Distributed Transactions

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Today's Topics

- What is correctness or different forms of consistency?
- Distributed transactions
- Transaction chains

Consistency and Performance

- Weaker consistency often means better performance
  - But harder for programmers to reason about system behavior

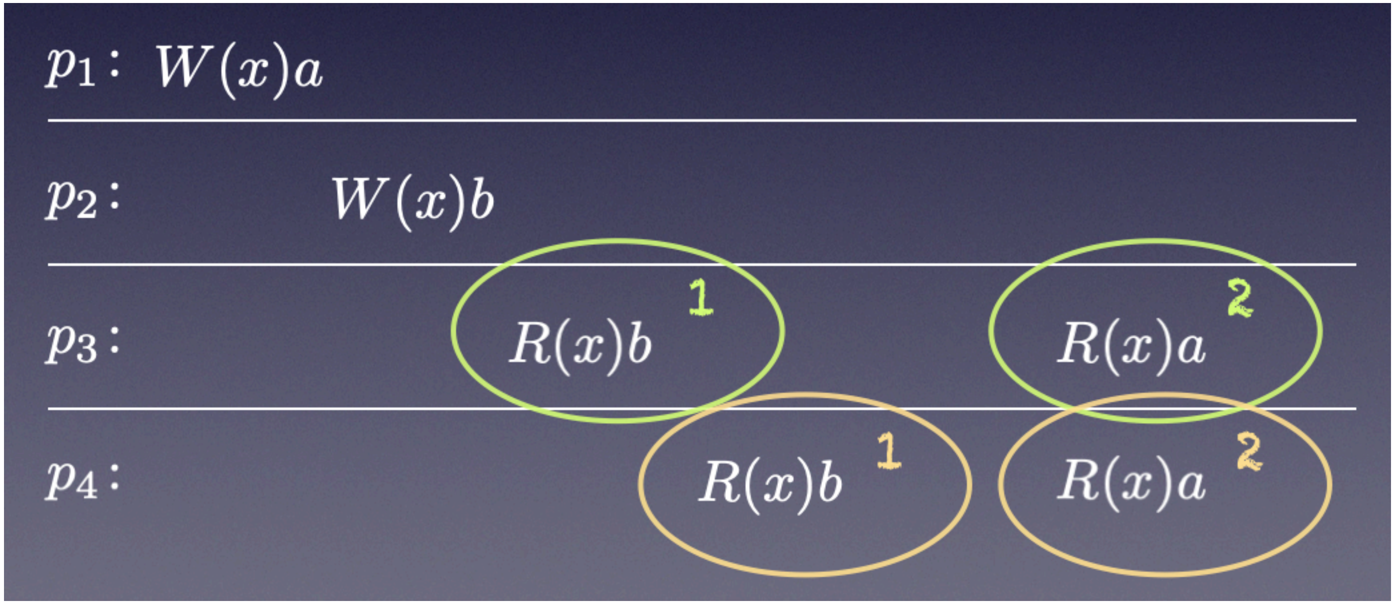
Sequential Consistency

- “The result of any execution is the same as if the operations of all the processes were executed in some sequential order and the operations of each individual process appear in this sequence in the order specified by its program” (Lamport, 1979)

- Coherence is the correctness criteria when restricted to a single memory location

Sequential Consistency

- Is the following execution sequentially consistent?



Sequential Consistency

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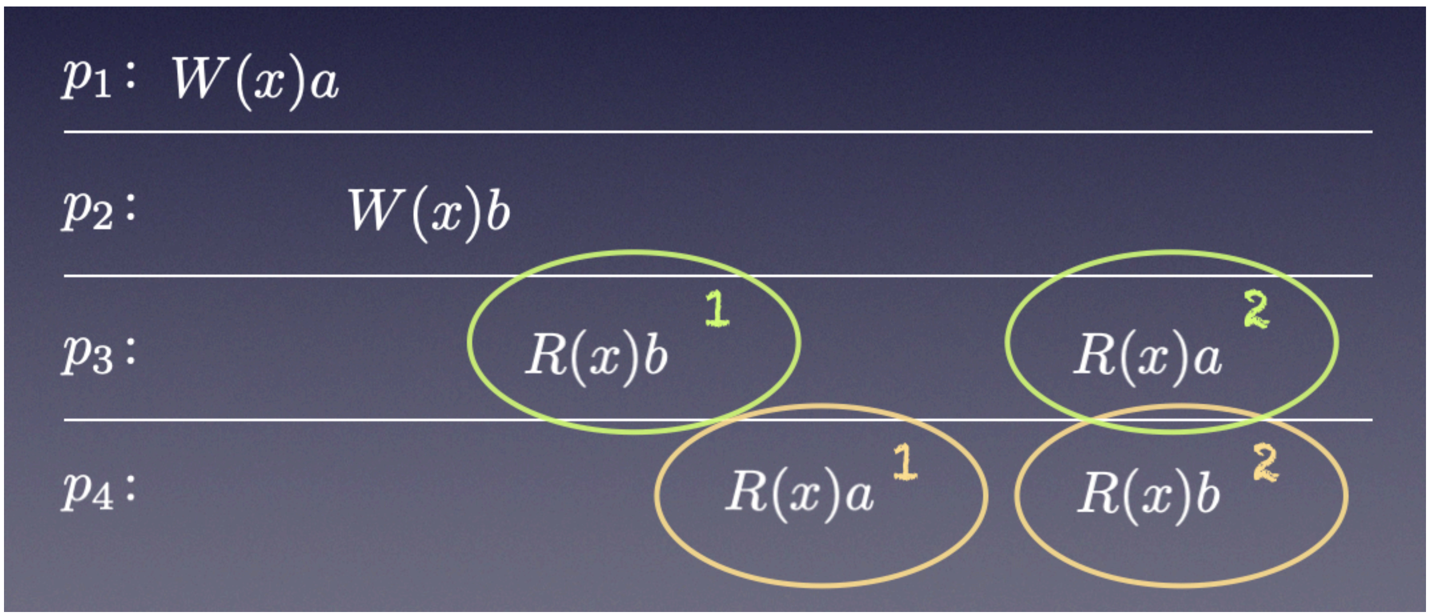
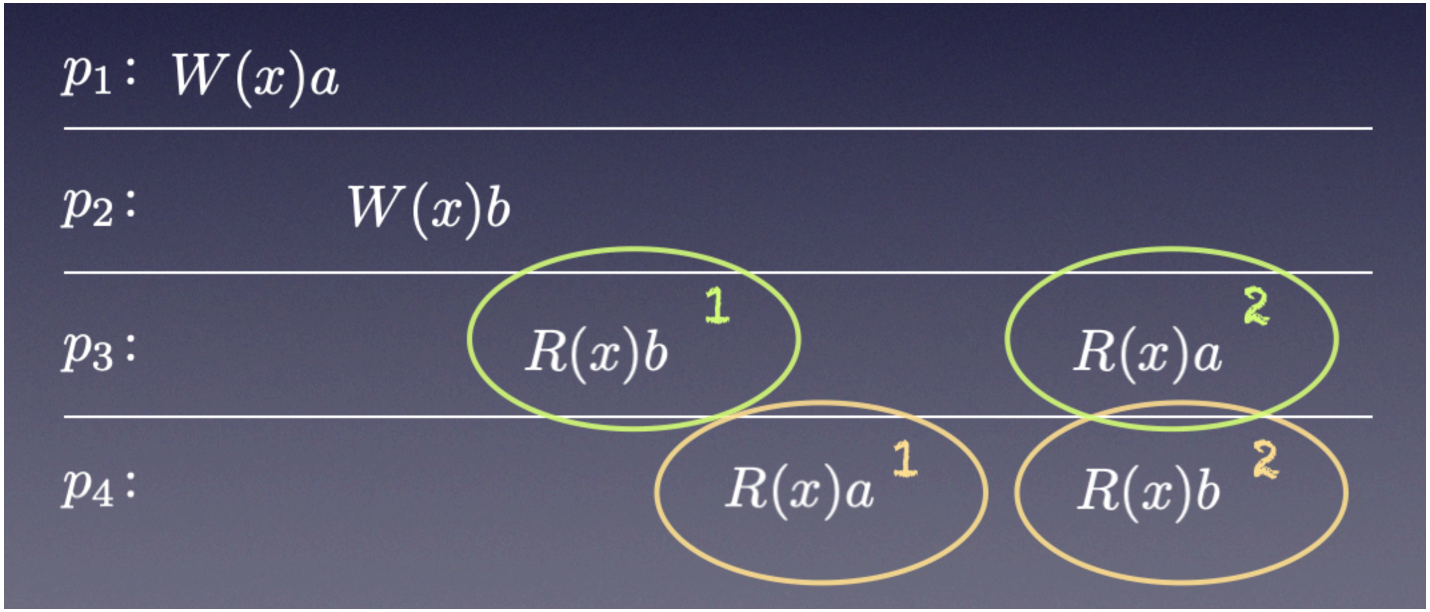


What could cause this behavior?



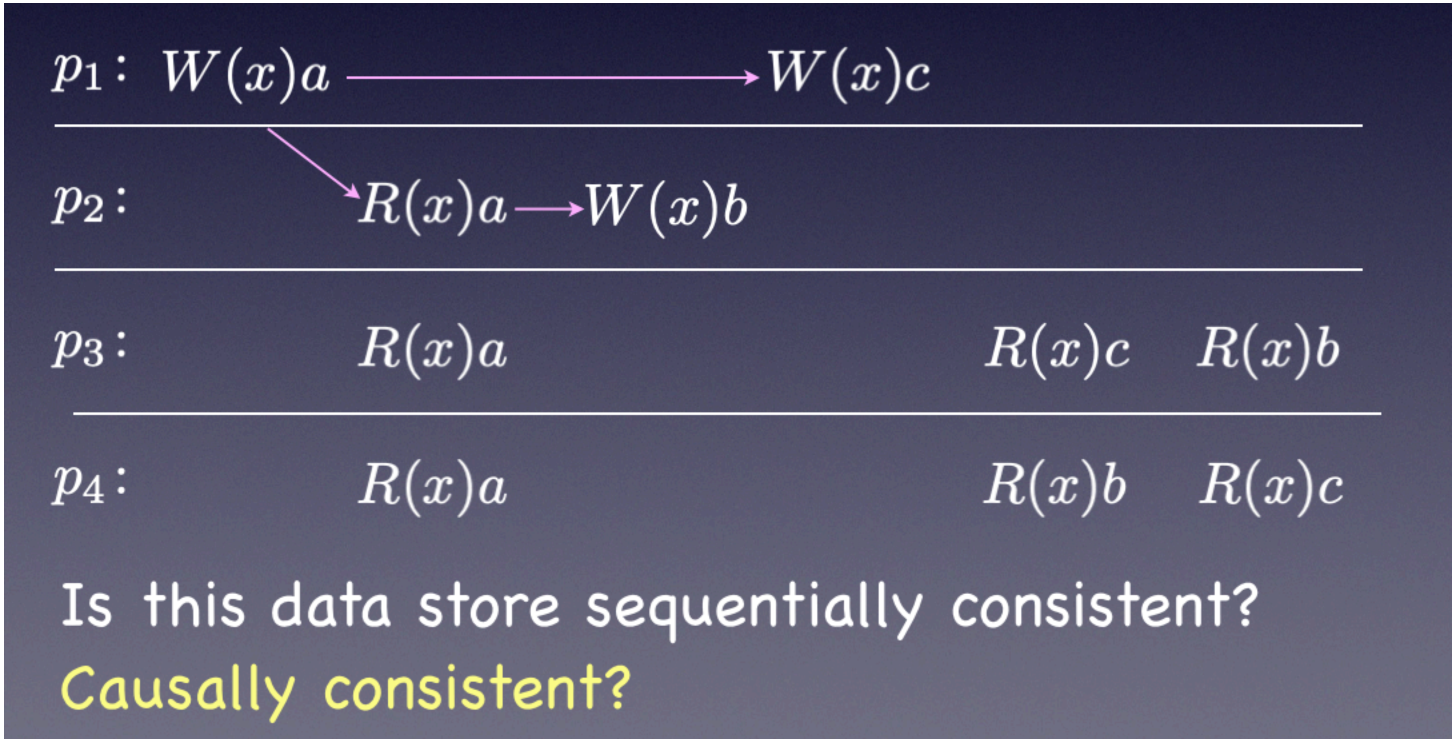
- Multiple caches & non-serialized updates
- Non-blocking operations
- Compiler rewrites

Linearizability

- "The result of any execution is the same as if the operations of all the processes were executed in some sequential order and the operations of each individual process appear in this sequence in the order specified by its program" (Lamport, 1979)
- In addition, if ts(A) < ts(B), then operation A should precede B in this sequence (Herlihy & Wing, 1991)

Causal Consistency

- Writes that are potentially causally related must be seen by all processes in the same order. Concurrent writes may be seen in a different order on different machines. (Hutto and Ahamad, 1990)



Causal Consistency

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$p_1:$	$W(x)a$		$W(x)c$		
$p_2:$		$R(x)a$			
$p_3:$		$R(x)a$	$W(x)b$	$R(x)c$	$R(x)b$
$p_4:$		$R(x)a$		$R(x)b$	$R(x)c$

Is this data store sequentially consistent?
Causally consistent?

Transactions

- Operations sometimes need to atomically update multiple data items
  - Transactions help cope with crashes and concurrency

- Example: calendar system, each user has a calendar
- Sched(u1, u2, t):

```
begin_transaction()
ok1 = reserve(u1, t)
ok2 = reserve(u2, t)
if ok1 and ok2:
    commit_transaction()
else abort_transaction()
```

Formalizing Correctness (Serializability)

- Atomic: state shows either all the effects of a transaction or none of them
- Consistent: transaction moves only between states where integrity holds
- Isolated: effects of transactions is the same as transactions running one after another
- Durable: once a transaction has committed, its effects remain in the database

Serializability

- Conflicting operations:
  - two updates to the same location
  - an update and an access to the same location
- Serializability check:
  - Order conflicting operations from different transactions
  - All ordering constraints between two transactions should go in the same direction
    - i.e., T1’s operations happened before T2’s operations or the other way around

Distributed Transactions

- Data distributed across multiple nodes
- How to provide serializable transactions in a distributed setting?

Idea #1

- tentative changes, later commit or undo (abort)

```
reserve_handler(u, t):
  if u[t] is free:
    temp_u[t] = taken    // A TEMPORARY VERSION
    return true
  else:
    return false

commit_handler():
  copy temp_u[t] to real u[t]
abort_handler():
  discard temp_u[t]
```

Idea #2

- Single entity decides whether to commit to ensure agreement
  - let's call it the Transaction Coordinator (TC)
- Client sends RPCs to nodes A, B
- Client's commit_transaction() sends "go" to TC
- TC/A/B execute distributed commit protocol
- TC reports "commit" or "abort" to client

2-Phase Commit

Coordinator c

I. sends VOTE-REQ to all participants

Participant p_i

II. send vote to Coordinator
    if vote = NO then
        decide := ABORT
        halt

III. if (all votes YES) then
        decide := COMMIT
    send COMMIT to all
else
        decide := ABORT
    send ABORT to all who voted YES
halt

IV. if received COMMIT then
        decide := COMMIT
    else
        decide := ABORT
    halt

Dealing with failures

- Failures result in timeouts
- What should the coordinator do when it times-out on a participant?
- What should the participant do when it times-out on the coordinator?
  - For the vote request?
  - For the decision?
- What state should the coordinator/participant maintain in stable storage?

Transaction Chains

- Lynx system for geo-distributed data
  - Low latency without needing to contact all shards
  - Serializable semantics if transactions have a certain structure
- Takes advantage of the fact that:
  - Most transaction systems have a fixed and known set of transactions

Why transaction chains?

Auction service

Bids

Bidder	Item	Price
Alice	Book	$100
Bob	Book	$20

Items

Seller	Item	Highest bid
Alice	iPhone	$20
Bob	Camera	$100

Alice

Datacenter-1

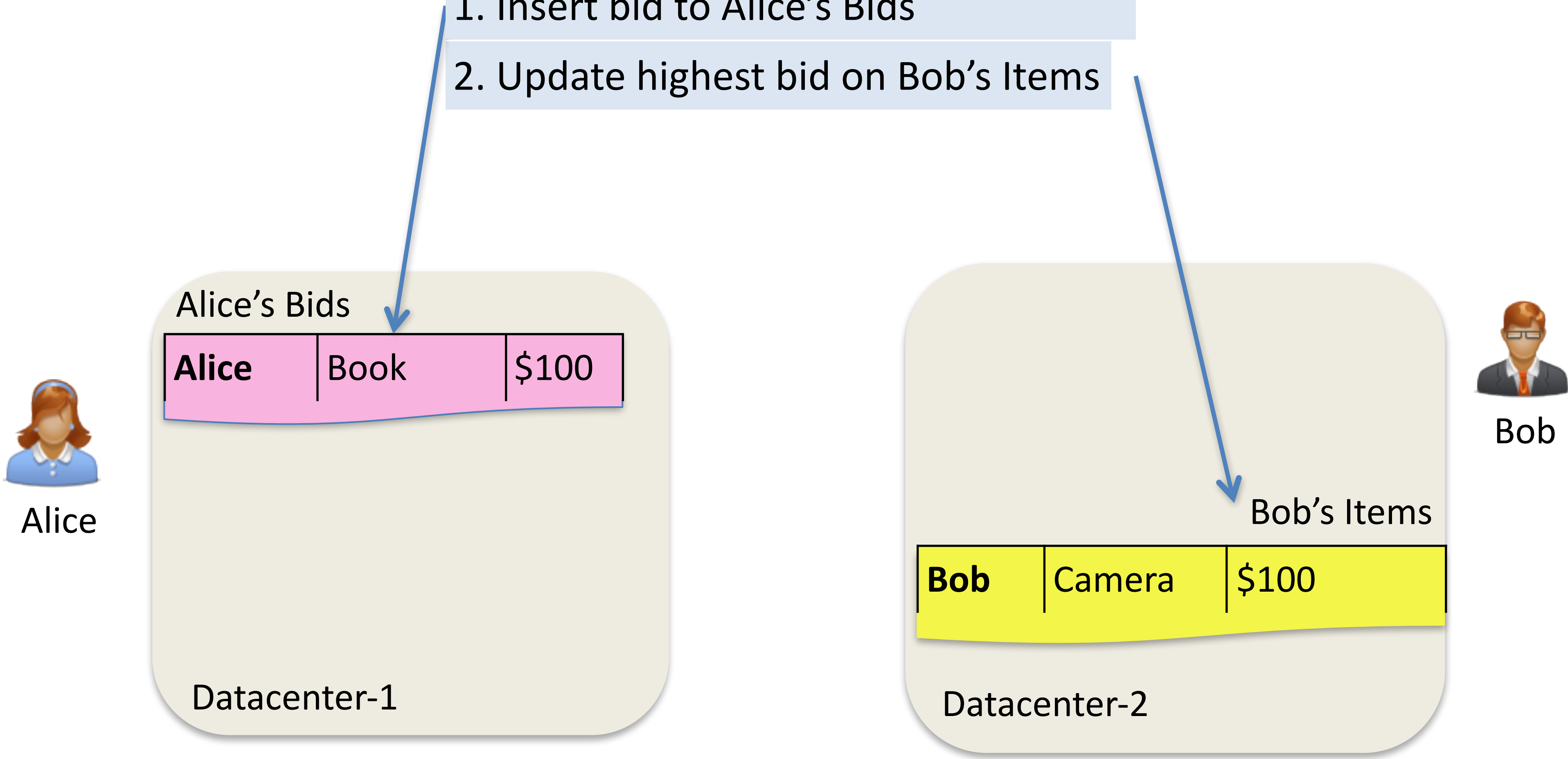
Datacenter-2

Bob

Why transaction chains?

Operation: Alice bids on Bob's camera

1. Insert bid to Alice's Bids
2. Update highest bid on Bob's Items



Why transaction chains?

Operation: Alice bids on Bob's camera

1. Insert bid to Alice's Bids
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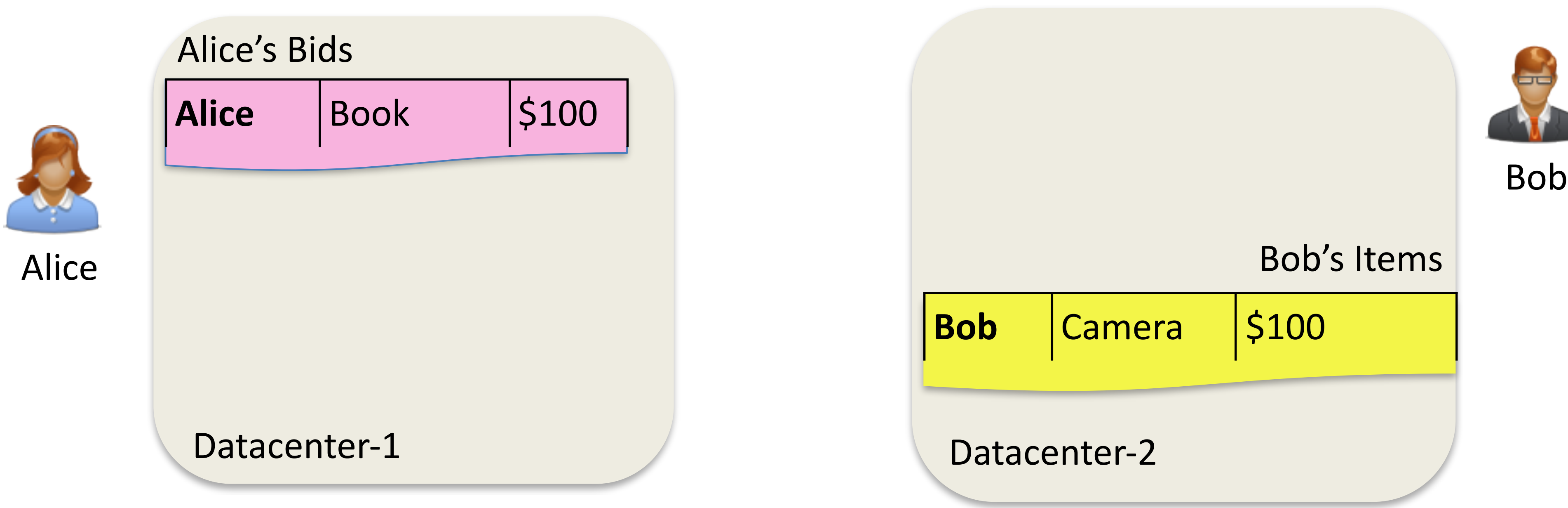
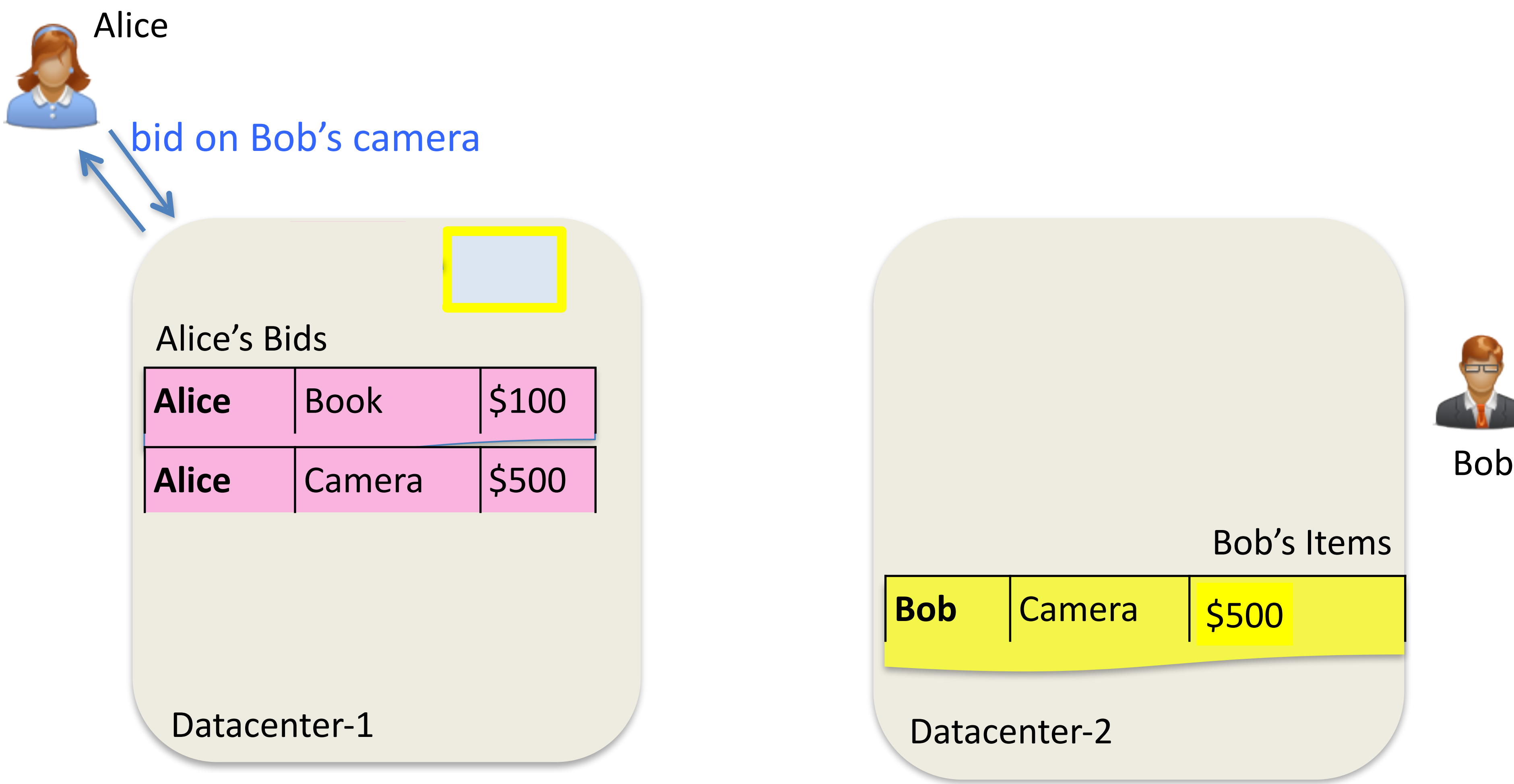


Low latency with first-hop return



Problem: what if chains fail?

1. What if servers fail after executing first-hop?

2. What if a chain is aborted in the middle?

Solution: provide all-or-nothing atomicity

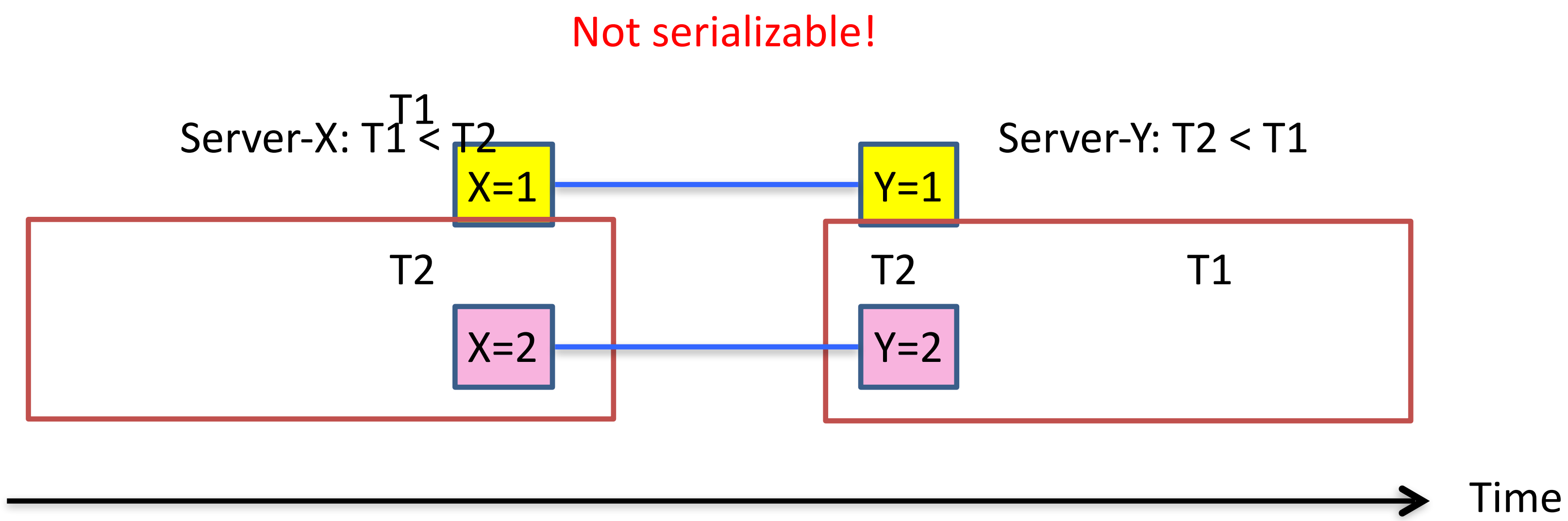
1. Chains are durably logged at first-hop
   - Logs are replicated to another closest data center
   - Chains are re-executed upon recovery

2. Chains allow user-aborts only at first hop

- First hop commits →all hops eventually commit

Problem: non-serializable interleaving

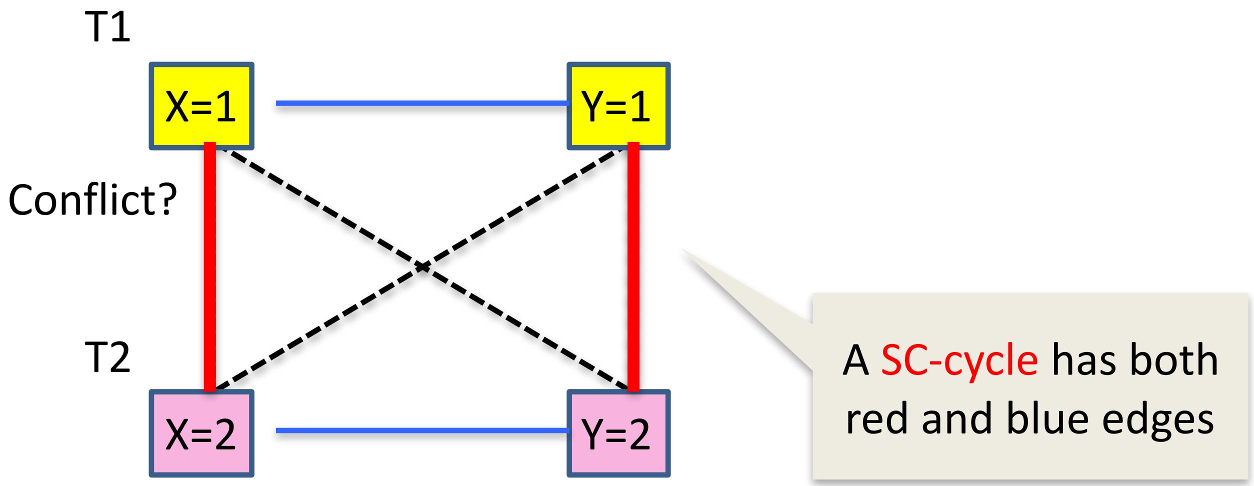
- Concurrent chains ordered inconsistently at different hops



- Traditional 2PL+2PC prevents non-serializable interleaving at the cost of high latency

Static Analysis

- Statically analyze all chains to be executed
  - Web applications invoke fixed set of operations



Serializable if no SC-cycle [Shasha et. al TODS'95]

How Lynx uses chains

- User chains: used by programmers to implement application logic
- System chains: used internally to maintain
  - Secondary indexes
  - Materialized join views
  - Geo-replicas

Example: secondary index

Bids (base table)

Bidder	Item	Price
Alice	Camera	$100
Bob	iPhone	$20

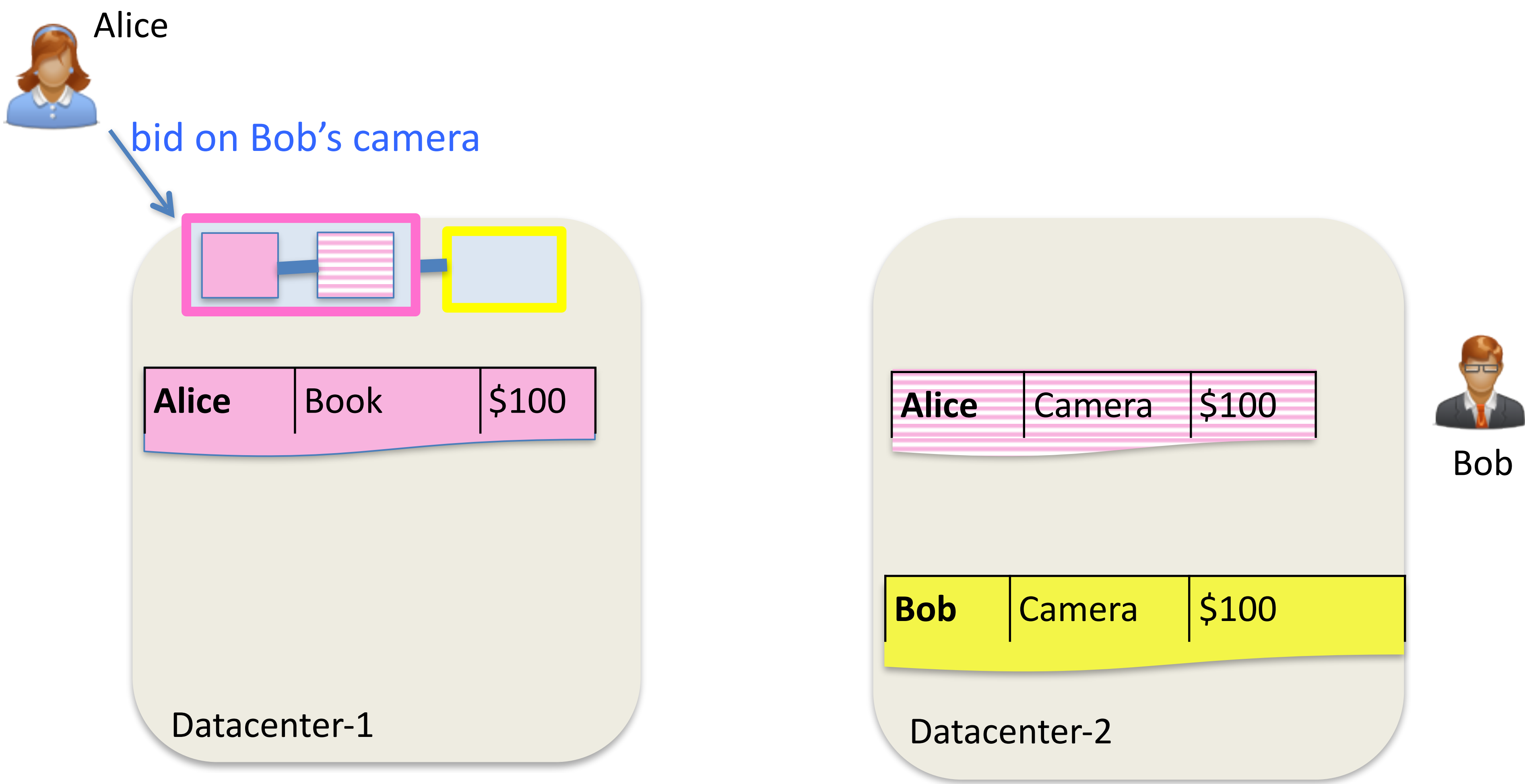
Bids (secondary index)

Bidder	Item	Price
Alice	Camera	$100
Bob	Car	$20

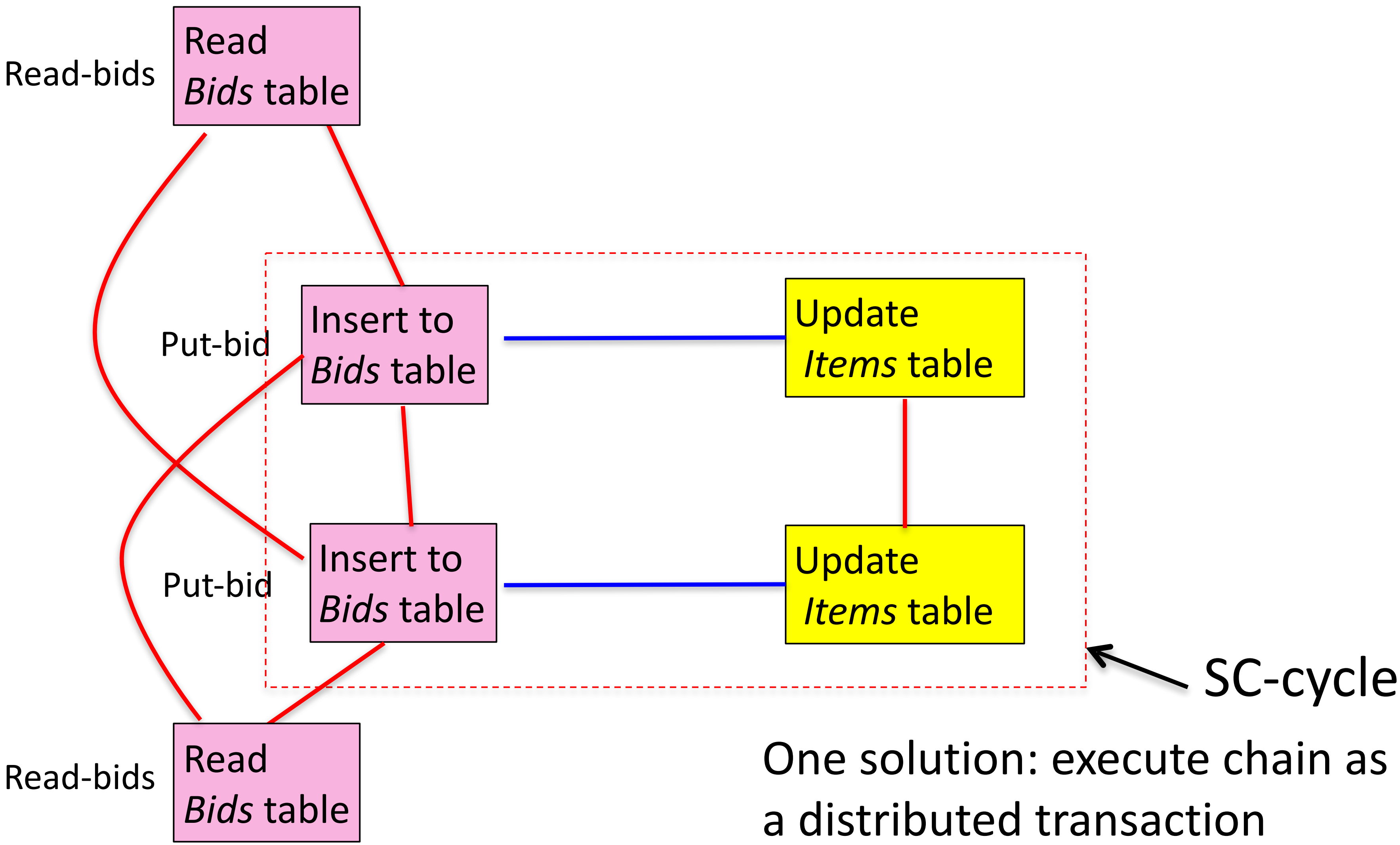
Alice	Book	$20
Alice	iPhone	$100

Bob	Car	$20
Bob	Camera	$100

Example user and system chain

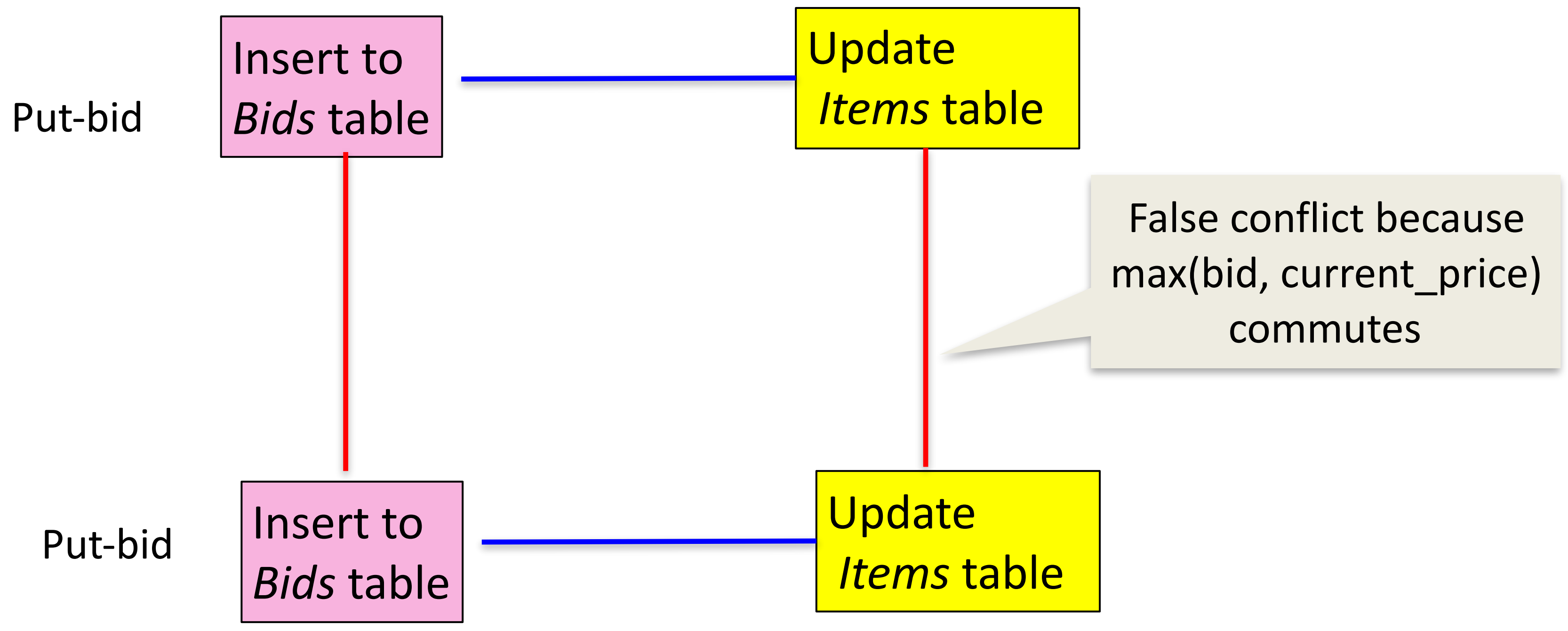


Static Analysis

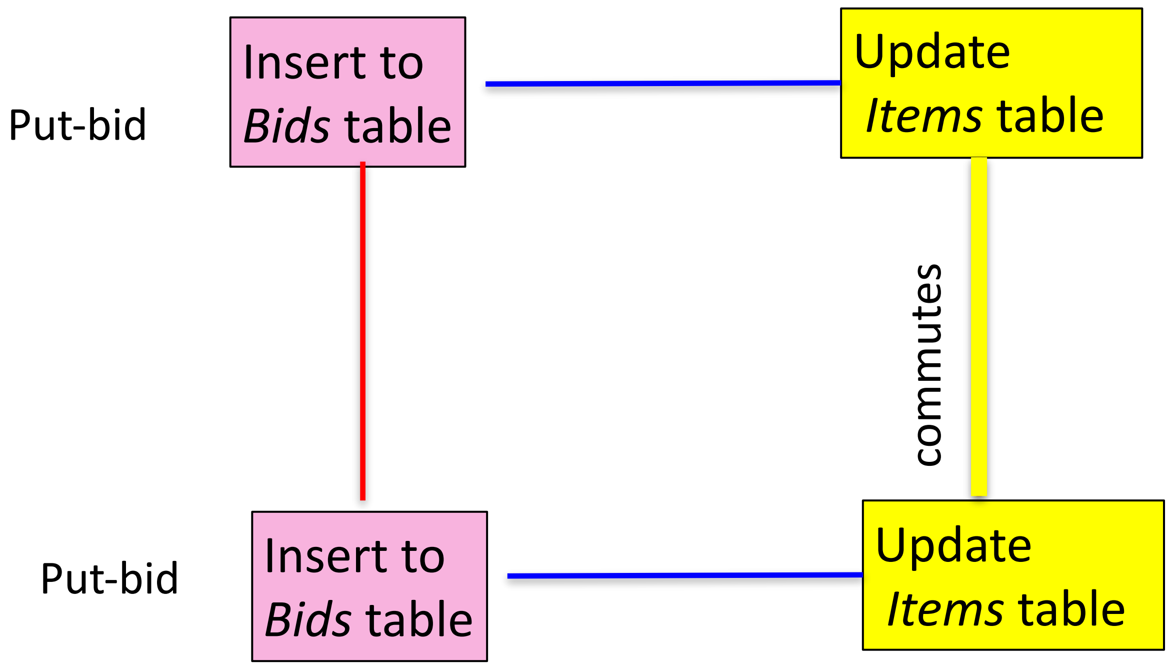


One solution: execute chain as a distributed transaction

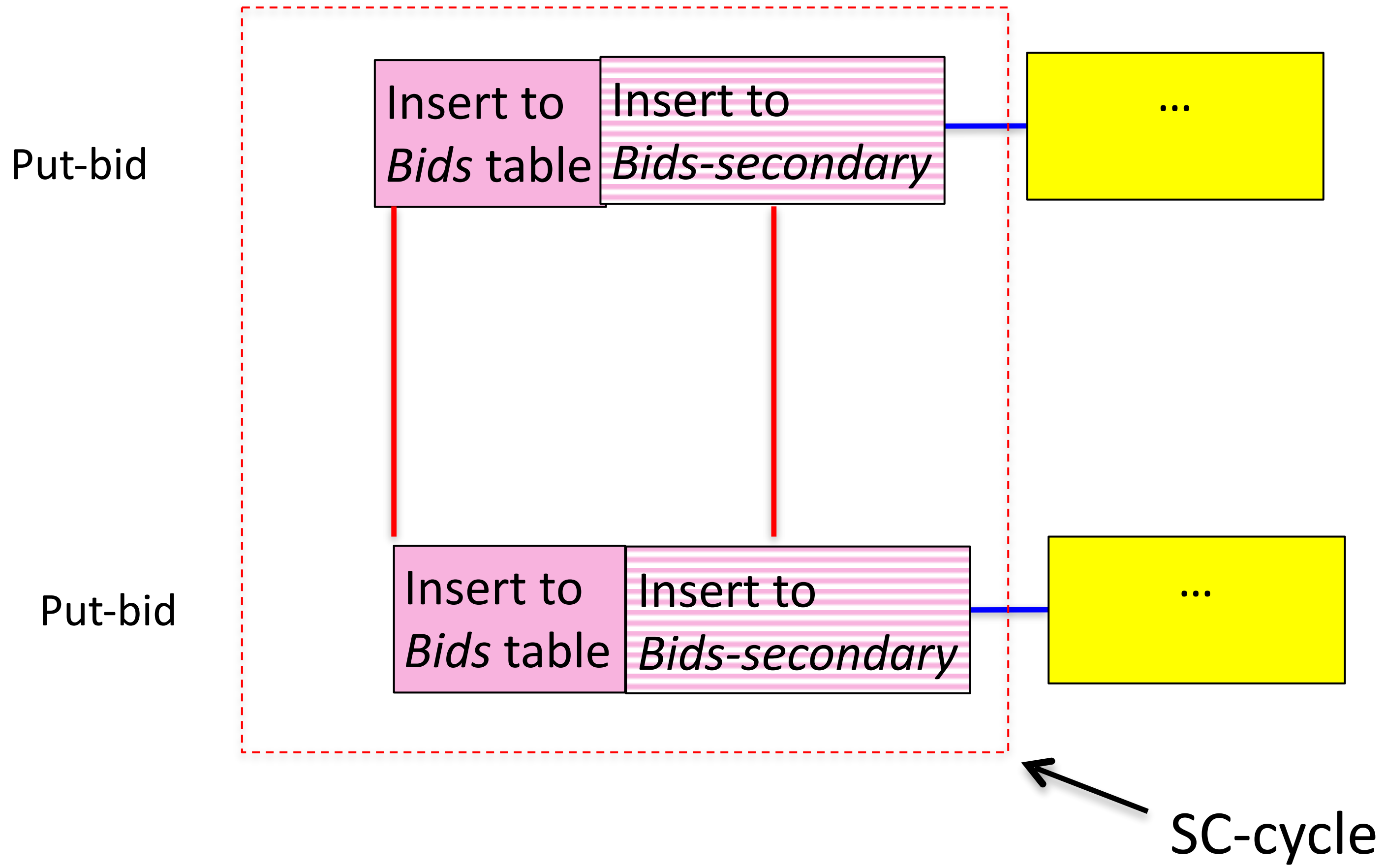
False conflicts in user chains



Solution: users annotate commutativity

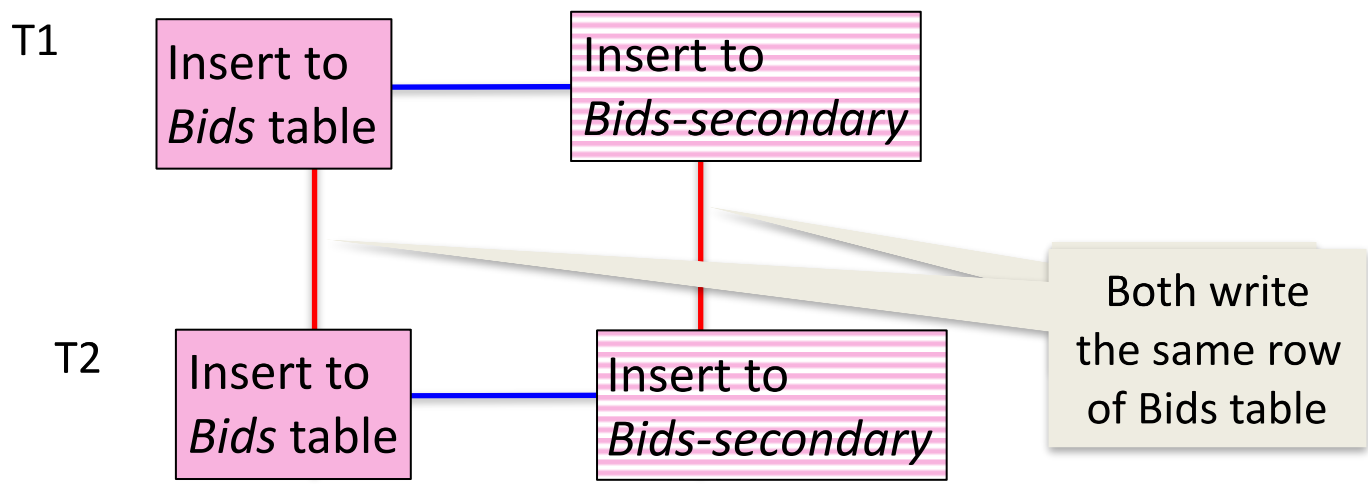


System chains



Solution: chains provide origin-ordering

- Observation: conflicting system chains originate at the same first hop server.



- Origin-ordering: if chains T1 < T2 at same first hop, then T1 < T2 at all subsequent overlapping hops.
  - Can be implemented cheaply → sequence number vectors

Limitations of Lynx/chains

1. Chains are not strictly serializable, only serializable.
2. Programmers can abort only at first hop