Consistency
Transactions
Transactional Memory

Chris Rossbach

cs378h

Picking up where we left off…

- Questions?
- Agenda
  - Transactions
  - Parallel Architectures

Two-phase commit

- N participants agree or don’t (atomicity)
- Phase 1: everyone “prepares”
- Phase 2: Master decides and tells everyone to actually commit
- What if the master crashes in the middle?

2PC: Phase 1

1. Coordinator sends REQUEST to all participants
2. Participants receive request and
3. Execute locally
4. Write VOTE_COMMIT or VOTE_ABORT to local log
5. Send VOTE_COMMIT or VOTE_ABORT to coordinator

Example—move: C→S1: delete foo from /, C→S2: add foo to /

Failure case:
S1 writes rm /foo, VOTE_COMMIT to log
S1 sends VOTE_COMMIT
S2 decides permission problem
S2 writes/sends VOTE_ABORT

Success case:
S1 writes rm /foo, VOTE_COMMIT to log
S1 sends VOTE_COMMIT
S2 writes add foo to /
S2 writes/sends VOTE_COMMIT

2PC: Phase 2

- Case 1: receive VOTE_ABORT or timeout
  - Write GLOBAL_ABORT to log
  - send GLOBAL_ABORT to participants
- Case 2: receive VOTE_COMMIT from all
  - Write GLOBAL_COMMIT to log
  - send GLOBAL_COMMIT to participants
- Participants receive decision, write GLOBAL_* to log

2PC corner cases

Phase 1

1. Coordinator sends REQUEST to all participants
2. X Participants receive request and
3. Execute locally
4. Write VOTE_COMMIT or VOTE_ABORT to local log
5. Send VOTE_COMMIT or VOTE_ABORT to coordinator

Phase 2

- Y Case 1: receive VOTE_ABORT or timeout
  - Write GLOBAL_ABORT to log
  - send GLOBAL_ABORT to participants
- Case 2: receive VOTE_COMMIT from all
  - W Write GLOBAL_COMMIT to log
  - send GLOBAL_COMMIT to participants
- Z Participants recv decision, write GLOBAL_* to log

- What if participant crashes at X?
- Coordinator crashes at Y?
- Participant crashes at Z?
- Coordinator crashes at W?

2PC limitation(s)

2PC limitation(s)

- Coordinator crashes at W, never wakes up

2PC limitation(s)

- Coordinator crashes at W, never wakes up
- All nodes block forever!

2PC limitation(s)

- Coordinator crashes at W, never wakes up
- All nodes block forever!
- Can participants ask each other what happened?

2PC limitation(s)

- Coordinator crashes at W, never wakes up
- All nodes block forever!
- Can participants ask each other what happened?
- 2PC: always has risk of indefinite blocking

2PC limitation(s)

- Coordinator crashes at W, never wakes up
- All nodes block forever!
- Can participants ask each other what happened?
- 2PC: always has risk of indefinite blocking
- Solution: (yes) 3 phase commit!
  - Reliable replacement of crashed “leader”
  - 2PC often good enough in practice

Nested Transactions

Nested Transactions

- Composition of transactions
  - E.g. interact with multiple organizations, each supporting txns
  - Travel agency: canonical example

Nested Transactions

- Composition of transactions
  - E.g. interact with multiple organizations, each supporting txns
  - Travel agency: canonical example
- Nesting: view transaction as collection of:
  - actions on unprotected objects
  - protected actions that my be undone or redone
  - real actions that may be deferred but not undone
  - nested transactions that may be undone

Nested Transactions

3 basic flavors:
* **Flat:** subsume inner transactions
* **Closed:** subsume w partial rollback
* **Open:** pause transactional context

- Composition of transactions
  - E.g. interact with multiple organizations, each supporting txns
  - Travel agency: canonical example
- Nesting: view transaction as collection of:
  - actions on unprotected objects
  - protected actions that my be undone or redone
  - real actions that may be deferred but not undone
  - nested transactions that may be undone

Nested Transactions

3 basic flavors:
* **Flat:** subsume inner transactions
* **Closed:** subsume w partial rollback
* **Open:** pause transactional context

- Composition of transactions
  - E.g. interact with multiple organizations, each supporting txns
  - Travel agency: canonical example
- Nesting: view transaction as collection of:
  - actions on unprotected objects
  - protected actions that my be undone or redone
  - real actions that may be deferred but not undone
  - nested transactions that may be undone
- Open Nesting details:
  - Nested transaction returns name and parameters of compensating transaction
  - Parent includes compensating transaction in log of parent transaction
  - Invoke compensating transactions from log if parent transaction aborted
  - Consistent, atomic, durable, but not isolated

Transactional Memory: ACI

Transactional Memory :

- Make multiple memory accesses atomic
- All or nothing – Atomicity
- No interference – Isolation
- Correctness – Consistency
- No durability, for obvious reasons

- Keywords : Commit, Abort, Speculative access,
  Checkpoint

Transactional Memory: ACI

Transactional Memory :

- Make multiple memory accesses atomic
- All or nothing – Atomicity
- No interference – Isolation
- Correctness – Consistency
- No durability, for obvious reasons

- Keywords : Commit, Abort, Speculative access,
  Checkpoint

```
remove(list, x) {
  lock(list);
  pos = find(list, x);
  if(pos)
     erase(list, pos);
  unlock(list);
}
```

Transactional Memory: ACI

Transactional Memory :

- Make multiple memory accesses atomic
- All or nothing – Atomicity
- No interference – Isolation
- Correctness – Consistency
- No durability, for obvious reasons

- Keywords : Commit, Abort, Speculative access,
  Checkpoint

```
remove(list, x) {
  lock(list);
  pos = find(list, x);
  if(pos)
     erase(list, pos);
  unlock(list);
}
```

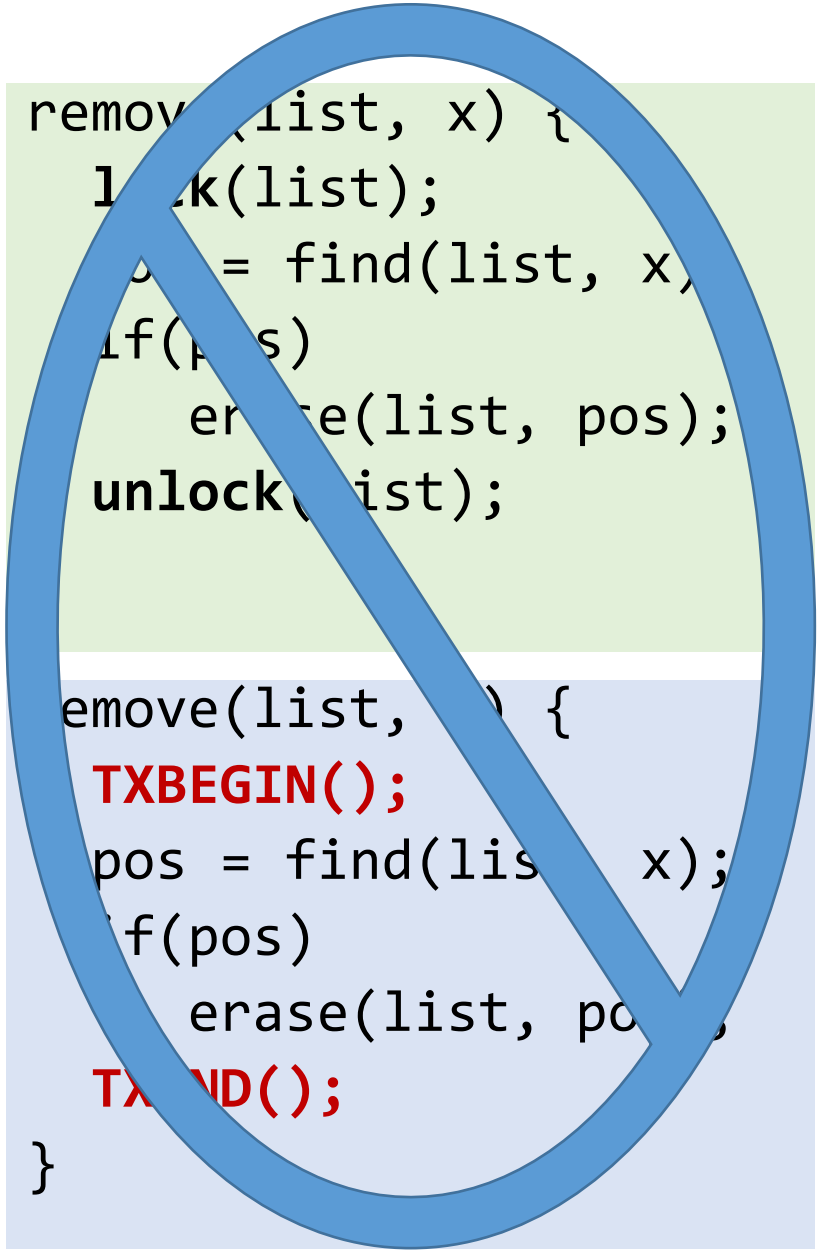
```
remove(list, x) {
  TXBEGIN();
  pos = find(list, x);
  if(pos)
     erase(list, pos);
  TXEND();
}
```

The **Real** Goal

```
remove(list, x) {
  lock(list);
  pos = find(list, x);
  if(pos)
     erase(list, pos);
  unlock(list);
}
```

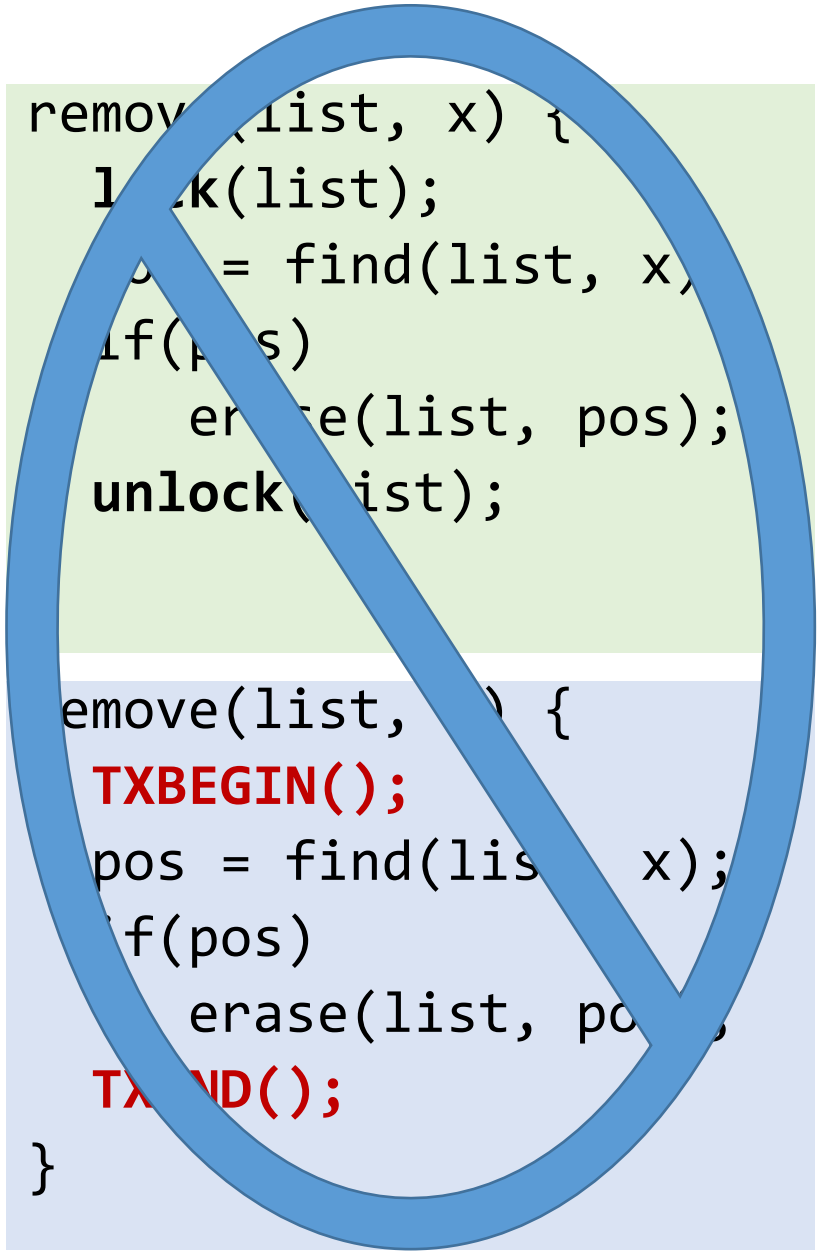
```
remove(list, x) {
  TXBEGIN();
  pos = find(list, x);
  if(pos)
     erase(list, pos);
  TXEND();
}
```

The **Real** Goal



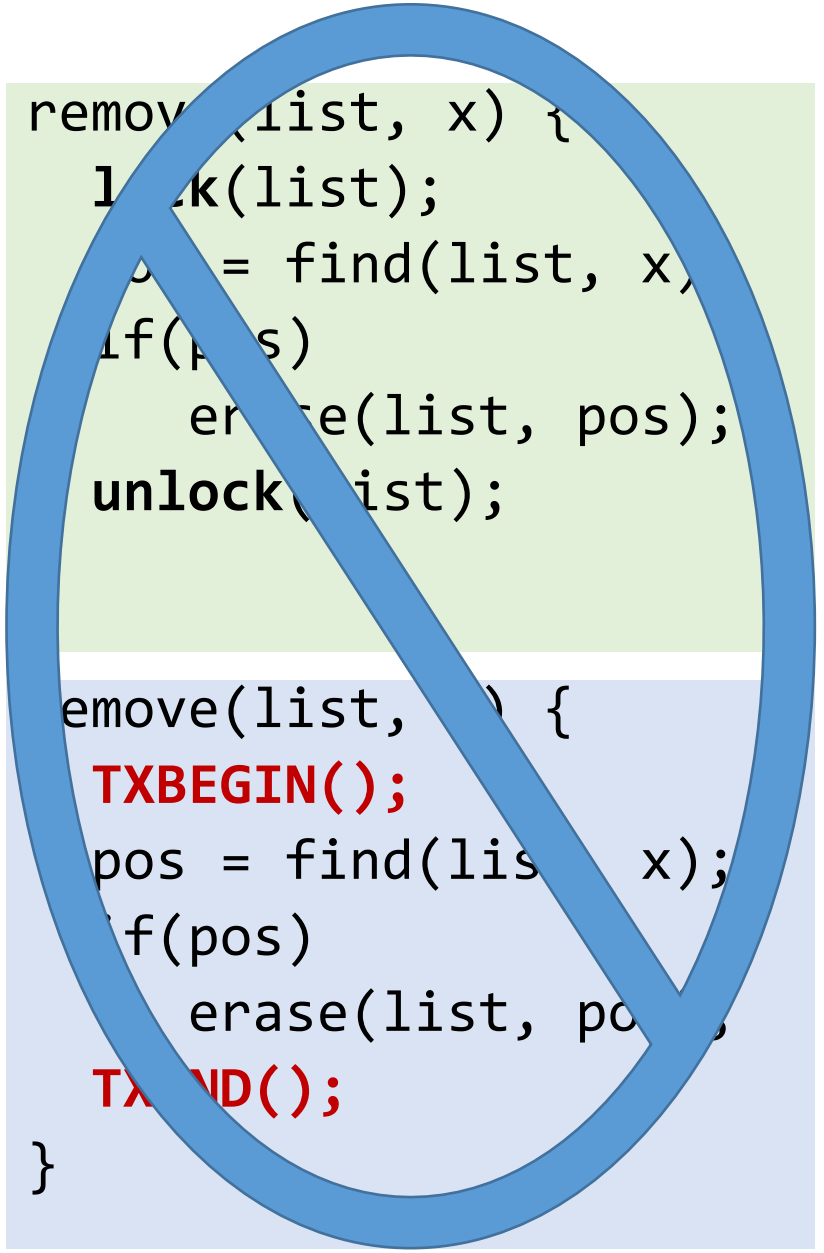
The **Real** Goal

```
remove(list, x) {
  atomic {
    pos = find(list, x);
    if(pos)
      erase(list, pos);
  }
}
```



The **Real** Goal

```
remove(list, x) {
  atomic {
    pos = find(list, x);
    if(pos)
      erase(list, pos);
  }
}
```



- Transactions: super-awesome
- Transactional Memory: also super-awesome, ***but***:
- Transactions != TM
- TM is an ***implementation technique***
- Often presented as programmer abstraction
- Remember Optimistic Concurrency Control

A Simple TM

```
pthread_mutex_t g_global_lock;

begin_tx() {
    pthread_mutex_lock(g_global_lock);
}

end_tx() {
    pthread_mutex_unlock(g_global_lock);
}

abort() {
    // can't happen
}
```

A Simple TM

```
remove(list, x) {
  begin_tx();
  pos = find(list, x);
  if(pos)
     erase(list, pos);
  end_tx();
}
```

```
pthread_mutex_t g_global_lock;

begin_tx() {
    pthread_mutex_lock(g_global_lock);
}

end_tx() {
    pthread_mutex_unlock(g_global_lock);
}

abort() {
    // can't happen
}
```

A Simple TM

```
remove(list, x) {
  begin_tx();
  pos = find(list, x);
  if(pos)
     erase(list, pos);
  end_tx();
}
```

```
pthread_mutex_t g_global_lock;

begin_tx() {
    pthread_mutex_lock(g_global_lock);
}

end_tx() {
    pthread_mutex_unlock(g_global_lock);
}

abort() {
    // can't happen
}
```

Actually, this works fine… But how can we improve it?

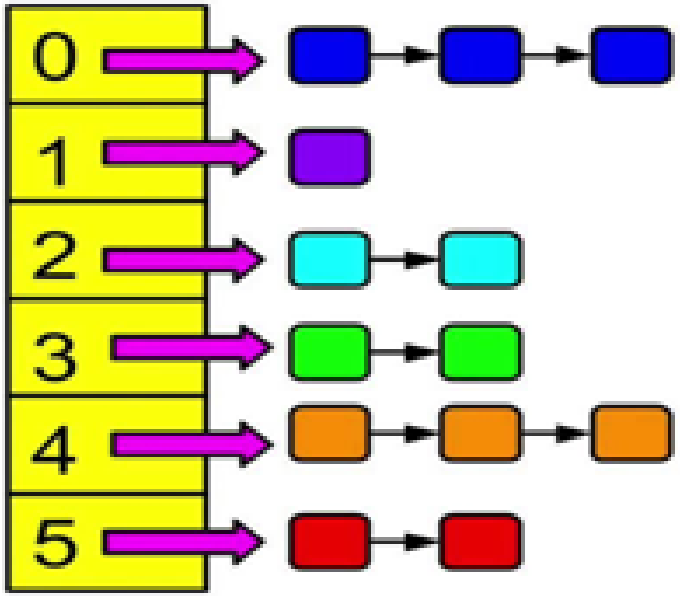
Concurrency Control Revisited

Concurrency Control Revisited

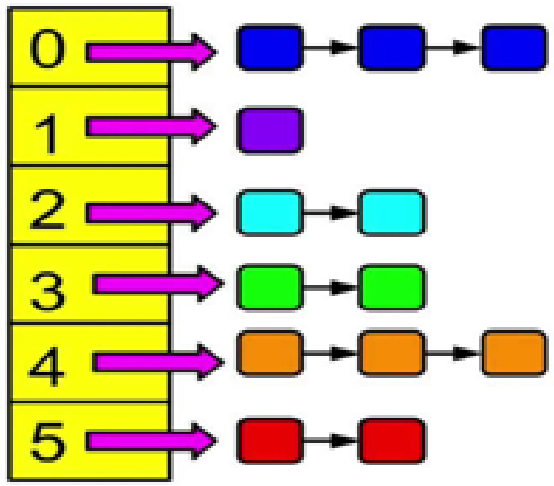
Consider a hash-table

Concurrency Control Revisited

Consider a hash-table

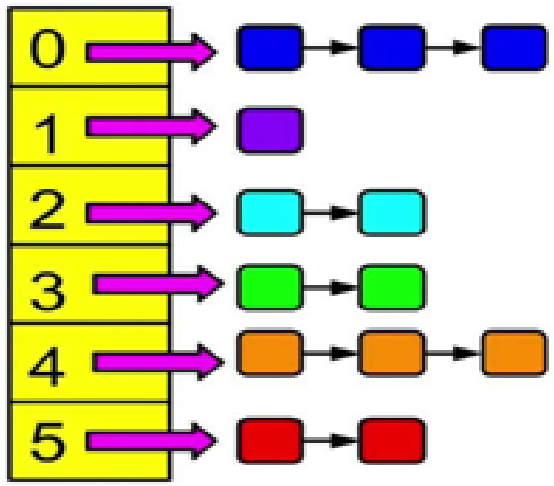


Concurrency Control Revisited



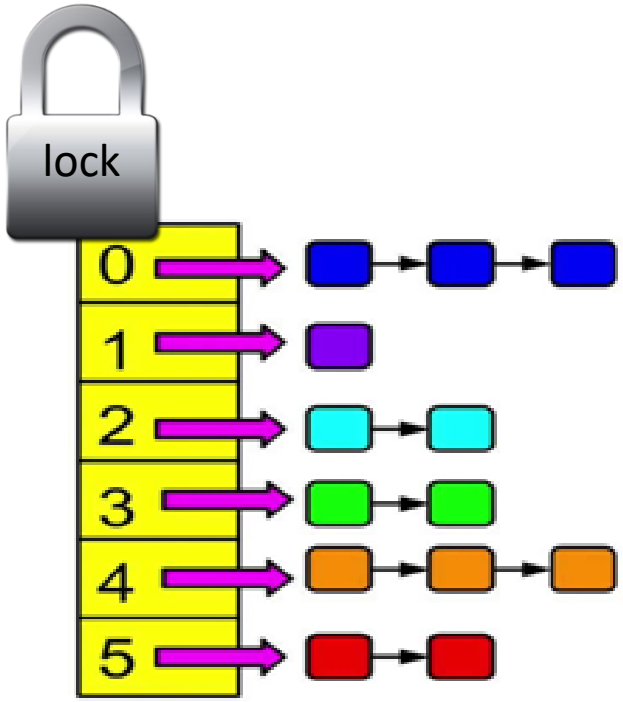
thread T1	thread T2
ht.add( );	ht.add( );
if(ht.contains( ))	if(ht.contains( ))
ht.del( );	ht.del( );

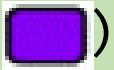
Concurrency Control Revisited



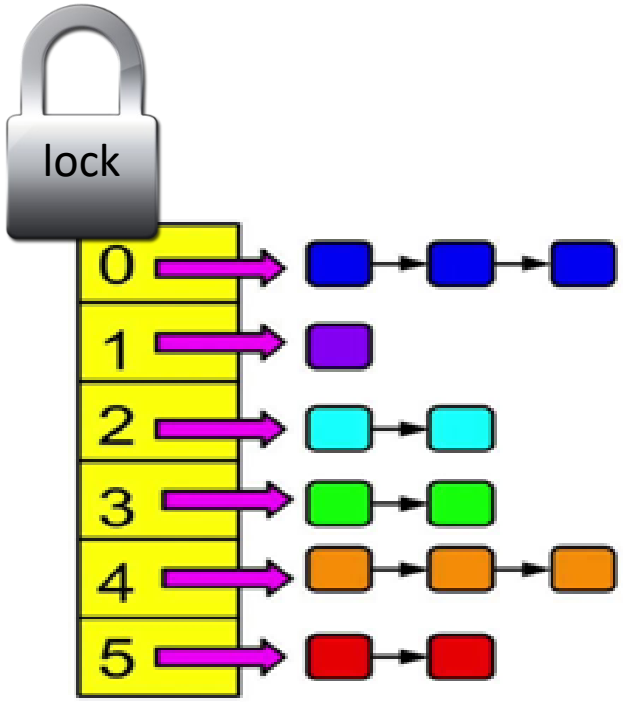
thread T1	thread T2
ht.add( );	ht.add( );
if(ht.contains( ))	if(ht.contains( ))
ht.del( ); ✗	ht.del( );

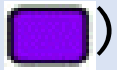
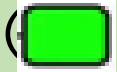
Concurrency Control Revisited



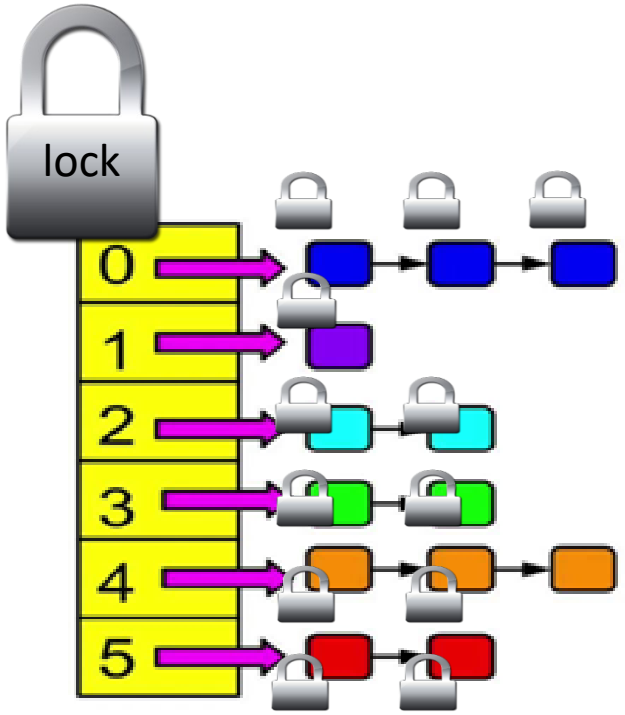
thread T1	thread T2
`ht.lock()`	`ht.lock();`
`ht.add(`  `);`	`ht.add(`  `);`
`if(ht.contains(`  `))`	`if(ht.contains(`  `))`
`ht.del(`  `);`	`ht.del(`  `);`
`ht.unlock();`	`ht.unlock();`

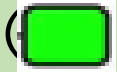
Pessimistic concurrency control



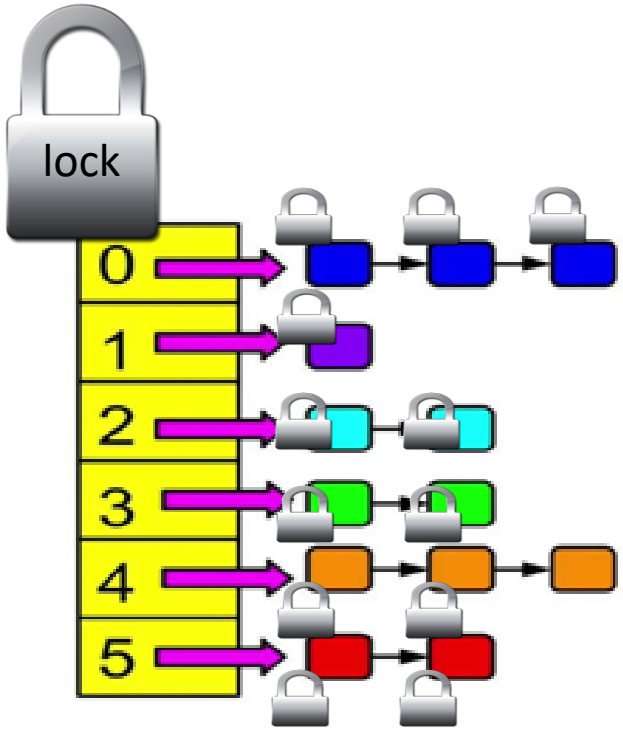
thread T1	thread T2
`ht.lock();`	`ht.lock();`
`ht.add(`  `);`	`ht.add(`  `);`
`if(ht.contains(`  `))`	`if(ht.contains(`  `))`
`ht.del(`  `);`	`ht.del(`  `);`
`ht.unlock();`	`ht.unlock();`

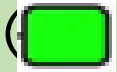
Pessimistic concurrency control



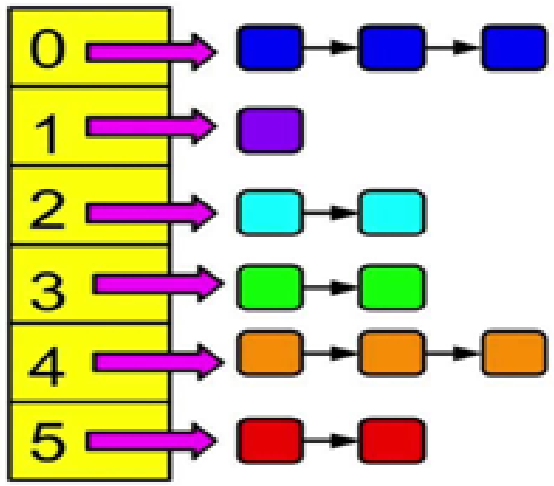
thread T1	thread T2
`ht.lock();`	`ht.lock();`
`ht.add(`  `);`	`ht.add(`  `);`
`if(ht.contains(`  `))`	`if(ht.contains(`  `))`
`ht.del(`  `);`	`ht.del(`  `);`
`ht.unlock();`	`ht.unlock();`

Optimistic concurrency control



thread T1	thread T2
`ht.lock();`	`ht.lock();`
`ht.add(`  `);`	`ht.add(`  `);`
`if(ht.contains(`  `))`	`if(ht.contains(`  `))`
`ht.del(`  `);`	`ht.del(`  `);`
`ht.unlock();`	`ht.unlock();`

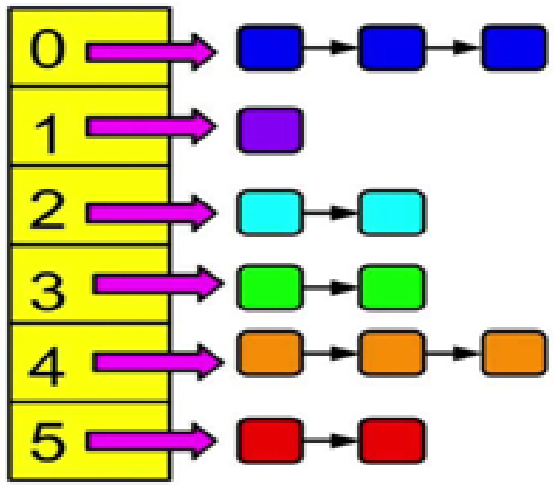
Optimistic concurrency control

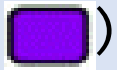
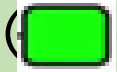


thread T1	thread T2
ht.add( );	ht.add( );
if(ht.contains( ))	if(ht.contains( ))
ht.del( );	ht.del( );

Optimistic concurrency control

What do we do when same data is accessed?



thread T1	thread T2
`ht.add(`  `);`	`ht.add(`  `);`
`if(ht.contains(`  `))` `ht.del(`  `);`	`if(ht.contains(`  `))` `ht.del(`  `);`

TM Primer

Key Ideas:

- Critical sections execute concurrently
- Conflicts are detected dynamically
- If conflict serializability is violated, rollback

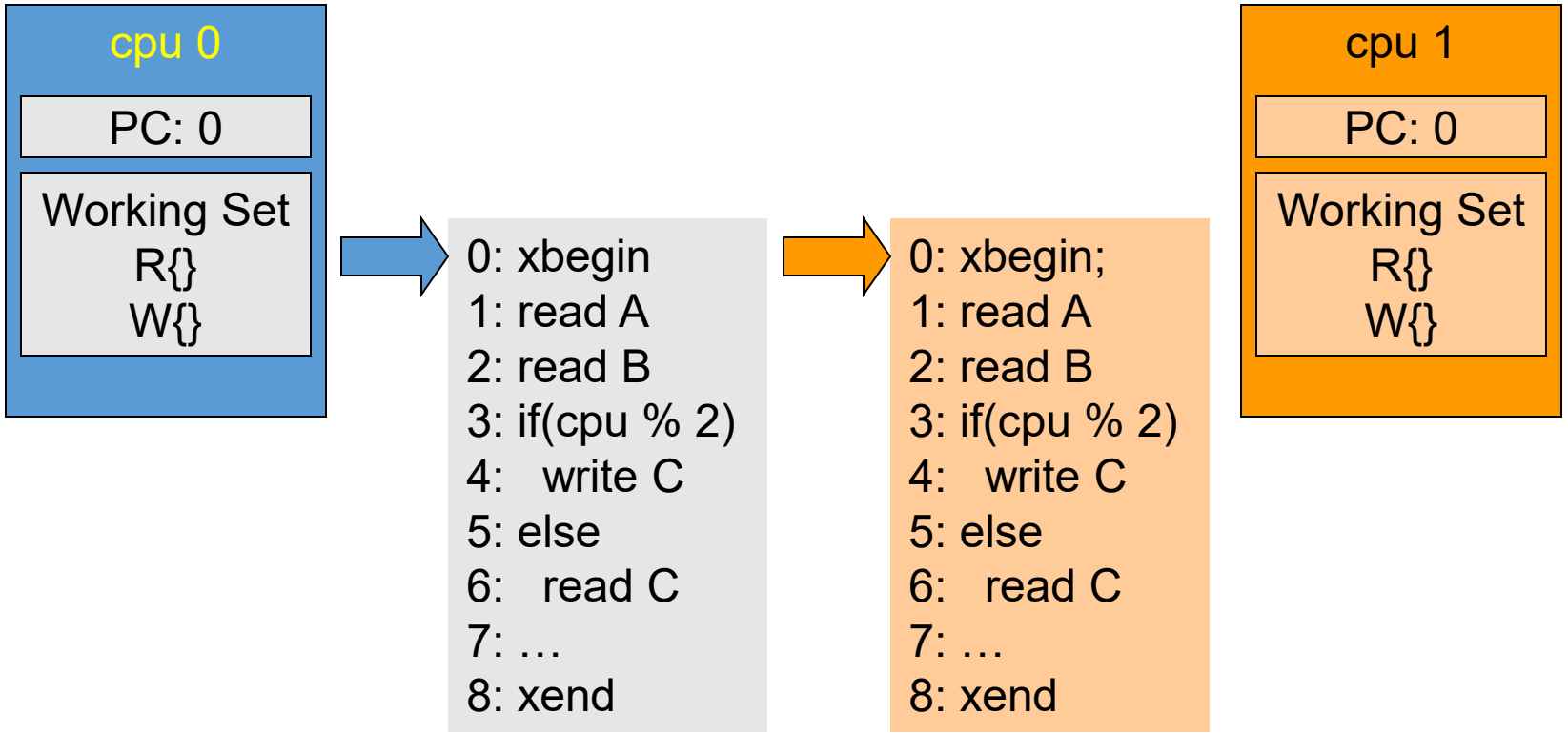
Key Abstractions:

- Primitives
  - **xbegin, xend, xabort**
- Conflict

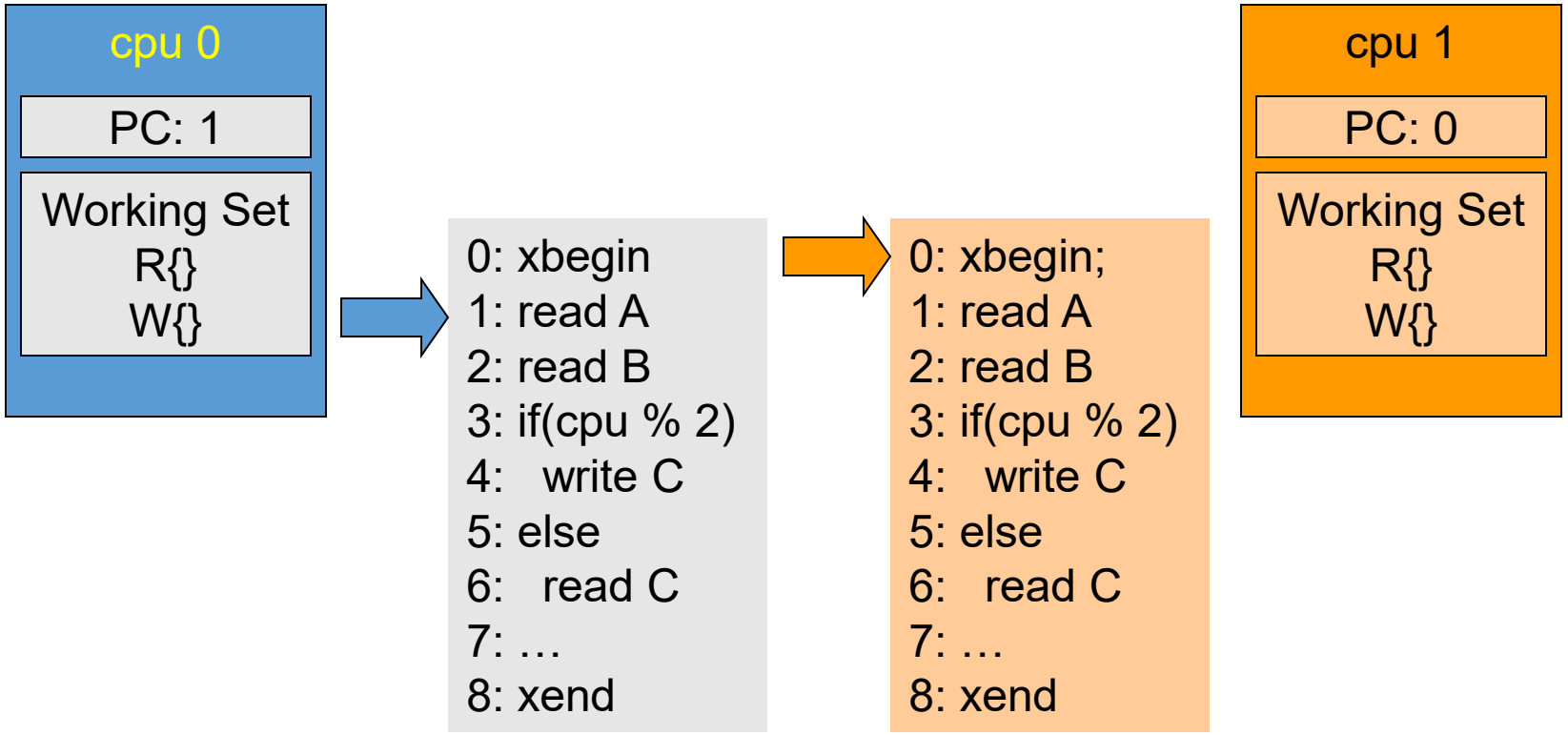
$$\varnothing \neq \{W_a\} \cap \{R_b \cup W_b\}$$

- Contention Manager
  - Need flexible policy

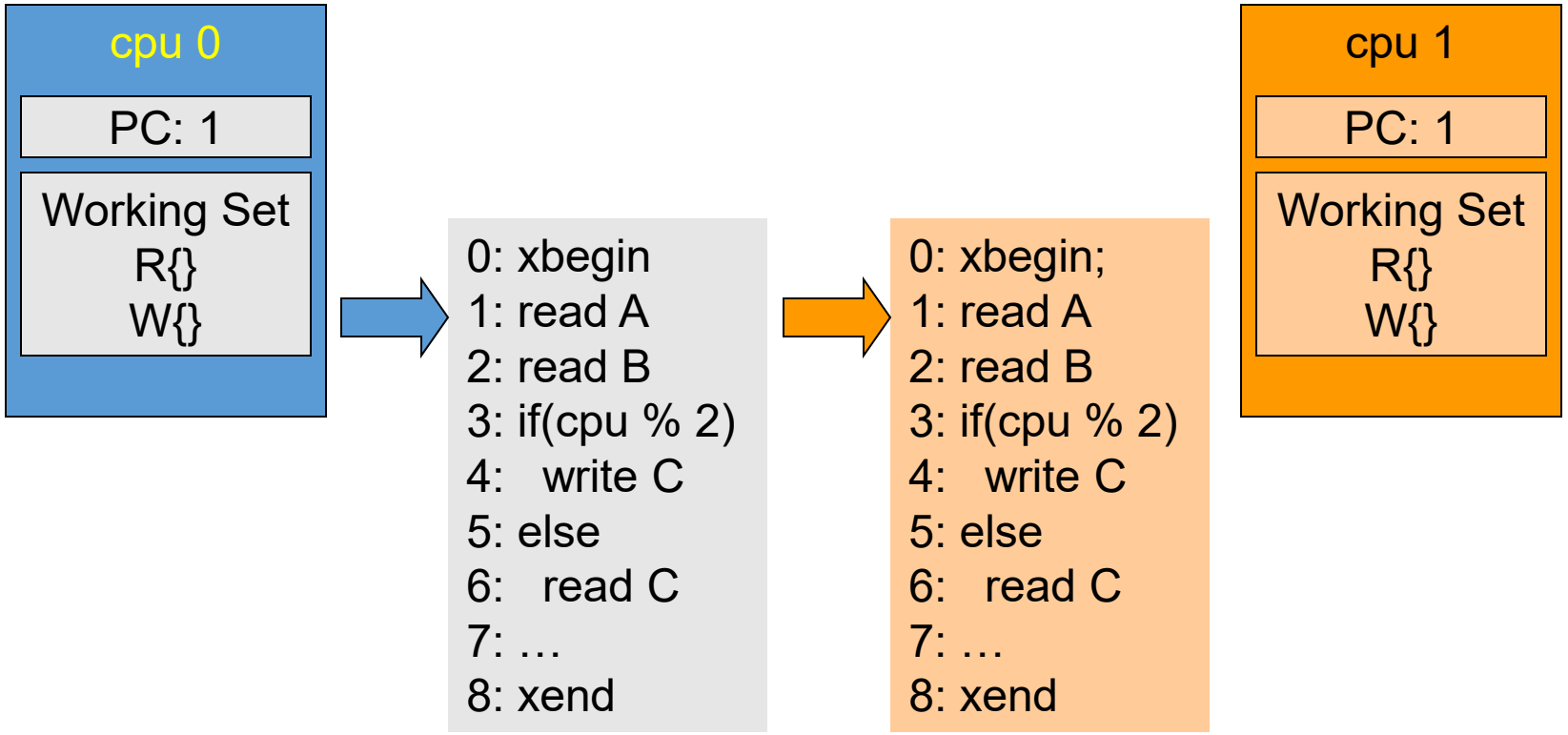
TM basics: example



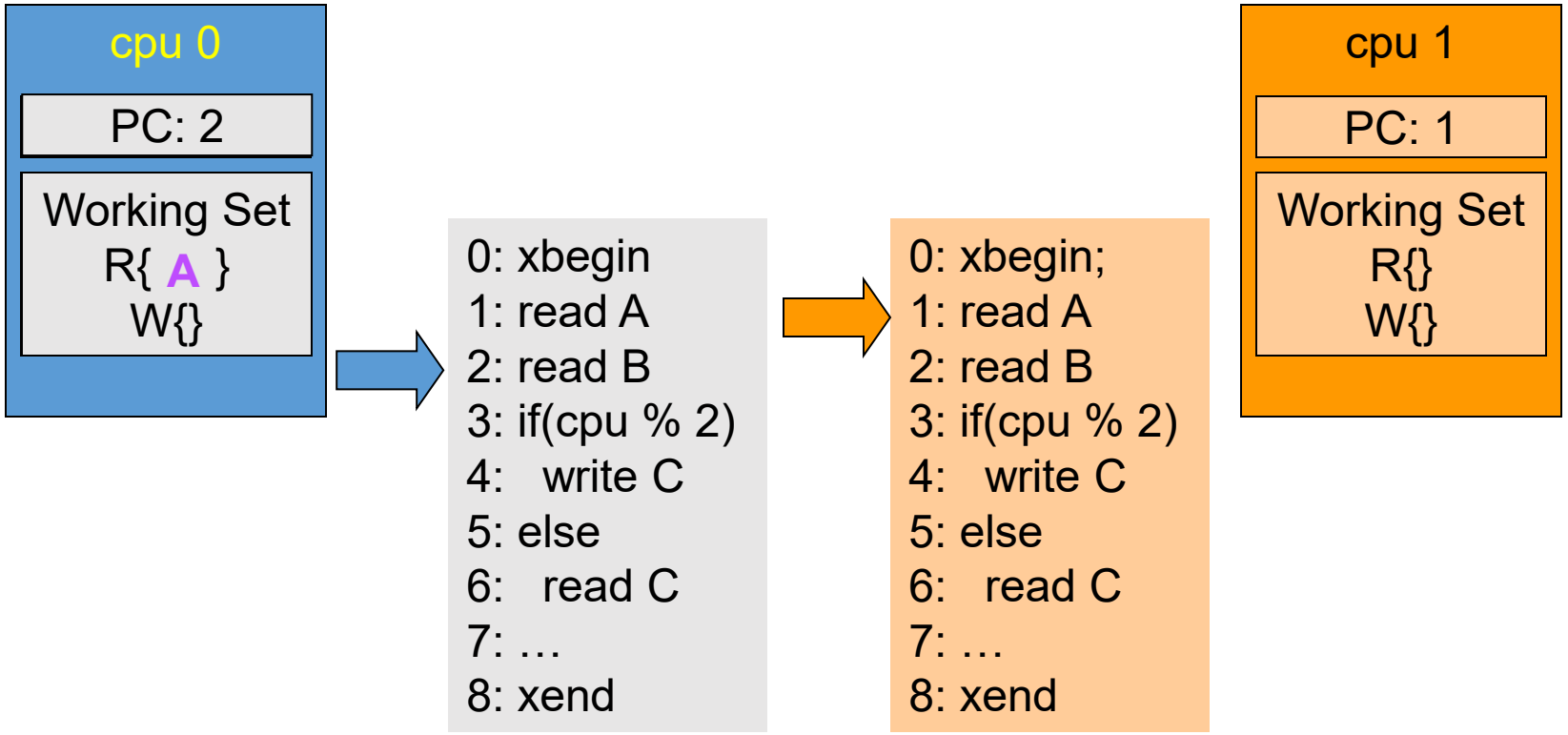
TM basics: example



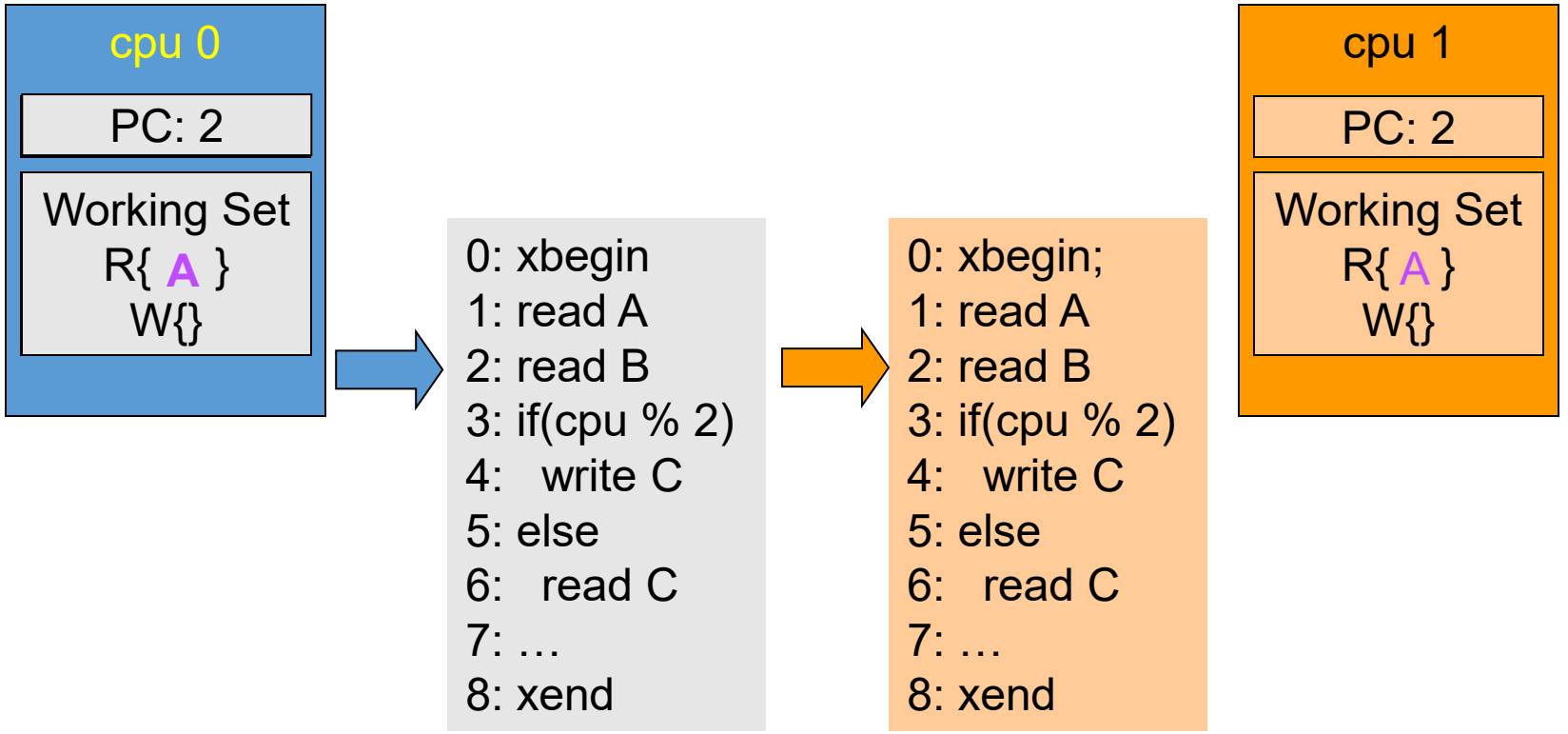
TM basics: example



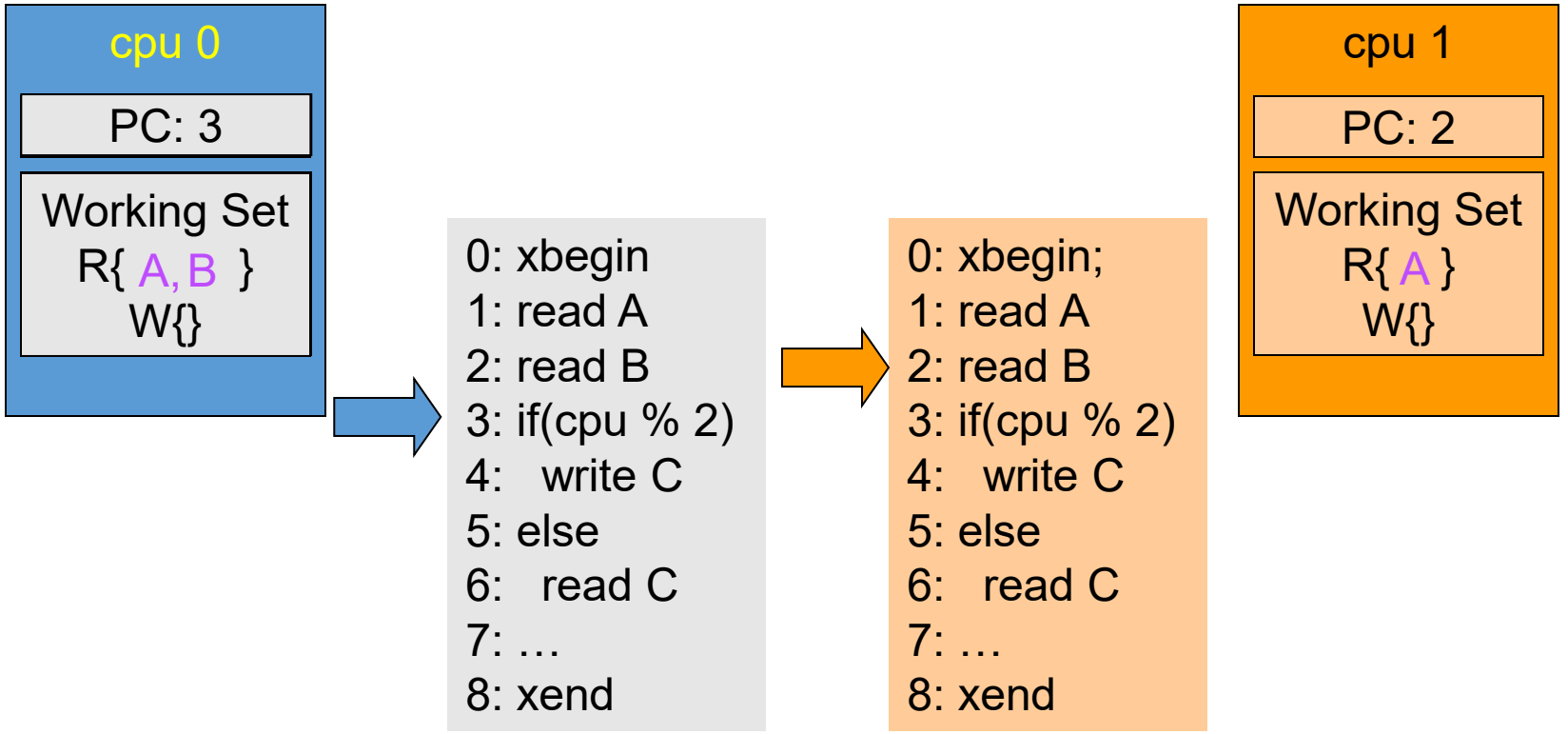
TM basics: example



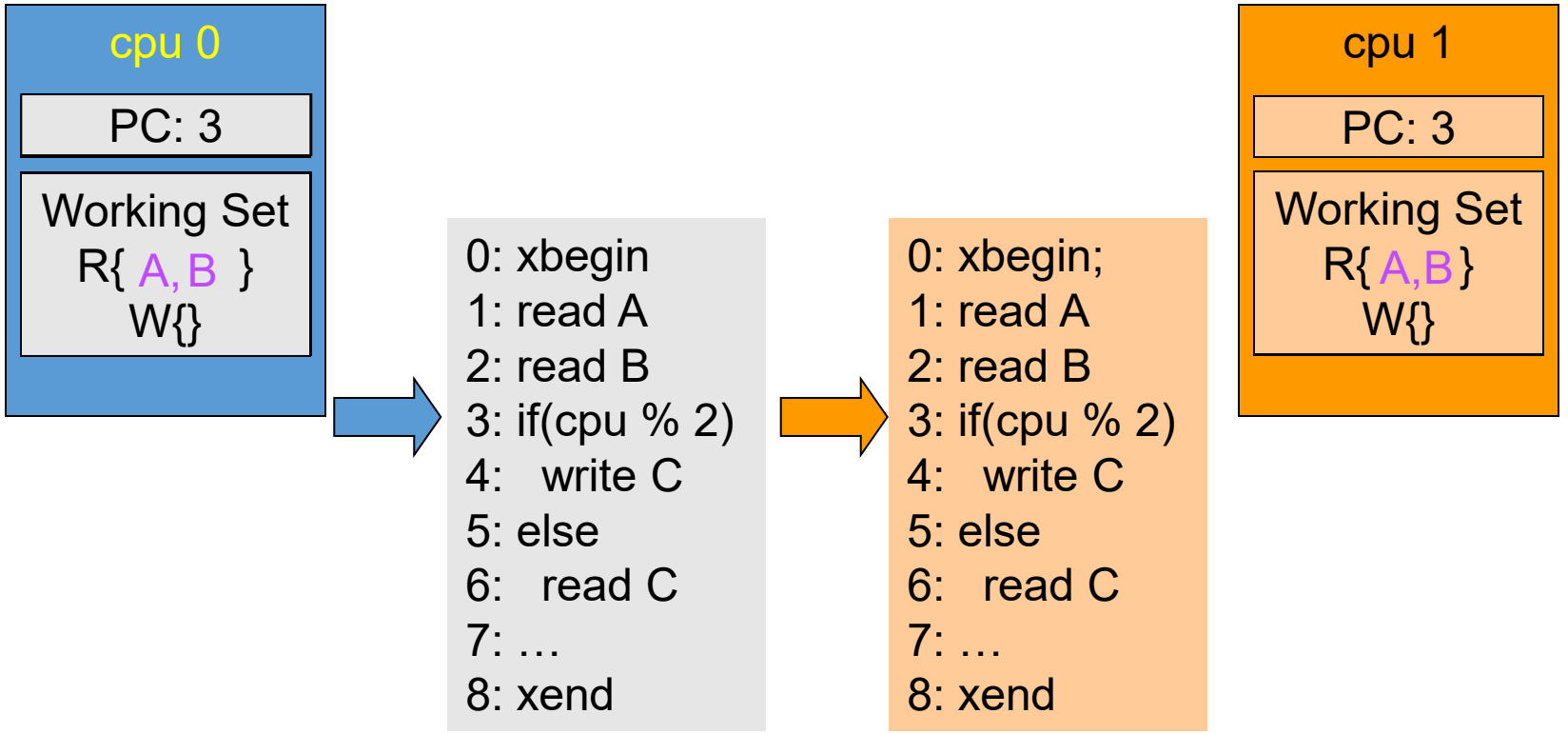
TM basics: example



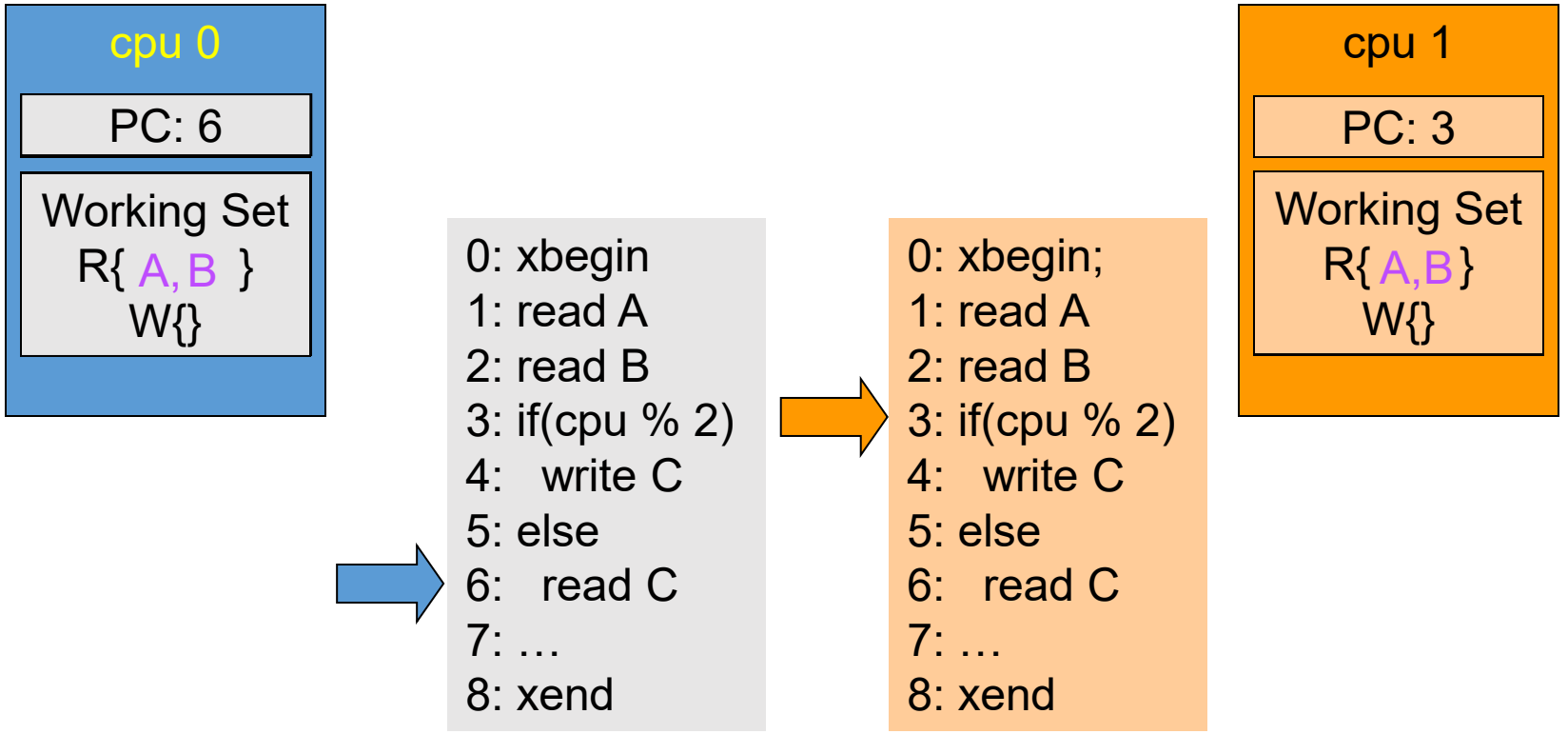
TM basics: example



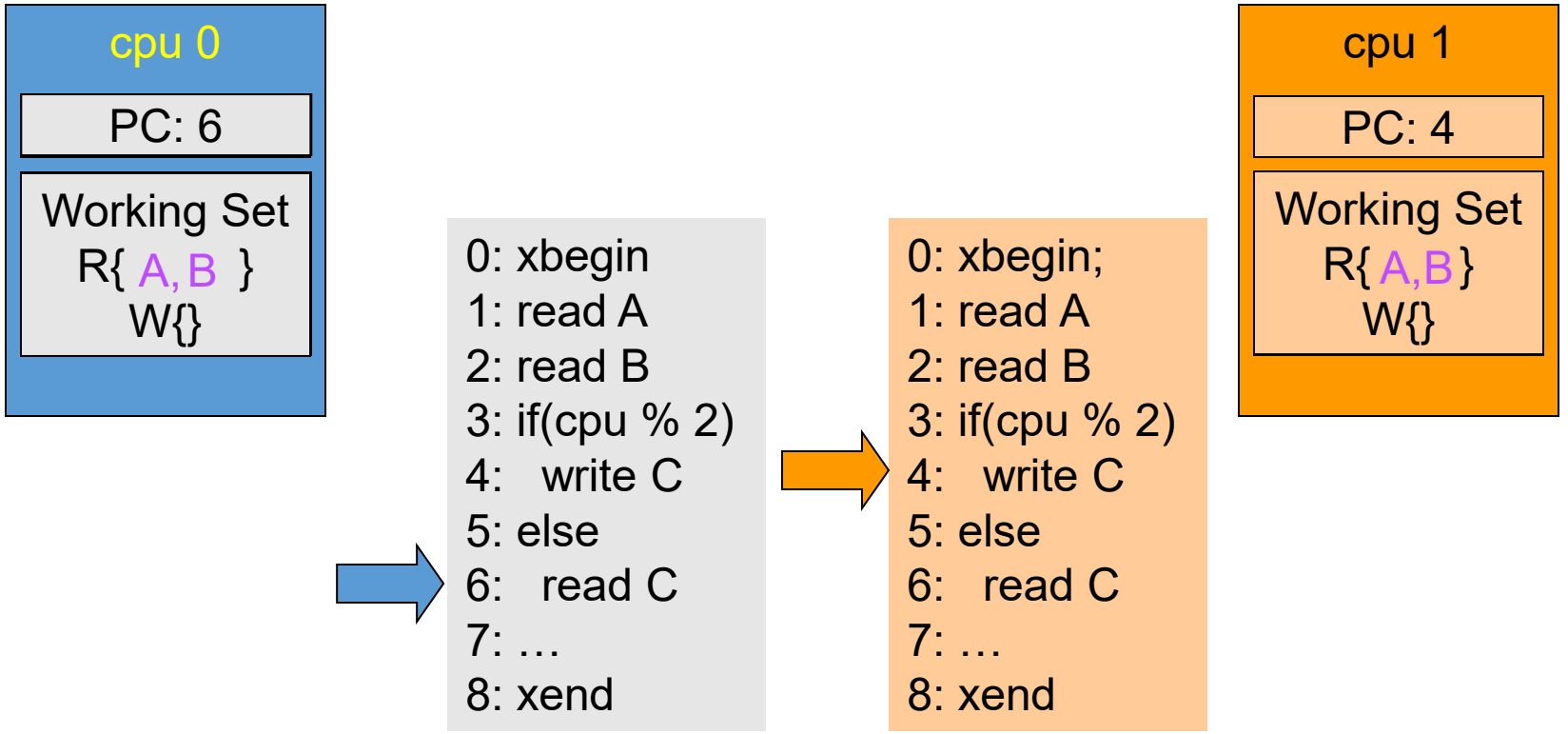
TM basics: example



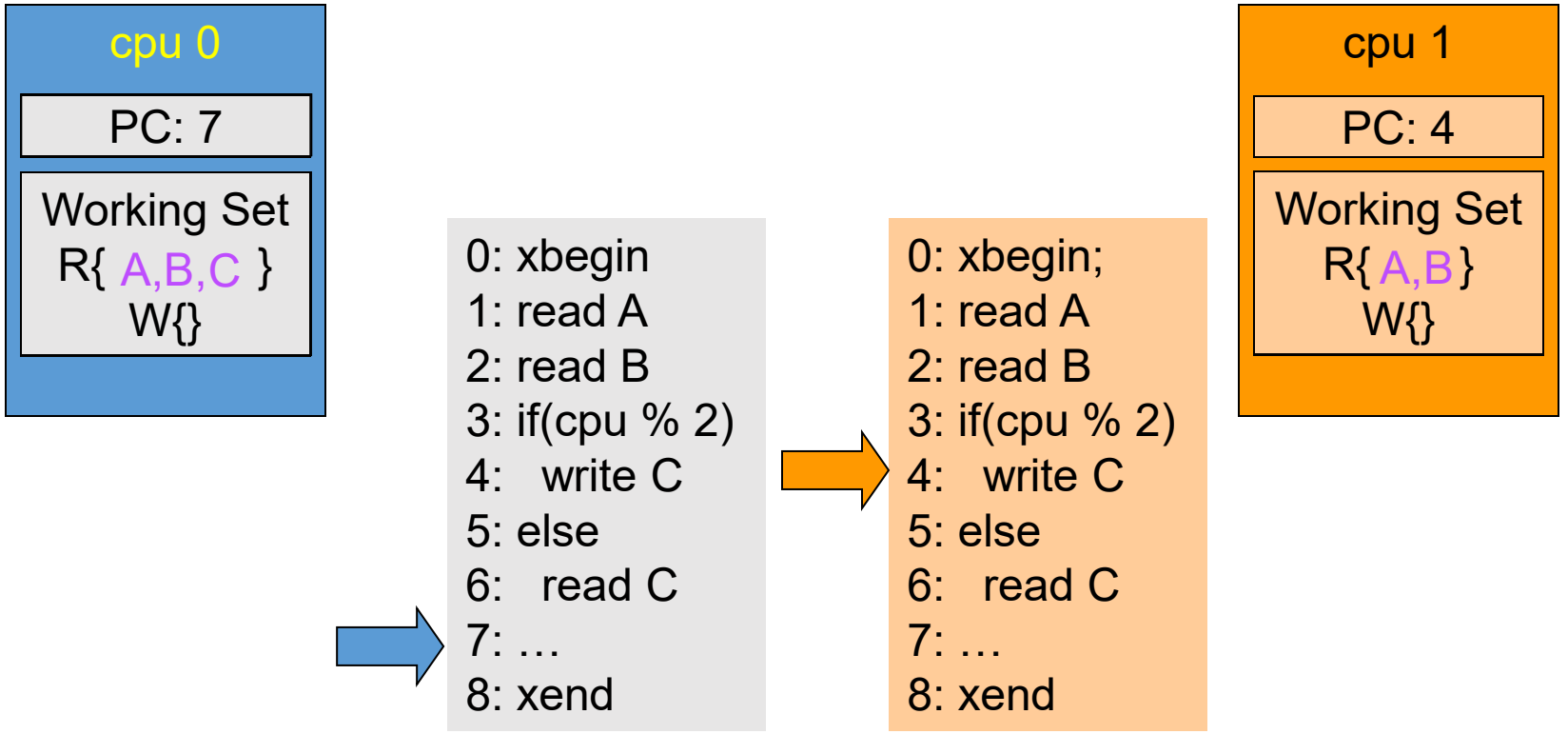
TM basics: example



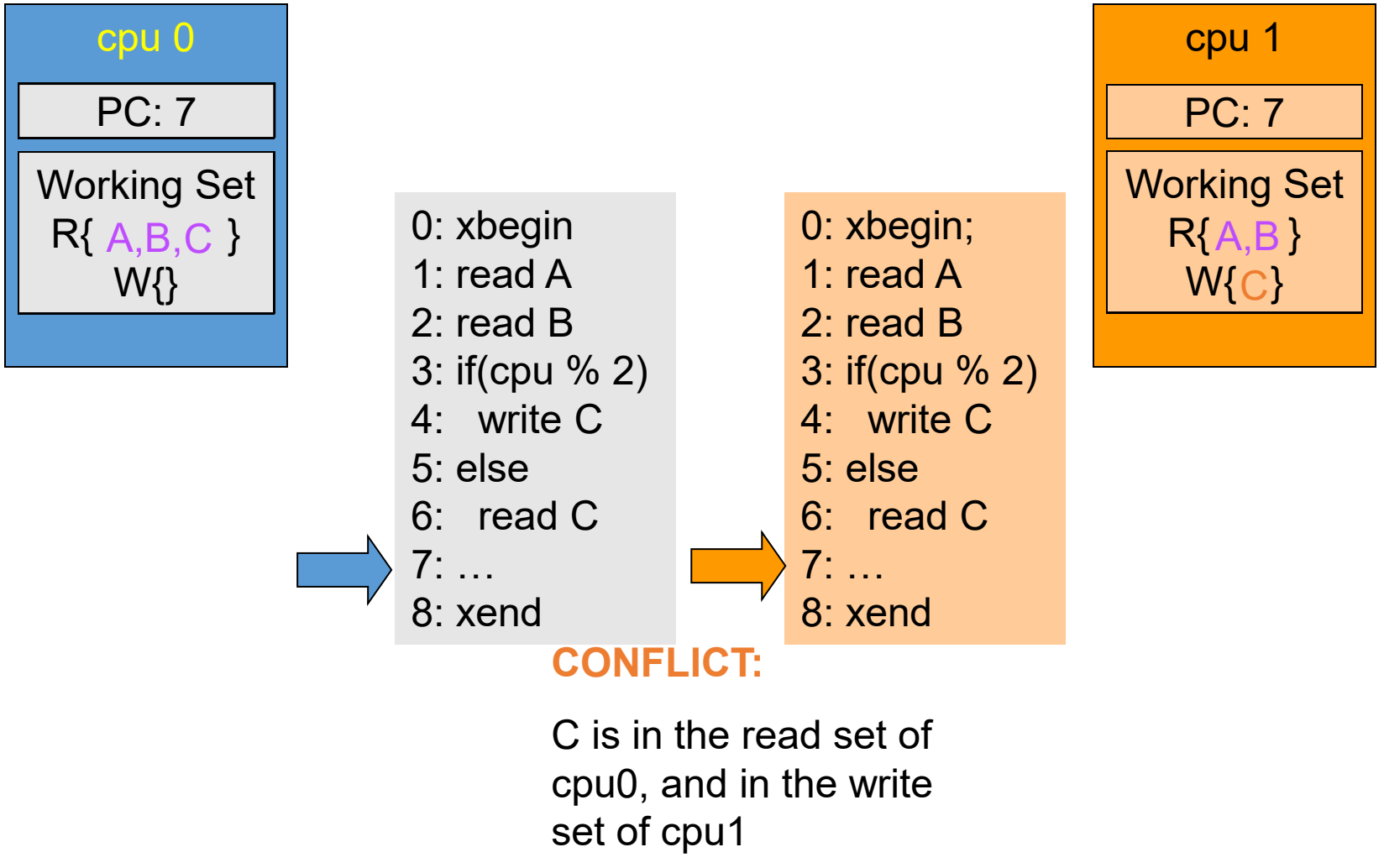
TM basics: example



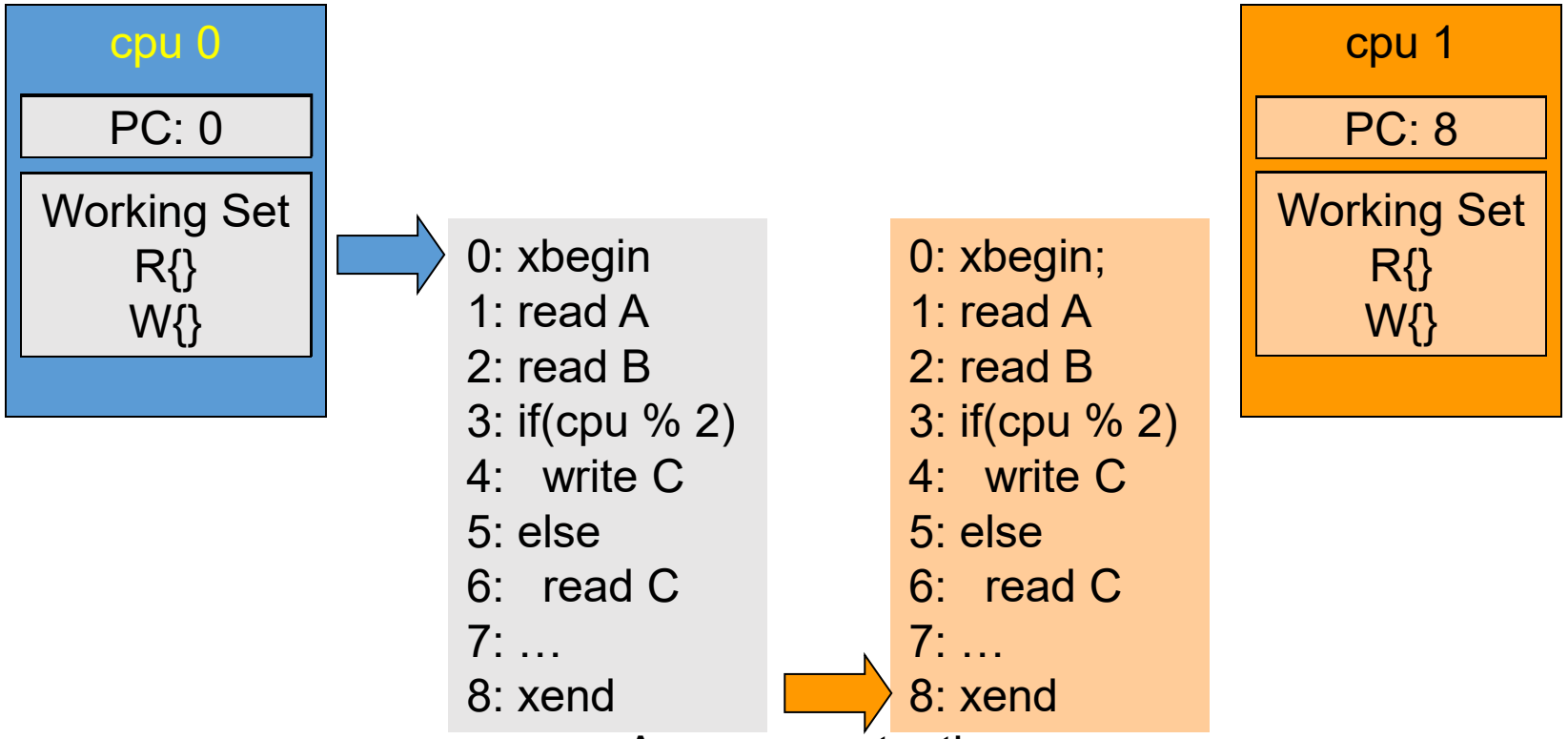
TM basics: example



TM basics: example



TM basics: example

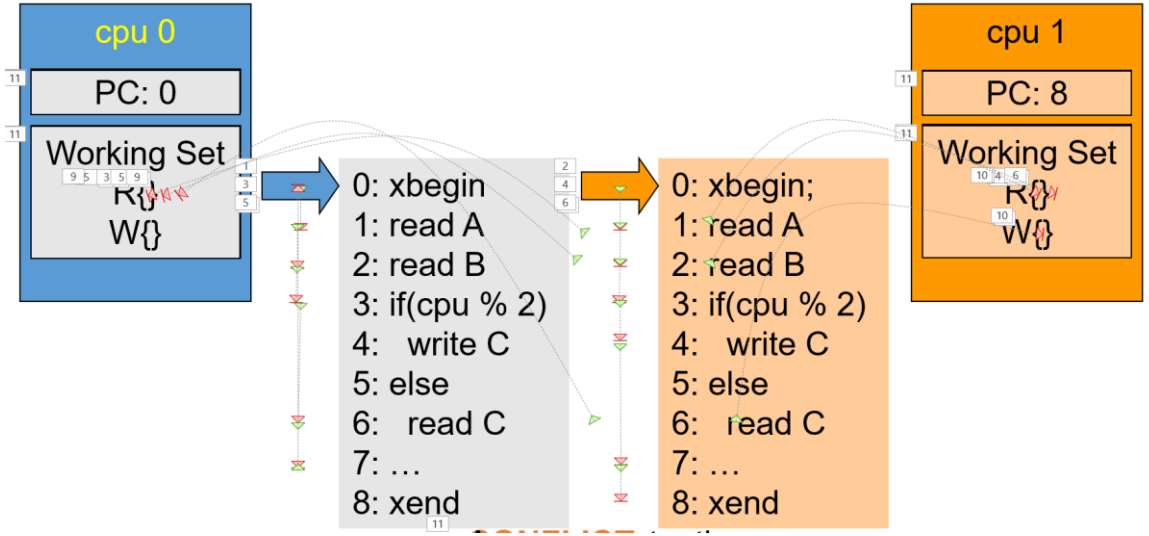


Assume contention manager decides cpu1 wins:

cpu0 rolls back

cpu1 commits

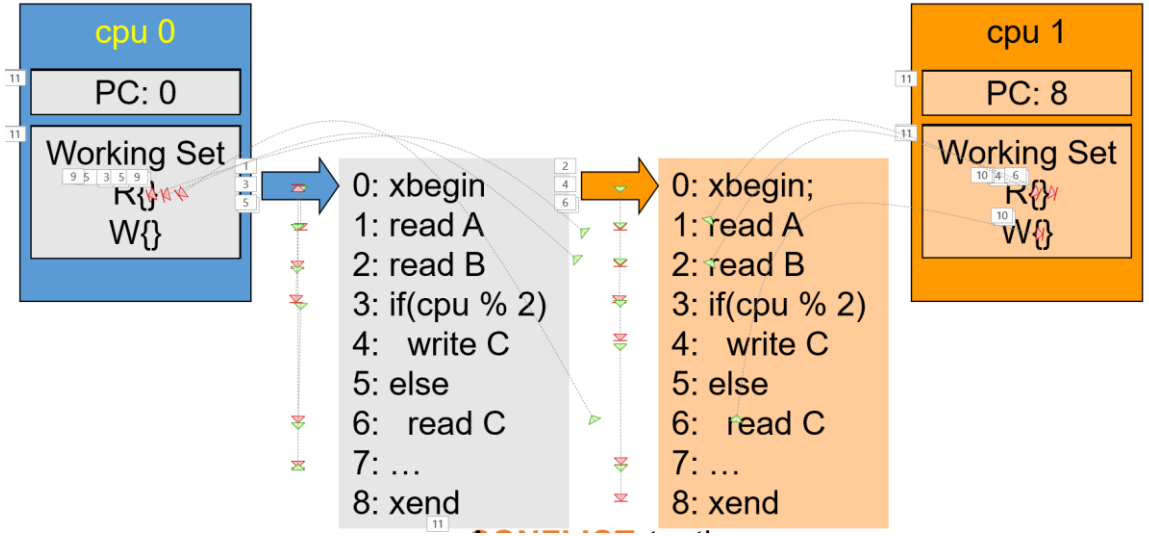
TM Implementation



TM Implementation

Data Versioning

- Eager Versioning
- Lazy Versioning



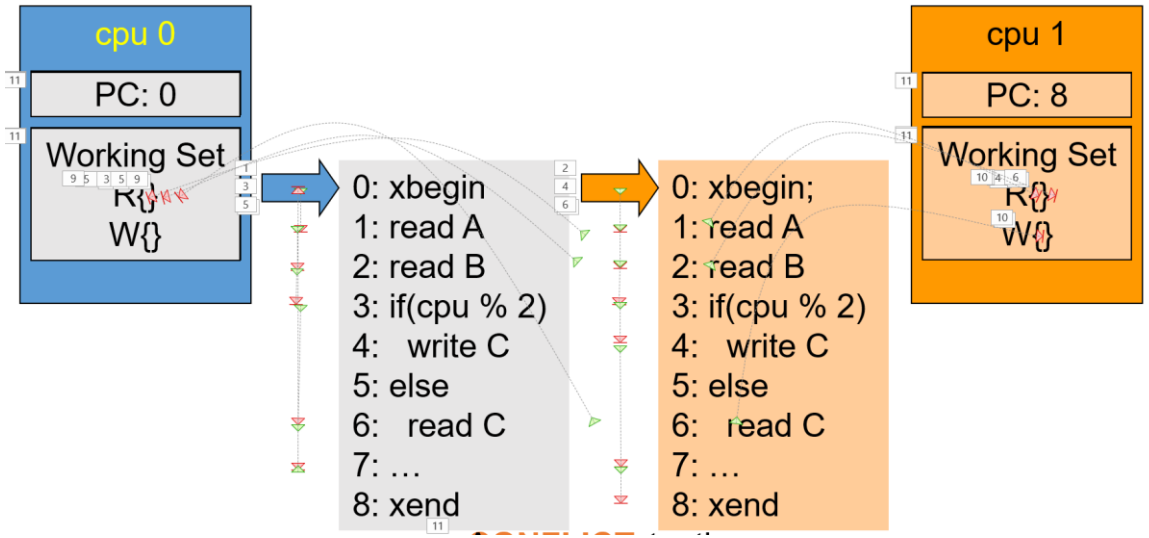
TM Implementation

Data Versioning

- Eager Versioning
- Lazy Versioning

Conflict Detection and Resolution

- Pessimistic Concurrency Control
- Optimistic Concurrency Control



TM Implementation

Data Versioning

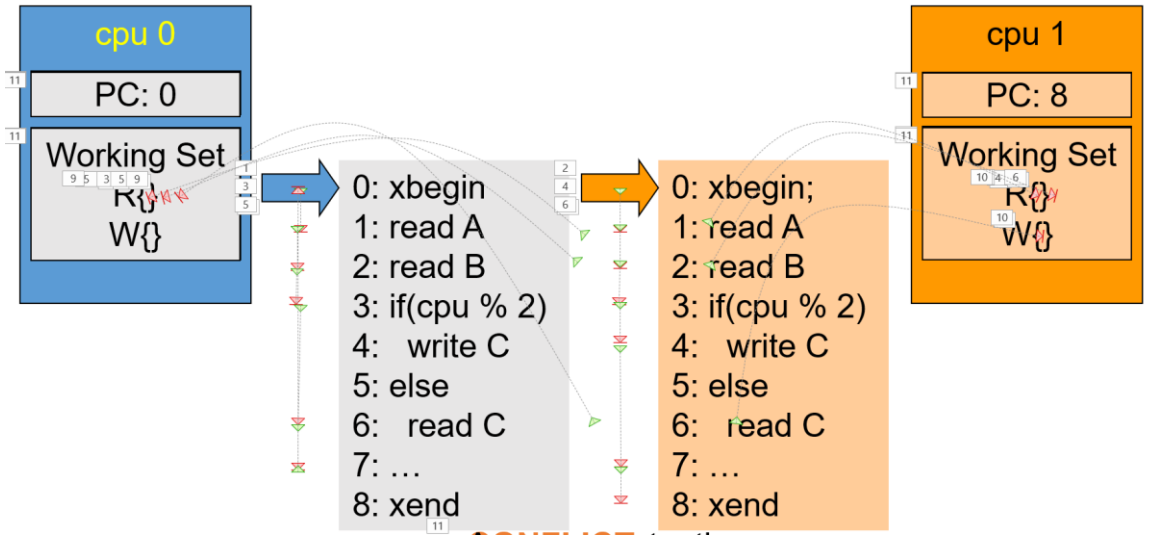
- Eager Versioning
- Lazy Versioning

Conflict Detection and Resolution

- Pessimistic Concurrency Control
- Optimistic Concurrency Control

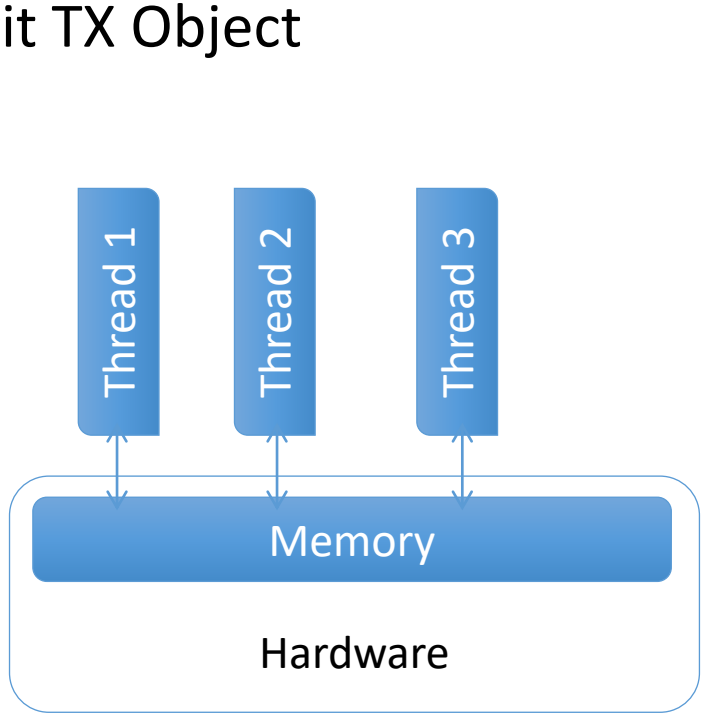
Conflict Detection Granularity

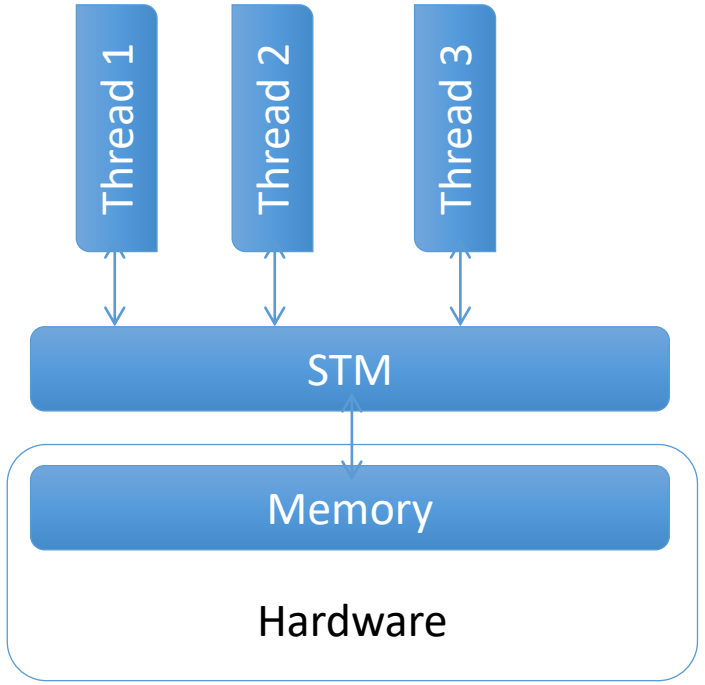
- Object Granularity
- Word Granularity
- Cache line Granularity



TM Design Alternatives

- Hardware (HTM)
  - Caches track RW set, HW speculation/checkpoint
- Software (STM)
  - Instrument RW
  - Inherit TX Object





Hardware Transactional Memory

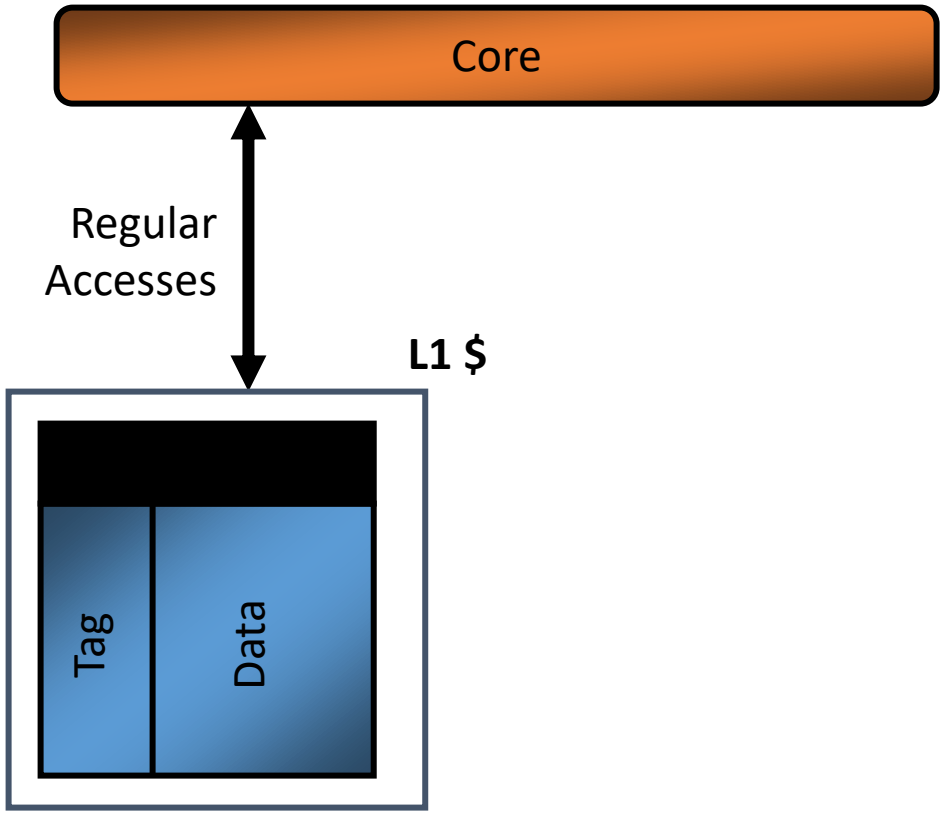
- Idea: Track read / write sets in HW
  - commit / rollback in hardware as well
- Cache coherent hardware already manages much of this
- Basic idea: cache == speculative storage
  - HTM ~= smarter cache
- Can support many different TM paradigms
  - Eager, lazy
  - optimistic, pessimistic

Hardware TM

- “Small” modification to cache

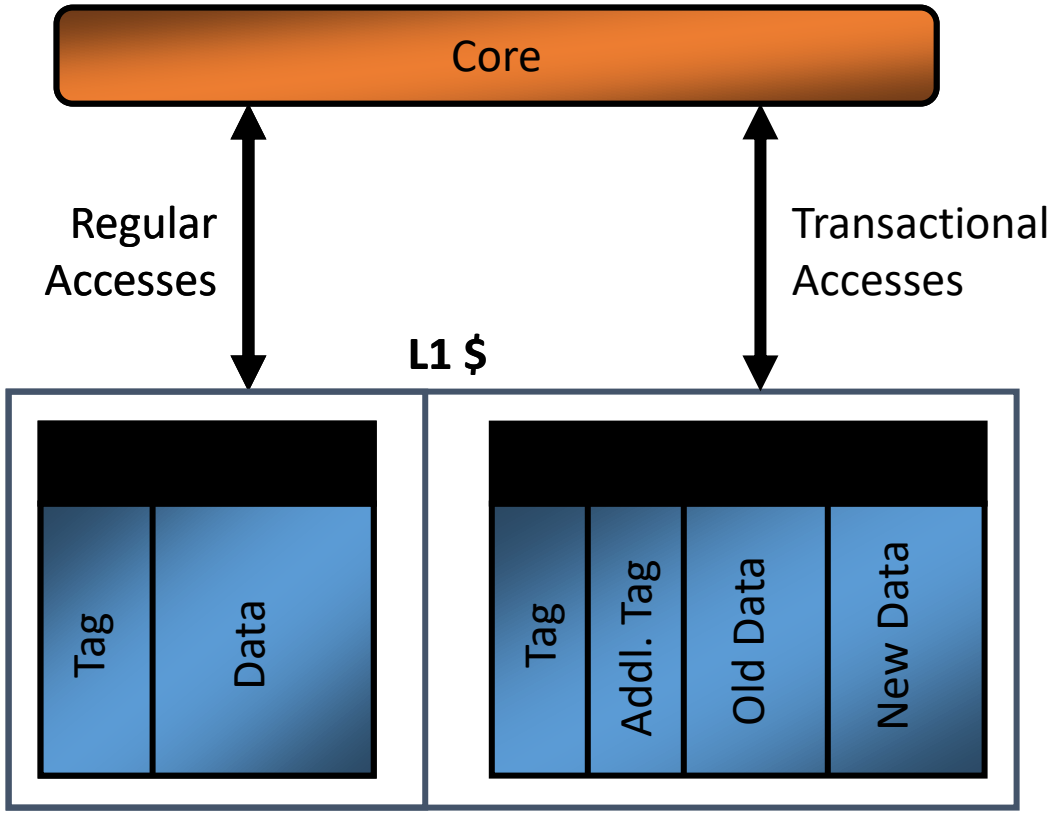
Hardware TM

- “Small” modification to cache



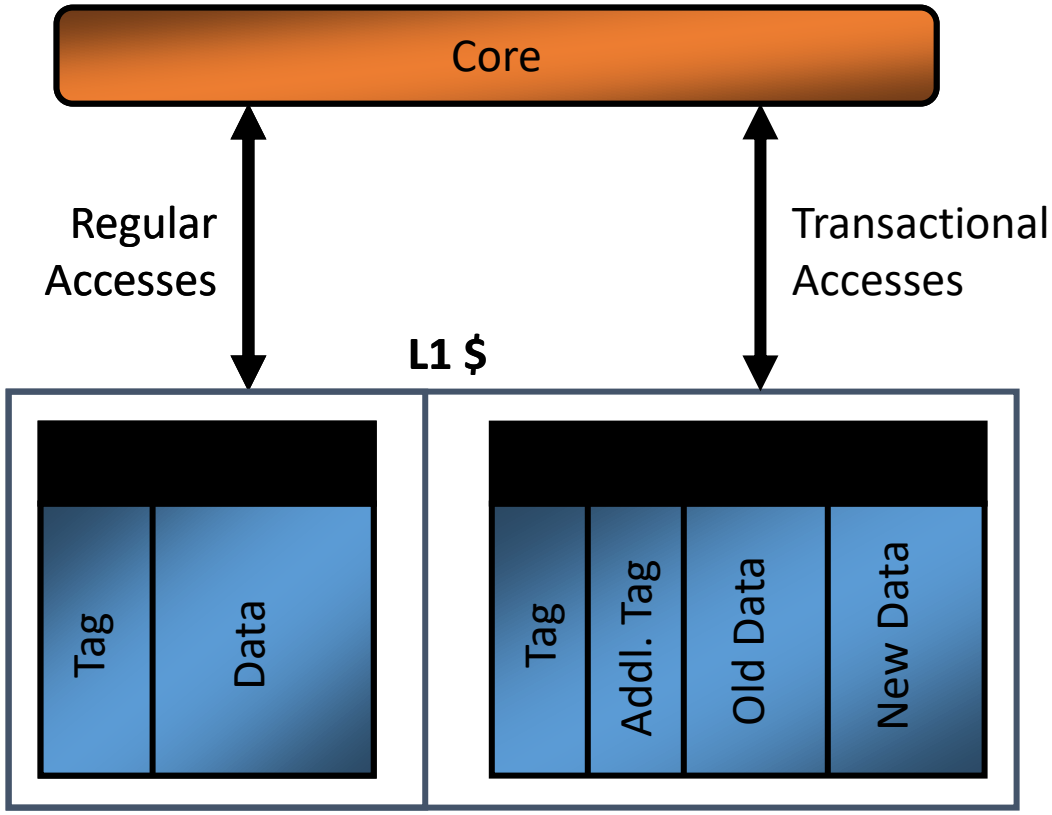
Hardware TM

- “Small” modification to cache



Hardware TM

- "Small" modification to cache

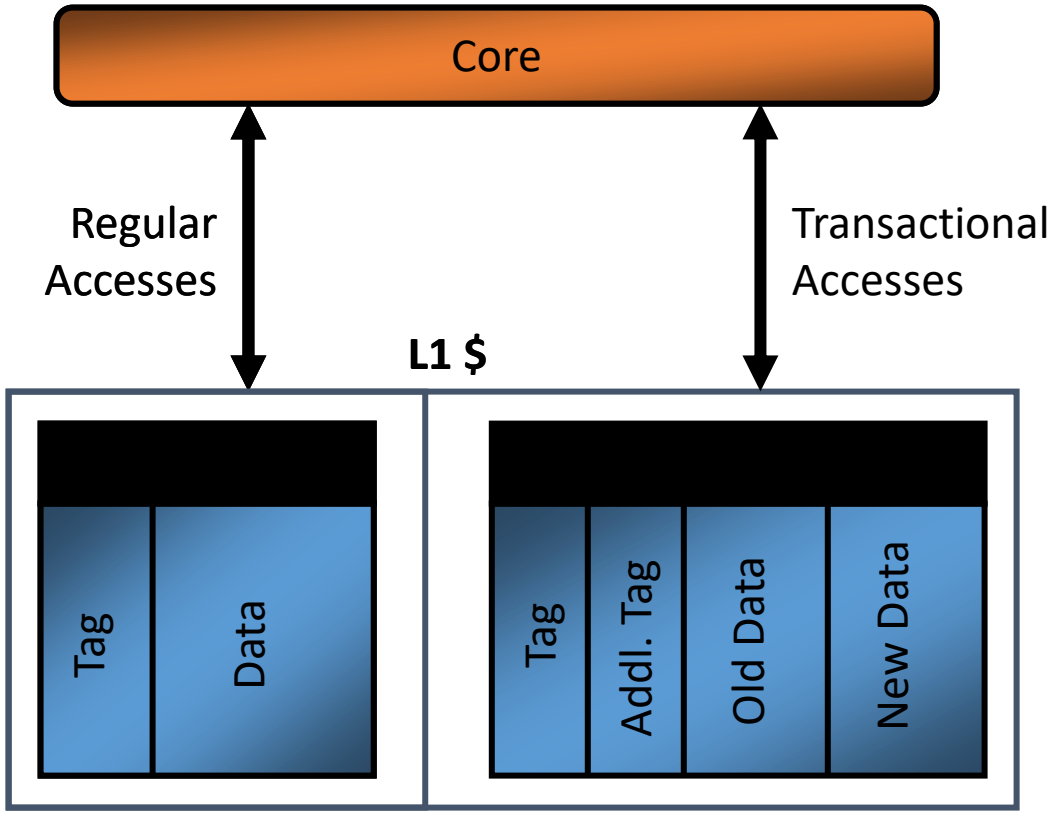


Key ideas

- *Checkpoint architectural state*
- *Caches: 'versioning' for memory*
- *Change coherence protocol*
- *Conflict detection in hardware*
- *'Commit' transactions if no conflict*
- *'Abort' on conflict (or special cond)*
- *'Retry' aborted transaction*

Hardware TM

- "Small" modification to cache



Key ideas

- *Checkpoint architectural state*
- *Caches: 'versioning' for memory*
- *Change coherence protocol*
- *Conflict detection in hardware*
- *'Commit' transactions if no conflict*
- *'Abort' on conflict (or special cond)*
- *'Retry' aborted transaction*

Pros/Cons?

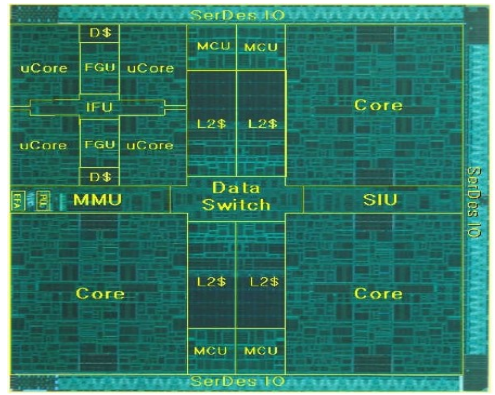
Case Study: SUN Rock

- Major challenge: diagnosing cause of Transaction aborts
  - Necessary for intelligent scheduling of transactions
  - Also for debugging code
  - debugging the processor architecture / µarchitecture
- Many unexpected causes of aborts
- Rock v1 diagnostics unable to distinguish distinct failure modes

Mask	Name	Description and example cause
0x001	EXOG	**Exogenous** - Intervening code has run: cps register contents are invalid.
0x002	COH	**Coherence** - Conflicting memory operation.
0x004	TCC	**Trap Instruction** - A trap instruction evaluates to "taken".
0x008	INST	**Unsupported Instruction** - Instruction not supported inside transactions.
0x010	PREC	**Precise Exception** - Execution generated a precise exception.
0x020	ASYNC	**Async** - Received an asynchronous interrupt.
0x040	SIZ	**Size** - Transaction write set exceeded the size of the store queue.
0x080	LD	**Load** - Cache line in read set evicted by transaction.
0x100	ST	**Store** - Data TLB miss on a store.
0x200	CTI	**Control transfer** - Mispredicted branch.
0x400	FP	**Floating point** - Divide instruction.
0x800	UCTI	**Unresolved control transfer** - branch executed without resolving load on which it depends

Table 1. cps register: bit definitions and example failure reasons that set them.

Case Study: SUN Rock



- Major challenge: diagnosing cause of Transaction aborts
  - Necessary for intelligent scheduling of transactions
  - Also for debugging code
  - debugging the processor architecture / µarchitecture
- Many unexpected causes of aborts
- Rock v1 diagnostics unable to distinguish distinct failure modes

Mask	Name	Description and example cause
0x001	EXOG	**Exogenous** - Intervening code has run: cps register contents are invalid.
0x002	COH	**Coherence** - Conflicting memory operation.
0x004	TCC	**Trap Instruction** - A trap instruction evaluates to "taken".
0x008	INST	**Unsupported Instruction** - Instruction not supported inside transactions.
0x010	PREC	**Precise Exception** - Execution generated a precise exception.
0x020	ASYNC	**Async** - Received an asynchronous interrupt.
0x040	SIZ	**Size** - Transaction write set exceeded the size of the store queue.
0x080	LD	**Load** - Cache line in read set evicted by transaction.
0x100	ST	**Store** - Data TLB miss on a store.
0x200	CTI	**Control transfer** - Mispredicted branch.
0x400	FP	**Floating point** - Divide instruction.
0x800	UCTI	**Unresolved control transfer** - branch executed without resolving load on which it depends

Table 1. cps register: bit definitions and example failure reasons that set them.

A Simple STM

```
pthread_mutex_t g_global_lock;

begin_tx() {
    pthread_mutex_lock(g_global_lock);
}

end_tx() {
    pthread_mutex_unlock(g_global_lock);
}

abort() {
    // can't happen
}
```

A Simple STM

```
pthread_mutex_t g_global_lock;

begin_tx() {
    pthread_mutex_lock(g_global_lock);
}

end_tx() {
    pthread_mutex_unlock(g_global_lock);
}

abort() {
    // can't happen
}
```

```
remove(list, x) {
  begin_tx();
  pos = find(list, x);
  if(pos)
     erase(list, pos);
  end_tx();
}
```

A Simple STM

```
pthread_mutex_t g_global_lock;

begin_tx() {
    pthread_mutex_lock(g_global_lock);
}

end_tx() {
    pthread_mutex_unlock(g_global_lock);
}

abort() {
    // can't happen
}
```

```
remove(list, x) {
  begin_tx();
  pos = find(list, x);
  if(pos)
     erase(list, pos);
  end_tx();
}
```

Is this Transactional Memory?

A Simple STM

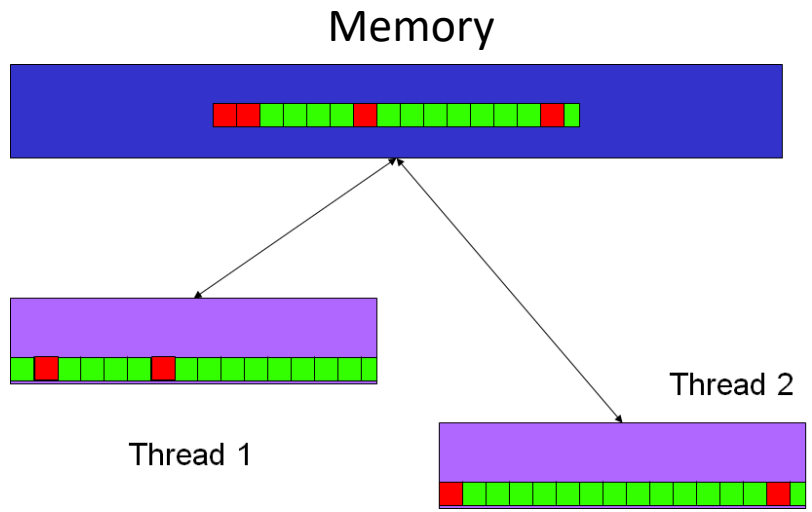
```
pthread_mutex_t g_global_lock;

begin_tx() {
    pthread_mutex_lock(g_global_lock);
}

end_tx() {
    pthread_mutex_unlock(g_global_lock);
}

abort() {
    // can't happen
}
```

```
remove(list, x) {
  begin_tx();
  pos = find(list, x);
  if(pos)
     erase(list, pos);
  end_tx();
}
```

Is this Transactional Memory?

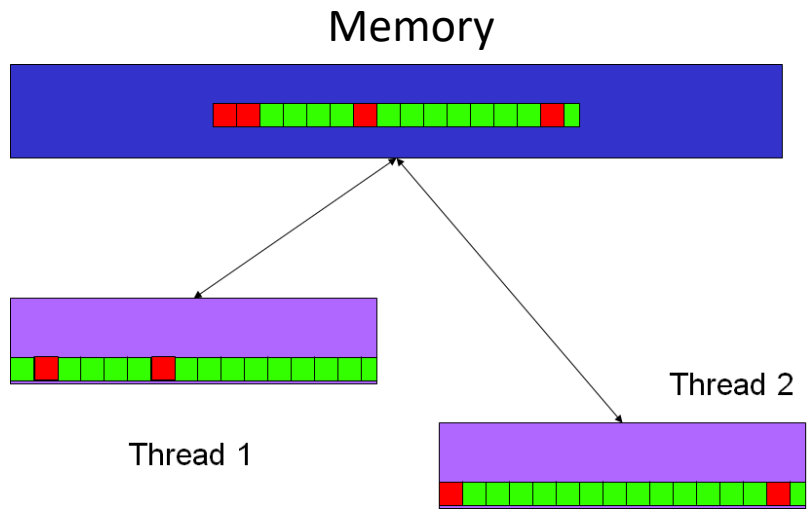
TM is a deep area: consider it for your project!

A Better STM: System Model



A Better STM: System Model

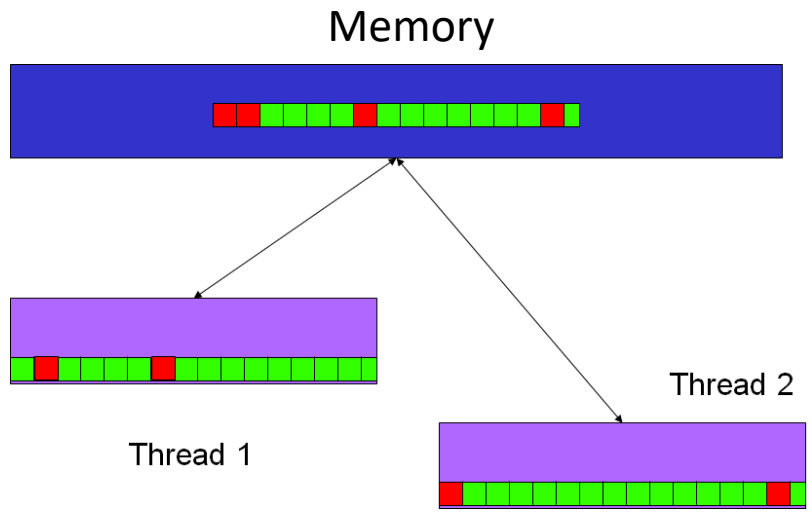
System == <threads, memory>



A Better STM: System Model

System == <threads, memory>

Memory cell support 4 operations:

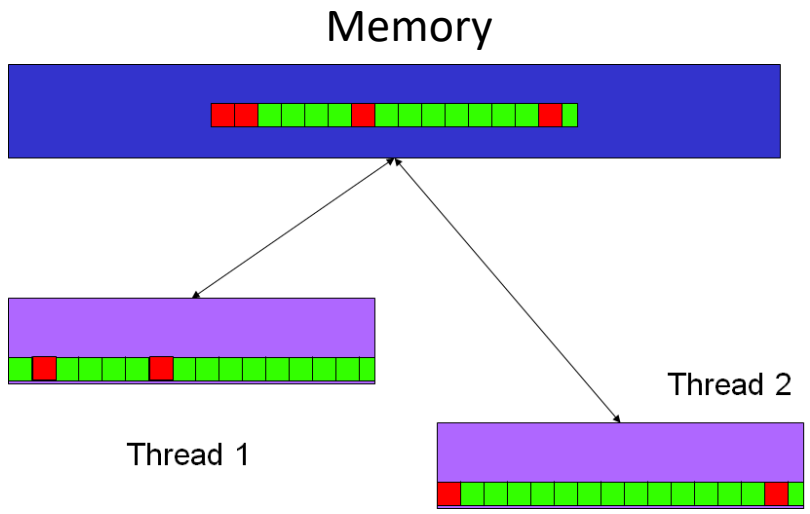


A Better STM: System Model

System == <threads, memory>

Memory cell support 4 operations:

- $Write^{i}(L,v)$ - *thread i writes v to L*

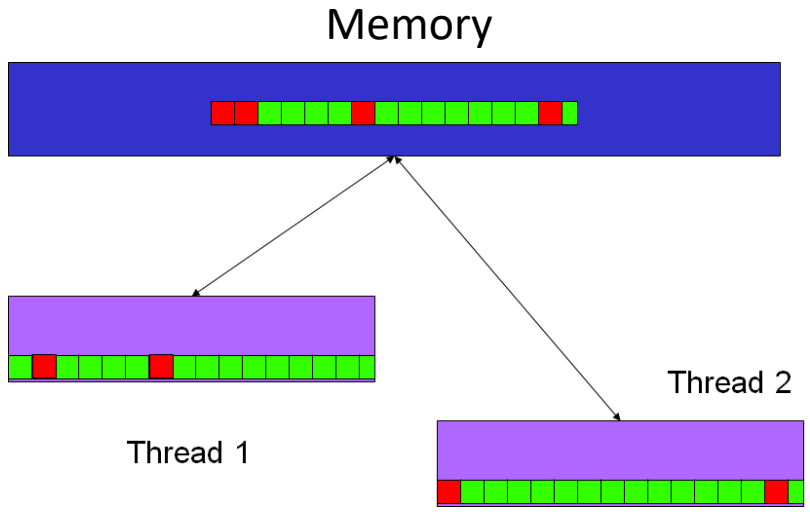


A Better STM: System Model

System == <threads, memory>

Memory cell support 4 operations:

- $Write^{i}(L,v)$ - *thread i writes v to L*
- $Read^{i}(L,v)$ - *thread i reads v from L*

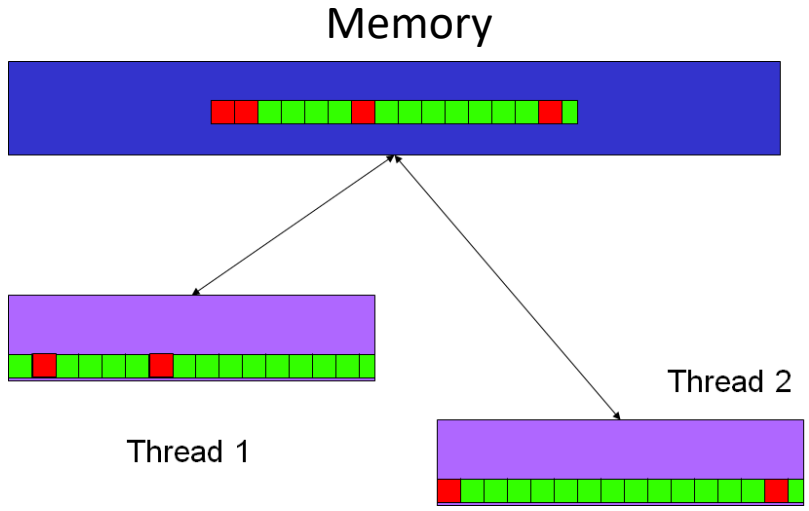


A Better STM: System Model

System == <threads, memory>

Memory cell support 4 operations:

- $Write^i(L,v)$ - *thread i writes v to L*
- $Read^i(L,v)$ - *thread i reads v from L*
- $LL^i(L,v)$ - *thread i reads v from L, marks L read by I*

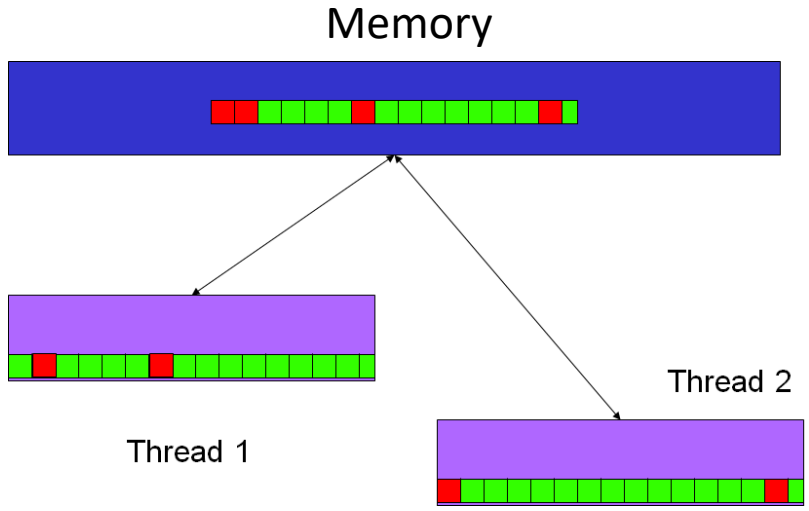


A Better STM: System Model

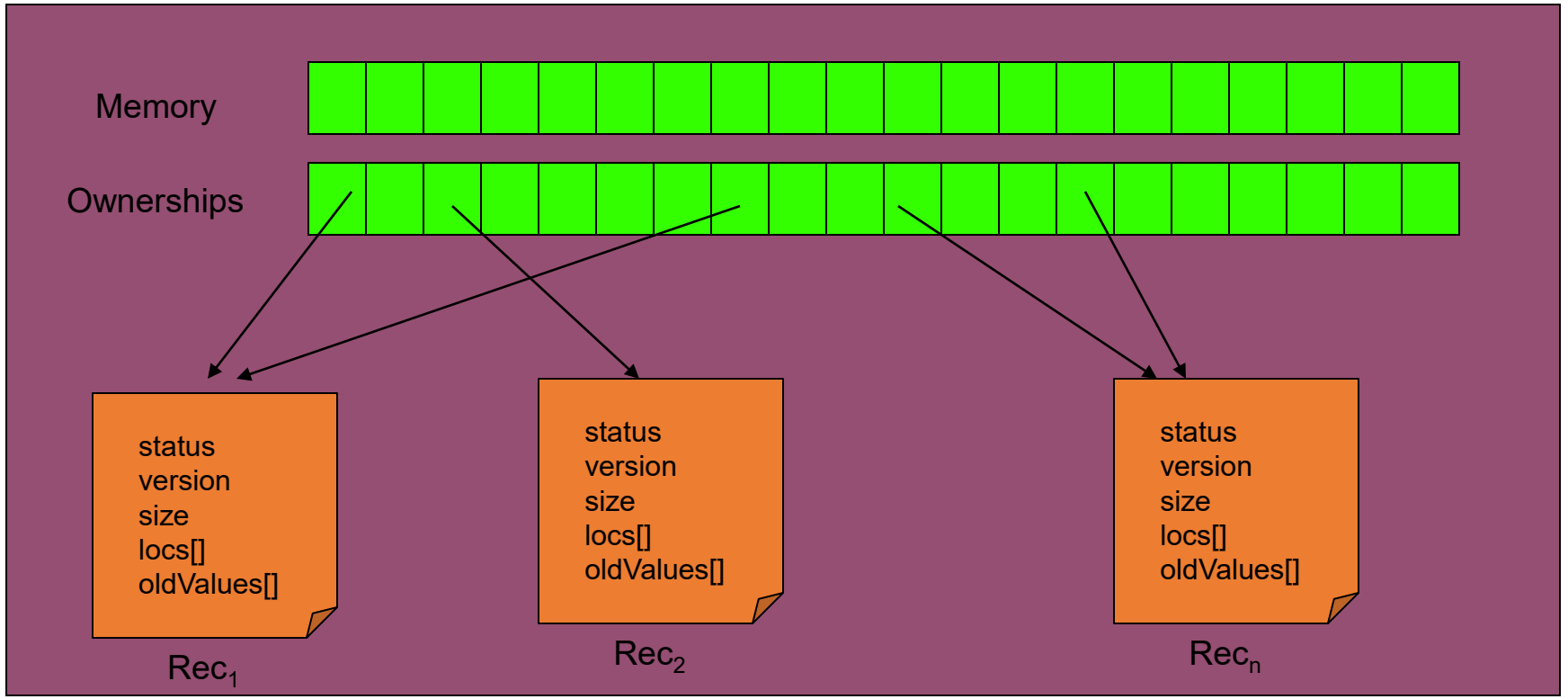
System == <threads, memory>

Memory cell support 4 operations:

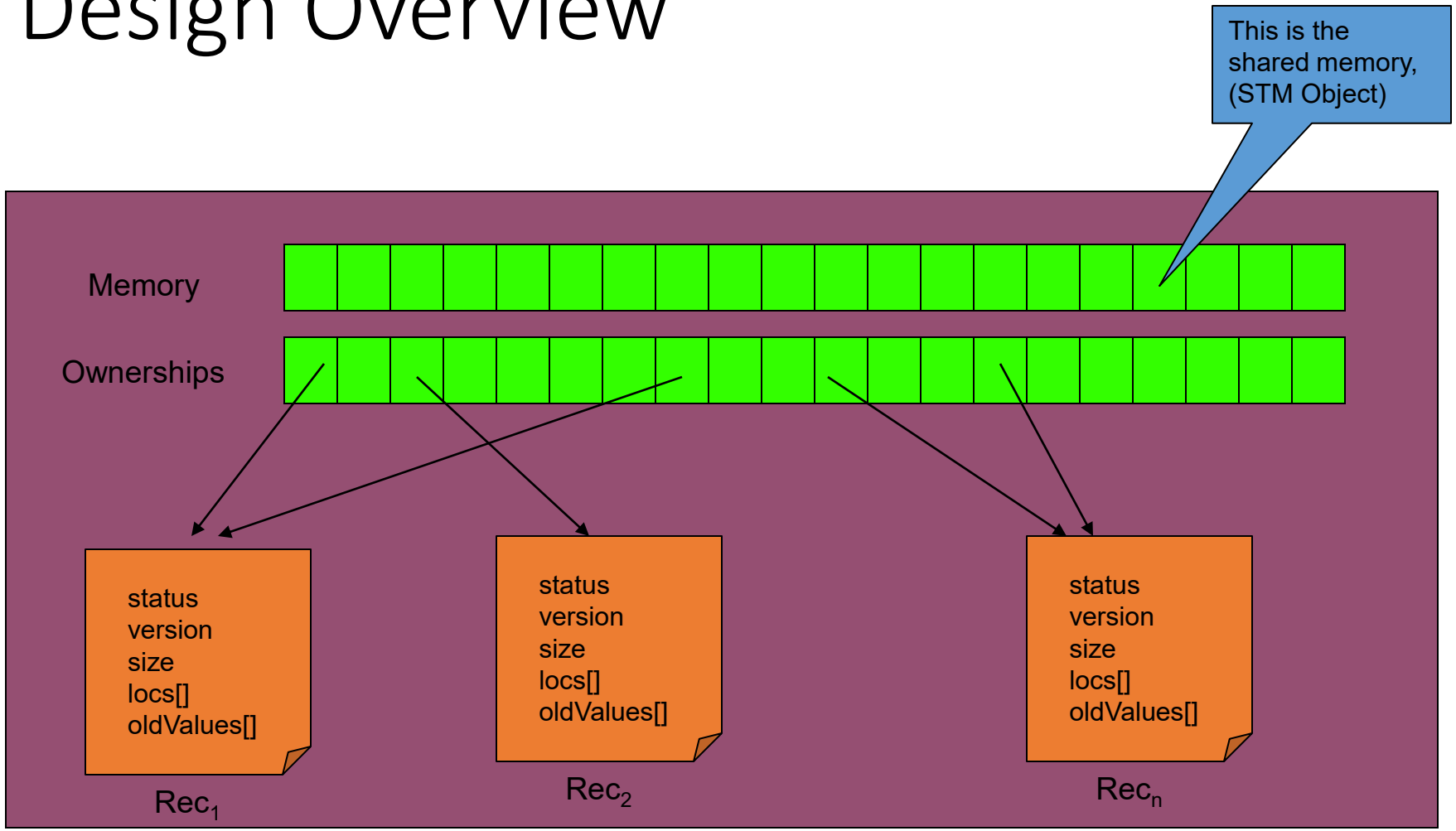
- $Write^i(L,v)$ - *thread i writes v to L*
- $Read^i(L,v)$ - *thread i reads v from L*
- $LL^i(L,v)$ - *thread i reads v from L, marks L read by I*
- $SC^i(L,v)$ - *thread i writes v to L*
  - returns *success* if L is marked as read by i.
  - Otherwise it returns *failure*.



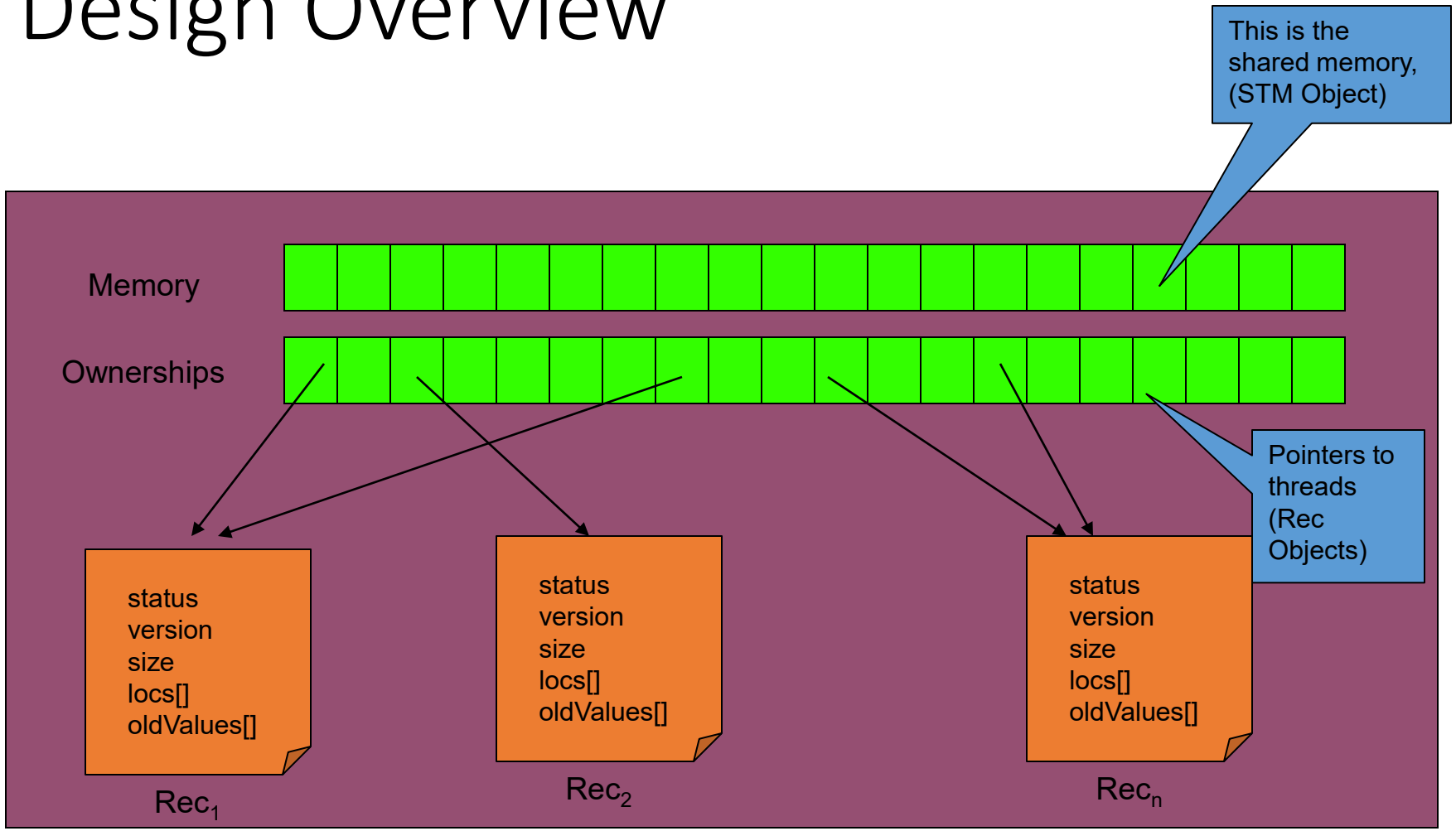
STM Design Overview



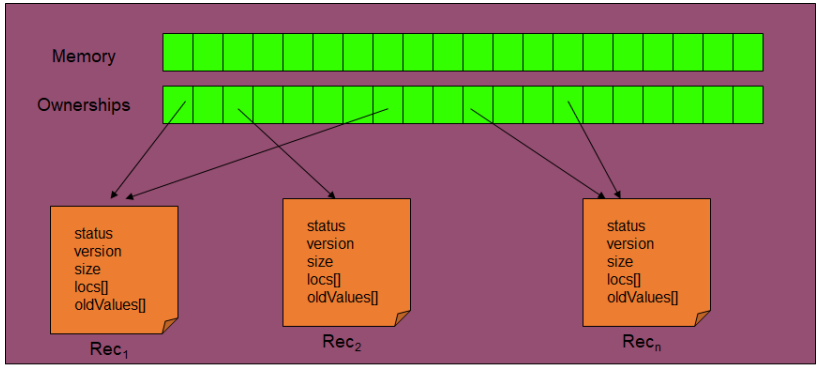
STM Design Overview



STM Design Overview



Threads: Rec Objects

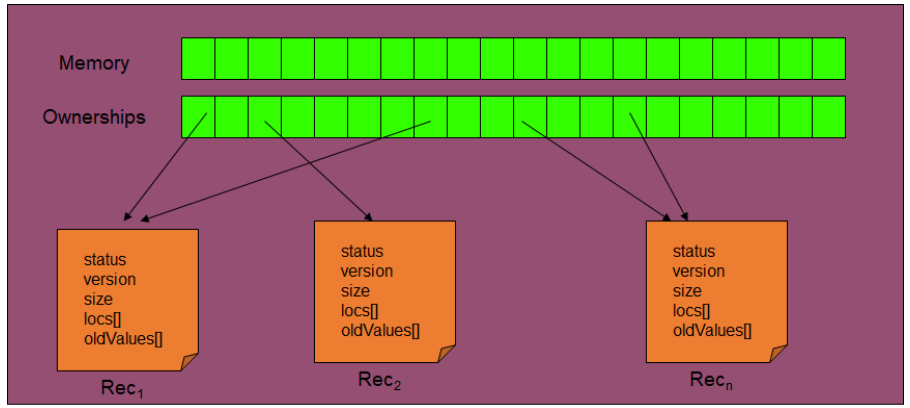



```
class Rec {
        boolean stable = false;
        boolean, int status= (false,0);  //can have two values…
        boolean allWritten = false;
        int version = 0;
        int size = 0;
        int locs[] = {null};
        int oldValues[] = {null};
}
```

Each thread → instance of Rec class *(short for record).*

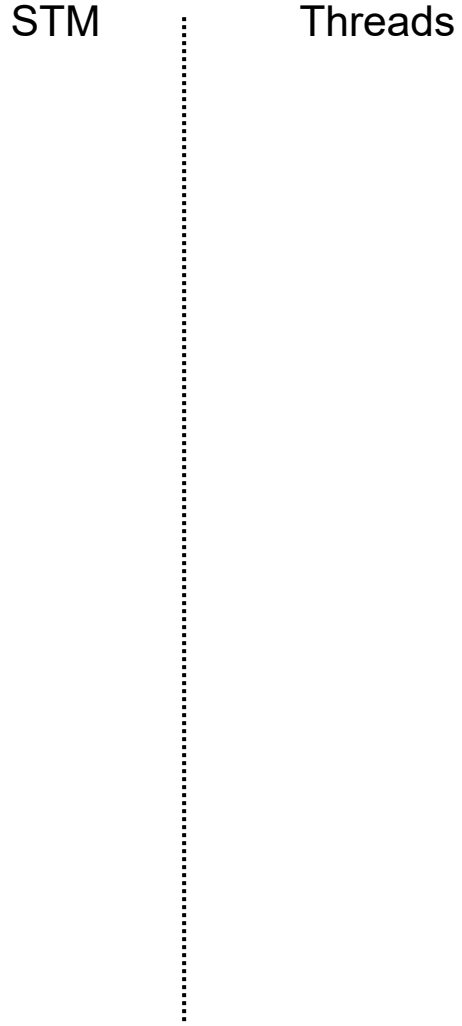
Rec instance defines current transaction on thread

Memory: STM Object

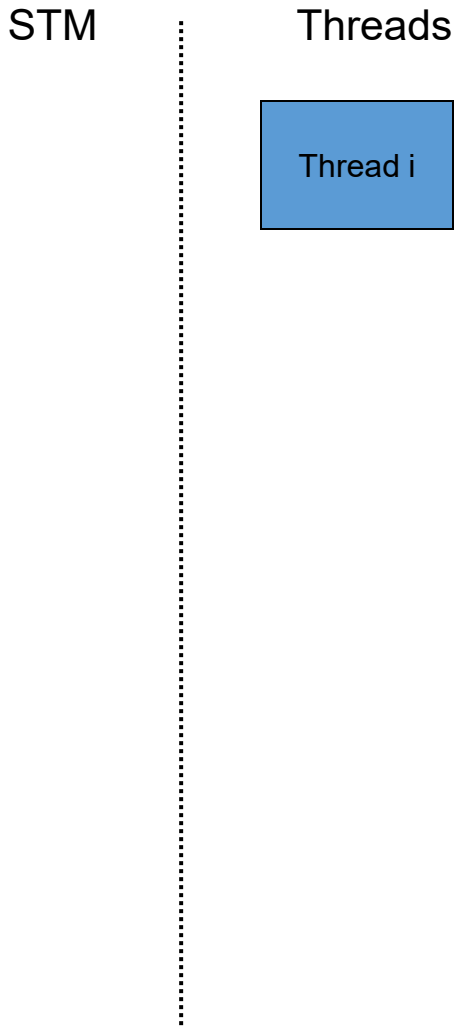



```
public class STM {
        int memory[];
        Rec ownerships[];

        public boolean, int[] startTranscation(Rec rec, int[] dataSet){...};

        private void initialize(Rec rec, int[] dataSet)
        private void transaction(Rec rec, int version, boolean isInitiator) {...};
        private void acquireOwnerships(Rec rec, int version) {...};
        private void releaseOwnershipd(Rec rec, int version) {...};
        private void agreeOldValues(Rec rec, int version) {...};
        private void updateMemory(Rec rec, int version, int[] newvalues) {...};
}
```

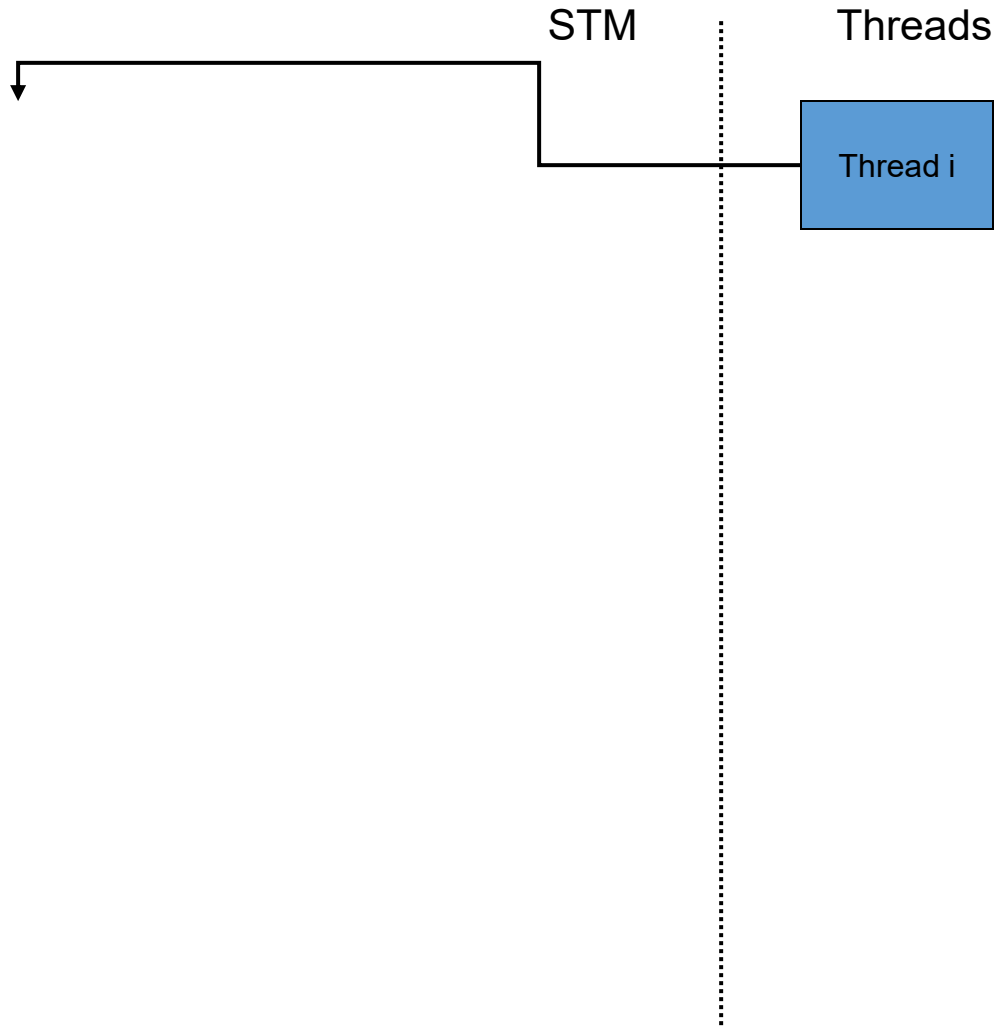
Flow of a transaction



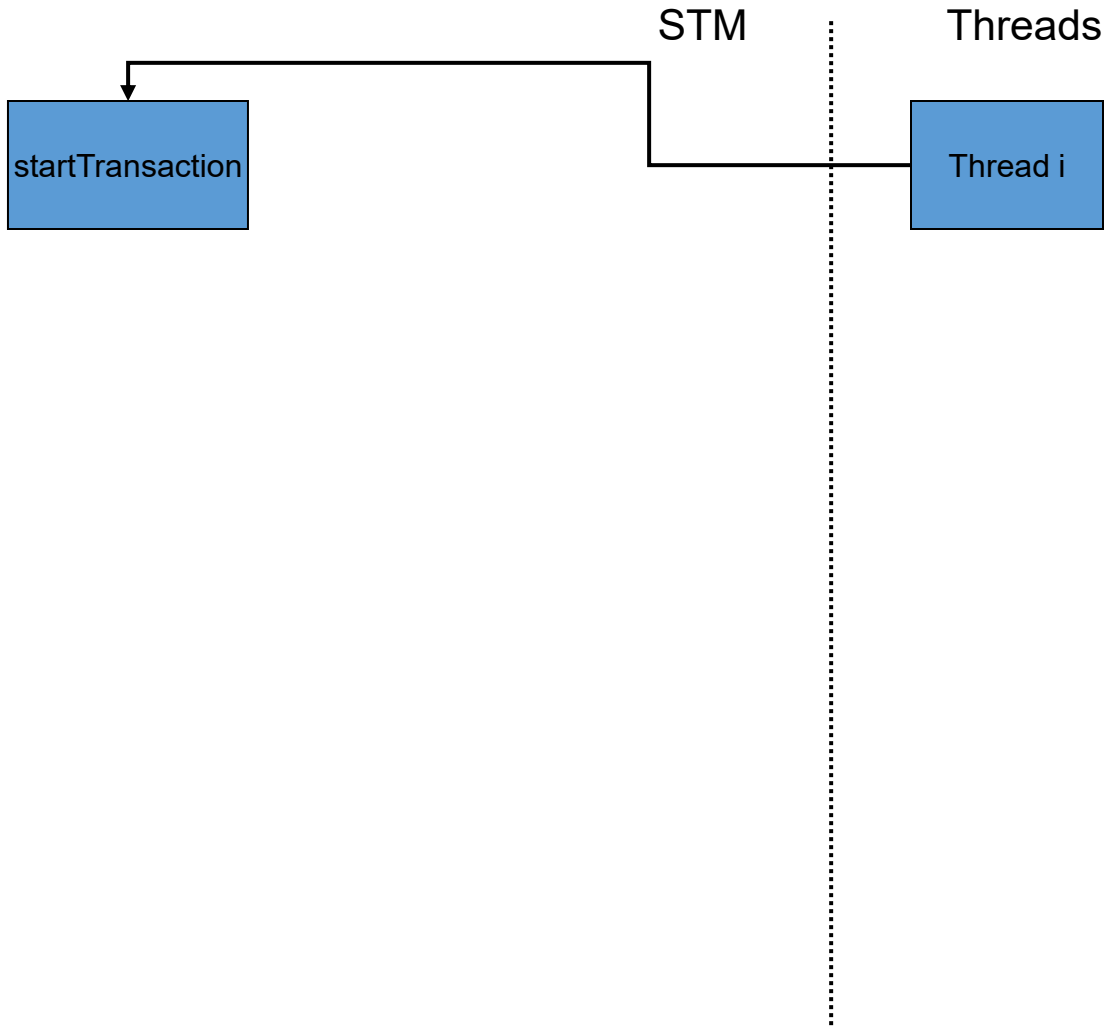
Flow of a transaction



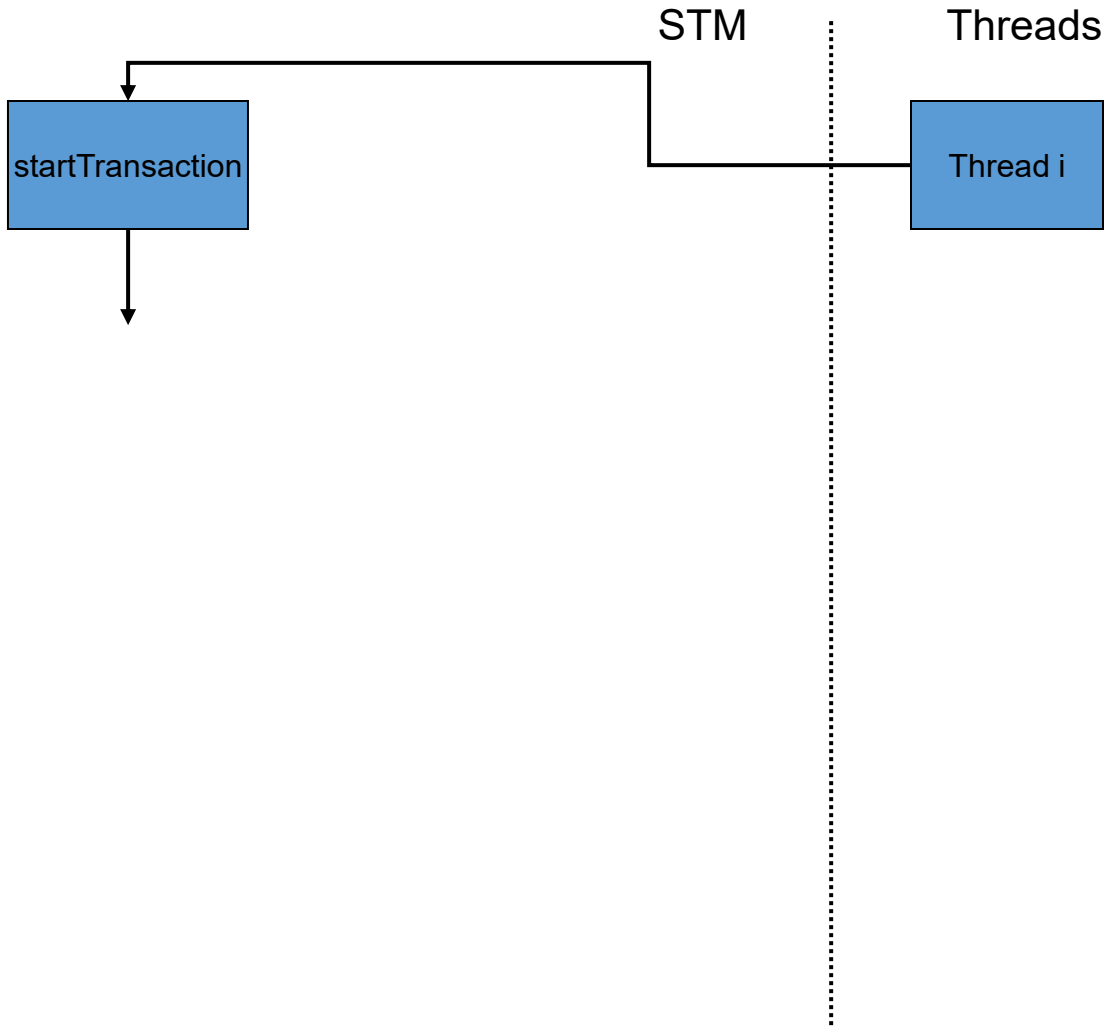
Flow of a transaction



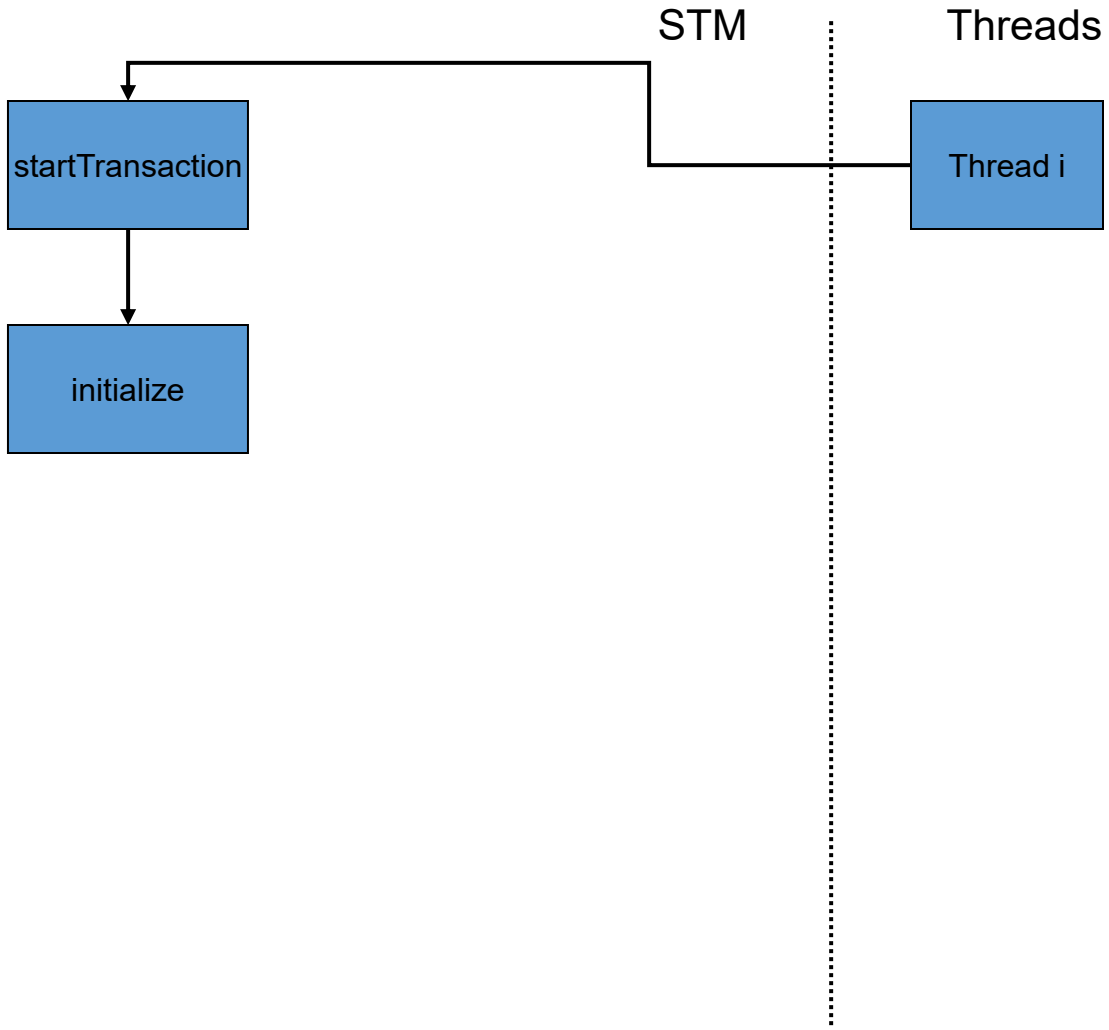
Flow of a transaction



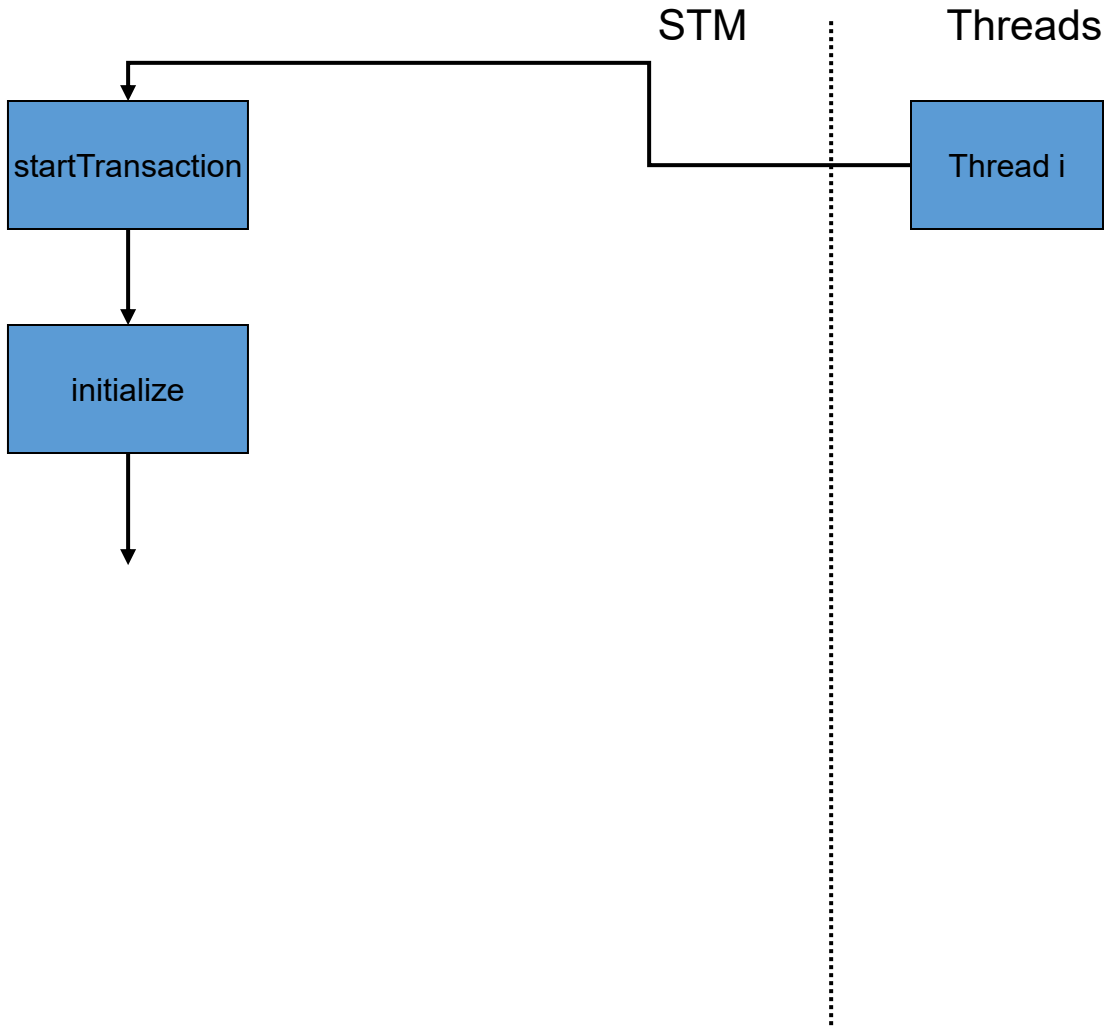
Flow of a transaction



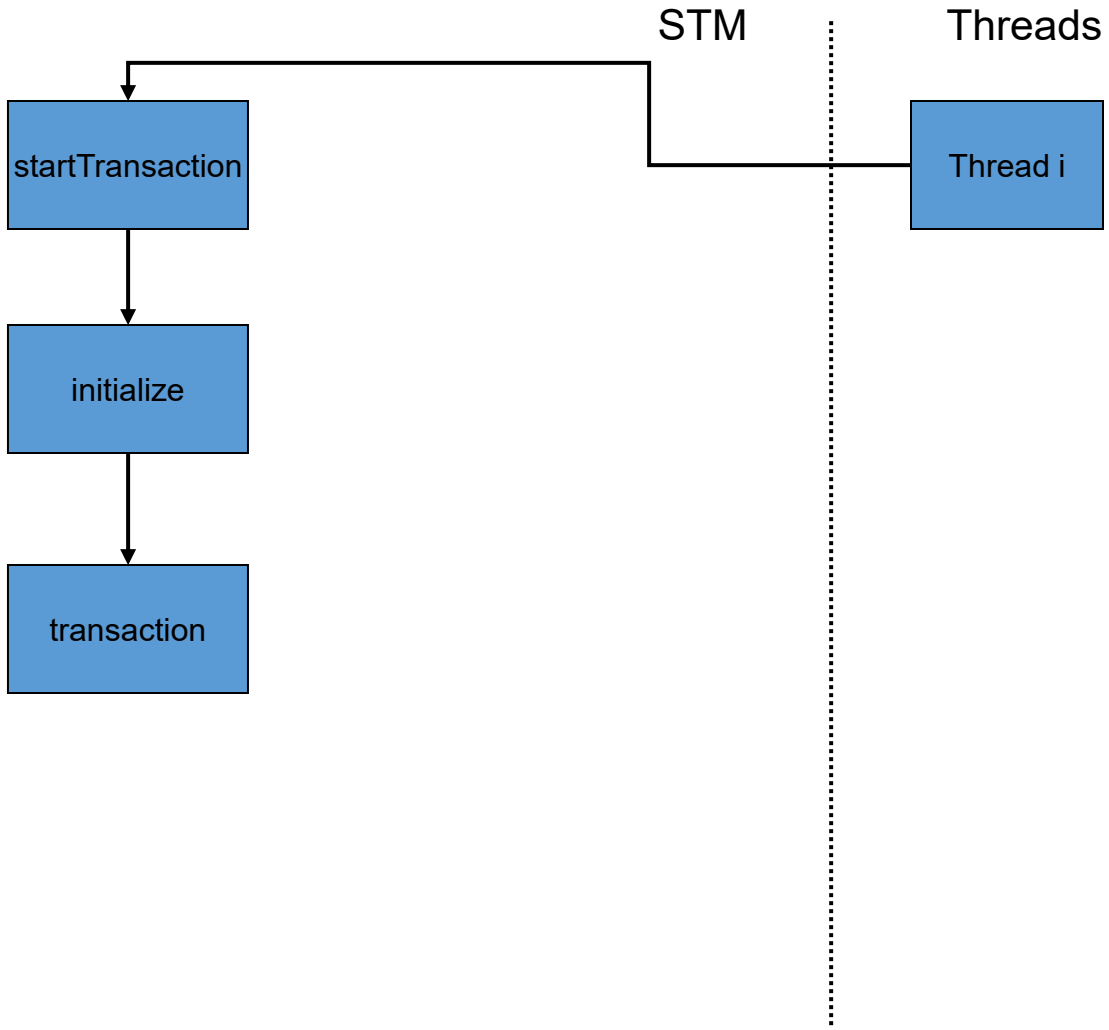
Flow of a transaction



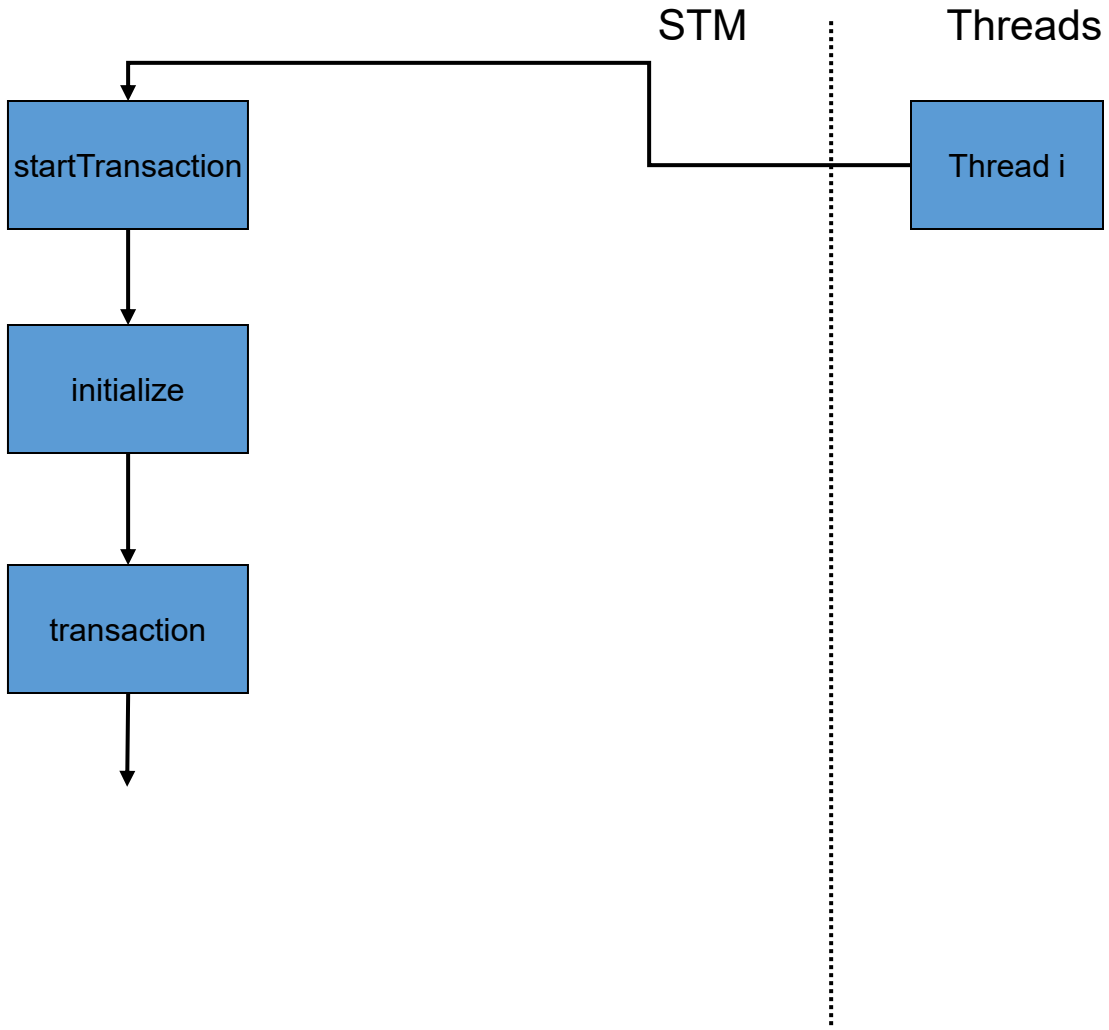
Flow of a transaction



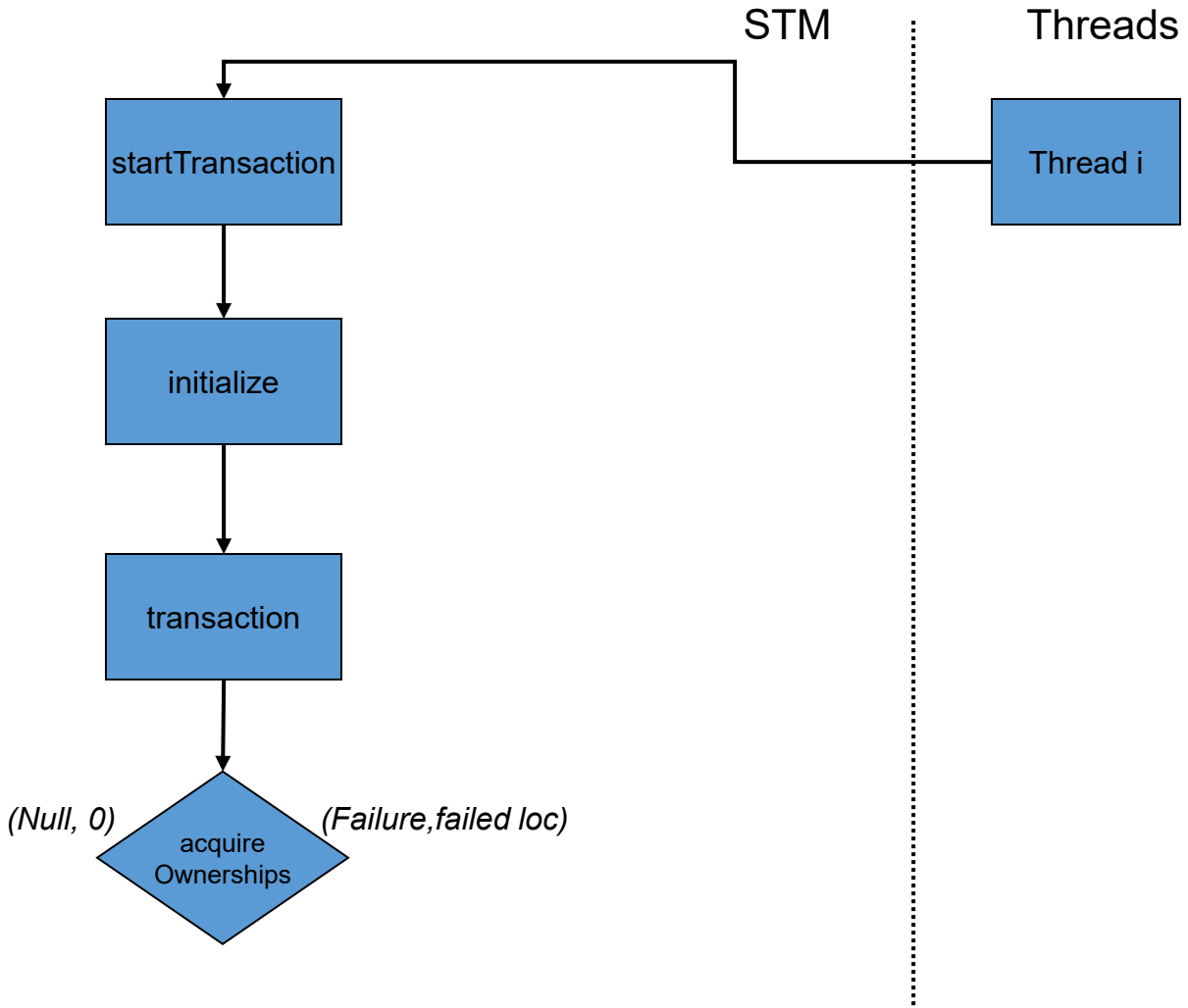
Flow of a transaction



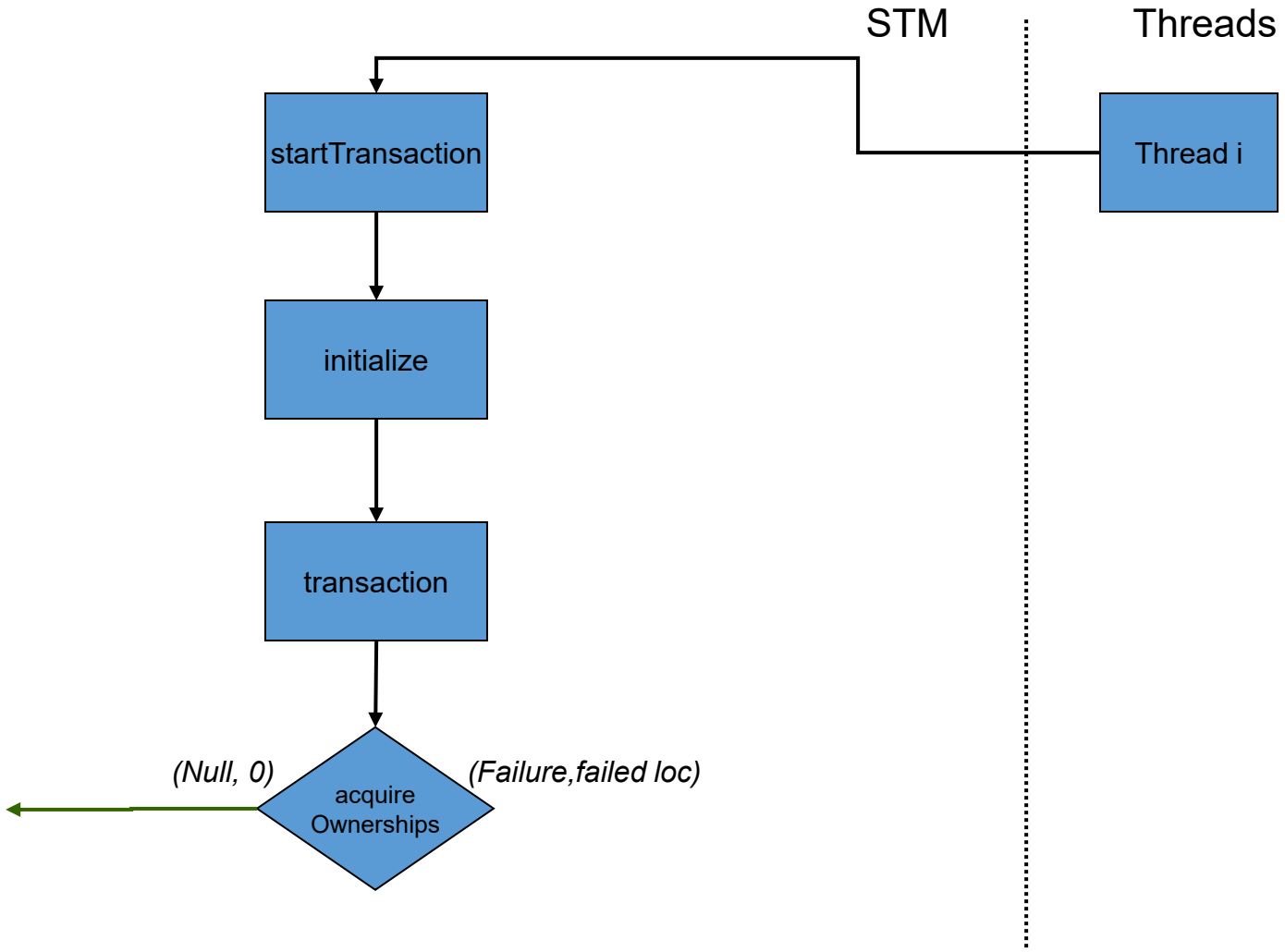
Flow of a transaction



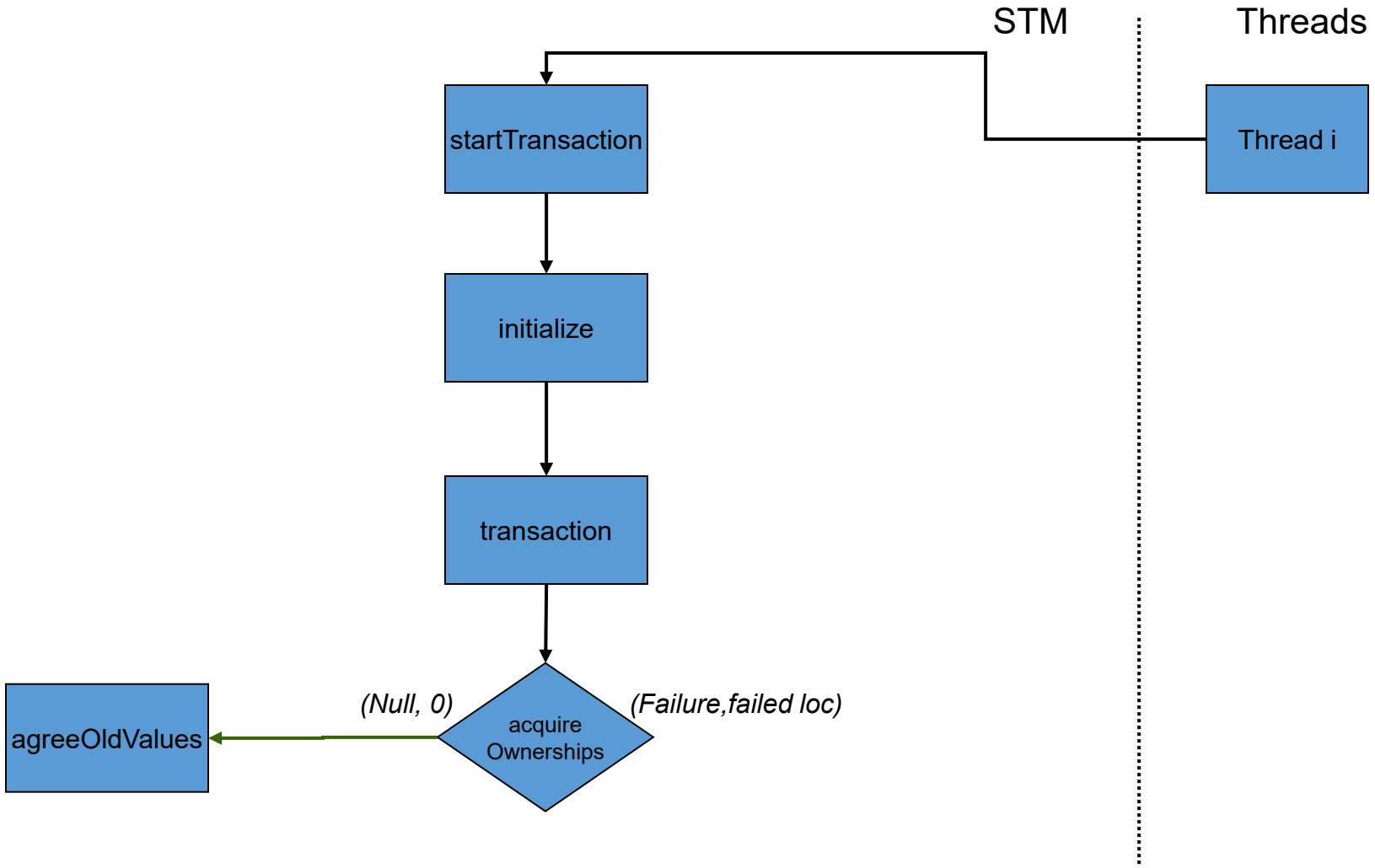
Flow of a transaction



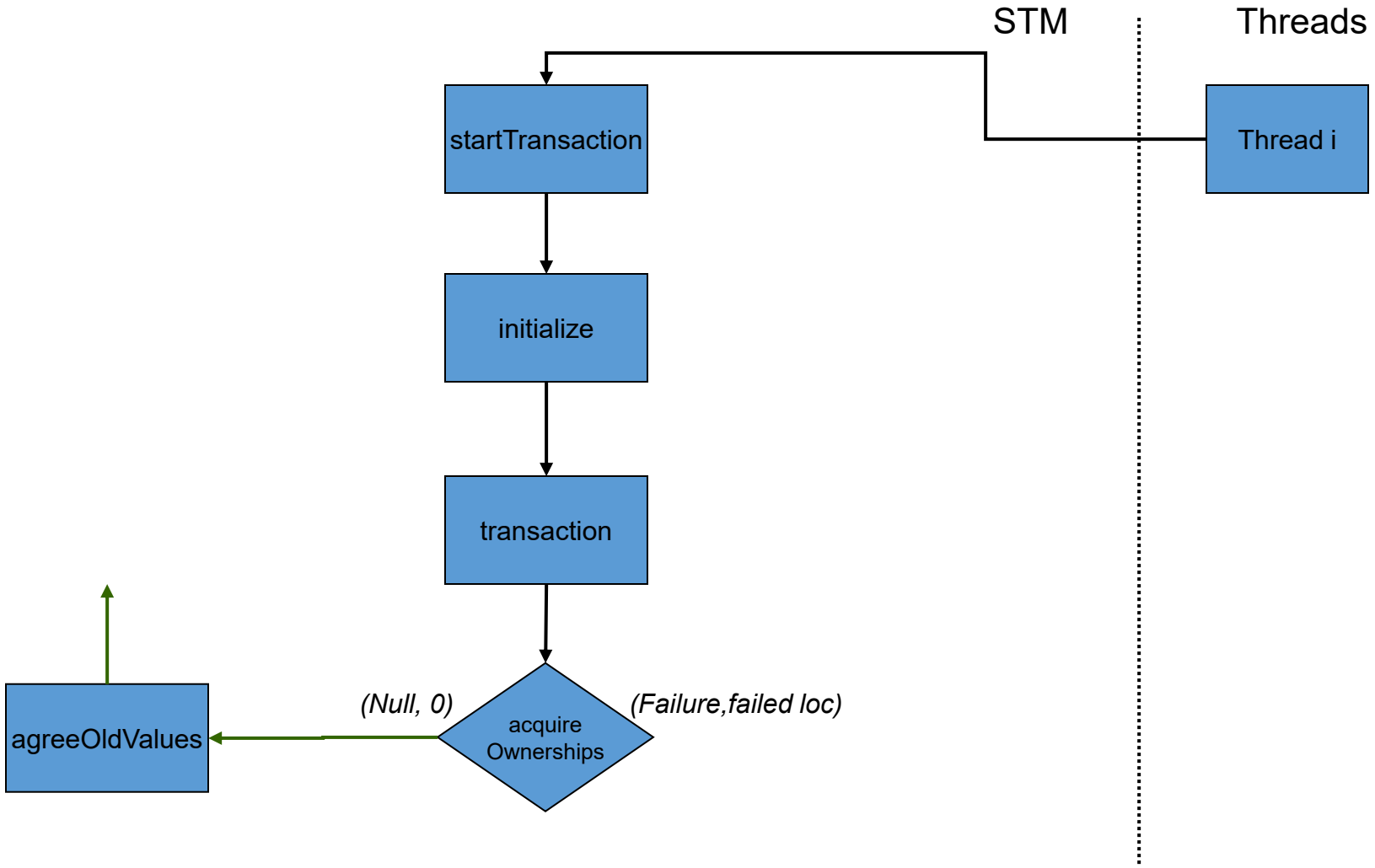
Flow of a transaction



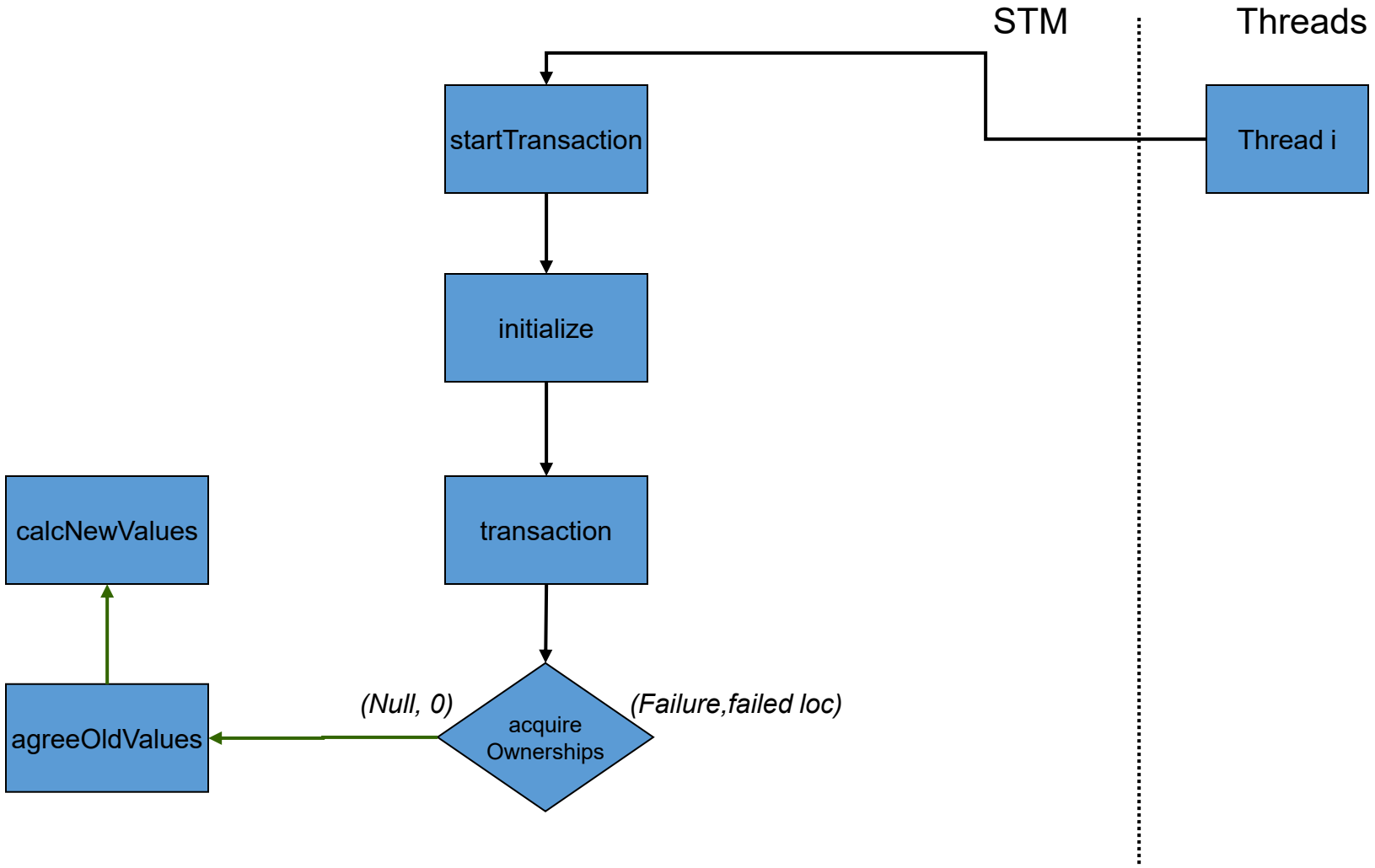
Flow of a transaction



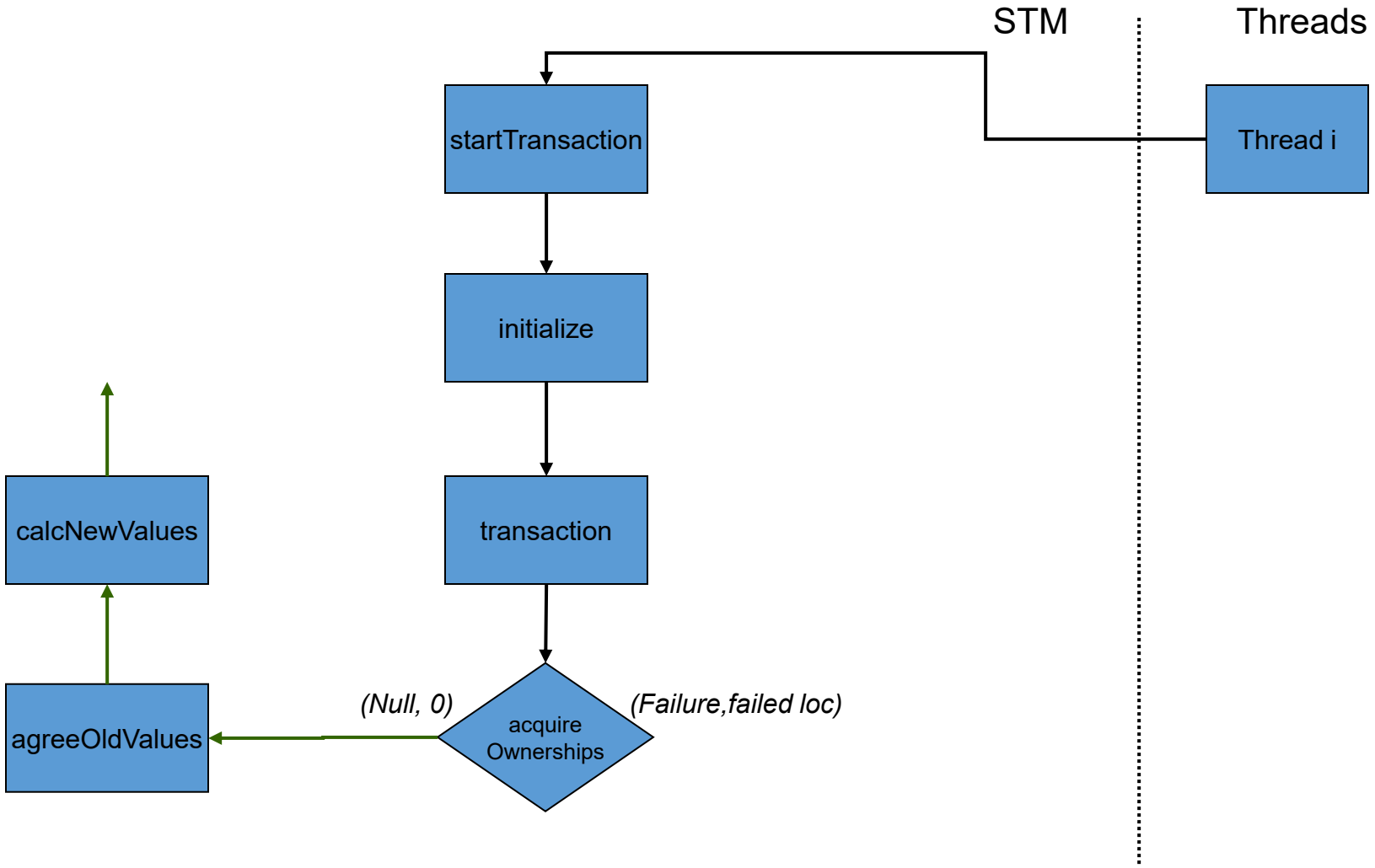
Flow of a transaction



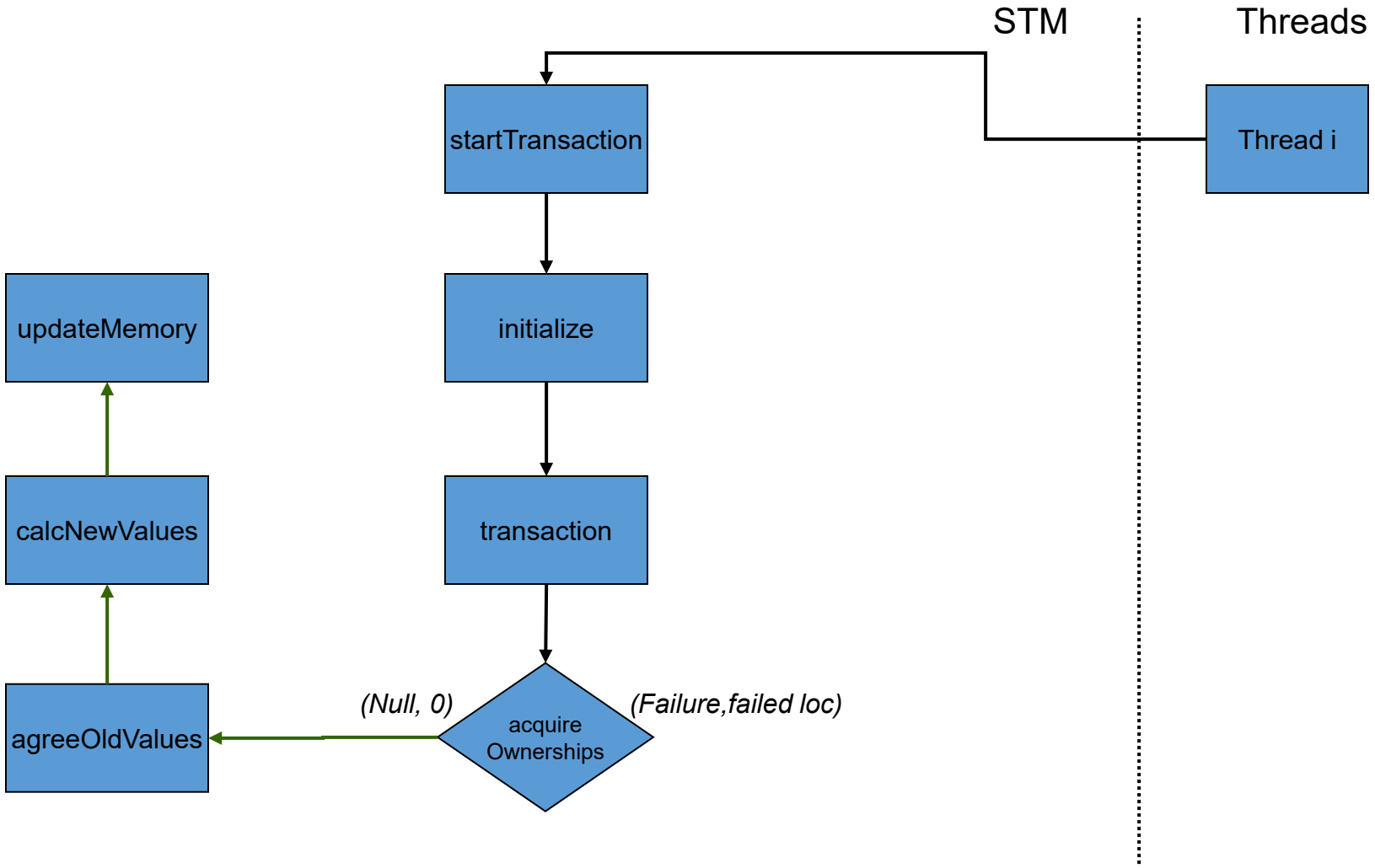
Flow of a transaction



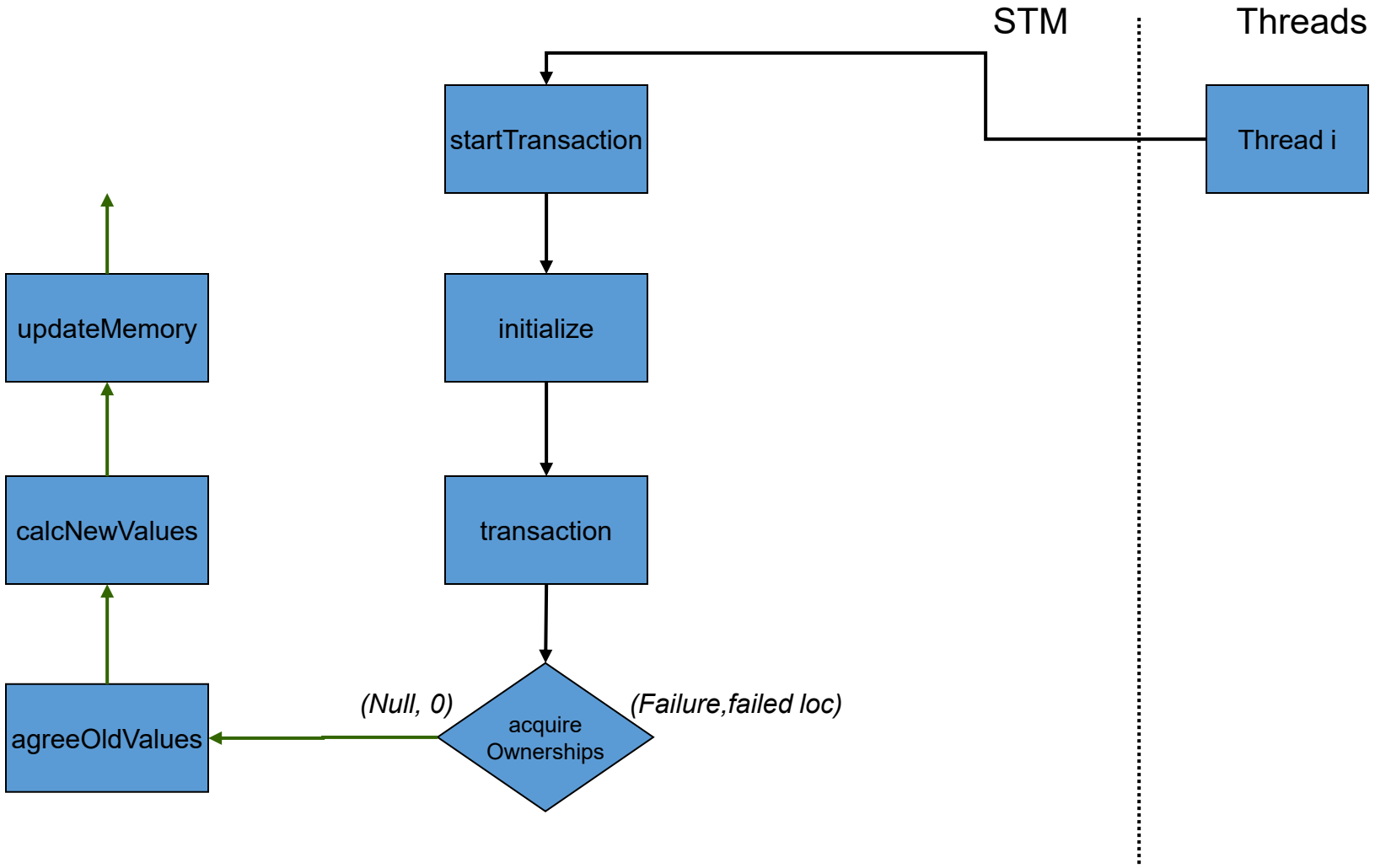
Flow of a transaction



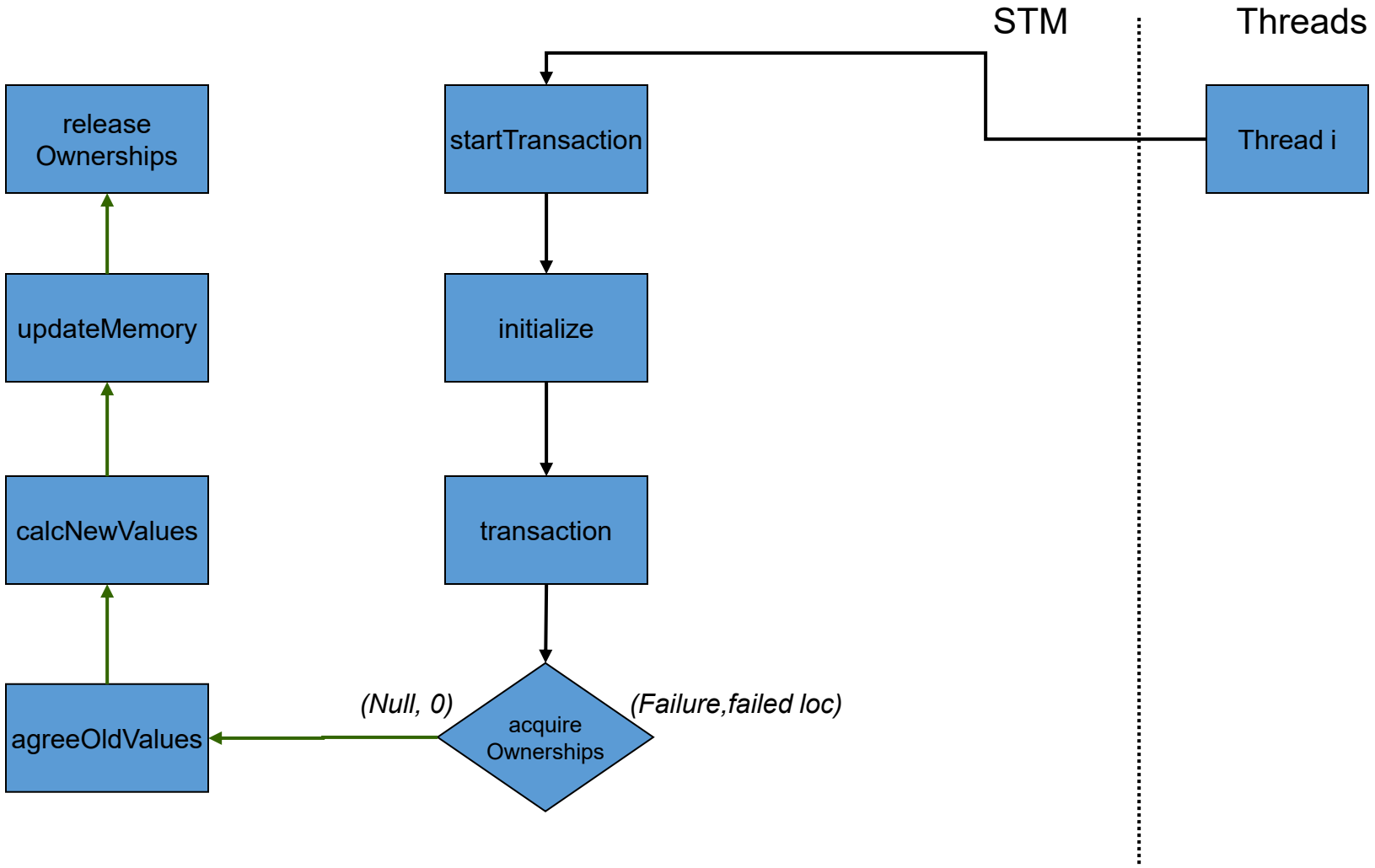
Flow of a transaction



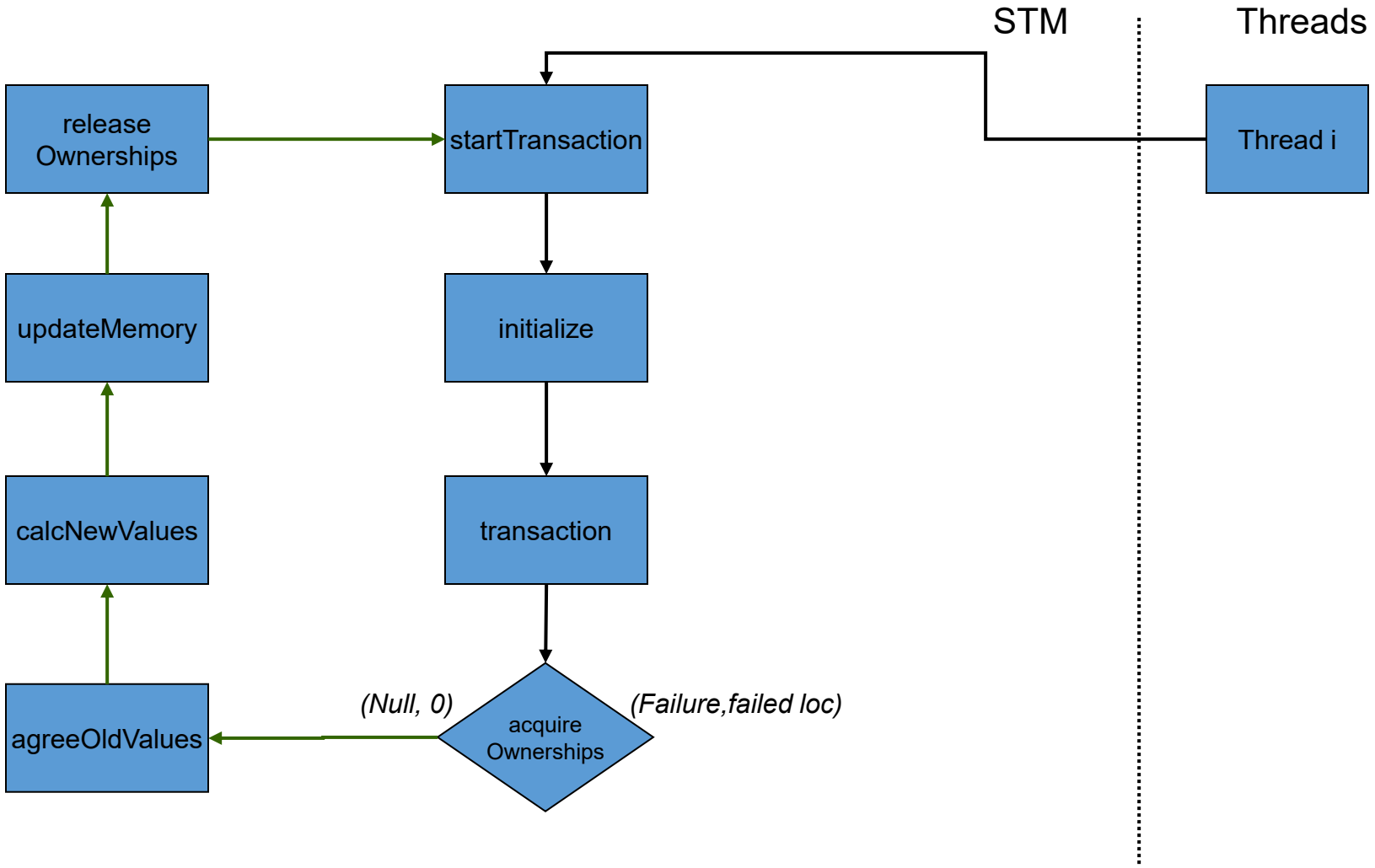
Flow of a transaction



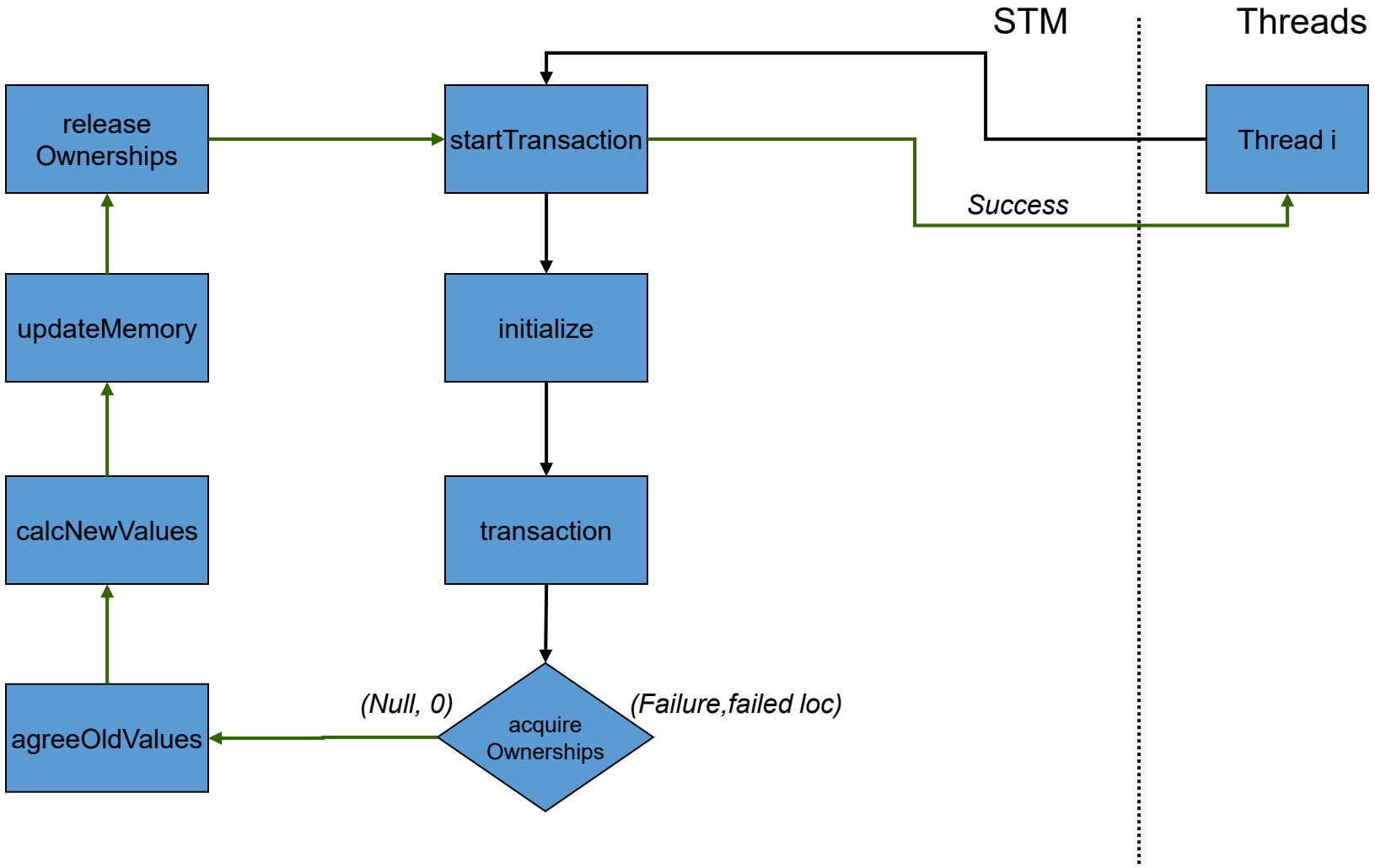
Flow of a transaction



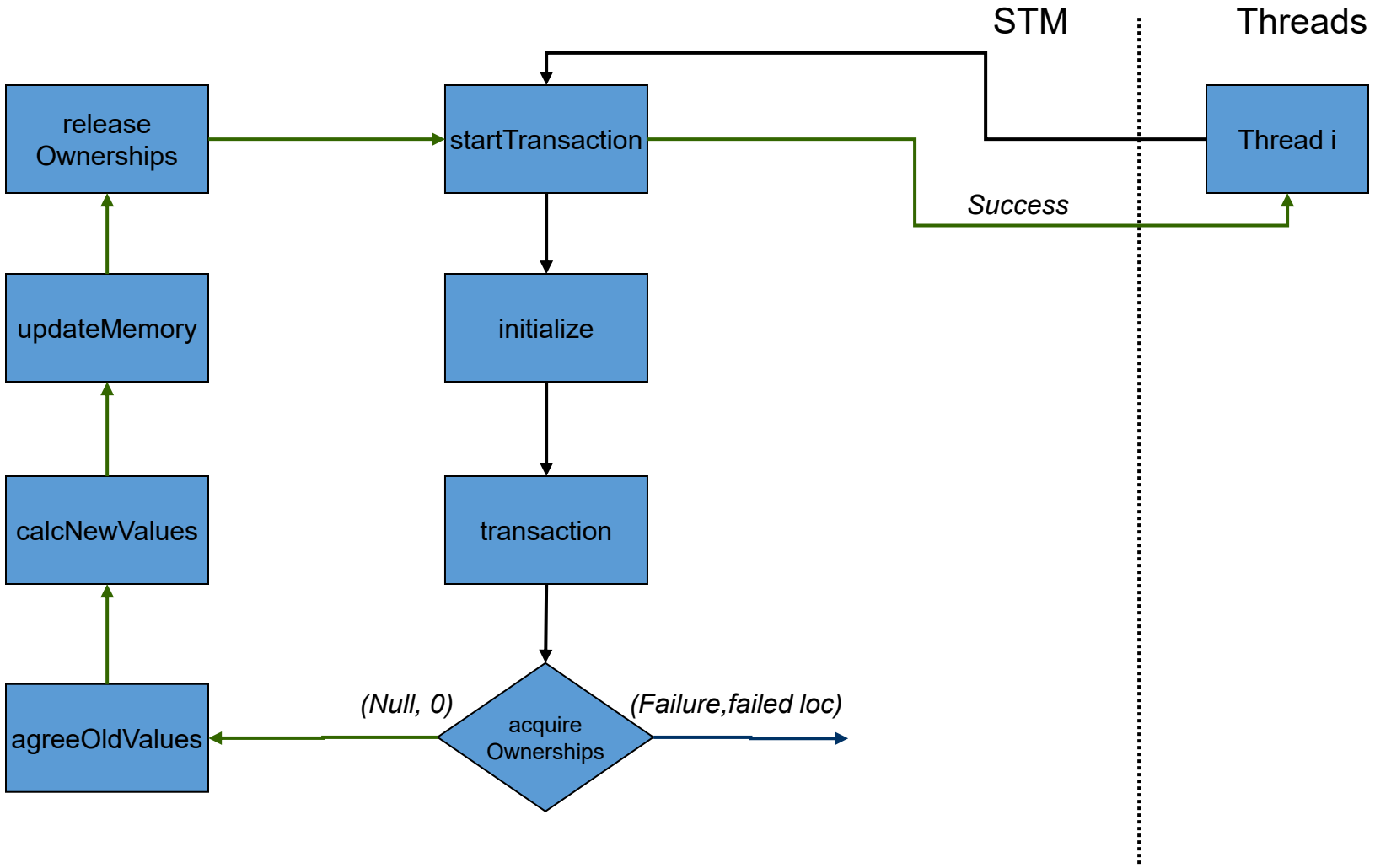
Flow of a transaction



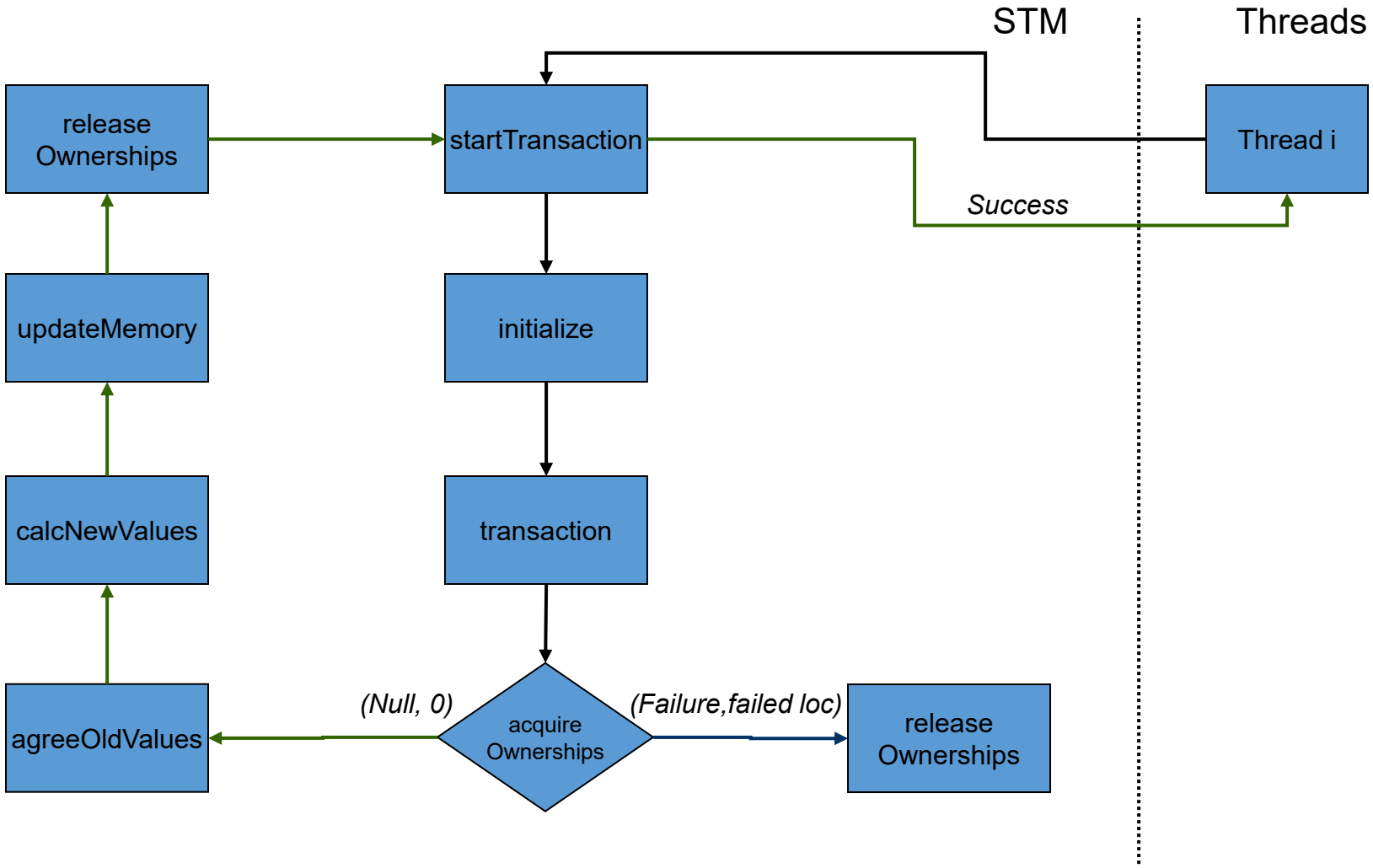
Flow of a transaction



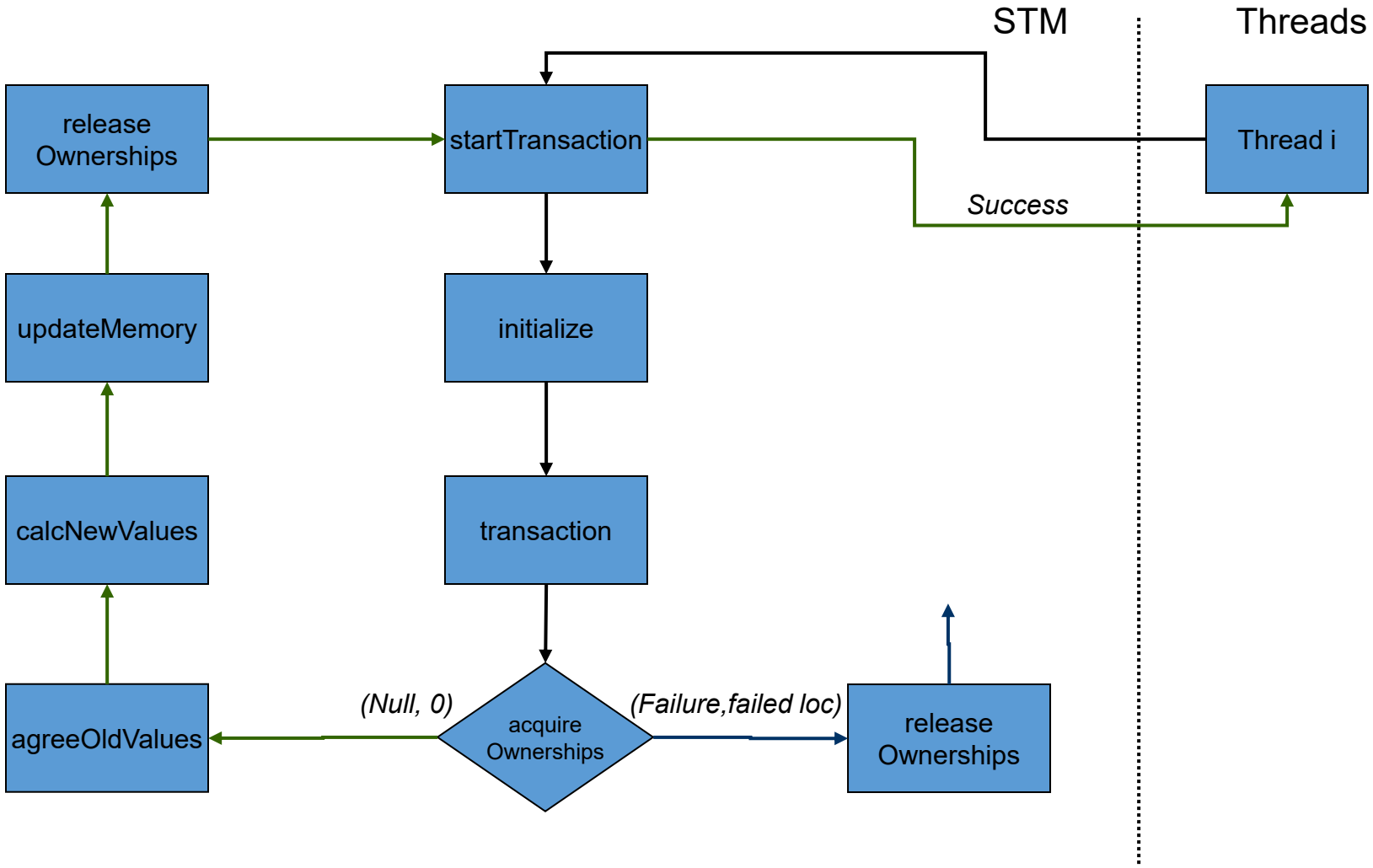
Flow of a transaction



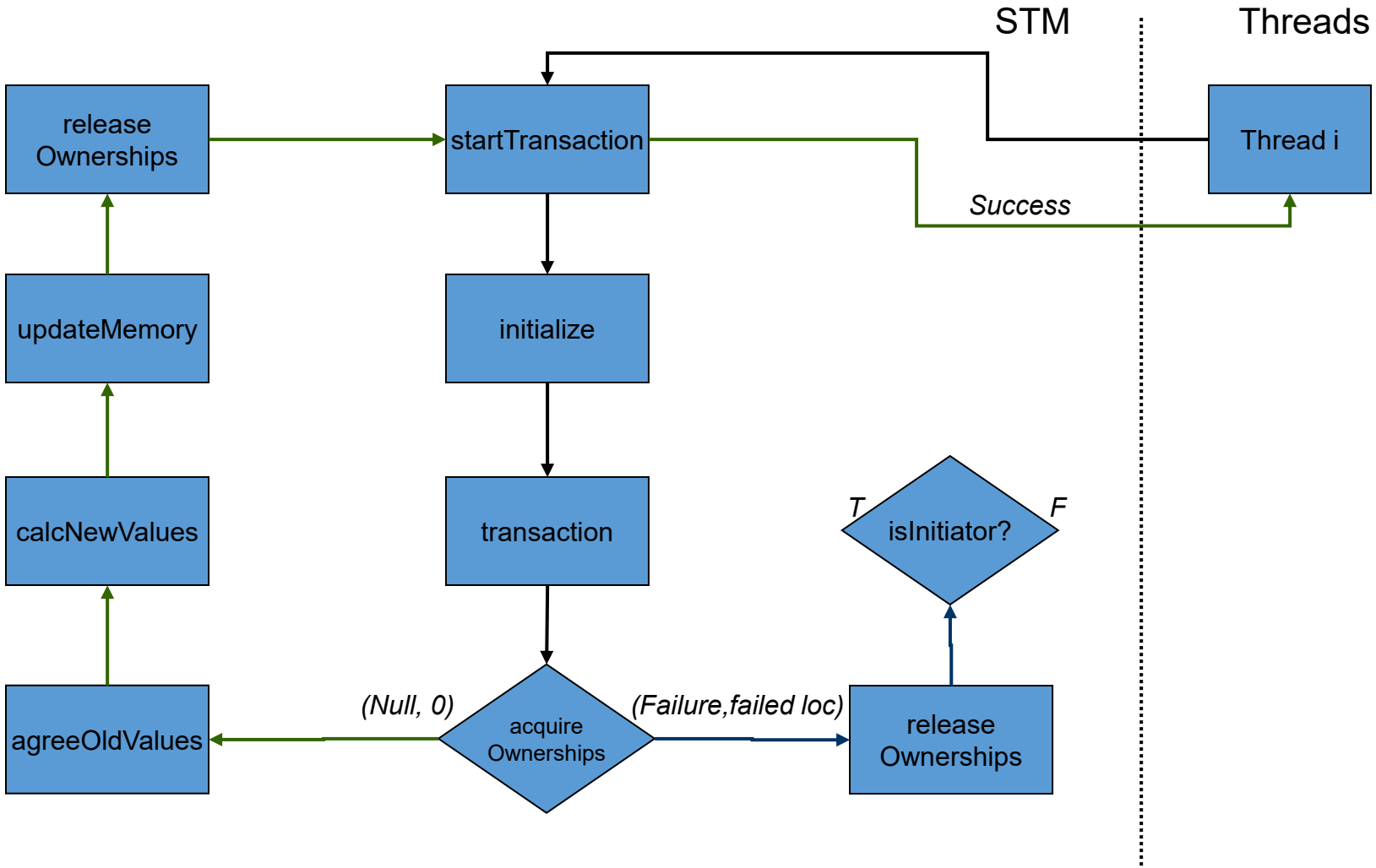
Flow of a transaction



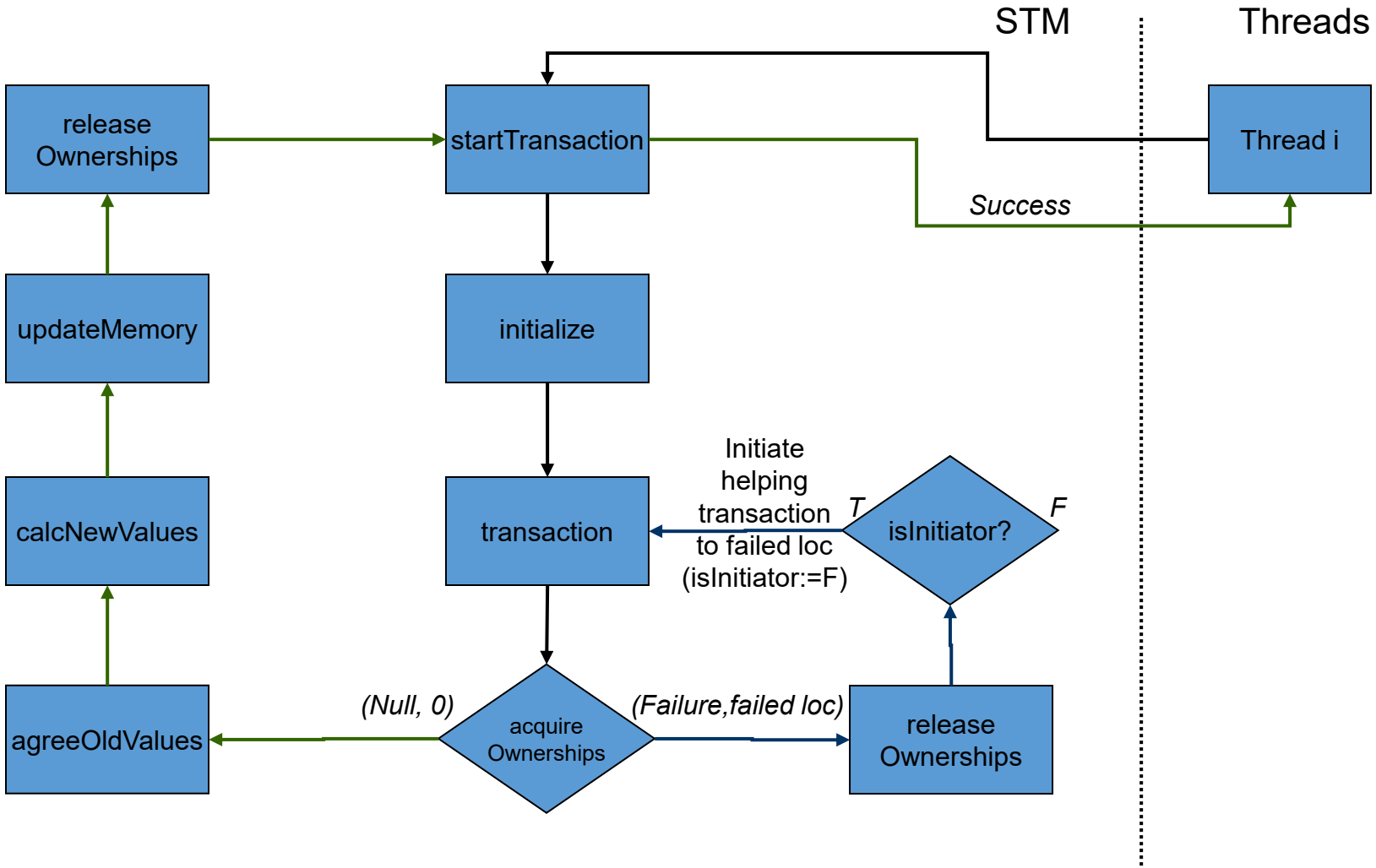
Flow of a transaction



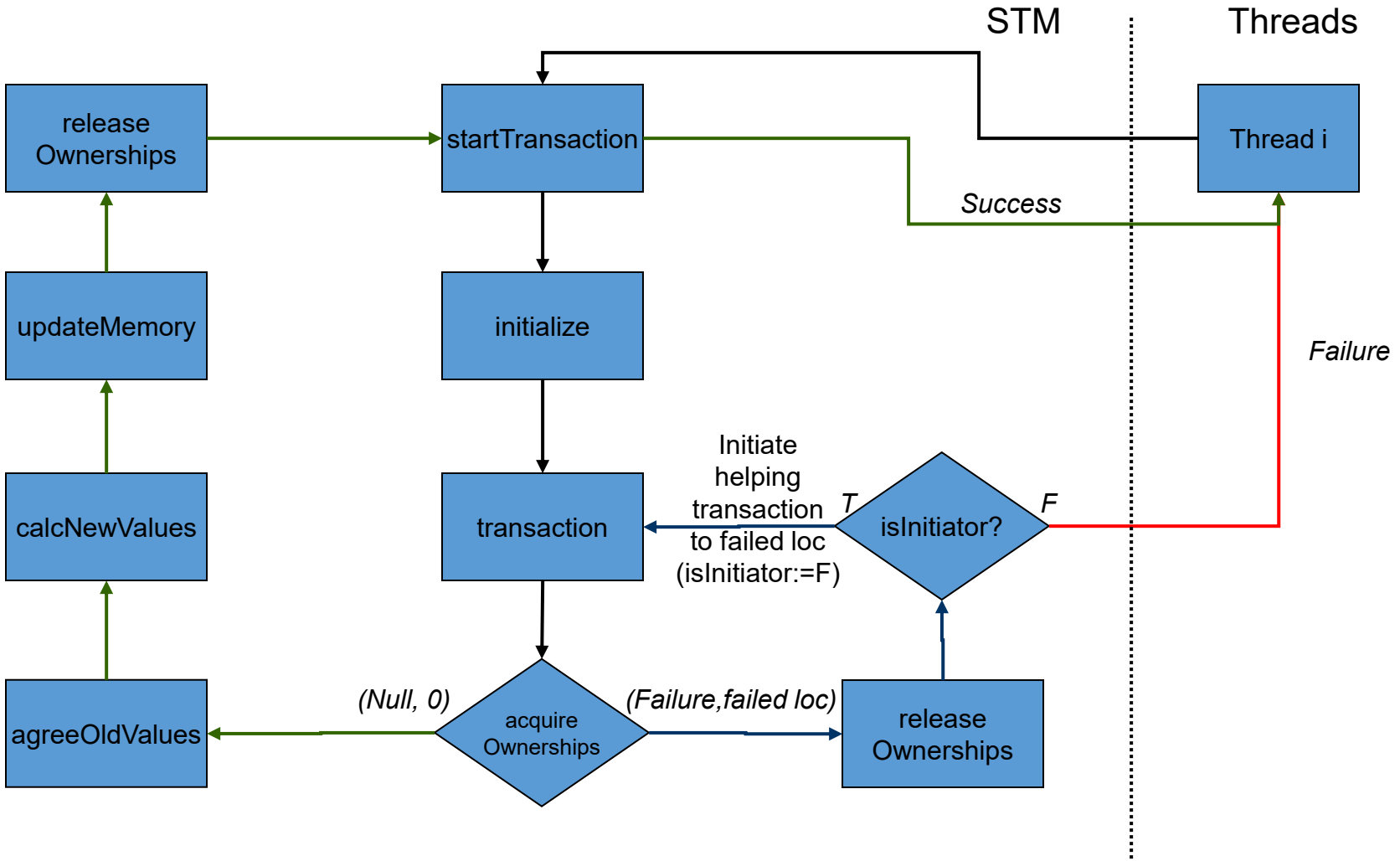
Flow of a transaction



Flow of a transaction



Flow of a transaction



Implementation

```
public boolean, int[] startTranscation(Rec rec, int[] dataSet) {
        initialize(rec, dataSet);
        rec.stable = true;
        transaction(rec, rec.version, true);
        rec.stable = false;
        rec.version++;
        if (rec.status) return (true, rec.oldValues);
        else return false;
}
```

Implementation

```
public boolean, int[] startTranscation(Rec rec, int[] dataSet) {
        initialize(rec, dataSet);
        rec.stable = true;
        transaction(rec, rec.version, true);
        rec.stable = false;
        rec.version++;
        if (rec.status) return (true, rec.oldValues);
        else return false;
}
```

rec – The thread that executes this transaction.
dataSet – The location in memory it needs to own.

Implementation

```
public boolean, int[] startTranscation(Rec rec, int[] dataSet) {
        initialize(rec, dataSet);
        rec.stable = true;
        transaction(rec, rec.version, true);
        rec.stable = false;
        rec.version++;
        if (rec.status) return (true, rec.oldValues);
        else return false;
}
```

rec – The thread that executes this transaction.
dataSet – The location in memory it needs to own.

This notifies other threads that I can be helped

Implementation

```
private void transaction(Rec rec, int version, boolean isInitiator) {
        acquireOwnerships(rec, version); // try to own locations

        (status, failedLoc) = LL(rec.status);
        if (status == null) {              // success in acquireOwnerships
                if (versoin != rec.version) return;
                SC(rec.status, (true,0));
        }

        (status, failedLoc) = LL(rec.status);
        if (status == true) {              // execute the transaction
                agreeOldValues(rec, version);
                int[] newVals = calcNewVals(rec.oldvalues);
                updateMemory(rec, version);
                releaseOwnerships(rec, version);
        }
        else {                             // failed in acquireOwnerships
                releaseOwnerships(rec, version);
                if (isInitiator) {
                        Rec failedTrans = ownerships[failedLoc];
                        if (failedTrans == null) return;
                        else {                          // execute the transaction that owns the location you want
                                int failedVer = failedTrans.version;
                                if (failedTrans.stable) transaction(failedTrans, failedVer, false);
                        }
                }
        }
}
```

Implementation

```
private void transaction(Rec rec, int version, boolean isInitiator) {
        acquireOwnerships(rec, version); // try to own locations

        (status, failedLoc) = LL(rec.status);
        if (status == null) {              // success in acquireOwnerships
                if (versoin != rec.version) return;
                SC(rec.status, (true,0));
        }

        (status, failedLoc) = LL(rec.status);
        if (status == true) {              // execute the transaction
                agreeOldValues(rec, version);
                int[] newVals = calcNewVals(rec.oldvalues);
                updateMemory(rec, version);
                releaseOwnerships(rec, version);
        }
        else {                             // failed in acquireOwnerships
                releaseOwnerships(rec, version);
                if (isInitiator) {
                        Rec failedTrans = ownerships[failedLoc];
                        if (failedTrans == null) return;
                        else {                          // execute the transaction that owns the location you want
                                int failedVer = failedTrans.version;
                                if (failedTrans.stable) transaction(failedTrans, failedVer, false);
                        }
                }
        }
}
```

rec – The thread that executes this transaction.
version – Serial number of the transaction.
isInitiator – Am I the initiating thread or the helper?

Implementation

```
private void transaction(Rec rec, int version, boolean isInitiator) {
        acquireOwnerships(rec, version); // try to own locations

        (status, failedLoc) = LL(rec.status);
        if (status == null) {              // success in acquireOwnerships
                if (versoin != rec.version) return;
                SC(rec.status, (true,0));
        }

        (status, failedLoc) = LL(rec.status);
        if (status == true) {              // execute the transaction
                agreeOldValues(rec, version);
                int[] newVals = calcNewVals(rec.oldvalues);
                updateMemory(rec, version);
                releaseOwnerships(rec, version);
        }
        else {                             // failed in acquireOwnerships
                releaseOwnerships(rec, version);
                if (isInitiator) {
                        Rec failedTrans = ownerships[failedLoc];
                        if (failedTrans == null) return;
                        else {                          // execute the transaction that owns the location you want
                                int failedVer = failedTrans.version;
                                if (failedTrans.stable) transaction(failedTrans, failedVer, false);
                        }
                }
        }
}
```

rec – The thread that executes this transaction.
version – Serial number of the transaction.
isInitiator – Am I the initiating thread or the helper?

Another thread own the locations I need and it hasn't finished its transaction yet.

So I go out and execute its transaction in order to help it.

Implementation

```
private void acquireOwnerships(Rec rec, int version) {
        for (int j=1; j<=rec.size; j++) {
                while (true) do {
                        int loc = locs[j];
                        if LL(rec.status) != null return;    // transaction completed by some other thread
                        Rec owner = LL(ownerships[loc]);
                        if (rec.version != version) return;
                        if (owner == rec) break; // location is already mine
                        if (owner == null) {        // acquire location
                                if ( SC(rec.status, (null, 0)) ) {
                                  if ( SC(ownerships[loc], rec) ) {
                                    break;
                                  }
                                }
                        }
                        else {// location is taken by someone else
                                if ( SC(rec.status, (false, j)) ) return;
                        }

                }

        }
}
```

If I'm not the last one to read this field, it means that another thread is trying to execute this transaction. Try to loop until I succeed or until the other thread completes the transaction

Implementation

```
private void agreeOldValues(Rec rec, int version) {
        for (int j=1; j<=rec.size; j++) {
                int loc = locs[j];
                if ( LL(rec.oldvalues[loc]) != null ) {
                        if (rec.version != version) return;
                        SC(rec.oldvalues[loc], memory[loc]);
                }
        }
}
```

Copy the dataSet to my private space

```
private void updateMemory(Rec rec, int version, int[] newvalues) {
        for (int j=1; j<=rec.size; j++) {
                int loc = locs[j];
                int oldValue = LL(memory[loc]);
                if (rec.allWritten) return;     // work is done
                if (rec.version != version) return;
                if (oldValue != newValues[j]) SC(memory[loc], newValues[j]);
        }
        if (! LL(rec.allWritten) ) {
             if (rec.version != version) SC(rec.allWritten, true);
        }
}
```

Selectively update the shared memory

HTM vs. STM

Hardware	Software
Fast (due to hardware operations)	Slow (due to software validation/commit)
Light code instrumentation	Heavy code instrumentation
HW buffers keep amount of metadata low	Lots of metadata
No need of a middleware	Runtime library needed
Only short transactions allowed (why?)	Large transactions possible

HTM vs. STM

Hardware	Software
Fast (due to hardware operations)	Slow (due to software validation/commit)
Light code instrumentation	Heavy code instrumentation
HW buffers keep amount of metadata low	Lots of metadata
No need of a middleware	Runtime library needed
Only short transactions allowed (why?)	Large transactions possible

How would you get the best of both?

Hybrid-TM

- Best-effort HTM (use STM for long trx)
- Possible conflicts between HW,SW and HW-SW Trx
  - What kind of conflicts do SW-Trx care about?
  - What kind of conflicts do HW-Trx care about?
- Some initial proposals:
  - HyTM: uses an ownership record per memory location (overhead?)
  - PhTM: HTM-only or (heavy) STM-only, low instrumentation

Questions?