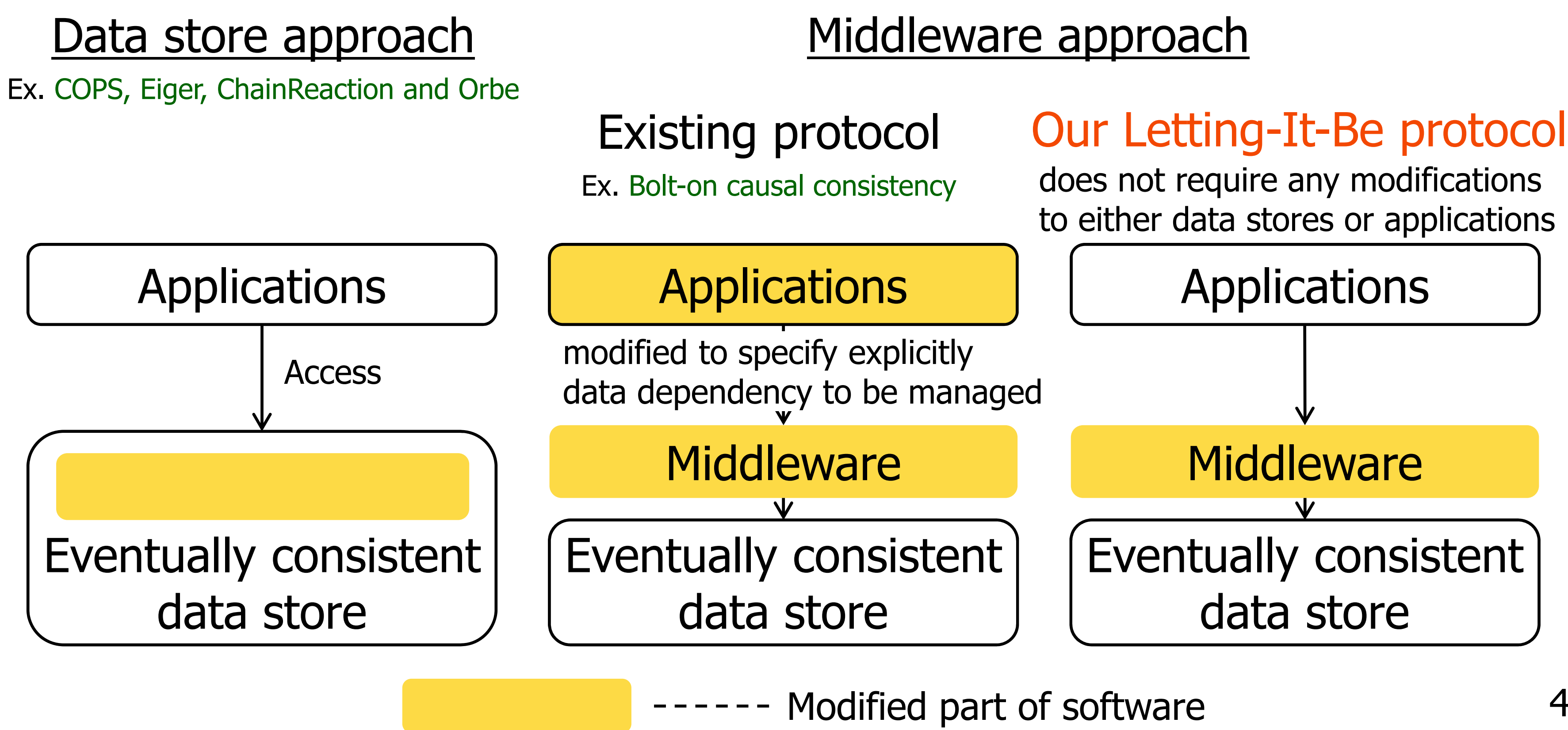
- An example: social networking site



- Precise definition
  - Write after read by the same process (client)
  - Write after write by the same process - illustrated above
  - Read after write of the same variable (data item) regardless of which process reads or writes

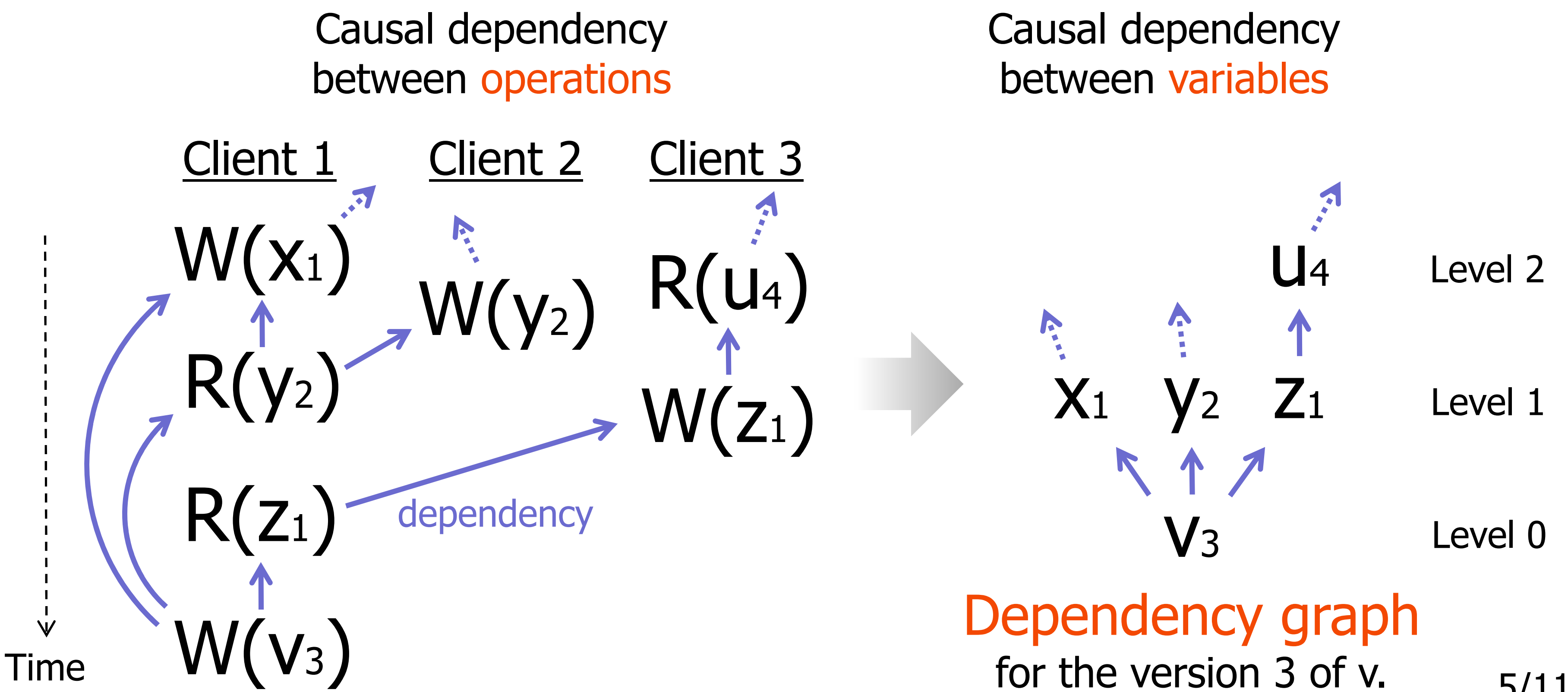
Contribution: Letting-It-Be protocol

- A protocol to achieve causal consistency on an eventually consistent data store.
- It requires no modification of applications and data stores.



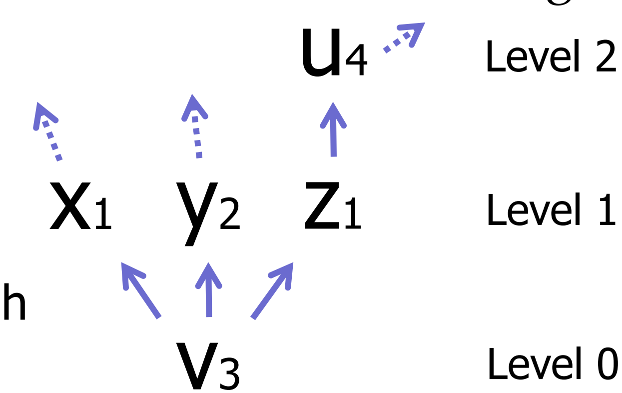
Causality resolution in general

- Servers maintain dependency graphs and resolve dependency for each operation.



Causality resolution

- Data store approach – write time Ex. COPS, Eiger, ChainReaction and Orbe
  - When a server receives a replica update of *v3*, before writing *v3*, the server confirms the cluster has level 1 vertexes, *x1*, *y2* and *z1*.
    - *u4* is confirmed when *z1* is written.
- Middleware approach – read time Ex. Bolt-on causal consistency, Letting-It-Be (our proposal)
  - It cannot implement write-time resolution.
    - Because a middleware cannot catch a replica update.
  - When a server receives a read request of *v*, the server confirms that the cluster has all the vertexes including *x1*, *y2*, *z1* and *u4*.

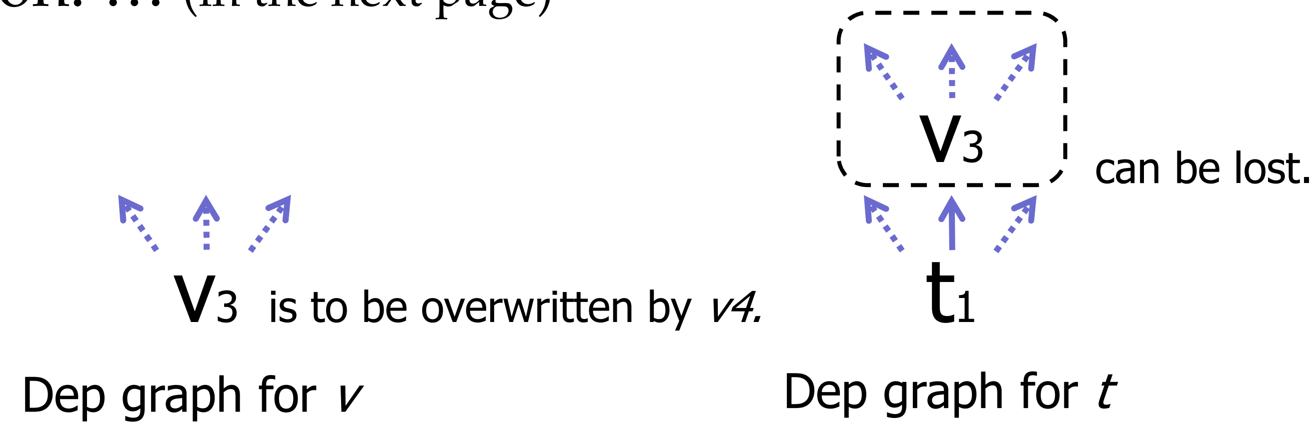


Dependency graph for v3

Problems of middleware approach

It requires no modification of a data store. But there are problems.

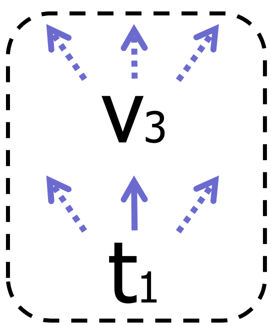
- Overwritten dependency graph
  - Dependency graph for *v4* overwrites graph for *v3* though it is still required as part of graphs for other variables.
  - Solution: … (in the next page)



- Concurrent overwrites by multiple clients
  - Multiple *v3* are written concurrently.
  - Solution: Mutual exclusion with CAS and vector clocks.

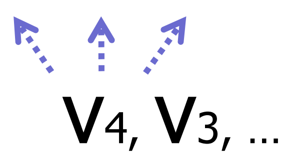
Solutions to overwritten dependency graph problem

- Bolt-on attaches entire graph (!) to all the variables.
  - It reduces the amount of data by forcing an app to specify deps explicitly.
  - It requires **modification of apps**. ☹
- Our Letting-It-Be keeps graphs for multiple versions such as *v4*, *v3*.
  - It reduces the amount of data by attaching only level 1 vertexes.
  - It requires **no modification of apps**. ☺
  - It traverses a graph across servers ☹, but marking technique reduces it.
  - It requires garbage collection of unnecessary old dep graphs. ☹



Bolt-on attaches entire graph.

Dep graph for *t*



Letting-It-Be keeps multiple versions of graphs up to level 1.

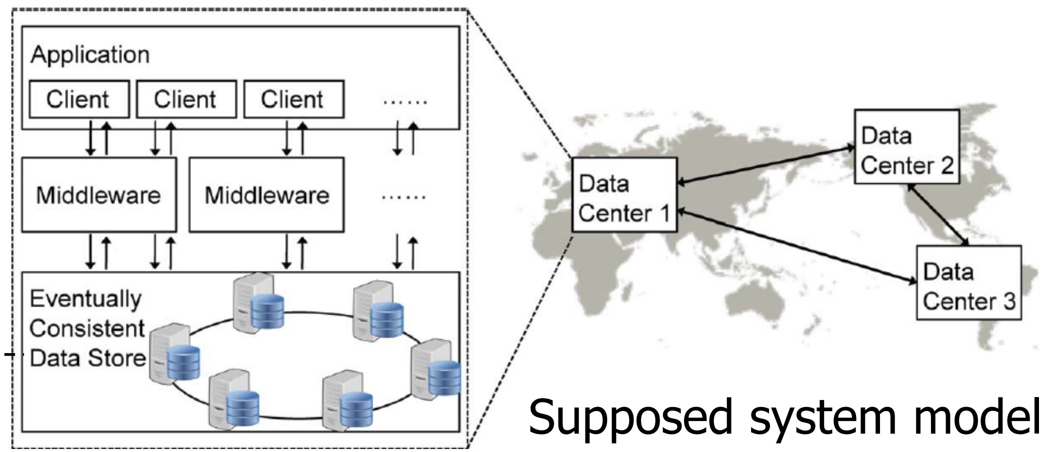
Dep graph for *v*

Performance

- Our contribution is a protocol that requires
  no modification of both apps and a data store.
- But, performance overheads should be acceptable. It depends on an application.

- Benchmark conditions
  - 2 clusters, each has 9 servers running Linux 3.2.0,
    and 50 ms of latency between the clusters
  - Apache Cassandra 2.1.0, configured as each cluster has one replica.
  - Letting-It-Be protocol implemented as a library in 3,000 lines of code
  - Yahoo! Cloud Serving Benchmark (YCSB) [ACM SOCC 2010] with Zipfian distribution

cassandra

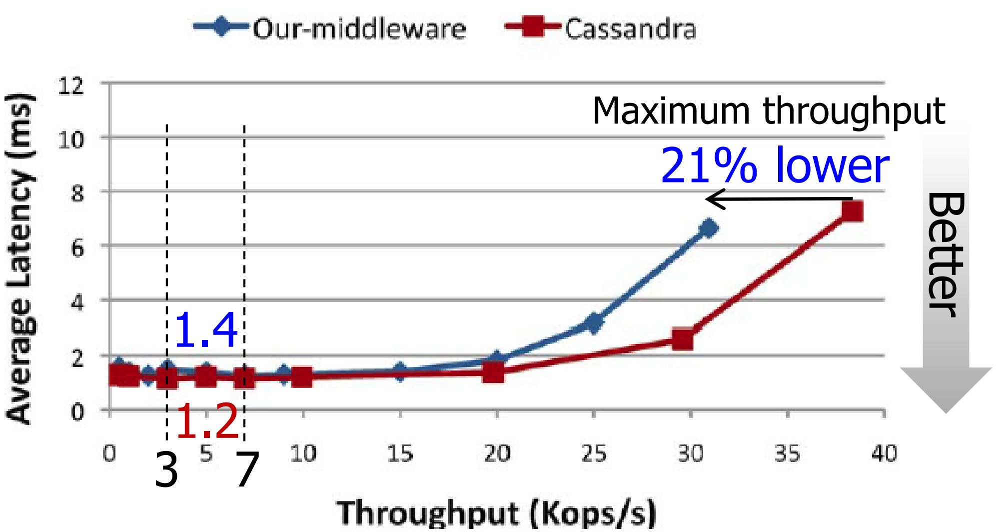


Supposed system model

Performance

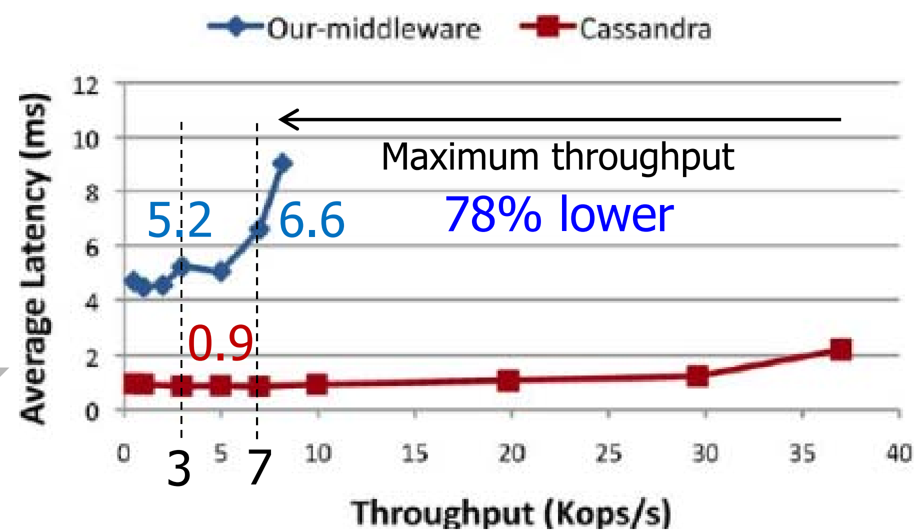
Best case:

Read latencies with read-heavy workload



Worst case:

Write latencies with write-heavy workload



- Overheads for reads are smaller than writes though the protocol does read-time resolution.
  - Marking already-resolved data items works well.
- Comparison with Bolt-on is part of future work.

Summary

- Letting-It-Be protocol maintains causal consistency over an eventually consistent data store.
  - We demonstrated that
    it works with a production-level data store, Apache Cassandra.
- It is unique in that it requires no modifications of applications and a data store.
- Future direction
  - A better **consistency model** that involves
    - less modification to each layer,
    - less costs,
    - less and simple interaction between layers,
    - easier extraction of consistency relationships from an application.