Parameterized and Runtime-tunable Snapshot Isolation in Distributed Transactional Key-value Stores

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Parameterized and Runtime-tunable Snapshot Isolation

RVSI: Relaxed Version Snapshot Isolation

Parameterized and Runtime-tunable Snapshot Isolation

RVSI: Relaxed Version Snapshot Isolation

Figure: Distributed key-value stores.

`put(K key, V val)`   `get(K key)`

Transactional semantics

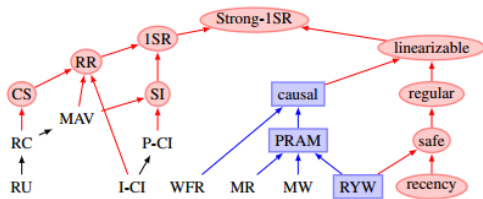existential consistency atomic visibility example

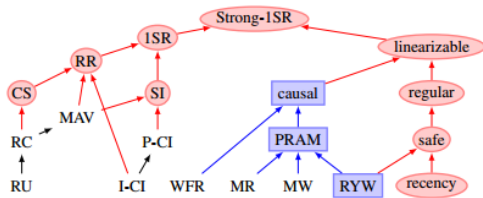Figure: Transactional consistency models (from [Bailis@VLDB'14]).

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Snapshot isolation (SI [Berenson@SIGMOD'95], [Adya@Thesis'99]):

▶ Read from the "latest" snapshot as of the time the transaction started

▶ No write-conflicting concurrent transactions

Reading the "latest" in a distributed setting
often requires intensive coordinations.

[1] GSI: Generalized Snapshot Isolation [Elnikety@SRDS'05]
[2] NMSI: Non-Monotonic Snapshot Isolation [Ardekani@SRDS'13]
[3] PL-FCV: Forward Consistent View [Aday@Thesis'99]
[4] PSI: Parallel Snapshot Isolation [Sovran@SOSP'11]

Reading the "latest" in a distributed setting
often requires intensive coordinations.

Relaxed variants of (distributed) SI:

GSI [1]: allows to read from "older" snapshots

NMSI [2]: allows to observe non-monotonically ordered snapshots

PL-FCV [3]: allows a transaction to observe the updates of transactions
that commit after it started

PSI [4]: causal ordering of transactions across sites

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Two possible drawbacks:

1. Unbounded inconsistency
   ▶ no specification of the severity of the anomalies w.r.t SI

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   ▸ no specification of the severity of the anomalies w.r.t SI

2. Untunable at runtime
   ▸ determined at the system design phase
   ▸ remain unchanged once the system is deployed

An online bookstore application for motivating
"bounded inconsistency" and "runtime-tuable":

Title	Authors	Publisher	Sales	Inventory	Ratings	Reviews	$\cdots$

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- inventory updated by concurrent
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- inventory updated by concurrent transactions committed *after* T_2 starts

Sales Analyst (T_3): Studying sales vs. ratings of a book
- sales and ratings from *separate snapshots*

The idea of "parameterized and runtime-tunable snapshot isolation".

- RVSI: Relaxed Version Snapshot Isolation

  k_1-BV: k_1-version bounded *backward* view

  k_2-FV: k_2-version bounded *forward* view

  k_3-SV: k_3-version bounded *snapshot* view

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[5]`http://www.aliyun.com/`

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- CHAMELEON prototype: distributed transactional key-value store
  - achieves RVSI
  - allows each transaction to tune its consistency level at runtime

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- CHAMELEON prototype: distributed transactional key-value store
  - achieves RVSI
  - allows each transaction to tune its consistency level at runtime
  - deployed on Aliyun [5]
  - explore the impacts of RVSI on the transaction abort rates

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RVSI: Relaxed Version Snapshot Isolation

Transaction T_i:

- begins with a start operation s_i
- contains a sequence of read or write operations
- ends with a commit operation c_i or an abort operation a_i

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x_i: version i of data item x written by T_i

$r_i(x_j)$: transaction T_i reading x_j

$w_i(x_i)$: transaction T_i writing x_i

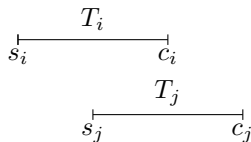History: modelling an execution of a transactional key-value store

- *time-precedes partial order* $\prec_h$ over operations

History: modelling an execution of a transactional key-value store

- *time-precedes partial order* $\prec_h$ over operations

Two transactions are *concurrent* if

$$s_i \prec_h c_j \wedge s_j \prec_h c_i$$

Snapshot isolation requires that

Snapshot Read: Each transaction reads data from the "lastest"
snapshot as of the time the transaction started

Snapshot Write: No write-conflicting concurrent transactions

A history h is in snapshot isolation if and only if it satisfies [Adya@Thesis'99]

Snapshot Read: All reads of transaction T_i occur at T_i's start time.

$$\forall r_i(x_{j \neq i}), w_{k \neq j}(x_k), c_k \in h :$$
$$(c_j \in h \wedge c_j \prec_h s_i) \wedge (s_i \prec_h c_k \vee c_k \prec_h c_j).$$

Snapshot Write: No concurrent committed transactions may write the same data item.

$$\forall w_i(x_i), w_{j \neq i}(x_j) \in h \implies (c_i \prec_h s_j \vee c_j \prec_h s_i).$$

- Parameters (k_1, k_2, k_3) to control the severity of the anomalies w.r.t SI

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[6]RC: Read Committed

- Parameters (k_1, k_2, k_3) to control the severity of the anomalies w.r.t SI

- RC [6] $\supset$ RVSI$(k_1, k_2, k_3) \supset$ SI

- RVSI$(\infty, \infty, \infty) =$ RC $\qquad$ RVSI$(1, 0, *) =$ SI

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[6]RC: Read Committed

Each transaction reads data from the "lastest" snapshot as of the time the transaction started. – "Snapshot Read" property of SI

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1. "stale" data versions   bounded staleness

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1. "stale" data versions   bounded staleness

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1. "stale" data versions   bounded staleness

2. "concurrent" data versions   bounded concurrency level

3. "non-snapshot" data versions   bounded distance
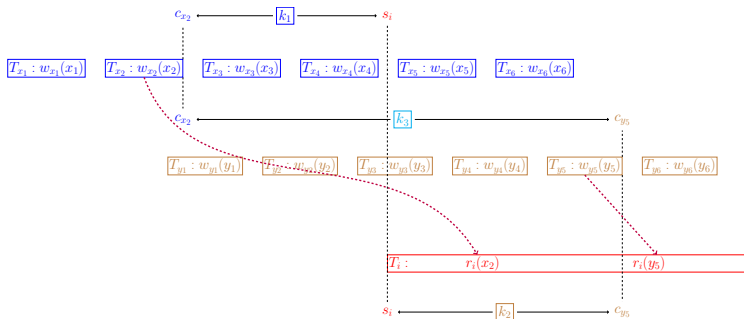
$(k_1\text{-BV})$

$$\forall r_i(x_j), w_k(x_k), c_k \in h : \left(c_j \in h \wedge \bigwedge_{k=1}^{m} (c_j \prec_h c_k \prec_h s_i) \right) \Rightarrow m < k_1,$$

$(k_2\text{-FV})$

$$\forall r_i(x_j), w_k(x_k), c_k \in h : \left(c_j \in h \wedge \bigwedge_{k=1}^{m} (s_i \prec_h c_k \prec_h c_j) \right) \Rightarrow m \leq k_2,$$

$(k_3\text{-SV})$

$$\forall r_i(x_j), r_i(y_l), w_k(x_k), c_k \in h : \left(\bigwedge_{k=1}^{m} (c_j \prec_h c_k \prec_h c_l) \right) \Rightarrow m \leq k_3.$$

$$h \in \mathsf{RVSI} \iff h \in k_1\text{-BV} \cap k_2\text{-FV} \cap k_3\text{-SV} \cap \mathsf{WCF}$$

$$\mathsf{RVSI}(1, 0, *) = \mathsf{SI}$$

RVSI: Relaxed Version Snapshot Isolation

CHAMELEON Protocol

CHAMELEON:

A prototype **partitioned replicated**

distributed transactional **key-value** store

CHAMELEON Prototype
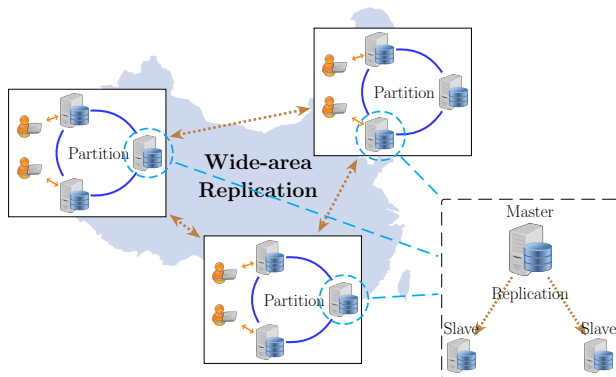
Classic **key-value** data model
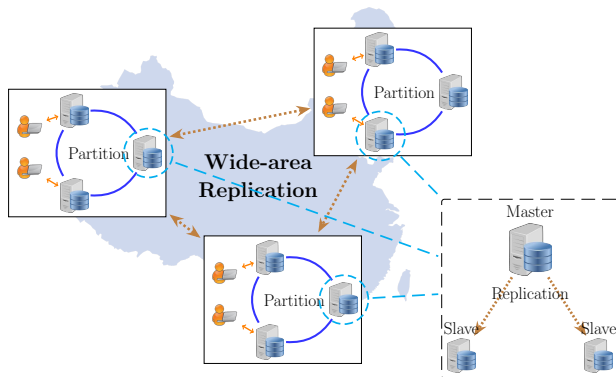
Key: (row key, column key)
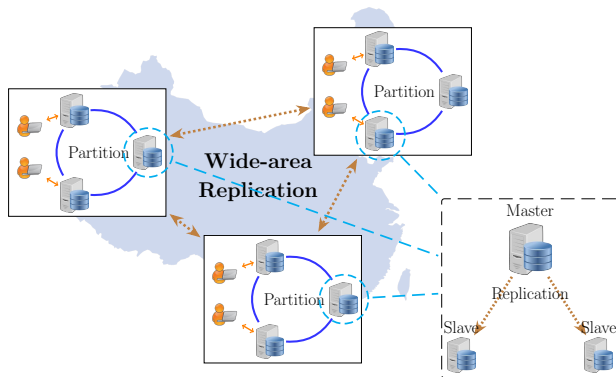
Chameleon Prototype
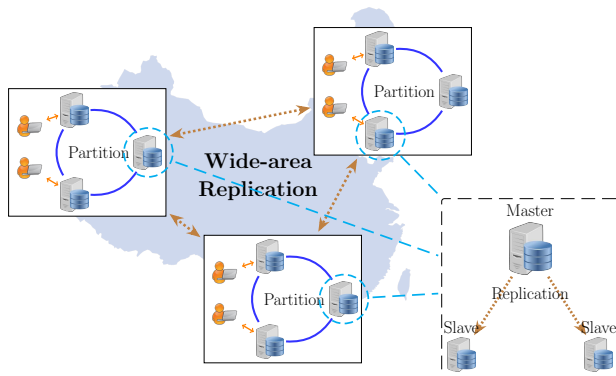
CHAMELEON Prototype

Keys are **partitioned** within a single datacenter.
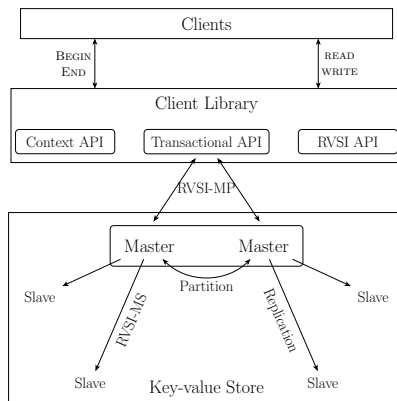
CHAMELEON Prototype

Each key is **replicated** in a master-slave manner across datacenters.
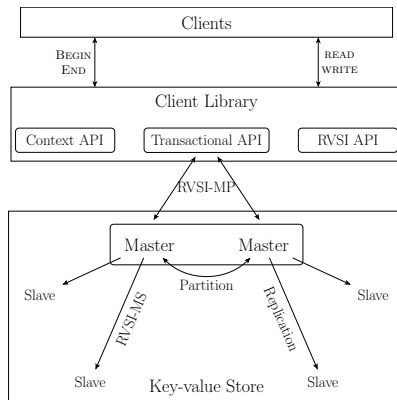
CHAMELEON Prototype

Transactions are first executed and committed on the masters,
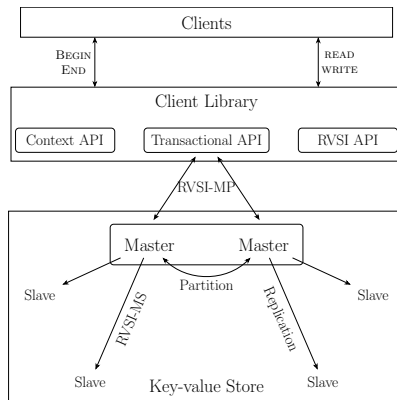and are then asynchronously propagated to slaves.

CHAMELEON Protocol

CHAMELEON Protocol

Partitioned replicated transactional key-value store

# CHAMELEON Protocol

Client library

CHAMELEON Protocol

```
// Initialize keys (ck, ck1, and ck2) here
ITx tx = new RVSITx(/** context **/);

tx.begin();

// Read and write
ITsCell tsCell = tx.read(ck);
ITsCell tsCell1 = tx.read(ck1);
tx.write(ck1, new Cell("R1C1"));
ITsCell tsCell2 = tx.read(ck2);

// Specify RVSI specs. (e.g., SVSpec)
RVSISpec sv = new SVSpec();
sv.addSpec({ck, ck1, ck2}, 2);
tx.collectRVSISpec(sv);
```

CHAMELEON Protocol
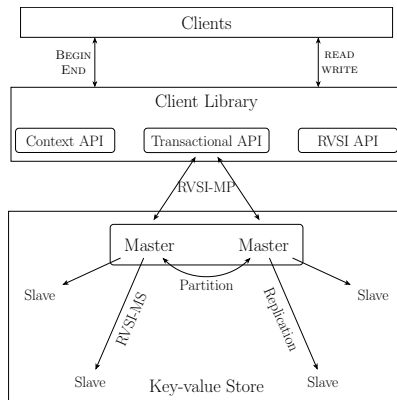
RVSI protocol: RVSI-MS + RVSI-MP

RVSI-MS Protocol

RVSI-MS: RVSI protocol for master-slave replication

In terms of *event* generation and handling:

Clients: Begin, Read, Write, End

Master: Start, Commit, Send

Slaves: Receive

RVSI-MS Protocol

TikZ overlay for RVSI-MS

RVSI-MS Protocol

Calculating version constraints:

RVSI-MP Protocol

Distributed transactions spanning multiple masters need to be committed atomically.

RVSI-MP Protocol

Distributed transactions spanning multiple masters need to be committed atomically.
Using the two-phase commit (2PC) protocol.

RVSI-MP Protocol

Assumes a timestamp oracle:

Clients:

Masters:

RVSI-MP Protocol

RVSI version constraints in 2PC protocol:

k_1-BV:

k_2-FV:

k_3-SV:

RVSI-MS Protocol

Algorithm 1 RVSI-MS: RVSI Protocol for Replication (for Executing Transaction T).

   Client-side methods:

1: **procedure** BEGIN()
2:     $T.sts \leftarrow$ **rpc-call** START() at master $\mathcal{M}$
3: **procedure** READ(x)
4:     $x.ver \leftarrow$ **rpc-call** READ(x) at any site
5: **procedure** WRITE(x, v)
6:     add (x, v) to $T.writes$
7: **procedure** END(T)
8:     $T.vc \leftarrow$ ADD-VC()
9:     $c/a \leftarrow$ **rpc-call** COMMIT($T.writes$, $T.vc$) at $\mathcal{M}$

RVSI-MP Protocol

Algorithm 2 RVSI-MP: RVSI Protocol for Partition (for Executing Transaction T).

Client-side methods:

1: **procedure** BEGIN()
2:      **return rpc-call** GETTS() at $\mathcal{T}$
3: **procedure** END()
4:      $T.vc \leftarrow$ ADD-VC()
5:      $c/a \leftarrow$ **rpc-call** C-COMMIT($T.writes$, $T.vc$) at $\mathcal{C}$

Timestamp oracle methods:

     $\mathcal{T}.ts$: for start-timestamps and commit-timestamps
6: **procedure** GETTS()
7:      **return** $++\mathcal{T}.ts$

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RVSI: Relaxed Version Snapshot Isolation

Impacts of RVSI specification

on the *transaction abort rates* in various scenarios

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Performance?

▶ Not done yet in this work

▶ CHAMELEON prototype is ...

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Transaction abort rates due to "vc-aborted" are *sensitive* to different values of k_1, k_2, or k_3, but those due to "wcf-aborted" are not.
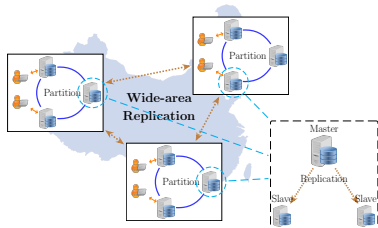
Transactions abort for two reasons:

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$$h \in \mathsf{RVSI} \iff h \in k_1\text{-}\mathsf{BV} \cap k_2\text{-}\mathsf{FV} \cap k_3\text{-}\mathsf{SV} \cap \mathsf{WCF}.$$

CHAMELEON prototype on Aliyun:

- 3 datacenters [1]
- 3 nodes in each datacenter
- Partition & Replication
- Clients in our lab [2]

---

[1]Located in East China, North China, and South China, respectively.
[2]Located in East China.
[3]https://github.com/hengxin/aliyun-ping-traces

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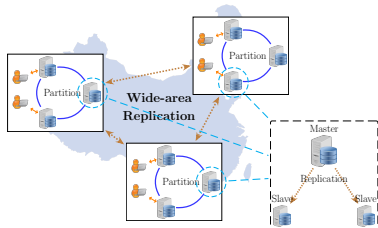
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- Partition & Replication
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(One-way) delays among nodes [3]:

Within datacenter: $1 \sim 2$ms

Across datacenters: $15 \sim 25$ms

Clients to nodes: $15 \sim 20$ms

[1] Located in East China, North China, and South China, respectively.

[2] Located in East China.

[3] https://github.com/hengxin/aliyun-ping-traces

Table: Three categories of workload parameters for experiments on Aliyun.

| Parameter		Value	
Transaction-related	#keys	$25 = 5$ (rows) $\times$ 5 (columns)	
	#clients	5, 10, 15, 20, 25, 30	
	#txs/client	1000	
	#ops/tx	$\sim$ Binomial(20, 0.5)	n
	rwRatio	1:2, 1:1, 4:1	
	zipfExponent	1	
Execution-related	minInterval	0ms	
	maxInterval	10ms	
	meanInterval	5ms	
RVSI-related	(k_1, k_2, k_3)	(1,0,0) (1,1,0) (1,1,1)	
		(2,0,0) (2,0,1) (2,1,1)	

under read-frequent workloads
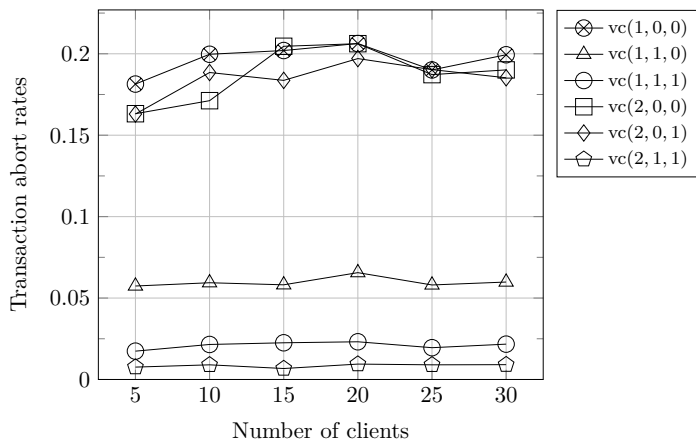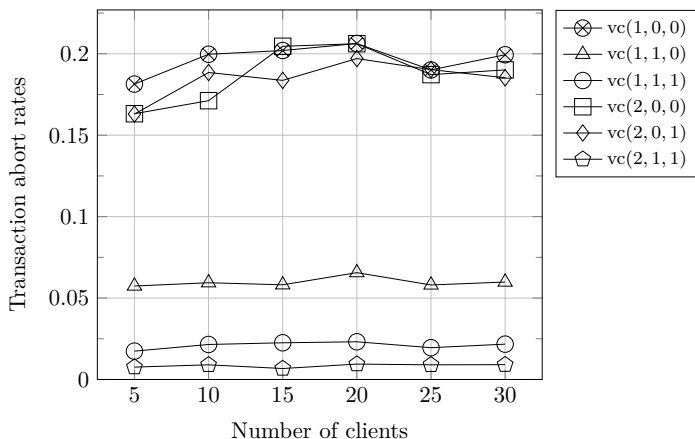
The transaction abort rates due to "vc-aborted"
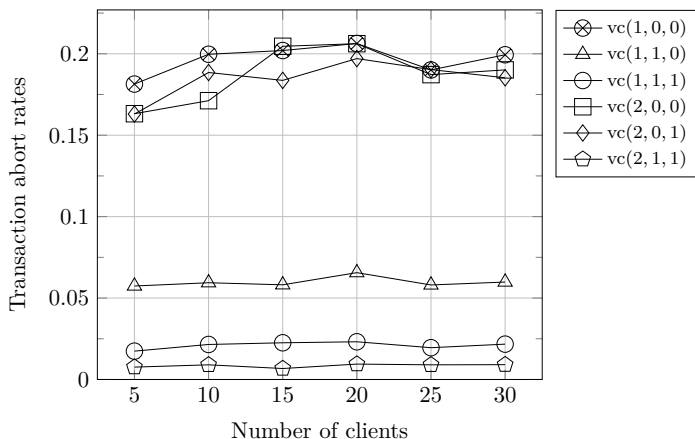
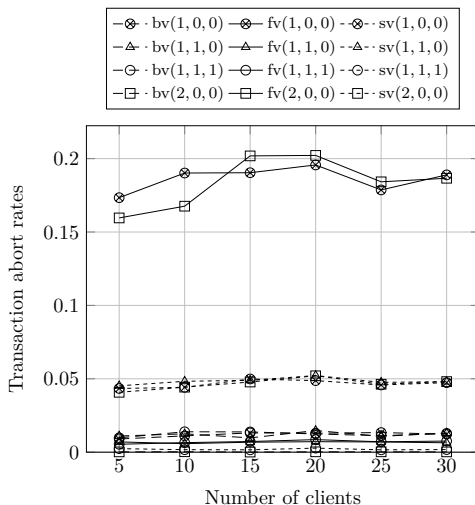The transaction abort rates due to "vc-aborted" can be greatly reduced by slightly increasing the values of k_1, k_2, or k_3:

$$vc(1, 0, 0) = 0.1994 \implies vc(2, 1, 1) = 0.0091 \quad (\#\text{clients} = 30)$$
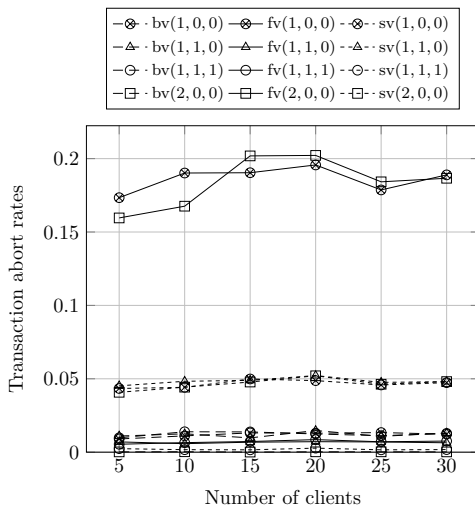
Most "vc-aborted" transactions abort because of violating k_2-FV.

$$fv(1,0,0) = 0.1889 \implies fv(2,0,0) = 0.1866 \implies fv(1,1,0) = 0.0064$$

Question: when does k_1 for k_1-BV take effect?

It seems that k_1-BV has *little* impact on the transaction abort rates.

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It seems that k_1-BV has *little* impact on the transaction abort rates.

It may be the case in the Aliyun scenarios.

What about other scenarios?

Three types of delays for **controlled experiments** on local hosts.

Types	Values (ms)	Explanation
issueDelay	5, 8, 10, 12, 15, 20	delays between clients and replicas
replDelay	5, 10, 15, 20, 30	delays between masters and slaves
2pcDelay	10, 20, 30, 40, 50	delays among masters
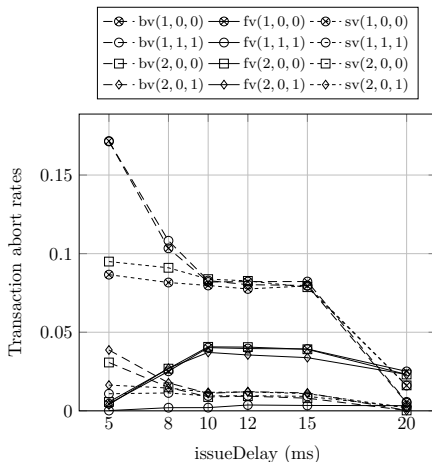
When the "issueDelay" gets shorter,
the impacts of k_2-FV go weaker,
and the impacts of k_1-BV have begun to emerge.

issueDelay $= 20$ms: $bv(1,0,0) = 0.0057$ $fv(1,0,0) = 0.0251$

issueDelay $= 15$ms: $bv(1,0,0) = 0.08225$ $fv(1,0,0) = 0.0393$

issueDelay $= 5$ms: $bv(1,0,0) = 0.1716$ $fv(1,0,0) = 0.0045$

issueDelay $= 20$ms: $\quad bv(1,0,0) = 0.0057 \quad\quad fv(1,0,0) = 0.0251$

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issueDelay $= 5$ms: $\quad bv(1,0,0) = 0.1716 \quad\quad fv(1,0,0) = 0.0045$

larger issueDelay $\implies$ longer transaction

more concurrent transactions

more likely to obtain data versions updated by concurrent transactions

more sensitive to k_2-FV

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k_1-BV: In controlled experiments, the impacts of k_1-BV emerge when the issueDelay gets shorter.

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k_2-FV: In the Aliyun scenarios, most transactions have been aborted because of violating k_2-FV.

k_1-BV: In controlled experiments, the impacts of k_1-BV emerge when the issueDelay gets shorter.

k_3-SV: Complex and challenging (involving multiple data items)