CAP Theorem & Causal Consistency

CS 475: Concurrent & Distributed Systems (Fall 2021)

Lecture 12

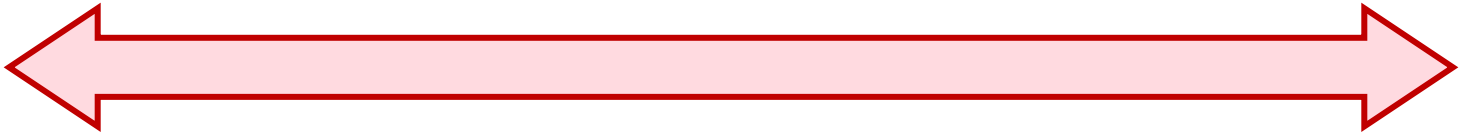
Yue Cheng

Some material taken/derived from:

- Princeton COS-418 materials created by Michael Freedman.
- MIT 6.824 by Robert Morris, Frans Kaashoek, and Nickolai Zeldovich.

Tradeoffs are fundamental?

2PC / Consensus **Eventual consistency**



Paxos / Raft **Dynamo**

"CAP" conjecture for distributed systems

- From keynote lecture by Eric Brewer (2000)
  - History: Eric started Inktomi, early Internet search site based around "commodity" clusters of computers
  - Using CAP to justify "BASE" model: Basically Available, Soft-state services with Eventual consistency

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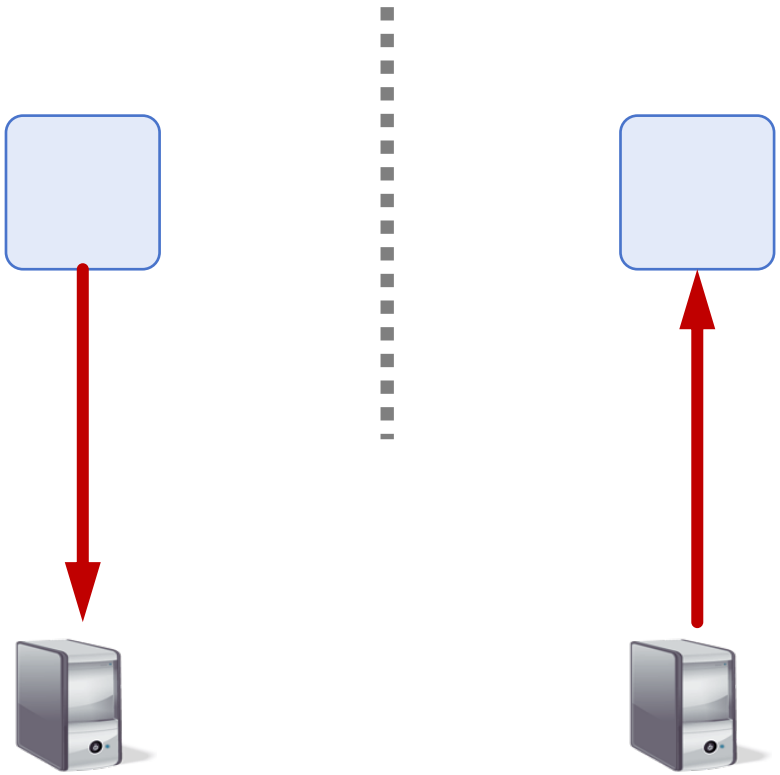
  - History: Eric started Inktomi, early Internet search site based around "commodity" clusters of computers
  - Using CAP to justify "BASE" model: Basically Available, Soft-state services with Eventual consistency
- Popular interpretation: 2-out-of-3
  - Consistency (Linearizability)
  - Availability
  - Partition Tolerance: Arbitrary crash/network failures

CAP Theorem: Proof



Not consistent

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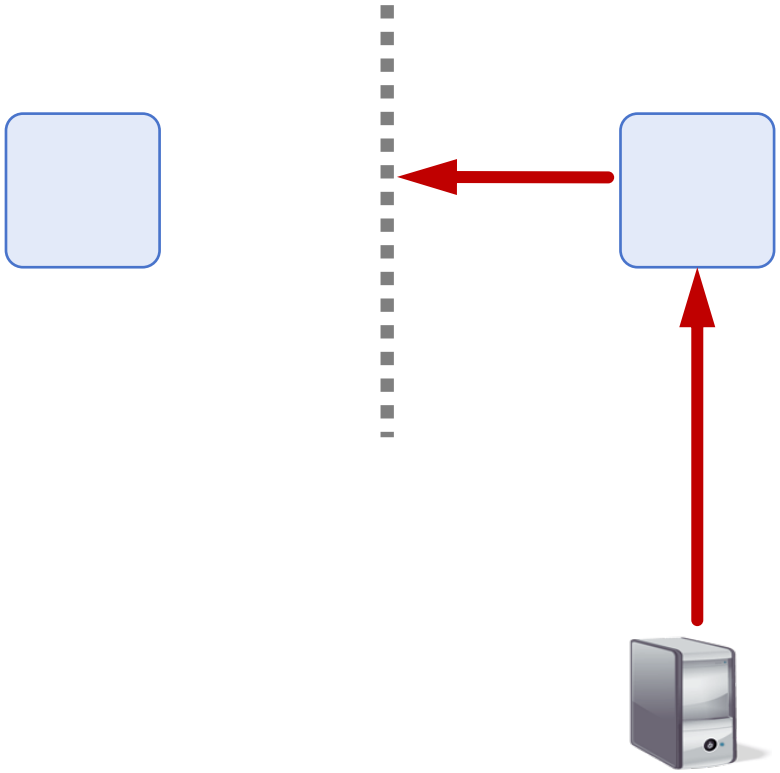

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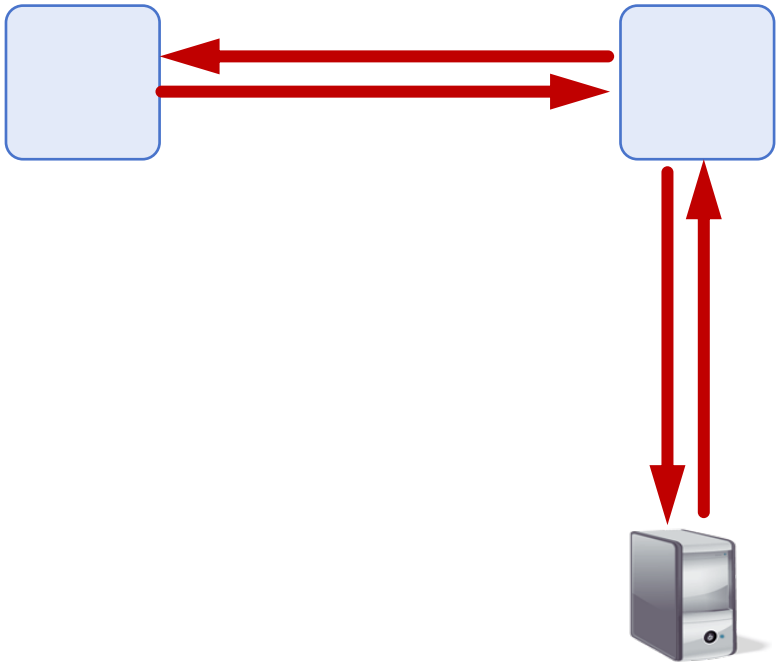

Not partition tolerant

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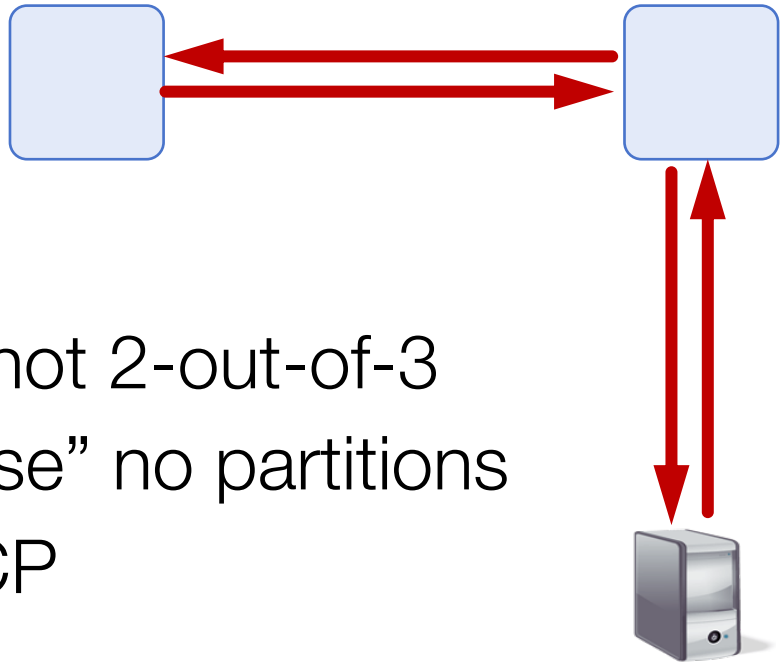
CAP Theorem: AP or CP



Criticism: It's not 2-out-of-3

- Can't "choose" no partitions
- So: AP or CP

Not partition tolerant

More tradeoffs L vs. C

- **L:** Low-latency: Speak to fewer than quorum of nodes?
  - 2PC: write N, read 1
  - Raft: write ⌊N/2⌋ + 1, read ⌊N/2⌋ + 1
  - General: $|W| + |R| > N$

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  - General: $|W| + |R| > N$
- L and C are fundamentally at odds
  - "C" = linearizability, sequential, serializability (more later)

PACELC

- If there is a partition (P):
  - How does system tradeoff A and C?
- Else (no partition)
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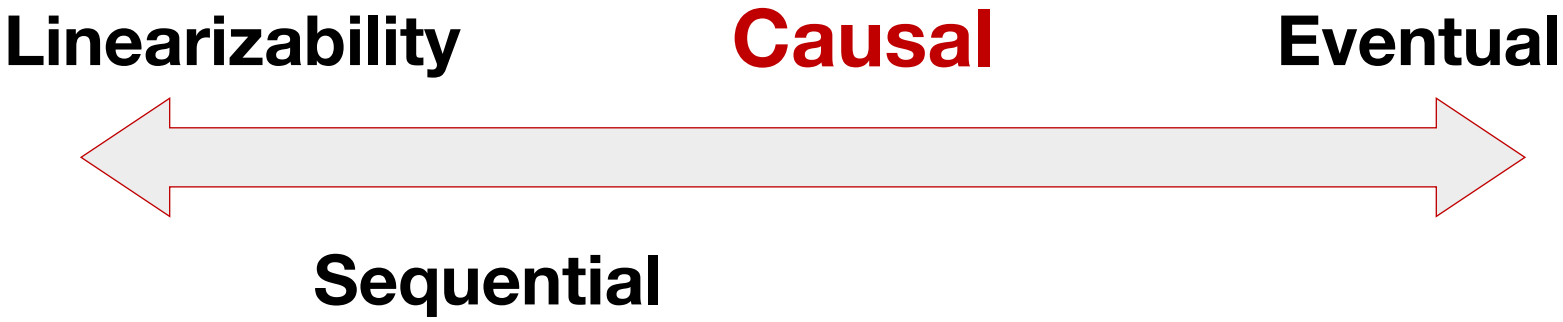
http://dbmsmusings.blogspot.com/2010/04/problems-with-cap-and-yahoos-little.html

Consistency models



Recall use of logical clocks (lec N?)

- Lamport clocks: $C(a) < C(z)$ Conclusion: None
- Vector clocks: $V(a) < V(z)$ Conclusion: $a \rightarrow \ldots \rightarrow z$

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- Distributed bulletin board application
  - Each post gets sent to all other users
  - Consistency goal: No user to see reply before the corresponding original message post
  - Conclusion: Deliver message only **after** all messages that **causally precede** it have been delivered

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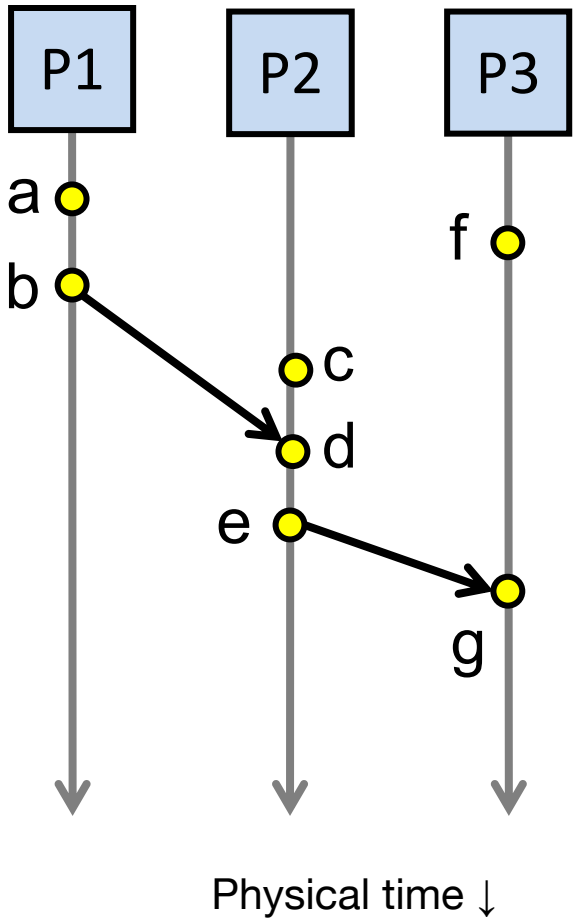
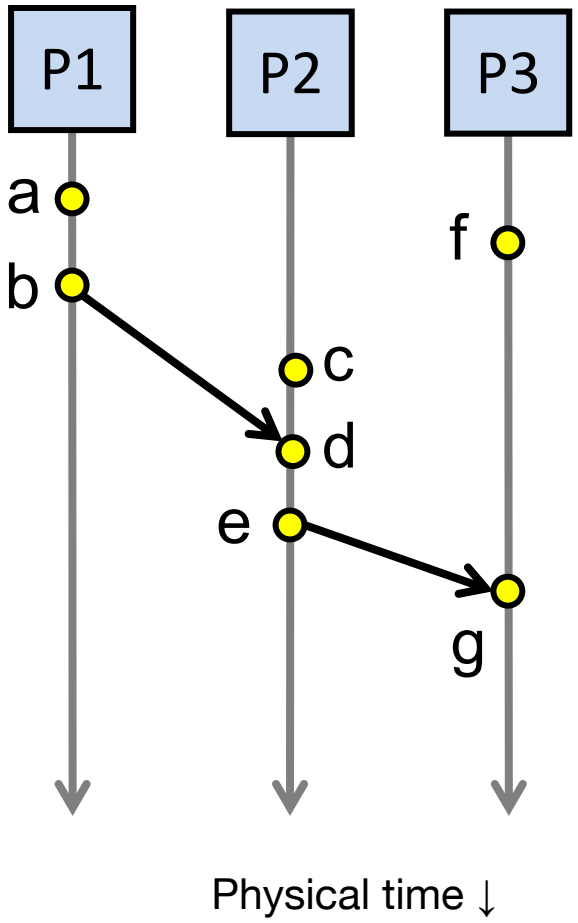


Causal Consistency

Operations	Concurrent?
a, b	
b, f	
c, f	
e, f	
e, g	
a, c	
a, e	



Causal Consistency

Operations	Concurrent?
a, b	**N**
b, f	**Y**
c, f	**Y**
e, f	**Y**
e, g	**N**
a, c	**Y**
a, e	**N**