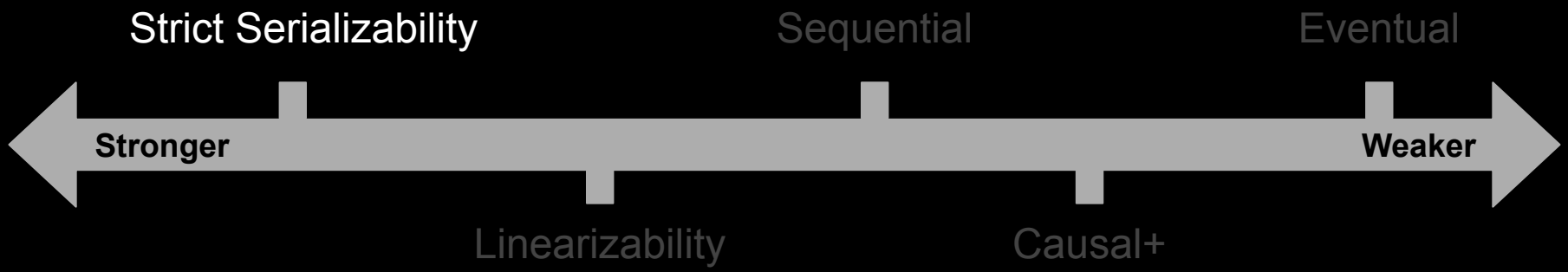
Consistency

March 30th+31st, 2022

Consistency Models

Consistency Models



Strict Serializability

- Transactions: Operations can span multiple objects (e.g., keys in KV store)
- Total order: There exists some legal total ordering of transactions.
  - Legal: In the total ordering, a read operation sees the latest write operation.
- Preserves real-time ordering: Any transaction *A* that completes before transaction *B* begins, occurs before *B* in the total order.
- Properties:
  - Writes in a completed transaction appear to all future reads
  - Once a read sees transaction and completes, all future reads must see new transaction

Pros: Easily reason about correctness of transactions

Cons: High read and write latencies

Strict Serializability Example

Strictly Serializable? **Yes**

P1: {W(x)b, W(y)b}

P2: {W(x)a}

P3: {R(x)a} {R(x)b}

P4: {R(x)b} {R(y)b}

Strictly Serializable? **No**

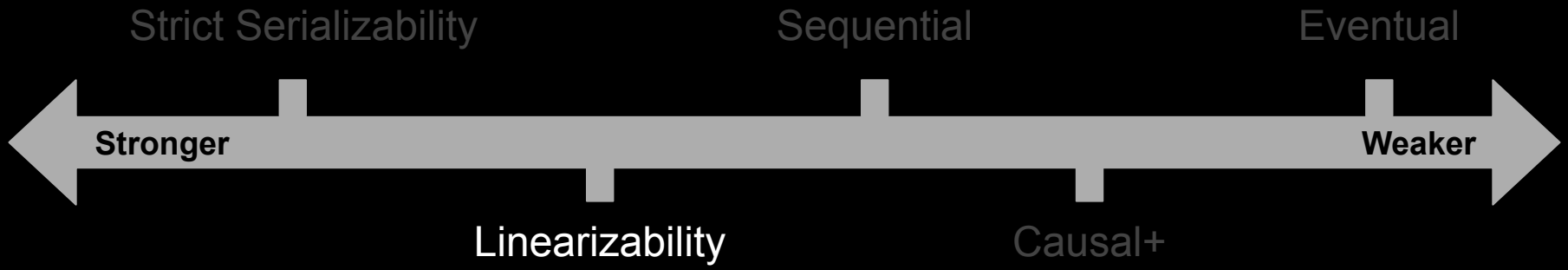
P1: {W(x)b, W(y)b}

P2: {W(x)a}

P3: {R(y)b} {R(x)a}

P4: {R(x)b} {R(y)b}

Consistency Models



Linearizability

- Total order: There exists some legal total order of operations
- Preserves real-time ordering: Any operation *A* that completes before operation *B* begins, occurs before *B* in the total order.
- Difference from *strict serializability*?
  - Single-object operations! No transactions!
- Properties
  - A completed write appears to all future reads
  - Once a read sees a new value, all future reads must return the new value (until new write)

Pros: Easy to reason about correctness

Cons: High read and write latencies

Linearizability Example

Linearizable? **No**

P1: W(x)a

P2: W(x)b

P3: R(x)b R(x)a

P4: R(x)b R(x)a

Linearizable? **Yes**

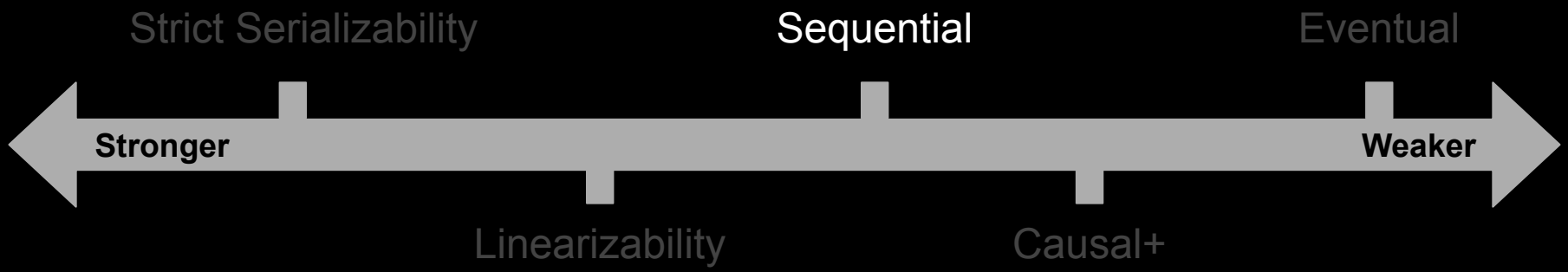
P1: W(x)a

P2: W(x)b

P3: R(x)a R(x)b

P4: R(x)a R(x)b

Consistency Models



Sequential Consistency

- Total order: There exists some legal total order of operations
- Preserves process ordering: Total order respects order of each process's operations.
- Difference from *linearizability*?
  - Order of ops across processes not determined by real-time

Pros: Can allow more orderings than linearizability → better performance

Cons: Many possible sequential executions → increased application complexity

Sequential Consistency Example

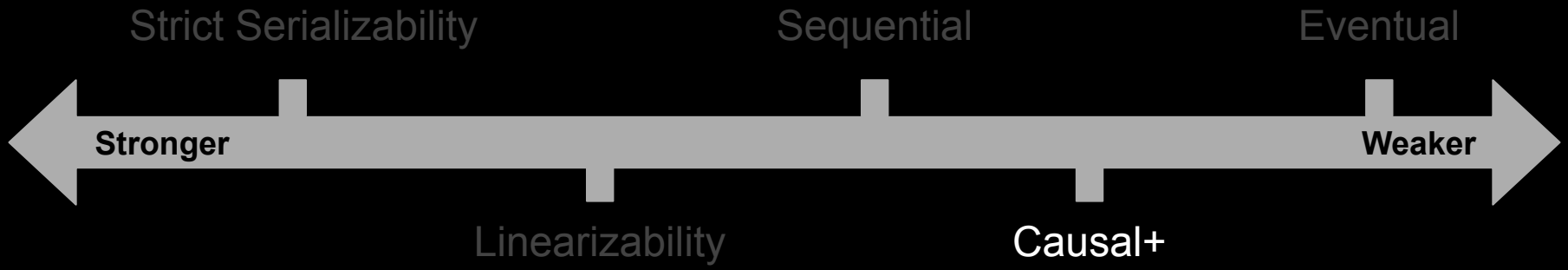
Sequentially Consistent? **Yes**

P1:	W(x)a			
P2:		W(x)b		
P3:			R(x)b	R(x)a
P4:			R(x)b	R(x)a

Sequentially Consistent? **No**

P1:	W(x)a			
P2:		W(x)b		
P3:			R(x)b	R(x)a
P4:			R(x)a	R(x)b

Consistency Models



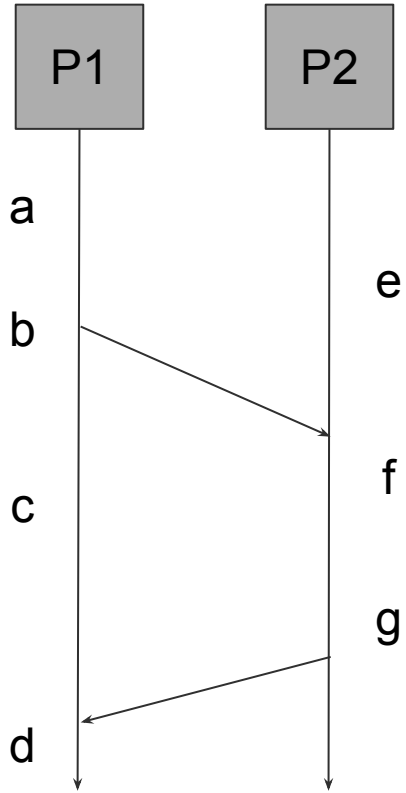
Causal+ Consistency

- Partial order: Order causally related ops the same way across all processes
- +: Replicas eventually converge
- Difference from *sequential consistency*?
  - Only causally related ops need to be ordered: no total order
  - Concurrent ops may be ordered differently across different processes

Pros: Preserves causality while improving efficiency

Cons: Need to reason about concurrency

Ops	Concurrent
a,b	**No**
a,e	**Yes**
a,g	**No**
c,e	**Yes**
c,d	**No**
d,g	**No**
d,f	**No**
e,g	**No**
a,d	**No**



Causal+ Consistency Example

Causally+ Consistent? Yes

P1: W(x)a

P2: W(x)b

P3: R(x)b R(x)a

P4: R(x)a

Causally+ Consistent? No

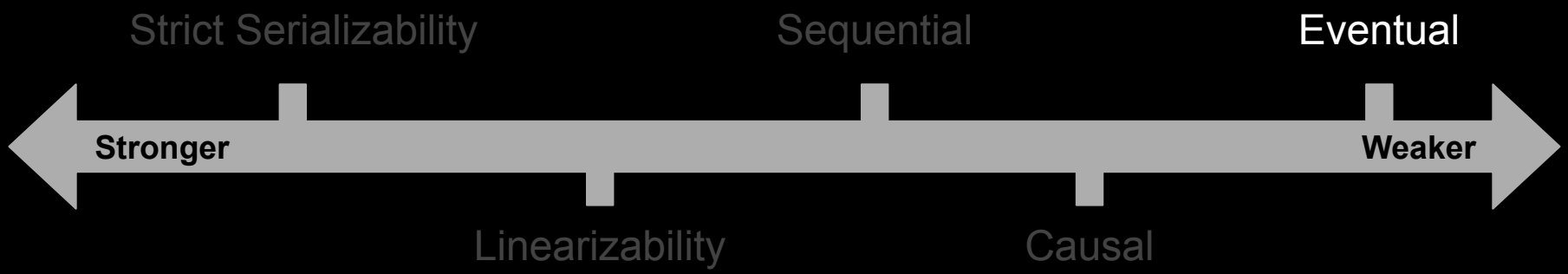
P1: W(x)a

P2: R(x)a W(x)b

P3: R(x)b R(x)a

P4: R(x)a

Consistency Models



Eventual Consistency

- Eventual convergence: If no more writes, all replicas *eventually* agree
- Difference from *causal consistency*?
  - Does not preserve causal relationships
  - Is the “+” in causal+
- Frequently used with application conflict resolution, anti-entropy

Pros: Highly available; think Dynamo

Cons: No safety guarantees, need conflict resolution

In a nutshell...

Strict Serializability: Total order + real time guarantees over *transactions*

Linearizability: Total order + real time guarantees over *operations*

Sequential consistency: Total order + process order

Causal+ consistency: Causally ordered + replicas eventually converge

Eventual consistency: Eventually everyone should agree on state

Exercise 1:

P1: {W(x) 1, W(y) 2} {R(y) 4}

P2: {W(x) 1, R(y) 4}

P3: {W(x) 0, W(y) 4}

P4: {R(x) 0} {R(x) 1}

Consistency Model:

Strictly Serializable	**Yes**
Linearizable	**Yes**
Sequential	**Yes**
Causal+	**Yes**
Eventual	**Yes**

Exercise 2:

P1:	W(x) 1			R(y) 4
P2:		R(x) 1		R(y) 4
P3:		R(x) 1	W(y) 4	
P4:		R(x) 1		R(y) 4

Consistency Model:

Linearizable	**Yes**
Sequential	**Yes**
Causal+	**Yes**
Eventual	**Yes**

Exercise 3:

P1:	W(x) 3				W(y) 7	
P2:		W(x) 1				
P3:			R(x) 1	R(x) 3		R(y) 7
P4:			R(x) 1	R(x) 3		R(y) 7
P5:			R(x) 1	R(x) 3		R(y) 7

Consistency Model:

Linearizable	**No**
Sequential	**Yes**
Causal+	**Yes**
Eventual	**Yes**

Exercise 4:

P1:	W(x) 3				W(y) 7	
P2:		W(x) 1				
P3:			R(x) 1	R(x) 3		R(y) 7
P4:			R(x) 3	R(x) 1		R(y) 7
P5:			R(x) 1	R(x) 3		R(y) 7

Consistency Model:

Linearizable	**No**
Sequential	**No**
Causal+	**Yes**
Eventual	**Yes**

Exercise 5:

P1:	W(x) 1					
P2:		W(x) 3				
P3:			W(x) 7			
P4:				R(x) 3	R(x) 7	R(x) 1
P5:				R(x) 3	R(x) 1	R(x) 7

Consistency Model:

Linearizable	**No**
Sequential	**No**
Causal+	**Yes**
Eventual	**Yes**

Exercise 6:

P1:	W(x) 1						
P2:		W(x) 3					
P3:			R(x) 3	W(x) 7			
P4:					R(x) 3	R(x) 7	R(x) 1
P5:					R(x) 3	R(x) 1	R(x) 7

Consistency Model:

Linearizable	**No**
Sequential	**No**
Causal+	**Yes**
Eventual	**Yes**

Exercise 7:

Consistency Model:

Linearizable	No
Sequential	No
Causal+	No
Eventual	Yes

P1: W(x) 1

P2: R(x) 1 W(x) 3

P3: R(x) 3 W(x) 7

P4: R(x) 3 R(x) 7 R(x) 1

P5: R(x) 3 R(x) 1 R(x) 7