Wide Area Storage Systems - A Quick Overview

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Storage Systems

- We have seen GFS and Bigtable
  - GFS is a cluster-scale, file system
  - Bigtable is a cluster-scale, multi-dimensional key-value store
  - Both provide scalability and high availability for cluster-scale applications
- We have seen Sinfonia
  - Provides strong consistency guarantees at cluster scale

- However, modern web-scale applications are used by millions of geographically distributed users

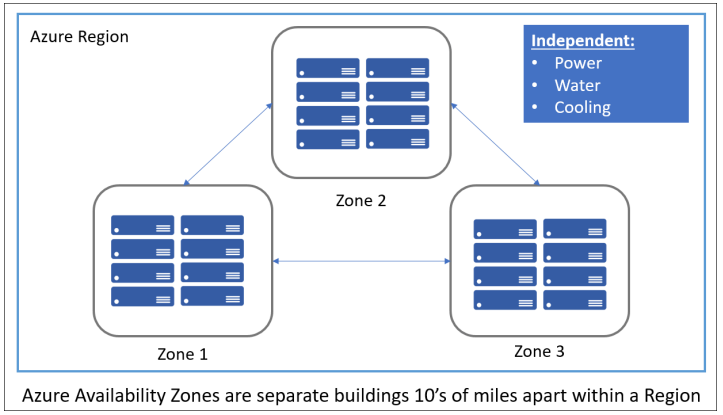
Problem

- One data center can’t solve it all
- Servicing data centers requires turning them off
  - Power systems, cooling systems, backbone routers, data center management systems
- Diurnal load patterns
  - Too much load during the day, too little during the night
- Geographically separated users
  - Too much latency for cross-continent operations
  - Cross-continent links are expensive

Solution

- Within a region: 3-5 data centers located within 10-100 miles apart
  - Improves availability – a data center can be turned off
- Across regions: build data centers based on user demand
  - Helps with diurnal load patterns
  - Reduces latency
  - Improves availability, disaster recovery

Microsoft Azure



Azure Availability Zones are separate buildings 10's of miles apart within a Region

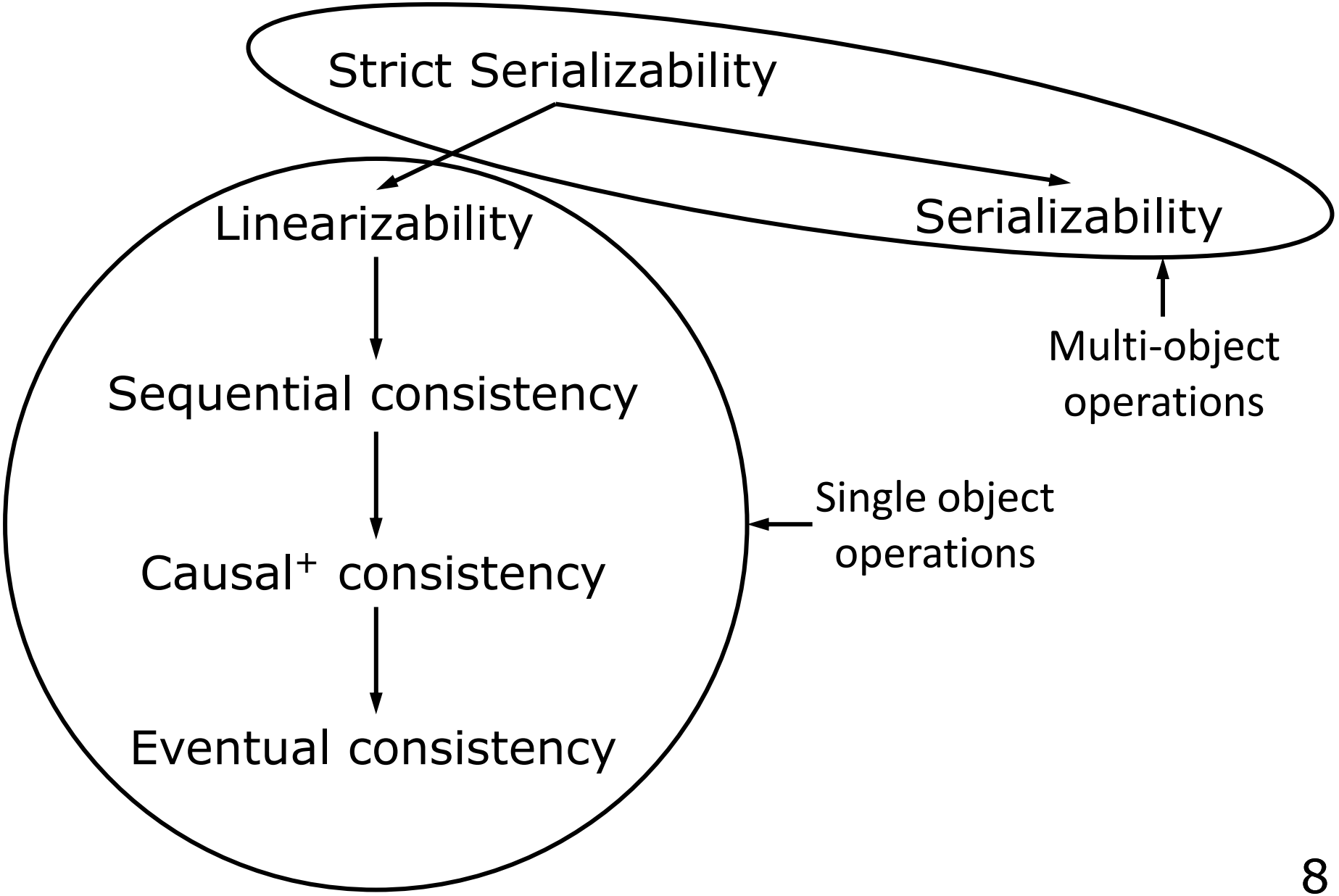
Consistency (Once Again)

Single or Multi-Object Operations

- Single object operations
  - Think key-value stores
  - get(key), put(key, value) operations
  - Each operation accesses one shard (partition)

- Multi-object operations
  - Think transactions and databases
  - Each transaction accesses multiple rows atomically
  - Each transaction may access one or more shards (partitions)

Consistency Hierarchy



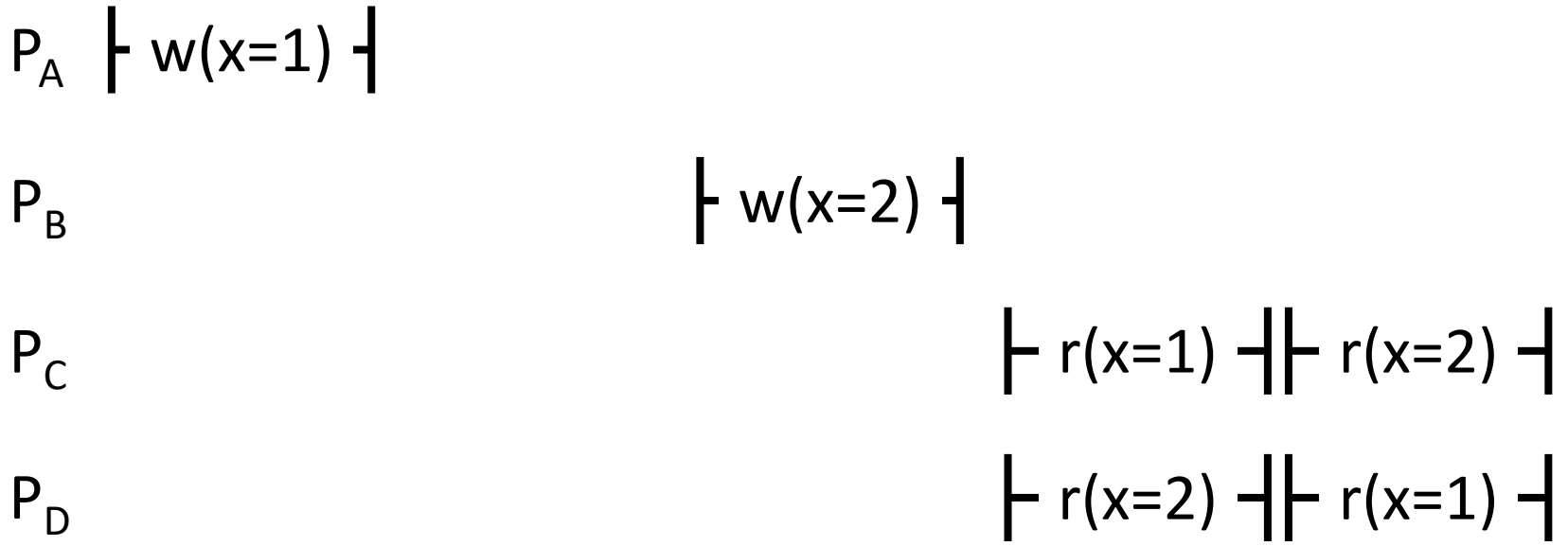
Consistency for Single-Object Operations (Partition Tolerant)

- Eventual consistency
  - All processes execute operations in any order
  - Assuming no new updates to a data item, all accesses to that item will eventually return the last updated value
    - Used in optimistically replicated systems
    - Weakest "reasonable" form of consistency for replicated data

- Causal$^+$ consistency
  - Causal: all processes execute operations in an order that satisfies causality (happens-before relation)
    - i.e., there are no cyclic dependencies among operations
  - Causal$^+$: data is eventually consistent also

Understanding Causal Consistency

- Causal: All processes execute operations in an order that satisfies causality (happens-before relation)
  - i.e., there are no cyclic dependencies among operations
- Are these operations causally consistent?



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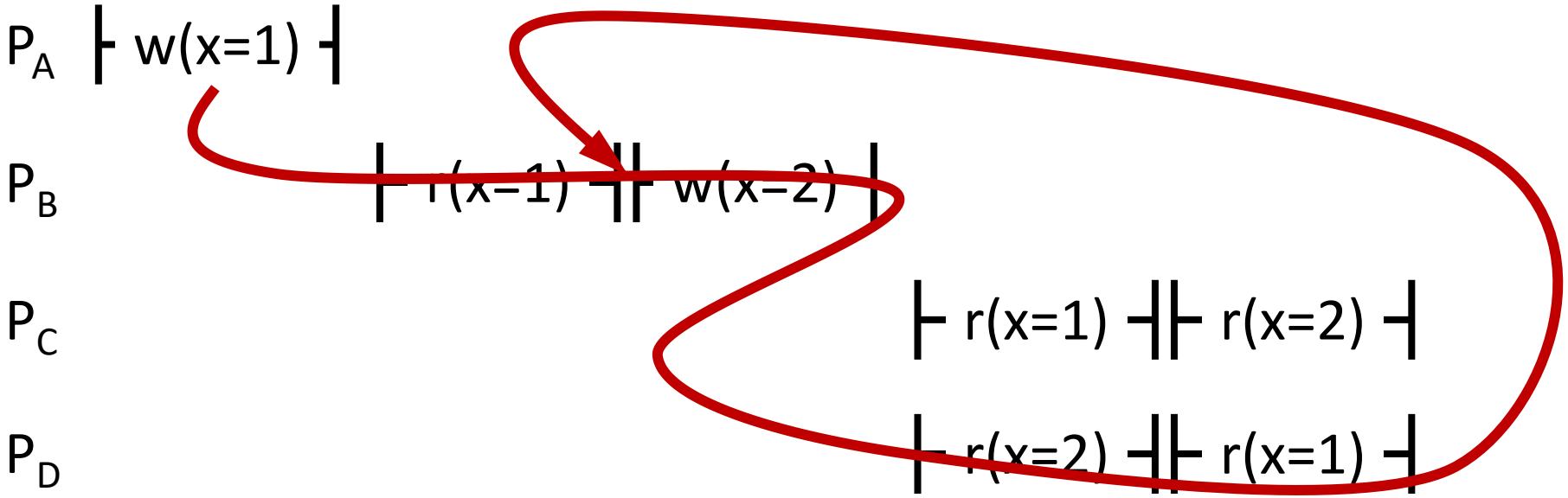


Consistency for Single-Object Operations (not Partition Tolerant)

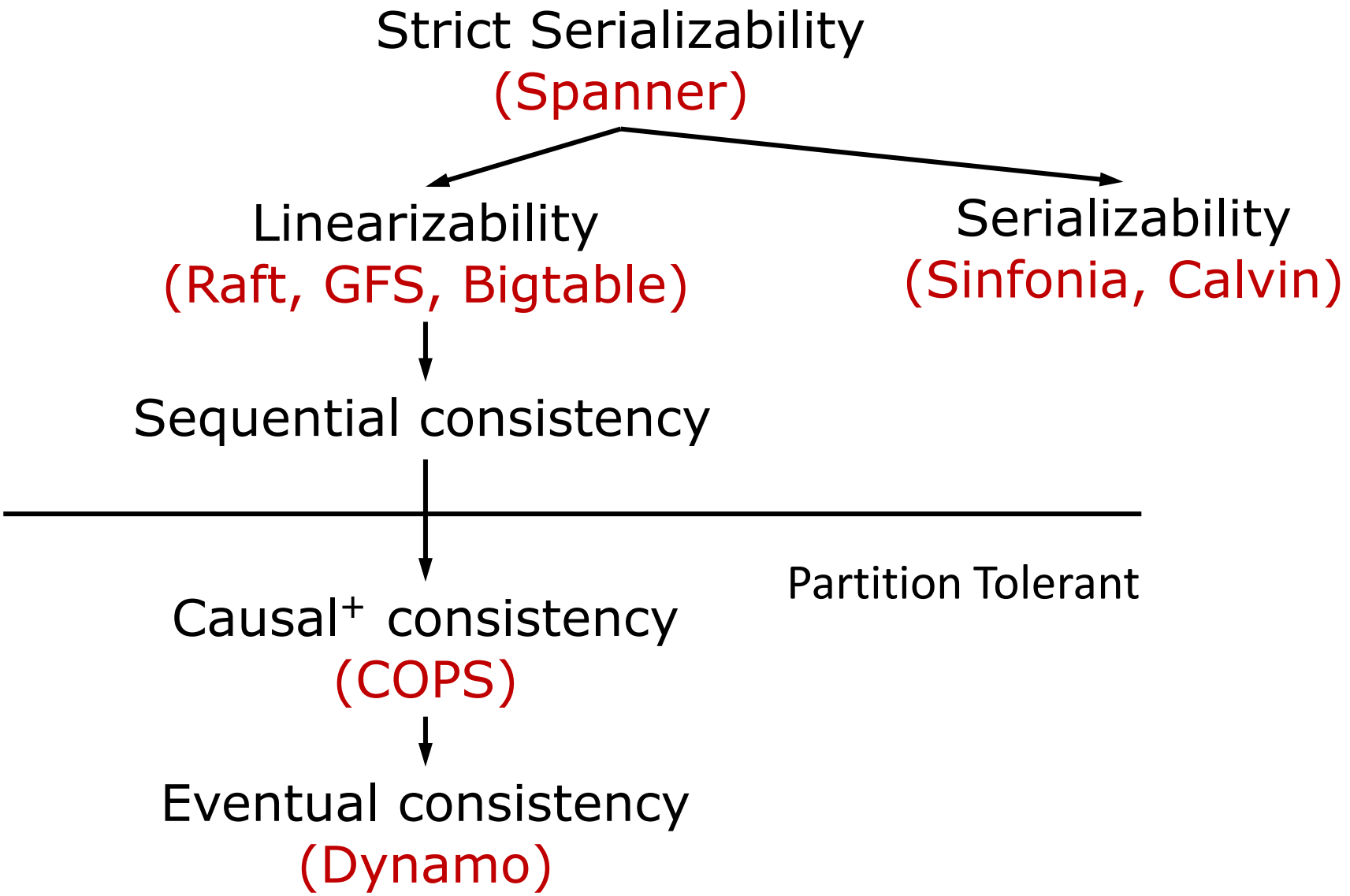
- Sequential consistency
  - All processes execute operations in some total order
    - Operations act as if they occurred (instantaneously), consistent with program order
    - Writes are totally ordered, even when not causally related, hence not partition tolerant

- Linearizability
  - All processes execute operations in some total order, while preserving real-time ordering
    - Operations act as if they occurred (instantaneously), consistent with program order, at some point in between invocation & response

Consistency for Multi-Object Operations

- Serializability
  - The outcome of executing transactions (e.g., resulting state) is equivalent to the outcome of its transactions executed sequentially without interleaving
- Strict serializability
  - Informally: Serializability + Linearizability
  - If Txn A completes before Txn B begins in real time, then A is ordered before B

Consistency Hierarchy



Questions to Keep in Mind

- We will be discussing Dynamo and Spanner
- How does each system provide the consistency property it says it does?
- What is the impact on availability, performance?
- What are the key differences (and similarities) in their design?