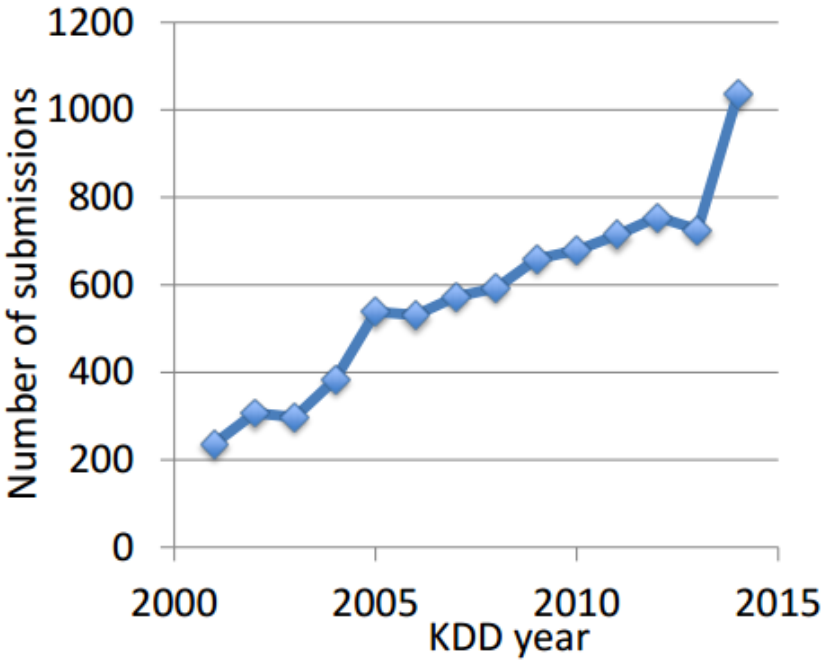
Big Data Challenges in a Product Group

Johannes Gehrke
Microsoft

Big Data

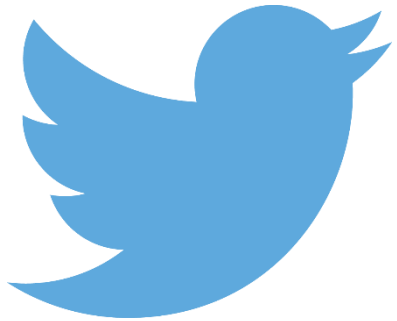
- 40% growth in data per year
- Cost of a disk drive to hold the world's music: <$400



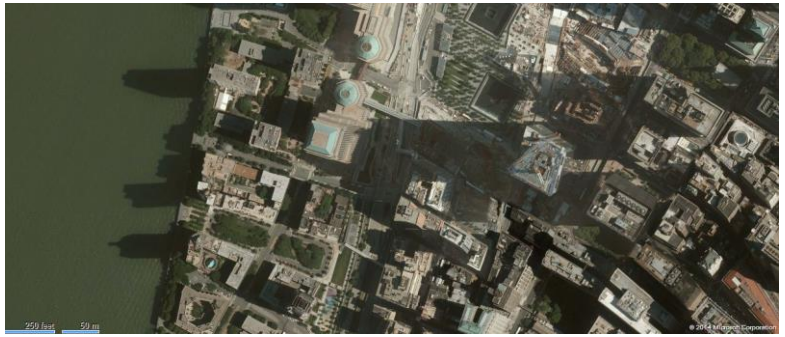
- Big Data:
  Data that is too large to store and analyze using traditional database systems.

- The three "V"s:
  - Volume
  - Velocity
  - Variety

Driving Factors: The Strategic Power of Data

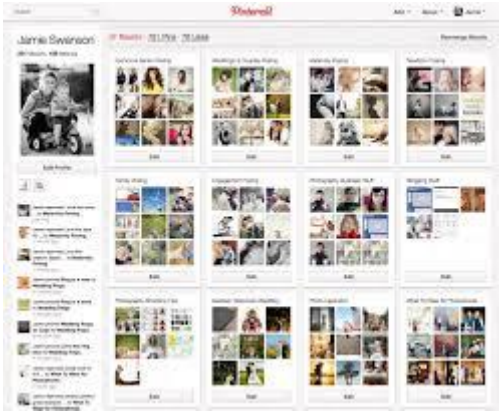


Driving Factors: The Strategic Power of Data (Contd.)



UBER

NETFLIX



myfitnesspal

duolingo

Driving Factors: The Cloud

Driving Factors: The Cloud (Contd.)

- Example: Azure

Windows Azure

- Scale:
  - 22 public regions
  - 250,000+ public facing websites
  - Millions of SQL databases
  - Tens of trillions of objects in Azure storage
  - Hundreds of millions of enterprise users
  - Tens of billions of authentications per week with Azure Active Directory

- Reach
  - Titanfall: 100,000 visual machines at launch day
  - Visual Studio Online: Released Nov 2013, now millions of active users

Source: Forbes.com

Driving Factors: The Office Cloud

- Let’s look at the cloud service behind the Outlook client
- Union of Exchange commercial service and Outlook.com
- Scale:
  - >2million commercial organizations
  - 500+ million accounts; 50+ million engaged users
  - 70+ billion messages per day
  - Over 100K servers
  - Exabytes of physical storage
  - Many 9s availability

Aaron Levie

@levie

Follow

Enterprise software used to be about making existing work more efficient. Now, the opportunity for software is to transform the work itself.

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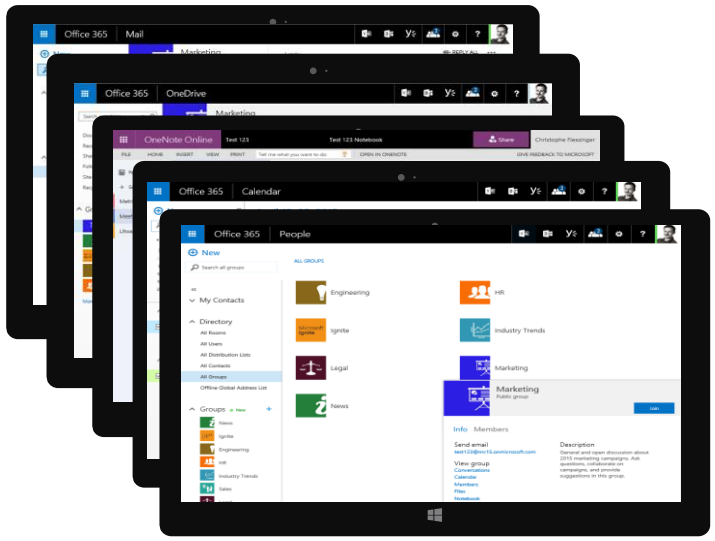
9:42 PM - 9 Apr 2015

Siloed Tools and Teams…



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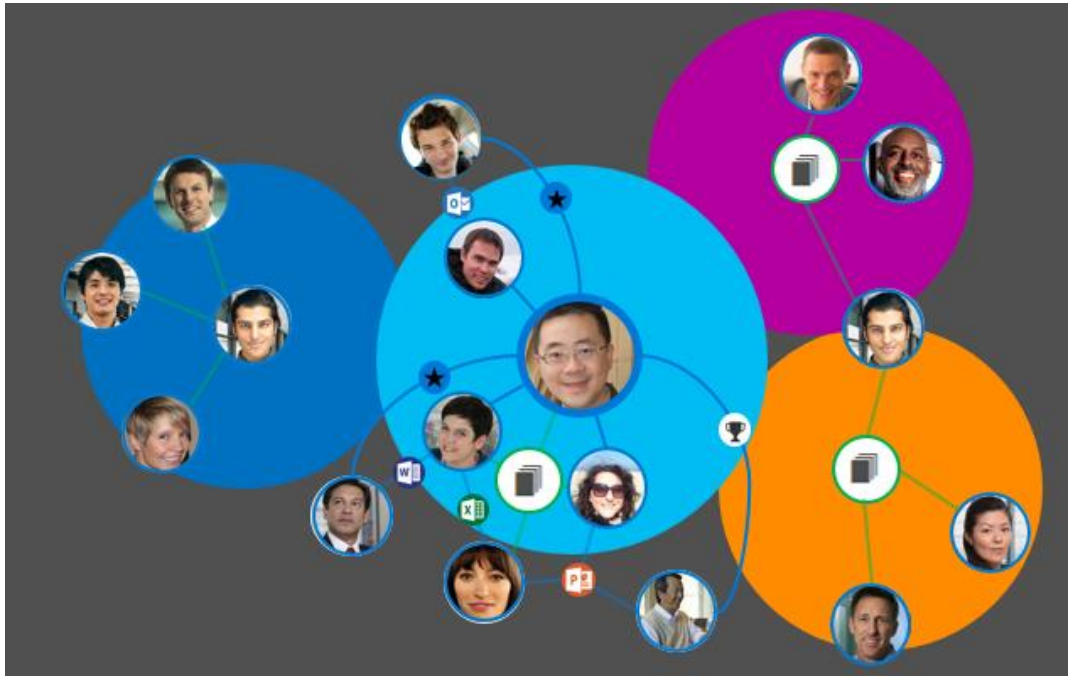
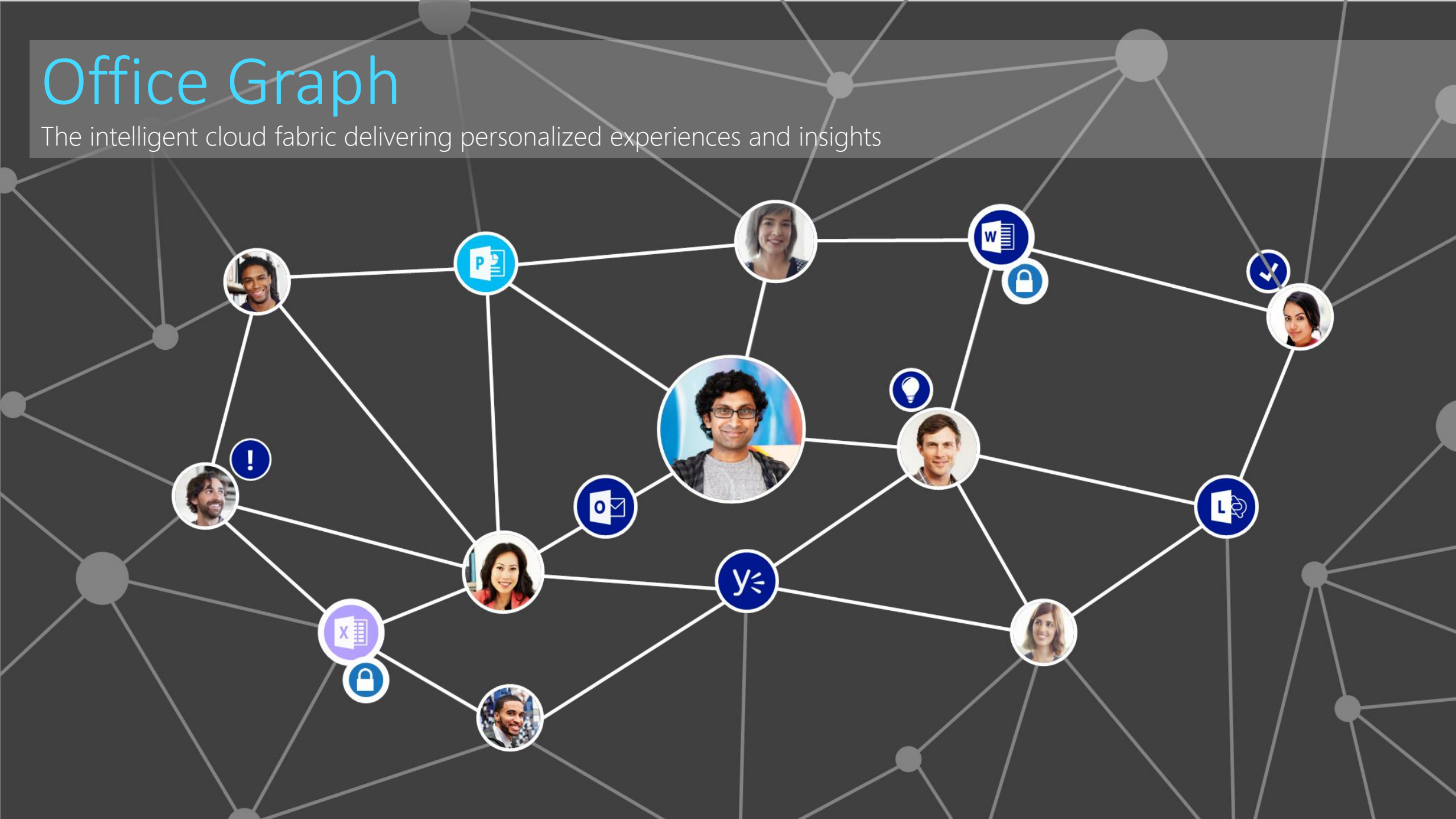


Office Graph

The intelligent cloud fabric delivering personalized experiences and insights



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Future Scenarios Weekly Sync

Dashboard

Data from: Past 30 days

My team's work map

887 ↑ +2%
Emails

67 ↓ -3%
Meetings

250 ↑ +2%
Skype

90 ↑ +2%
Yammer

My work life balance

16% Emails sent outside of business hours
6% more than company average

12% Meetings outside of business hours
3% more than company average

10% Skype sessions outside of business hours
7% more than company average

25% Yammer conversations outside of business hours
1% less than company average

Your business hours are 9AM to 6PM, M-F

My meeting time

Time spent during business hours
60%
12% more than company average

Time spent with other teams
20%
2% less than company average

Time spent with customers
30%
5% more than company average

My team's interactions by location

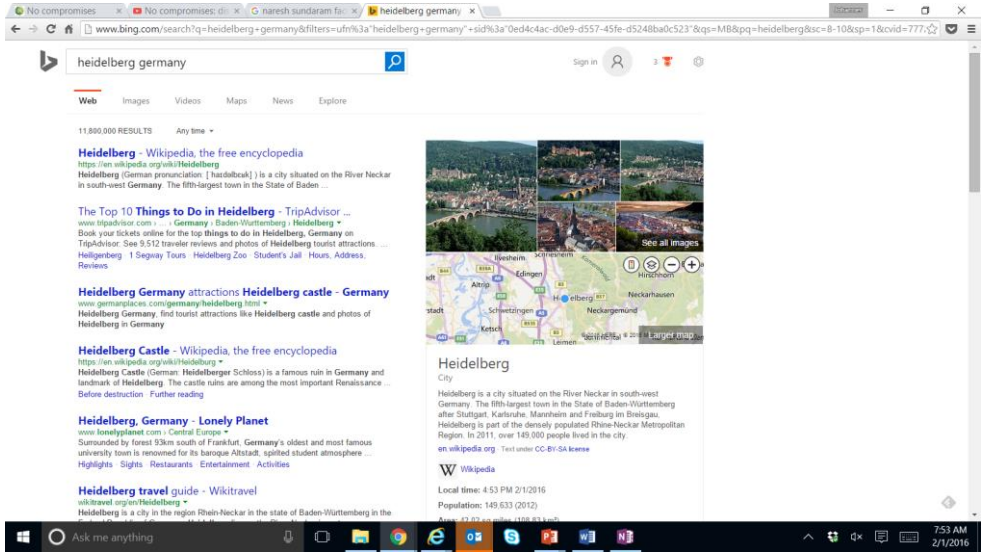
Redmond, WA USA
587 ↓ -3%
Interactions

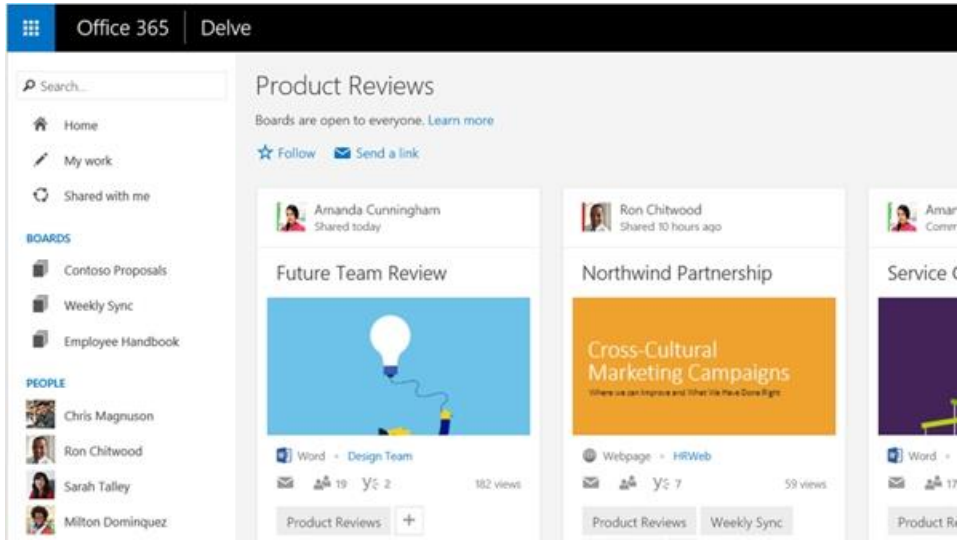
New York, NY USA
203 ↑ +2%
Interactions

Sydney, Australia
171 ↓ -1%
Interactions

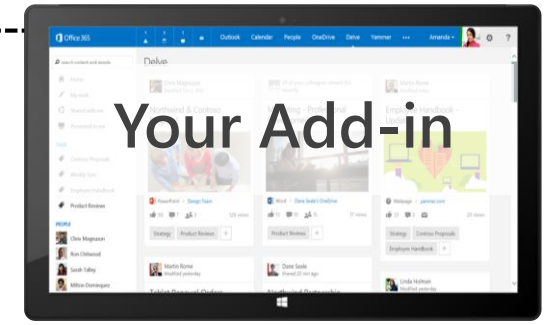
Delve and Office Graph: Concepts

- Move enterprise search beyond IR technology (TF/IDF)
- Entity centric-notion of navigating content
- Data as a strategic asset

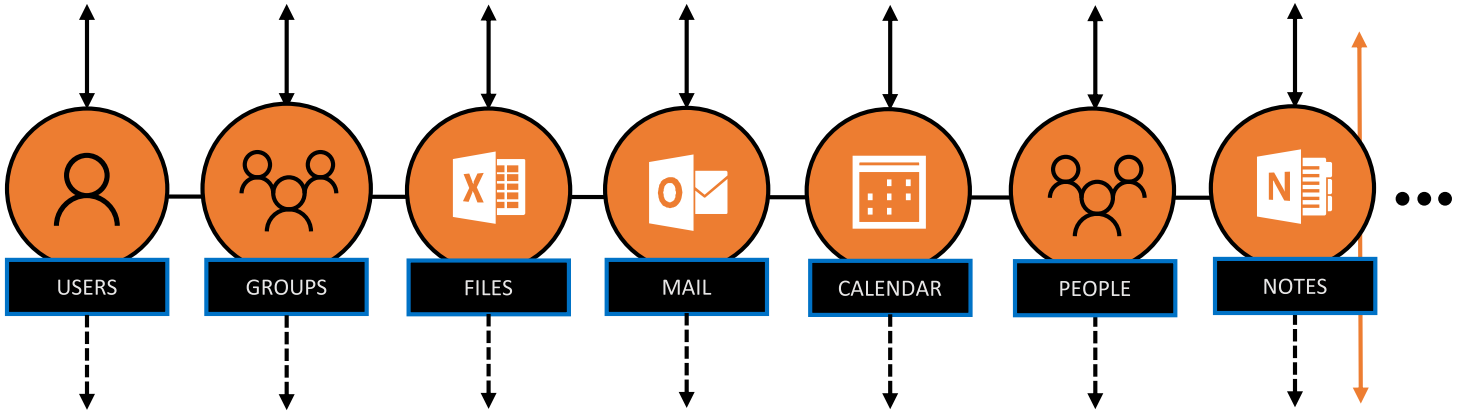




Microsoft Graph Developer API's



https://graph.microsoft.com/



Insights from Office Graph

Other MS cloud services

Office Graph: Technology

- Confluence of:
  - Distributed systems
  - Database systems/Big data
  - Data science/ML

- This talk:
  - FARM [NSDI'14, SOSP'15]
  - Trill [VLDB'14]
  - Cloud abstractions for collaboration [SIGMOD'15]

This Talk

- Scalable transactions with FARM
- Collaboration through data-driven coordination
- MSR Impact in Big Data

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Modified today

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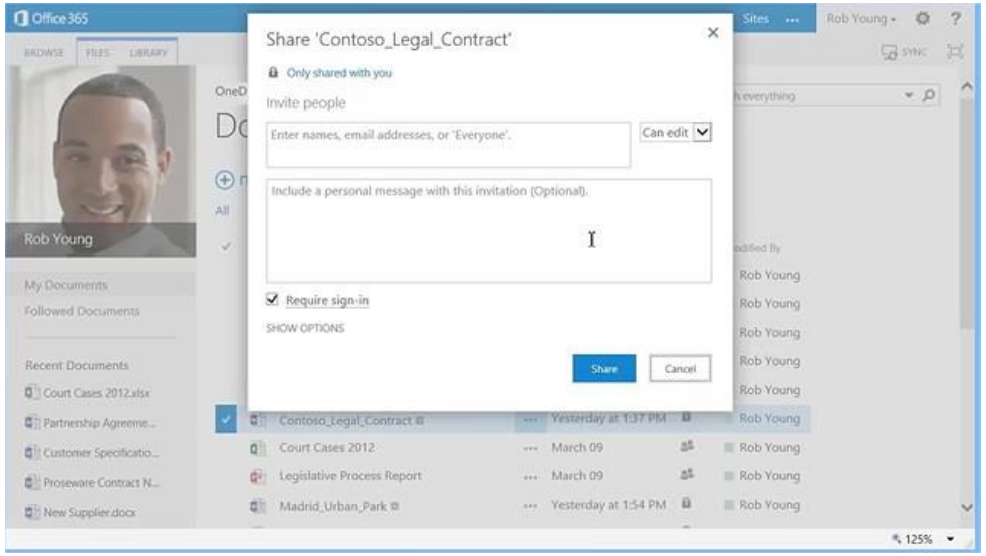
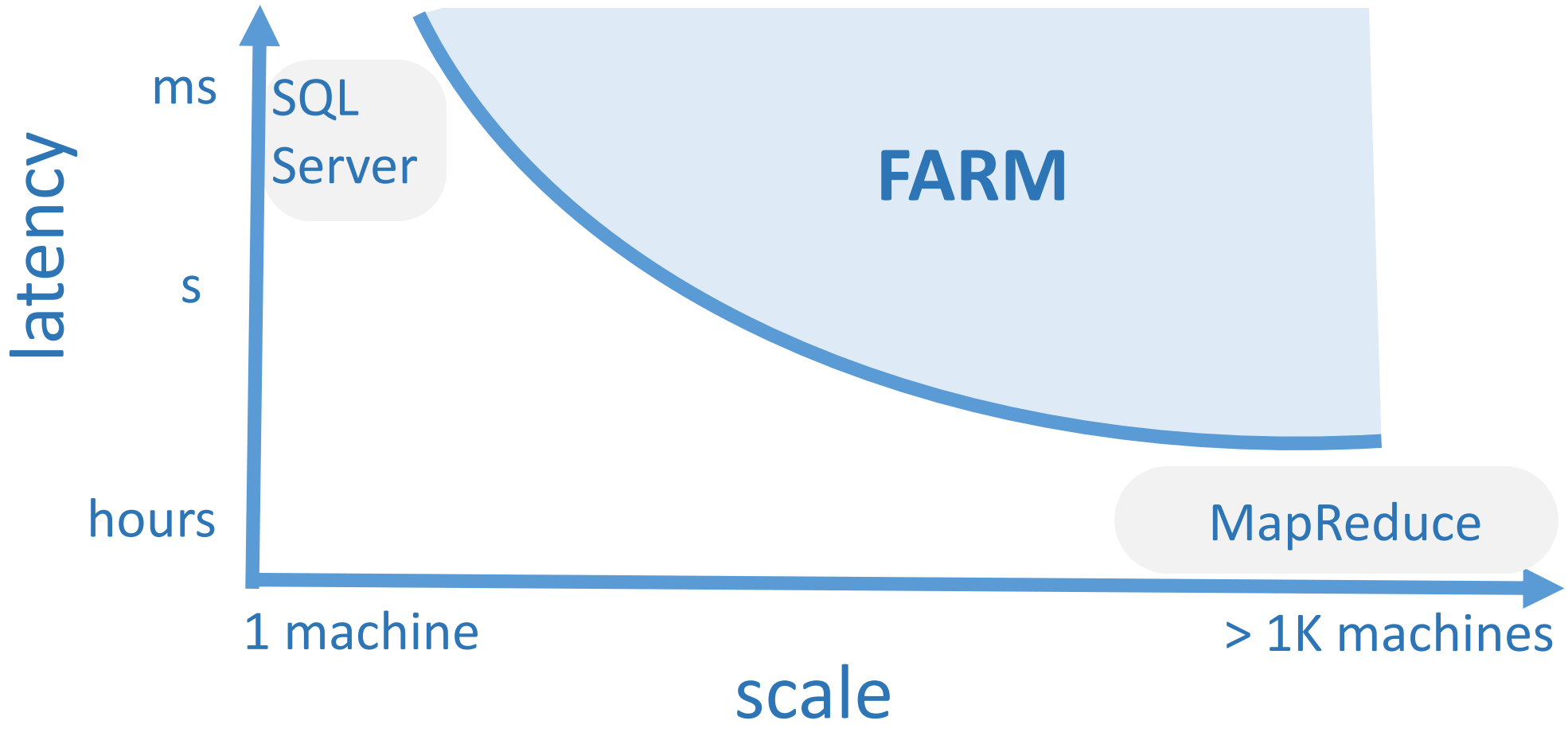
Future Scenarios Weekly Sync

Access Control in the Enterprise

- On the web, we have access to every document over which we search
  - At least at coarse granularity
- In the enterprise, (in general) every user sees a different subset of documents → The “personal view of the enterprise graph that a user sees is different for every user

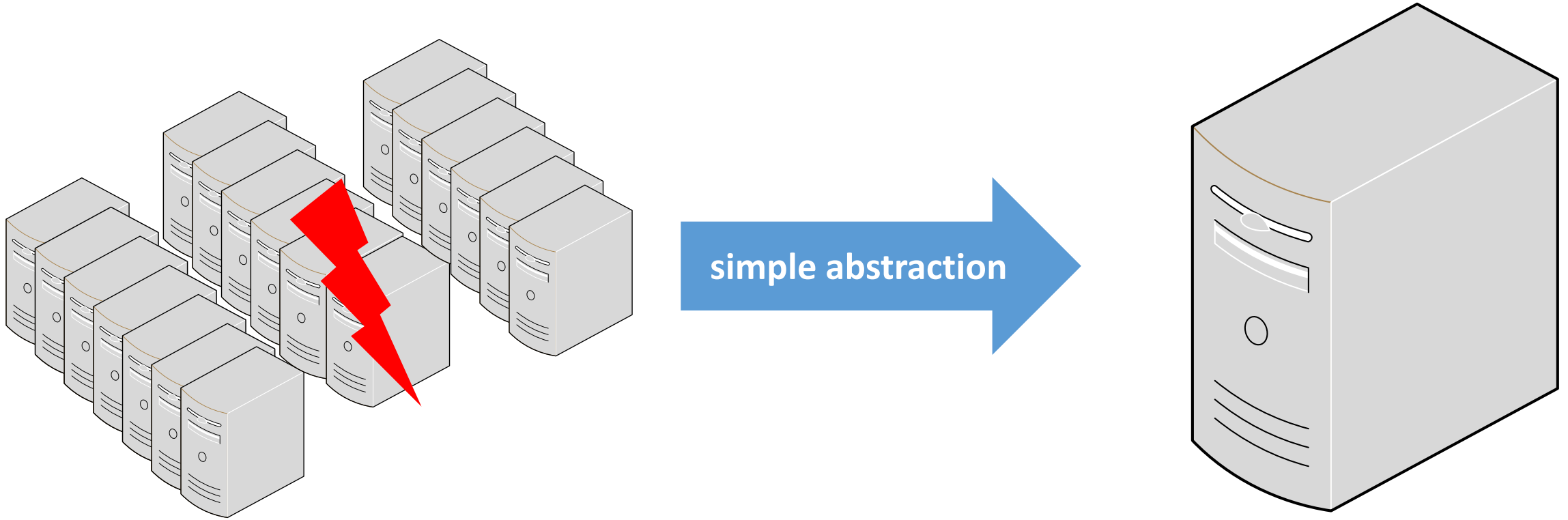


What We Need: Low Latency at Scale



FARM simplifies building low latency apps

- **transactions and replication simplify programming**
  - hide failures, distribution, and concurrency
  - **abstraction** that transactions run sequentially on a reliable server



Avoid compromises by harnessing new hardware

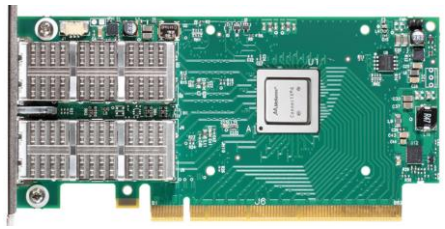
- strong consistency
  - strict serializability
- high availability
  - recovery from failure to peak performance in tens of milliseconds
- good performance
  - millions of transactions per second with sub millisecond latencies

FARM is enabled by three hardware trends

- cheap DRAM
  - currently <$5/GB
  - cost effective to keep data in DRAM

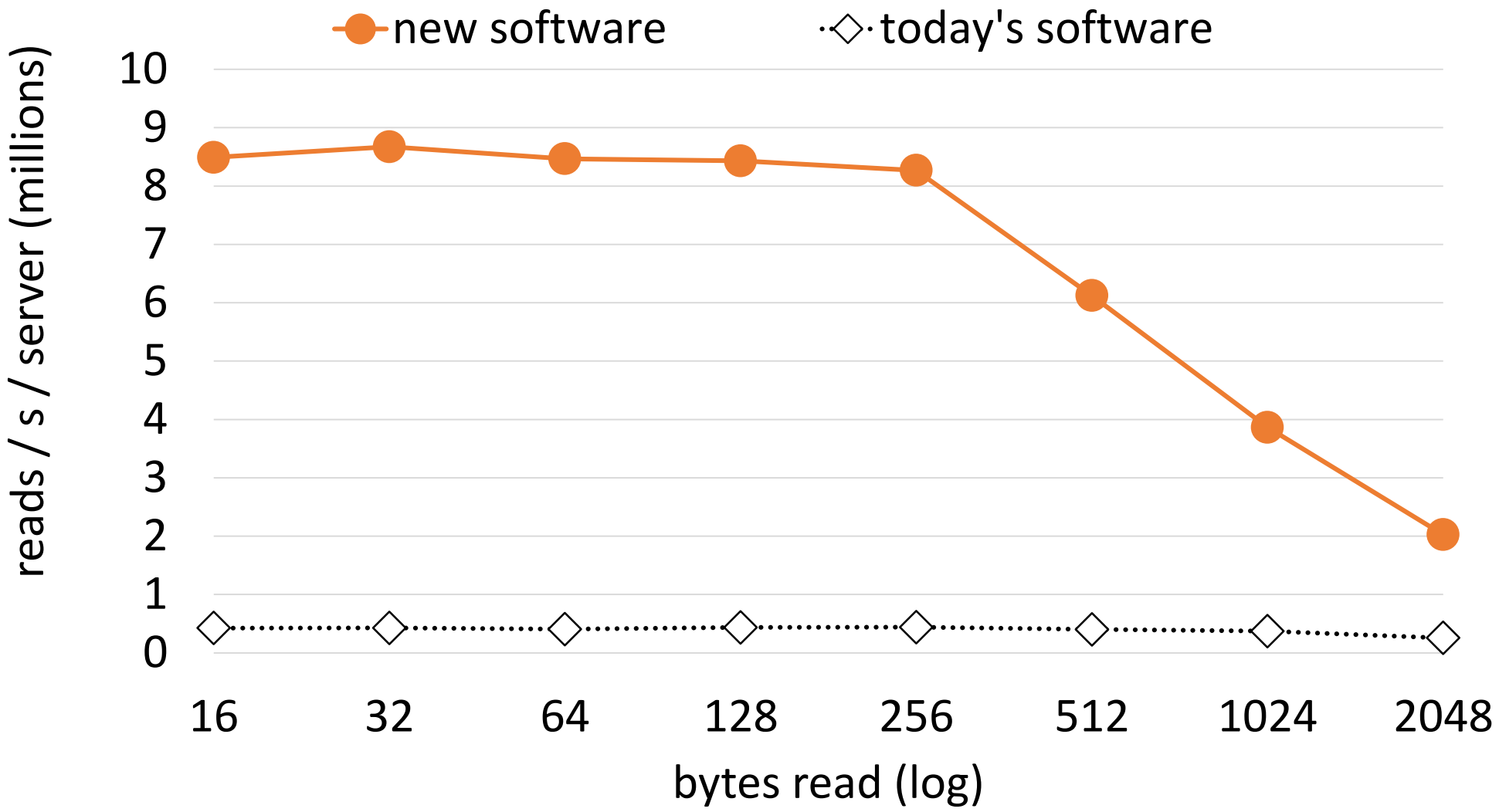
- non-volatile DRAM
  - DRAM + SSD + lithium ion batteries in power supply
  - 1.15x cost of DRAM

- fast commodity networks with RDMA
  - CX3: 40 Gb/s, 35 M msg/s, and 3 µs latency on Ethernet
  - CX4: 100 Gb/s, 150 M msg/s

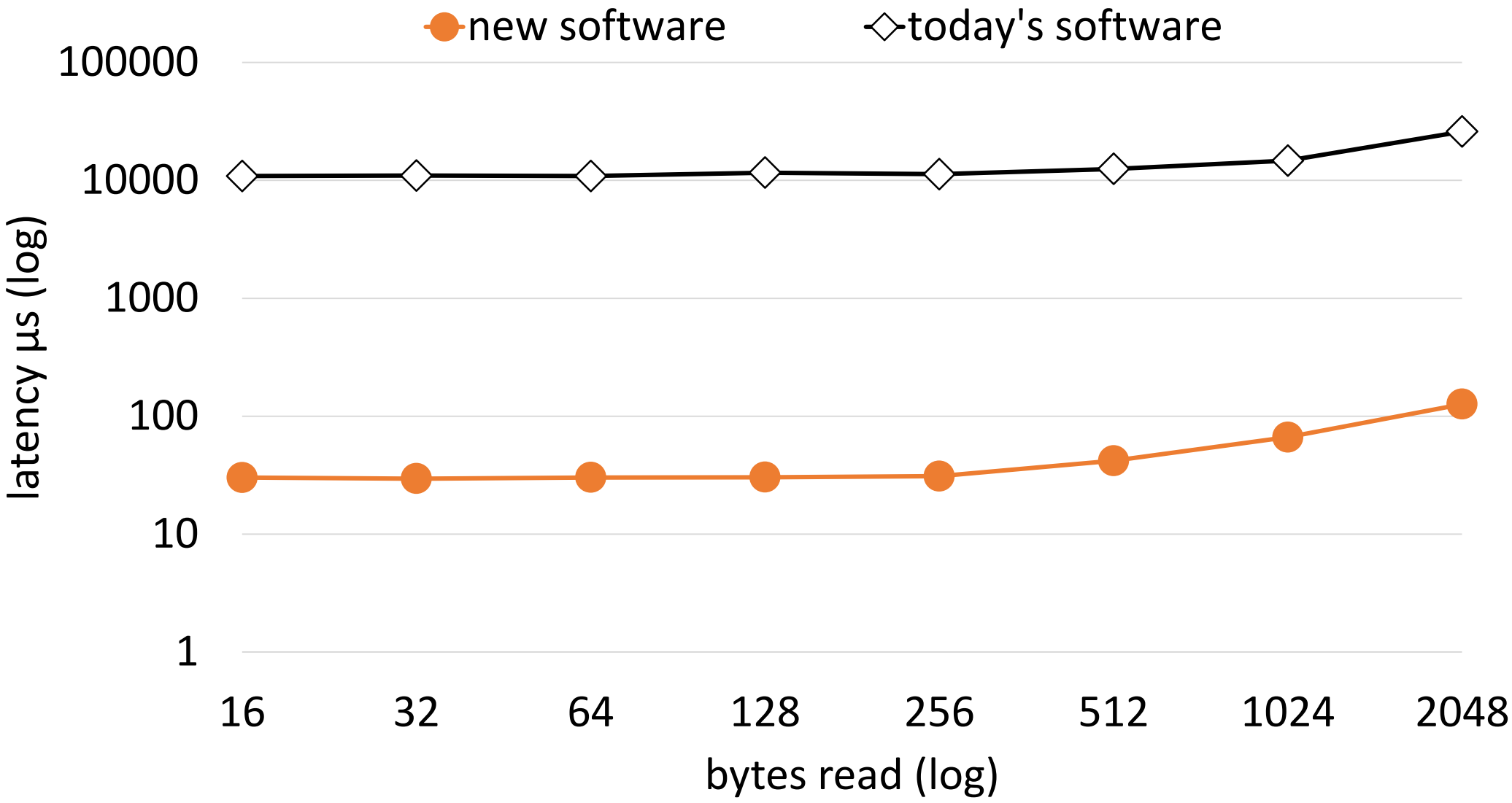


existing software benefits little because of CPU bottlenecks

The hardware is not enough: throughput

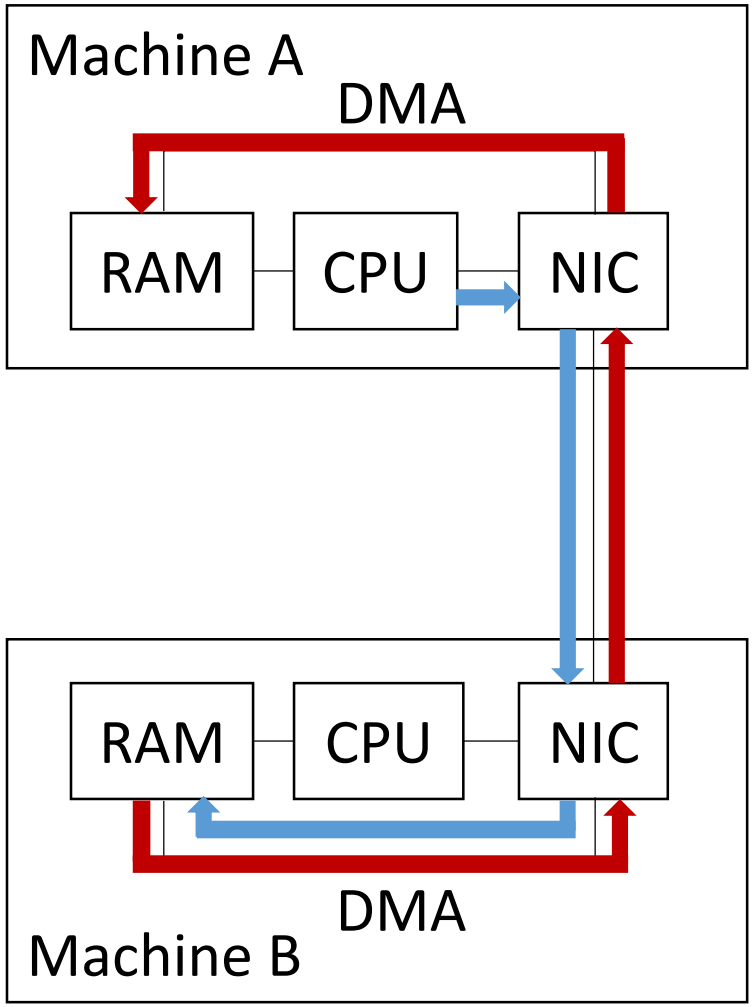


The hardware is not enough: latency

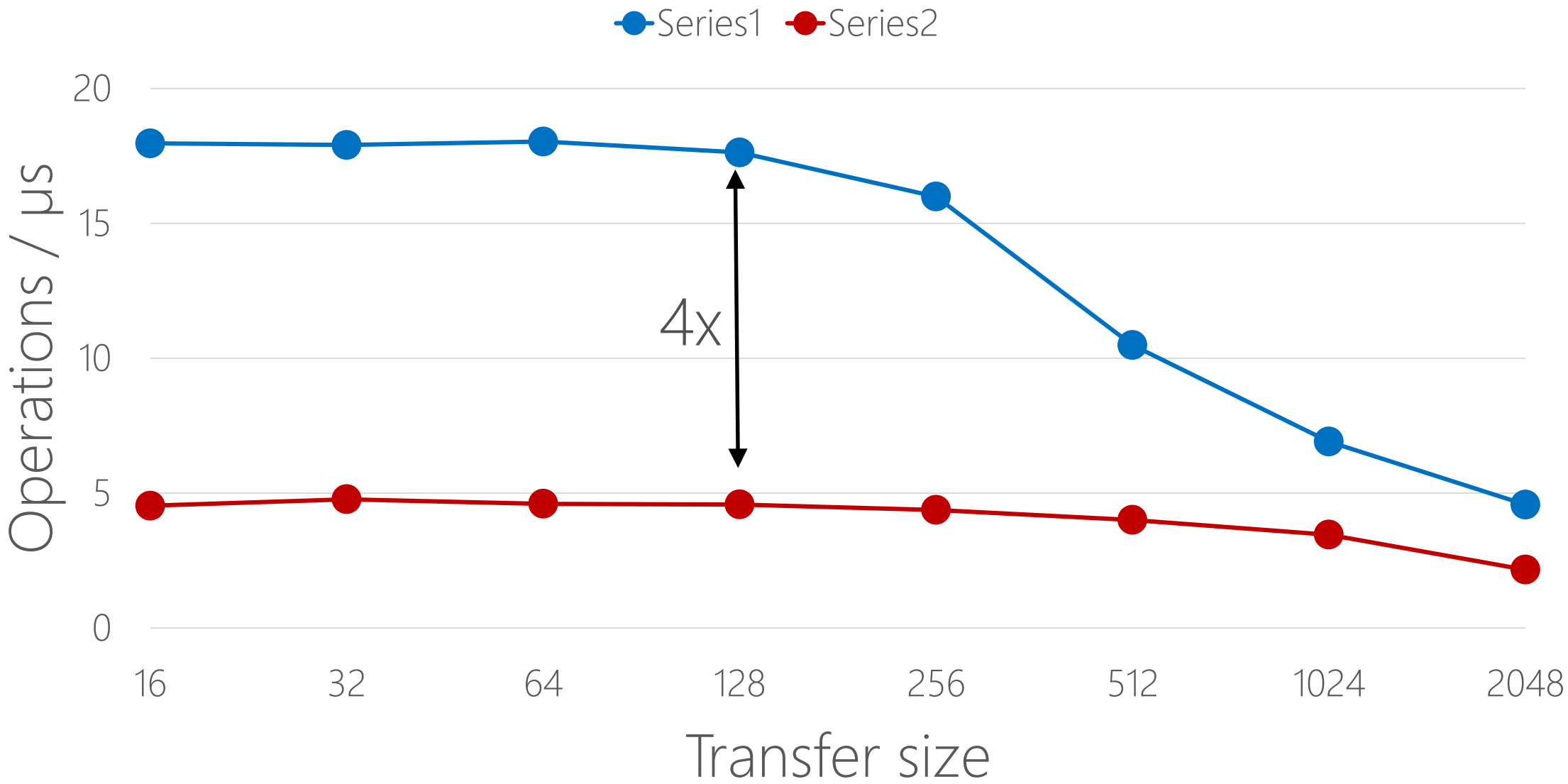


Remote direct memory access (RDMA)

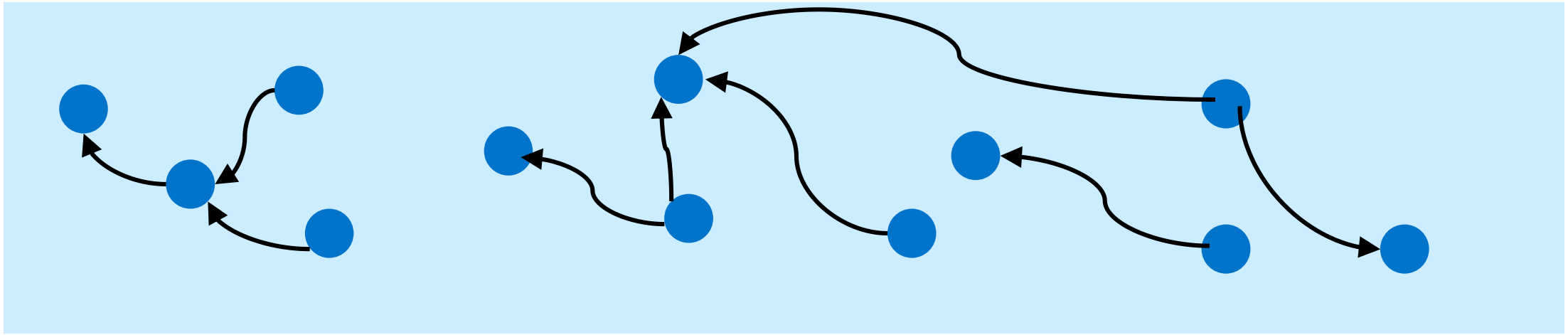
- One-sided reads and writes of remote memory
  - remote CPU not involved
  - kernel bypass
- FARM uses RDMA to reduce CPU overhead
  - one-sided reads of remote data
  - one sided writes into transaction logs

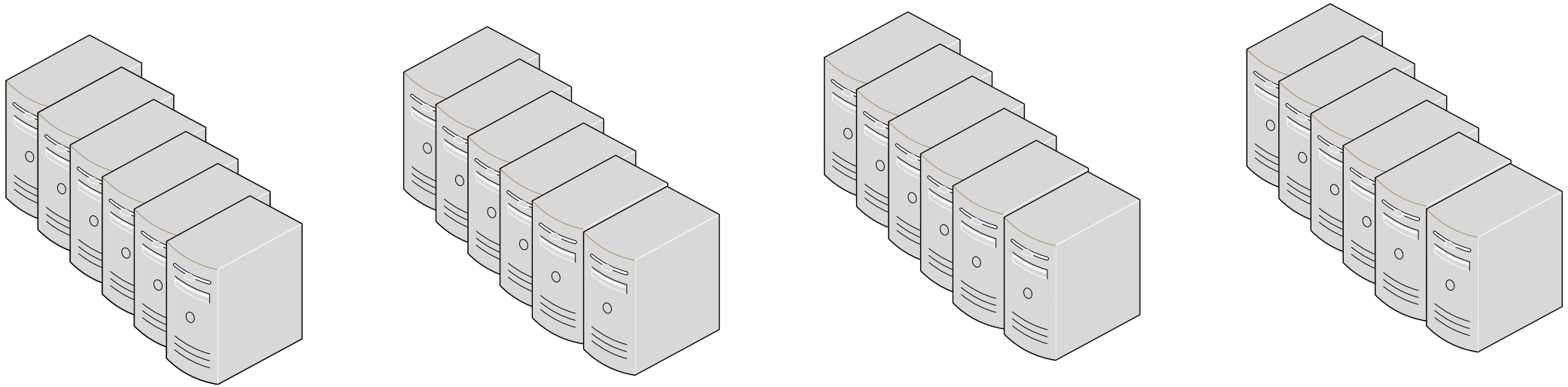


Why one-sided operations?



FARM provides transactional memory





FARM exploits new hardware effectively

- New transaction, replication, and recovery protocols
- Three principles
  - Use RDMA to eliminate CPU overhead on the server side
  - Minimize RDMA operations to reduce CPU on the client side: Use as few messages as possible
  - Exploit parallelism effectively: Allow new transactions to be performed during recovery

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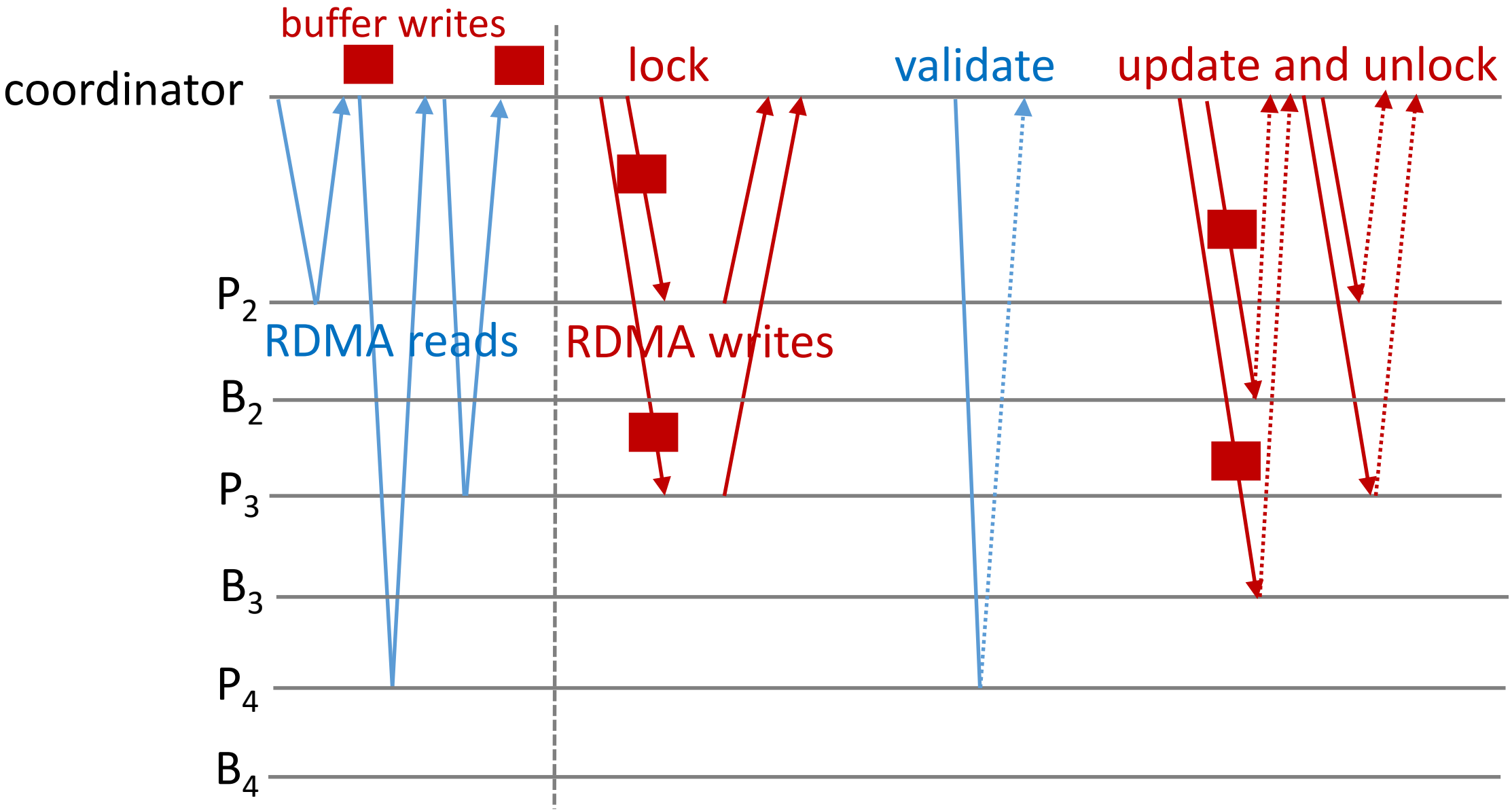
Transaction Protocol

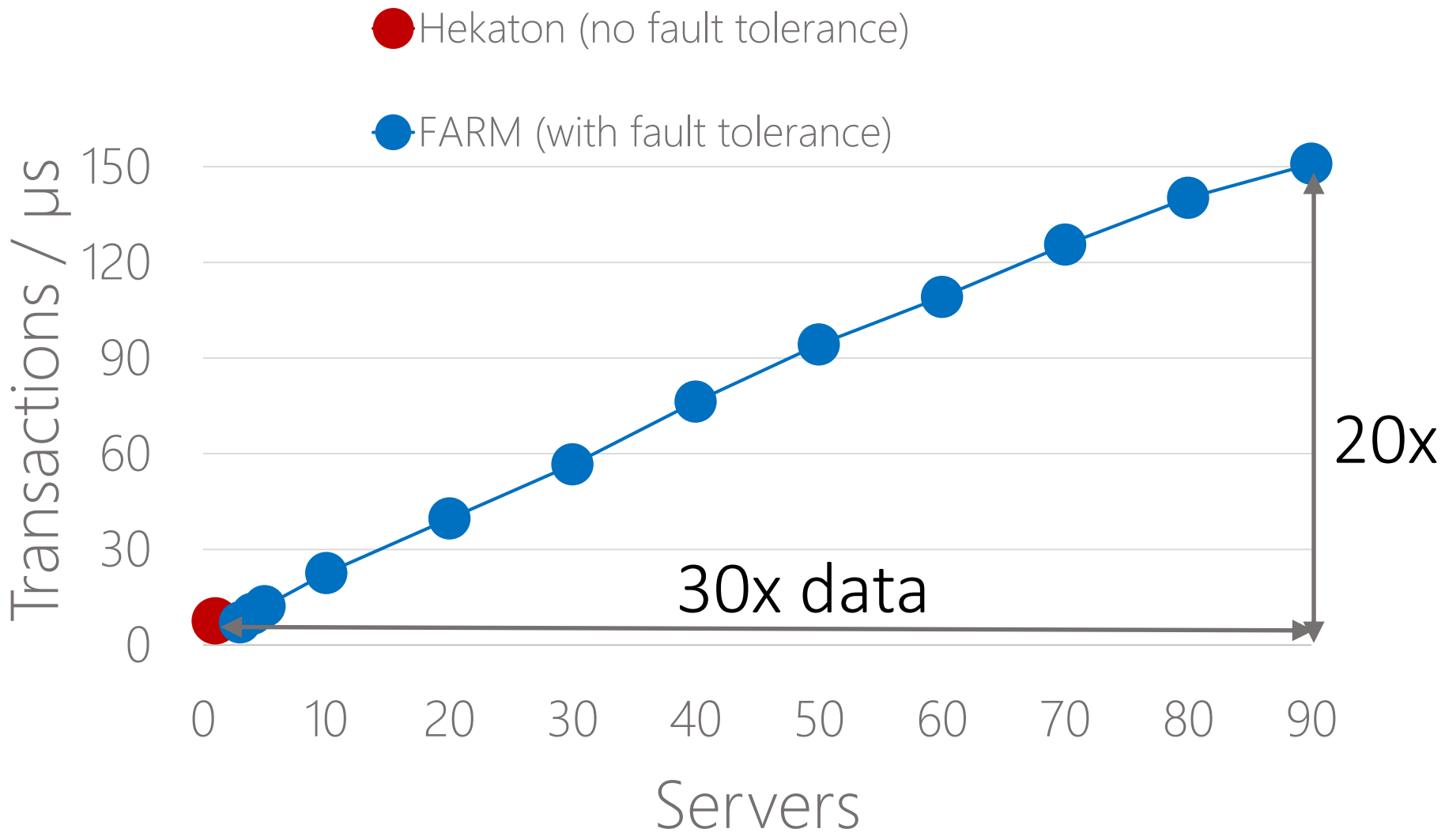


FARM API

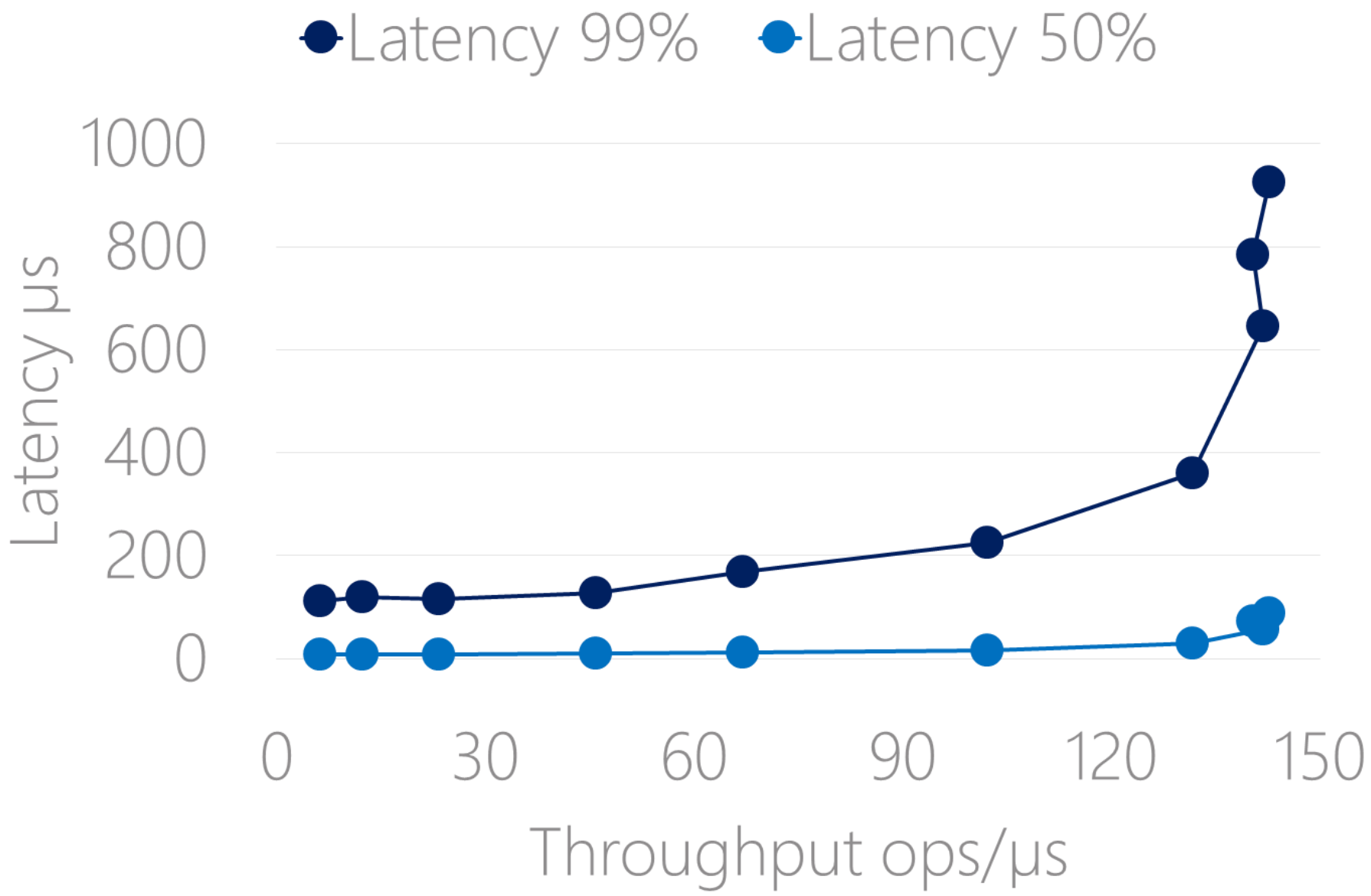
storage and transactions

```
Transaction CreateTransaction()
ObjBuf *Transaction::Alloc(size, locality_hint)
ObjBuf *Transaction::Read(addr, size)
ObjBuf *Transaction::OpenForWrite(ObjBuf)
void Transaction::Free(ObjBuf)
void Transaction::Commit()
```

Scalability TATP



Performance TATP



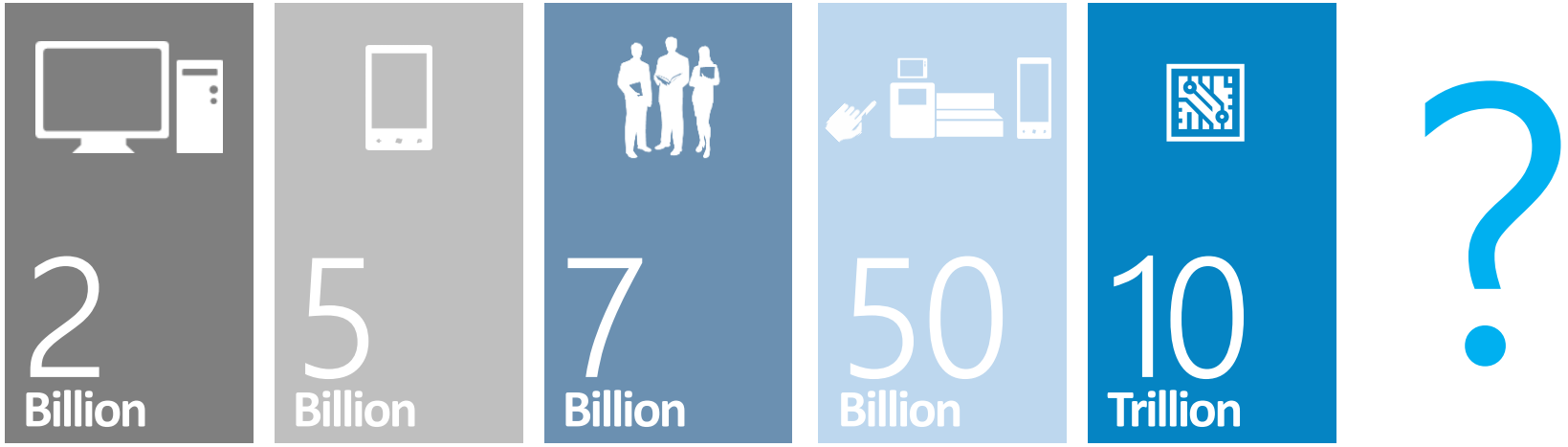
FARM: Summary

- Scaling out distributed transactions and graph operations with
  - strong consistency
  - high availability
  - high throughput
  - low latency

This Talk

- Scalable transactions with FARM
- Collaboration through data-driven coordination
- MSR Impact in Big Data

Ubiquitous Devices



"Web 2.0 Collage" was designed by: AJ Batac (allanjosephbatac.com)

Enabling Coordination

- Assume Tom and Meg want to coordinate itineraries
  - Fly on the same flight, in adjacent seats
  - Also stay in the same hotel if possible

Coordination: Enrollment

- Students want to enroll in classes with their friends
- Help with homework/moral support
- Already happens with out-of-band communication

- Interesting coordination scenarios:
- Negative constraints:
  Avoid the section my ex-* is in
- Strong mutual dependencies:
  I will take this tough class only if my smart friend Ashwin takes it too

Coordination: SIGMOD 2011

Room Sharing among attendees of the 2011 ACM SIGMOD Conference

The conference officers have set up a web page where interested attendees of the conference can register their interest in sharing rooms at the conference hotel. Through this service attendees can enter their details so that interested people can contact each other.

To register your interest, please submit your information at: http://bit.ly/sigm_share_room (URL shortener service forwarding to a Google Spreadsheets form). This service is provided solely as a convenience to participants that seek to share accommodation costs. Please contact directly participants that have expressed interest. The organizers will not be involved in the process nor are they responsible for possible abuse of the information you provide.

https://spreadsheets.google.com/spreadsheet/viewform?formkey=dEVscThIZkVJMkdJeUFCX1pSZVFPUXc6MQ

Sharing a room at the Conference Hotel?

This form allows people who want to stay at the conference hotel to express their interest in sharing rooms.
Please fill out the following form, all people expressing interest in sharing a room can then contact each other by looking at the
following page http://bit.ly/sigm_share_room_list

* Required

Name *

email *

Period you wish to stay at the hotel *

Please add any constraints on sharing a room (gender, etc)

Submit

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https://spreadsheets.google.com/spreadsheet/pub?hl=en&hl=en&key=0A

Sharing a room at the Conference Hotel? : List

Timestamp	Name	email	Period you wish to stay at the hotel	Please add any constraints on sharing a room (gender, etc)
5/10/2011 6:15:25			12/06/2011-16/06/2011	Female
5/10/2011 6:38:39			June 13 - June 17 (4 nights)	I will be interested to share a room (only females) during the conference. thanks!
5/10/2011 16:38:58			12-17 June	Males only. I already have a room reservation -- looking to fill the other bed and split the cost.
5/10/2011 18:34:49			5 nights June 12-16 (inclusive)	
5/12/2011 13:03:30			13th-16th June	prefer females (i'm a girl)
5/13/2011 12:45:54			12-17 June	
5/14/2011 12:20:15			Check-in 11 , Check-out 15	n/a I'm easy going :)
5/23/2011 22:47:20			12th-17th	
5/25/2011 23:16:36			June 12 - June 17	male
6/4/2011 13:10:08			June 12th	Gender: male

Data-Driven Coordination

It is not just the applications that are data-driven, the coordination itself is data-driven!

Users want to agree on a choice of data values, not on the time of day of when they call each other to jointly enroll in a course

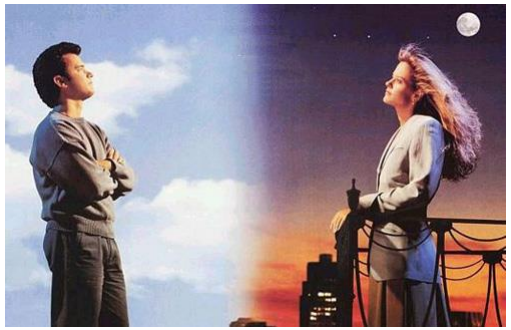
Today typically achieved with out-of-band communication

- Or through an ad-hoc solution for a given scenario...

We want to *defer* the coordination until a suitable value is there

Data-Driven Coordination

- Provide a declarative abstraction and mechanism to support coordination
  - Being declarative is fundamental principle in query and update languages
  - Coordination pertains to data, so should be expressed at the same level
  - Meg says: “Book me a ticket on the same flight as Tom”
  - System takes care of the actual coordination



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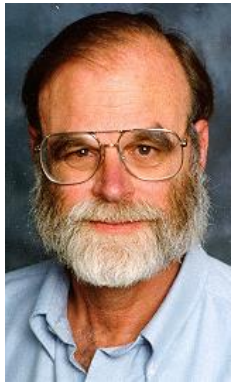
ACID Transactions and Coordination



ACID Properties of a transaction

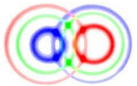
- Atomicity
- Consistency
- Isolation
- Durability

Coordination requires relaxing isolation

- For semantic reasons, not for performance (such as lower isolation levels, eventual consistency)
- We still want atomicity and durability

And the communication due to coordination should be “controlled“

- Keep the “residual" isolation

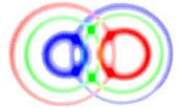


Entangled Queries

- Example scenario: Harry and Voldemort want to travel to NYC on the same flight
- In addition, Harry needs to travel on United

Harry's Entangled Query

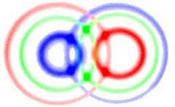
```
SELECT 'Harry', fno INTO ANSWER Reservation
WHERE
    fno IN (SELECT fno FROM Flights WHERE dest='JFK')
    AND ('Voldemort', fno) IN ANSWER Reservation
CHOOSE 1
```



Harry's Entangled Query (Contd.)

```
SELECT 'Harry', fno INTO ANSWER Reservation
WHERE
    fno IN (SELECT fno FROM Flights WHERE dest='JFK')
    AND ('Voldemort', fno) IN ANSWER Reservation
CHOOSE 1
```

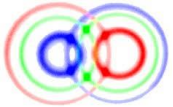
- Voldemort's answer must also be in the Reservation table



Voldemort's Entangled Query

```
SELECT 'Voldemort', fno INTO ANSWER Reservation
WHERE
   fno IN (SELECT fno FROM Flights F, Airlines A
                WHERE F.dest='JFK' and F.fno = A.fno AND
   A.airline = 'United' )
   AND ('Harry', fno) IN ANSWER Reservation
CHOOSE 1
```

```
SELECT 'Harry', fno INTO ANSWER Reservation
WHERE
   fno IN (SELECT fno FROM Flights WHERE dest='JFK')
   AND ('Voldemort', fno) IN ANSWER Reservation
CHOOSE 1
```

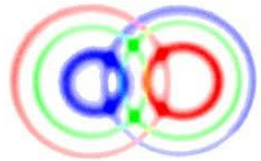


Entangled Queries

- Harry and Voldemort want to travel to NYC on the same flight
- In addition, Harry needs to travel on United

What We Want: Transactions

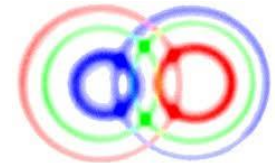
- Scenario
  - Harry and Voldemort want to fly to NYC on the same flight
  - If they can make a flight booking together, then they want to stay in the same hotel
  - This booking should be a transaction



Harry's Entangled Transaction

```
BEGIN TRANSACTION WITH TIMEOUT 2 DAYS;

SELECT `Harry', fno, fdate AS @ArrivalDay
INTO ANSWER FlightReservation

WHERE fno, date IN (SELECT fno, fdate FROM Flights
WHERE dest=`JFK')

AND (`Voldemort', fno, fdate) IN ANSWER
FlightReservation

CHOOSE 1;


-- (Code to perform flight booking)


SET @StayLength = `2011-10-30' - @ArrivalDay;
```

```
SELECT `Harry', hid, @ArrivalDay, @StayLength INTO
ANSWER HotelReservation

WHERE hid IN (SELECT hid FROM Hotels WHERE
location=`NYC')

AND (`Voldemort', hid, @ArrivalDay, @StayLength) IN
ANSWER HotelReservation

CHOOSE 1;


-- (Code to perform hotel booking)


COMMIT;
```



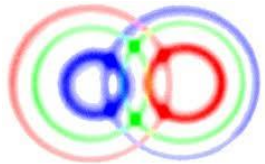
Consistency

Recall ACID consistency:

- Every transaction, if executed by itself on a consistent database, will produce another consistent database.

What is the analogous property for entangled transactions?

```
BEGIN TRANSACTION WITH TIMEOUT 2 DAYS;

SELECT `Harry', fno, fdate AS @ArrivalDay INTO ANSWER FlightReservation
WHERE fno, date IN (SELECT fno, fdate FROM Flights WHERE dest=`JFK')
AND (`Voldemort', fno, fdate) IN ANSWER FlightReservation
CHOOSE 1;

-- (Code to perform flight booking omitted)

SET @StayLength = `2011-10-30' - @ArrivalDay;

SELECT `Harry', hid, @ArrivalDay, @StayLength
INTO ANSWER HotelReservation
WHERE hid IN (SELECT hid FROM Hotels WHERE location=`NYC')
AND (`Voldemort', hid, @ArrivalDay, @StayLength) IN ANSWER HotelReservation
CHOOSE 1;

-- (Code to perform hotel booking omitted)

COMMIT;
```



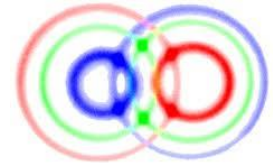
Consistency

Entangled Query Oracle

- Process that executes alongside an entangled transaction
- For an entangled query, the oracle chooses a valid answer (=ground the query on the database) and returns it to any entangled query
- Has no direct effect on the database's state

Oracle Consistency:

- Suppose an entangled transaction executes by itself on an initially consistent database, using an entangled query oracle to obtain answers to the entangled queries. Then the execution will produce another consistent database.



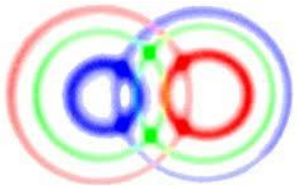
Isolation

Anomaly-based definition:

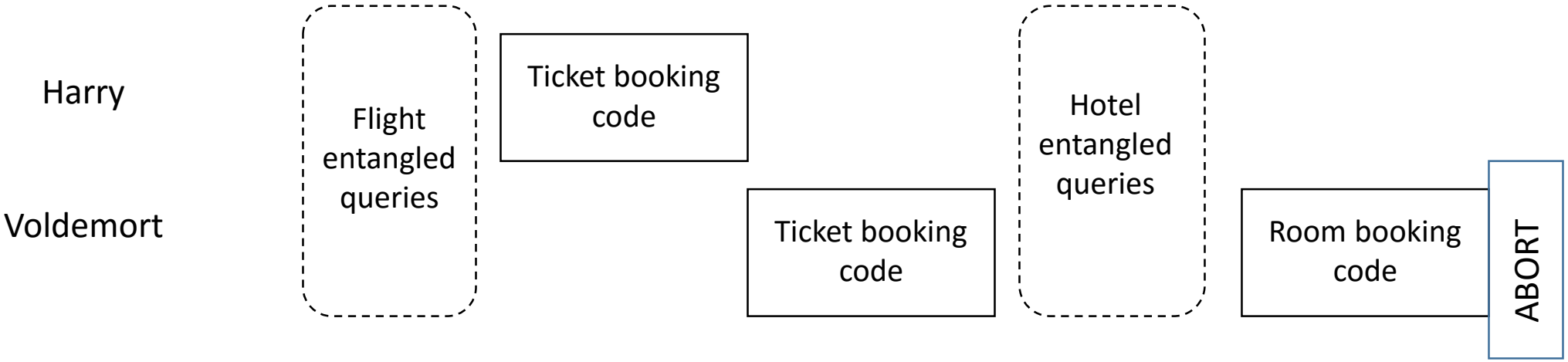
- No dirty reads, no unrepeatable reads, etc.

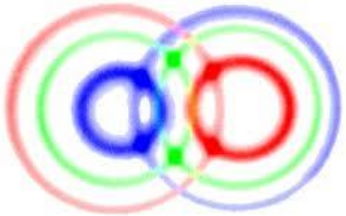
Two new anomalies

- Widowed Transactions
- Unrepeatable quasi-reads

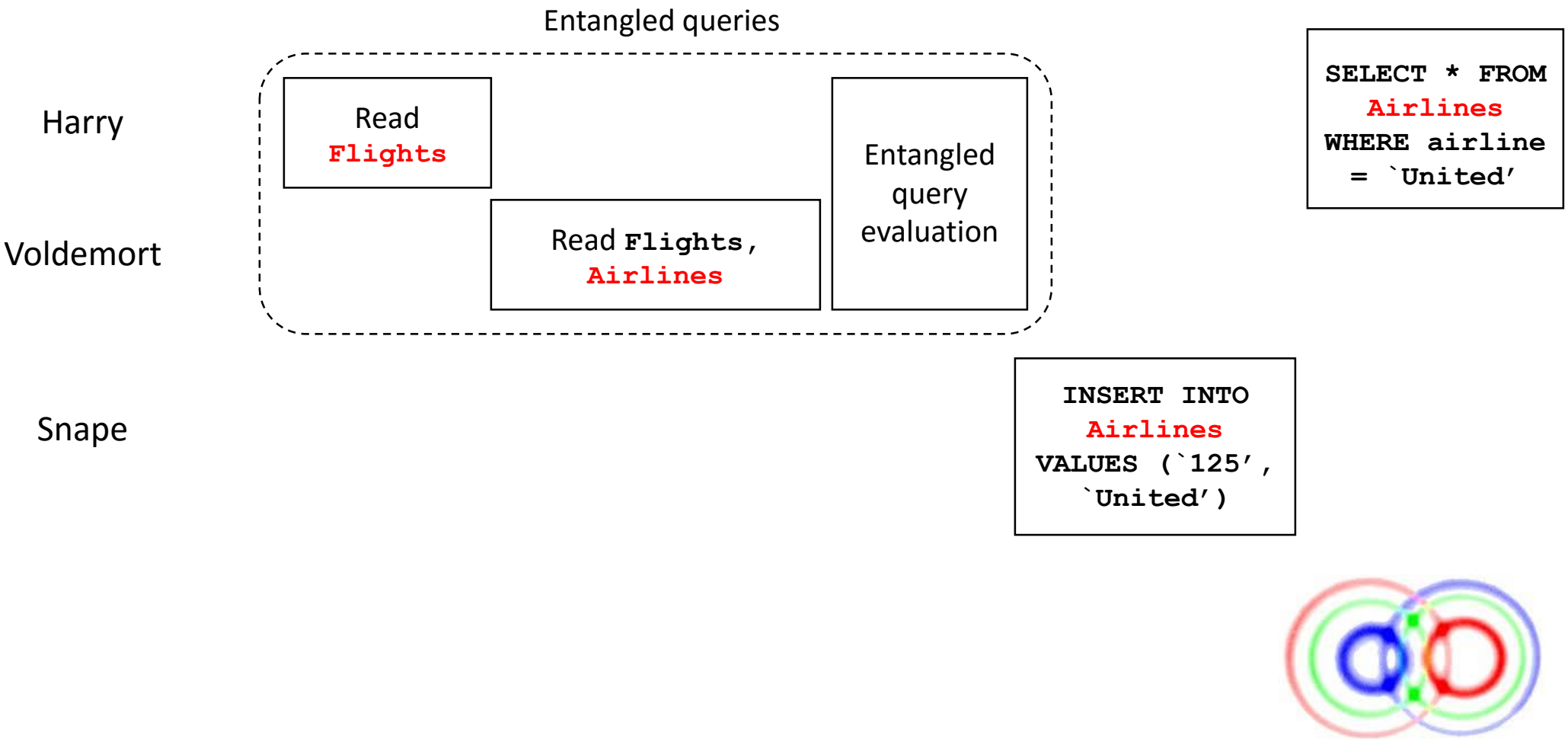


New Anomaly 1: Widowed Transactions



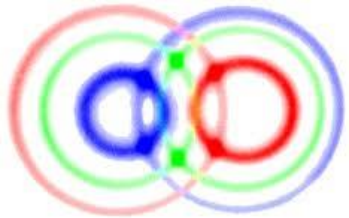


New Anomaly 2: Unrepeatable Quasi-Reads



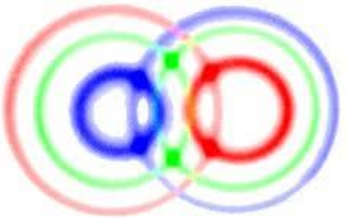
Eliminating These Anomalies

- How to avoid widowed transactions?
  - Group commit of all the transactions that are connected through entangled queries
- Unrepeatable quasi-reads
  - Appropriate locking of data structures



Putting Everything Together

- Traditional ACID Properties:
  - Atomicity
  - Consistency → Oracle Consistency
  - Isolation → Two new phenomena
  - Durability
- We can now define
  - Oracle-serializability: Serial schedule with a suitable oracle that provides answers to entangled queries
  - Entangled isolation: Schedule does not have any anomalies
- Putting everything together: Any schedule that is entangled-isolated is also oracle-serializable
- Integrates existing transactions and entangled transactions seamlessly



Putting Everything Together (Contd.)

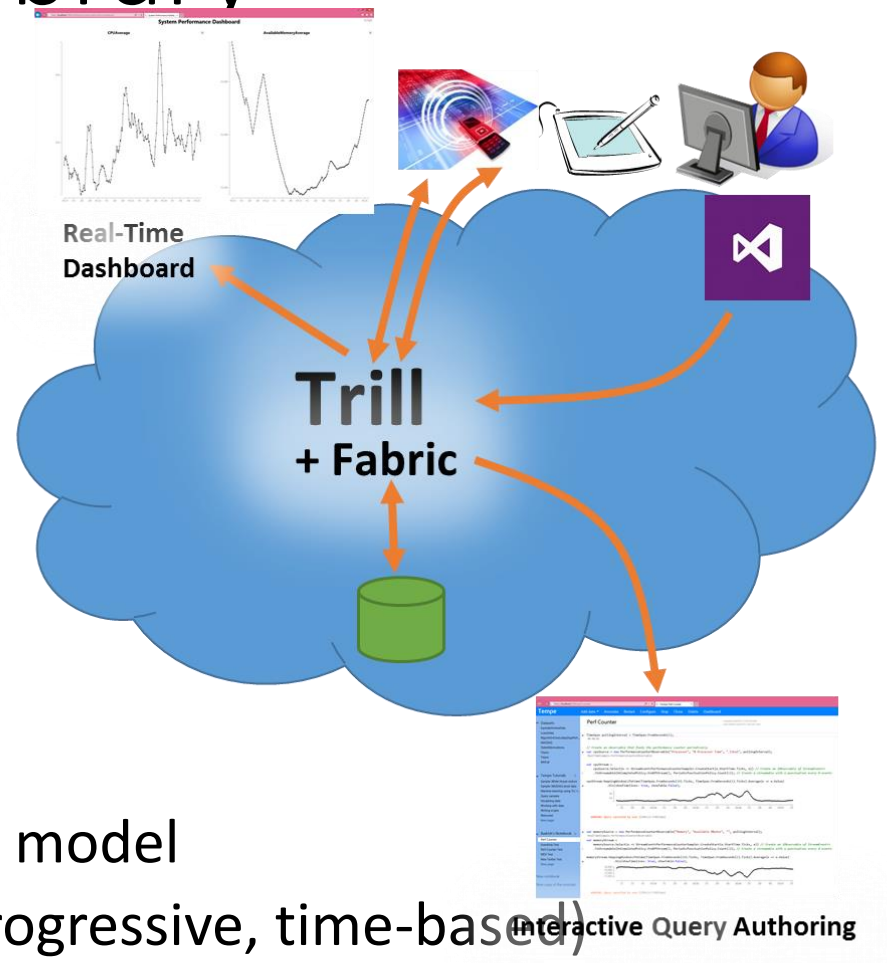
- We are starting to understand the basics of low-level cloud abstractions, their performance and how new hardware impacts them
  - This is also a research pattern that we understand well
- But we are just starting to understand higher-level programming/ML abstractions
  - I talked about coordination
  - We see in general a need for ranking, recommendation, talking to devices, security, etc.
  - This is a much less understood research pattern

This Talk

- Scalable transactions with FARM
- Collaboration through data-driven coordination
- MSR Impact in Big Data

Trill: Fast Streaming Analytics Library

- Performance
  - 2-4 **orders of magnitude** faster than traditional SPEs
  - For relational queries, comparable to best DBMS
  - User-controlled latency specification
    - explicit latency vs. throughput tradeoff
- Fabric & language integration
  - Built as high-level language (HLL) library component
  - Works with arbitrary HLL data-types & libraries
- Query model
  - Extended LINQ syntax based on tempo-relational query model
  - Supports broad & rich analytics scenarios (relational, progressive, time-based)



Trill's Use Cases

- Azure Stream Analytics Cloud service
- With Scope for Bing Ads
- With Orleans for Halo game monitoring & debugging
- …

- Key enabler: performance + fabric & language integration + query model

http://research.microsoft.com/en-us/projects/trill/

Orleans

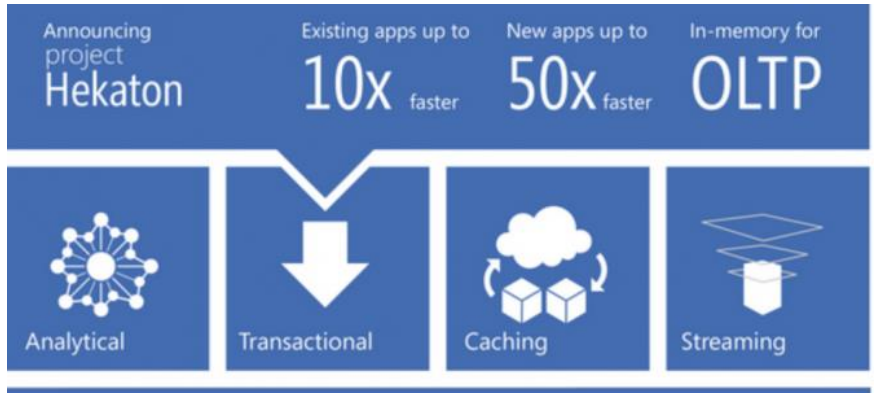
- Orleans distributed agent platform: http://github.com/dotnet/orleans
  - Halo Reach (Nov. 2011) Halo 4 (Dec. 2012), Halo 5 (Oct. 2015)
    - All back end services: Players, games, statistics, regions, scoreboards, ….
    - 10s of services, 10s to 100s of machines each, 100Ks of requests per second
    - Bursty load (evenings, weekends) and peak load at product launch
  - Orleans public preview, April 2014. Open source in GitHub, January 2015.
  - Other Microsoft users: Skype, Azure, MSN, Game Studios (many games), …
    - Examples: intelligent cache, telemetry, user profiles.
  - Many 3rd parties: Honeywell, Mesh Systems (IoT), Gigya (identity mgmt), …

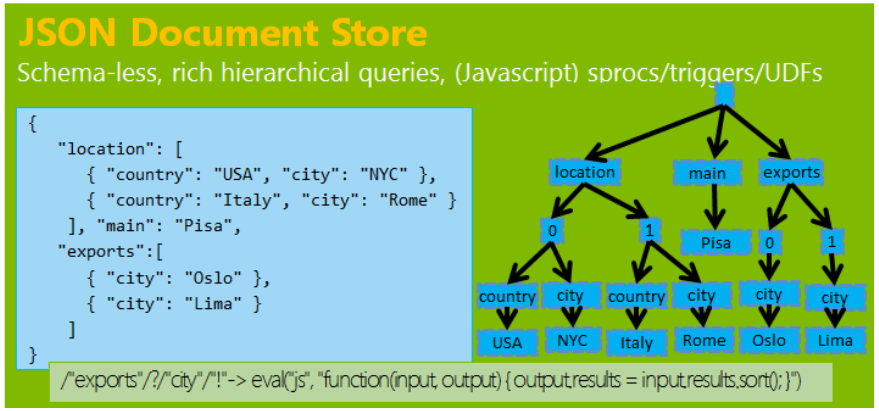
References:

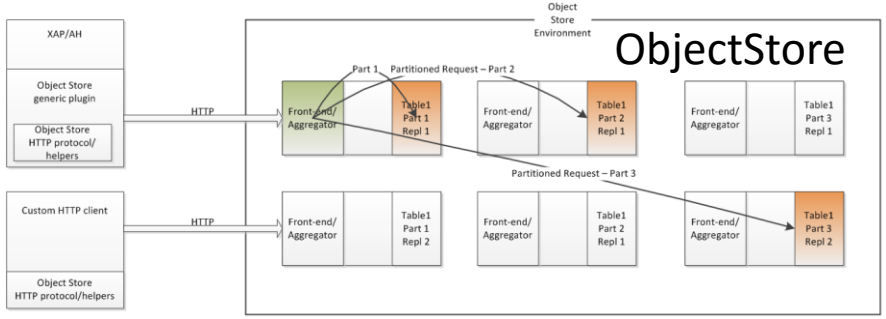
- Philip A. Bernstein, Sergey Bykov, Alan Geller, Gabriel Kliot, and Jorgen Thelin, Orleans: Distributed Virtual Actors for Programmability and Scalability, no. MSR-TR-2014-41, 24 March 2014.
- http://research.microsoft.com/en-us/projects/orleans/

Bw-Tree/LLAMA

- Key-sequential index in SQL Server Hekaton
  - Lock-free for high concurrency, consistent with Hekaton's overall non-blocking main memory architecture
- Indexing engine in Azure DocumentDB
  - Rich query processing over a schema-free JSON model, with *automatic indexing*
  - Sustained document ingestion at high rates
- Sorted key-value store in Bing ObjectStore
  - Support range queries
  - Optimized for flash SSDs
- http://research.microsoft.com/deuteronomy/

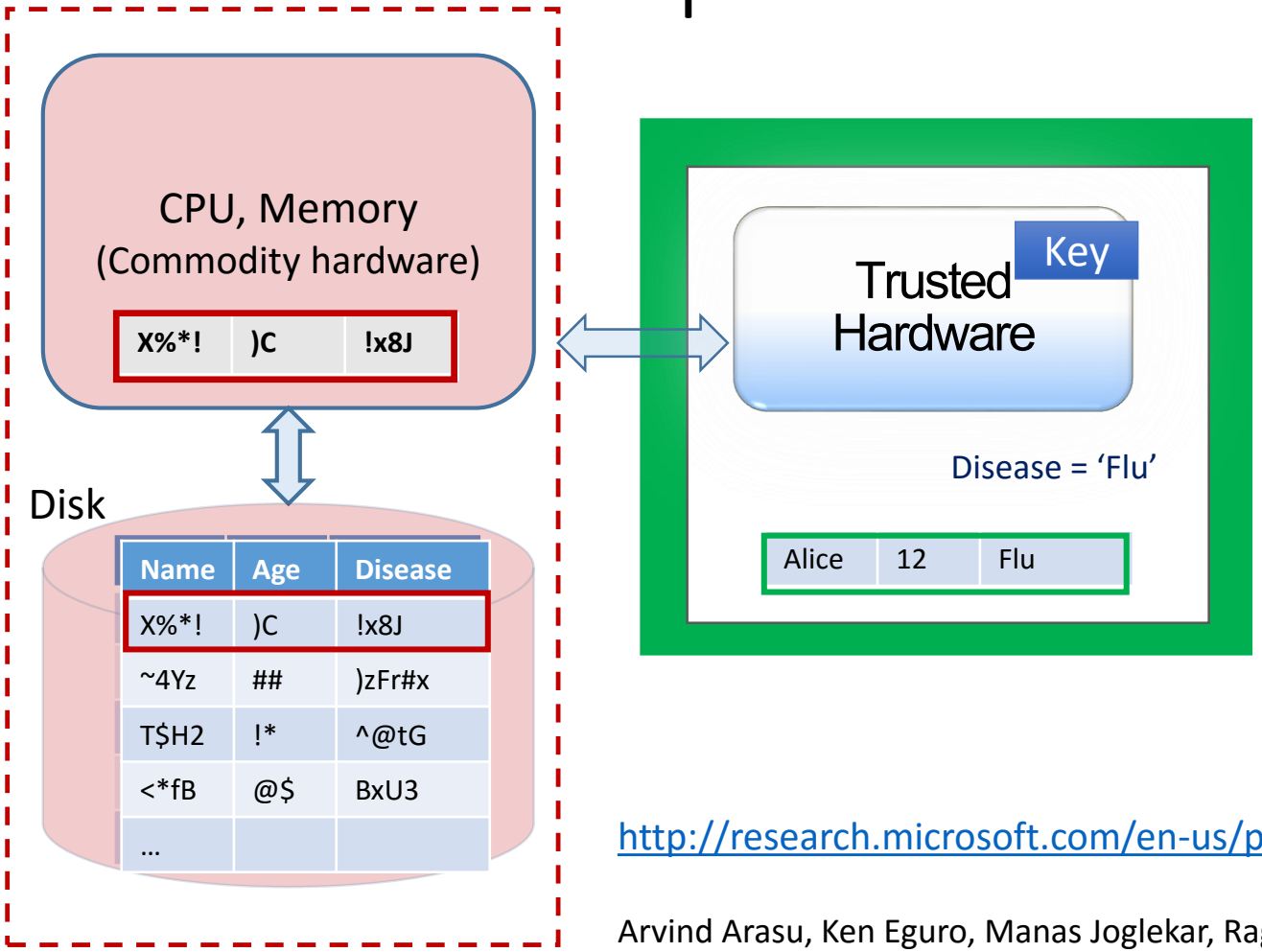






Cipherbase

Untrusted Machine



Secure Co-Processor

http://research.microsoft.com/en-us/projects/cipherbase/

Arvind Arasu, Ken Eguro, Manas Joglekar, Raghav Kaushik, Donald Kossmann, Ravi Ramamurthy: Transaction processing on confidential data using cipherbase. ICDE 2015: 435-446

Arvind Arasu, Spyros Blanas, Ken Eguro, Raghav Kaushik, Donald Kossmann, Ravishankar Ramamurthy, Ramarathnam Venkatesan: Orthogonal Security with Cipherbase. CIDR 2013

Summary

- We are pushing the boundaries on scale, performance
  - Office Graph, Delve, Microsoft infrastructure
- We are looking for ways to make our developers and customers more efficient through high-level abstractions
- ASG/MSR have a great collaboration in many areas
  - Now only performance improvements, but new classes of problems

Thank You

johannes@microsoft.com

References

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  - Aleksandar Dragojevic, Dushyanth Narayanan, Miguel Castro, Orion Hodson: FaRM: Fast Remote Memory. NSDI 2014: 401-414
  - Aleksandar Dragojevic, Dushyanth Narayanan, Edmund B. Nightingale, Matthew Renzelmann, Alex Shamis, Anirudh Badam, Miguel Castro: No compromises: distributed transactions with consistency, availability, and performance. SOSP 2015: 54-70
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  - Sudip Roy, Lucja Kot, Gabriel Bender, Bailu Ding, Hossein Hojjat, Christoph Koch, Nate Foster, Johannes Gehrke: The Homeostasis Protocol: Avoiding Transaction Coordination Through Program Analysis. SIGMOD Conference 2015: 1311-1326
  - Konstantinos Mamouras, Sigal Oren, Lior Seeman, Lucja Kot, Johannes Gehrke: The Complexity of Social Coordination. PVLDB 5(11): 1172-1183 (2012)
  - Nitin Gupta, Milos Nikolic, Sudip Roy, Gabriel Bender, Lucja Kot, Johannes Gehrke, Christoph Koch: Entangled Transactions. PVLDB 4(11): 887-898 (2011)
  - Nitin Gupta, Lucja Kot, Sudip Roy, Gabriel Bender, Johannes Gehrke, Christoph Koch: Entangled queries: enabling declarative data-driven coordination. SIGMOD Conference 2011: 673-684