Phase Reconciliation for Contended In-Memory Transactions

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```
IncrTxn(k Key) {
    INCR(k, 1)
}

LikePageTxn(page Key, user Key) {
    INCR(page, 1)
    liked_pages := GET(user)
    PUT(user, liked_pages + page)
}

FriendTxn(u1 Key, u2 Key) {
    PUT(friend:u1:u2, 1)
    PUT(friend:u2:u1, 1)
}
```

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}
```

Problem

Applications experience write contention on popular data

Ellen DeGeneres @TheEllenShow

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If only Bradley's arm was longer. Best photo ever. #oscars

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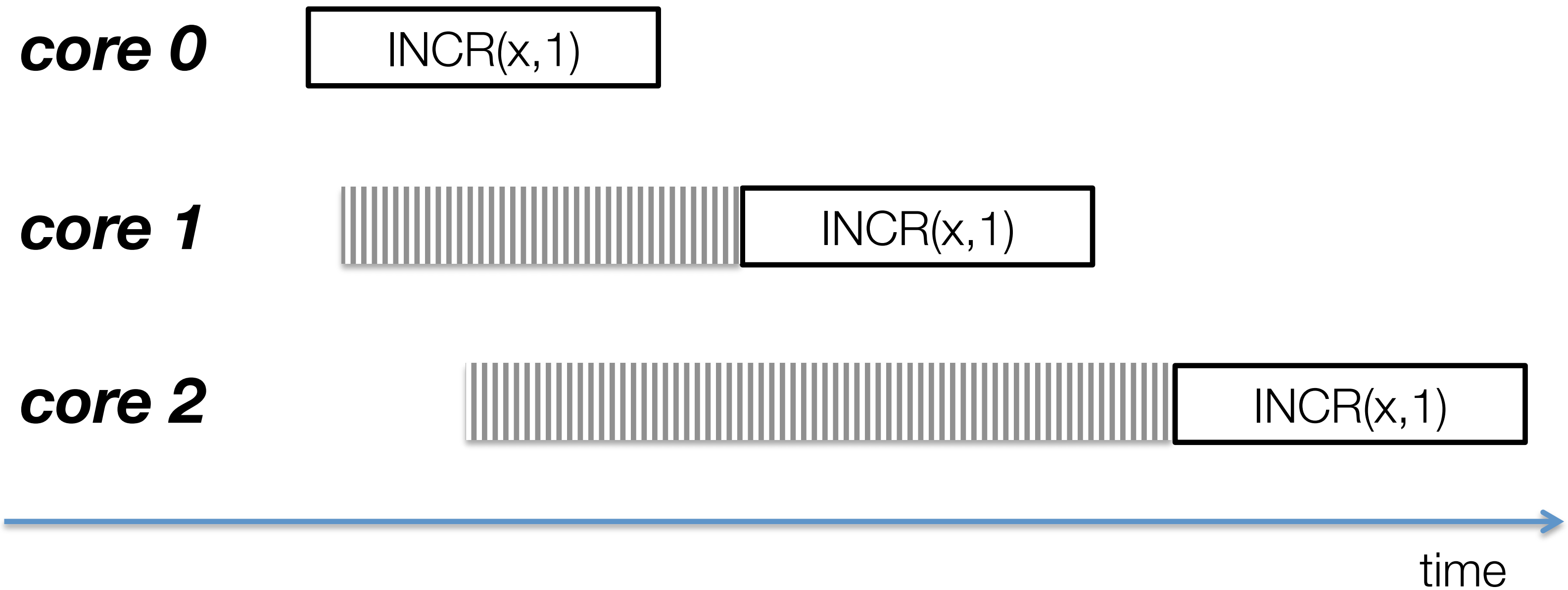
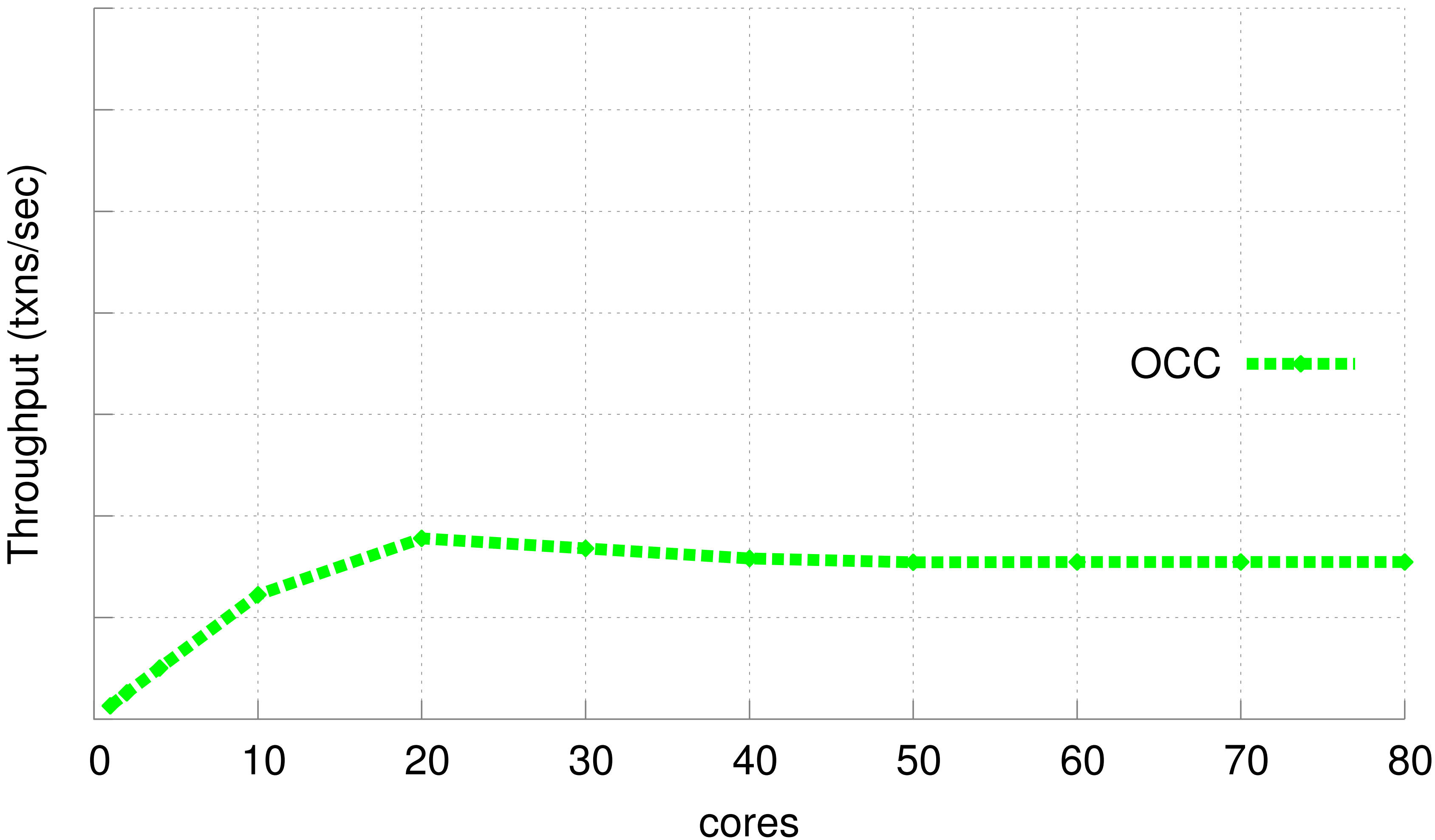
Concurrency Control Enforces Serial Execution

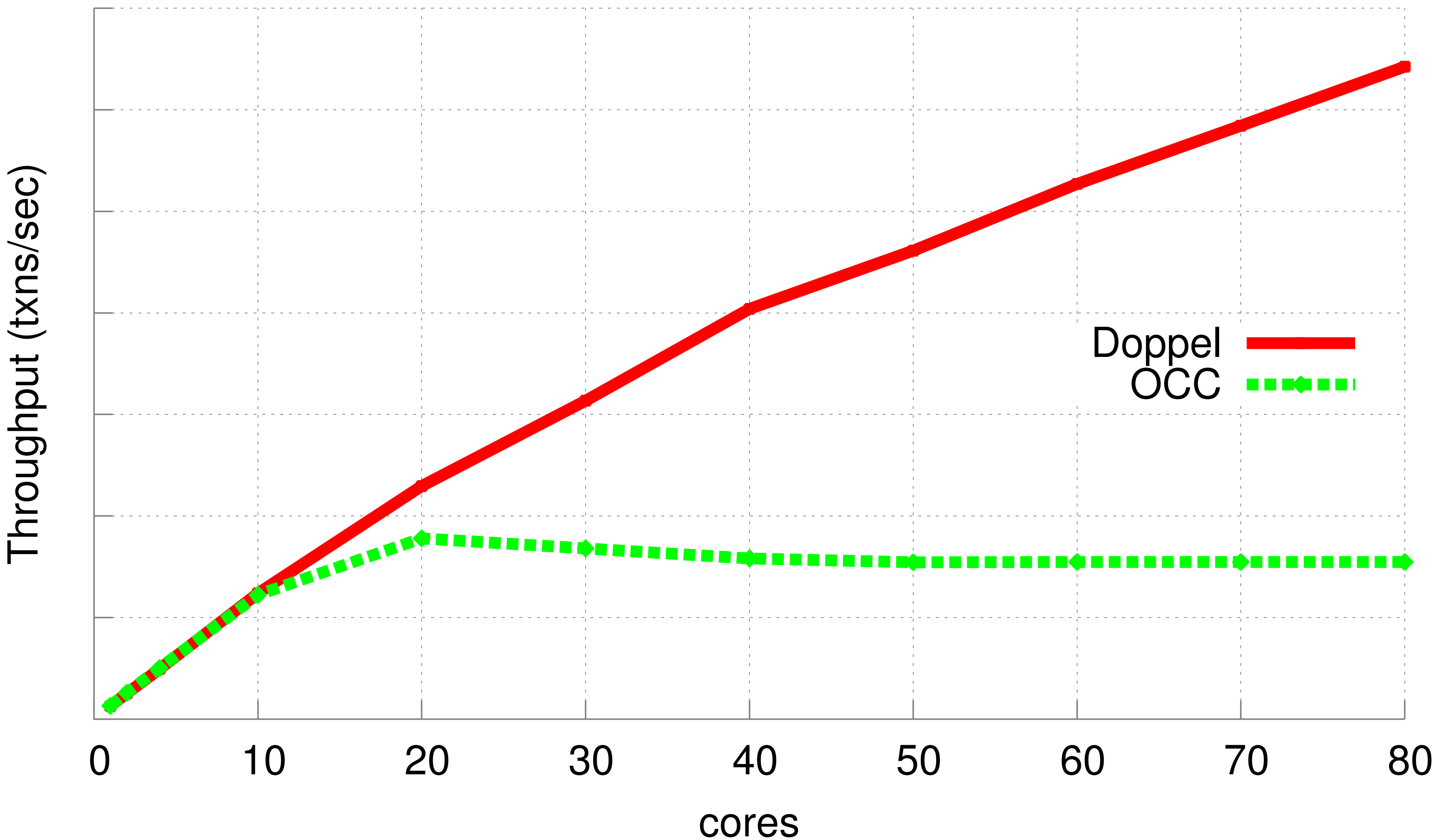


Transactions on the same records execute one at a time

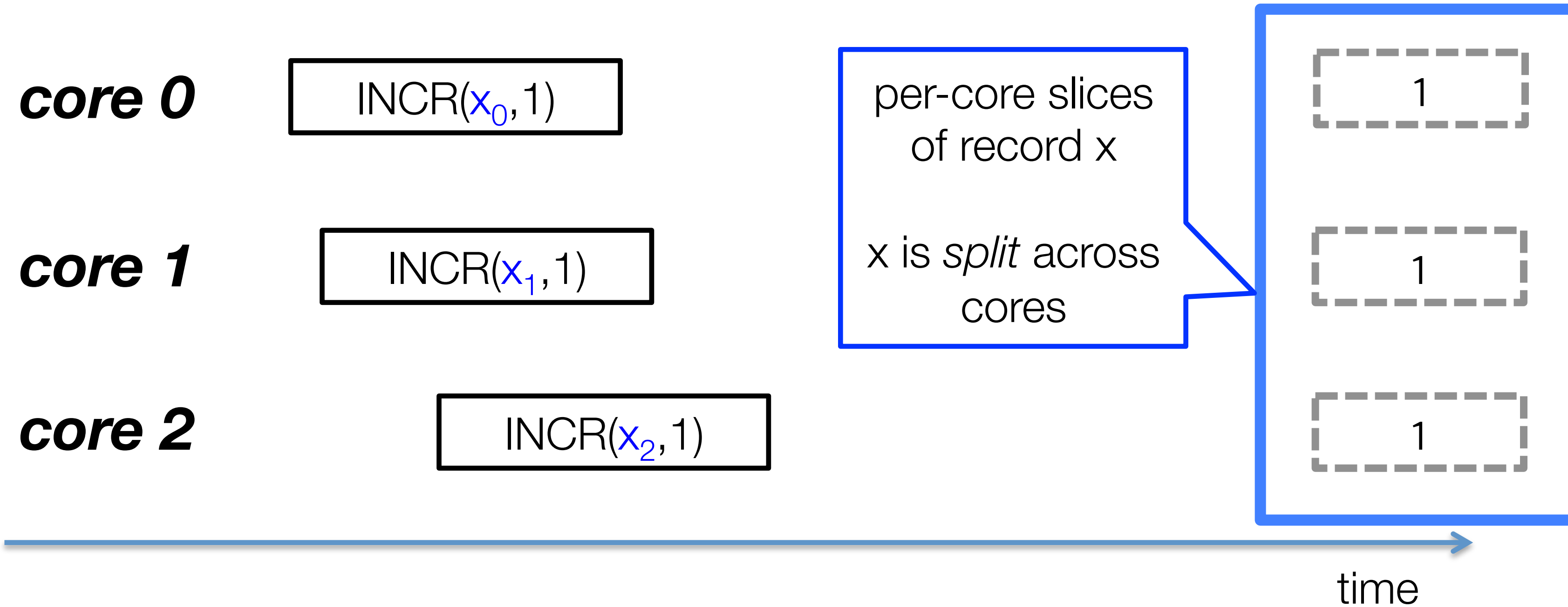
Throughput on a Contentious Transactional Workload



Throughput on a Contentious Transactional Workload



INCR on the Same Records Can Execute in Parallel



- Transactions on the same record can proceed in parallel on *per-core slices* and be *reconciled* later
- This is correct because INCR commutes

Databases Must Support General Purpose Transactions

```
IncrTxn(k Key) {
    INCR(k,
}
```

Must happen atomically

```
IncrPutTxn(k1 Key, k2 Key, v Value) {
    INCR(k1, 1)
    PUT(k2, v)
}
```

```
PutMaxTxn(k1 Key, k2 Key) {
    v1 := GET(k1)
    v2 := GET(k2)
    if v1 > v2:
        PUT(k1, v2)
    else:
        PUT(k2, v1)
    return v1,v2
}
```

Must happen atomically

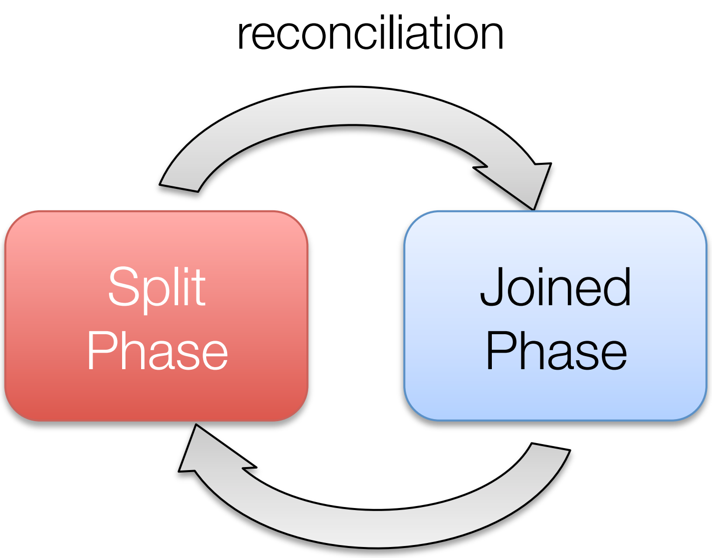
Returns a value

Challenge

Fast, general-purpose serializable transaction execution with per-core slices for contended records

Phase Reconciliation

- Database automatically detects contention to split a record among cores
- Database cycles through *phases*: split, reconciliation, and joined



Doppel, an in-memory transactional database

Contributions

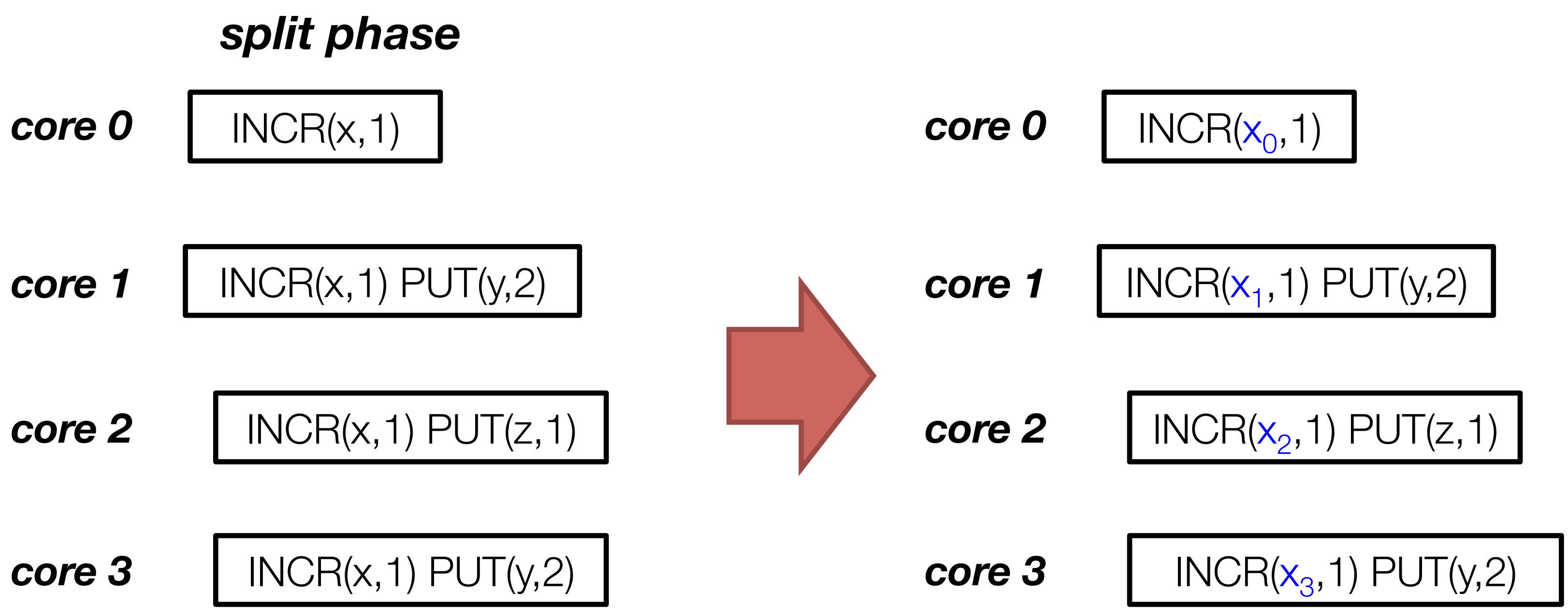
Phase reconciliation

- Splittable operations
- Efficient detection and response to contention on individual records
- Reordering of split transactions and reads to reduce conflict
- Fast reconciliation of split values

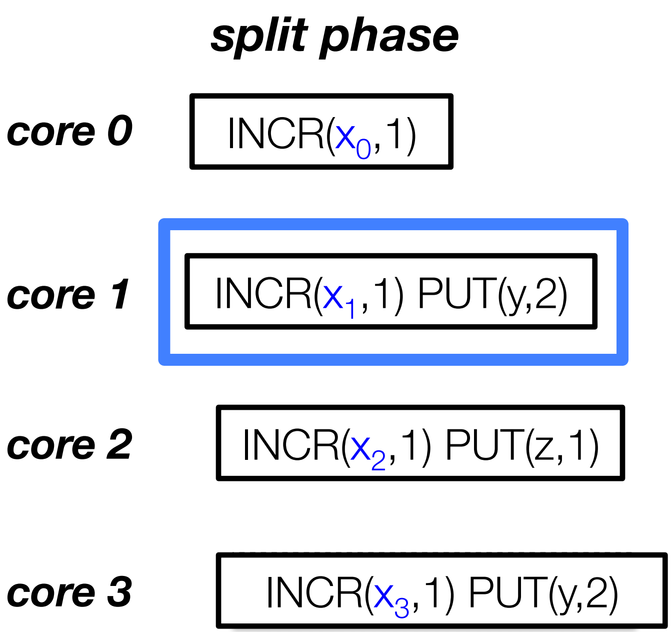
Outline

1. Phase reconciliation
2. Operations
3. Detecting contention
4. Performance evaluation

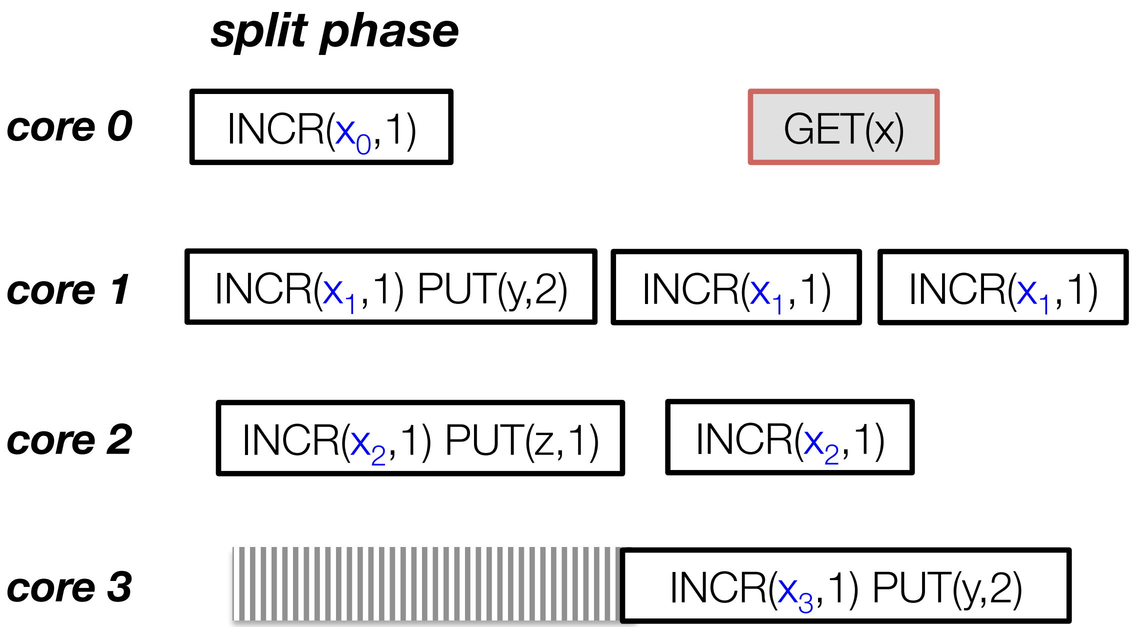
Split Phase



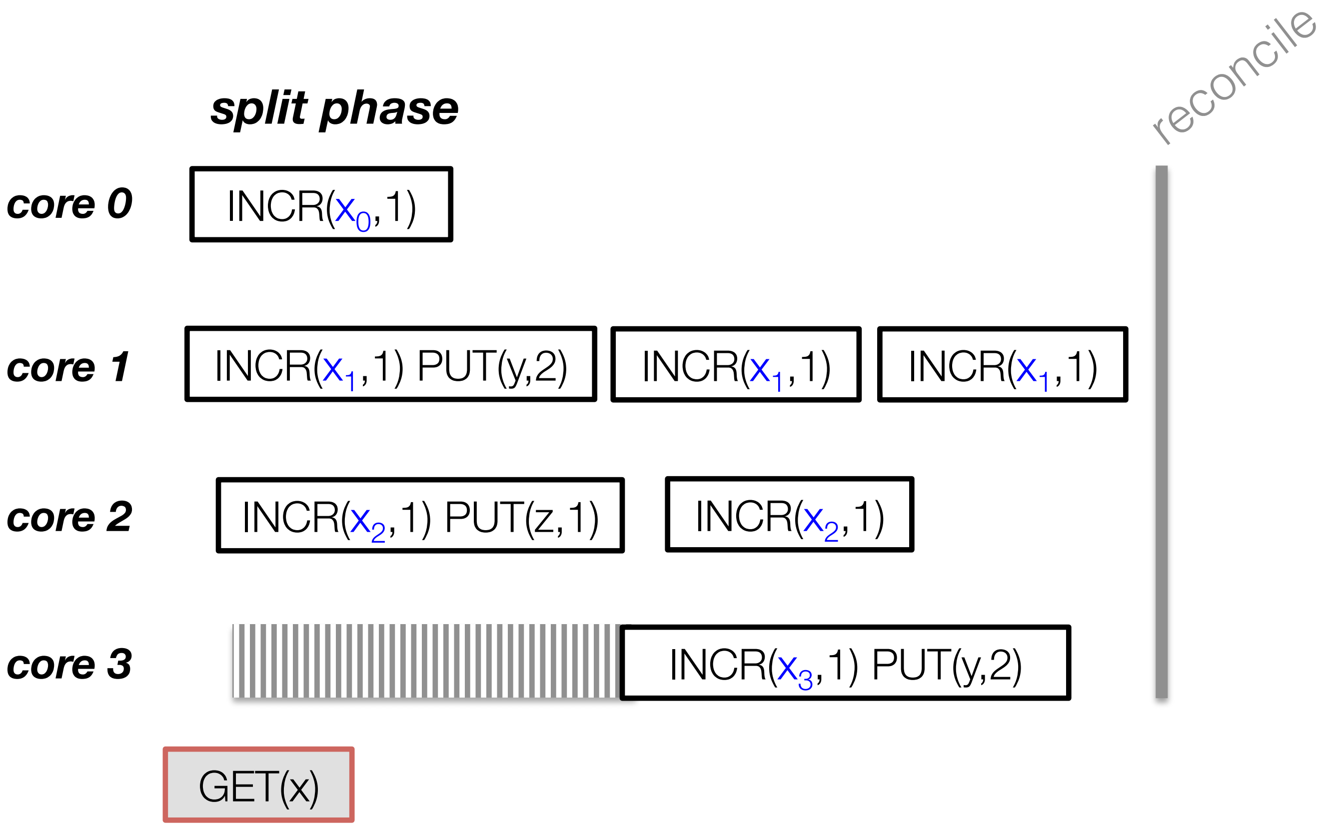
- The *split phase* transforms operations on contended records (x) into operations on per-core slices (x_0, x_1, x_2, x_3)



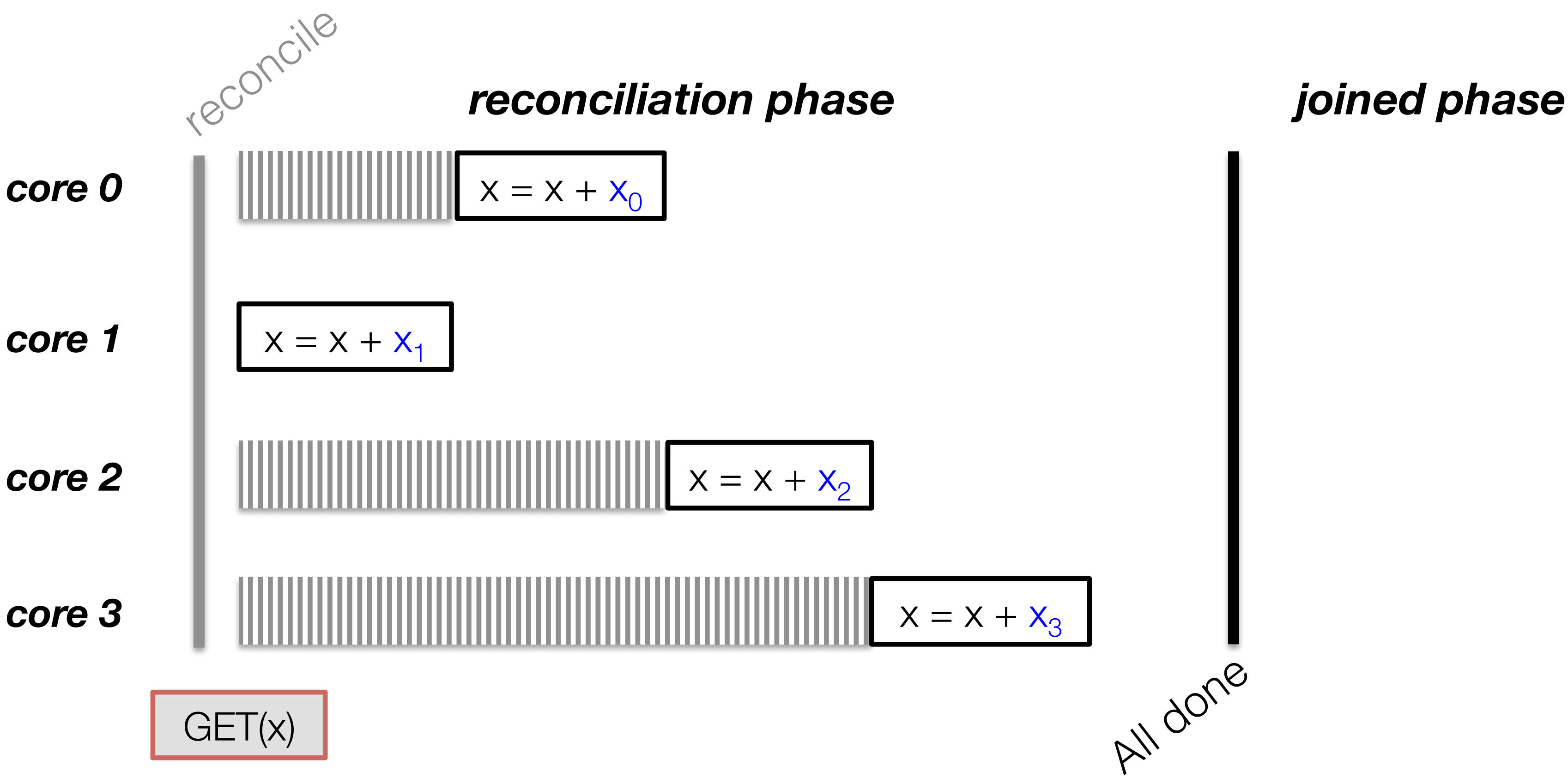
- Transactions can operate on split and non-split records
- Rest of the records use OCC (y, z)
- OCC ensures serializability for the non-split parts of the transaction



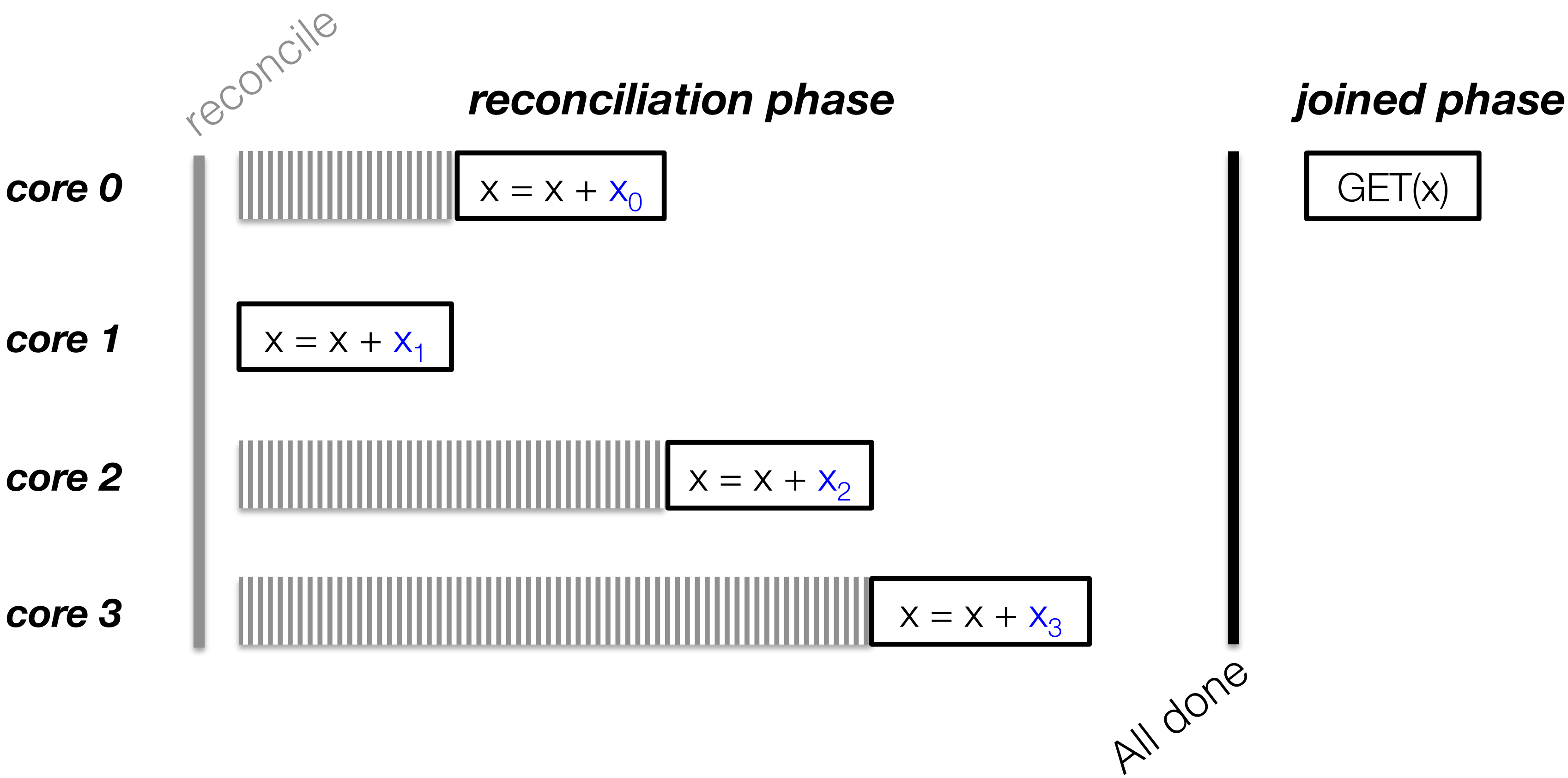
- Split records have assigned operations for a given split phase
- Cannot correctly process a read of x in the current state
- *Stash* transaction to execute after reconciliation



- All threads hear they should reconcile their per-core state
- Stop processing per-core writes



- Reconcile state to global store
- Wait until all threads have finished reconciliation
- Resume stashed read transactions in joined phase



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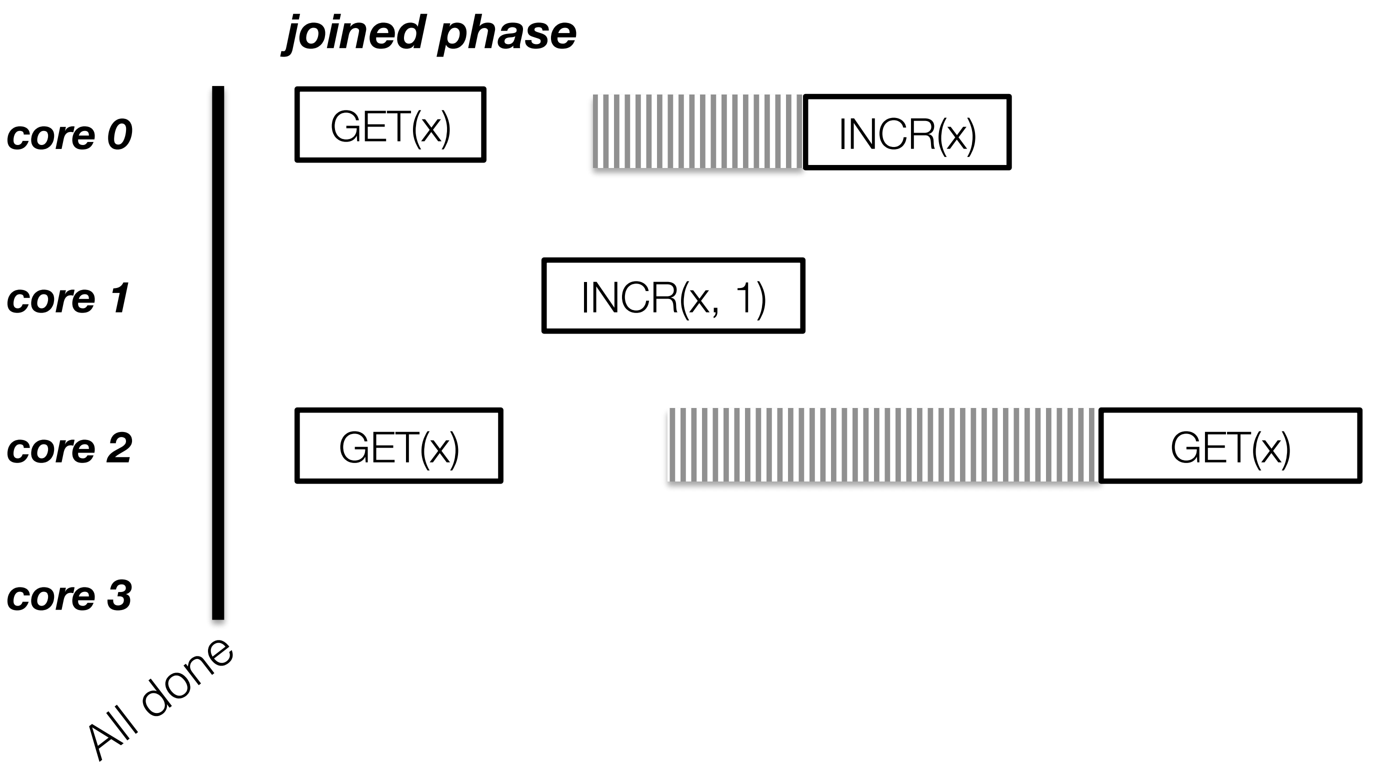
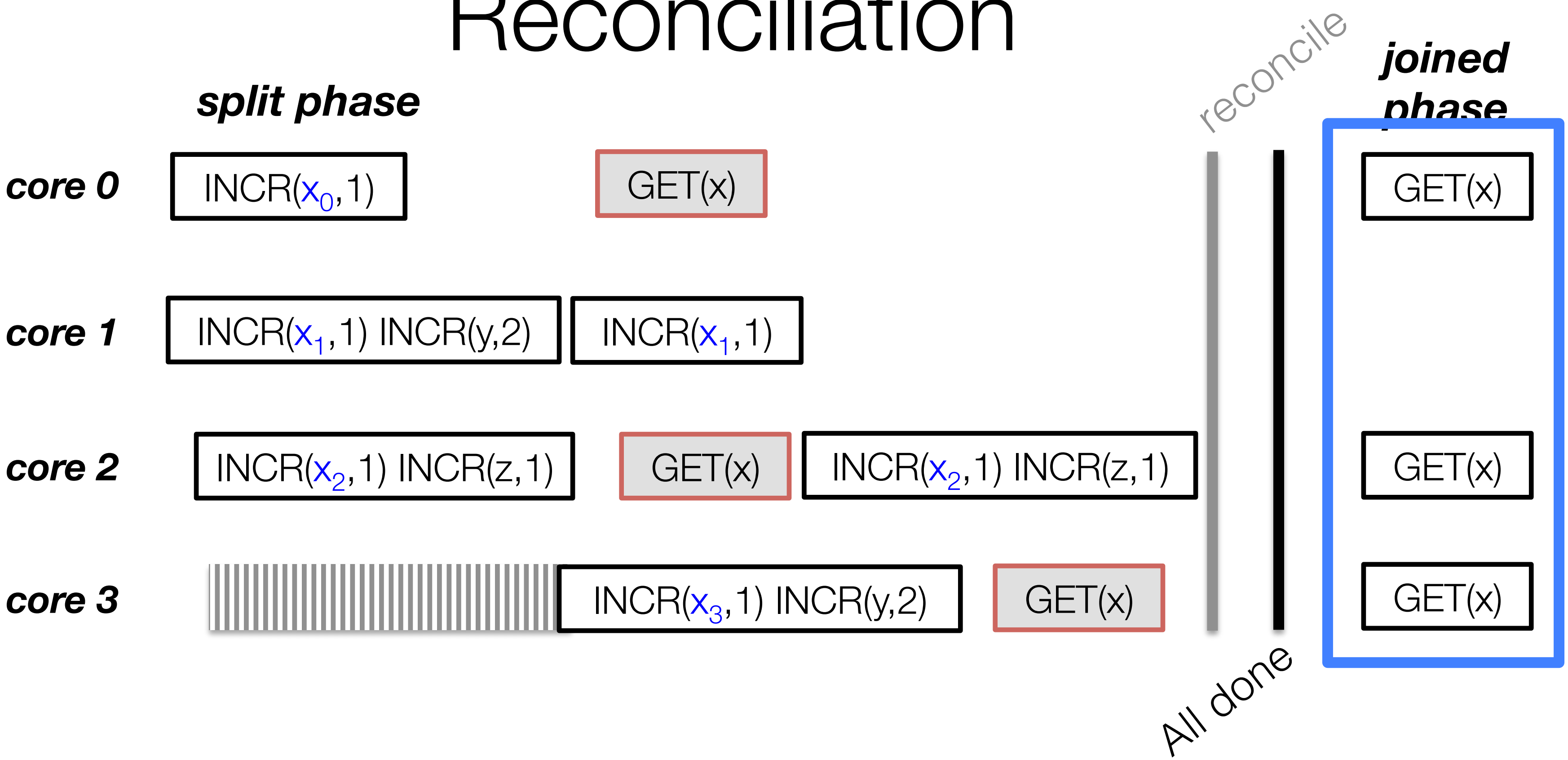


- Process new transactions in joined phase using OCC
- No split data

Batching Amortizes the Cost of Reconciliation



- Wait to accumulate stashed transactions, batch for joined phase
- Amortize the cost of reconciliation over many transactions
- Reads would have conflicted; now they do not

Phase Reconciliation Summary

- Many contentious writes happen in parallel in split phases
- Reads and any other incompatible operations happen correctly in joined phases

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Operation Model

Developers write transactions as stored procedures which are composed of *operations* on keys and values:

Traditional key/value operations	`value GET(k)` `void PUT(k, v)`	Not splittable

Operations on numeric values which modify the existing value	`void INCR(k, n)`
	`void MAX(k, n)`
	`void MULT(k, n)`
		Splittable

Ordered PUT and insert to an ordered list	`void OPUT(k, v, o)` `void TOPK_INSERT(k, v, o)`	Splittable

MAX Can Be Efficiently Reconciled

core 0 `MAX(x`$_0$`,55)` `MAX(x`$_0$`,2)` 55

core 1 `MAX(x`$_1$`,10)` `MAX(x`$_1$`,27)` 27

core 2 `MAX(x`$_2$`,21)` 21

`x = 55`

- Each core keeps one piece of state x_i
- O(#*cores*) time to reconcile x
- Result is compatible with any order

What Operations Does Doppel Split?

Properties of operations that Doppel can split:

- Commutative
- Can be efficiently reconciled
- Single key
- Have no return value

However:

- Only one operation per record per split phase

Outline

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Which Records Does Doppel Split?

- Database starts out with no split data
- Count conflicts on records
  - Make key split if *#conflicts* > *conflictThreshold*
- Count stashes on records in the split phase
  - Move key back to non-split if *#stashes* too high

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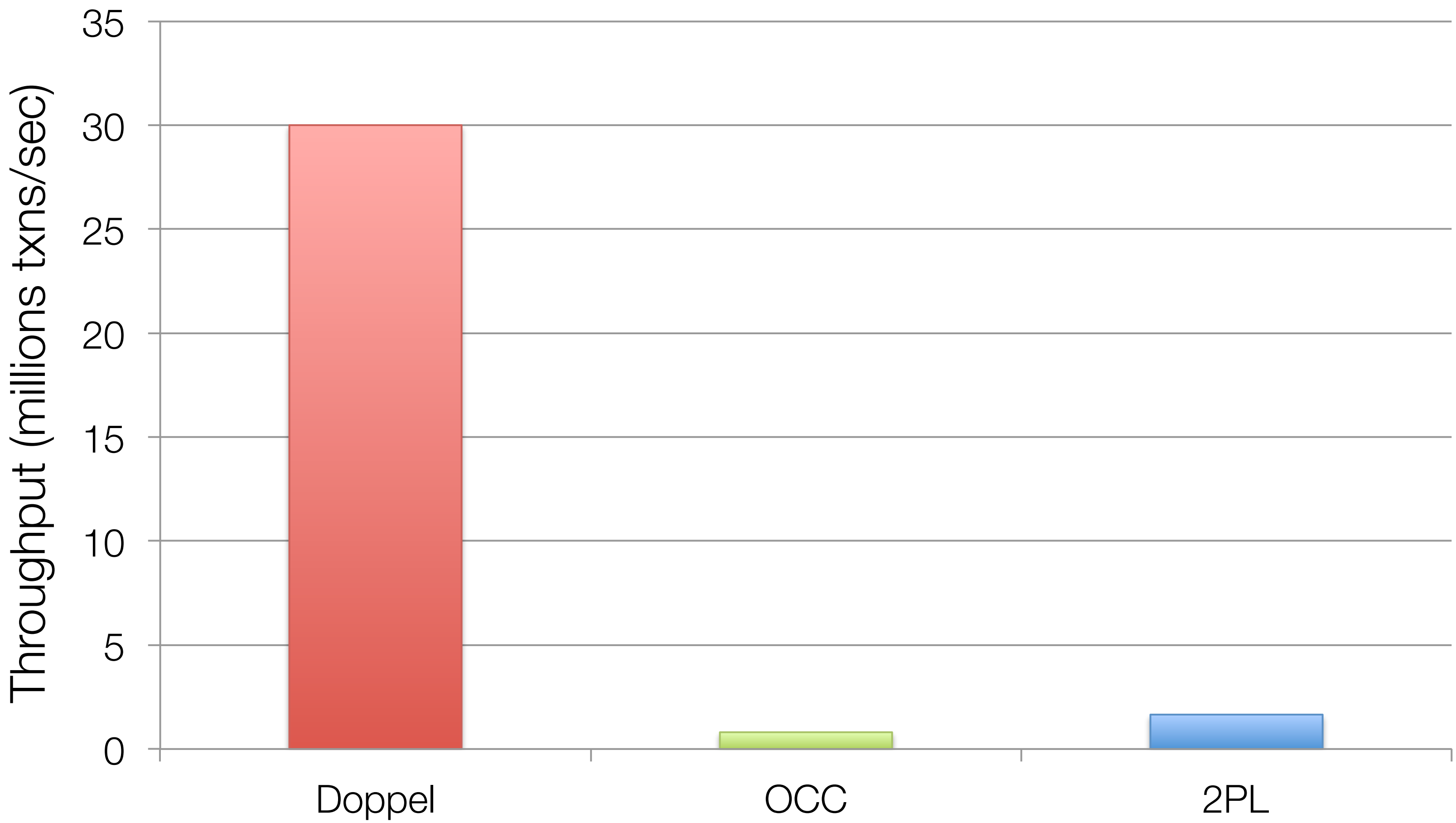
Experimental Setup and Implementation

- All experiments run on an 80 core Intel server running 64 bit Linux 3.12 with 256GB of RAM
- Doppel implemented as a multithreaded Go server; one worker thread per core
- Transactions are procedures written in Go
- All data fits in memory; don’t measure RPC
- All graphs measure throughput in transactions/sec

Performance Evaluation

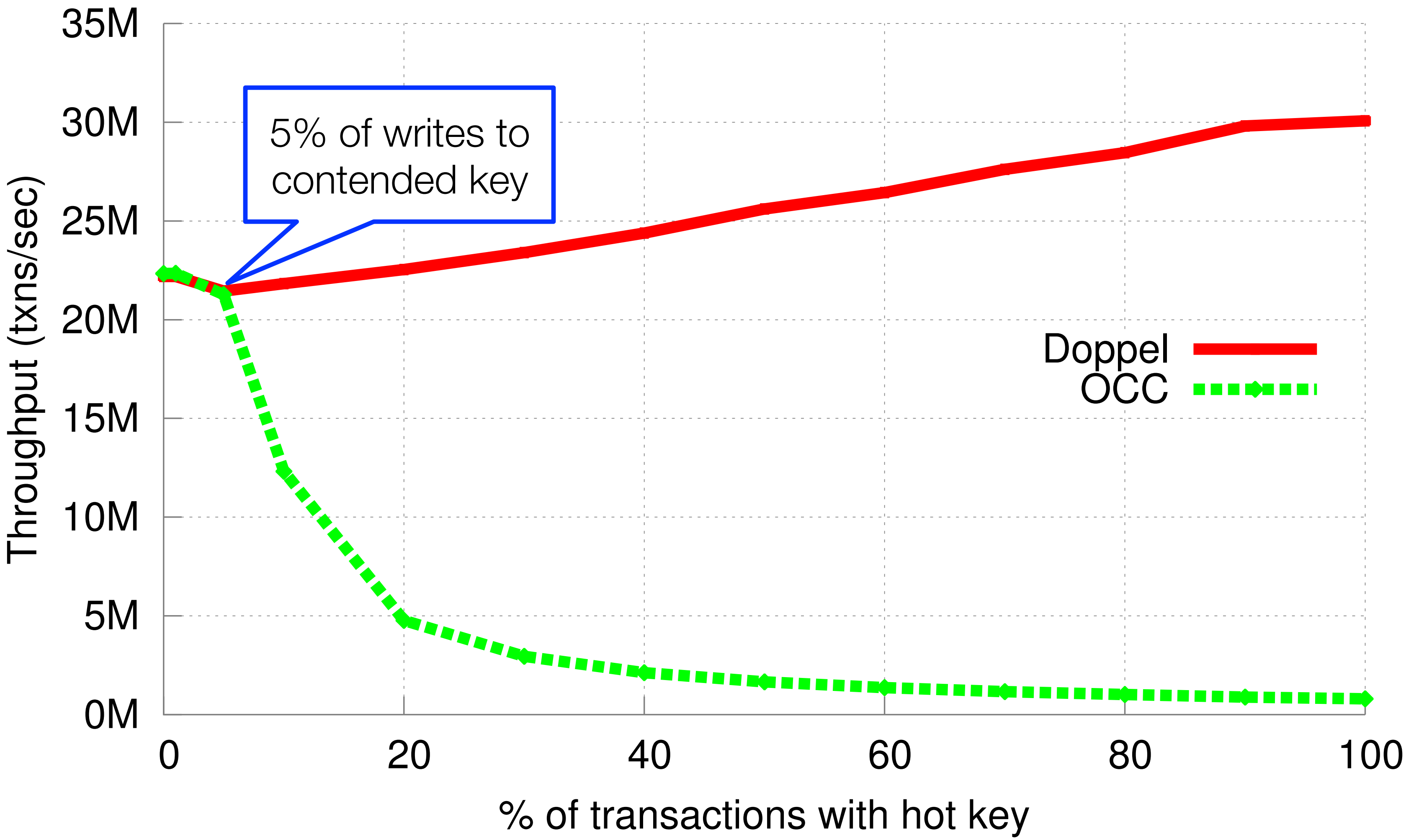
- How much does Doppel improve throughput on contentious write-only workloads?
- What kinds of read/write workloads benefit?
- Does Doppel improve throughput for a realistic application: RUBiS?

Doppel Executes Conflicting Workloads in Parallel



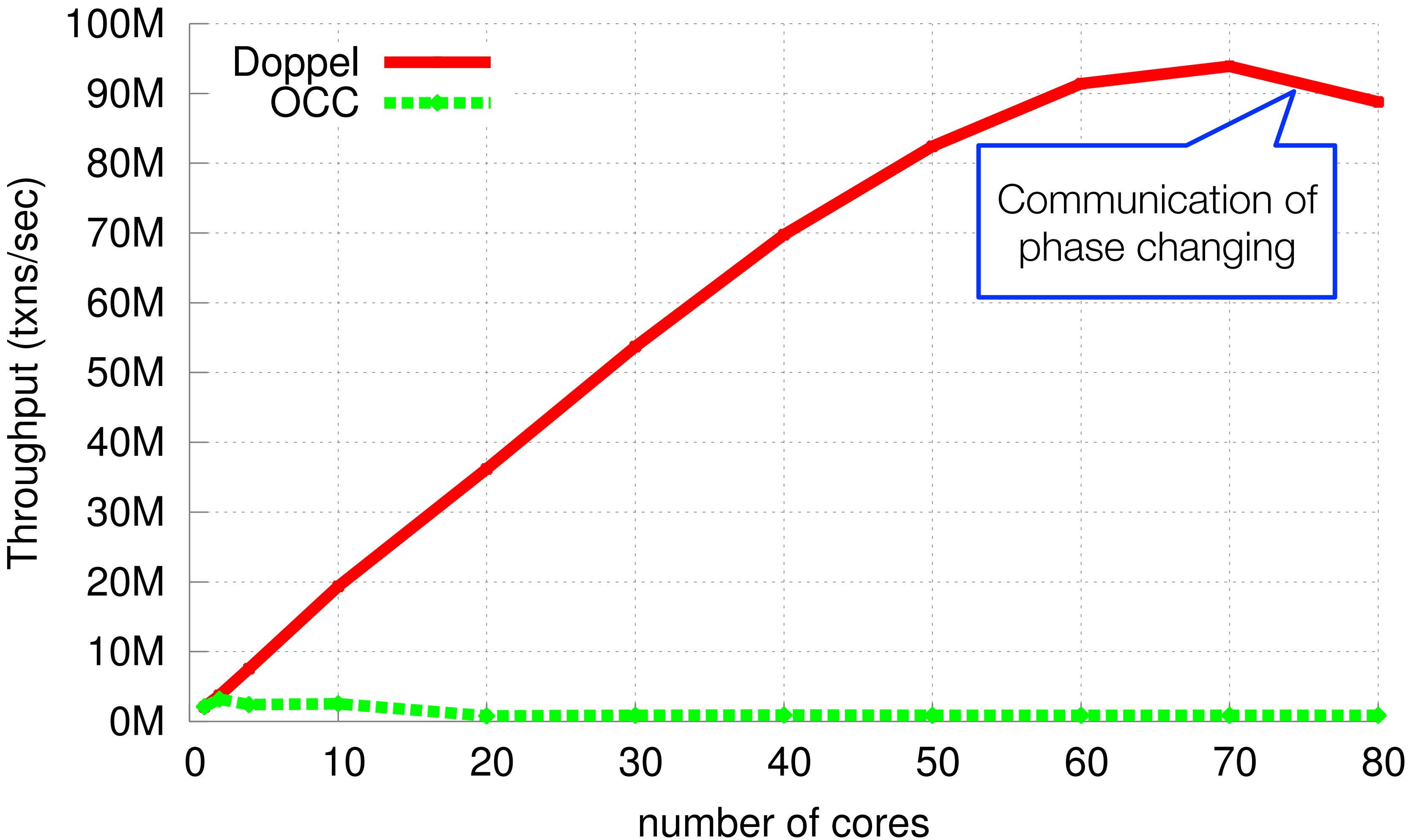
20 cores, 1M 16 byte keys, transaction: INCR(x,1) all on same key

Doppel Outperforms OCC Even With Low Contention



20 cores, 1M 16 byte keys, transaction: INCR(x,1) on different keys

Contentious Workloads Scale Well



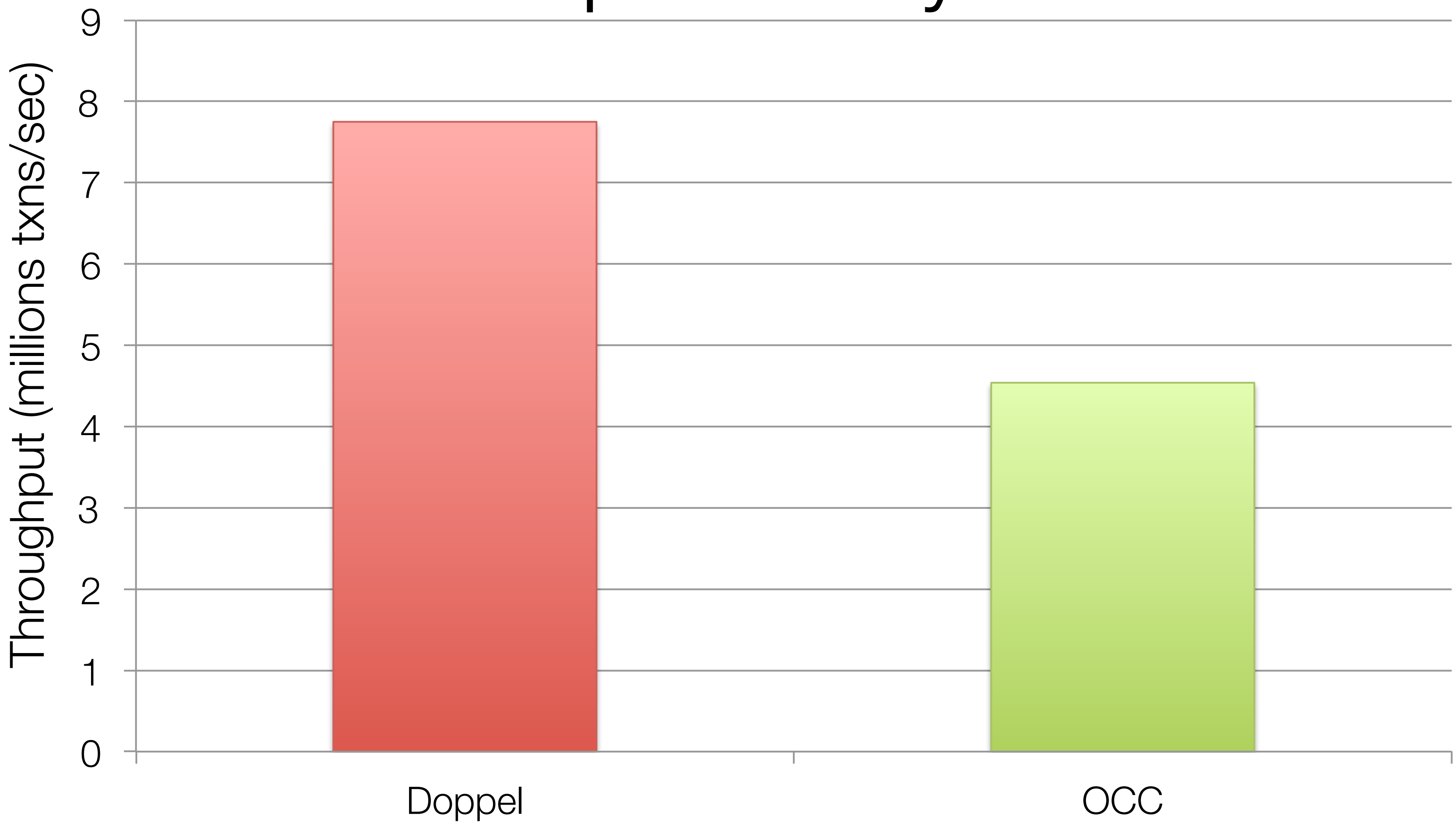
1M 16 byte keys, transaction: INCR(x,1) all writing same key

LIKE Benchmark

- Users liking pages on a social network
- 2 tables: users, pages
- Two transactions:
  - Increment page's like count, insert user like of page
  - Read a page's like count, read user's last like
- 1M users, 1M pages, Zipfian distribution of page popularity

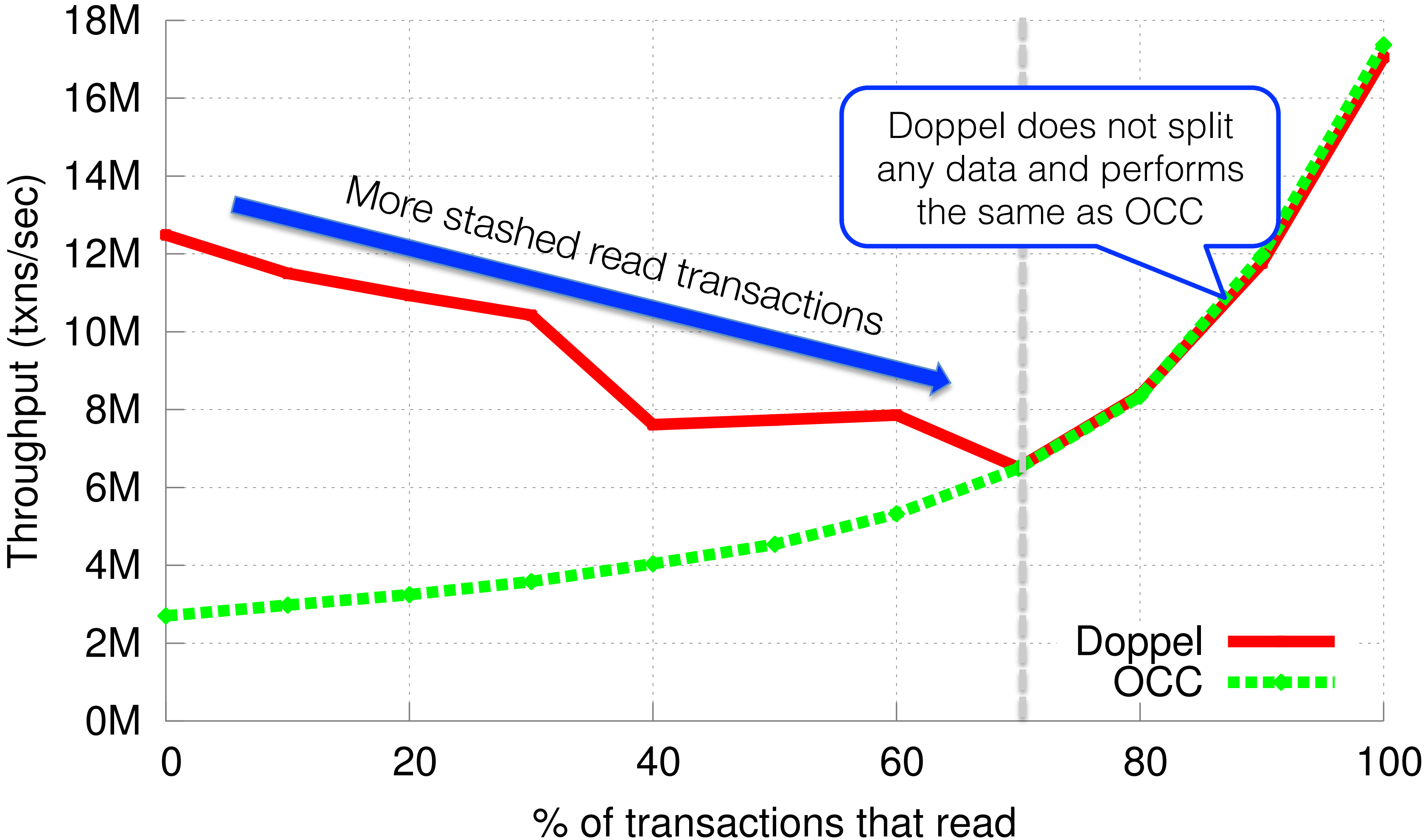
Doppel splits the page-like-counts for popular pages
But those counts are also read more often

Benefits Even When There Are Reads and Writes to the Same Popular Keys



20 cores, transactions: 50% LIKE read, 50% LIKE write

Doppel Outperforms OCC For A Wide Range of Read/Write Mixes



20 cores, transactions: LIKE read, LIKE write

RUBiS

- Auction application modeled after eBay
  - Users bid on auctions, comment, list new items, search
- 1M users and 33K auctions
- 7 tables, 17 transactions
- 85% read only transactions (RUBiS bidding mix)

- Two workloads:
  - Uniform distribution of bids
  - Skewed distribution of bids; a few auctions are very popular

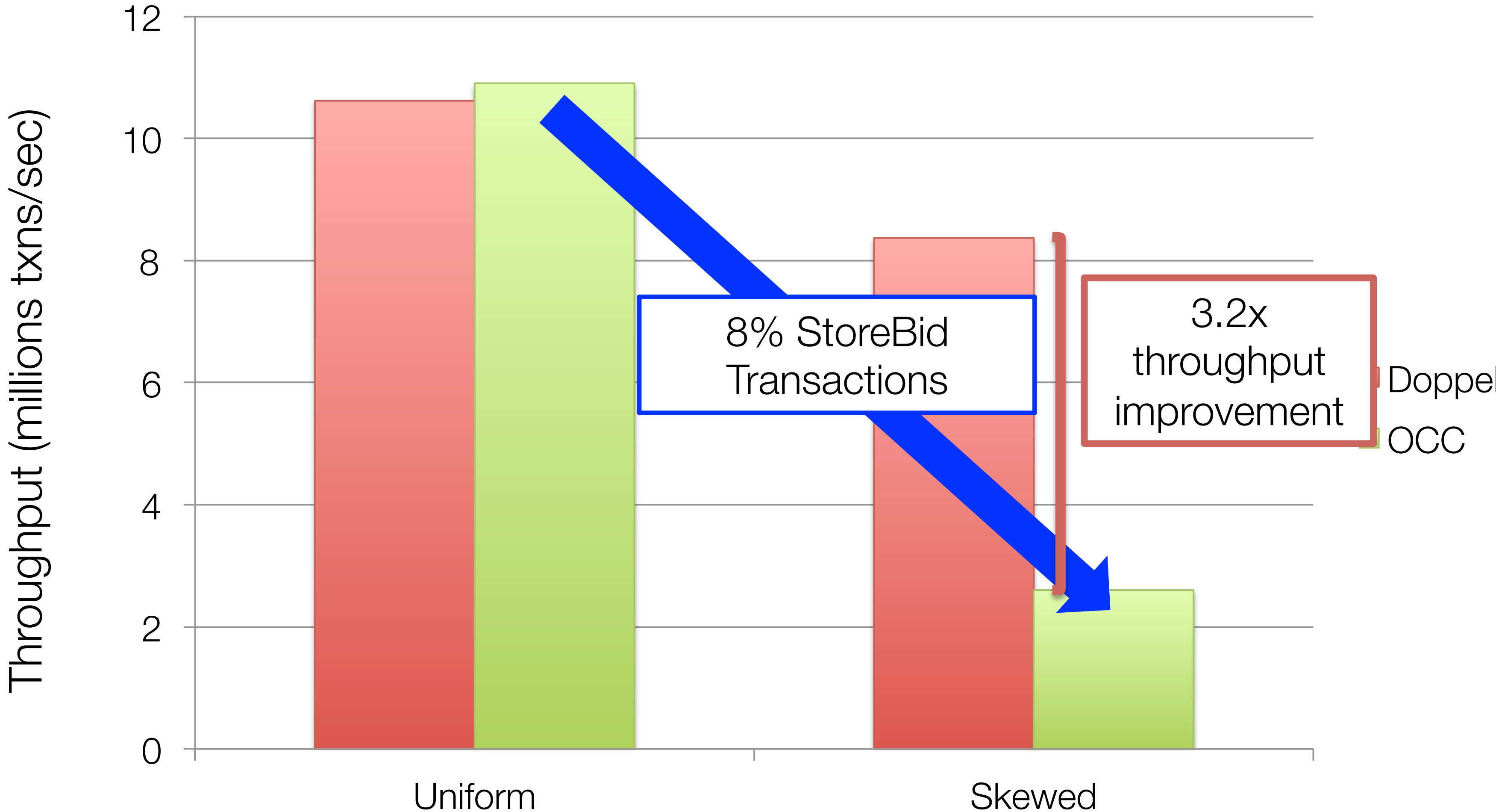
StoreBid Transaction

```
StoreBidTxn(bidder, amount, item) {
    INCR(NumBidsKey(item),1)
    MAX(MaxBidKey(item), amount)
    OPUT(MaxBidderKey(item), bidder, amount)
    PUT(NewBidKey(), Bid{bidder, amount, item})
}
```

All commutative operations on potentially conflicting auction metadata

Inserting new bids is not likely to conflict

Doppel Improves Throughput on an Application Benchmark



80 cores, 1M users 33K auctions, RUBiS bidding mix

Related Work

- Commutativity in distributed systems and concurrency control
  - [Weihl ’88]
  - CRDTs [Shapiro ’11]
  - RedBlue consistency [Li ’12]
  - Walter [Lloyd ’12]
- Optimistic concurrency control
  - [Kung ’81]
  - Silo [Tu ’13]
- Split counters in multicore OSes

Conclusion

Doppel:

- Achieves parallel performance when many transactions conflict by combining per-core data and concurrency control
- Performs comparably to OCC on uniform or read-heavy workloads while improving performance significantly on skewed workloads.

CSAIL

http://pdos.csail.mit.edu/doppel