Transparent Support for Partial Rollback in Software Transactional Memories

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Euro-Par 2013

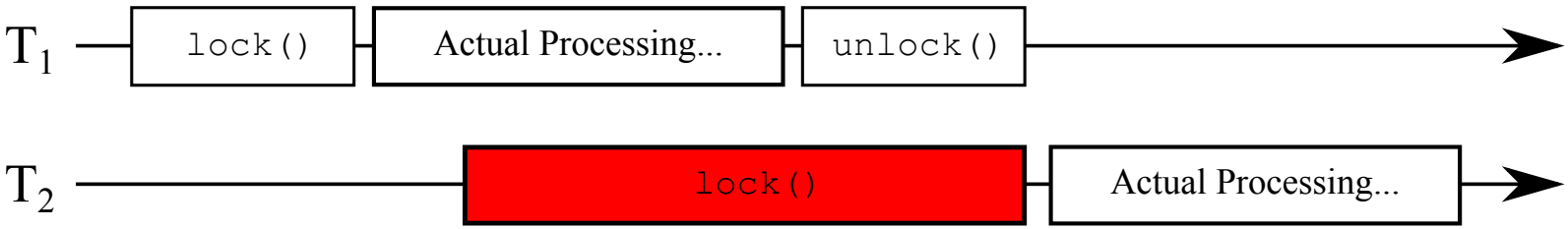
Research Context: Explicit Synchronization

- The most fundamental (and simple!) synchronization primitive is the lock

```
1 void transfer_money(int *bal1, int *bal2, int amount) {
2     lock(&global_lock);
3     if(*bal1 - amount > 0) {
4         *bal1 -= amount;
5         *bal2 += amount;
6     }
7     unlock(&global_lock);
8 }
```

Research Context: Explicit Synchronization (2)

- Locks can be forced to block until released! ☹



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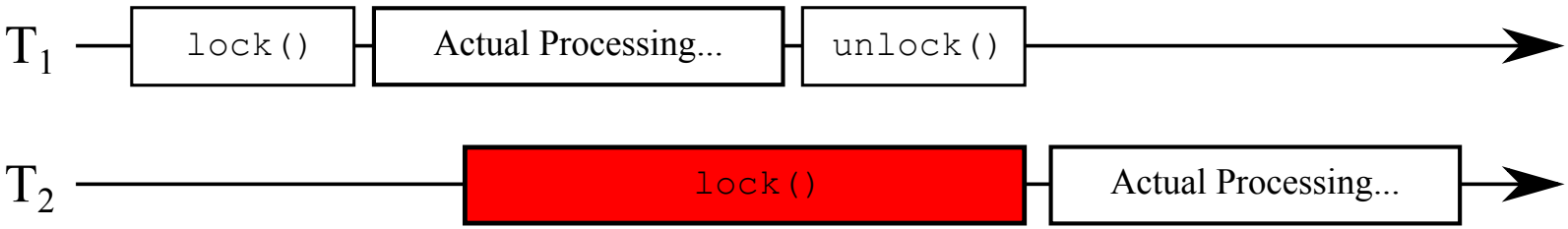


- It is very simple
- There is no *real* concurrency

Research Context: Fine Grain Locking

- Gives better perfomance
- Poor programmability and transparency
- Debugging is a nightmare

- Yet it still has problems
  - Deadlocks
  - Livelocks
  - Convoying
  - Priority Inversion
  - ...

```
1  void transfer_money(int *bal1,
       int *bal2, int amount) {
2
3      lock(&lock_bal1);
4      if(*bal1 - amount > 0) {
5          *bal1 -= amount;
6          unlock(&lock_bal1);
7
8          lock(&lock_bal2);
9          *bal2 += amount;
10         unlock(&lock_bal2);
11     } else {
12             unlock(&lock_bal1);
13     }
14 }
```

Research Context: Fine Grain Locking (2)

- Locks do not compose!

```
1  void deposit(int *bal, int amnt)
       {
2      lock(&lock_balance);
3      *bal += amnt;
4      unlock(&lock_balance);
5  }
6
7  void withdraw(int *bal, int amnt)
         {
8      lock(&lock_balance);
9      if(*bal - amnt > 0) {
10         *bal -= amnt;
11     }
12     unlock(&lock_balance);
13 }
```

```
1 void transfer(int *bal1, int *
      bal2, int amnt) {
2     withdraw(bal1, amnt);
3     deposit(bal2, amnt);
4 }
5
6 int sum(int *bal1, int *bal2)
      {
7     return *bal1 + *bal2;
8 }
```

Research Context: Software Transactional Memories

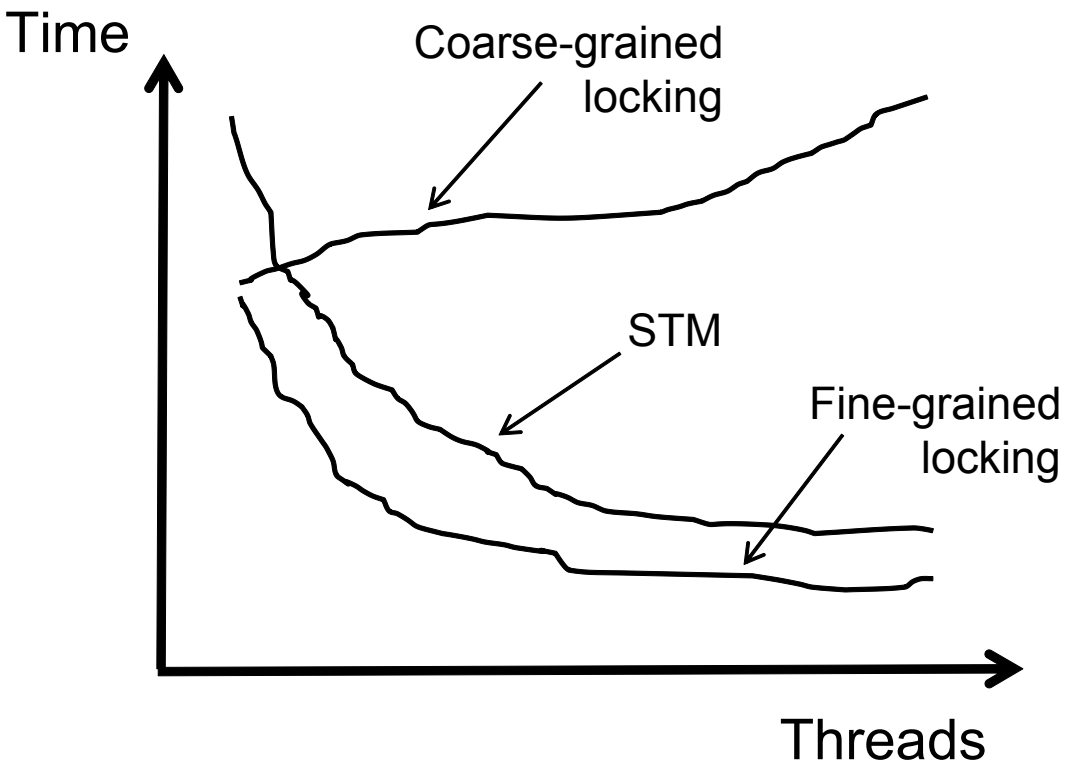
- Key idea:
  - Hide away synchronization issues from the programmer
  - Replace locks with atomic transactions

- Advantages:
  - Avoid deadlocks, priority inversions, convoying
  - Simpler to reason about, verify, compose
  - Provide synchronization transparency in concurrent applications
  - Synchronization code becomes less error-prone

```
1 void transfer(int *bal1, int *bal2, int amnt) {
2     atomic {
3         withdraw(bal1, amnt);
4         deposit(bal2, amnt);
5     }
6 }
```

Research Context: Software Transactional Memories

- Optimistic execution yields performance gains similar to fine grain locking at the simplicity of coarse grain locking



Partial Rollback: Motivations

- In Software Transactional Memories conflicts are handled via Conflict Detection and Management (CDMAN) algorithms
- Generally when a conflict arises some transaction is aborted
  - Thread's execution is rolled back
  - All the work carried out in the transaction is squashed

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- Generally when a conflict arises some transaction is aborted
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- Partial rollback could save a portion of this work
  - It can reduce the overall amount of work to be performed
  - Must be supported with minimal housekeeping overhead

Target CDMAN Algorithm: Commit-Time Locking

- Used in implementations such as TL2 or TinySTM
- Relies on a Global Version Clock (GVC)
  - A shared global counter
  - Atomically incremented by means of atomic CAS
  - Stored as Trastaction-Start Timestamp (TST) when a Tx begins
- Shared data are associated with
  - A lock bit
  - A timestamp

Target CDMAN Algorithm: Commit-Time Locking (2)

- On R/W operations the data's timestamp is compared to TST
- If it is greater, a conflict arises and the Tx is aborted

- At commit time all write locations' lock bits are locked and their timestamps are rechecked
- If no conflicts arise
  - New values are written back into shared objects
  - Their timestamps are updated
  - The GVC is incremented

Partial Rollback: Algorithm Sketch

1. When a read conflict arises, we sequentially extend the snapshot:
   - All previous reads are revalidated
   - The first invalid read is the execution restarting point

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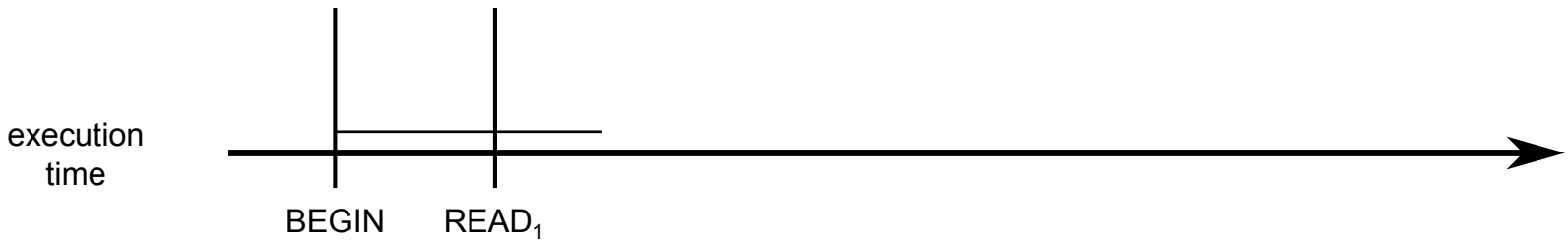

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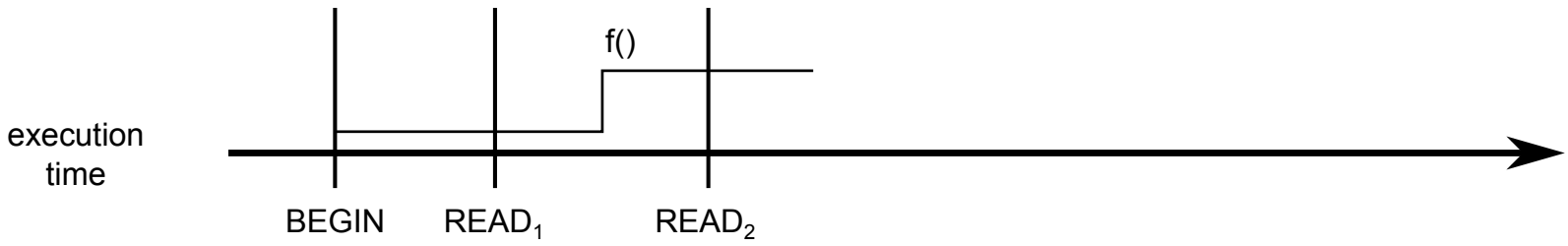

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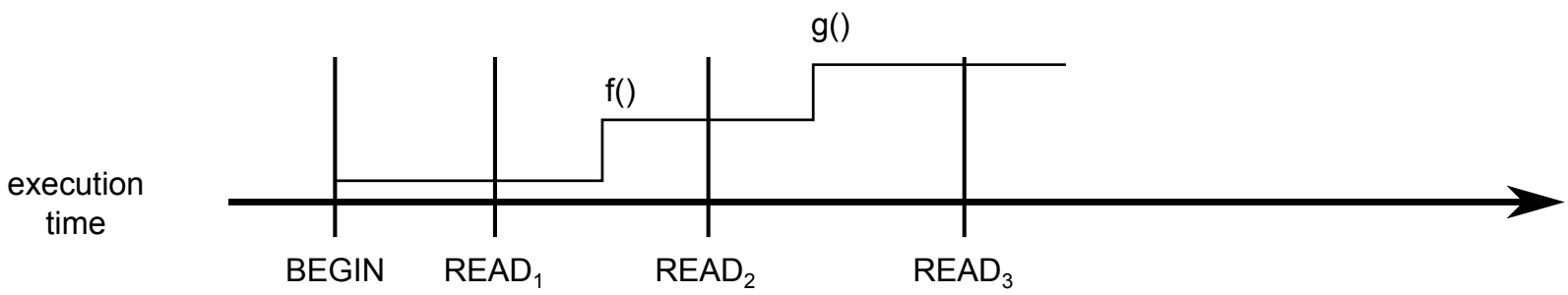

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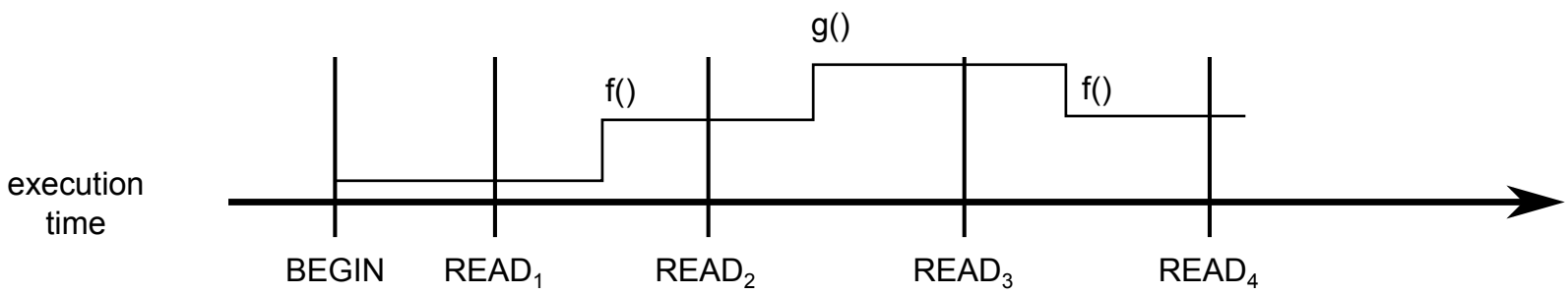

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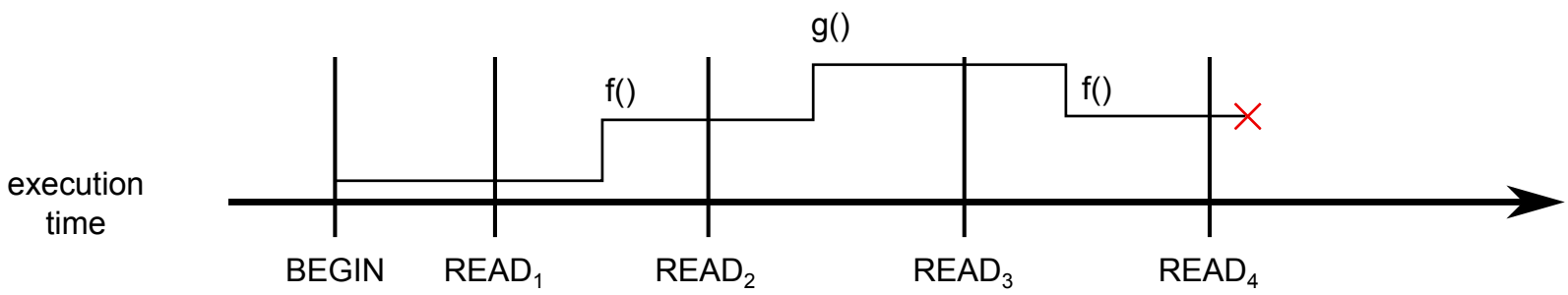

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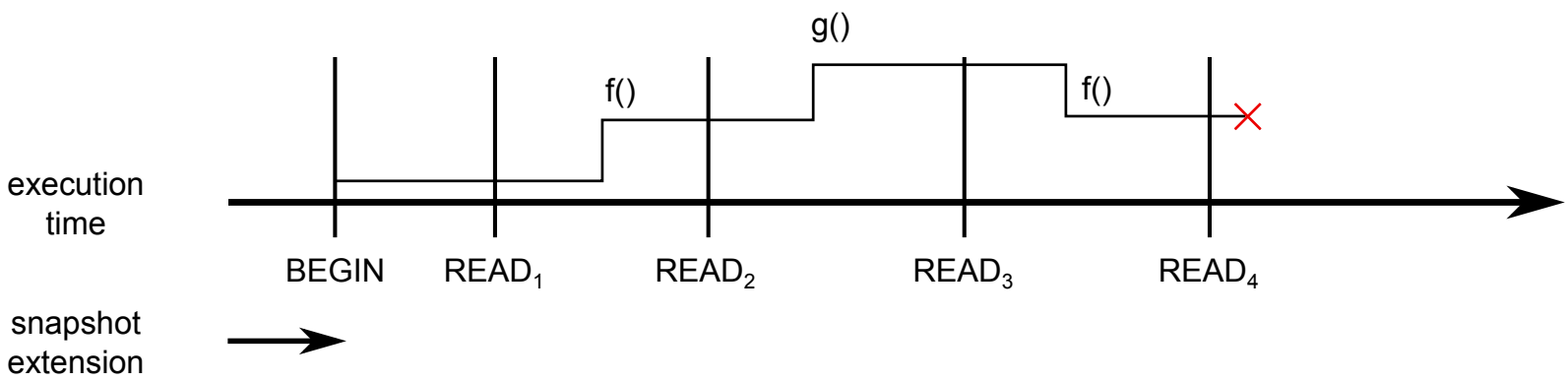

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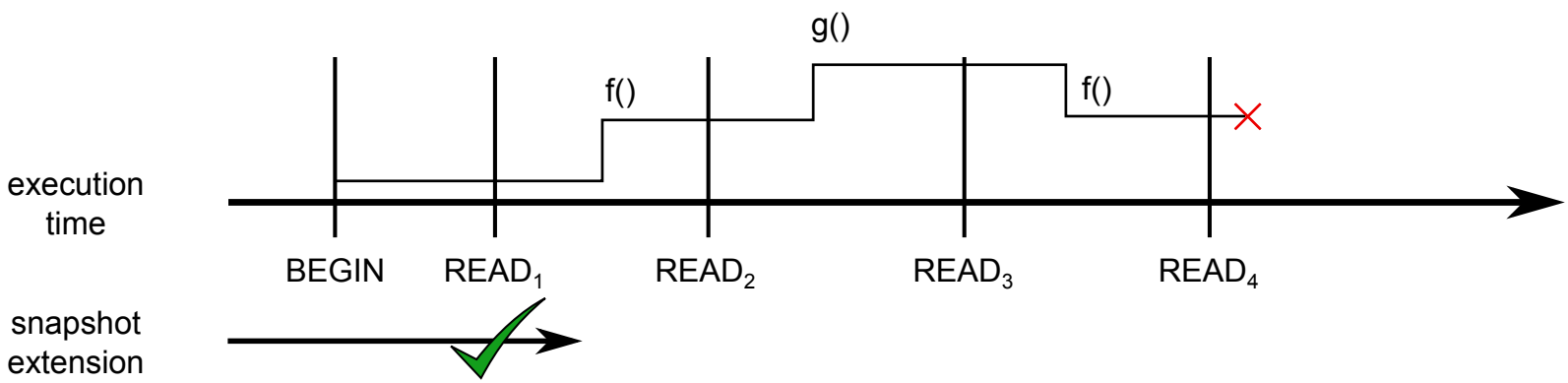

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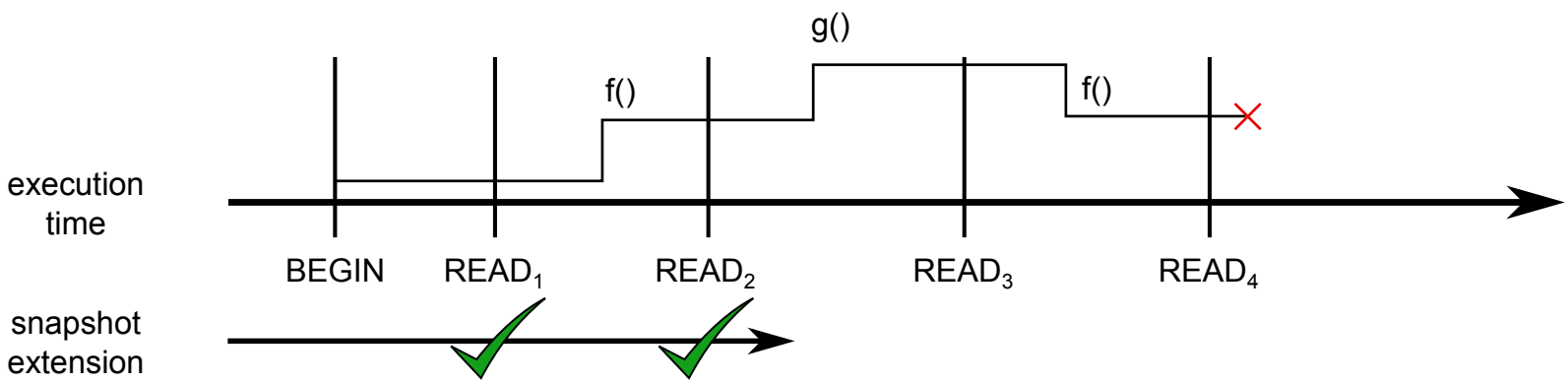

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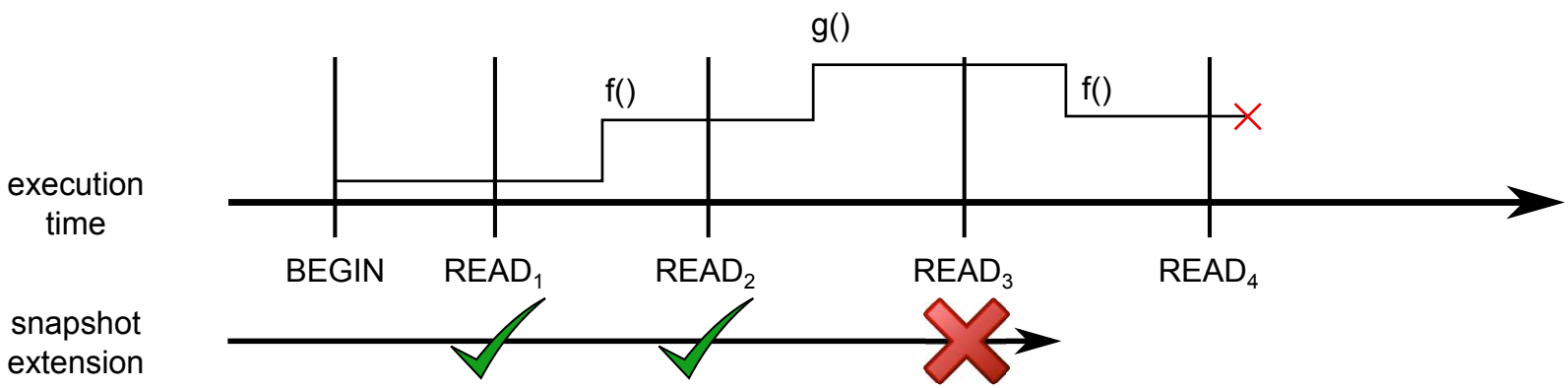

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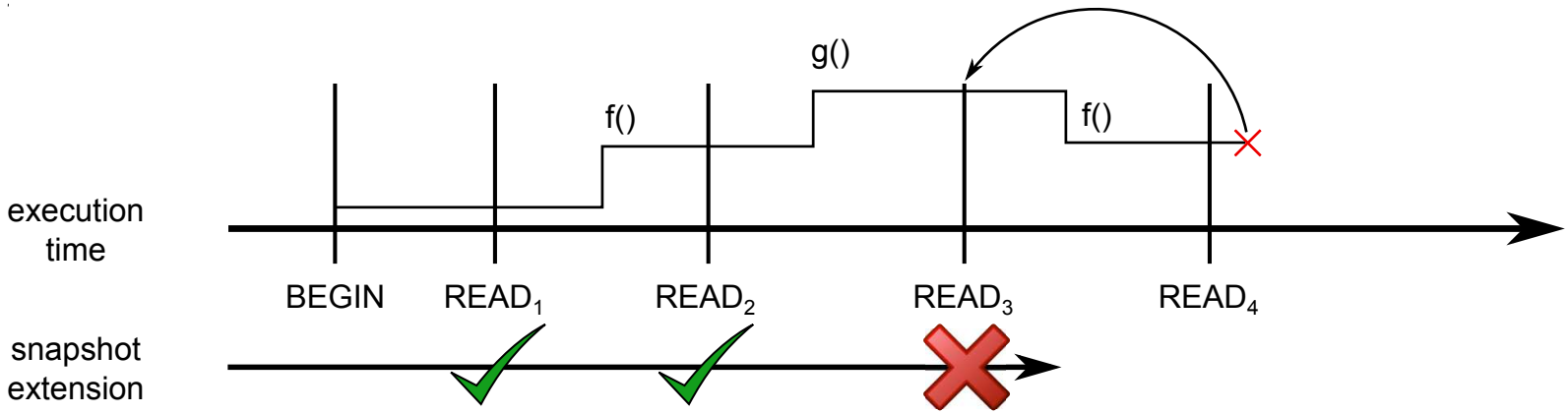

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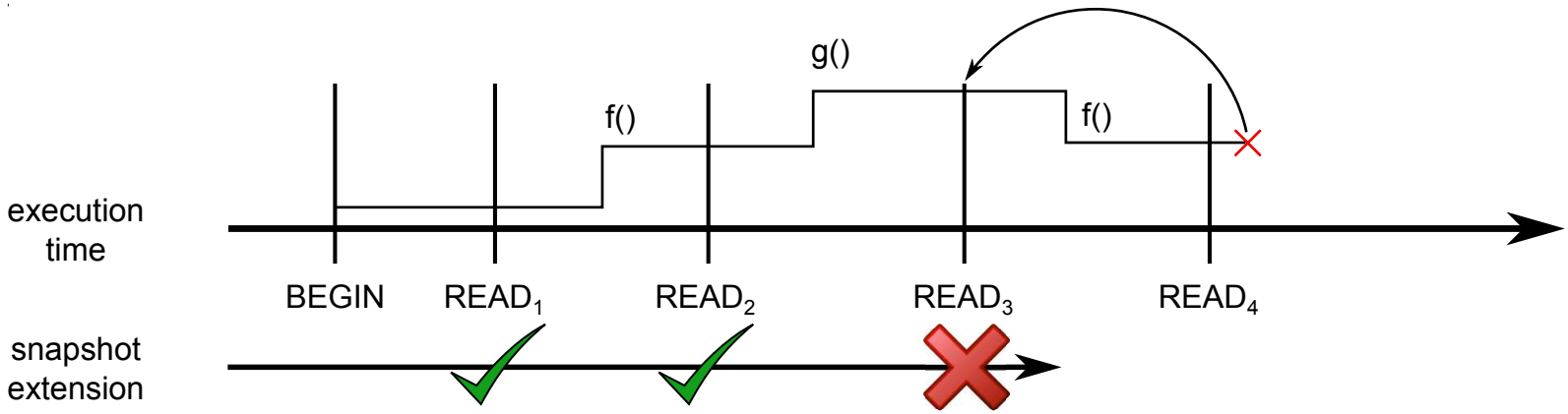

2. Coherency between read/write sets is ensured by determining causality relations

Partial Rollback: Algorithm Sketch

3. Thread-private data are transparently logged
   - This is necessary to reproduce the same execution path within the transaction

```
1  int i, j;
2
3  atomic {
4      for(i = 0; i < 10; i++) {
5          j = shared_read(&shared_object);
6          if(i == j) {
7              shared_write(&other_object, j);
8          }
9      }
10 }
```

Partial Rollback: Algorithm Sketch

3. Thread-private data are transparently logged
   - This is necessary to reproduce the same execution path within the transaction

```
1  void f(int *j) {
2    int i;
3
4    atomic {
5        for(i = 0; i < 10; i++) {
6            *j = shared_read(&shared_object);
7            if(i == *j) {
8                shared_write(&other_object, *j);
9            }
10       }
11   }
12 }
```

Partial Rollback: Algorithm Sketch

3. Thread-private data are transparently logged
   - The application-level code is instrumented by relying on Hijacker, an assembly-level code manipulator, targeting x86/x86_64 assembly code
     - `mov` instruction are identified at compile time
     - a lightweight assembly module is inserted before them
     - it fastly computes the target address of the memory update operation

Partial Rollback: Algorithm Sketch

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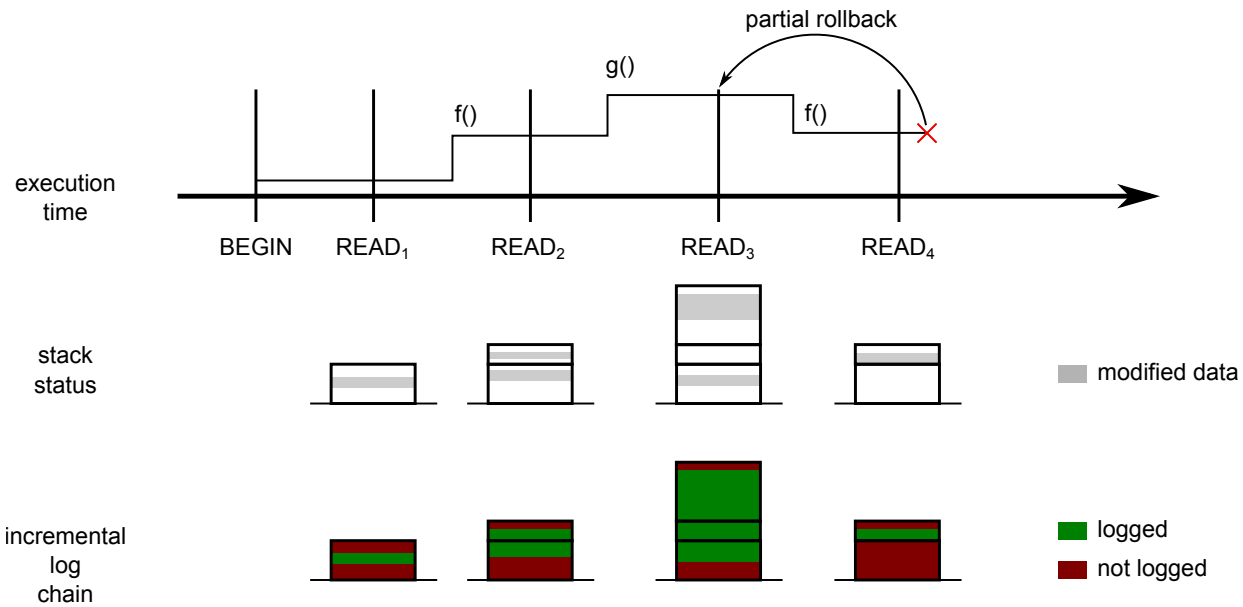
   - The application-level code is instrumented by relying on Hijacker, an assembly-level code manipulator, targeting x86/x86_64 assembly code
     - `mov` instruction are identified at compile time
     - a lightweight assembly module is inserted before them
     - it fastly computes the target address of the memory update operation
   - When a Tx begins, a stack-update interval is defined $I = [sp, sp]$
   - The computed destination/size of `mov` instructions is used to update the boundaries of I
   - Before a transactional read, Hijacker inserts code to log the stack-update interval and CPU state
   - After the stack-update interval is logged, we again set $I = [sp, sp]$

Partial Rollback: Algorithm Sketch

4. Upon a partial rollback, the CPU state and stack state are put back in place
   - CPU states are managed via System V `getcontext()`/`setcontext()`
   - A stack restore is performed incrementally
   - The stack log chain is backward traversed
   - Already-updated portions are no longer updated



Advantages of the approach

- We enforce full transparency: no modification to the application code is required
- Update-stack regions are contiguous: efficient logs via optimized `movs` instructions
- Pointer variables are trivially handled
- Compilers can optimize out stack frames without affecting correctness

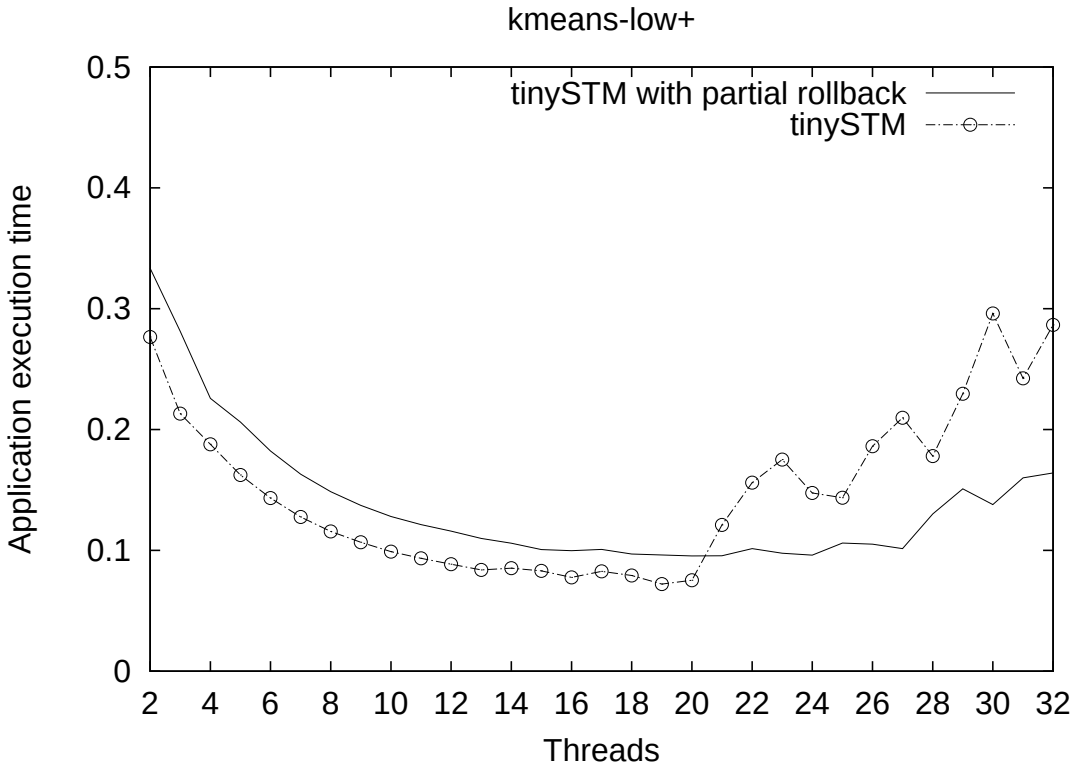
Experimental Results

- Implementation within TinySTM
- Reference benchmark: STAMP STM suite
  - ssca2
  - kmeans
- No bias towards conflicting in early phase of Txs
- We vary the amount of data on which they operate

- 32-core HP ProLiant server, NUMA architecture
- 64 Gb RAM
- Linux Kernel 2.6.32-5-amd64 – Debian 6

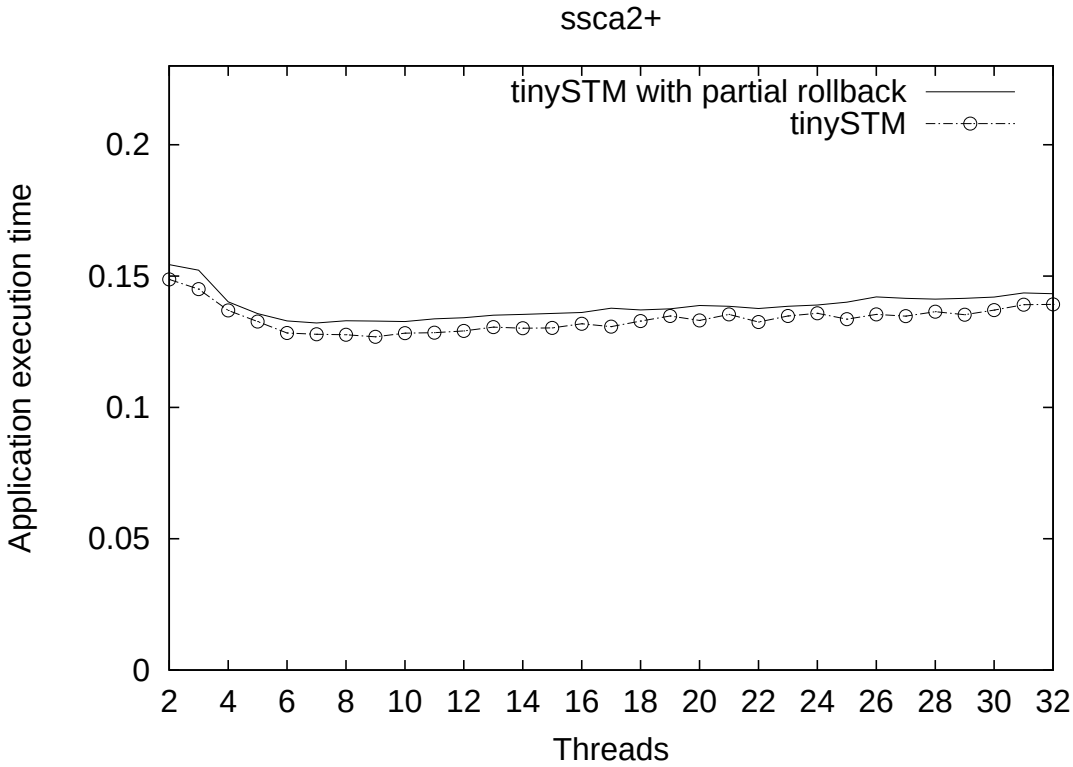
Experimental Results

- Medium transactional computation, small data set: *high contention*
- Execution time reduced by 40%



Experimental Results

- Small transactional computation, medium data set: *low contention*
- Limited overhead, $\leq 7\%$



Thanks for your attention

Questions?

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