Repairing Transaction Conflicts in Optimistic MVCC

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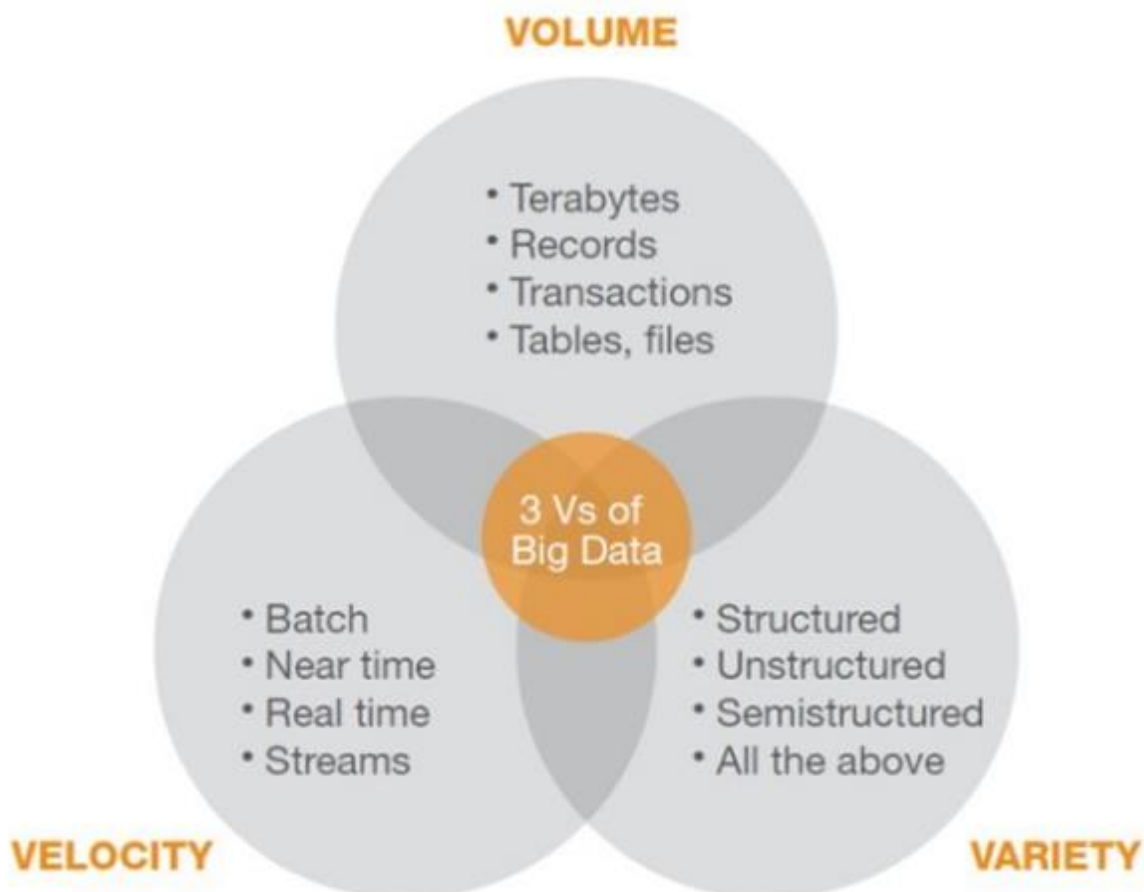
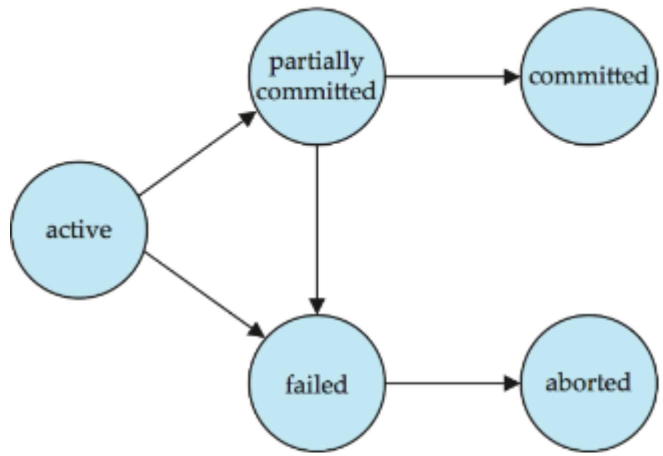
Big Data


VOLUME
• Terabytes
• Records
• Transactions
• Tables, files
3 Vs of Big Data
• Batch
• Near time
• Real time
• Streams
VELOCITY
• Structured
• Unstructured
• Semistructured
• All the above
VARIETY

What is a Transaction?

- A ***transaction*** is a unit of program execution that accesses and possibly updates various data items.
- E.g., transaction to transfer 50,000,000 IRR from account A to account B:
  1. **read**(A)
  2. A := A – 50000000
  3. **write**(A)
  4. **read**(B)
  5. B := B + 50000000
  6. **write**(B)



- Two main issues to deal with:
  - Failures of various kinds, such as hardware failures and system crashes
  - Concurrent execution of multiple transactions

Concurrent Executions

- Multiple transactions are allowed to run concurrently in the system. Advantages are:
  - **Increased processor and disk utilization**, leading to better transaction *throughput*
    - E.g. one transaction can be using the CPU while another is reading from or writing to the disk
  - **Reduced average response time** for transactions: short transactions need not wait behind long ones.

What if something goes wrong?

ACID Properties

- When running transactions, to preserve the integrity of data the database system must ensure:
- **Atomicity.** Either all operations of the transaction are properly reflected in the database or none are.
- **Consistency.** Execution of a transaction in isolation preserves the consistency of the database.
- **Isolation.** Although multiple transactions may execute concurrently, each transaction must be unaware of other concurrently executing transactions. Intermediate transaction results must be hidden from other concurrently executed transactions.
- **Durability.** After a transaction completes successfully, the changes it has made to the database persist, even if there are system failures.

Concurrency Control protocols

- Mechanisms to achieve isolation, atomicity and consistency
- That is, to control the interaction among the concurrent transactions in order to prevent them from destroying the consistency of the database
- Variants:
  - Pessimistic vs. Optimistic
  - Single-version vs. Multi-version

Optimistic MVCC is Awesome!

- Each transaction can only see a snapshot of database
  - Based on its start timestamp
- All modifications are only visible to the transaction itself, before it commits
- Read-only transactions never fail
- A validation phase is required before a successful commit for R/W transactions

But …

- What if the validation phase fails?
- We have to abort and restart
  - The entire computation is thrown away
  - That's really unfortunate

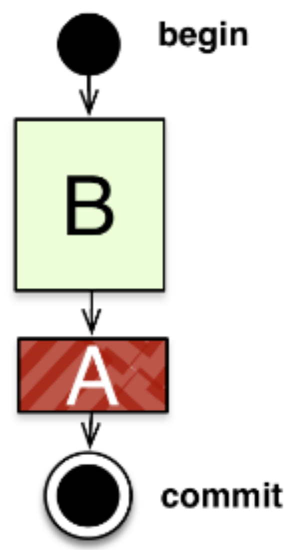
Can we do better?

If we have a partial roll back solution…

- When does it matter?
  - High-contention data objects
  - Long-running transactions

If we have a partial roll back solution…

- What can we save?

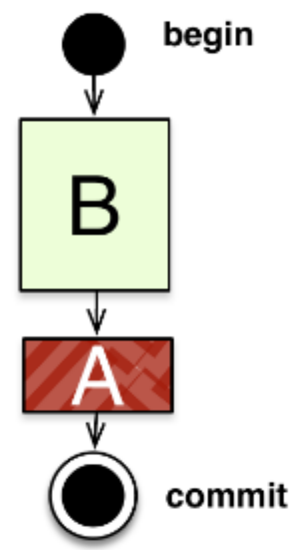


(b)

If we have a partial roll back solution…

- What can we save?

```
/* fm = from, acc = account and bal = balance */
Transf                    acc, amount) {
 START
 SELECT                   FROM Account WHERE id=:fm_acc;

 IF(am                    .0;
 ELSE                     ;

 IF(fm                    {
  SELE                     FROM Account WHERE id=:to_acc;

  fm_ba                    (amount + fee);
  to_ba                    amount;

  UPDA                    :fm_bal_final WHERE id=:fm_acc;
  UPDA                    :to_bal_final WHERE id=:to_acc;
  UPDA                    bal+:fee WHERE id=:FEE_ACC_ID;
  COMM
 } ELS
}
```



(b)

If we have a partial roll back solution…

- What are the requirements of such a solution?
  - Have minimal overhead
    - It's paid for all transactions, even the ones that succeed validation
  - Quickly narrow down the conflicting portions of the transactions and fix them
    - Better be faster than "abort and restart"!

Validation in Optimistic MVCC

- Mainly two approaches:
  - Read-set validation + Phantom avoidance
  - Predicate-based[1]
    - Uses a variation of precision locking[2]

[1] T. Neumann, T. Mühlbauer, and A. Kemper. Fast serializable multi-version concurrency control for main-memory database systems. In SIGMOD, 2015.
[2] J. R. Jordan, J. Banerjee, and R. B. Batman. Precision locks. In Proceedings of the 1981 ACM SIGMOD International Conference on Management of Data, SIGMOD '81

Validation in Optimistic MVCC – Predicate-based

- What are predicates?

```
/* fm = from, acc = account and bal = balance */
TransferMoney(fm_acc, to_acc, amount) {
 START;
 SELECT bal INTO :fm_bal FROM Account WHERE id=:fm_acc;

 IF(amount < 100) fee = 1.0;
 ELSE fee = amount * 0.01;

 IF(fm_bal > amount+fee) {
  SELECT bal INTO :to_bal FROM Account WHERE id=:to_acc;

  fm_bal_final = fm_bal - (amount + fee);
  to_bal_final = to_bal + amount;

  UPDATE Account SET bal=:fm_bal_final WHERE id=:fm_acc;
  UPDATE Account SET bal=:to_bal_final WHERE id=:to_acc;
  UPDATE Account SET bal=bal+:fee WHERE id=:FEE_ACC_ID;
  COMMIT;
 } ELSE ROLLBACK;
}
```

Validation in Optimistic MVCC – Predicate-based

- How can we use predicates?
  - These are the only pieces of information gathered about read operations during execution
  - The list of versions created by each transaction is also maintained, called "undo buffer"
  - Validation of **T** consists of:

Predicates have a greater potential.
We can use them for partial rollback and compensate the failure with almost no overhead.

MV3C: MVCC with Closures

- Step 1: Write transaction programs in MV3C DSL to encode dependency info in them
  (predicates ⇔ blocks of code)
- Step 2: Execute a transaction starting from its root predicates and create predicate graph
- Step 3: Validate in topological order
- Step 4: Repair.

  If validation fails
  - Cleanup failed predicates
  - Retry with a new timestamp

```
/* fm = from, acc = account and bal = balance */
TransferMoney(fm_acc, to_acc, amount) {
 START;

  IF(amount < 100) fee = 1.0;
  ELSE fee = amount * 0.01;

 P1 Account WHERE id=:fm_acc => fm_acc_entry
 IF(fm_acc_entry.bal > amount+fee) {
  fm_acc_entry.bal -= (amount + fee);
  fm_acc_entry.persist();

  P2 Account WHERE id=:to_acc => to_acc_entry
   to_acc_entry.bal += amount;
   to_acc_entry.persist();

  P3 Account WHERE id=:FEE_ACC_ID => fee_acc_entry
   fee_acc_entry.bal += fee;
   fee_acc_entry.persist();
   COMMIT;
 } ELSE ROLLBACK;
}
```

Step 1: Writing MV3C Programs

- Translating T-SQL/PL-SQL into MV3C DSL
  - Identify all read operations as possible failure points
    - Encapsulate data selection criteria into the predicate
  - Create dependency graph to identify blocks of code that depend on the result of some operation
  - Partition dependency graph into nested sub graphs
    - Each subgraph is the minimal transitive closure of a sub graph with a read operation as root.

Step 2: Executing MV3C Programs

- Read-Write conflicts are detected at validation time.
- How to deal with Write-Write conflicts?
  - Optimistic MVCC has no chance of recovering from this case.
    - Among all concurrent write transactions into the same object, only one might succeed => serial execution
  - MV3C can only perform the conflicted section
    - It is an optional parameter than can be specified system-wide and table-wide, and can be overridden by each update operation

Step 3: Validation

- Validation is done in topological order
  - If a predicate fails validation, all its children predicates are marked as failed without performing validation on them

```
/* fm = from, acc = account and bal = balance */
TransferMoney(fm_acc, to_acc, amount) {
 START;

  IF(amount < 100) fee = 1.0;
  ELSE fee = amount * 0.01;

 P1 Account WHERE id=:fm_acc => fm_acc_entry
 IF(fm_acc_entry.bal > amount+fee) {
  fm_acc_entry.bal -= (amount + fee);
  fm_acc_entry.persist();

  P2 Account WHERE id=:to_acc => to_acc_entry

   to_acc_entry.bal += amount;
   to_acc_entry.persist();

  P3 Account WHERE id=:FEE_ACC_ID => fee_acc_entry

   fee_acc_entry.bal += fee;
   fee_acc_entry.persist();
   COMMIT;
 } ELSE ROLLBACK;
}
```

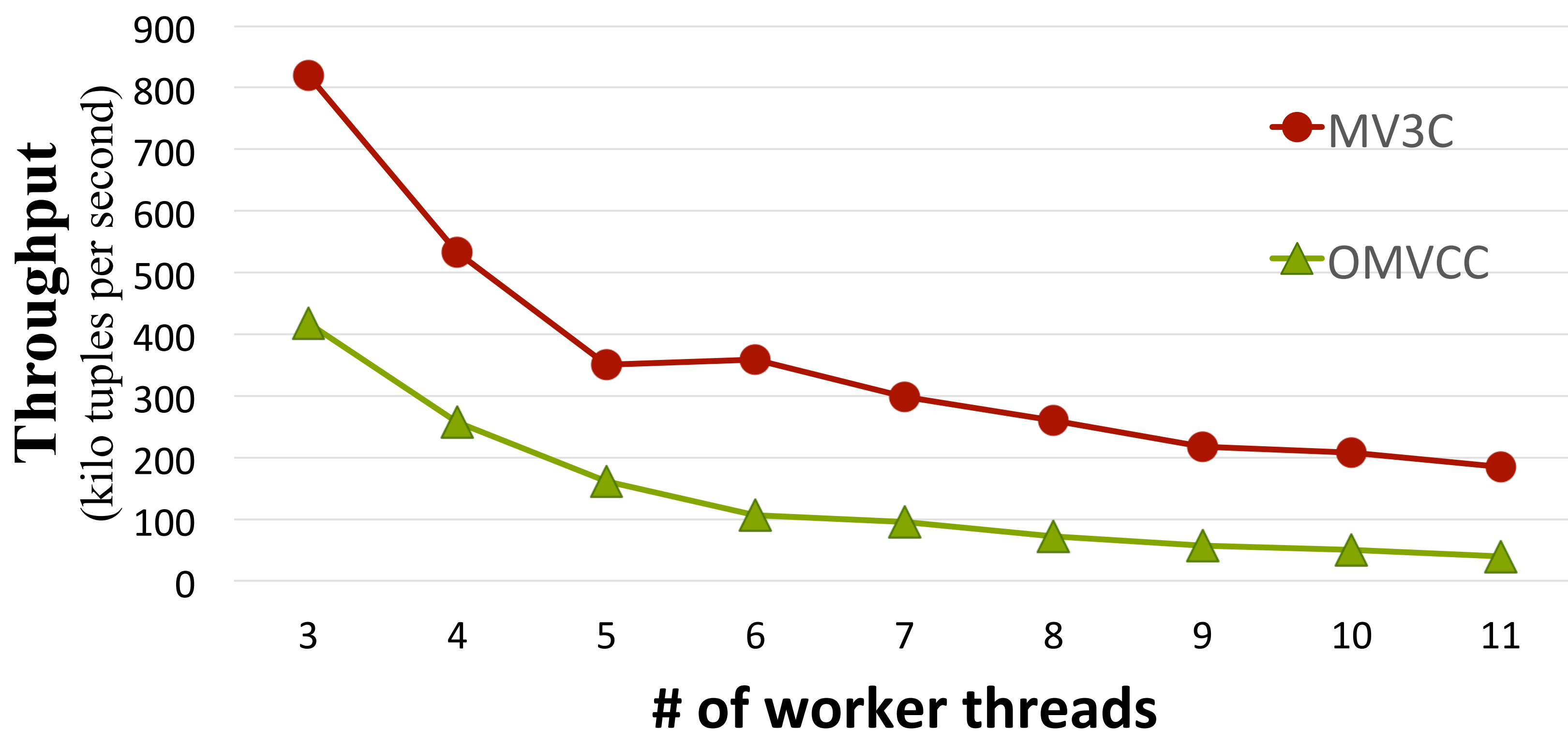
Step 4: Repair

- Removes all the versions created by failed predicates
- Executes the closures bound to top-level failed predicates

```
/* fm = from, acc = account and bal = balance */
TransferMoney(fm_acc, to_acc, amount) {
 START;

  IF(amount < 100) fee = 1.0;
  ELSE fee = amount * 0.01;

 P1 Account WHERE id=:fm_acc => fm_acc_entry
  IF(fm_acc_entry.bal > amount+fee) {
   fm_acc_entry.bal -= (amount + fee);
   fm_acc_entry.persist();

   P2 Account WHERE id=:to_acc => to_acc_entry
    to_acc_entry.bal += amount;
    to_acc_entry.persist();

   P3 Account WHERE id=:FEE_ACC_ID => fee_acc_entry
    fee_acc_entry.bal += fee;
    fee_acc_entry.persist();
    COMMIT;
  } ELSE ROLLBACK;
}
```

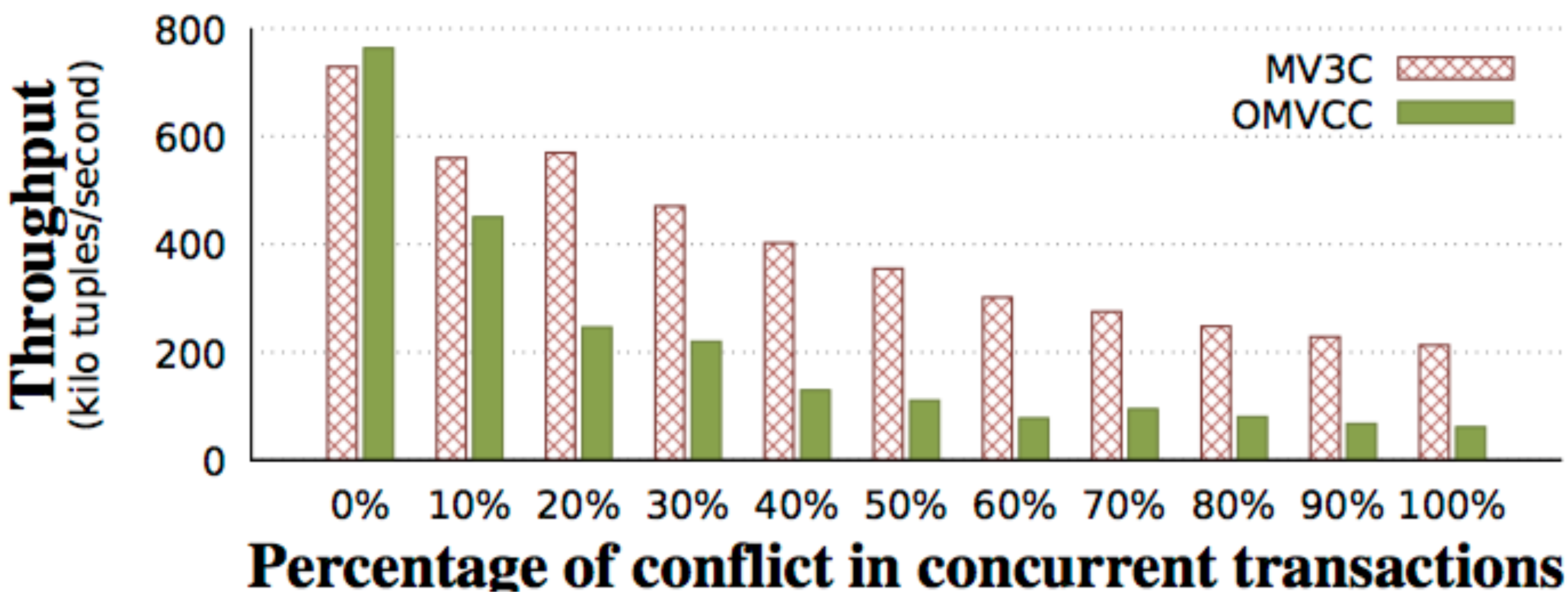
Experimental Results

Banking: Impact of increased concurrency

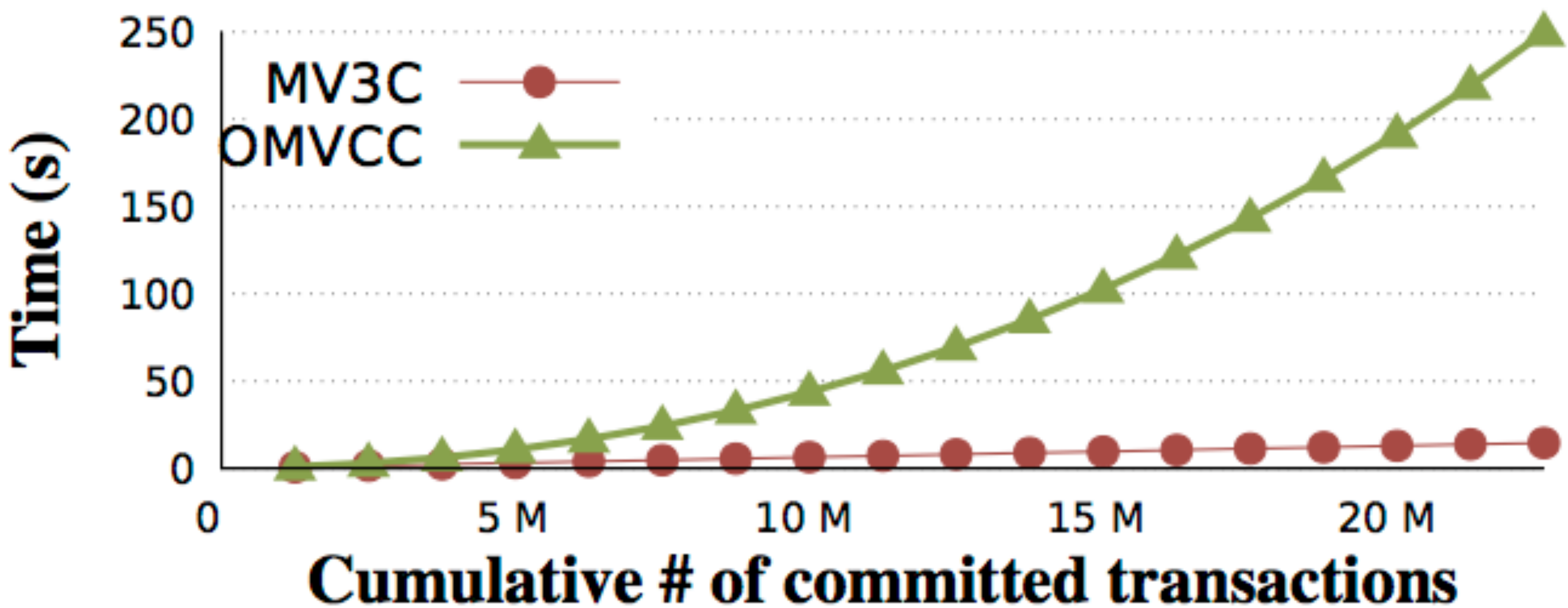


Banking: Impact of amount of conflict

- with 10 concurrent transactions



Banking: The cumulative Effect

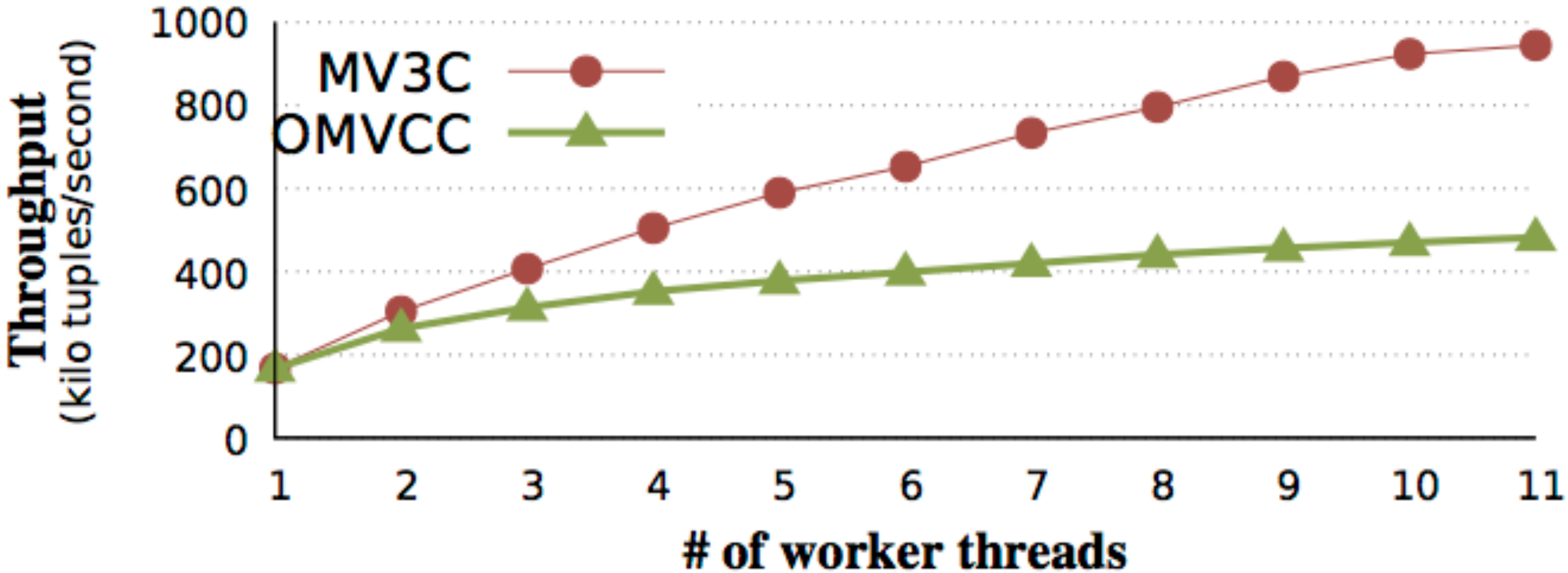


Trading Benchmark

- simulates a simplified trading system
- Tables:
  - Security(s_id, symbol, s_price)
  - Customer(c_id, cipher_key)
  - Trade(t_id, t_encrypted_data)
  - TradeLine(t_id, tl_id, tl_encrypted_data)
- Transactions:
  - TradeOrder
  - PriceUpdate

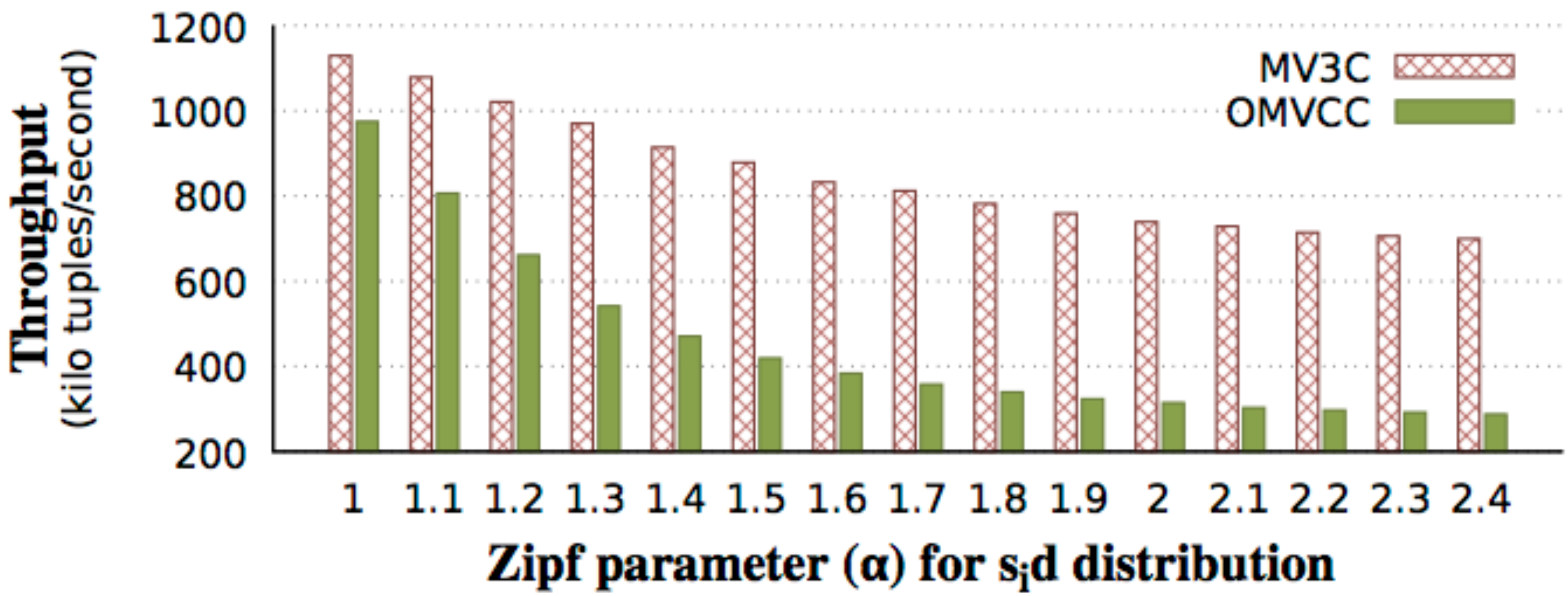
Trading: Impact of increased concurrency

- Fixed α = 1.4



Trading: Impact of amount of conflict

- with 10 concurrent transactions



Conclusion

- An efficient conflict resolution mechanism can have a considerable performance improvement for high-contention or long-running transactions.
- MV3C is an algorithm that can make use of compilation and program semantics for building an efficient conflict resolution mechanism for Optimistic MVCC.
- Performs better than Optimistic MVCC under higher contention
- Has almost no overhead compared to Optimistic MVCC