भारतीय प्रौद्योगिकी संस्थान हैदराबाद
Indian Institute of Technology Hyderabad

MICHIGAN STATE UNIVERSITY

An Innovative Approach to Achieve Compositionality Efficiently using Multi-Version Object Based Transactional Systems

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Outline

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Transaction

Sequence of instructions guaranteed to execute atomically.

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History

Concurrent execution of transactions.

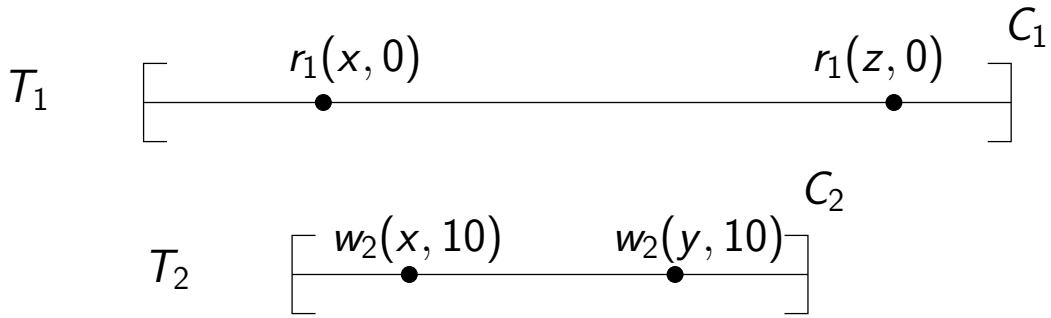

Figure: History of an STM

STMs Cont'd..

Introduction

- **Software Transaction Memory Systems(STMs)** are a convenient programming interface for a programmer to access shared memory using concurrent threads without worrying about concurrency issues.

STMs Cont'd..

Introduction

- **Software Transaction Memory Systems(STMs)** are a convenient programming interface for a programmer to access shared memory using concurrent threads without worrying about concurrency issues.
- Traditionally, STMs export the following methods:
  - t_begin()
  - t_read()
  - t_write()
  - tryC() and tryA()

  We refer to these as Read-Write STMs(or RWSTM).

A thread safe concurrent linked-list(LL) using STM

Algorithm 1 Insert(LL, e): Invoked by a thread to insert an element e into a linked-list LL. This method is implemented using transactions.

```
1:  retry = 0;
2:  while (true) do
3:      id = t_begin(retry);
4:      ...
5:      ...
6:      v = t_read(id, x);                    ▷ reads the value of x as v
7:      ...
8:      ...
9:      t_write(id, x, v');                   ▷ writes a value v' to x
10:     ...
11:     ...
12:     ret = tryC(id);                       ▷ tryC can return commit or abort
13:     if (ret == commit) then
14:         break;
15:     else
16:         retry++;
17:     end if
18: end while
```

Working of STMs methods

Working of STMs methods

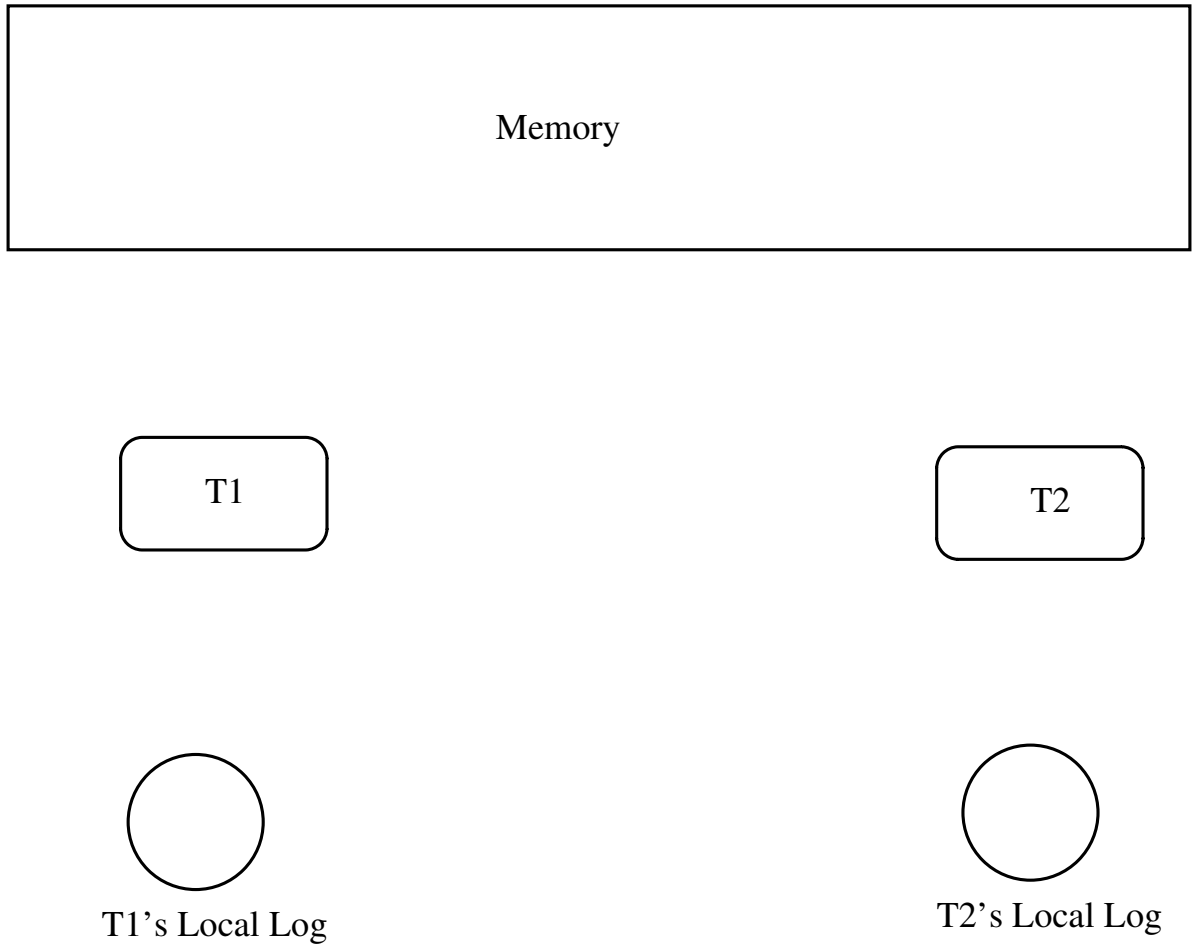

Figure: Working of STM System

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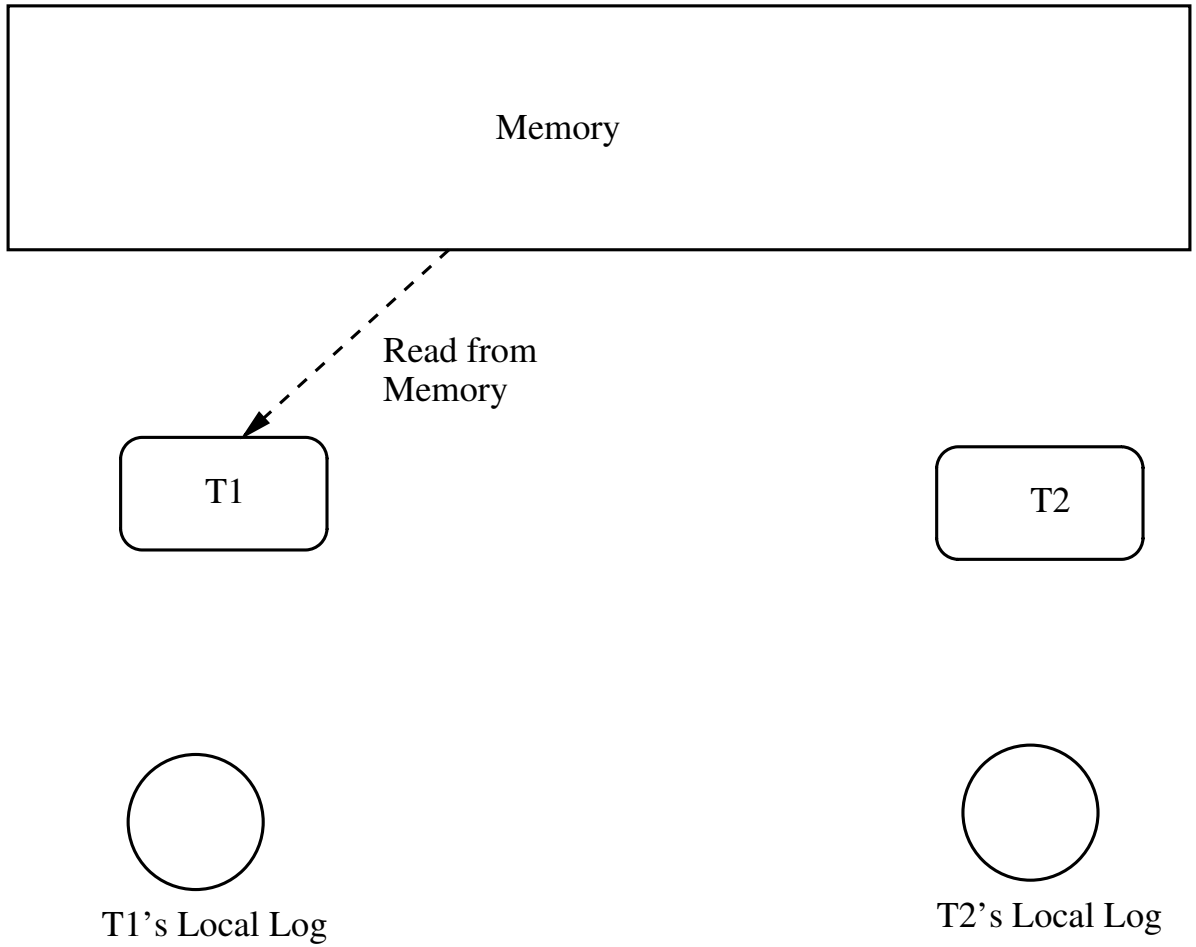

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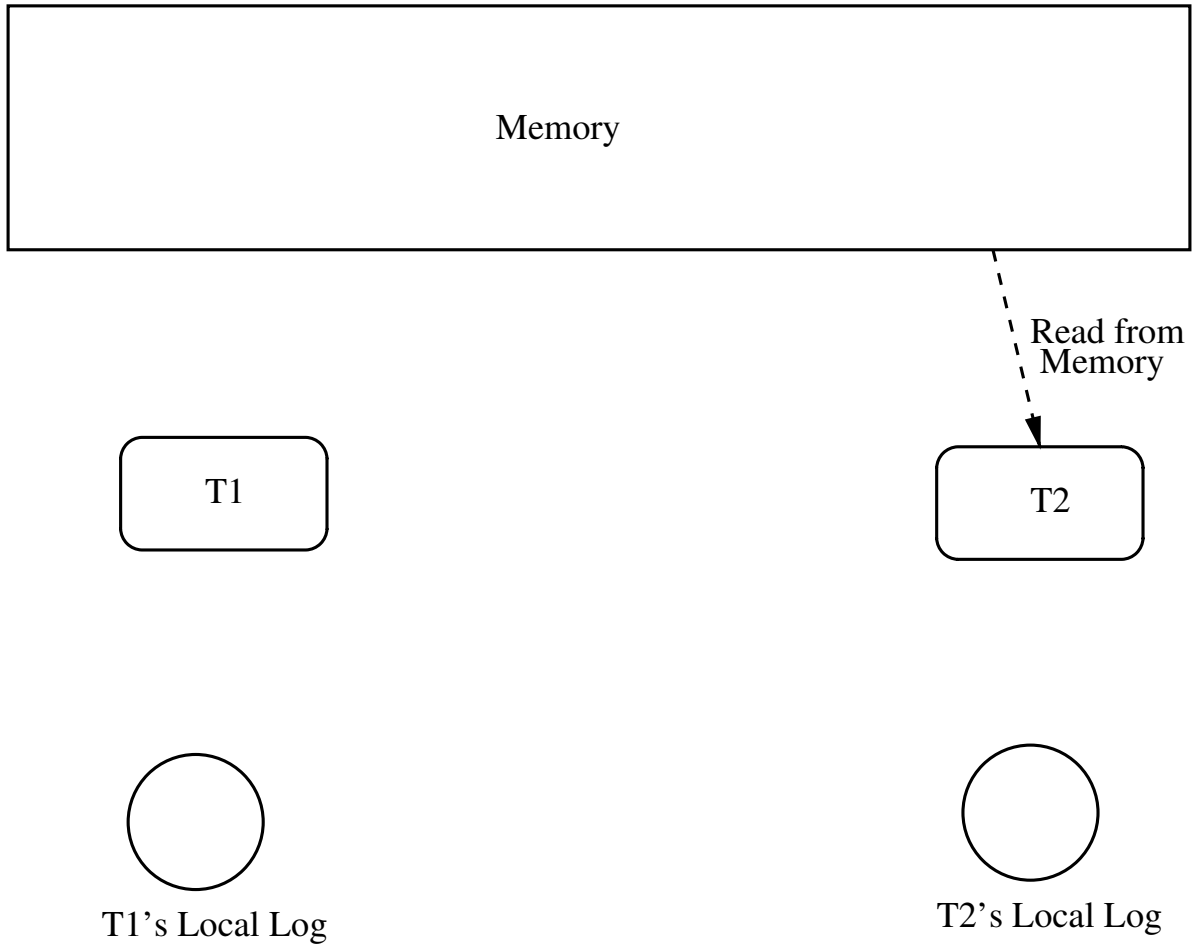

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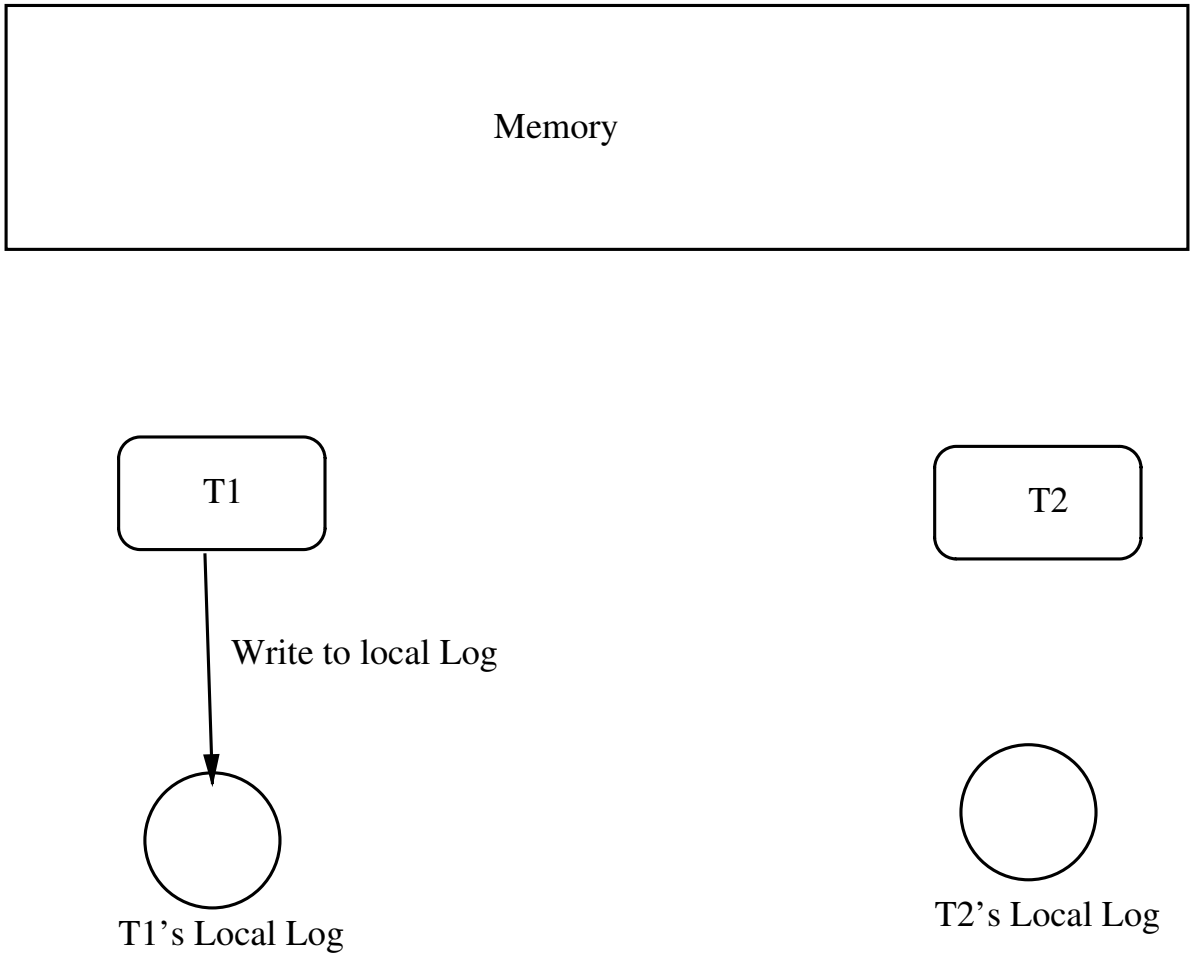

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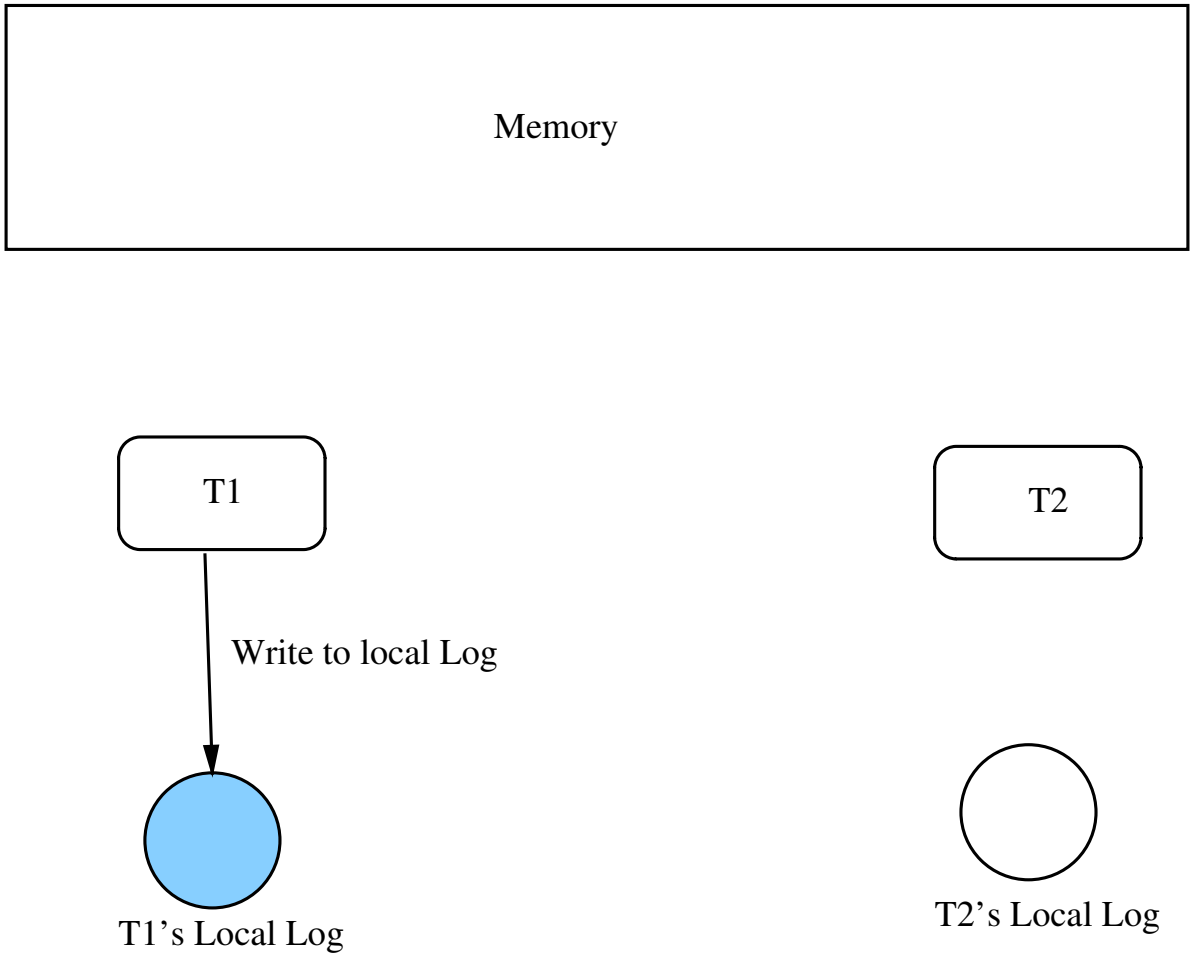

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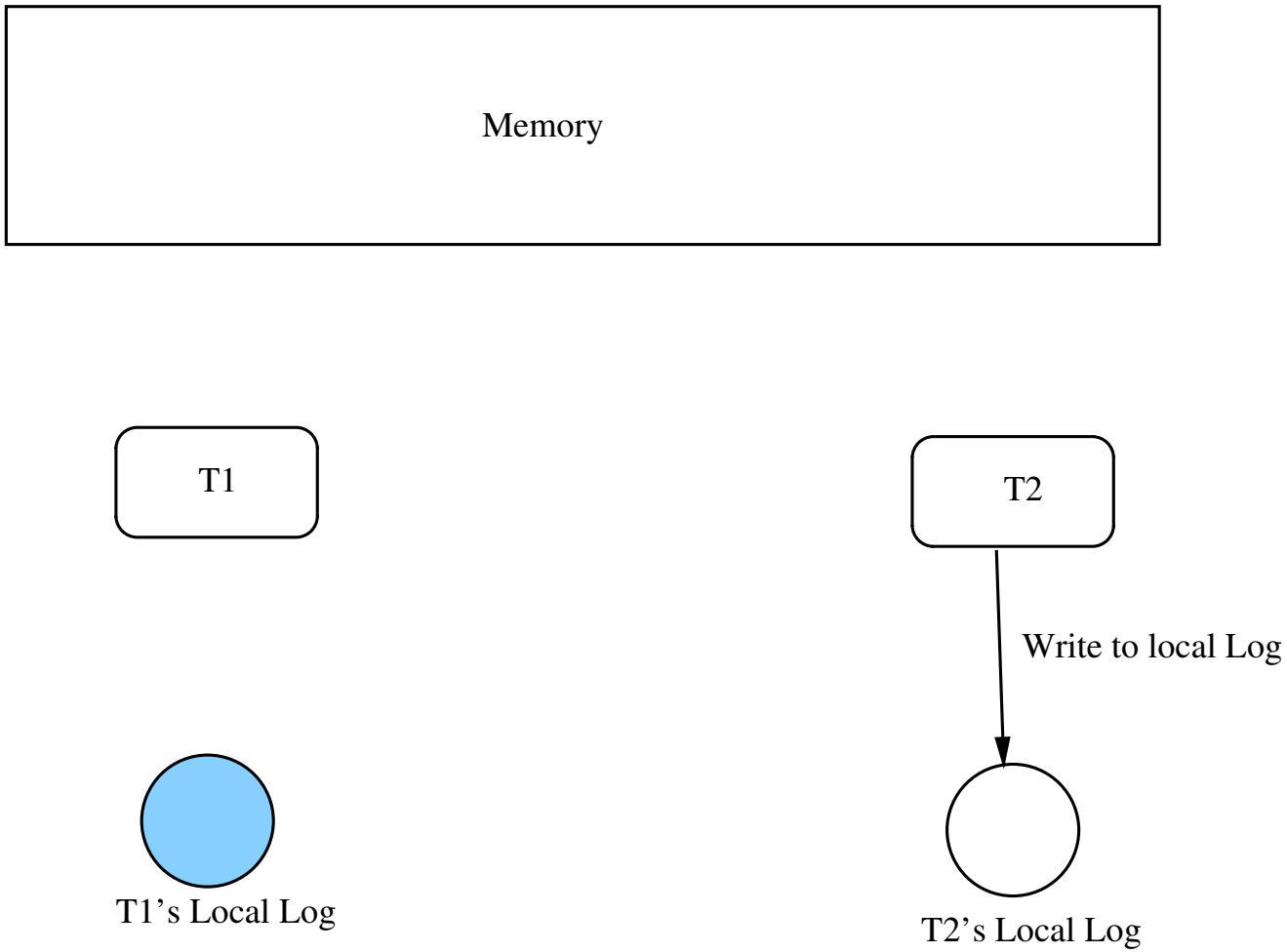

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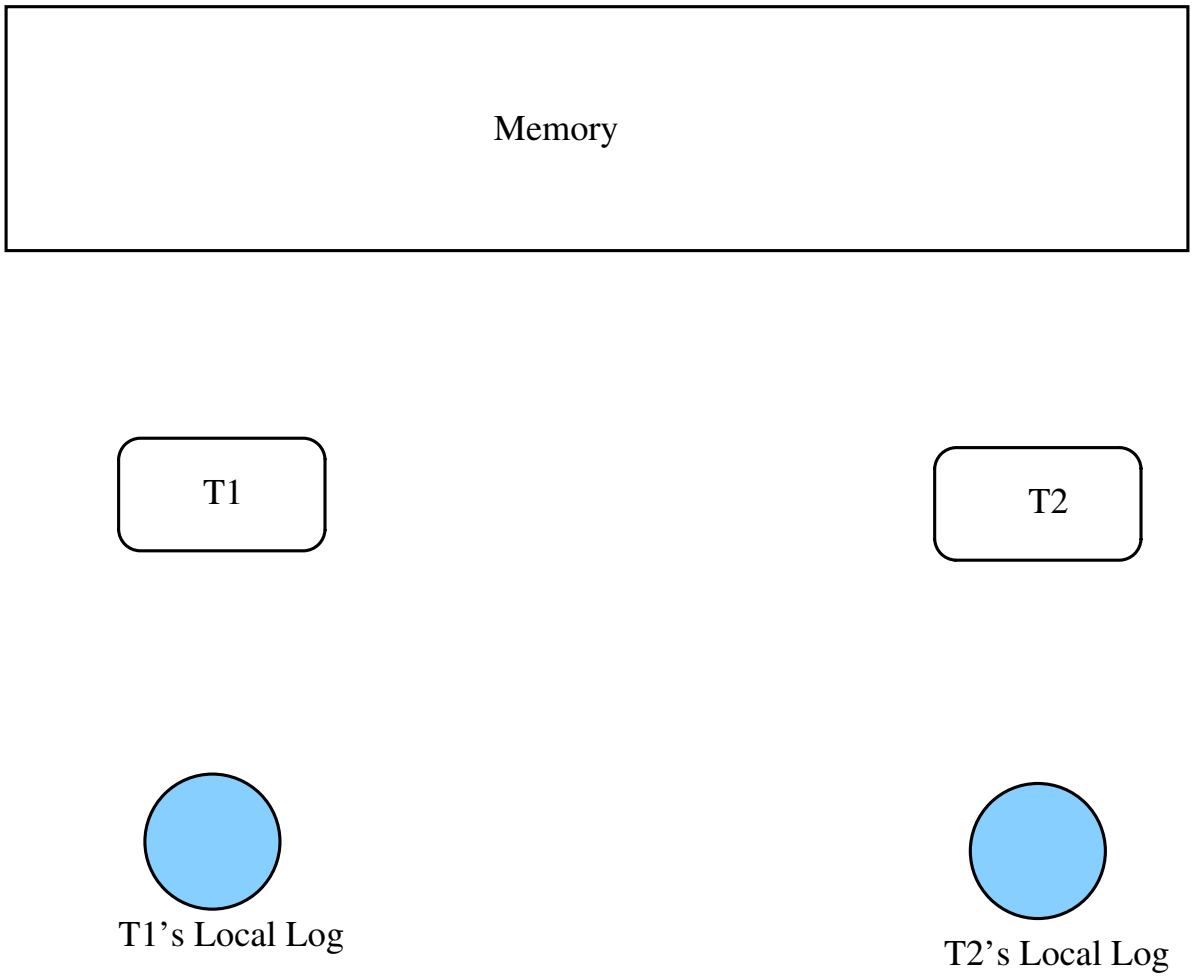

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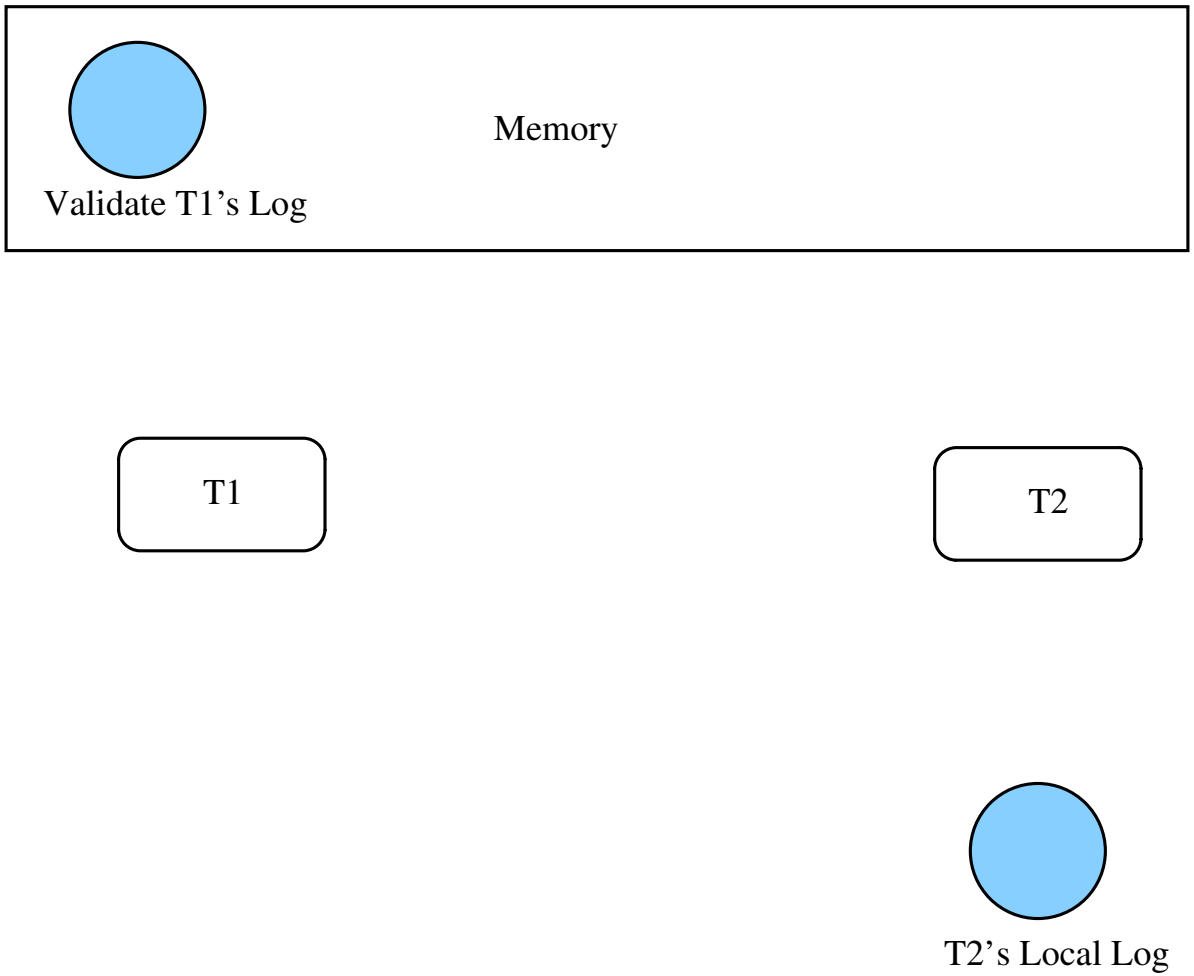

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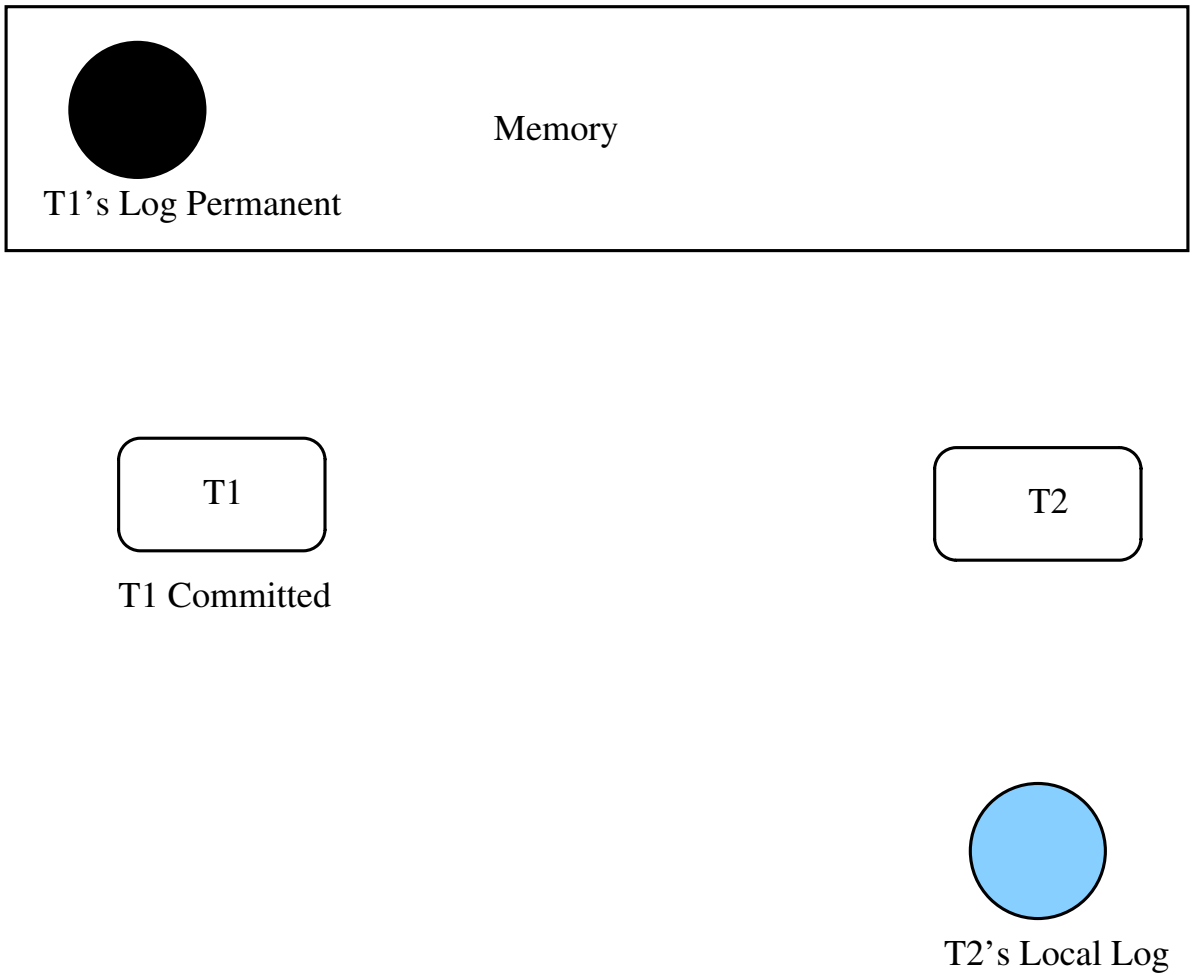

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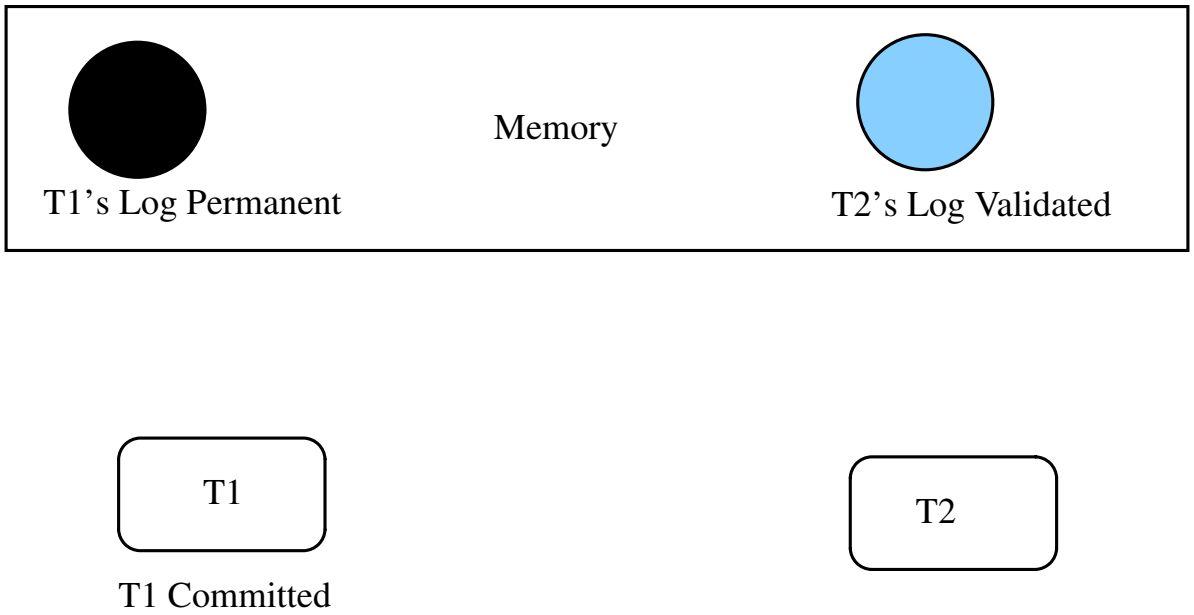

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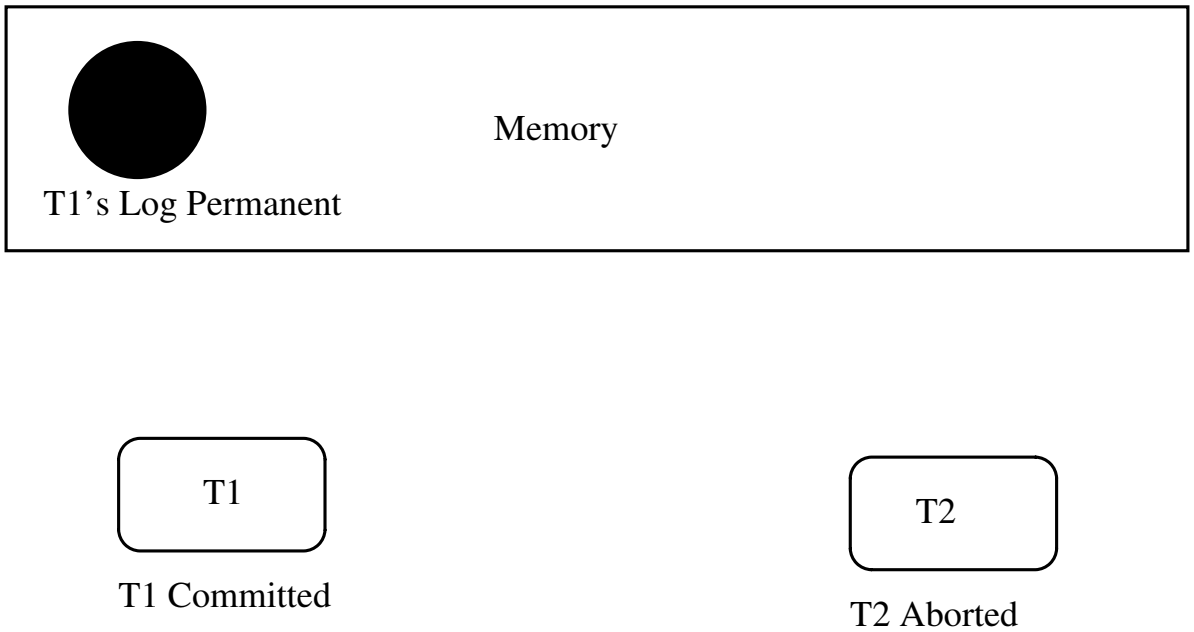

Figure: Working of STM System

Correctness of STM System: Opacity [a]

[a] Guerraoui, R., Kapalka, M.: On the Correctness of Transactional Memory. PPoPP, 2008

Correctness of STM System: Opacity [a]

Opacity

1. It is a popular correctness-criteria for STMs which is stronger than serializability.
2. Opacity like serializability requires that the concurrent execution including the aborted transactions be equivalent to some serial execution.

[a] Guerraoui, R., Kapalka, M.: On the Correctness of Transactional Memory. PPoPP, 2008

Correctness of STM System Cont'd..

Example of opacity

- H: $r_1(x,0)\, w_2(x,10)\, w_2(y,10)\, C_2\, r_1(y,A)\, A_1$

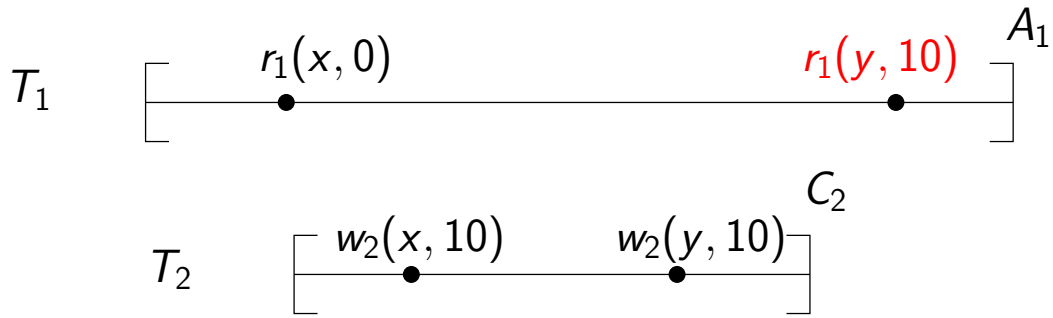

Figure: History H is not Opaque but Serializable

Correctness of STM System Cont'd..

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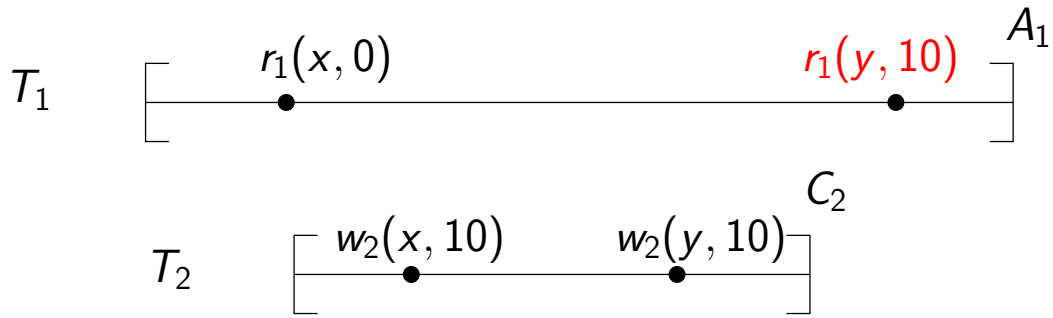

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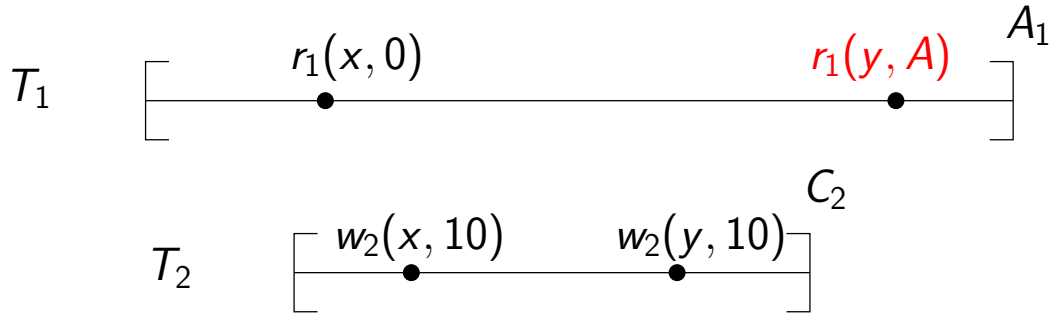

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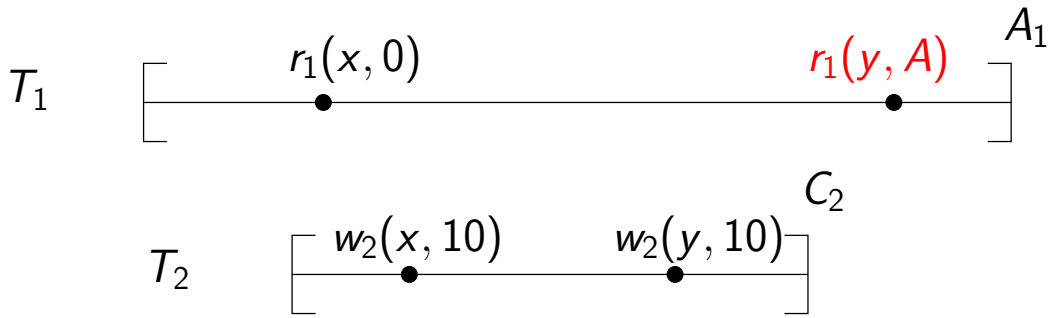

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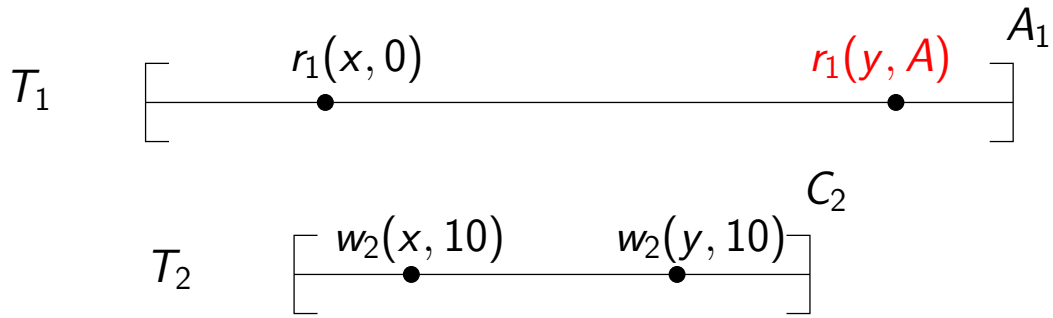

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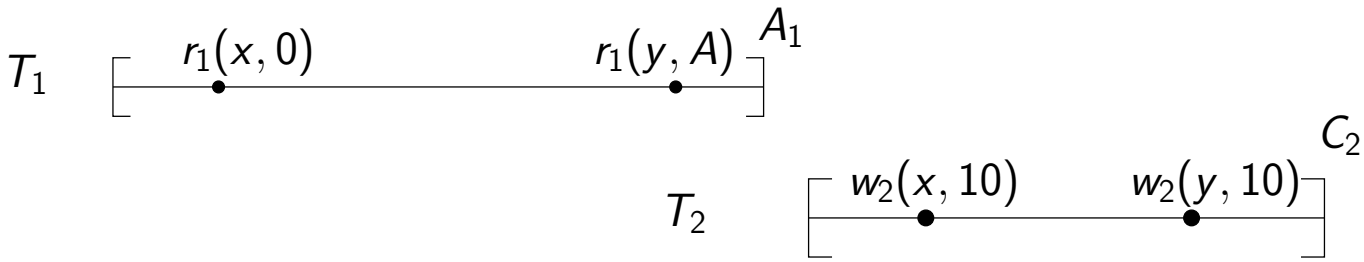

Figure: Equivalent serial history S: T_1, T_2

Outline

Problem with read-write STMs

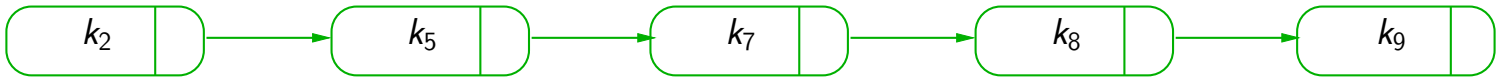

Figure: A sample concurrent list

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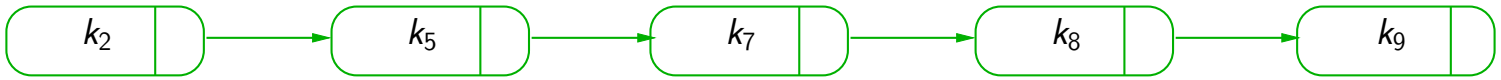

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T_1: lookup(k_5), lookup(k_8) & T_2: delete(k_7)

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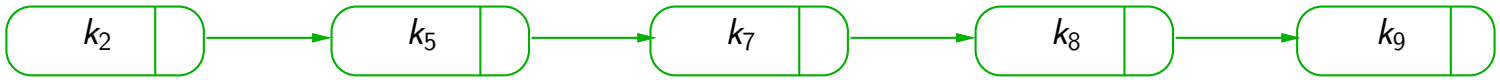

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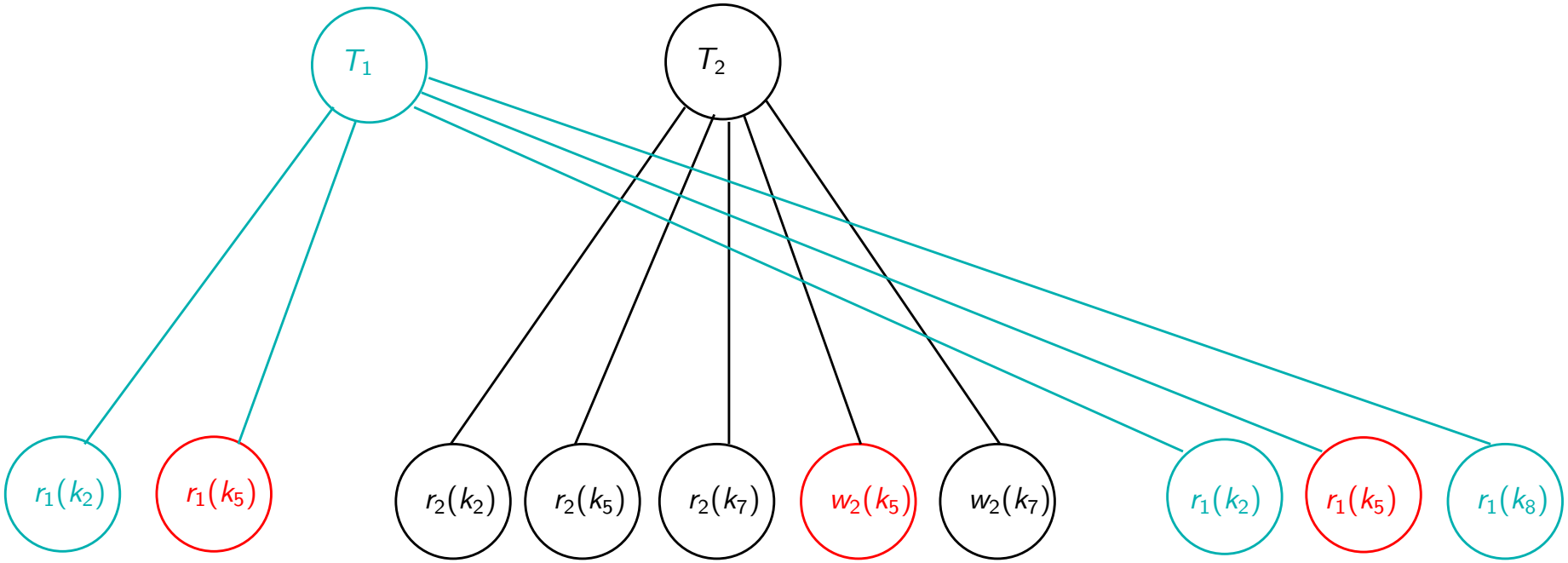

Figure: Tree Structure : conflicts are ($r_1(k_5)$, $w_2(k_5)$) and ($w_2(k_5)$, $r_1(k_5)$)

Problem at read-write level

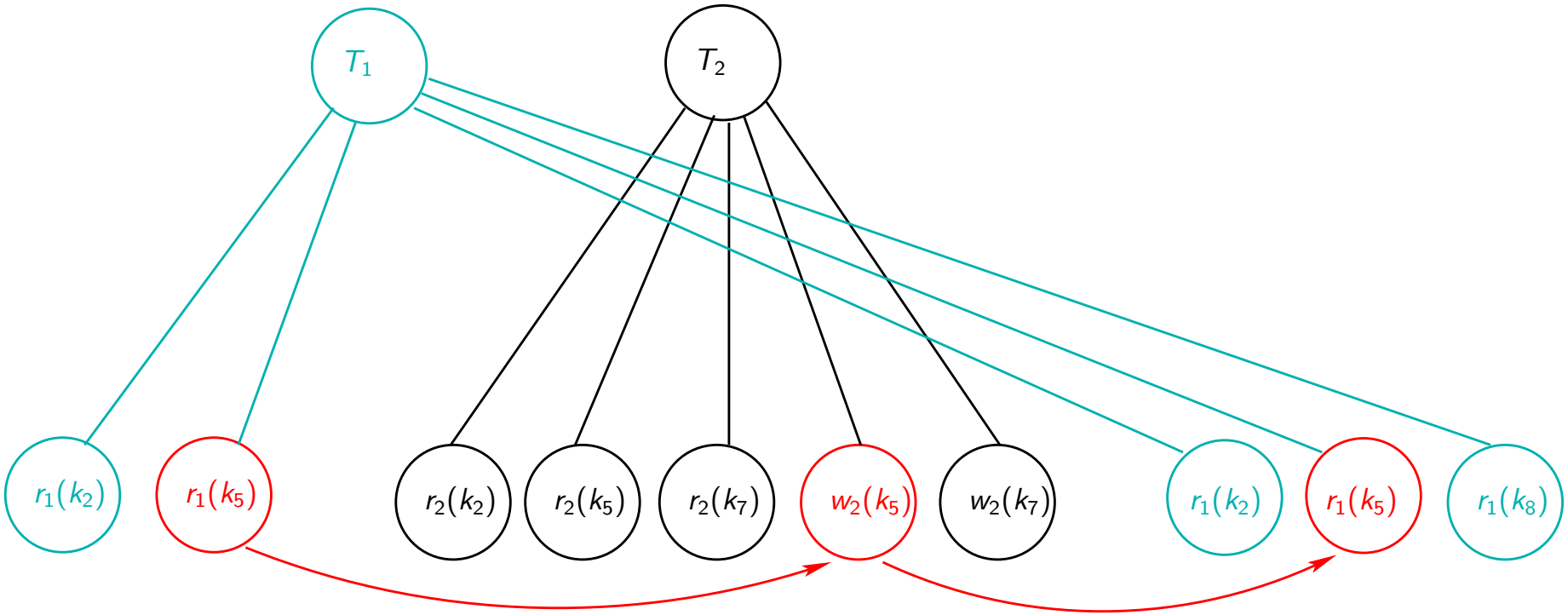

Figure: Tree Structure

Schedule cannot be accepted by a RWSTM.

Problem at read-write level

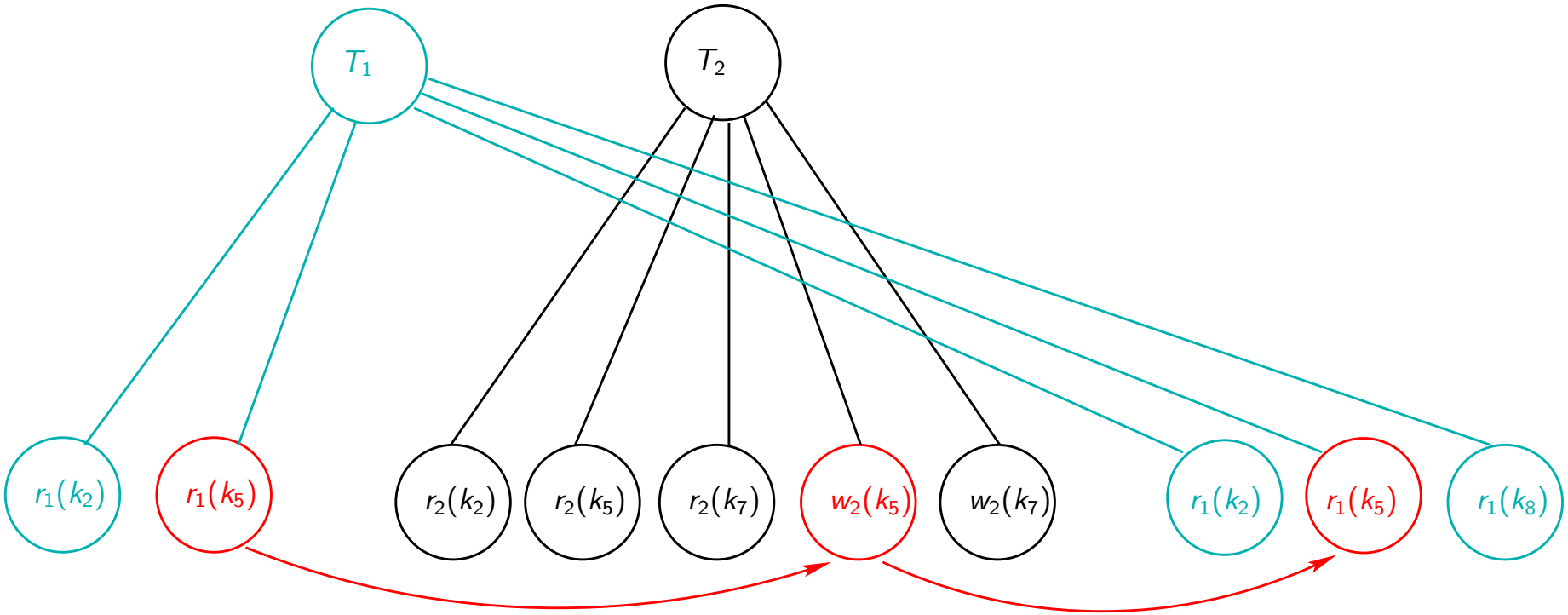

Figure: Tree Structure

Schedule cannot be accepted by a RWSTM.

Figure: Cycle (Not Serial)

Outline

- **Object-based STMs (OSTM)** operate on higher level objects rather than primitive read & writes which act upon memory locations.

[b] Herlihy, M., Koskinen, E., Transactional boosting: a methodology for highly-concurrent transactional objects. PPoPP'08
[c] Hassan, Ahmed and Palmieri, Roberto and Ravindran, Binoy, Optimistic Transactional Boosting, PPoPP'14

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- OSTM for stacks may export *t_begin()*, *t_push()*, *t_pop()*, *t_peek()* *and tryC()*.

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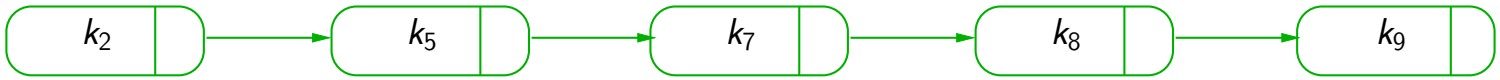
OSTM

Execution at layer-1



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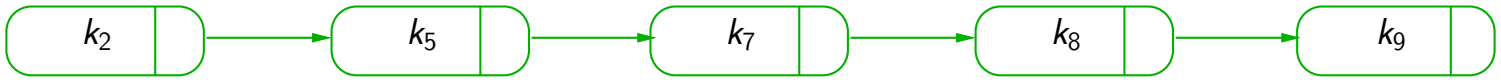
[d] Gerhard Weikum and Gottfried Vossen. 2001. Transactional Information Systems Book

OSTM

Execution at layer-1



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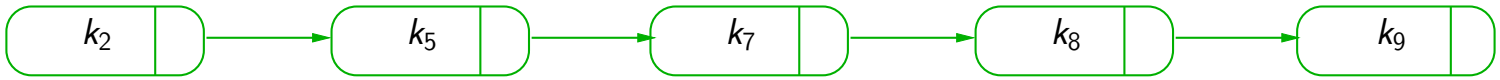

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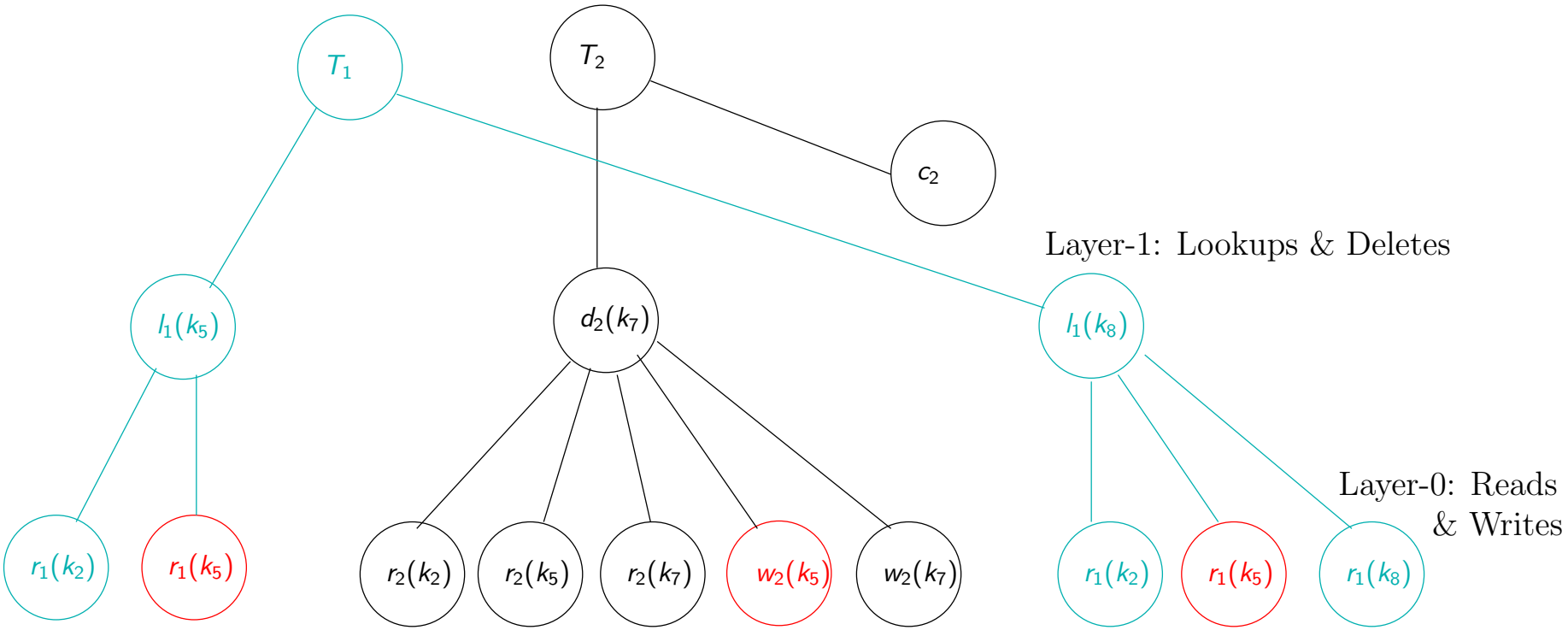

Figure: Tree Structure : no conflict at Layer-1 [d]

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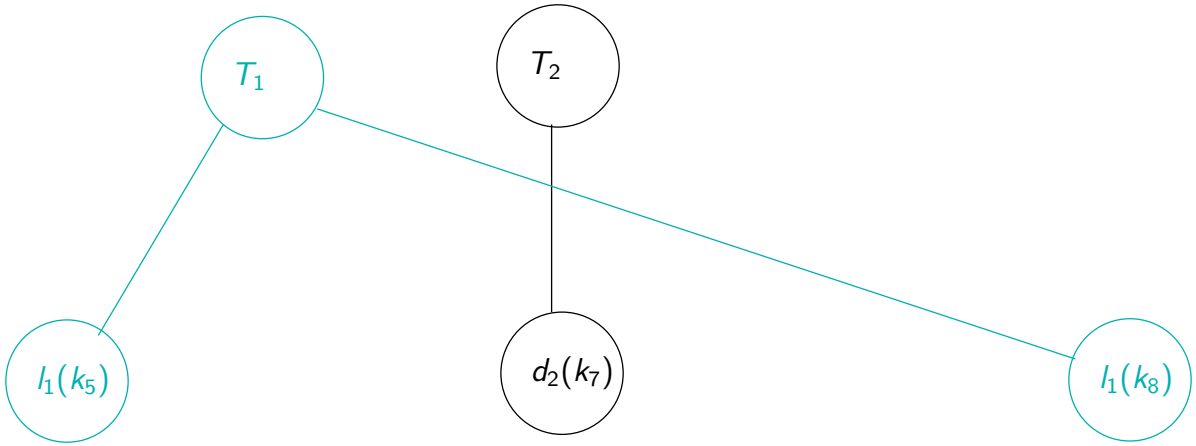
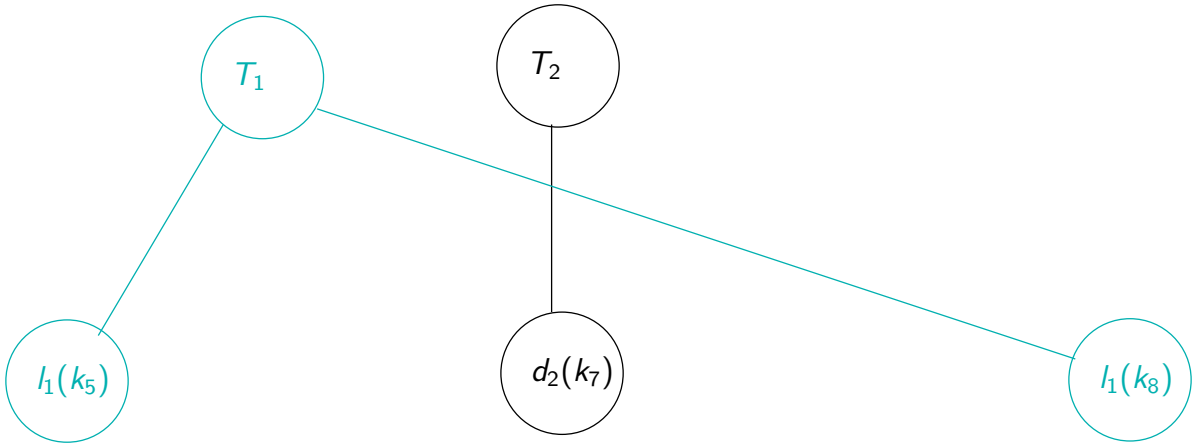


Figure: Pruned Tree



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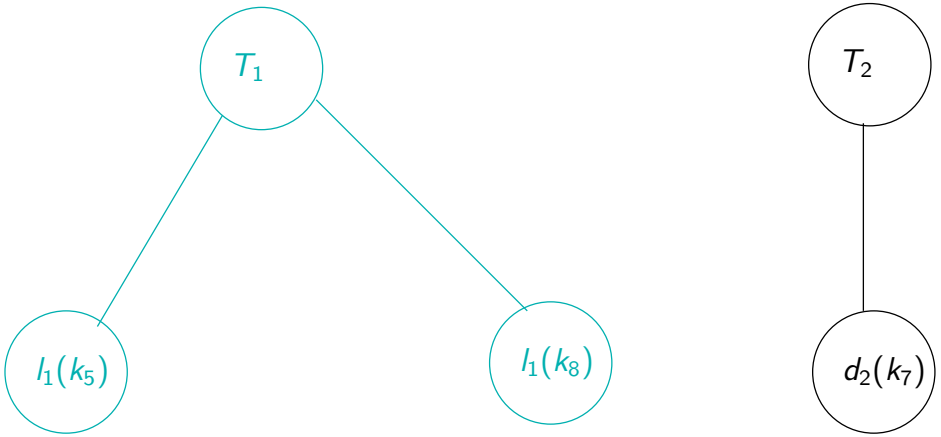
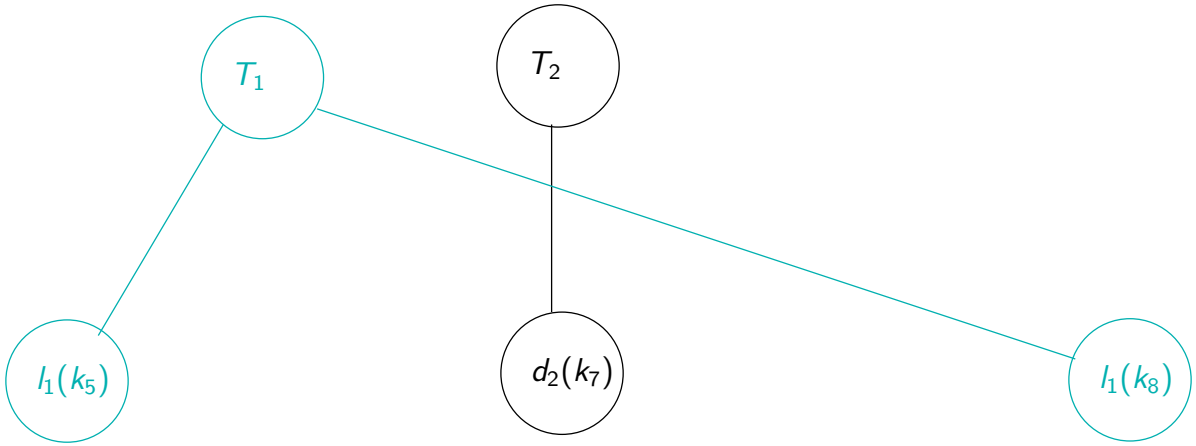


Figure: Sequential Schedule



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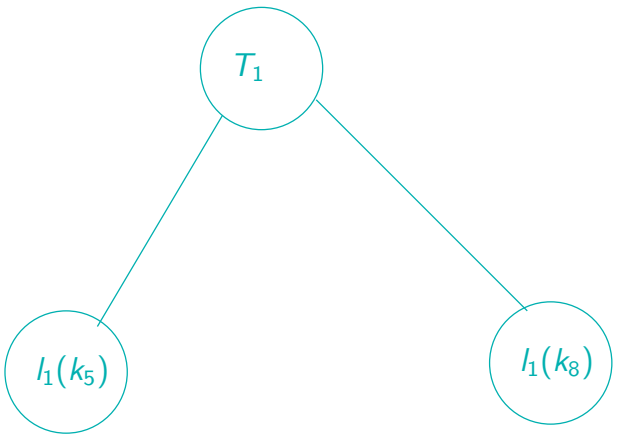

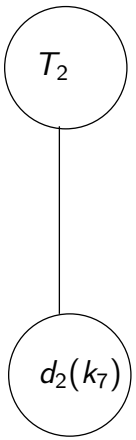

Figure: Sequential Schedule

Figure: Serial History

Inefficiency with OSTM

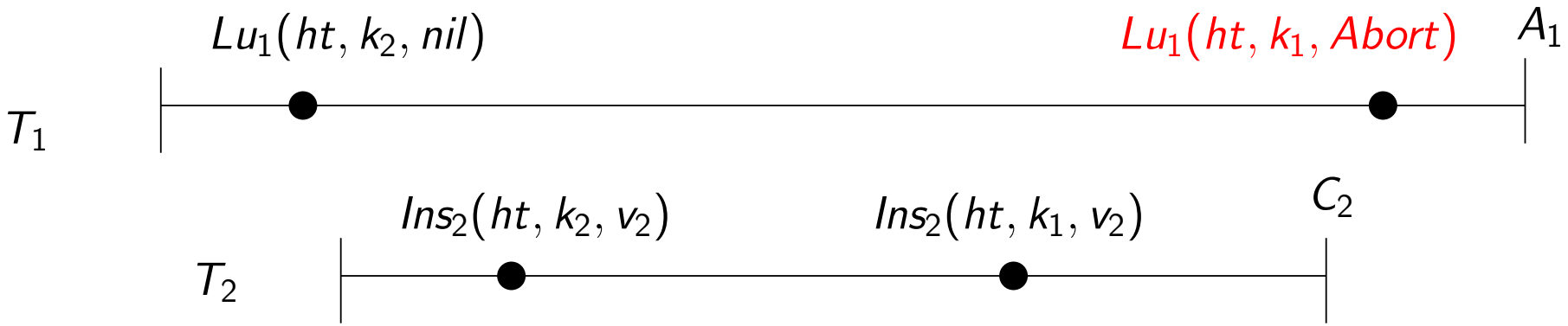

Figure: Single version OSTM

Outline

Motivation towards MV-OSTM

Advantages of multi-version[e] over single version RWSTM

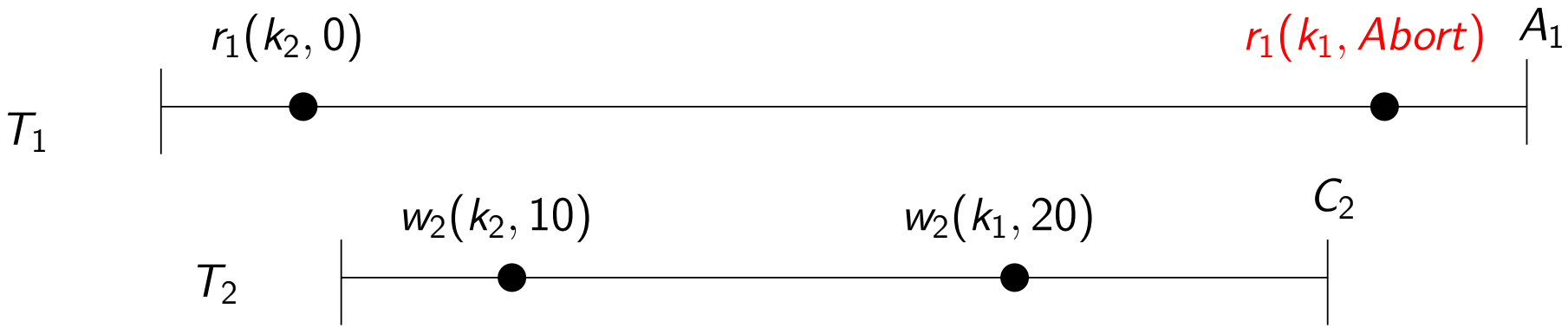

Figure: Single version RWSTM

[e] Kumar P., Peri S., and K. Vidyasankar. A TimeStamp Based Multi-version STM Algorithm. ICDCN, 2014

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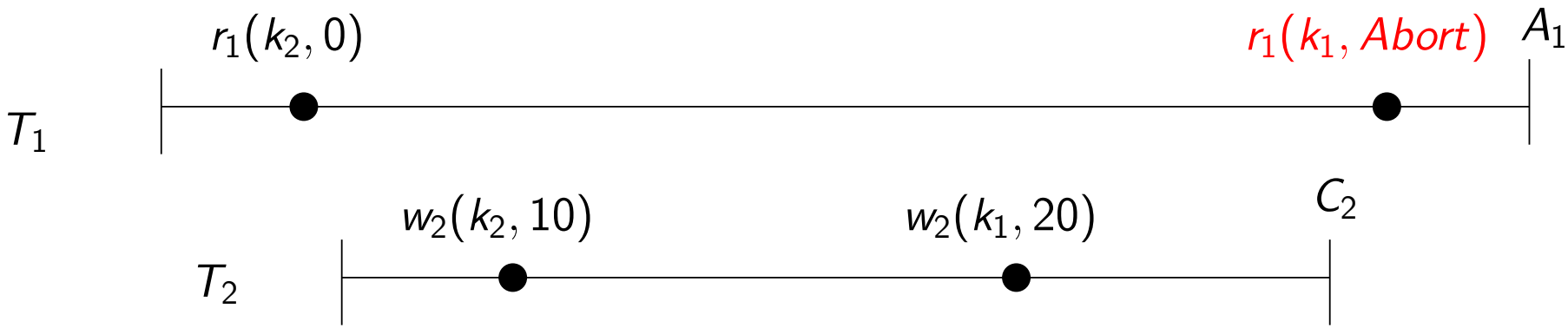

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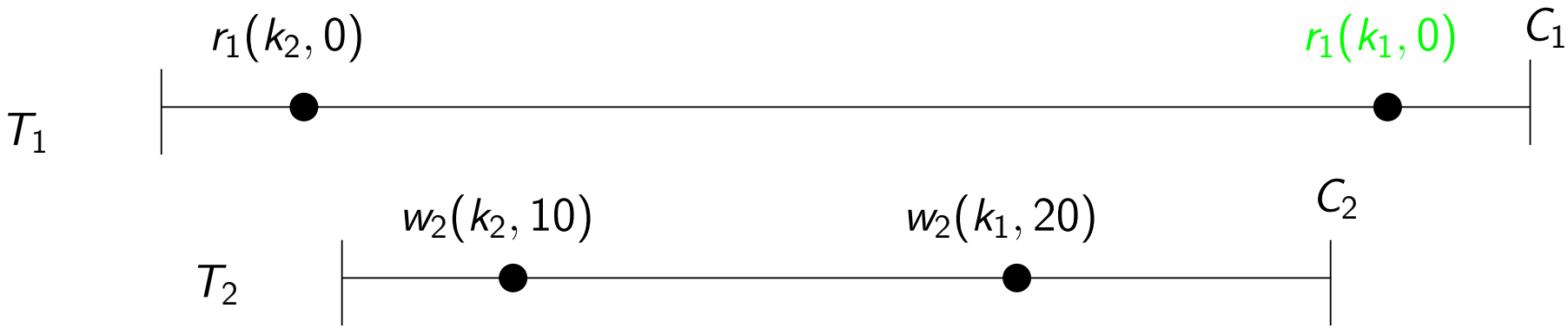

Figure: Multi-version RWSTM (MV-RWSTM) : (T_1, T_2)

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Proposed Algorithm : MV-OSTM

Advantages of multi-version over single version OSTM

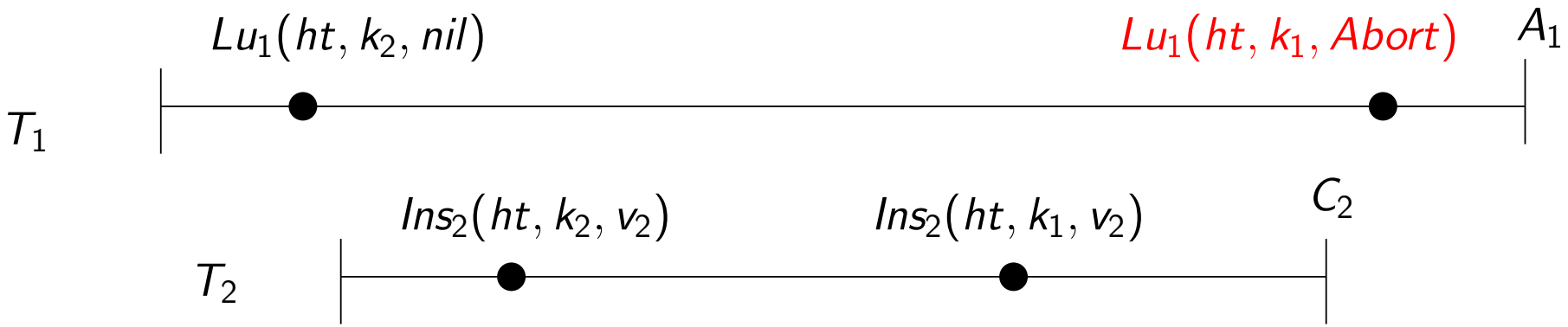

Figure: Single version OSTM

Proposed Algorithm : MV-OSTM

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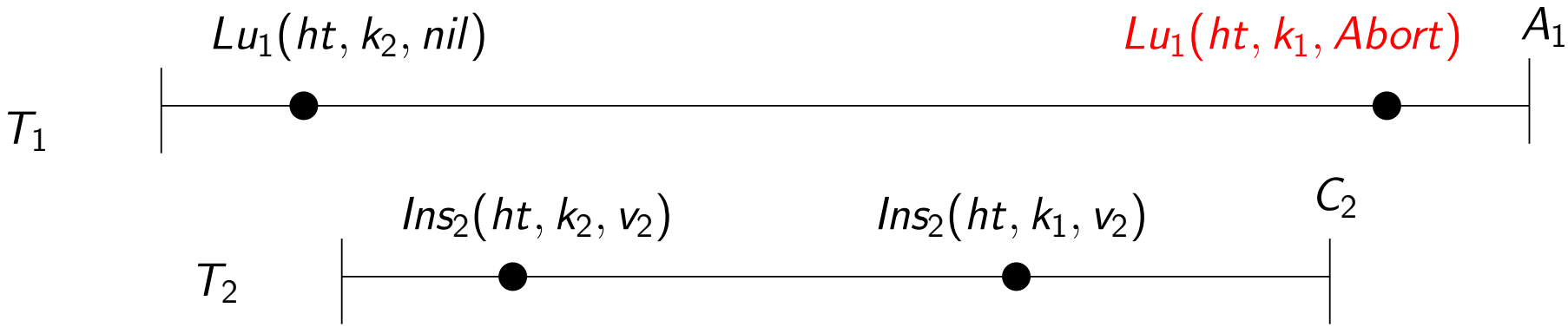

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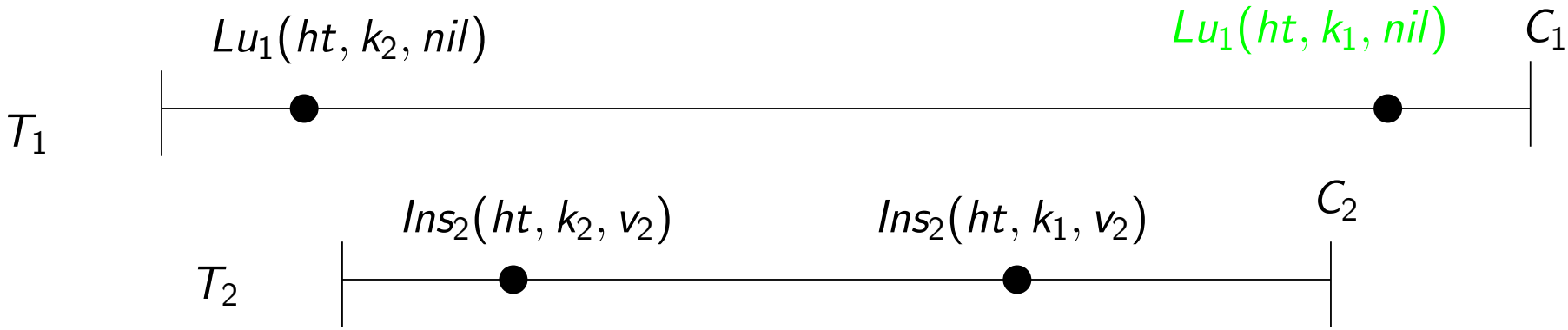

Figure: Multi-version OSTM (MV-OSTM) : (T_1, T_2)

Proposed Algorithm : MV-OSTM

High-level data structure

- A transaction T_i is assigned a unique timestamp i, when invoked.
- Timestamps are monotonically increasing.
- T_i can issue t_lookup(), t_insert(), t_delete() and tryC() methods.

[f] Sathya Peri, Ajay Singh, and Archit Somani, Efficient means of Achieving Composability using Object based Conflicts on Transactional Memory, NETYS'18

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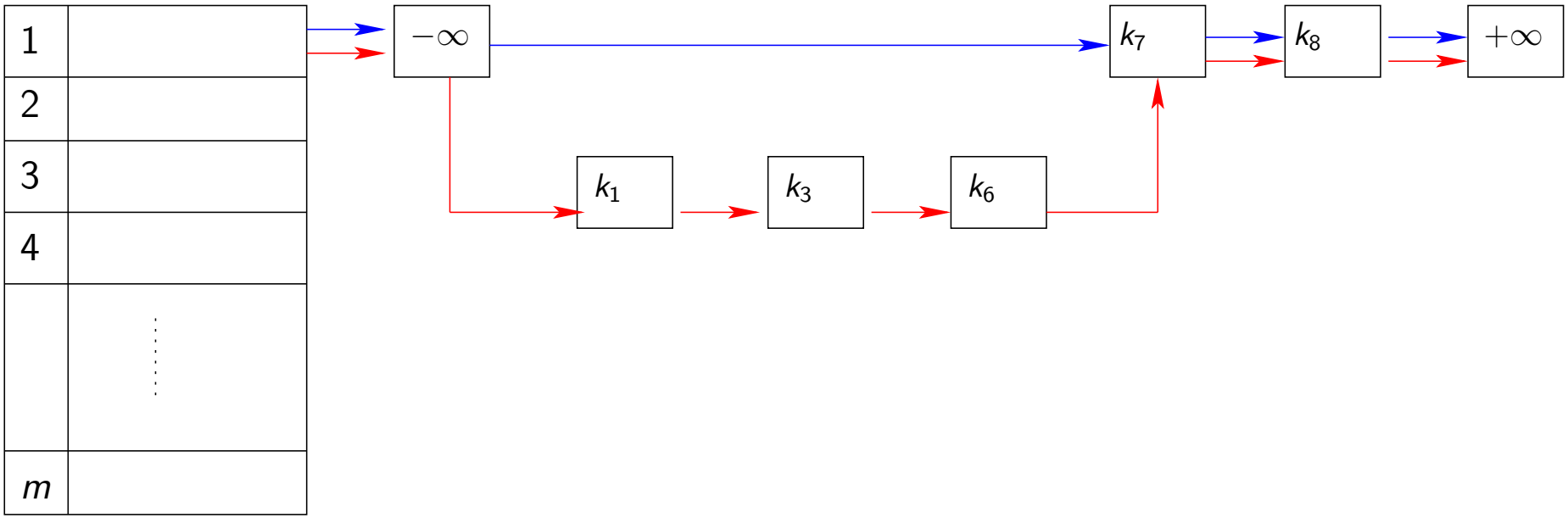

Figure: MV-OSTM design[f]

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Proposed Algorithm : MV-OSTM

High-level data structure cont'd..

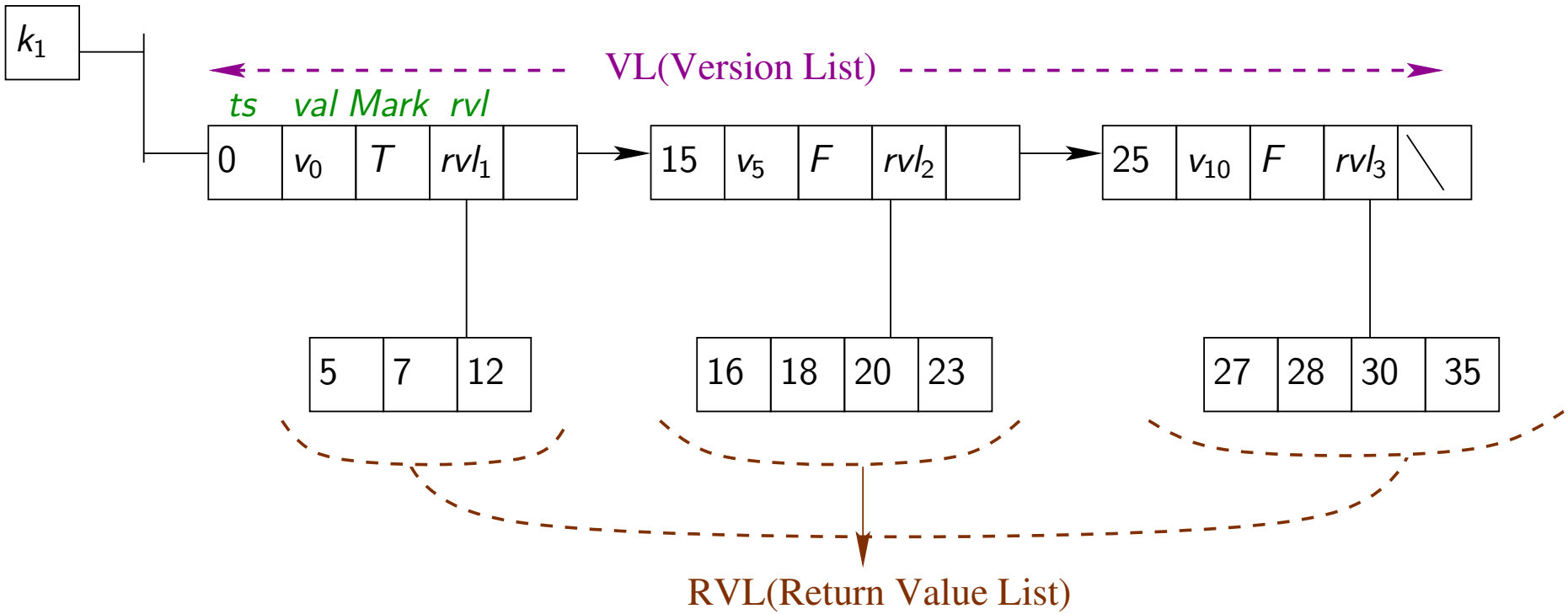

Figure: Data Structure for maintaining versions

Proposed Algorithm : MV-OSTM

t_lookup() method

- **t_lookup() rule:** T_i on invoking $Lu_i(k_1)$ lookups the value v inserted by a transaction T_j that commits before $Lu_i(k_1)$ and j is the largest timestamp $\leq i$.

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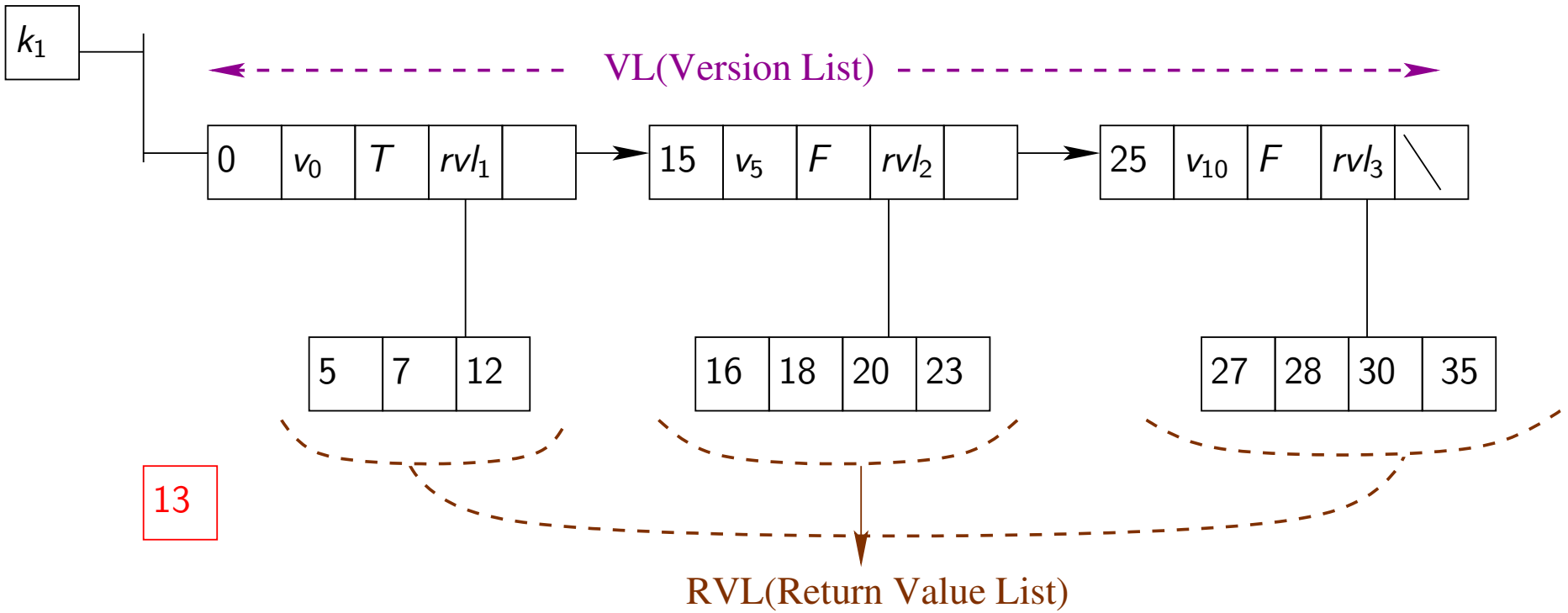

Figure: Lookup on key k_1 by T_{13}

Proposed Algorithm : MV-OSTM

t_lookup() method cont'd..

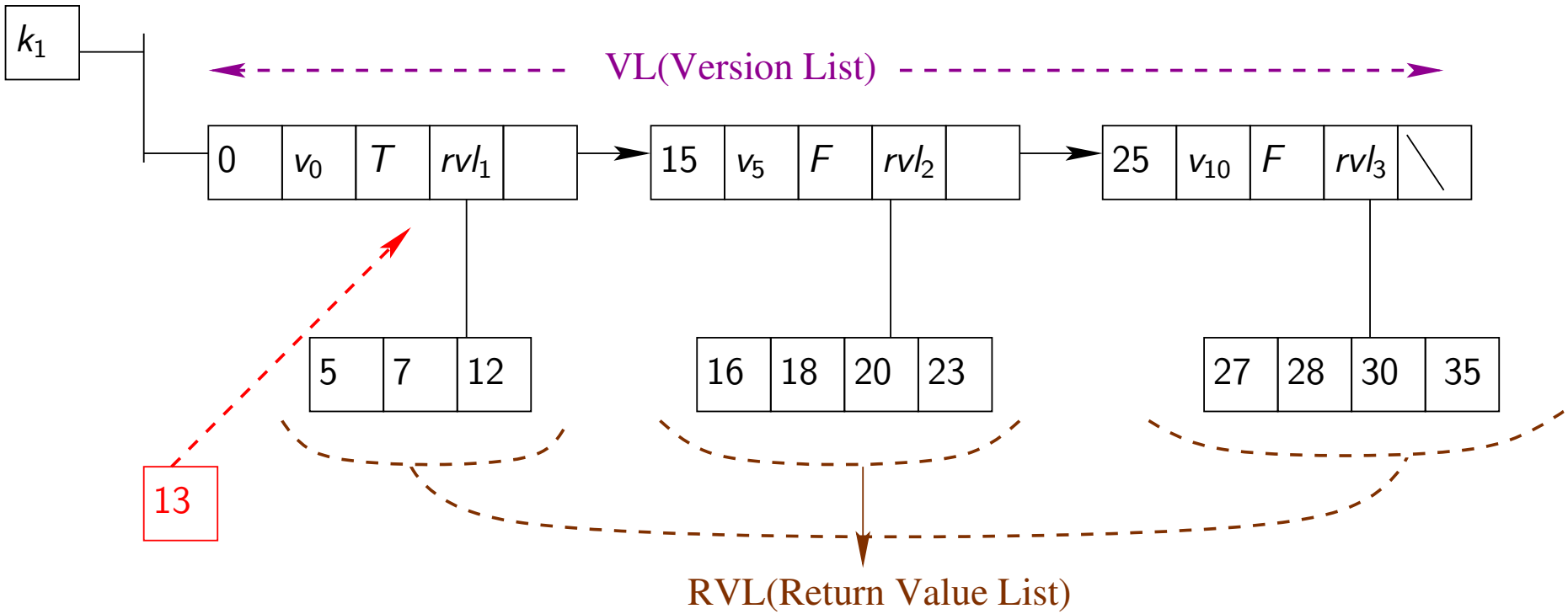

Figure: T_{13} searching appropriate place in version list of k_1

Proposed Algorithm : MV-OSTM

t_lookup() method cont'd..

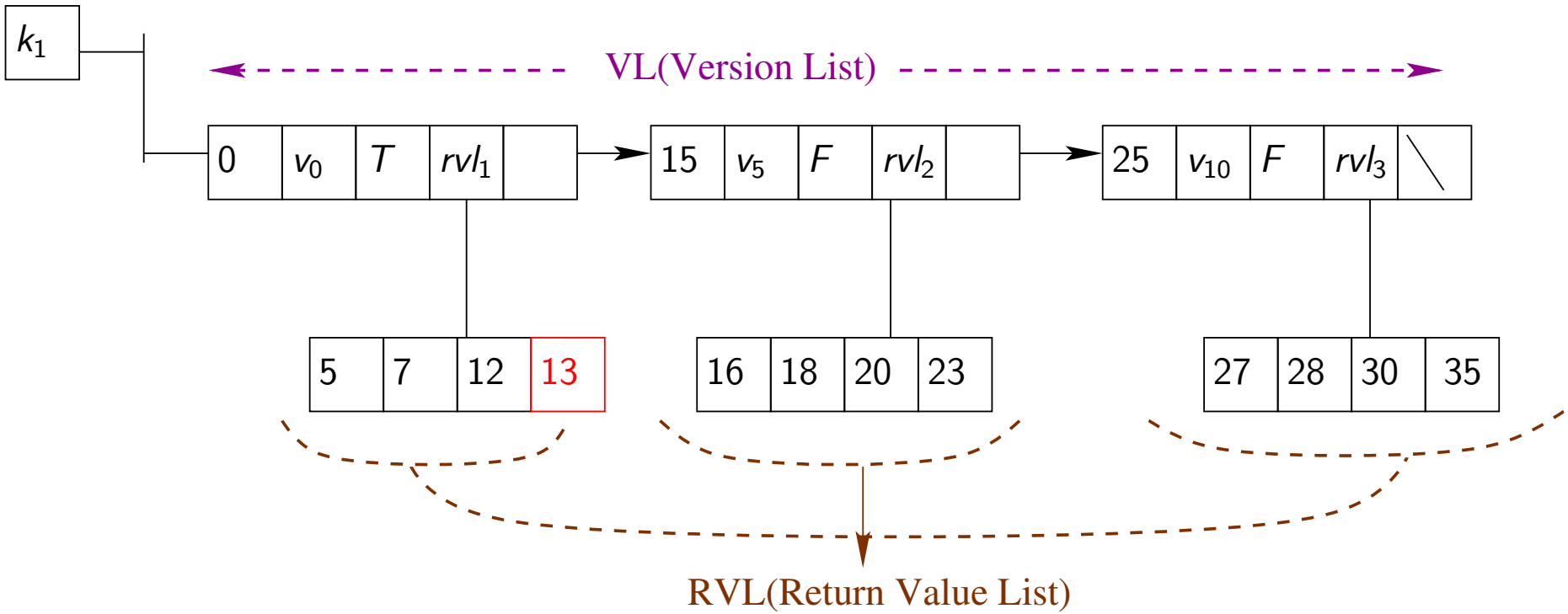

Figure: T_{13} successfully added into rvl_1

Proposed Algorithm : MV-OSTM

t_insert(), t_delete(), and tryC() methods

- **t_insert() and t_delete() rule:** T_i inserts and delete into local memory. The actual effect of both the methods will come in tryC().
- **tryC() rule:** T_i on invoking tryC() operation checks for each key k, in its Insert set and Delete set:
  1. If a transaction T_k has lookups k from T_j and k is committed with $j < i < k$, then $tryC_i()$ returns abort.
  2. otherwise, the transaction T_i is allowed to commit.

Proposed Algorithm : MV-OSTM

tryC() : t_insert() method

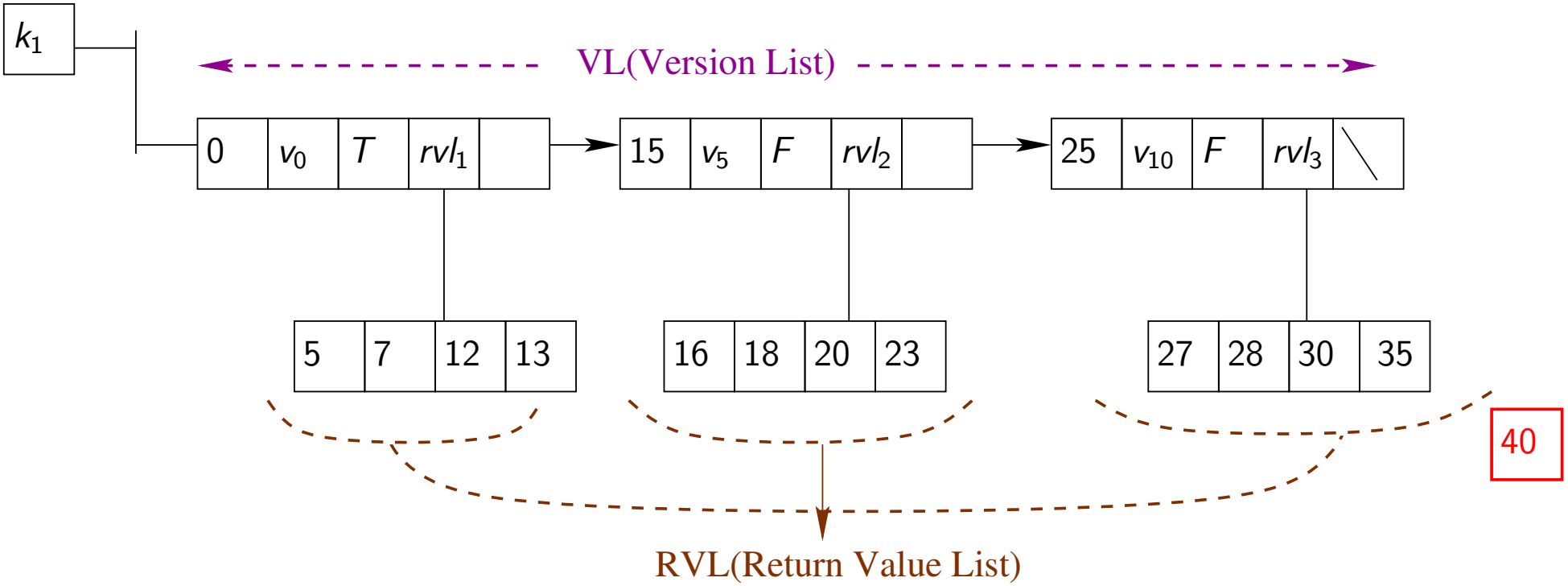

Figure: Insert a version of key k_1 by T_{40}

Proposed Algorithm : MV-OSTM

tryC() : t_insert() method cont'd..

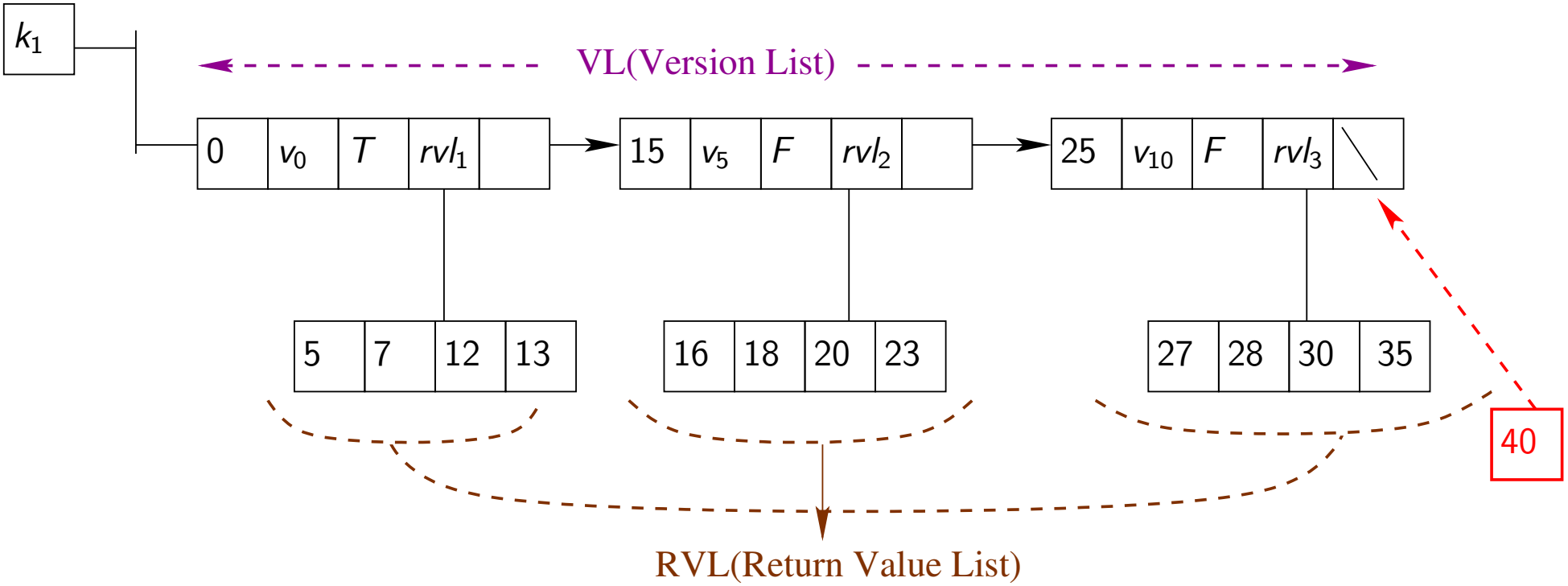

Figure: T_{40} searching appropriate place in version list of k_1

Proposed Algorithm : MV-OSTM

tryC() : t_insert() method cont'd..

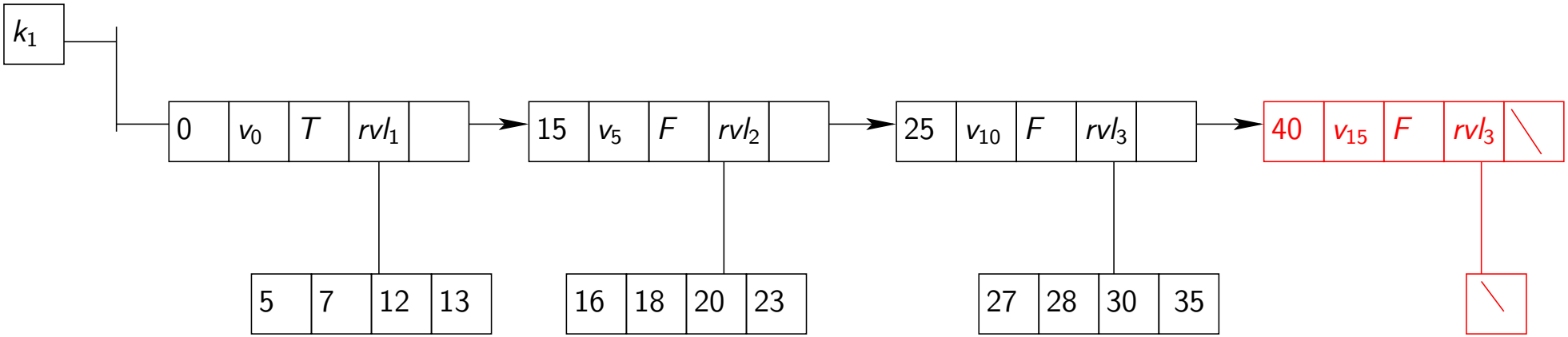

Figure: T_{40} successfully created a new version of k_1

Proposed Algorithm : MV-OSTM

tryC() : t_insert() method cont'd..

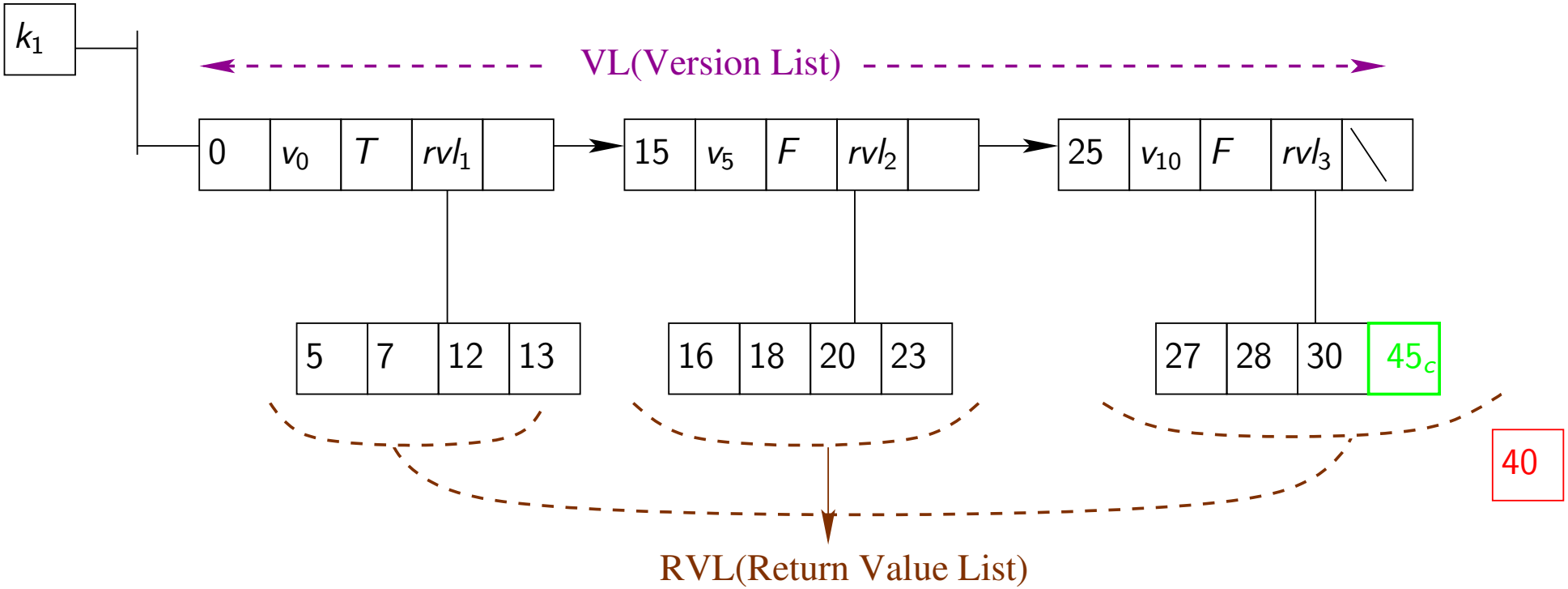

Figure: Insert a version of key k_1 by T_{40}

Proposed Algorithm : MV-OSTM

tryC() : t_insert() method cont'd..

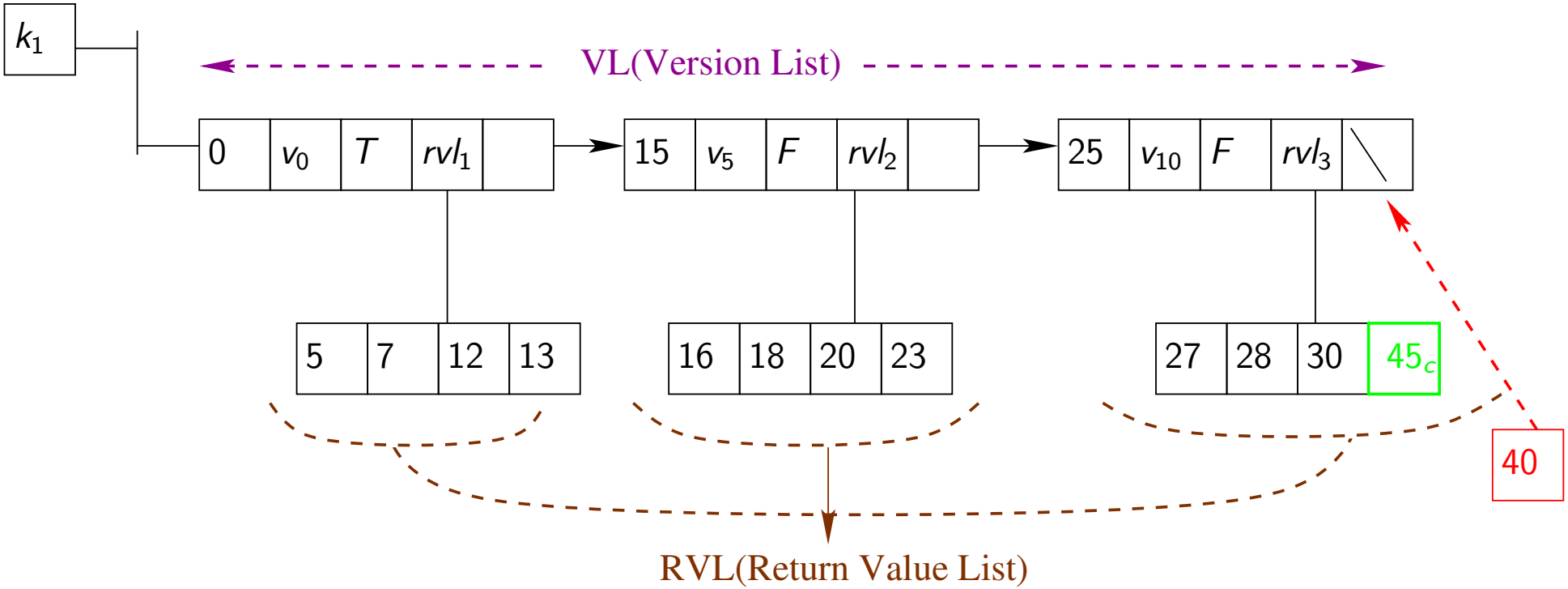

Figure: T_{40} searching appropriate place in version list of k_1

Proposed Algorithm : MV-OSTM

tryC() : t_insert() method cont'd..

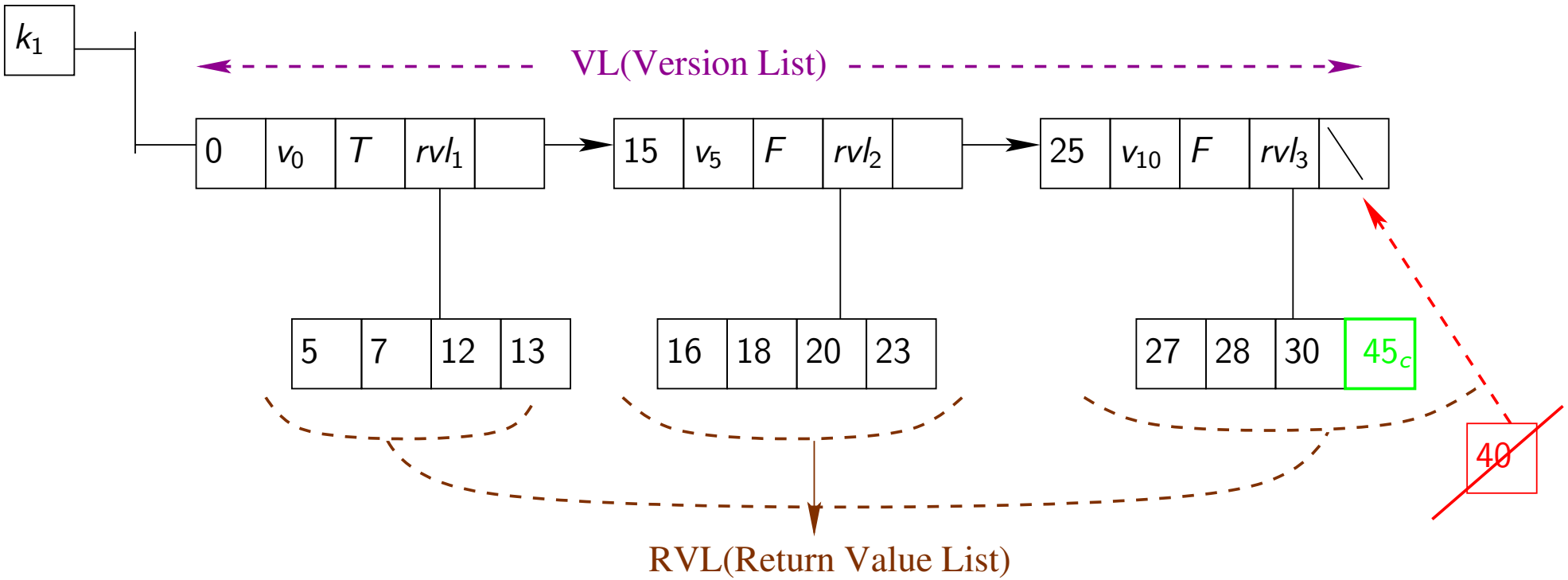

Figure: Abort T_{40} : T_{45} committed before T_{40}

Correctness of MV-OSTM [g]

Theorem (1)

Any history generated by HT-MVOSTM is opaque.

Theorem (2)

HT-MVOSTM with unbounded versions ensures that lookup methods do not return abort.

[g] Arxiv Link: https://arxiv.org/abs/1712.09803

Outline

Experimental Evaluation

Setup

- Intel(R) Xeon(R) CPU, 32 GB RAM, 56 Threads.
- We have compared proposed HT-MVOSTM with HT-OSTM / Elastic STM(ESTM)[a] / Read Write STM (RWSTM) / Multi-Version Time stamp ordering Protocol(HT-MVTO).
- We have compared proposed list-MVOSTM with list-OSTM / Boosted-list / NOrec-list[b] / Trans-list[c] / list-MVTO

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[a] Felber, P., Gramoli, V., Guerraoui, R.: Elastic Transactions. J. Parallel Distrib. Comput.100(C), 2017

[b] Dalessandro, L., Spear, M.F., Scott, M.L.: NOrec: Streamlining STM by Abolishing Own-ership Records. In Govindarajan, R., Padua, D.A., Hall, M.W., eds.: PPOPP'10

[c] Zhang, D., Dechev, D.: Lock-free Transactions Without Rollbacks for Linked Data Structures. SPAA'16

Experimental Evaluation Cont'd..

- Lookup Intensive Workload: lookup:90%, insert:8% & delete:2%
- Update Intensive Workload: lookup:10%, insert:45% & delete:45%

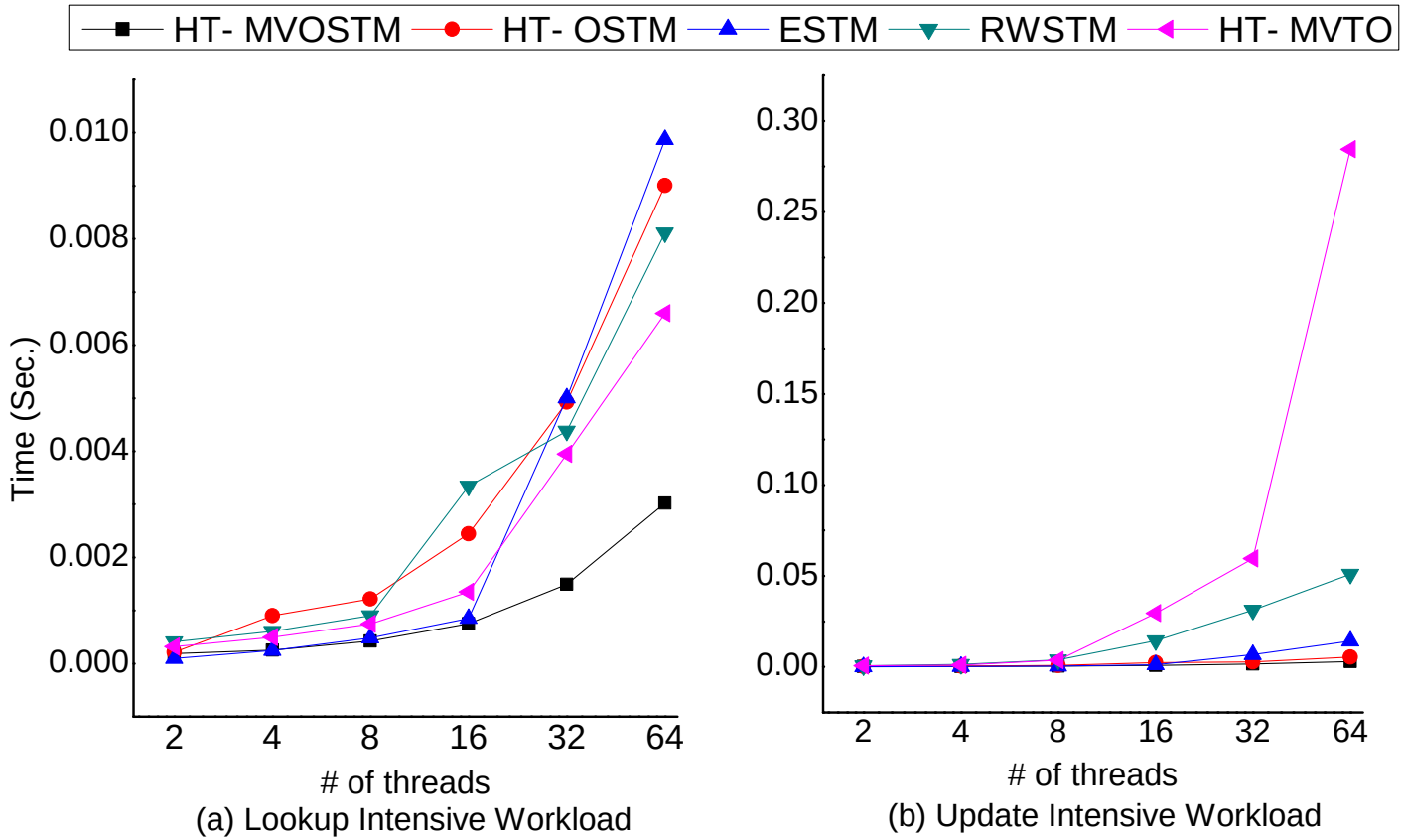

Figure: Performance of HT-MVOSTM

- Proposed HT-MVOSTM gives better performance while improving the concurrency.

Experimental Evaluation Cont'd..

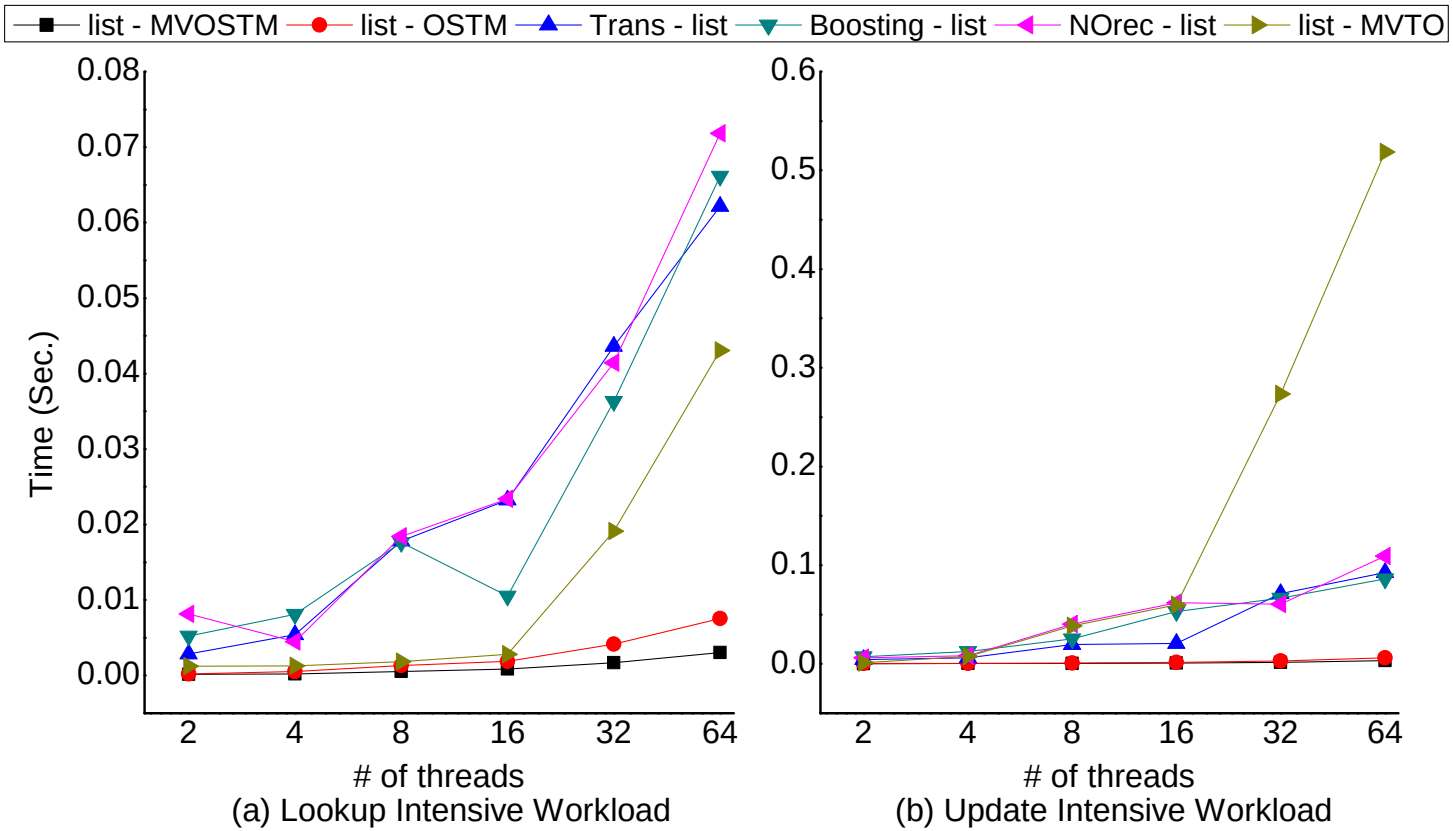

Figure: Performance of list-MVOSTM

- Proposed list-MVOSTM gives better performance while improving the concurrency.

Outline

Conclusion

- We have combined both multi-version and OSTM ideas carefully called as MV-OSTM, for harnessing greater concurrency in STMs.

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- HT-MVOSTM shows average speedup of 6.3, 11.2, 4.7, 2.7 times for state of the art HT-MVTO, RWSTM, ESTM & HT-OSTM respectively.

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- HT-MVOSTM shows average speedup of 6.3, 11.2, 4.7, 2.7 times for state of the art HT-MVTO, RWSTM, ESTM & HT-OSTM respectively.
- The average speedup achieved by list-MVOSTM from state of the art list-MVTO, NOrec-list, Boosting-list, Trans-list, list-OSTM are 91.5, 29.5, 23, 24, 2.1 respectively.

Outline

- MV-OSTM model can be extended to **Starvation-free multi-version OSTM (SF-MVOSTM)**.

[h] Ni, Yang and Menon, Vijay S. and Adl-Tabatabai, Ali-Reza and Hosking, Antony L. and Hudson, Richard L. and Moss, J. Eliot B. and Saha, Bratin and Shpeisman, Tatiana, Open Nesting in Software Transactional Memory, PPoPP '07

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- MV-OSTM can be enlarged to other data structures like Queue, Stack, Tree etc.

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- MV-OSTM can be enlarged to other data structures like Queue, Stack, Tree etc.
- An interesting aspect is exploring **Nesting**[h] for MV-OSTM in which one object-based transaction invokes other read-write transaction.

[h] Ni, Yang and Menon, Vijay S. and Adl-Tabatabai, Ali-Reza and Hosking, Antony L. and Hudson, Richard L. and Moss, J. Eliot B. and Saha, Bratin and Shpeisman, Tatiana, Open Nesting in Software Transactional Memory, PPoPP '07


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