Script generated by TTT

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TECHNISCHE UNIVERSITÄT MÜNCHEN
FAKULTÄT FÜR INFORMATIK

Programming Languages

Concurrency: Transactions

Dr. Axel Simon and Dr. Michael Petter
Winter term 2014

Abstraction and Concurrency

Two fundamental concepts to build larger software are:

abstraction : an object storing certain data and providing certain functionality may be used without reference to its internals

composition : several objects can be combined to a new object without interference

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Consider an example:

- a linked list data structure exposes a fixed set of operations to modify the list structure, such as `PushLeft` and `ForAll`
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⇝ unlike sequential algorithms, thread-safe algorithms cannot always be composed to give new thread-safe algorithms

Transactional Memory [2]

Idea: automatically convert `atomic` blocks into code that ensures atomic execution of the statements.

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atomic {
  // code
  if (cond) retry;
  atomic {
    // more code
  }
  // code
}
```

Execute code as *transaction*:

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- provide a `retry` keyword similar to the `wait` of monitors

Managing Conflicts

Definition (Conflicts)

A conflict *occurs* when accessing the same piece of data, a conflict is *detected* when the TM system observes this, it is *resolved* when the TM system takes action (by delaying or aborting a transaction).

Design choices for transactional memory implementations:

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Design choices for TM that allow conflicts to happen:

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   - *tentative* detect conflicts before transactions commit, e.g. aborting when transaction TA reads while TB may writes the same location
   - *committed* detect conflicts only against transactions that have committed

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Concurrency control
- pessimistic
- optimistic
  - version management
    - lazy — redo
    - eager — undo
  - Conflict detection
    - eager
    - validating
    - lazy
      - reference of conflict
        - tentative
        - committed

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- serializability for transactions is insufficient to perform synchronization between threads

Consistency During Transactions

Consistency during a transaction.

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Definition (opacity)

A TM system provides *opacity* if failing transactions are serializable w.r.t. committing transactions.

⇝ failing transactions still sees a consistent view of memory

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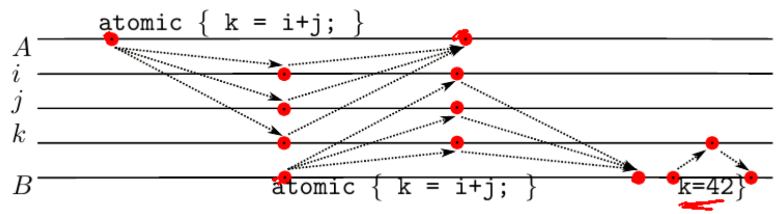
Definition (SLA)

The *single-lock atomicity* is a model in which the program executes as if all transactions acquire a single, program-wide mutual exclusion lock.

Properties of Single-Lock Atomicity



Observation:

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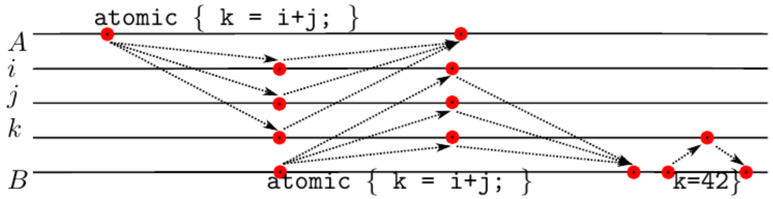

Observation:

- SLA enforces order between TM and non-TM accesses ✓

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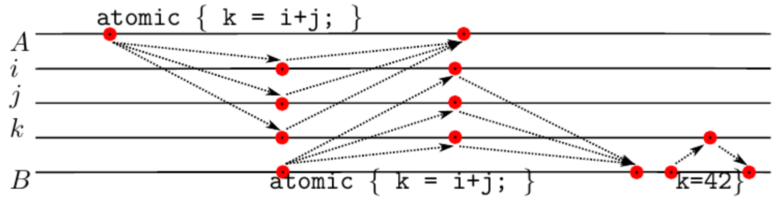

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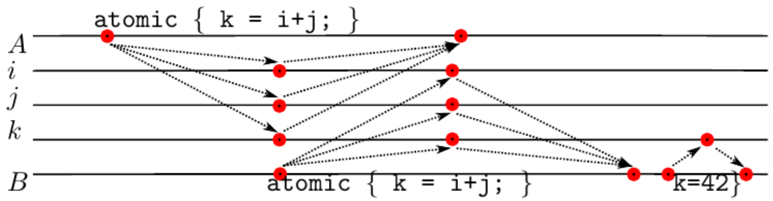

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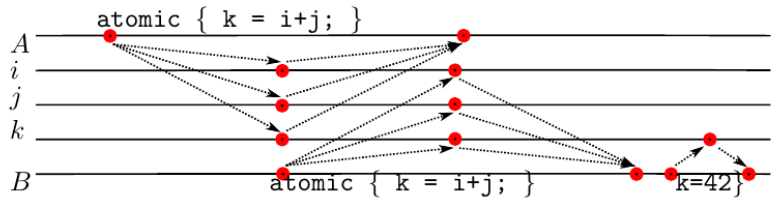

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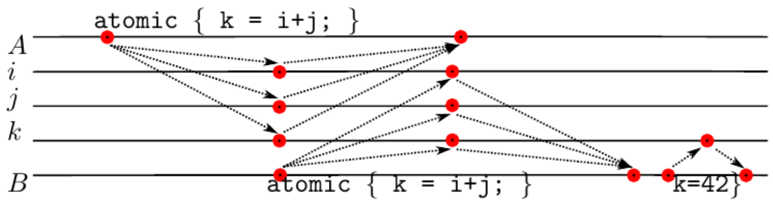

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- the content of non-TM memory conveys information which `atomic` block has executed, even if the TM regions do not access the same memory
  - ▸ SLA makes it possible to use `atomic` block for synchronization

Disadvantages of the SLA model

The SLA model is *simple* but often too strong:

1. SLA has a weaker *progress* guarantee than a transaction should have

```
// Thread 1
atomic {
  while (true) {};
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// Thread 2
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  int tmp = x; // x in TM
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2. SLA correctness is too strong in practice

```
// Thread 1
data = 1;
atomic {
}
ready = 1;
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// Thread 2
atomic {
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⇝ need a weaker model for more flexible implementation of *strong isolation*

Transactional Sequential Consistency

How about a more permissive view of transaction semantics?

- TM should not have the blocking behaviour of locks
- ⇝ the programmer cannot rely on synchronization

Definition (TSC)

The *transactional sequential consistency* is a model in which the accesses within each transaction are sequentially consistent.

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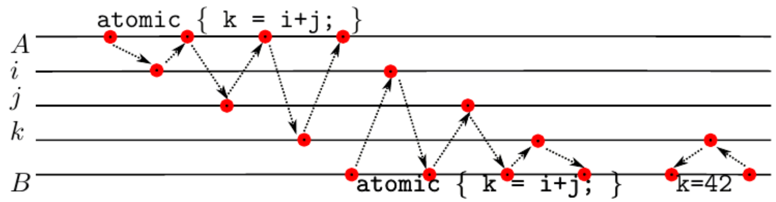

- TSC is weaker: gives *strong isolation*, but allows parallel execution ✓
- TSC is stronger: accesses within a transaction may *not* be re-ordered ⚠

Quick Quiz

Associate one item on the left with one or two on the right.

1. a transaction waits rather than creating a conflict
2. in case of a conflict, a kind of log is needed
3. no opacity: a zombie transaction sees an inconsistent state
4. no guarantee if a program accesses variables via TM and non-TM
5. a write in a transaction is immediately globally visible

- redo and undo 2
- conflict detection 3
- concurrency control 1
- isolation 4
- version management 5

- eager, 5
  lazy 3
- optimistic,
  pessimistic 1
- strong,
  weak 4

Translation of `atomic`-Blocks

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Convert `atomic` blocks as follows:

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atomic {
  // code
}
```

$\Longrightarrow$

```
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  // code with ReadTx and WriteTx
} while (!CommitTx());
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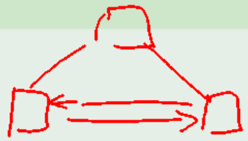
- translation can be done using a pre-processor
  - determining a minimal set of memory accesses that need to be transactional requires a good static analysis
  - *idea*: translate all accesses to global variables and the heap as TM
  - more fine-grained control using manual translation
- an actual implementation might provide a `retry` keyword
  - when executing `retry`, the transaction aborts and re-starts
  - the transaction will again wind up at `retry` unless its *read set* changes
  - ⇝ block until a variable in the read-set has changed
  - similar to condition variables in monitors

Transactional Memory for the Queue

If a preprocessor is used, `PopRight` can be implemented as follows:

double-ended queue: removal



```
int PopRight(DQueue* q) {
  QNode* oldRightNode;
  QNode* rightSentinel = q->right;
  atomic {
    oldRightNode = rightSentinel->left;
    if (oldRightNode==leftSentinel) retry;
    QNode* newRightNode = oldRightNode->left;
    newRightNode->right = rightSentinel;
    rightSentinel->left = newRightNode;
  }
  int val = oldRightNode->val;
  free(oldRightNode);
  return val;
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```

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  int val = oldRightNode->val;
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```

- the transaction will abort if other threads call `PopRight`
- if the queue is empty, it may abort if `PushLeft` is executed

A Software TM Implementation

A software TM implementation allocates a *transaction descriptor* to store data specific to each `atomic` block, for instance:

- *undo-log* of writes if writes have to be undone if a commit fails
- *redo-log* of writes if writes are postponed until a commit
- *read-* and *write-set*: locations accessed so far
- *read-* and *write-version*: time stamp when value was accessed

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TL2 stores a *global version* counter and:

- a read version in each *object* (allocate a few bytes more in each call to `malloc`, or inherit from a *transaction object* in e.g. Java)
- a redo-log in the transaction descriptor
- a read- and a write-set in the transaction descriptor
- a read-version: the version when the transaction started

Principles of TL2

The idea: obtain a version `tx.RV` from the global clock when starting the transaction, the *read-version*, and set the versions of all written cells to a new version on commit.
A read from a field at `offset` of object `obj` is implemented as follows:

transactional read

```
int ReadTx(TMDesc tx, object obj, int offset) {
  if (&(obj[offset]) in tx.redoLog) {
    return tx.redoLog[&obj[offset]];
  } else {
    atomic { v1 = obj.timestamp; locked = obj.sem<1; };
    result = obj[offset];
    v2 = obj.timestamp;
    if (locked || v1 != v2 || v1 > tx.RV) AbortTx(tx);
  }
  tx.readSet = tx.readSet.add(obj);
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`WriteTx` is simpler: add or update the location in the redo-log.

Committing a Transaction

A transaction can succeed if none of the read locations has changed:

committing a transaction

```
bool CommitTx(TMDesc tx) {
  foreach (e in tx.writeSet)
    if (!try_wait(e.obj.sem)) goto Fail;
  WV = FetchAndAdd(&globalClock);
  foreach (e in tx.readSet)
    if (e.obj.version > tx.RV) goto Fail;
  foreach (e in tx.redoLog)
    e.obj[e.offset] = e.value;
  foreach (e in tx.writeSet) {
    e.obj = WV; signal(e.obj.sem);
  }
  return true;
Fail:
  // signal all acquired semaphores
  return false;
}
```


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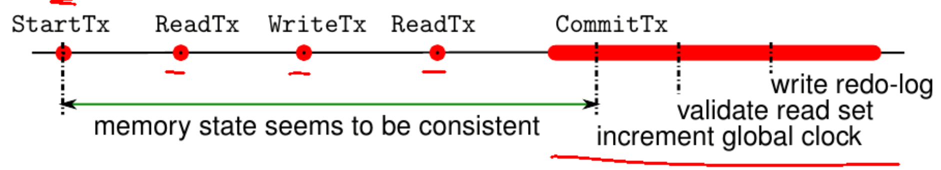

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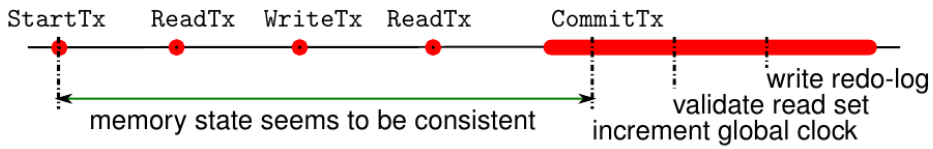

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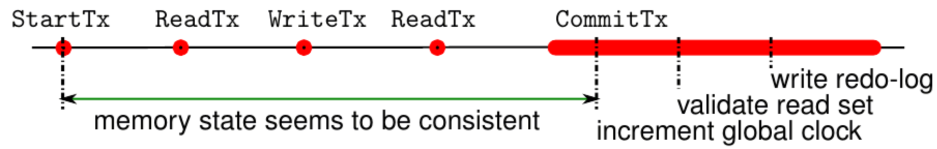

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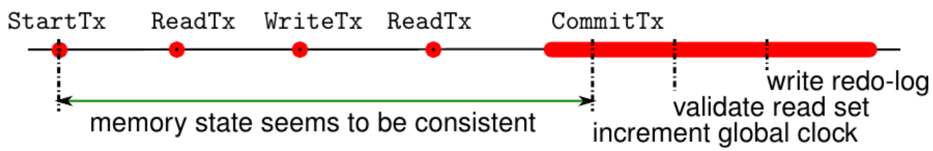

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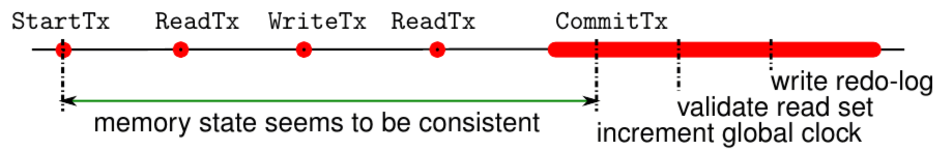

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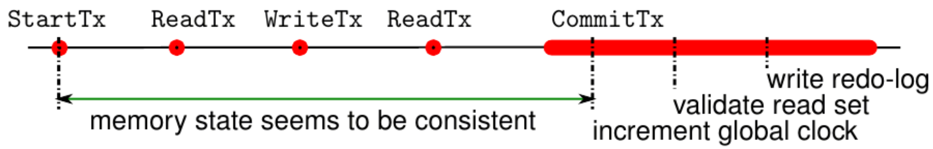

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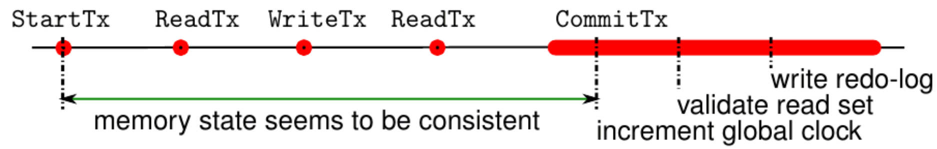

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  - read version+lock, `lfence`, read value, `lfence`, read version

General Challenges when using TM

Executing `atomic` blocks by repeatedly trying to executing them non-atomically creates new problems:

- a transaction might unnecessarily be aborted