Transactions in RAMCloud

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RAMCloud Design Review
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Where's my CMPXCHG?

We can't even increment a value safely with our poor API.

Example: Unsafe Increment

```
data = ramcloud.read(table, 10)
ramcloud.write(table, 10, data + 1)
```

Problem: Race condition

- If you're surprised, Professor Ousterhout is teaching the introductory operating systems course this quarter.

What primitives do apps need for concurrency?

Hypothesis:
If latency is sufficiently low, can provide a high level of consistency

- Can push complex object operations to apps
- A lot of other NoSQL systems don't do this

Outline

1. Conditional operations for single objects
2. Transactions for multiple objects

RAMCloud's Conditional API

- Each object has a monotonically increasing version number
- Predicates specify whether an object must exist
  and whether it must have a given version number

```
read(table ID, object ID, predicates) → data, version
write(table ID, object ID, predicates, data) → version
delete(table ID, object ID, predicates)
```

Example: Atomic Increment

```
label .again:
  data, v1 = ramcloud.read(table, 10, None)
  try:
      v2 = ramcloud.write(table, 10, Pred(version=v1), data + 1)
  except: # Someone else changed the object first!
      goto .again
```

Transactions Are a Useful Building Block

- Apps may need to simultaneously update multiple objects
  - Transferring money across users
  - Updating a shared data structure

- Transactions make this easy (well, relatively)
  - Apps can maintain database invariants

- Alternatives are too difficult
  - Locking isn't an option – we can't detect when apps crash
  - Expired leases (locks with timeouts) are difficult to clean
  - Lockless data structures are tricky

Optimistic Concurrency Control

- Transactions proceed without locking
- During commit, make sure the objects read have not changed

We expect few conflicts:

- Writes are rare
- Transactions are rarer
  - Some apps won't need them
  - Most writes can use conditional API
- Conflicts are rarer yet
- High speed $\Rightarrow$ fewer conflicts

Optimistic Transactions API

Minitransaction – packaged set of conditional operations to execute atomically

- Modeled after Sinfonia

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Example: Move $20 from account 1 to account 2

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label .again:
  tx = ramcloud.Transaction()
```

Minitransaction

Object	Pred	Operation

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Example: Move $20 from account 1 to account 2

```
label .again:
  tx = ramcloud.Transaction()
  d1, v1 = tx.read(ACC, 1)
```

Minitransaction

Object	Pred	Operation
ACC: 1	v_1	

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Example: Move $20 from account 1 to account 2

```
label .again:
  tx = ramcloud.Transaction()
  d1, v1 = tx.read(ACC, 1)
  tx.write(ACC, 1, d1 - 20)
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Object	**Pred**	**Operation**
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  tx.write(ACC, 2, d2 + 20)
  try:
      tx.commit()
  except:
      goto .again
```

Minitransaction

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ACC: 1	v_1	write($d_1 - 20$)
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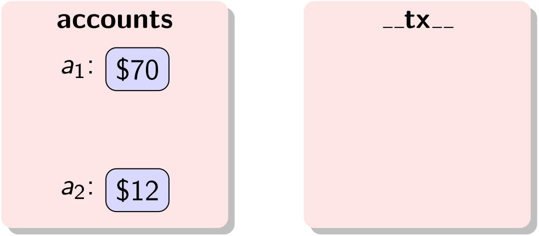
Approaches

1. Client-Side Transactions
   - No server modifications required – built on the conditional API
2. Two-Phase Commit (2PC)
   - Better performance

Client-Side Transactions

Idea: Put the values together into a single object which we can update atomically.

Transferring \$20 from a_1 to a_2:



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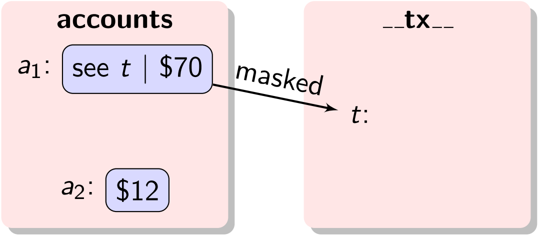

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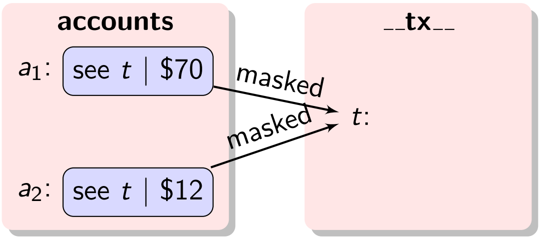

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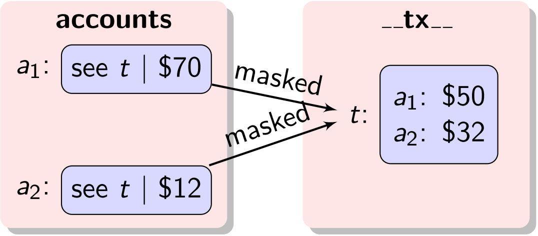

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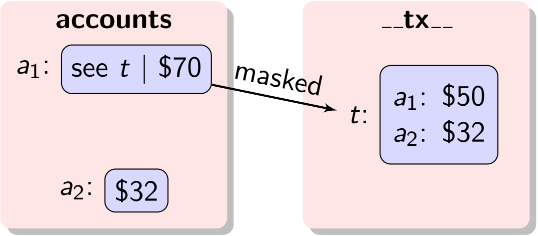

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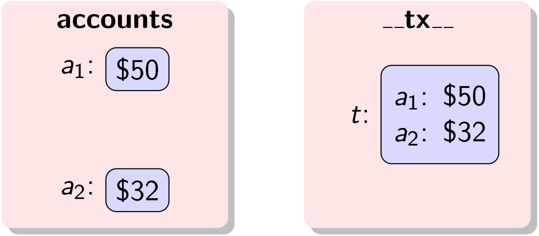

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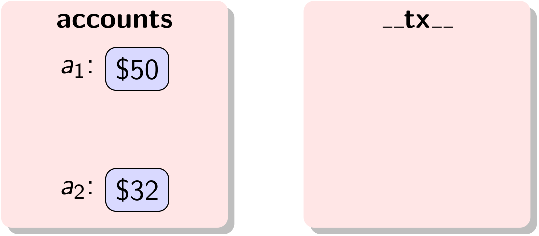

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Optimization

- Server-side changes for cheap masking
  - Saves rewriting the data to the log in step 1

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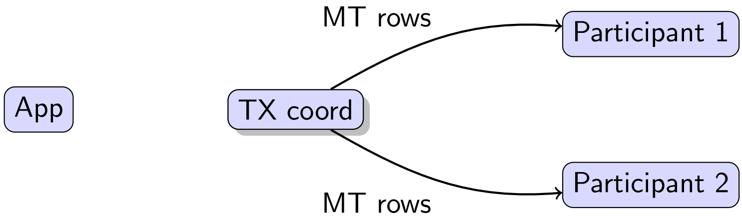

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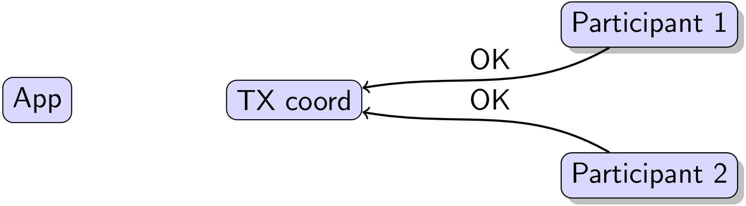

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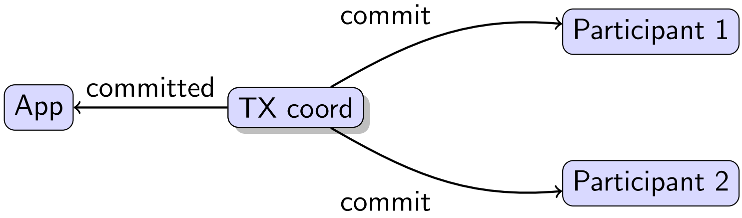

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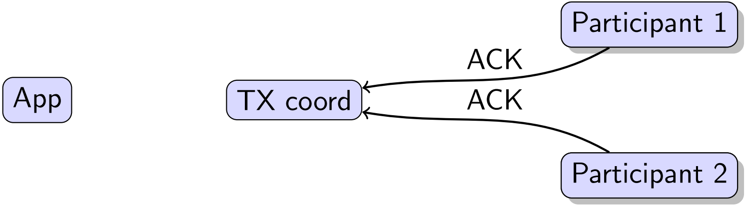

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6. Coordinator cleans log entries

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Optimizations

- App acts as transaction coordinator
  - App/coordinator does not log
  - Participant list replicated on all participants instead

Client-Side vs 2PC Comparison

Bytes written to the log:

- Client-side: 3x (mask, super-object, write-back)
- Client-side with server mods: 2x (super-object, write-back)
- 2PC flavors: 1x

Serial RPCs for app to resume processing, including log appends:

- Client-side flavors: 4 (mask, super-object)
- 2PC: 5
- 2PC with app coordinating: 2

What's this hiding?

- Client-side flavors require weak access control
  - Apps write back values for others' crashed transactions
- Complexity

Conclusion

- Low latency affords us high consistency
- Conditional API provides atomic ops for a single object
- Optimistic transactions for multiple objects
  - Optimized client-side approach about twice as slow as 2PC
  - We haven't decided on an approach, may try both

Questions/Comments

Some for the audience:

- Do applications need transactions?
- Are conflicts as rare as we hope?
- Client-side or 2PC?