State-Machine Replication for Planet-Scale Systems

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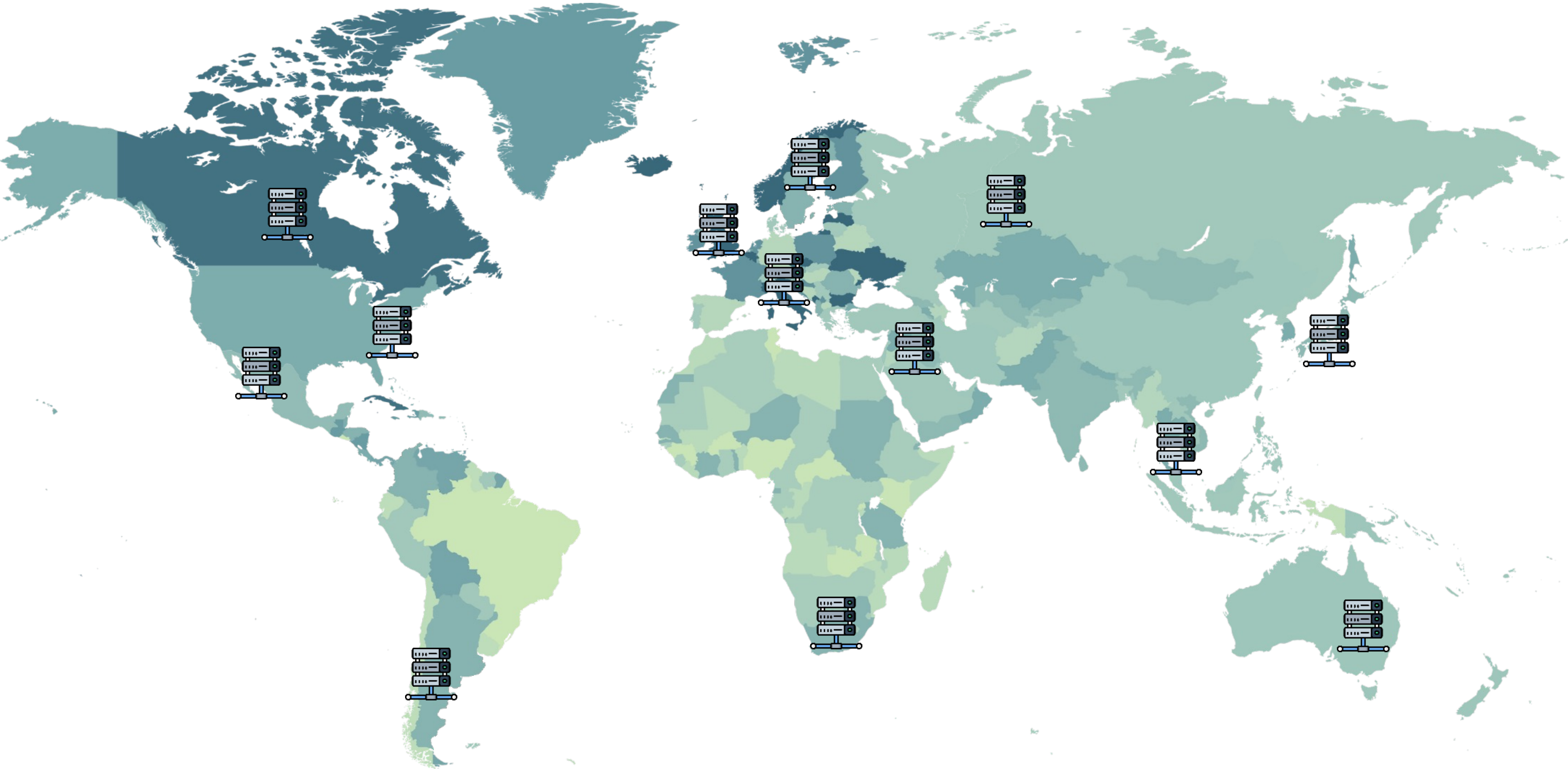
Presentation by **Yannis Marketakis**

In the context of HY559 (Computer Science Department, UOC)

In a nutshell

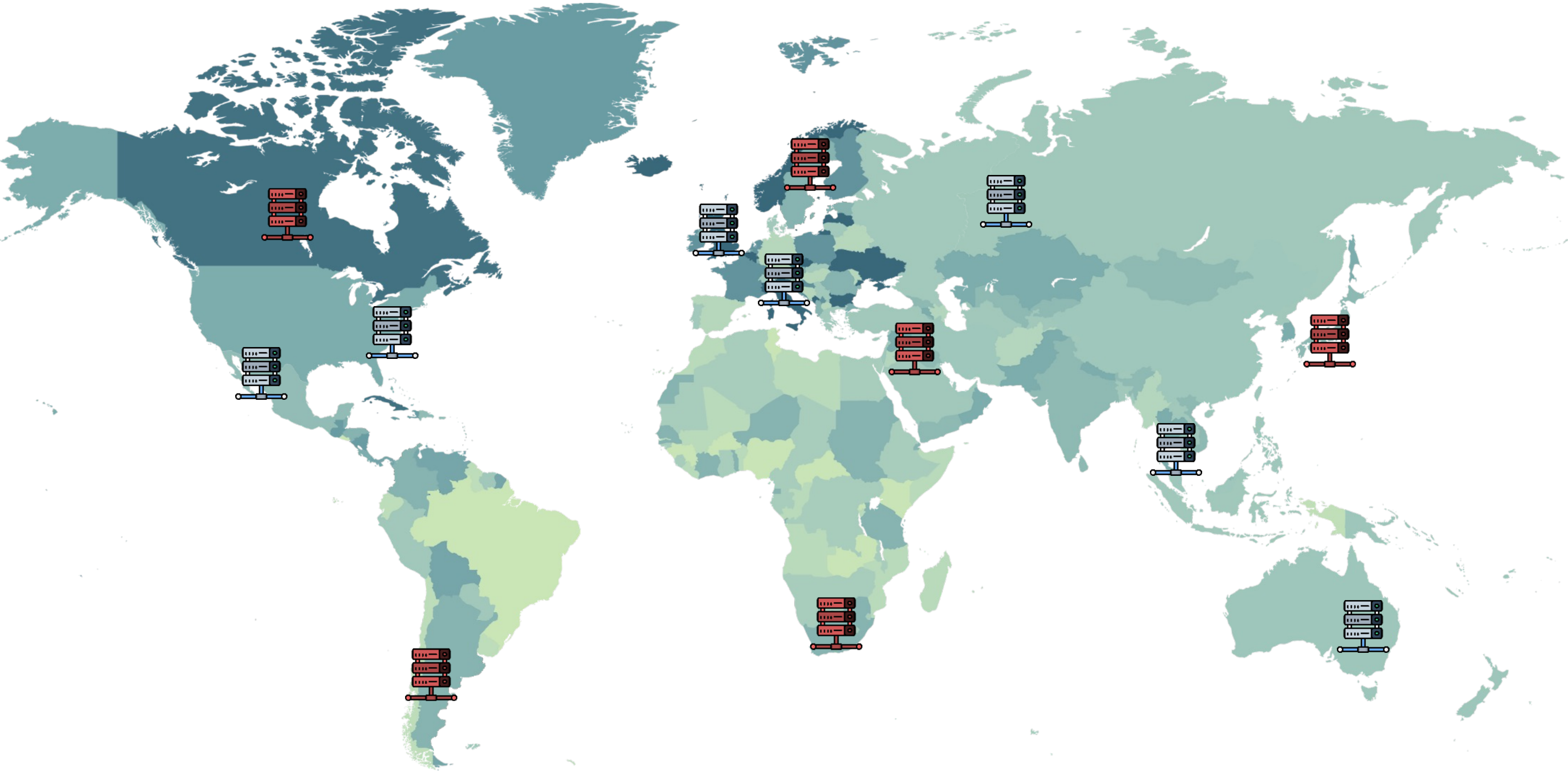
- The context
  - Applications that run at multiple sites scattered across the globe
- The problem
  - State-Machine Replication (SMR) protocols are poorly suited for planet-scale applications
  - Majorities might involve faraway replicas → increase client-perceived latency
- The contribution
  - The number of concurrent failures in geo-distributed systems is low (1 or 2)
- The results
  - Smaller fast quorums
  - Flexible fast path condition

Planet-Scale Systems



- Leader-based SMR are not ideal
  - Unfair for clients far away from the leader
  - Adding more sites does not help → the leader must replicate commands to more sites

The observation



- Common SMR protocols provide a level of fault tolerance that is unnecessarily high for geo-distributed systems
  - 6 out of 13 can fail concurrently

The observation

- The number of concurrent site-failures in geo-distributed systems is low: typically 1 or 2
- In general geo-distributed systems are designed to be resilient to failures (e.g. multiple servers in different regions)
- The idea: Separate the maximum number of failures (***f***) from the overall number of sites (***n***)

ATLAS

- A leaderless SMR protocol

- Similarly to other leaderless protocols (i.e. EPaxos, Mencius) it permits processing commands
  - In **one** round-trip using a *fast past*
  - In **two** round-trips using a *slow path*

- ATLAS main features
  - Use smaller fast quorums
  - Flexible *fast path* condition

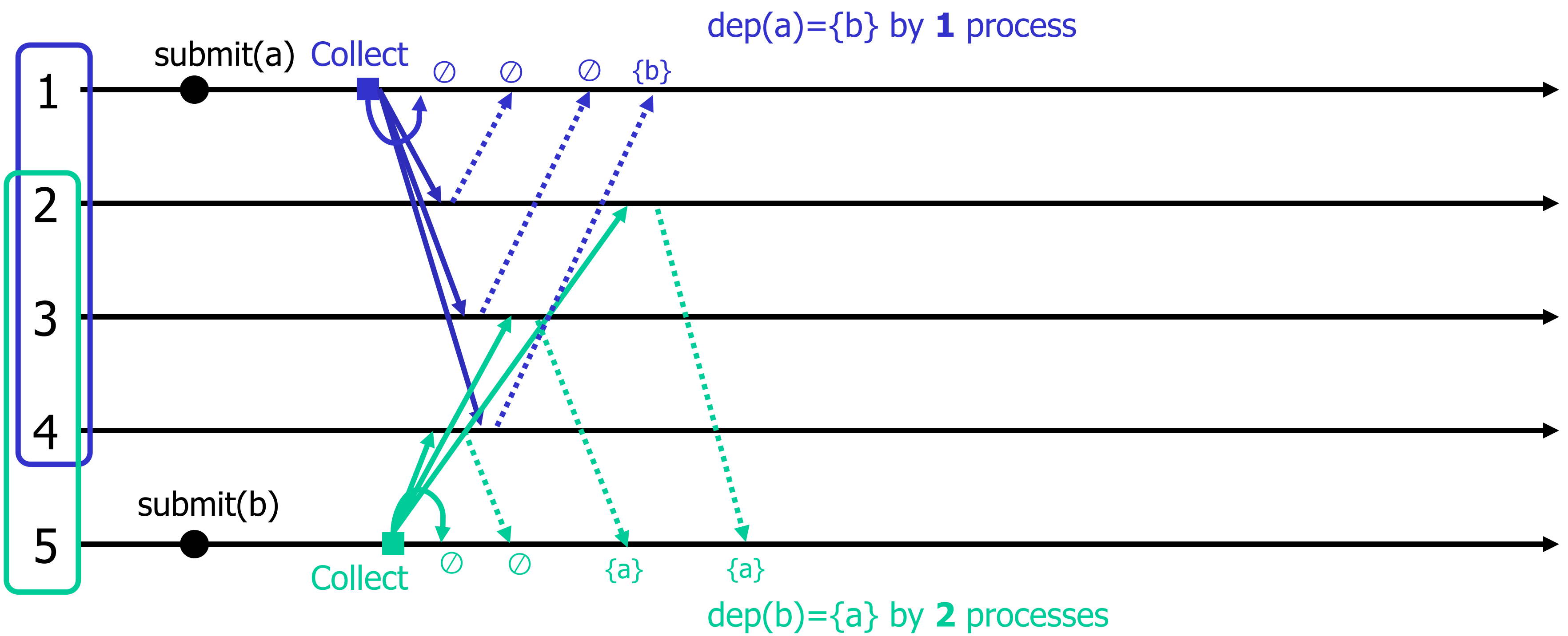
ATLAS – Smaller fast quorums

- Fast-quorums (bigger than a majority) increase latency due to far-away replicas

Protocol	Quorum
Generalized Paxos	$\frac{2n}{3}$
Epaxos	$\frac{3n}{4}$
ATLAS	$\frac{n}{2} + f$

- Smaller values of f
- → Smaller fast quorums
- → reduced latency
- → essential for planet-scale applications

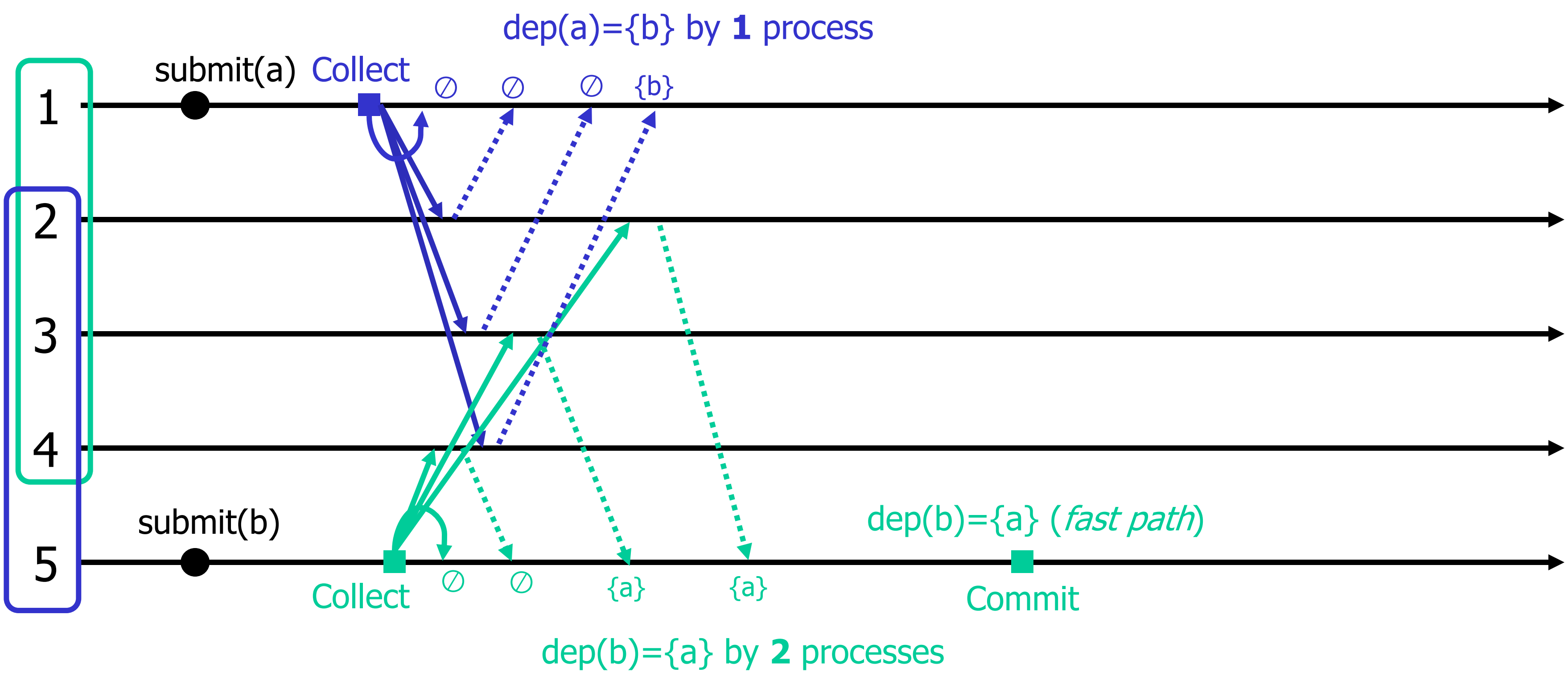
ATLAS example (n=5, f=2)



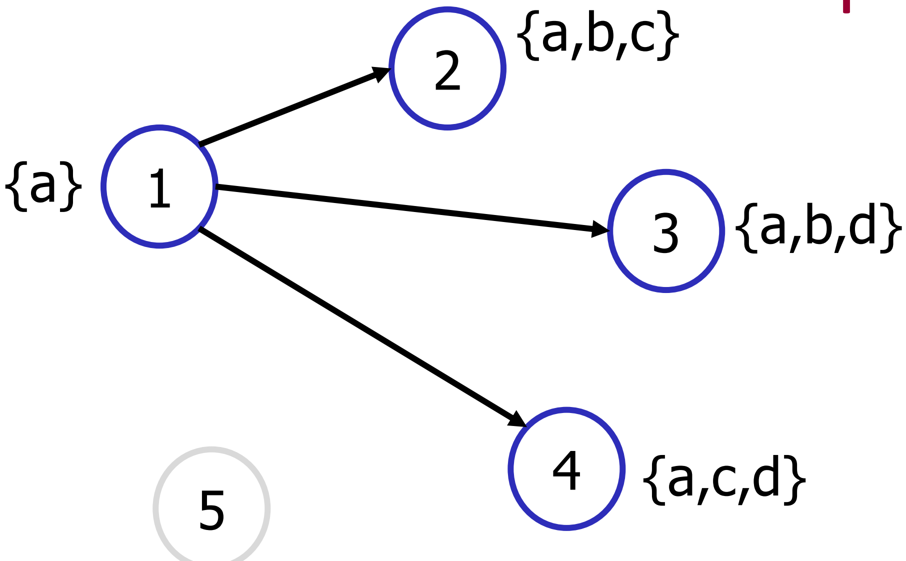
ATLAS – Flexible fast-path condition

- Take the *fast path* even when non-commuting commands are submitted concurrently
  - Allows processing more commands via the fast path
- Compared to existing approaches (GPaxos, EPaxos) ATLAS does not require fast-quorum replies to match exactly
  - It is enough if every dependency is reported by at least *f* processes
- With the provision of a (simpler) failure recovery mechanism
  - Recover decisions made by failed replicas while they were short-cutting via the fast path

ATLAS example (n=5, f=2)



ATLAS – Flexible fast-path condition example (*f*=2)



$$\bigcup_{Q} dep = \bigcup_{f} Q\ dep$$

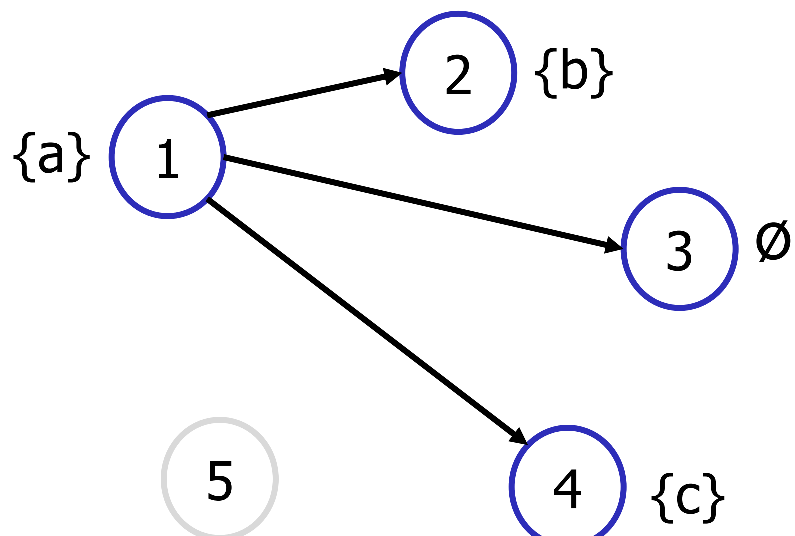
$$\{a,b,c,d\} = \{a,b,c,d\}$$

ATLAS: ✓ other SMR: ×

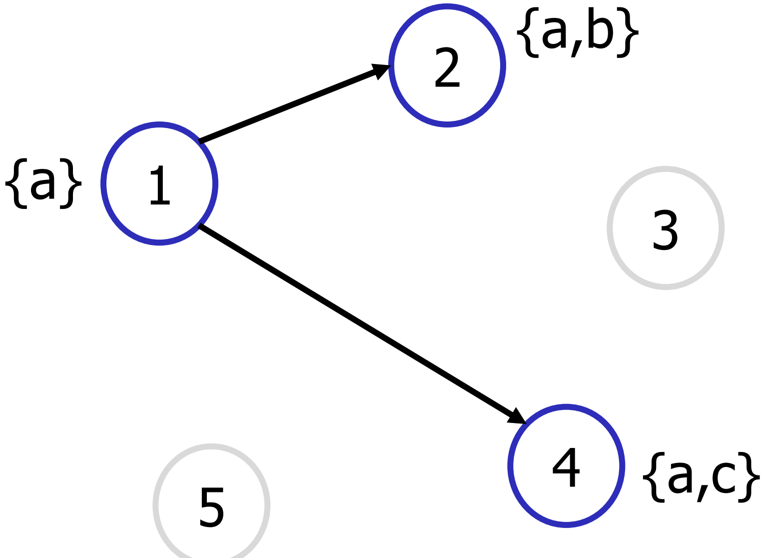
$$\bigcup_{Q} dep \neq \bigcup_{f} Q\ dep$$

$$\{a,b,c\} \neq \emptyset$$

ATLAS: × other SMR: ×



ATLAS – Flexible fast-path condition example (f=1)



$$\bigcup_{Q} dep = \bigcup_{f} Q\ dep$$

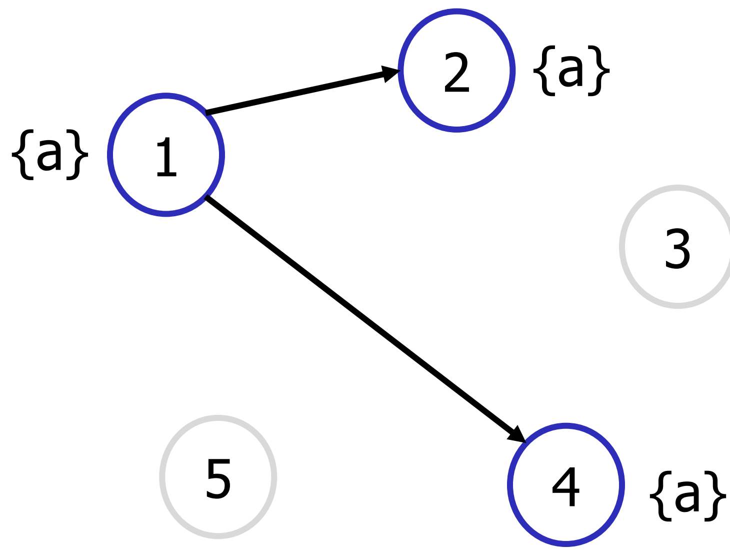
$$\{a, b, c\} = \{a, b, c\}$$

ATLAS: ✓ other SMR: ✗

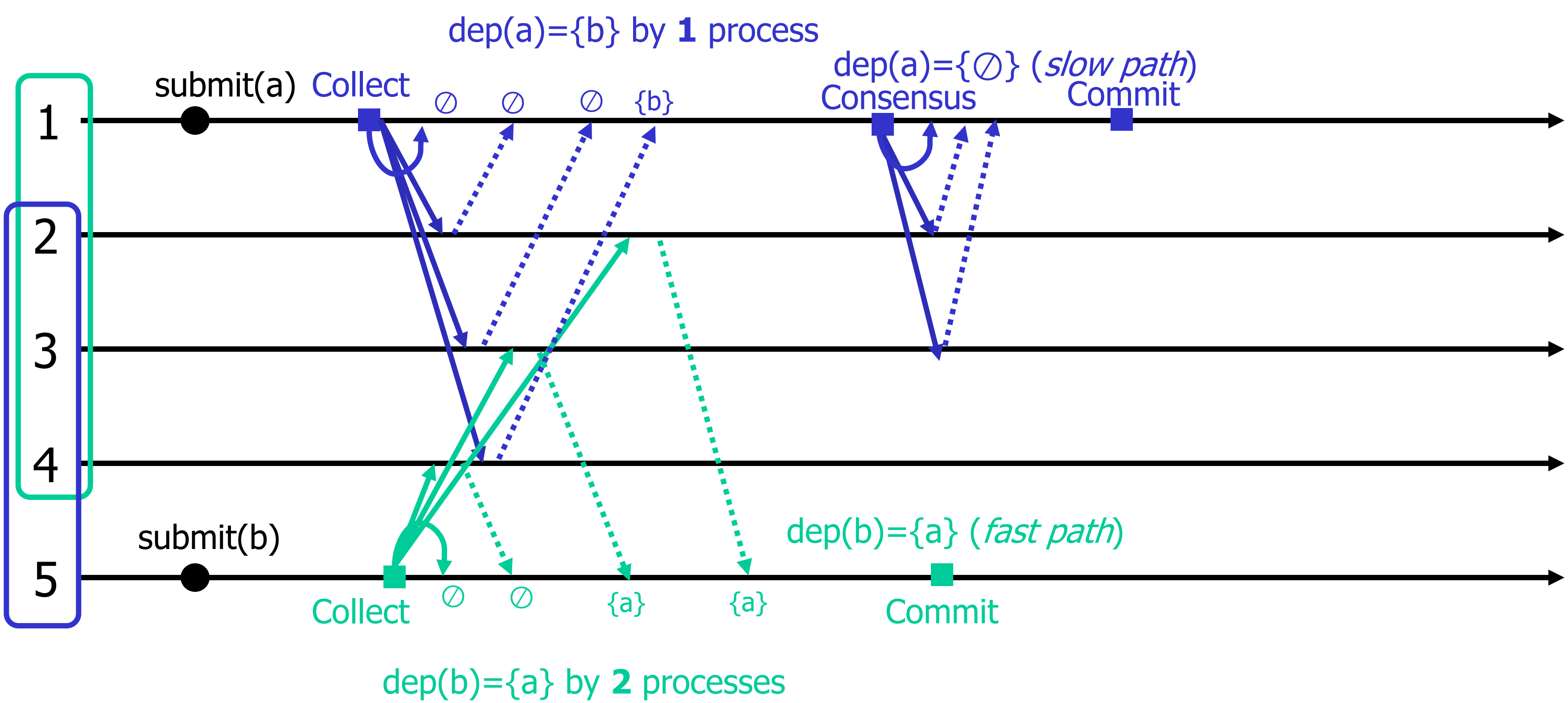
$$\bigcup_{Q} dep = \bigcup_{f} Q\ dep$$

$$\{a\} = \{a\}$$

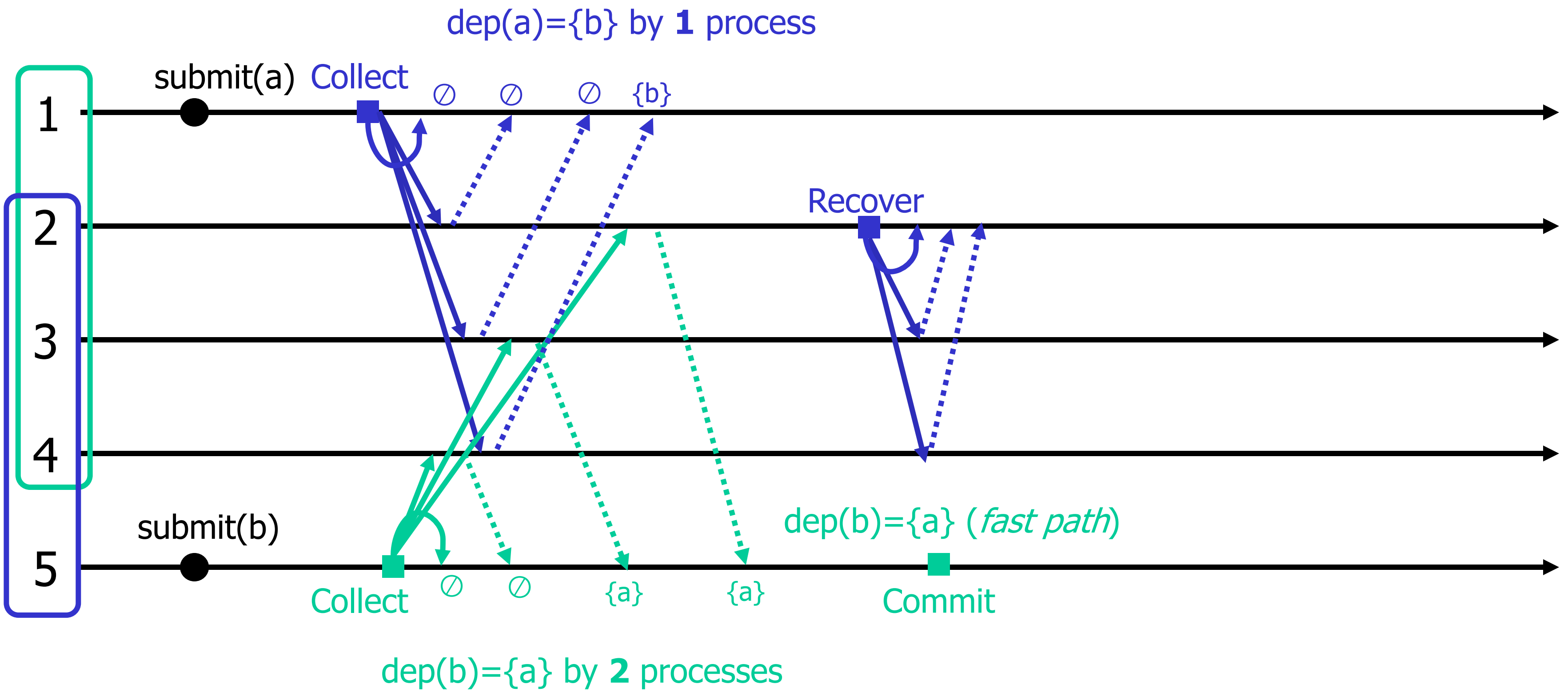
ATLAS: ✓ other SMR: ✓



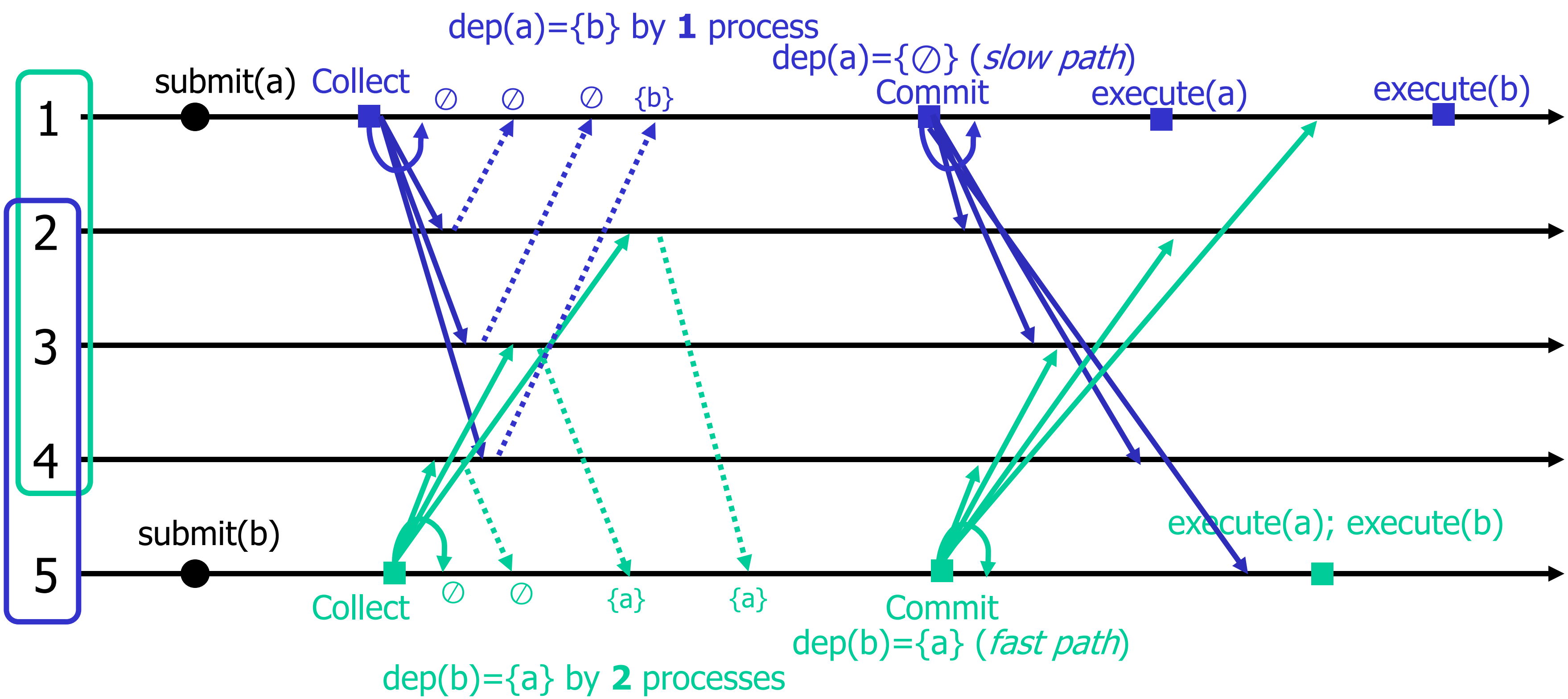
ATLAS example (n=5, f=2)



ATLAS example (n=5, f=2)

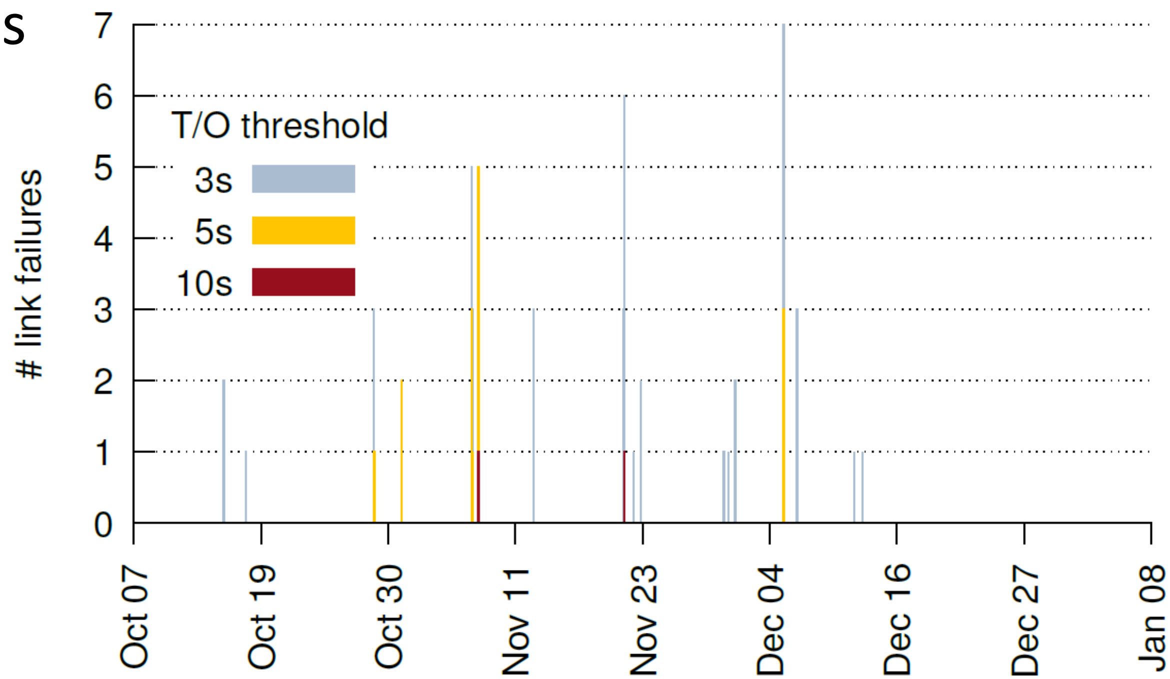


ATLAS example (n=5, f=2)

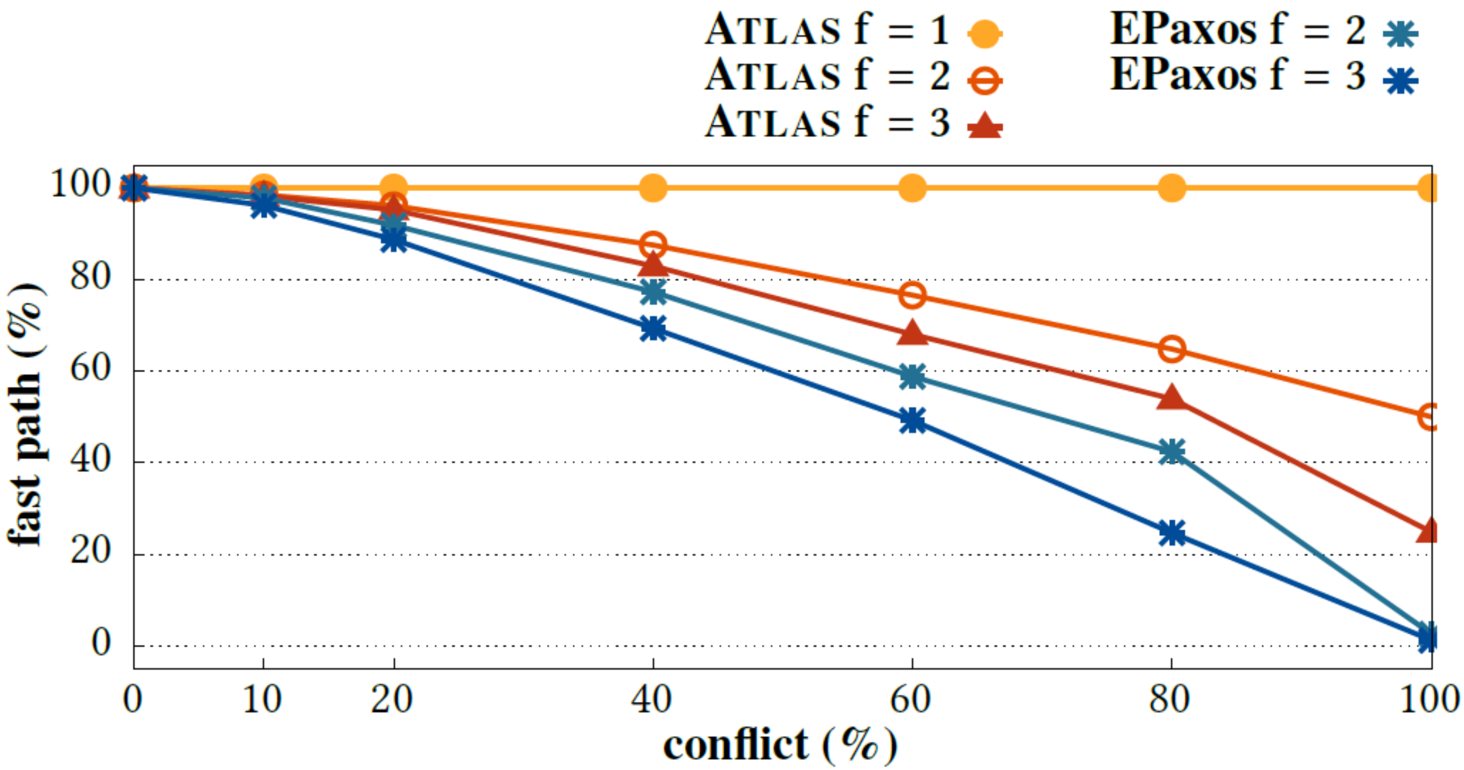


Evaluation – Bounds of Failures

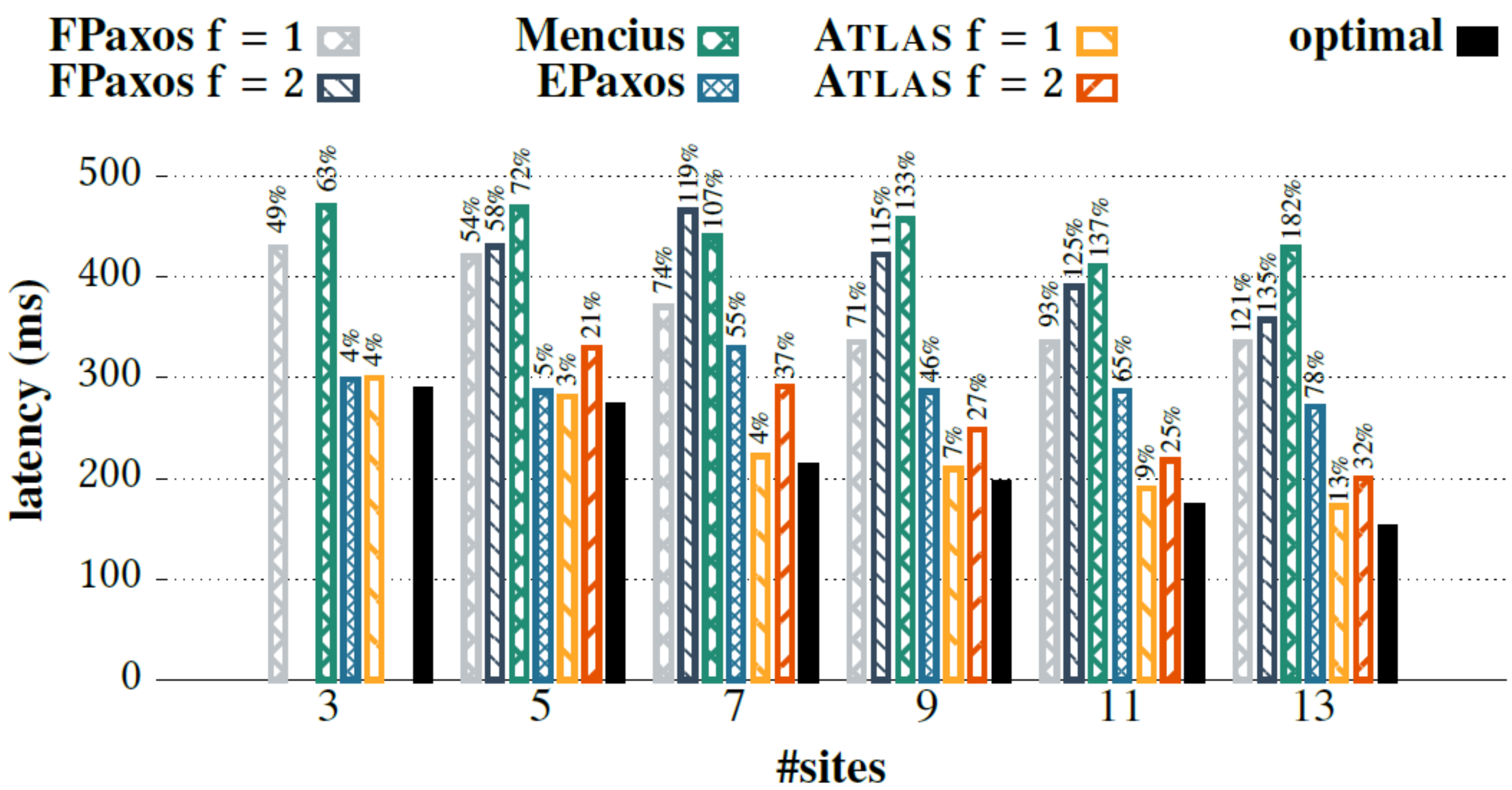
- 13 sites in various locations
  - Asia (4), Australia (1), Europe (4), N. America (3), S. America (1)
- Setting:
  - Sites ping each every second
- Noticeable events
  - Delays between a single site and others



Evaluation – *fast path* likelihood



Evaluation – Average latency



Conclusion

- ATLAS is a State-Machine Replication protocol tailored for planet-scale systems
- Key features: (a) smaller fast quorums and (b) flexible *fast path* condition
- The number of concurrent failures are not bound to the overall number of nodes/sites
  - This may compromise liveness but not safety
  - E.g. if more than f sites fail, then ATLAS will block until enough of them are reachable

References and Links

- Citation
  - Enes, V., Baquero, C., Rezende, T.F., Gotsman, A., Perrin, M. and Sutra, P., 2020, April. State-machine replication for planet-scale systems. In Proceedings of the Fifteenth European Conference on Computer Systems (pp. 1-15).
- Link to paper
  - https://dl.acm.org/doi/abs/10.1145/3342195.3387543
- Link to these slides
  - https://github.com/ymark/HY559-2023-Fall

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