MYE017 Distributed Systems

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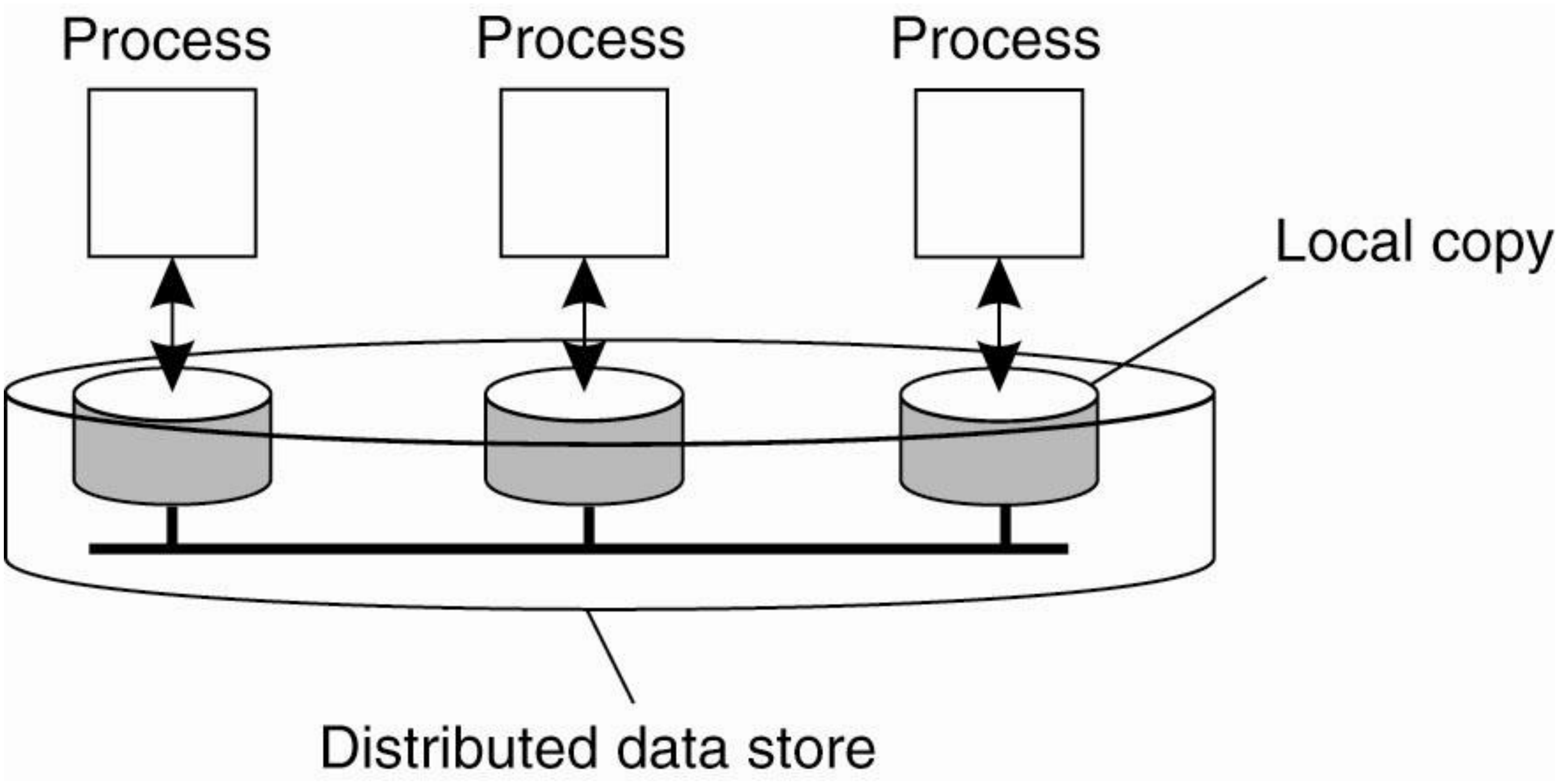
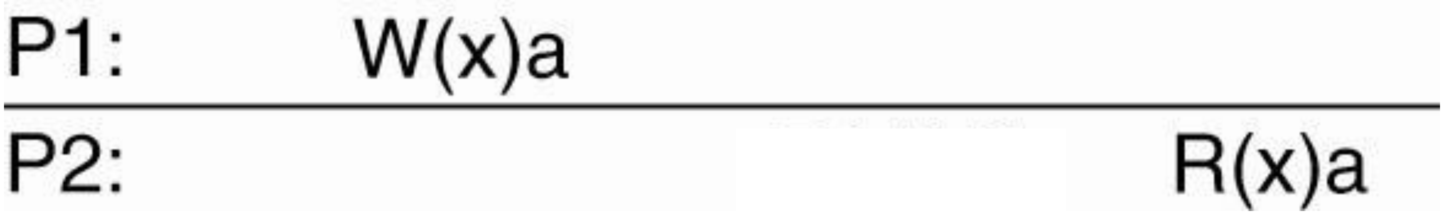
Data-centric consistency models



The general organization of a logical data store, physically distributed and replicated across multiple processes

Strict consistency

Any read on a data item x returns the value of the most recent write to x

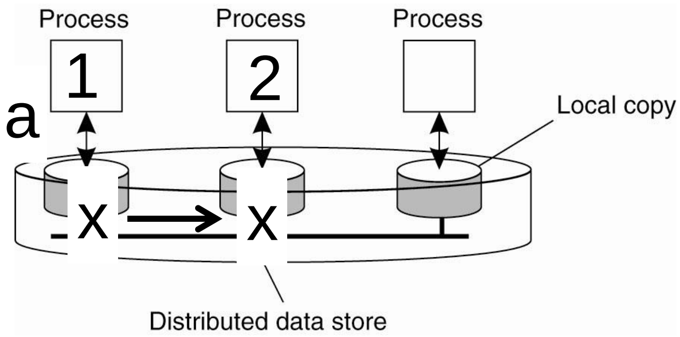


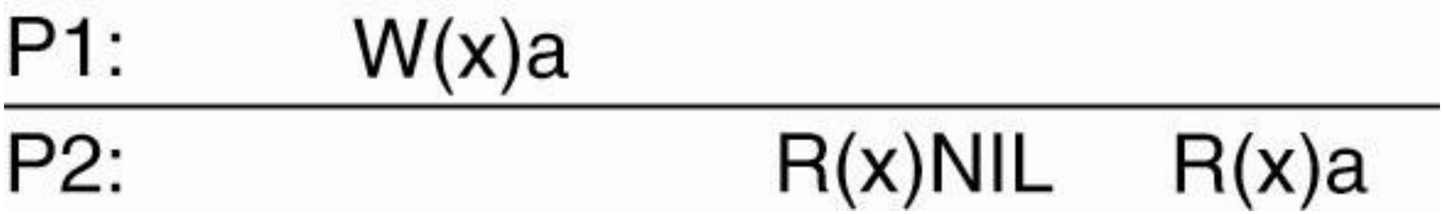
P1: W(x)a

P2: R(x)a

Behavior of two processes operating on the same data item. The horizontal axis is time.

Weaker consistency





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P1:      W(x)a
P2:                        R(x)NIL     R(x)a
```

Behavior of two processes operating on the same data item. The horizontal axis is time.

Sequential consistency

A data store is *sequentially consistent (SC)* when:

The result of <u>any execution</u> on the data store is the same as if the read and write operations by all processes

- Were executed in some sequential order *on a single copy* of the store
- The operations in this sequence appear in the order specified by each individual process' program

An execution:

E1:	P1:	W(x)a				
E2:	P2:		W(x)b			
E3:	P3:			R(x)b		R(x)a
E4:	P4:				R(x)b	R(x)a

A sequential order: (*history H*)

$W_1(x)b$

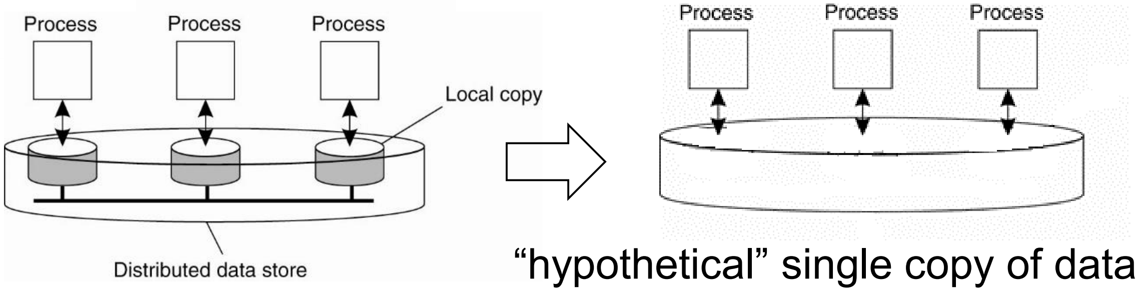
$R_3(x)b$

$R_4(x)b$

$W_2(x)a$

$R_3(x)a$

$R_4(x)a$

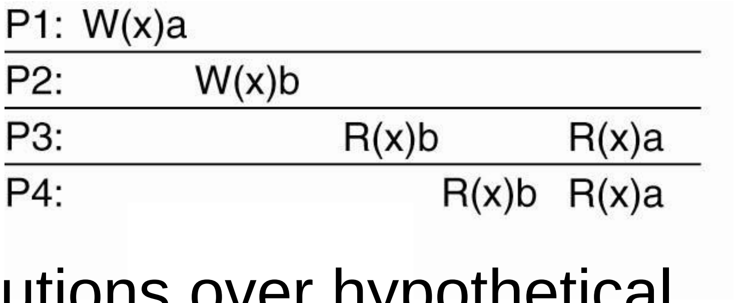


"hypothetical" single copy of data store

Tanenbaum & Van Steen, Distributed Systems: Principles and Paradigms, 2e, (c) 2007 Prentice-Hall, Inc. All rights reserved. 0-13-239227-5

More formally

- E_i : Sequence of read or write operations executed by process P_i over data store S
  - E.g. $E_3 = R_3(x)b\ R_3(x)a$



P1: W(x)a

P2: W(x)b

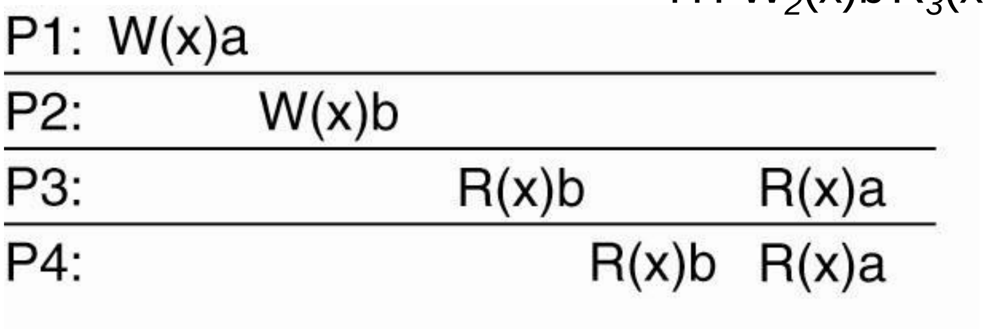
P3: R(x)b R(x)a

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

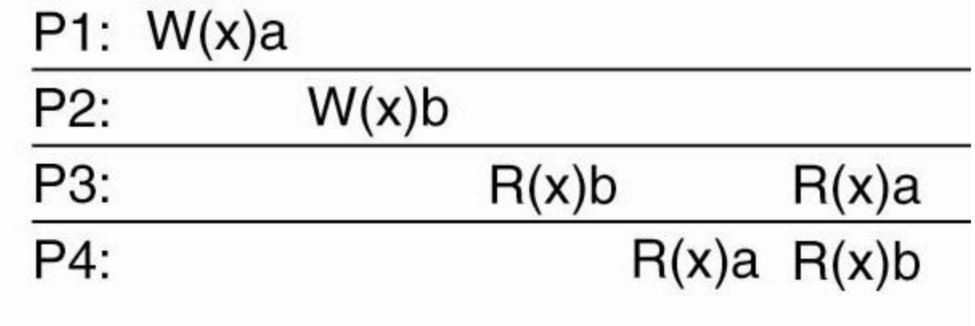
- History H : sequence of op executions over hypothetical centralized data store S′
  - H is an interleaving of E_i i=1, .., n
- All acceptable histories H must respect
  - The order of operations in individual executions
  - Data coherence (read last value written)

Sequential consistency

H : $W_2(x)b\ R_3(x)b\ R_4(x)b\ W_1(x)a\ R_3(x)a\ R_4(x)a$


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

(a)


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

(b)

(a) A sequentially consistent data store.

(b) A data store that is not sequentially consistent.

Sequential consistency

Data type: 4-location byte-valued read/write snapshot register

location	value
1	0
2	0
3	0
4	0

A multi-location read-write memory has

- a set of locations (or addresses)
- operations such as
    - read(*a*)
    - write(*a*, *w*)
    - snapshot()
- snapshot() returns a set of values, one for each location

Sequential consistency

Two replicas at sites X and Y, clients located at T and U

a legal history

(write(1, 5), "OK")

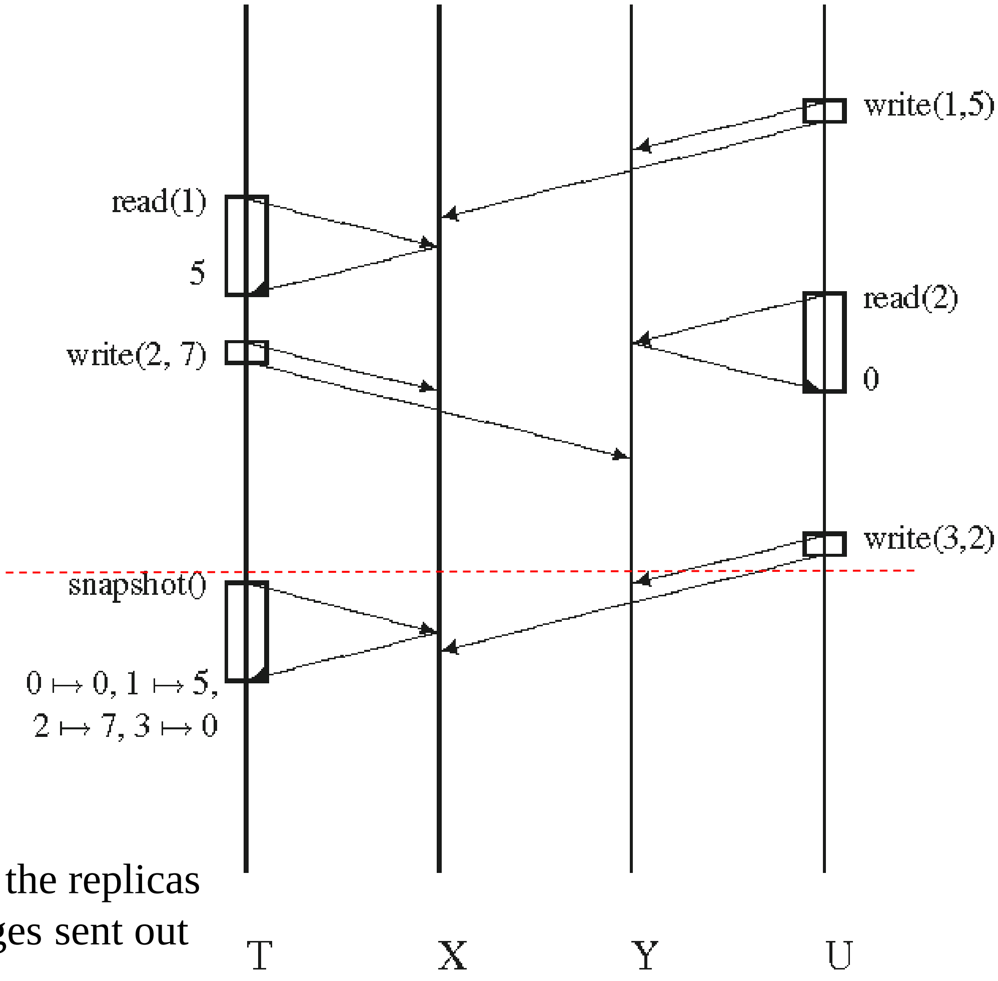
(read(1), 5)

(read(2), 0)

(write(2, 7), "OK")

(snapshot(), $(0 \mapsto 0, 1 \mapsto 5, 2 \mapsto 7, 3 \mapsto 0)$)

(write(3, 2), "OK")



Implementation rules:

- each read or snapshot is done on one replica
- each write is done on both replicas
- different writes are done in the same order at the replicas
- a write returns to the client as soon as messages sent out

From "Consistency Models for Replicated Data", A. D. Fekete, Krithi Mamamritham

B. Charron-Bost, F. Pedone, and A. Schiper (Eds.): Replication, LNCS 5959, pp. 1–17, 2010.
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Linearizability

A data store is *linearizable* when:

The result of any execution on the data store is the same as if the (read/write) operations by all processes

- Were executed in some sequential order on a single copy of the store
- The operations of each individual process appear in this sequence in the order specified by its program

Additionally

- If the duration of $OP_1(x)$ is entirely before the duration of $OP_2(y)$ (in same or different clients) then $OP_1(x)$ must precede $OP_2(y)$ in this seq. order

Linearizable execution

Implementation rules:

- each read or snapshot is done on one replica
- each write is done on both replicas
- different writes are done in the same order at the replicas
- <u>a write doesn’t return to the client until acked</u>

a legal history

(write(1, 5), “OK”)

(read(1), 5)

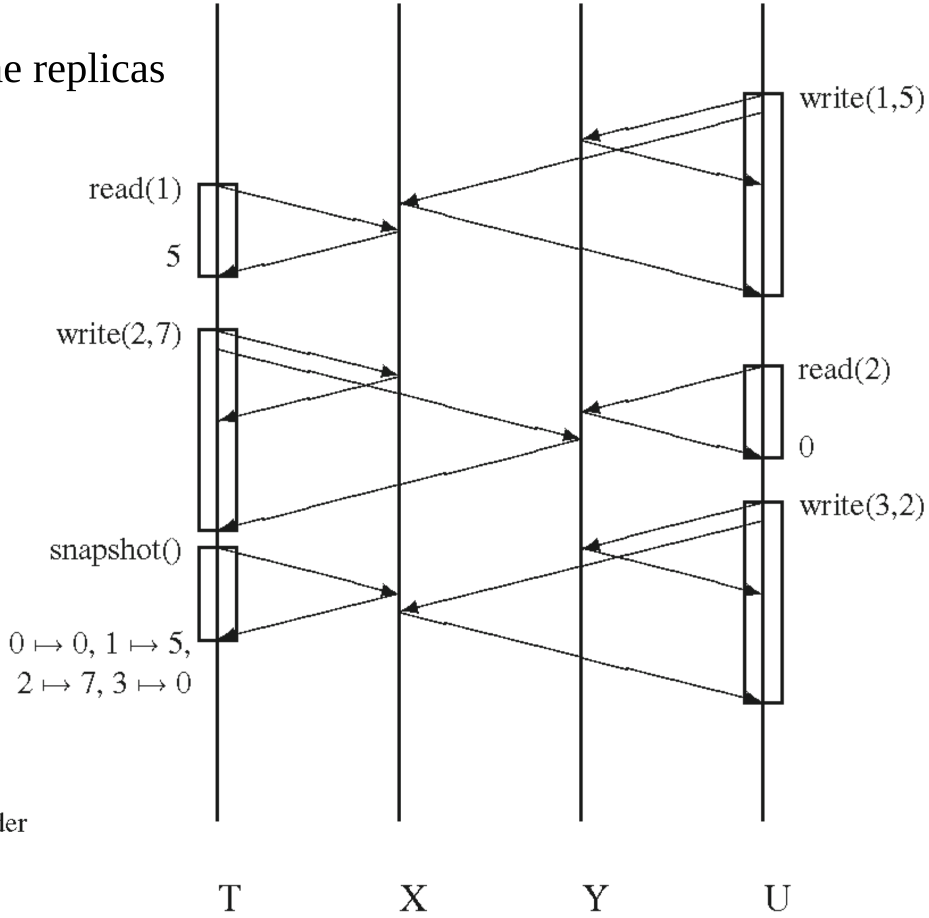
(read(2), 0)

(write(2, 7), “OK”)

(snapshot(), $(0 \mapsto 0, 1 \mapsto 5, 2 \mapsto 7, 3 \mapsto 0)$)

(write(3, 2), “OK”)

the order of operations as they occur in the sequence must not contradict any order information visible to an observer of the system execution.



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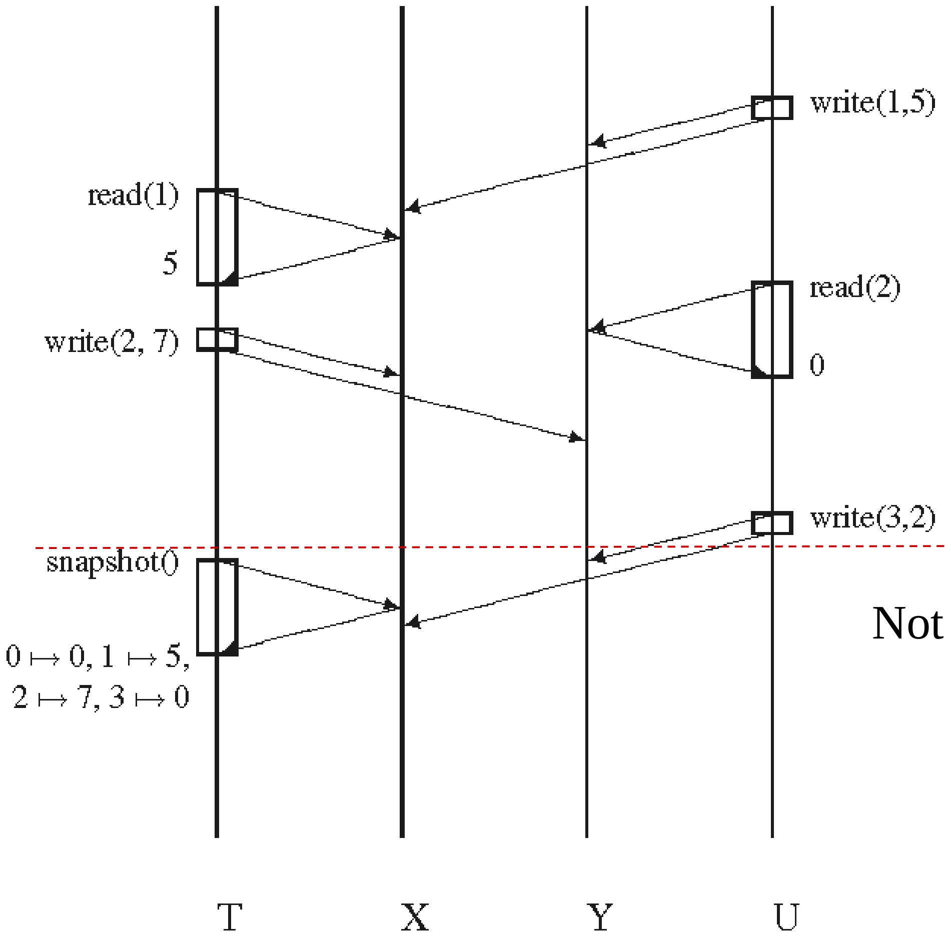
SC but not linearizable

4-location byte-valued snapshot memory



a legal history

(write(1, 5), “OK”)

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(read(2), 0)

(write(2, 7), “OK”)

(snapshot(), (0 $\mapsto$ 0, 1 $\mapsto$ 5, 2 $\mapsto$ 7, 3 $\mapsto$ 0)

(write(3, 2), “OK”)

Not linearizable!!

From “Consistency Models for Replicated Data”, A. D. Fekete, Krithi Mamamritham

B. Charron-Bost, F. Pedone, and A. Schiper (Eds.): Replication, LNCS 5959, pp. 1–17, 2010.
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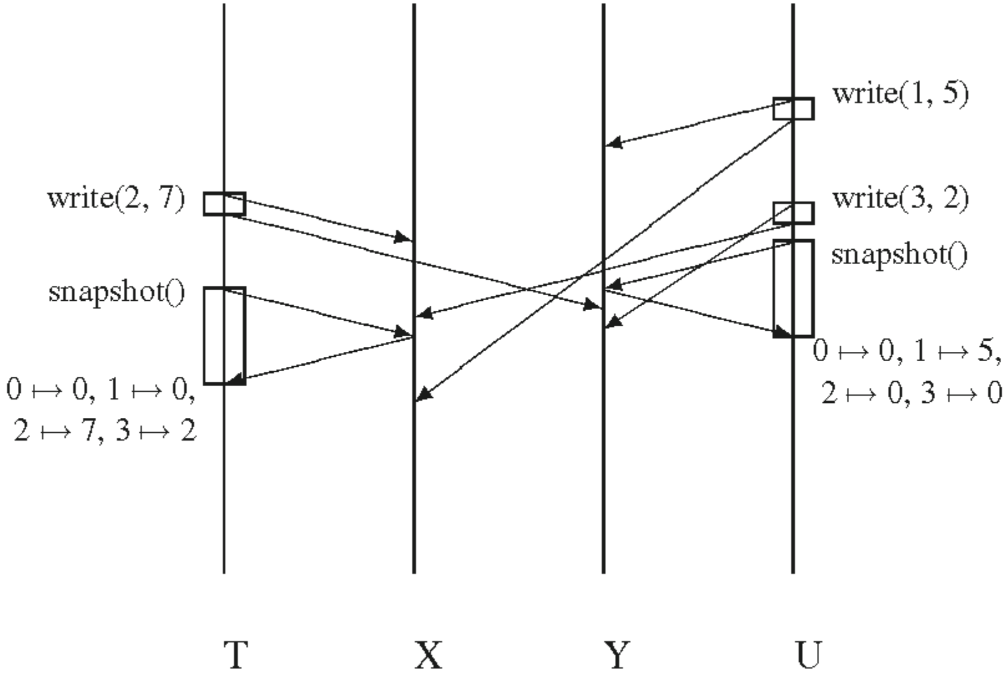
Weak consistency

Implementation rules:

- each read or snapshot is done on one replica
- each write is done on both replicas
- ~~different writes are done in the same order at the replicas~~
- a write returns to the client as soon as messages sent out



Cannot find a legal history that would satisfy either linearizability or SC conditions