Distributed Systems

Spring Semester 2020

Lecture 17: Existential Consistency

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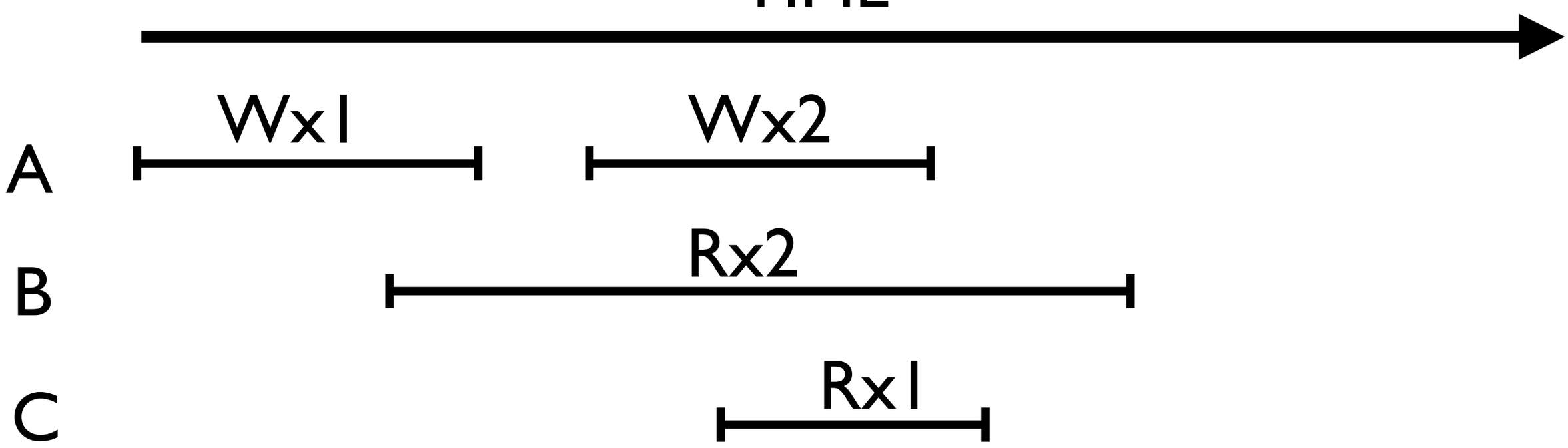
Linearizability

There exists a total order of all operations, that matches real-time (for non-overlapping ops), and in which each read sees most recent preceding write.



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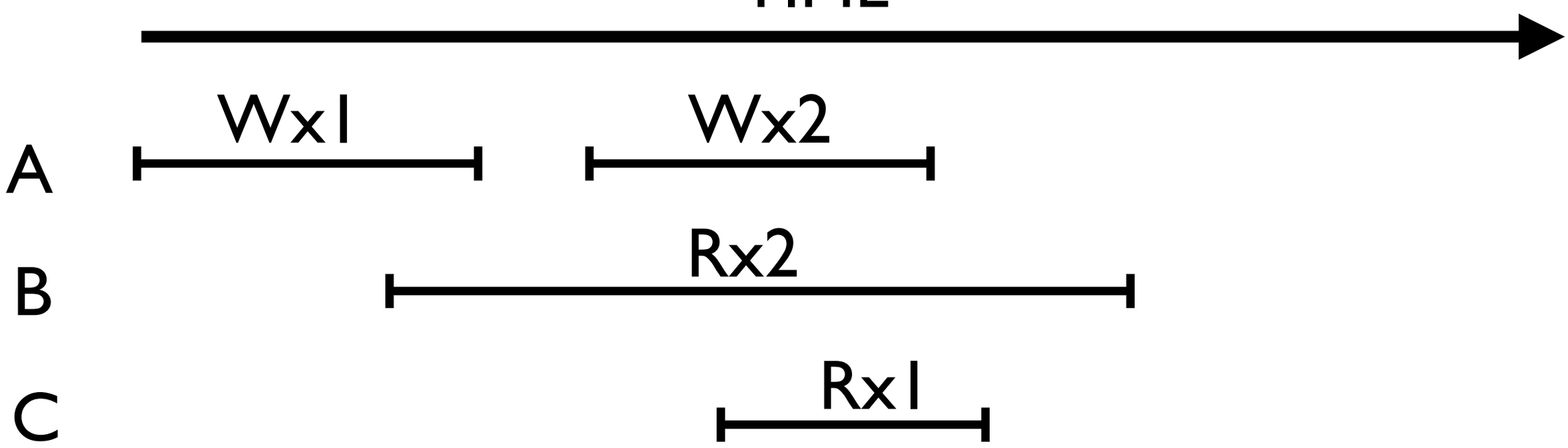


Linearizable order: Wx1 Rx1 Wx2 Rx2

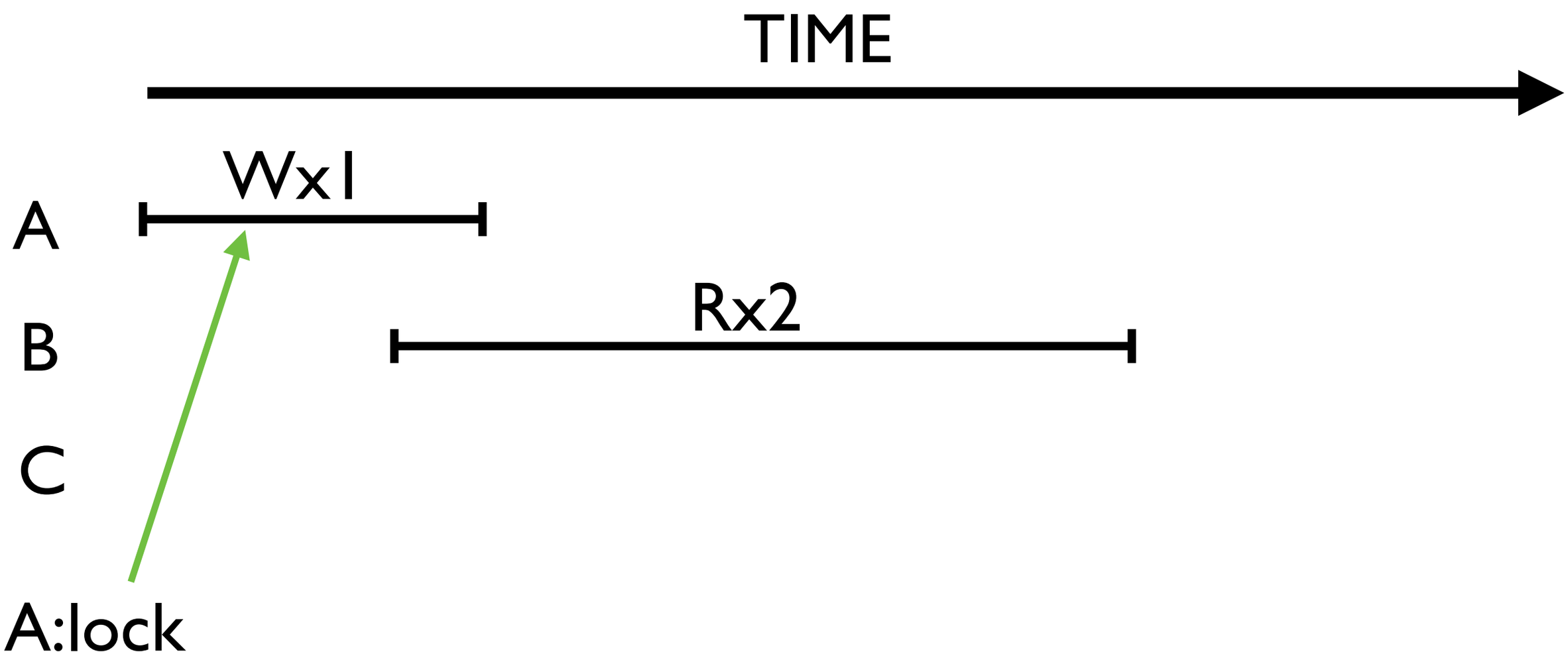
obeys real-time rule — Wx1->Wx2 and Wx1->Rx1

obeys value rule

Linearizability

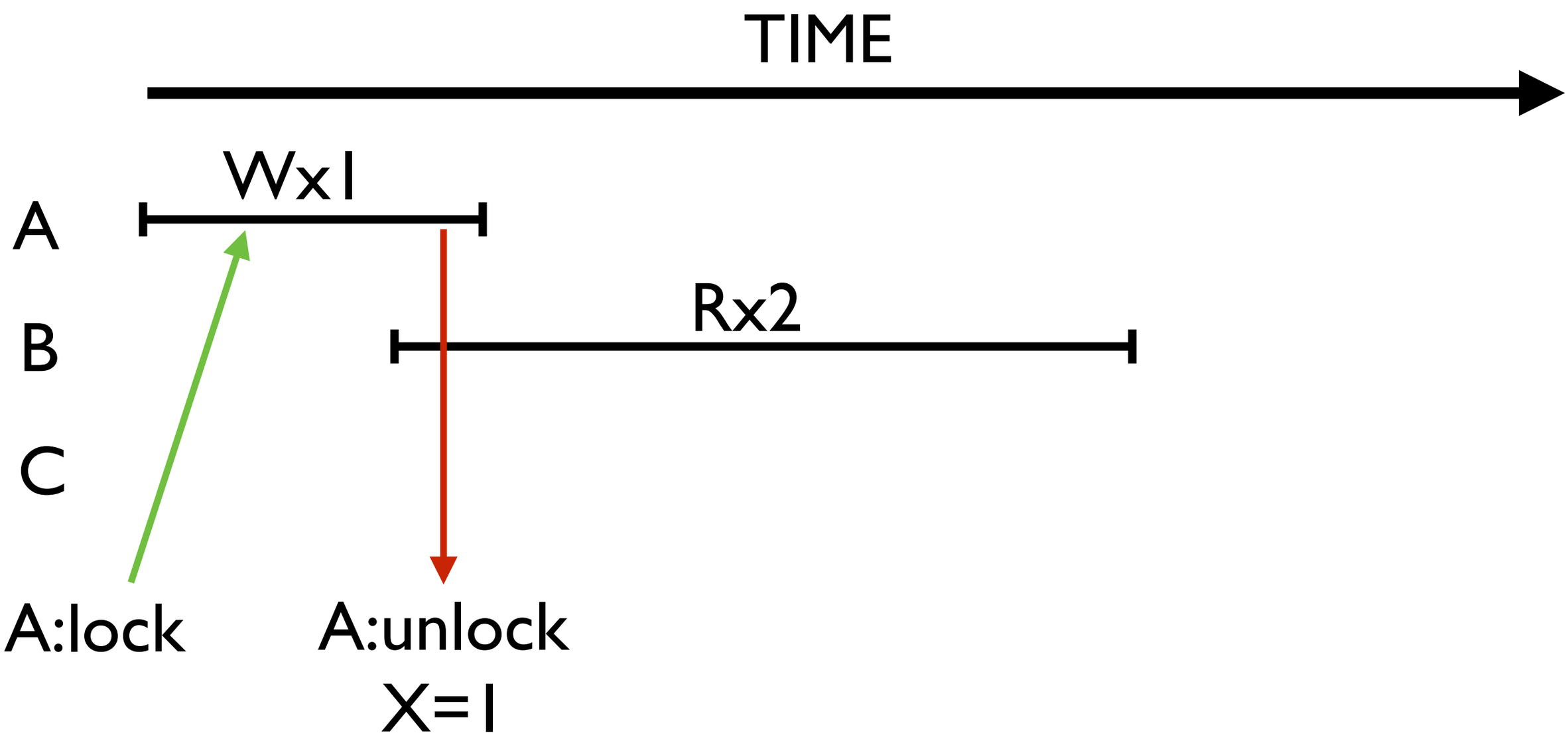
A get's lock (might have been blocked waiting for it)

Linearizability



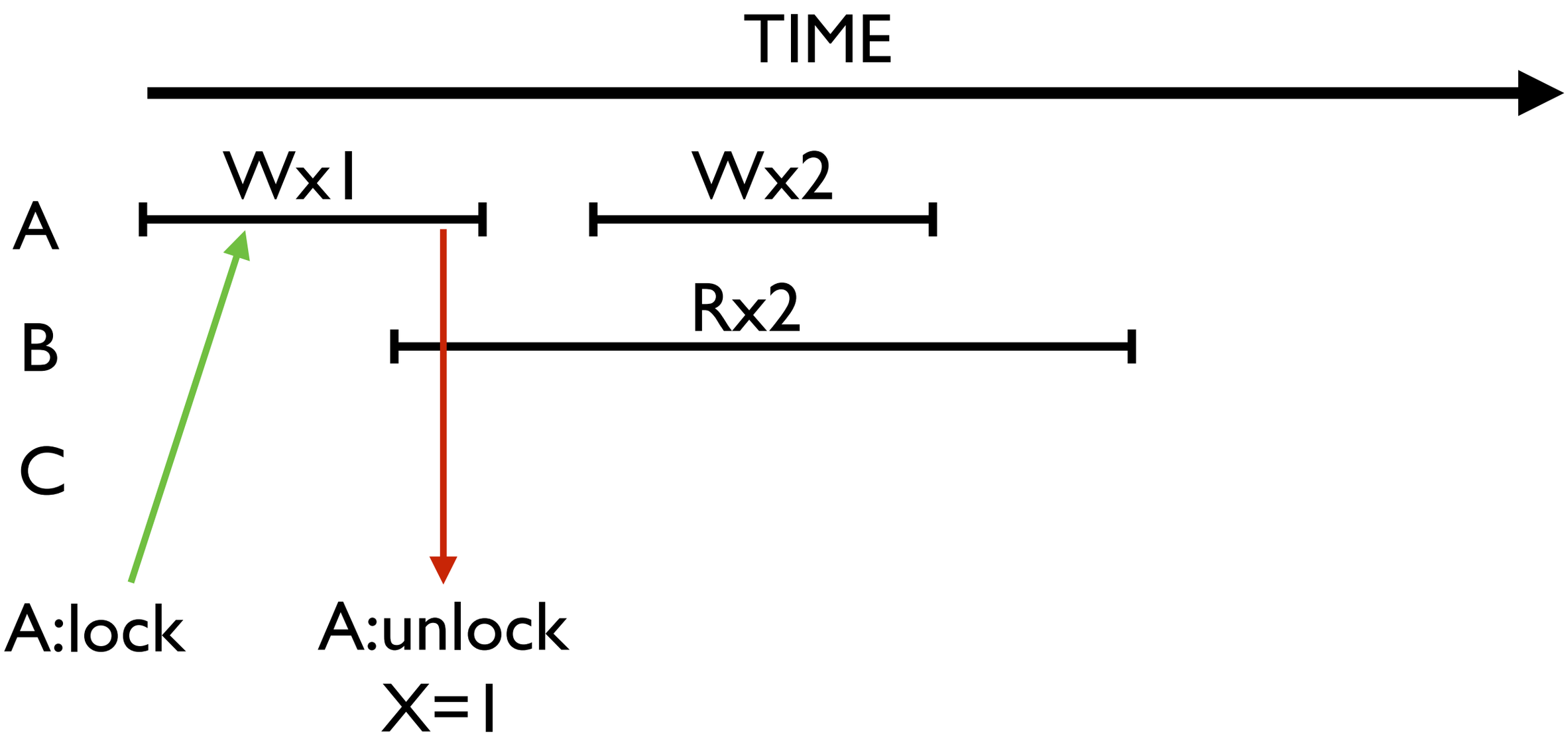
B starts read but gets delayed in the network
(or blocks on lock)

Linearizability



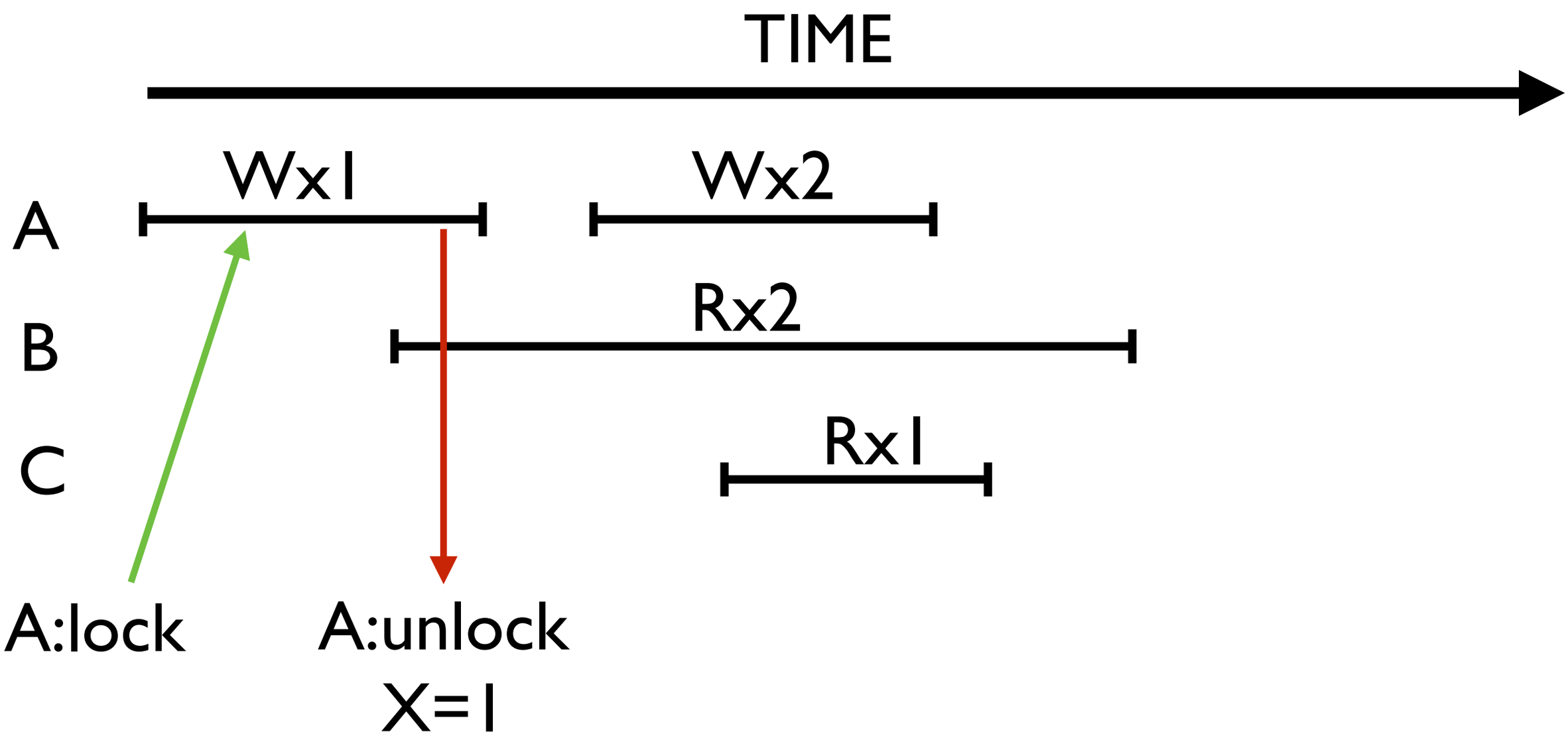
A release lock — think X=1 instantaneously happens

Linearizability



B still in flight has not acquired lock
A starts another write

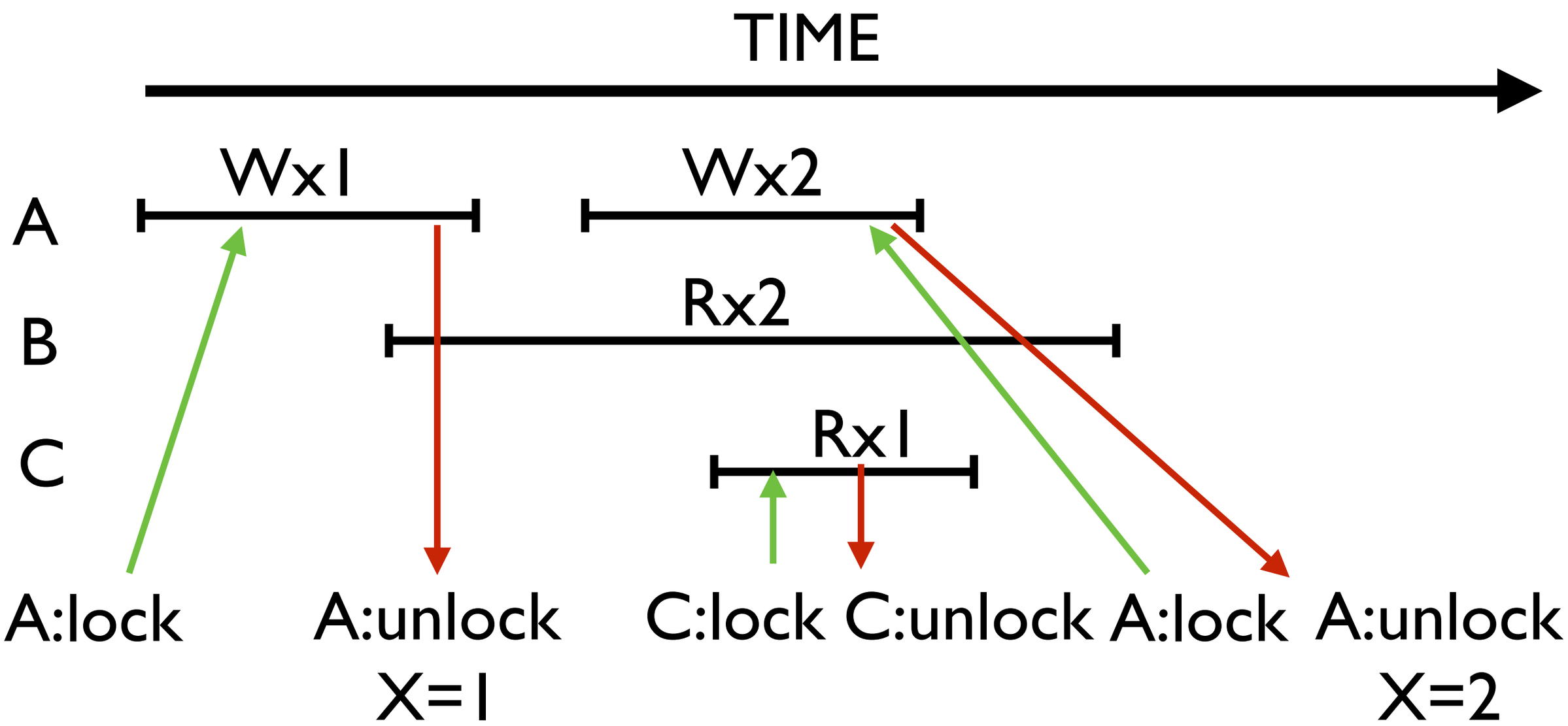
Linearizability



C start's an op while B and A are inflight

3 Concurrent ops

Linearizability



For what ever reason's C gets lock first then A then B —
This would lead to a Linear consistent order of
A:Wx1,C:Rx1,A:Wx2, B:Rx2

Checking Linearizablility

- Tricky — if writes and reads overlap
  - several orderings could be valid must check the results of all overlapping operations and see if they form one of the valid orders
- but strictly subsequent (in "Real Time") operations must see side effects of prior completed operations
- They would like to check "passively"

Linearizability is a "Local Model"

- Can spot violations by looking at traces of individual keys — no need to consider multi-key traces
- Simply evaluating all ops on a key tells you if the linearizable consistency was met

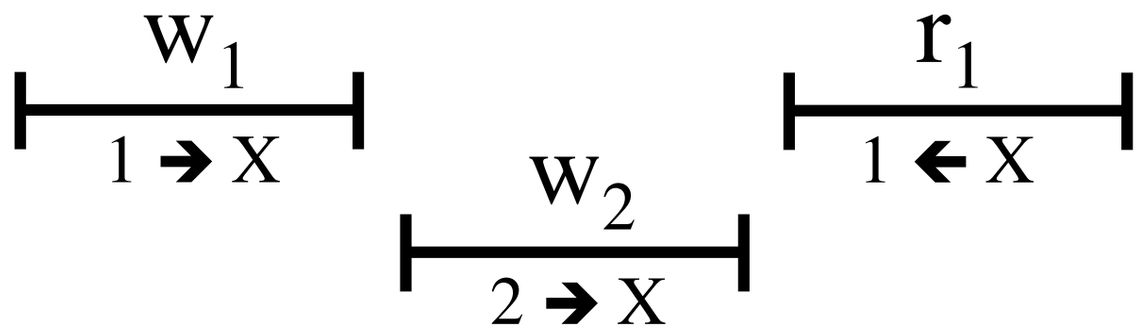
So how do they do it

- Randomly select a small subset of keys
- Trace all operations (reads and writes) on the key
- Analyze the trace offline for violations

The Trace

- **key**, **r/w**, **value** hash, **start** time, **end** time, …

Each read can be matched to its write and the operations can be ordered based on start and end times — overlaps/concurrency can be detected

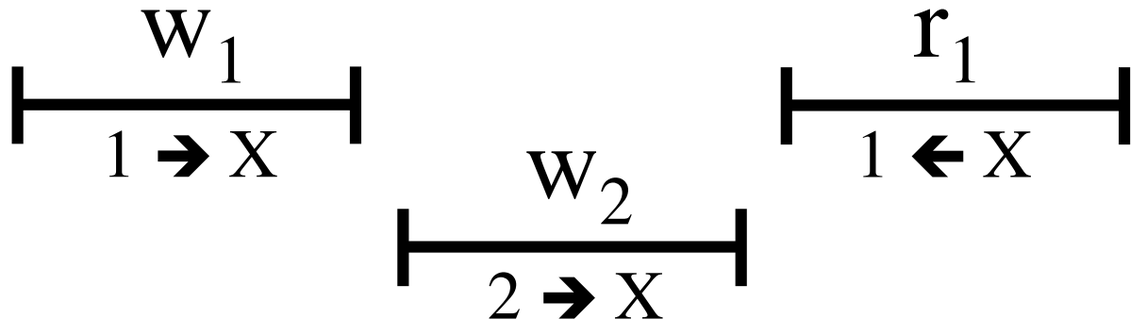


(a) Execution.

W1:X=1, strictly precedes W2: X=2, which strictly precedes read R1, that sees the value of W1

Graph construction

- node for each read and write
- edges for time ordering
  if op2.start > op1.end
  then edge(op1,op2)
- edges for value ordering
  if op2.read == op1.write
  then edge(op1,op2)



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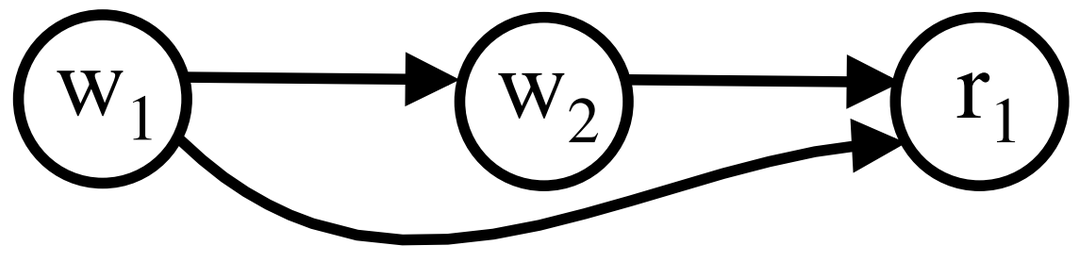
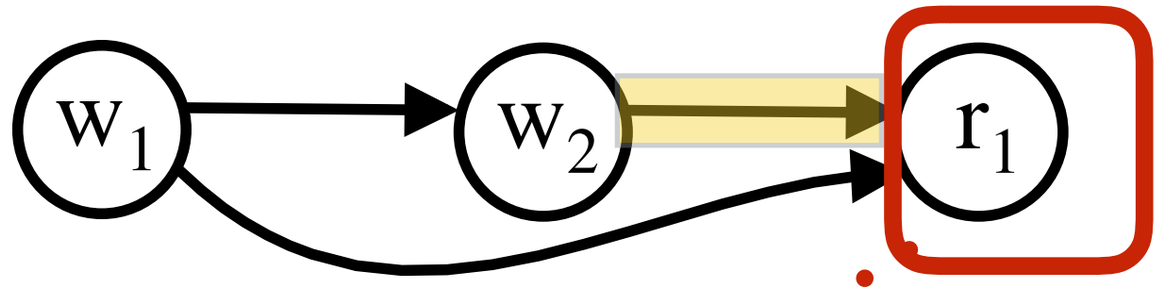


(b) Graph before merge.

"Linearizability: requires that there exits a total order that is **legal**, and agrees with the real-time ordering of ops. A total order is legal if it a read is ordered after the write it observed with no other writes between"

Graph construction

- Merge: put read nodes into their write nodes.
- If read's go behind a more recent write we will get a cycle
  - NO loop linearizable
  - Loop no legal total order



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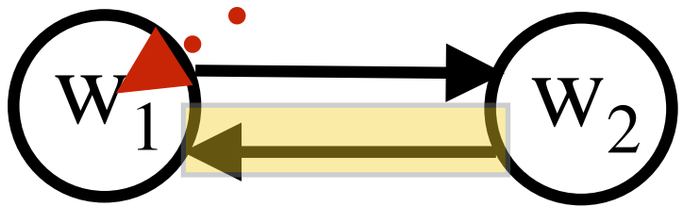
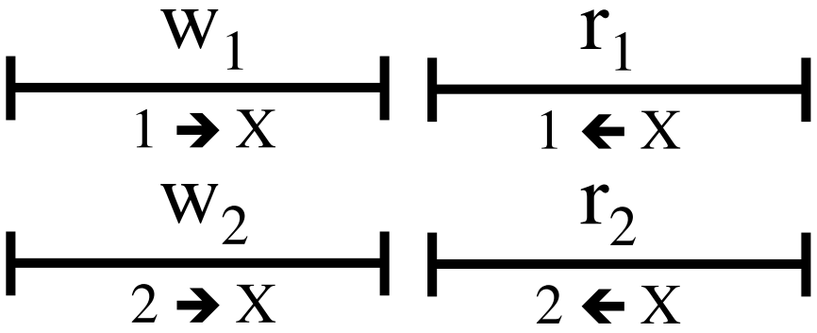


(c) Graph after merge.

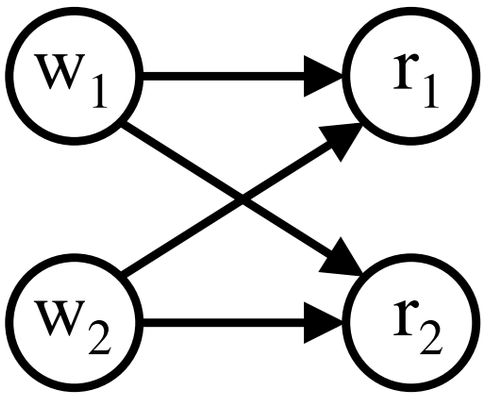
STALE READ ANOMALLY

"Linearizability: requires that there exits a total oder that is **legal**, and agrees with the real-time ordering of ops. A total order is legal if it a read is ordered after the write it observed with **no other writes between**"

Total Order Anomaly



(a) Execution



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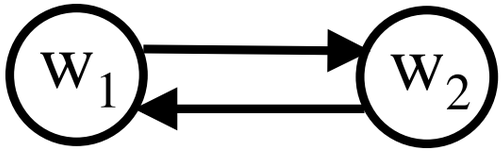

(c) Graph after merge.

- Linearizability requires that there is a single consistent total order for all operations on an object
- All observed side effects of concurrent operations must agree on a single order
- eg. either X=1,X=2 or X=2,X=1 is ok but not both!

Will their technique make mistakes?

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Yes if clocks are wrong.

Wx1 Wx2 Rx1

Will their technique make mistakes?

Their approach does not check non-sampled keys

Why can't things like causal consistency not be checked?

this is legal under causal consistency:

```
C0: Wx1
C1:   Rx1
C2:     Rx0
```

this is illegal:

```
C0: Wx1
C1:   Rx1 Wy2
C2:         Ry2 Rx0
```

Online Consistency Checking Practical Consistency

- "Principled" approach too expensive for realtime use — yet would really like to know how this system is doing and detect when things are going wrong
- So instead take a much simpler approach — get see if caches are consistent ;-)

Results

	Anomalous Reads	Percentage Of Filtered (241M)	Percentage Of Overall (937M)
Linearizable	3,628	0.00151%	0.00039%
Stale Read	3,399	0.00141%	0.00036%
Total Order	229	0.00010%	0.00002%
Per-object Seq	607	0.00025%	0.00006%
Per-User	378	0.00016%	0.00004%
Read-after-Write			
Global	3,399	0.00141%	0.00036%
Per-Region	1,558	0.00065%	0.00017%
Per-Cluster	519	0.00022%	0.00006%

Wow only 0.004% of reads show linearizability anomalies

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Wow only 0.004% of reads show linearizability anomalies

- Few writes (1 in 450)
- Locality (consistency better within writer's cache)
- Fast invalidation messages

What do the results mean?

Conclusion

- low-cost checking technique
- low-consistency design can provide remarkably high consistency!
  - i.e. they rarely display stale data to the user — sheds doubt on need for costly consistent designs
- consistency not always a correctness question — freshness of info shown to users
- FB specific results — but maybe representative of many web-sites