

Consistency Models



COS 418/518: Distributed Systems
Lecture 14

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Consistency Models

- Contract between a distributed system and the applications that run on it
- A consistency model is a set of **guarantees** made by the distributed system

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Linearizability

- All replicas execute operations in **some** total order
- That total order preserves the **real-time ordering** between operations
 - If operation A **completes** before operation B **begins**, then A is ordered before B in real-time
 - If neither A nor B completes before the other begins, then there is no real-time order
 - (But there must be *some* total order)

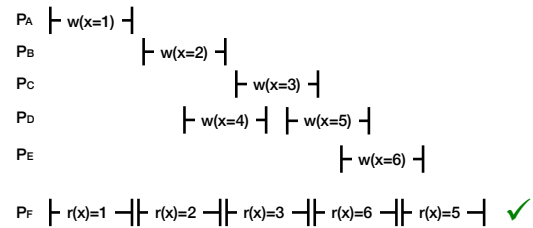
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Real-Time Ordering Examples

P _A	⊢ w(x=1) ⊣
P _B	⊢ w(x=2) ⊣
P _C	⊢ w(x=3) ⊣
P _D	⊢ w(x=4) ⊣ ⊢ w(x=5) ⊣
P _E	⊢ w(x=6) ⊣

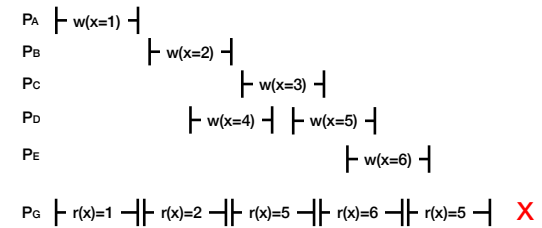
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Linearizable?



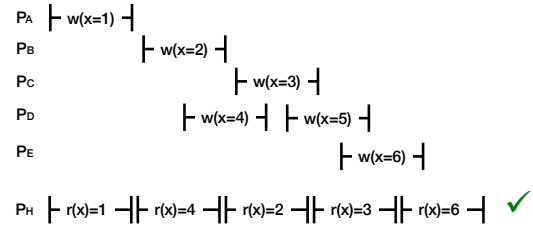
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Linearizable?



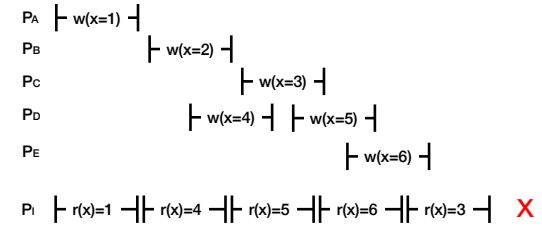
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Linearizable?



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Linearizable?



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Linearizability == “Appears to be a Single Machine”

- Single machine processes requests one by one in order it receives them
 - Will receive requests ordered by real-time in that order
 - Will receive all requests in some order
- Atomic Multicast, Viewstamped Replication, Paxos, and RAFT provide Linearizability
- Single machine processing incoming requests one at a time also provide Linearizability ☺

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Linearizability is Ideal?

- Hides the complexity of the underlying distributed system from applications!
 - Easier to write applications
 - Easier to write correct applications
- But, performance trade-offs

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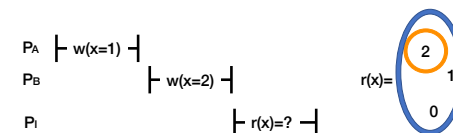
Stronger vs Weaker Consistency

- Stronger consistency models
 - + Easier to write applications
 - More guarantees for the system to ensure
 - Results in performance tradeoffs
- Weaker consistency models
 - Harder to write applications
 - + Fewer guarantees for the system to ensure

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Strictly Stronger Consistency

- A consistency model **A** is strictly stronger than **B** if it allows a strict subset of the behaviors of **B**
 - Guarantees are strictly stronger



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Sequential Consistency

- All replicas execute operations in **some** total order
- That total order preserves the **process ordering** between operations
 - If process P issues operation A before operation B, then A is ordered before B by the process order
 - If operations A and B are done by different processes then there is no process order between them
 - (But there must be *some* total order)

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Sequential Consistency $\approx$ “Appears to be a Single Machine”

- Single machine processes requests one by one in order it receives them
 - Will receive requests ordered by process order in that order
 - Will receive all requests in some order

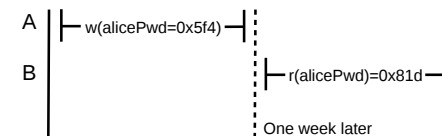
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Linearizability is strictly stronger than Sequential Consistency

- Linearizability: $\exists$ total order + real-time ordering
- Sequential: $\exists$ total order + process ordering
 - Process ordering $\subseteq$ Real-time ordering

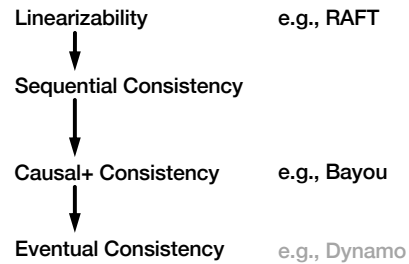
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Sequential But Not Linearizable



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Consistency Hierarchy



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Causal+ Consistency

- Partially orders all operations, does not totally order them
 - Does not look like a single machine
- Guarantees
 - For each process, $\exists$ an order of all writes + that process's reads
 - Order respects the happens-before ($\rightarrow$) ordering of operations
 - + replicas converge to the same state
 - Skip details, makes it stronger than eventual consistency

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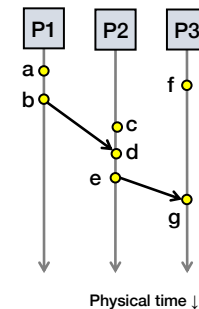
Causal Consistency

- Writes that are **potentially** causally related must be seen by all processes in same order.
 - Concurrent writes may be seen in a different order on different processes.
- Concurrent: Ops not causally related

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Causal Consistency

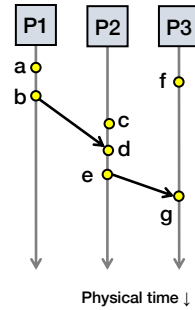
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Causal Consistency

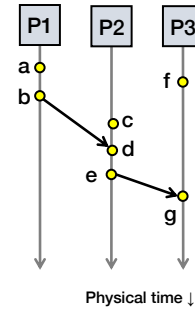
Operations	Concurrent?
a, b	
b, f	
c, f	
e, f	
e, g	
a, c	
a, e	



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Causal Consistency

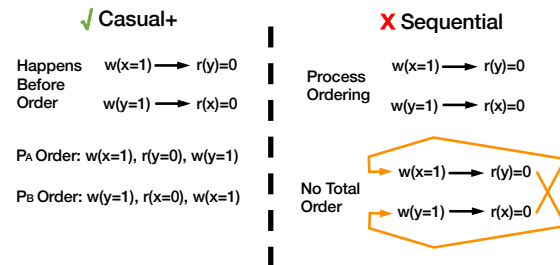
Operations	Concurrent?
a, b	N
b, f	Y
c, f	Y
e, f	Y
e, g	N
a, c	Y
a, e	N



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Causal+ But Not Sequential

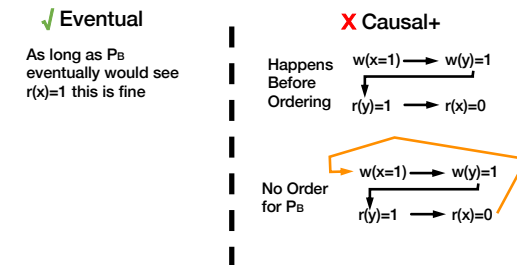
$P_A \vdash w(x=1) \dashv \vdash r(y)=0 \dashv$
 $P_B \vdash w(y=1) \dashv \vdash r(x)=0 \dashv$



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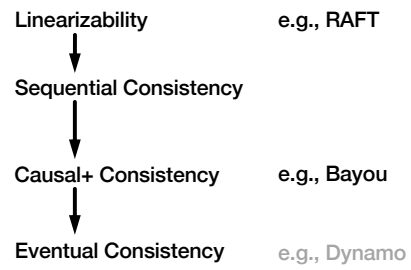
Eventual But Not Causal+

$P_A \vdash w(x=1) \dashv \vdash w(y)=1 \dashv$
 $P_B \vdash r(y)=1 \dashv \vdash r(x)=0 \dashv$



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Consistency Hierarchy



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