Dependability and Security with Clouds-of-Clouds

lessons learned from *n* years of research

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WORKSHOP ON DEPENDABILITY AND INTEROPERABILITY IN HETEROGENEOUS CLOUDS (DIHC13)
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Outline

- Motivation
- Opportunities and challenges
- Storage – DepSky
- Processing – BFT MapReduce
- Services – EBAWA
- Conclusions

3 example clouds-of-clouds

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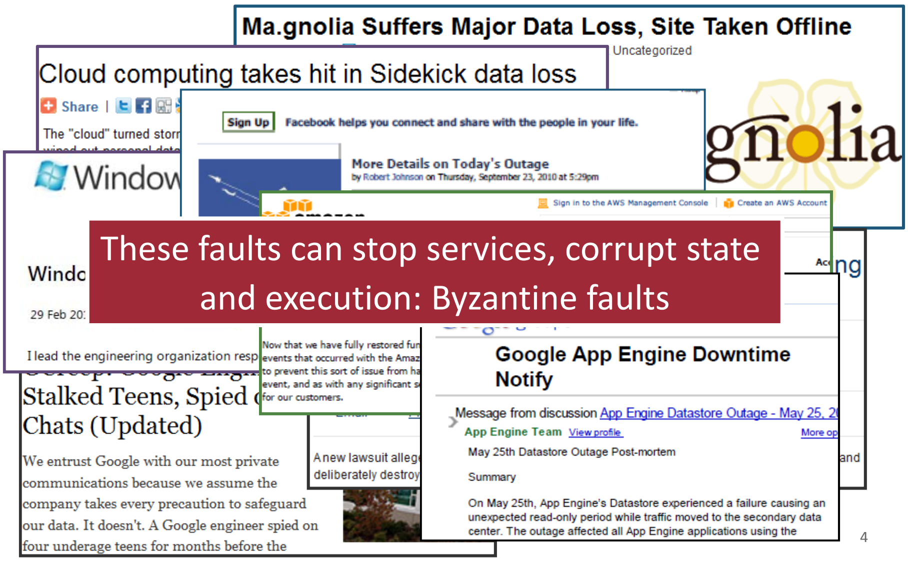
Clouds are complex so they fail



These faults can stop services, corrupt state and execution: Byzantine faults

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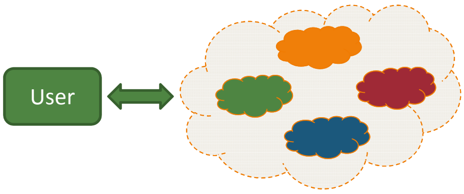
Cloud-of-Clouds

- Consumer runs service on a set of clouds forming a virtual cloud, what we call a cloud-of-clouds
- Related to the notion of federation of clouds
  - "Federation of clouds" suggests a virtual cloud created by providers
  - "Cloud-of-clouds" suggests a virtual cloud created by consumers, possibly for improving dep&sec



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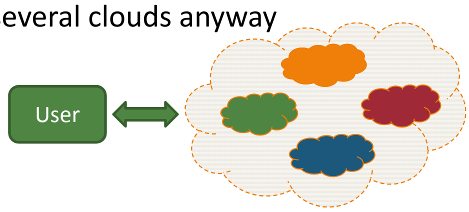
Cloud-of-Clouds dependability+security

- There is cloud redundancy and diversity
- so even if some clouds fail a cloud-of-clouds that implements replication can still guarantee:
  - Availability – if some stop, the others are still there
  - Integrity – they can vote which data is correct
  - Disaster-tolerance – clouds can be geographically far
  - No vendor lock-in – several clouds anyway



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Replication / geo-replication in clouds

- Provides opportunities and challenges
- Some data from Amazon EC2
  - Not different clouds but close enough
  - Data collected ~hourly during August 2-15, 2013
  - One micro instance (virtual server) per Amazon region

Geographical redundancy and diversity

Amazon EC2 regions and availability zones

- Each region is completely independent
- Each availability zone (AZ) is isolated
- Note: personal map, positions may not be accurate

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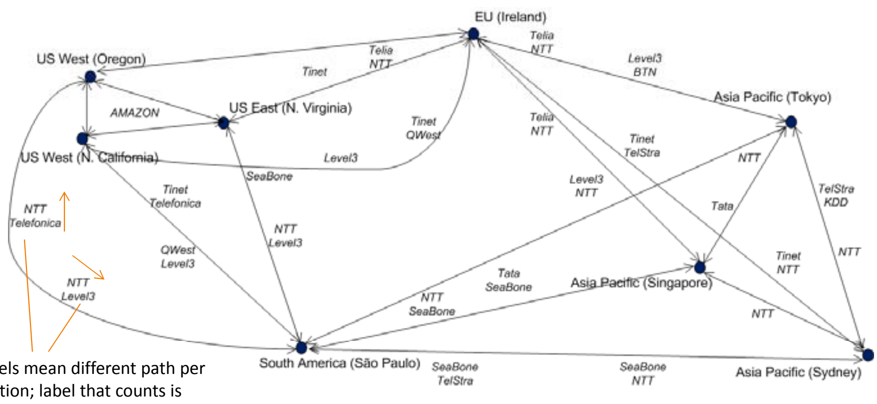
Network redundancy and diversity



2 labels mean different path per direction; label that counts is the closest to the destination

- ASs provide another level of diversity (most ISPs have more than one)
- ISPs observed on the August 2nd (a few changes were observed in 2 weeks)
- This is not the complete graph, several edges are missing

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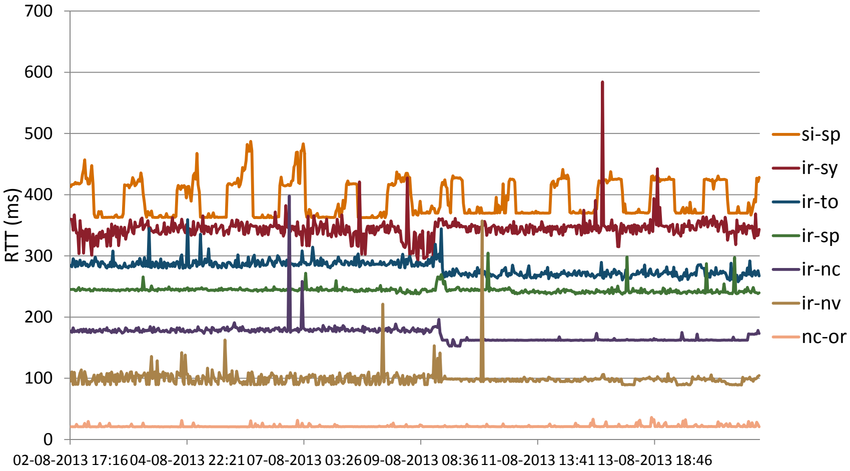
Latency: high and variant



Compare with 0.2ms in an Ethernet LAN…

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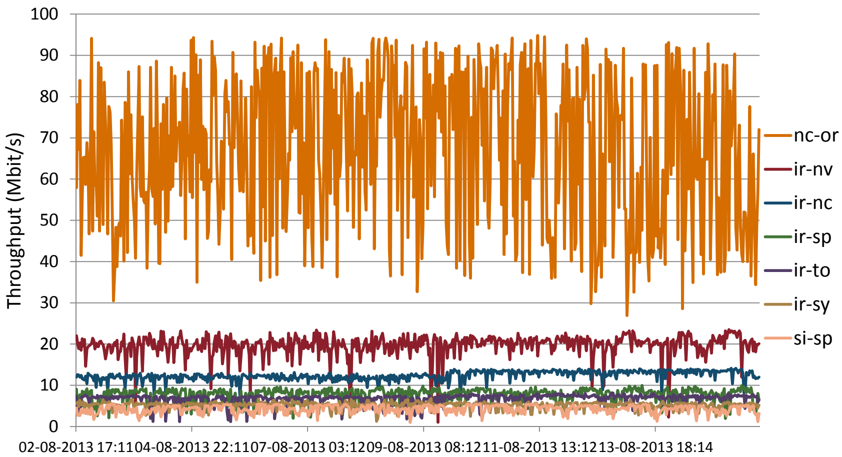
Throughput: low and variant



- Same pairs as in previous slide but opposite order
- Important: the throughput is higher with better instances (we used *micro*)

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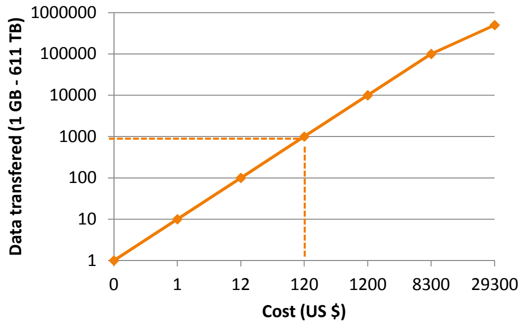
Economic cost (data transfer)

- Cost for data transfer IN to EC2 from Internet: 0 $
- Cost for data transfer OUT from EC2 to Internet:
  - Vertical axis is data transferred and has logarithmic scale



Data obtained on Aug. 2013 at http://aws.amazon.com/ec2/pricing/

CAP theorem

- It is impossible for a web service to provide the following three guarantees:
  - Consistency
  - Availability
  - Partition-tolerance
- Network diversity suggests partitions are unlikely
  - Nodes may get isolated but not sets of nodes from others
  - But relaxed consistency may be offered in they happen
  - Current research topic; we won't address it

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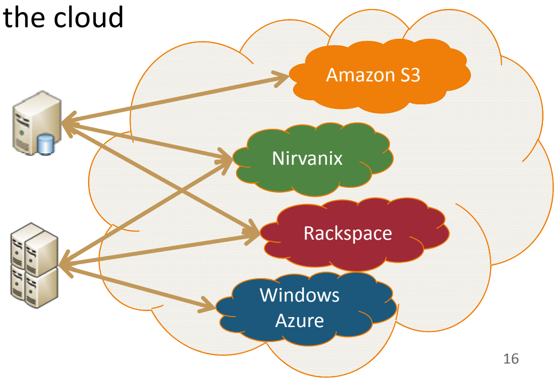
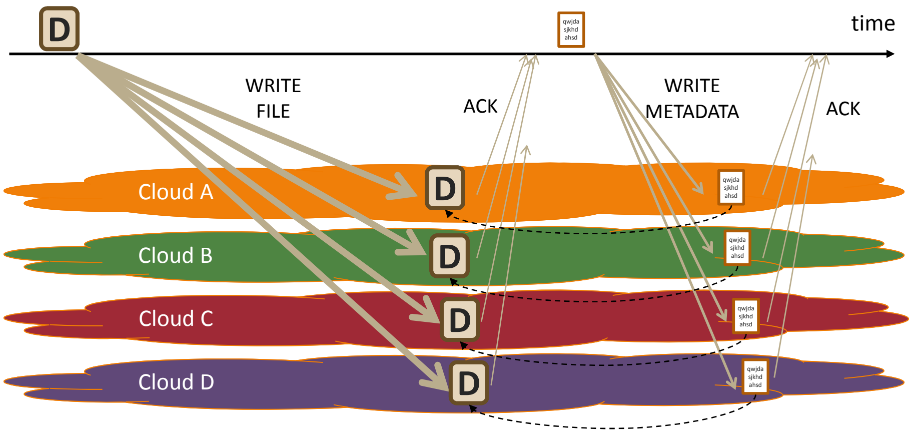
DepSky

- (Client-side) library for cloud-of-clouds storage
  - File storage, similar to Amazon S3: read/write data, etc.
- Use storage clouds as they are:
  - No specific code in the cloud
- Data is updatable
  - Byzantine quorum replication protocols for consistency



Write protocol



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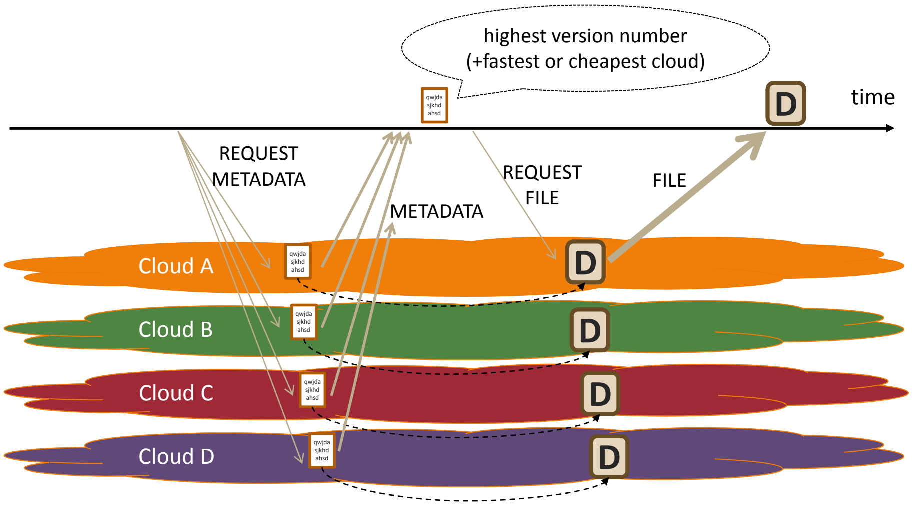
Read protocol



File is fetched from other clouds if signature doesn't match the file

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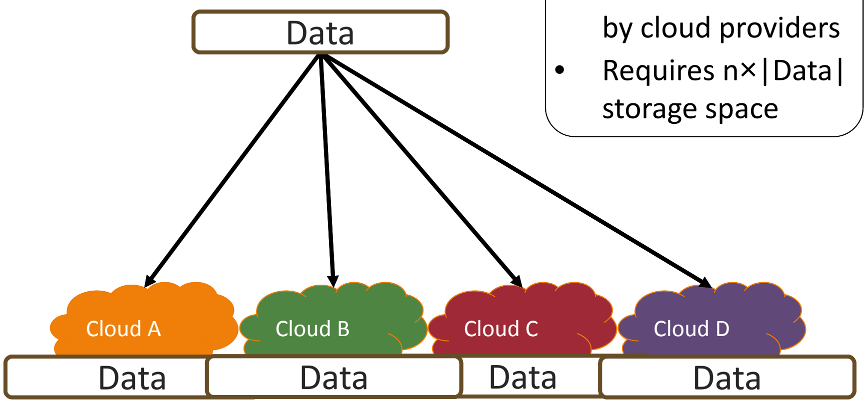
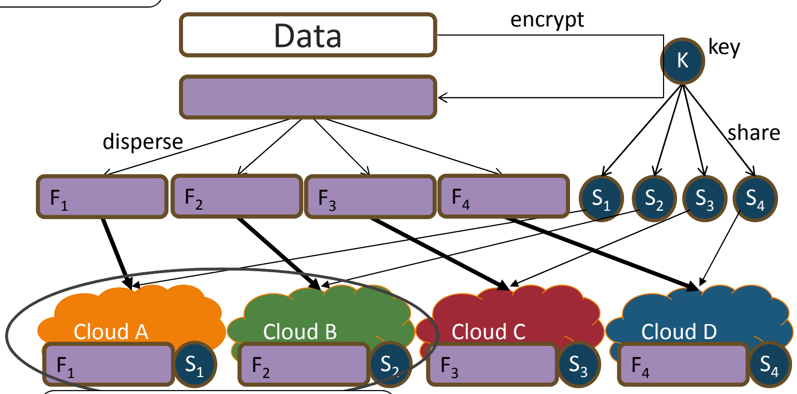
Limitations of the solution so far

- Data is accessible by cloud providers
- Requires n×|Data| storage space



Combining erasure codes and secret sharing

Only for data, not metadata



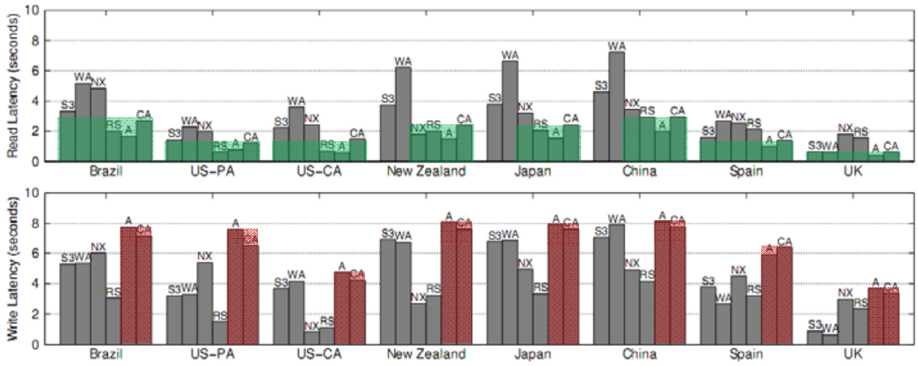
Encrypted so data can't be read at a cloud!

Only twice the size of storage, not 4 times!

DepSky latency

100KB files, clients in PlanetLab nodes

DepSky **read** latency is close to the cloud with the **best** latency



DepSky **write** latency is close to the cloud with the **worst** latency

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Lessons from Depsky

- Provides: availability, integrity, disaster-tolerance, no vendor lock-in, confidentiality
- Insights:
  - Some clouds can be faulty so we need Byzantine quorum system protocols (to reason about subsets of clouds)
  - Signed data allows reading from a single cloud, so faster or cheaper than average
  - Erasure codes can reduce the size of data stored
  - Secret sharing can be used to store cryptographic keys in clouds (avoiding the need of a key distribution service)

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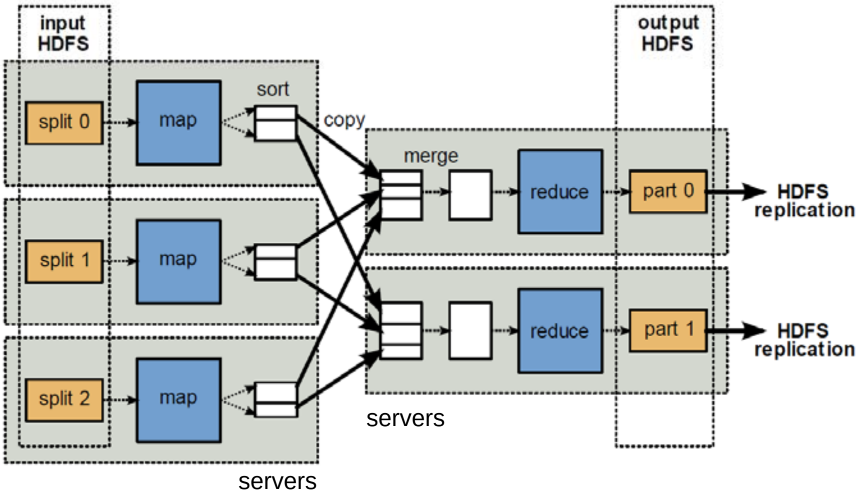
What is MapReduce?

- Programming model + execution environment
  - Introduced by Google in 2004
  - Used for processing large data sets in clusters of servers
- Hadoop MapReduce, an open-source MapReduce
  - The most used, the one we have been using
  - Includes HDFS, a file system for large files

MapReduce basic idea



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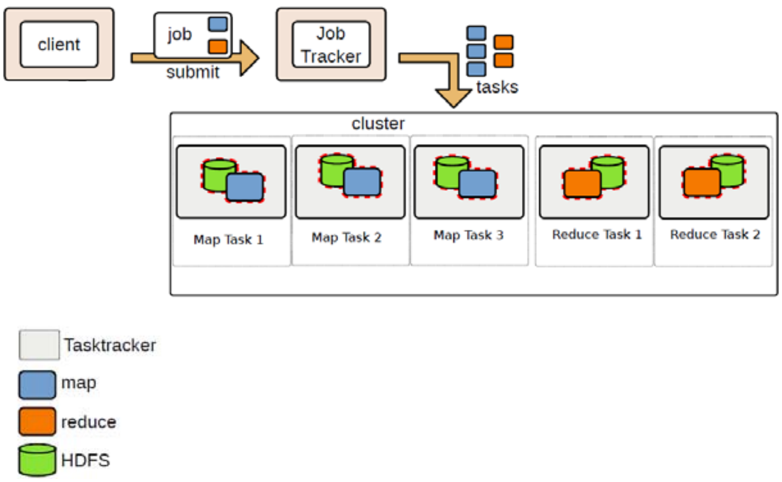
Job submission and execution



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The problem

- The original Hadoop MR tolerates the most common faults
  - Job tracker detects and recovers crashed/stalled map/reduce tasks
  - Detects corrupted files (a hash is stored with each block)
- But execution can be corrupted, tasks can return wrong output
- and clouds can suffer outages

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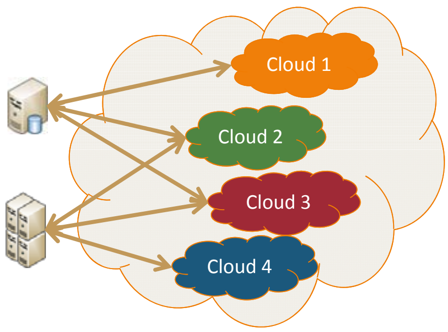
BFT MapReduce

- Basic idea: to replicate tasks in different clouds and vote the results returned by the replicas
  - Inputs initially stored in all clouds



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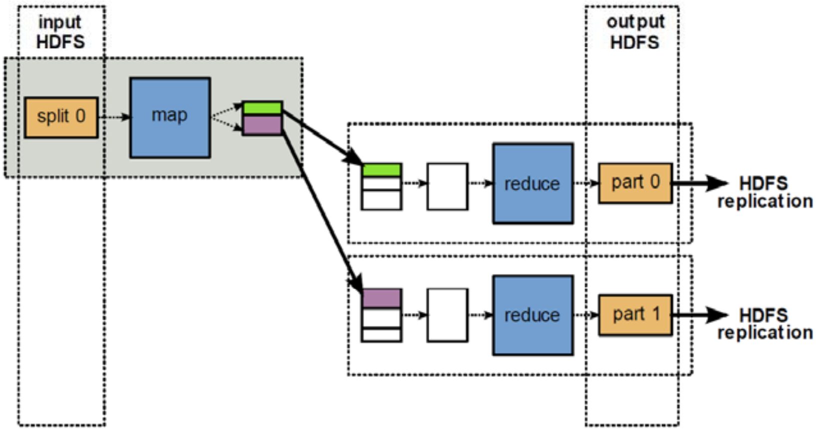
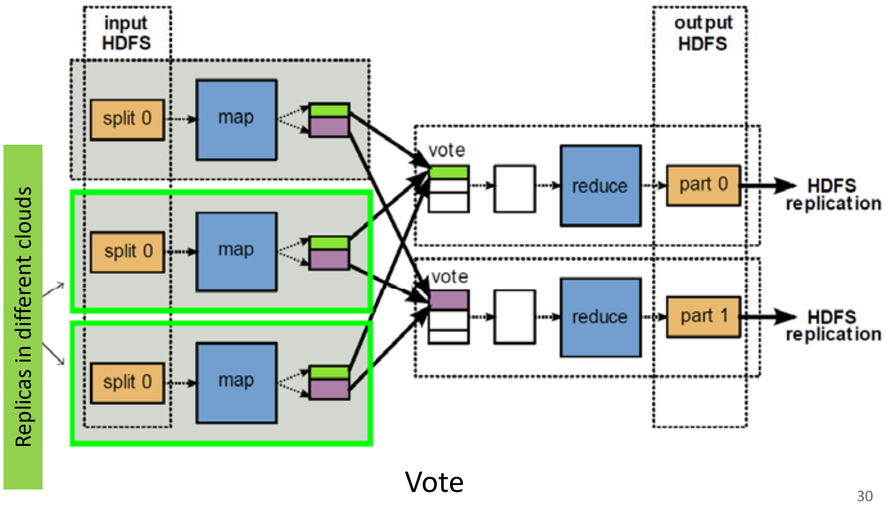
Original MR – Map perspective

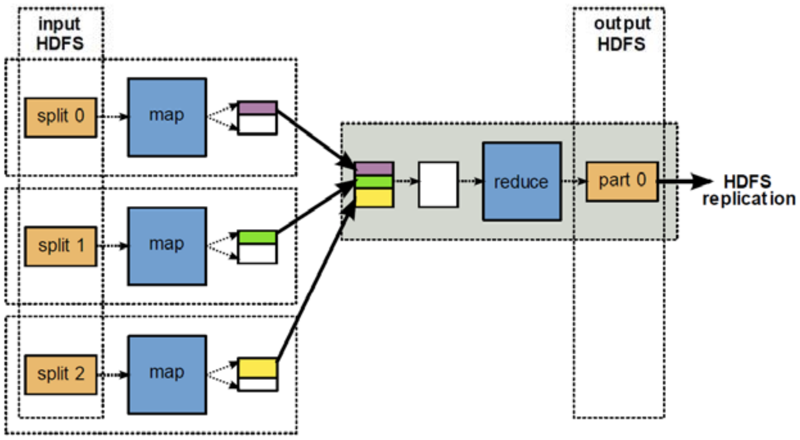


BFT MR – Map perspective



Vote

Original MR – Reduce perspective



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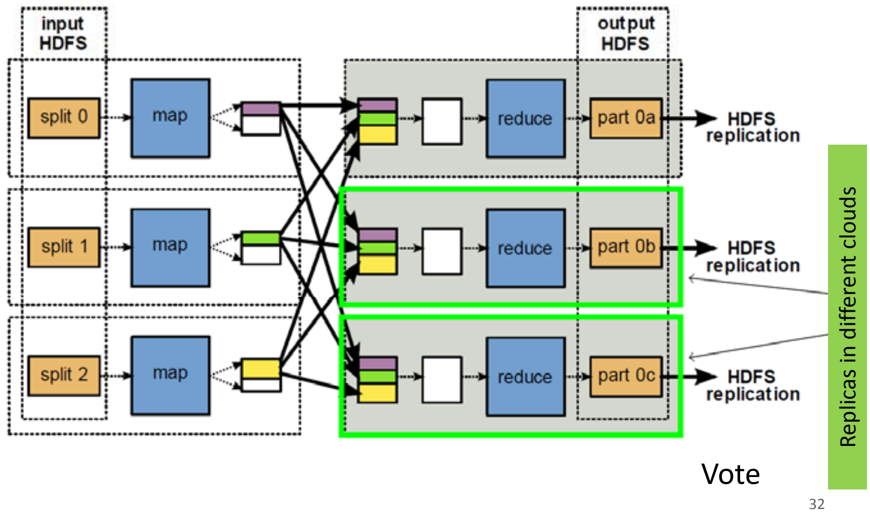
BFT MR – Reduce perspective



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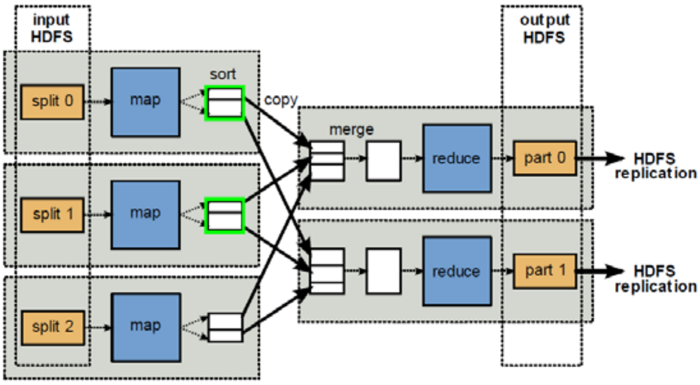
Deferred execution

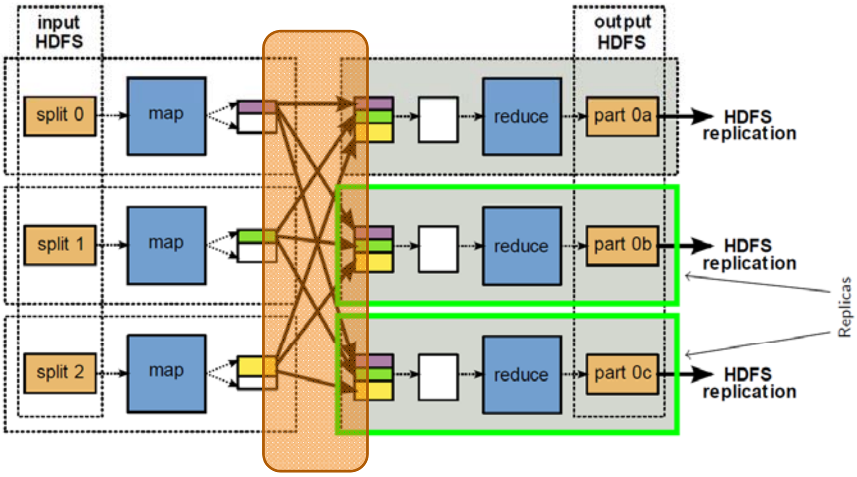
- Faults are uncommon; consider max. of *f* faults
- JT creates only *f+1* replicas in *f+1* clouds (*f* in standby)
- If results differ or one cloud stops, request 1 more (up to *f*)



Distributed job tracker

- Job tracker controls all task executions in the task trackers (e.g., start task, detect faults)
  – If job tracker is in one cloud, separated from many task trackers by the internet
    - high latency to control operations
    - single point of failure
- Distributed job tracker
  – Each cloud has one job tracker (JT)
  – Each JT controls the tasks in its cloud, no “remote control”

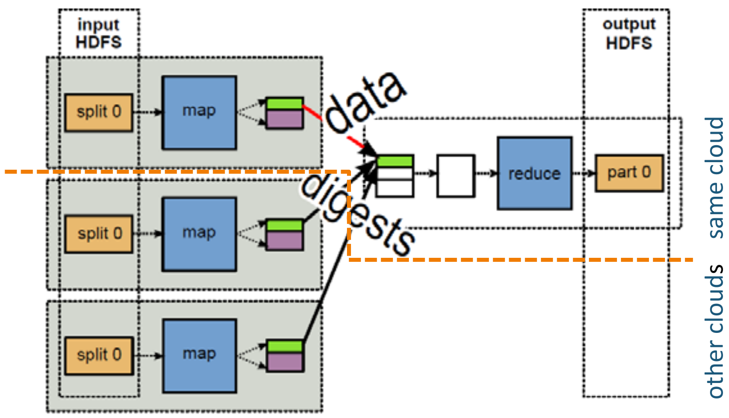
WAN communication



- All this communication through the WAN => high delay and $ cost
  - data transferred per pair can even be the size of the split (e.g., MBs)

Solution: digest communication

- Reduces fetch the map task outputs
  - Intra-cloud fetch: output fetched normally
  - Inter-cloud fetch: only hash of the output fetched



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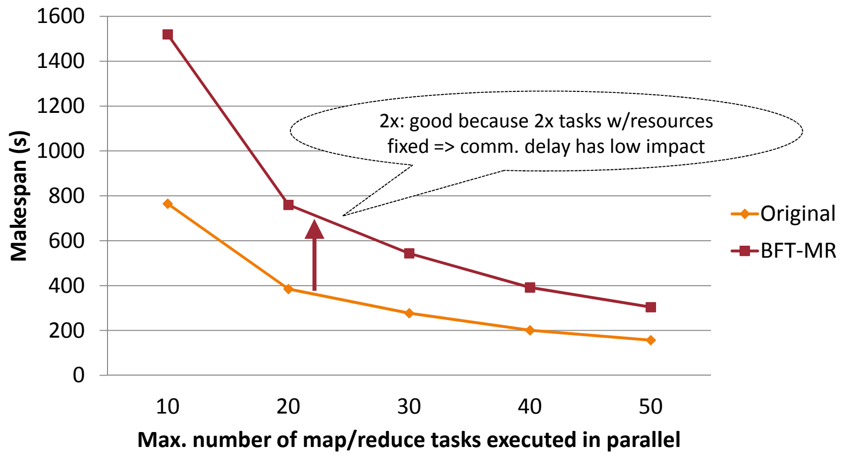
Makespan varying parallelism



- Estimated analytically based on another BFT-MR we implemented; *f=1*

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Lessons from BFT MapReduce

- Provides: availability, integrity, disaster-tolerance, no vendor lock-in (no confidentiality)
- Insights:
  – Tasks can be replicated in different clouds to mask faulty executions / faulty clouds
  – Defer execution to reduce # tasks executed without faults
  – Control components should be placed in all clouds to avoid control operations between clouds (high delays)
  – Send only digests between clouds to avoid huge communication delays and costs

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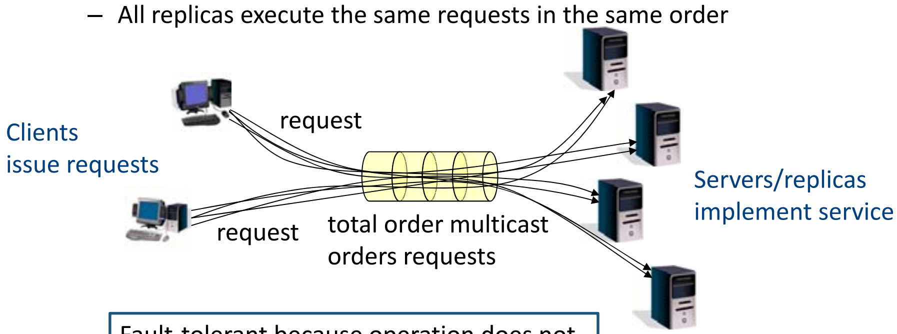
State Machine Replication (SMR)

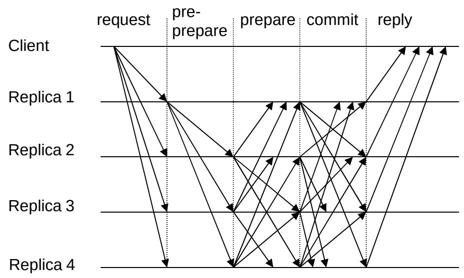
- Can be used to replicate "any" service
  - Ex: file sys., k.v. store, DBs, authentication serv., coordination serv.,…
  - All replicas start in the same state
  - All replicas execute the same requests in the same order



Fault-tolerant because operation does not depend on all replicas, *f* can be faulty

BFT SMR is expensive in WANs

- Example: PBFT (Castro&Liskov'99)
  - Several communication steps, messages, votes
  - Ok for LANs but if steps are through a WAN…



f=1

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EBAWA

Efficient Byzantine Algorithm for Wide Area networks

- EBAWA is a BFT SMR algorithm like PBFT…
- …but with a set of mechanisms for making it efficient in WANs…
- …which make it adequate for clouds-of-clouds

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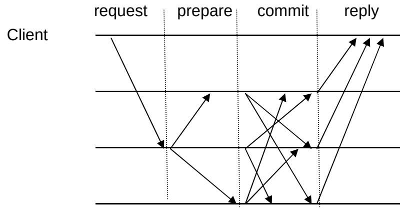
Unique Sequential Identifier Generator service (USIG)

- Replicas include a trusted module: USIG
  - Local module, implemented to be trusted (e.g., in hardware), simple interface
  - Simple: monotonic counter + cryptographic mechanism
- Interface:
  - createUI: assigns a signed unique identifier to a message m
  - verifyUI: checks if the unique id is valid for message m

Benefits of USIG

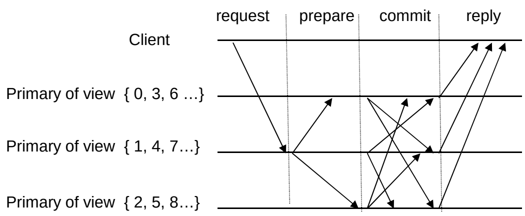
- USIG prevents certain kinds of faults/misbehavior
  - Faulty replicas can't send 2 messages with the same id
- This allows cutting:
  - The number of servers from *3f+1* to *2f+1*
  - Number of communication steps by one (lower latency)
- Together they greatly reduce the #messages:

f=1



Rotating primary

- The primary only orders a batch of requests per view, then the next replica becomes the primary
  - Prevents performance attacks (e.g., faulty server slows down service) – critical in WANs due to high timeouts
  - Reduces latency as client can access the closest replica
  - Provides load balancing



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Asynchronous views

- A replica starts an agreement as soon as it receives a client request by sending a prepare message
  - Servers without pending client requests skip their turn by sending a special message

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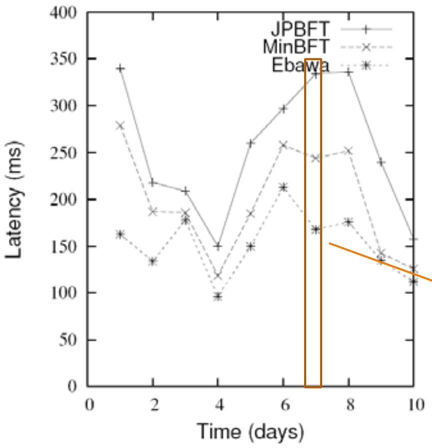
Performance in PlanetLab – Europe



- Nodes:
  - Portugal (client)
  - France
  - Italy
  - Germany (primary)
  - Spain
- EBAWA avg. latency 43% lower than JPBFT's

Lessons from EBAWA

- Provides: availability, integrity, disaster-tolerance, no vendor lock-in (no confidentiality)
- Insights:
  - Reducing the communication steps (with the USIG) reduces the latency
  - Reducing the number of replicas (with the USIG) reduces costs
  - Rotating the primary allows preventing performance attacks, load balancing, client can access closest replica (reduc. latency)
  - Asynchronous views reduce waiting, thus latency
  - Waiting for *n-f* clouds allows disregarding the *f* with higher RTT

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Lessons learned

- Clouds-of-clouds: solution for consumers to create dependable&secure clouds on top of cloud offerings
  - We've seen clouds-of-clouds for: storage, processing, services
- Usable or latency/cost too high?
  - Latency: if we disregard processing delays, the latency is a few RTTs, but the same with "normal" clouds (e.g., min 2 RTTs for an HTTP request)
  - Cost: higher, but dependability&security aren't free

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Lessons learned

- Important design goals:
  - to reduce the number of communication steps
  - to reduce the data sent out of the individual clouds
  - to reduce the number of messages
  - to reduce the size of the data stored
  - to reduce the number of replicas
  - to do control locally in every cloud
- We've seen several mechanisms to tackle these goals:
  - Byzantine quorum system protocols; auto-verifiable (signed) files; erasure codes; task replication; deferred task execution; local control components; digest communication between clouds; the USIG service; rotating primary; asynchronous views; waiting for *n-f* replicas

Thank you!

Further reading:

- My paper at DIHC 2013's post-proceedings
- A. N. Bessani *et al.* DepSky: Dependable and Secure Storage in a Cloud-of-Clouds. ACM Transactions on Storage, to appear (also at EuroSys 2010)
- M. Correia *et al.* On the Feasibility of Byzantine Fault-Tolerant MapReduce in Clouds-of-Clouds. In Proc. DISCCO 2012
- G. S. Veronese *et al.* EBAWA: Efficient Byzantine Agreement for Wide-Area Networks. In Proc. HASE 2010
- all available at: http://homepages.gsd.inesc-id.pt/~mpc/

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