Towards validating software transactional memory libraries

Martin Nowack (martin@se.inf.tu-dresden.de);
Christof Fetzer
TU Dresden, Germany

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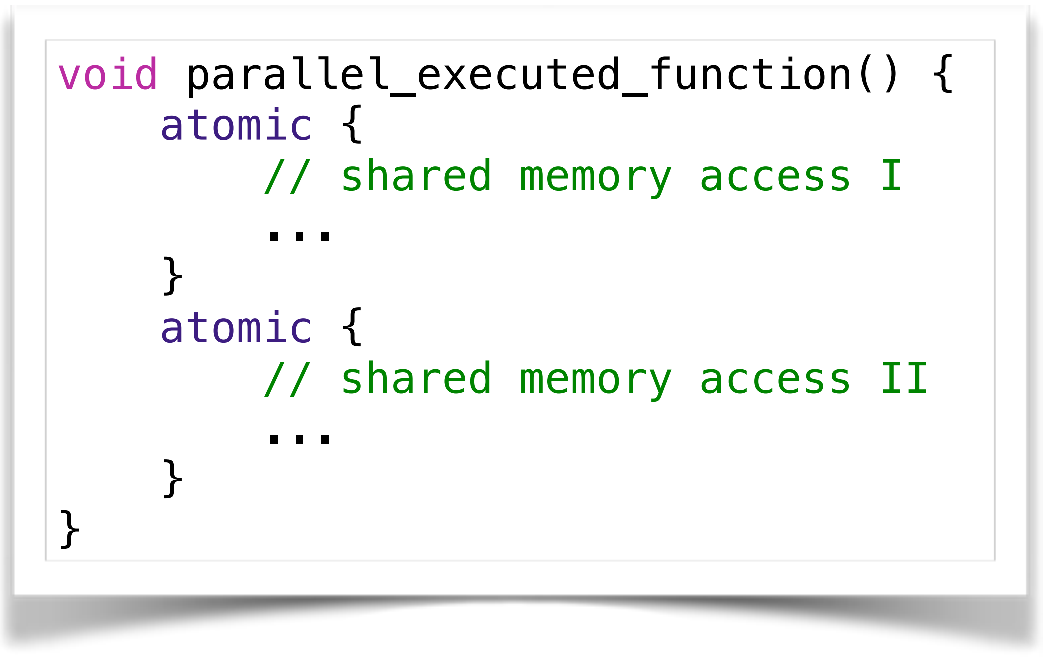
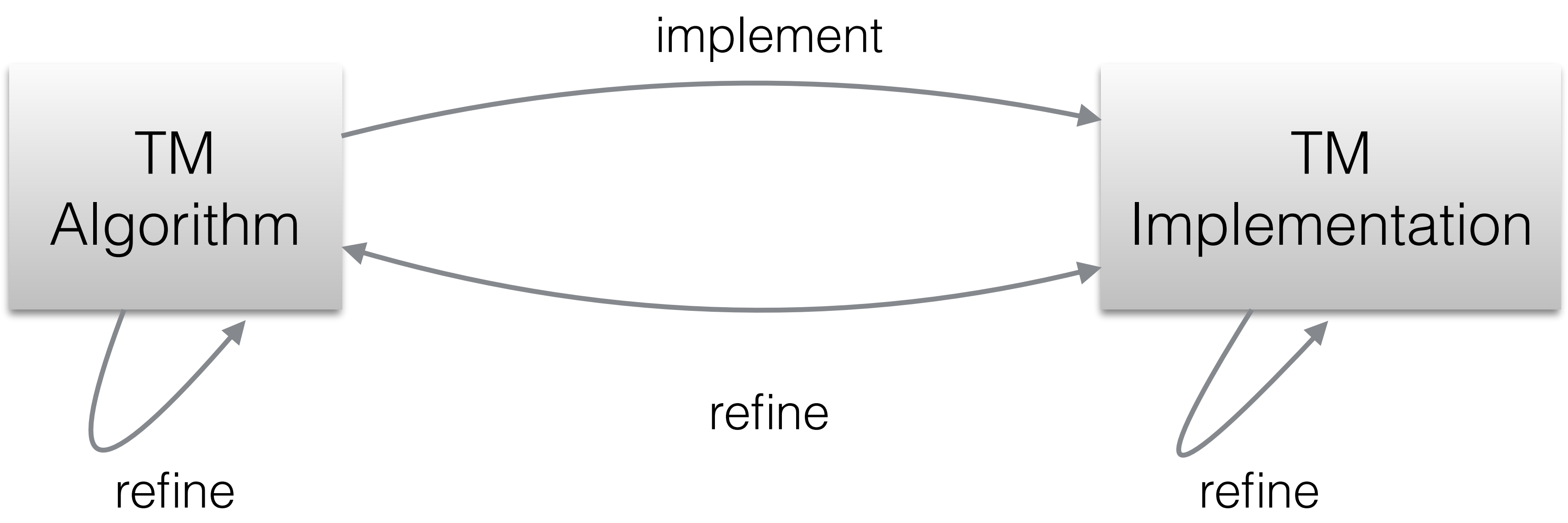
Motivation

- **Goal:** Provide easy-to-use synchronisation mechanism for Joe Programmer
  - ➡ Ease reasoning by providing illusion of atomic behaviour of code sections

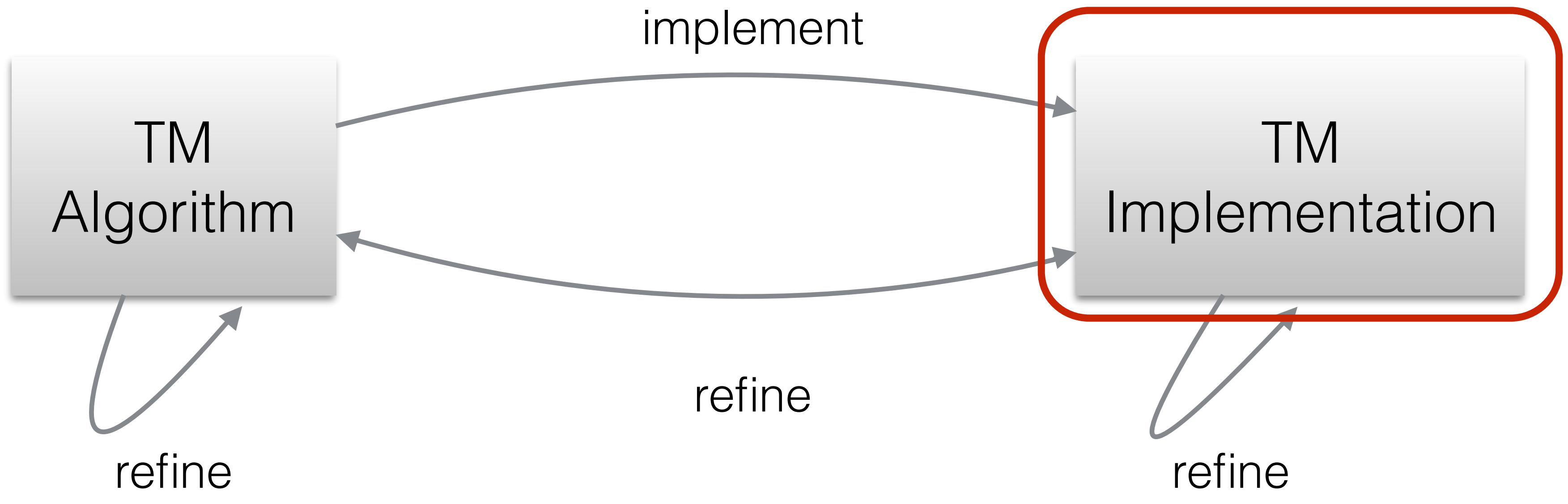
- Development of (S)TM algorithms and libraries are a daunting task



```
void parallel_executed_function() {
    atomic {
        // shared memory access I
        ...
    }
    atomic {
        // shared memory access II
        ...
    }
}
```



How to validate?



Model checking [1,2]

→Abstract
but systematic

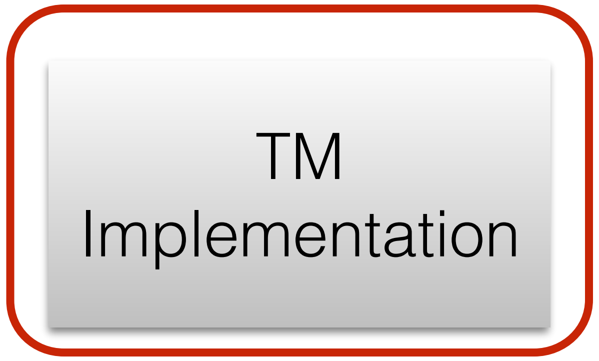
Software Testing

→unit test [3]
→stress test [3]

→Real Code

[1] “Towards Formally Specifying and Verifying Transactional Memory” Doherty et al., ENTCS, 2009
[2] “Implementing and Evaluating a Model Checker for Transactional Memory Systems”, Baek et al., ICECCS, 2010
[3] “TMunit: Testing software transactional memories”,Harmanci et al., Transact, 2009

How to Validate Implementations?



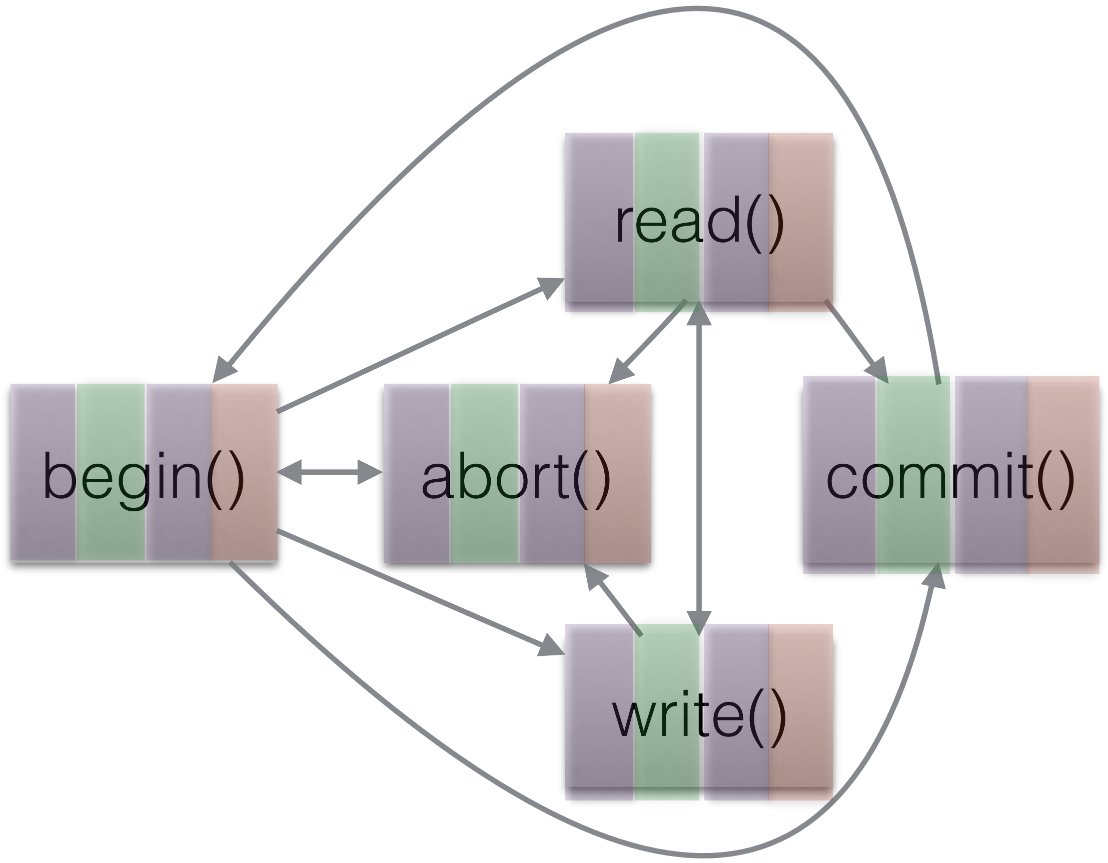
- How to test TM?
  Test different combinations of that protocol

- Two types of bugs [1]:

  - Bohr: sequentially executed code trigger bugs in the general case

  - Heisen: hard to trigger, e.g. due to concurrency

TM API and protocol



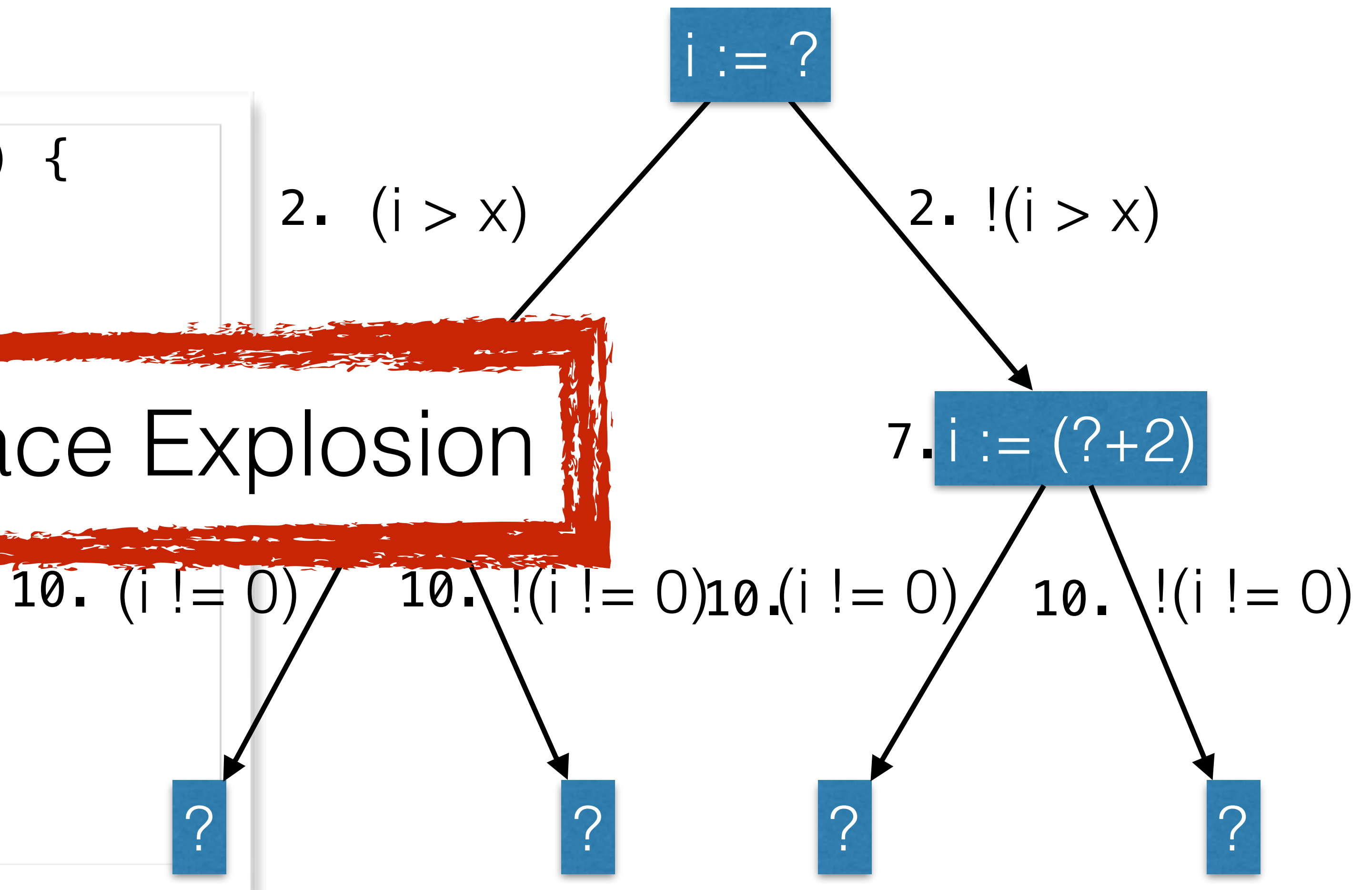
1. Gray, Jim. "Why do computers stop and what can be done about it?." Symposium on reliability in distributed software and database systems. 1986.

Symbolic Execution [1,2]

```
unsigned char x = 5;

1.  unsigned char foo(unsigned char i) {
2.    if (i > x) {
3.      // true branch
4.      i++;
5.    } else {
6.      // false branch
7.      i = i + 2;
8.    }
9.
10.   assert(i != 0);
11.
12.   return i;
13. }
```

State Space Explosion

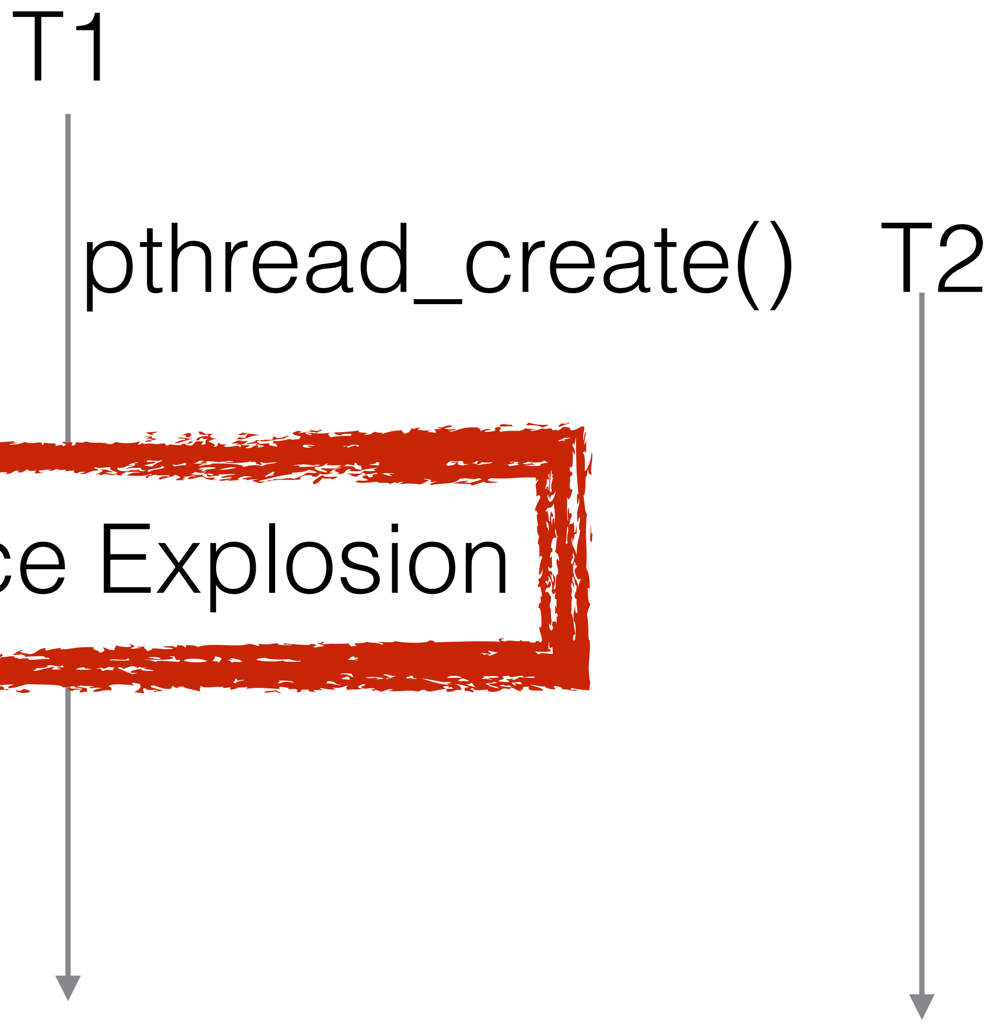


Ask solver: ✓ i := 9 ✓ i := 255 ✓ i := 2 ✗ no solution

[1] “Symbolic Execution and Program Testing ” King, ComACM, 1976

Symbolic Execution for Multithreaded Application

- Generalized Symbolic Execution [1]:
  - Symbolic Execution
  - Extended with Model Checker
  - Check all possi leavings
    - interleaving only on lock operation
    - Partial-order reduction [2]

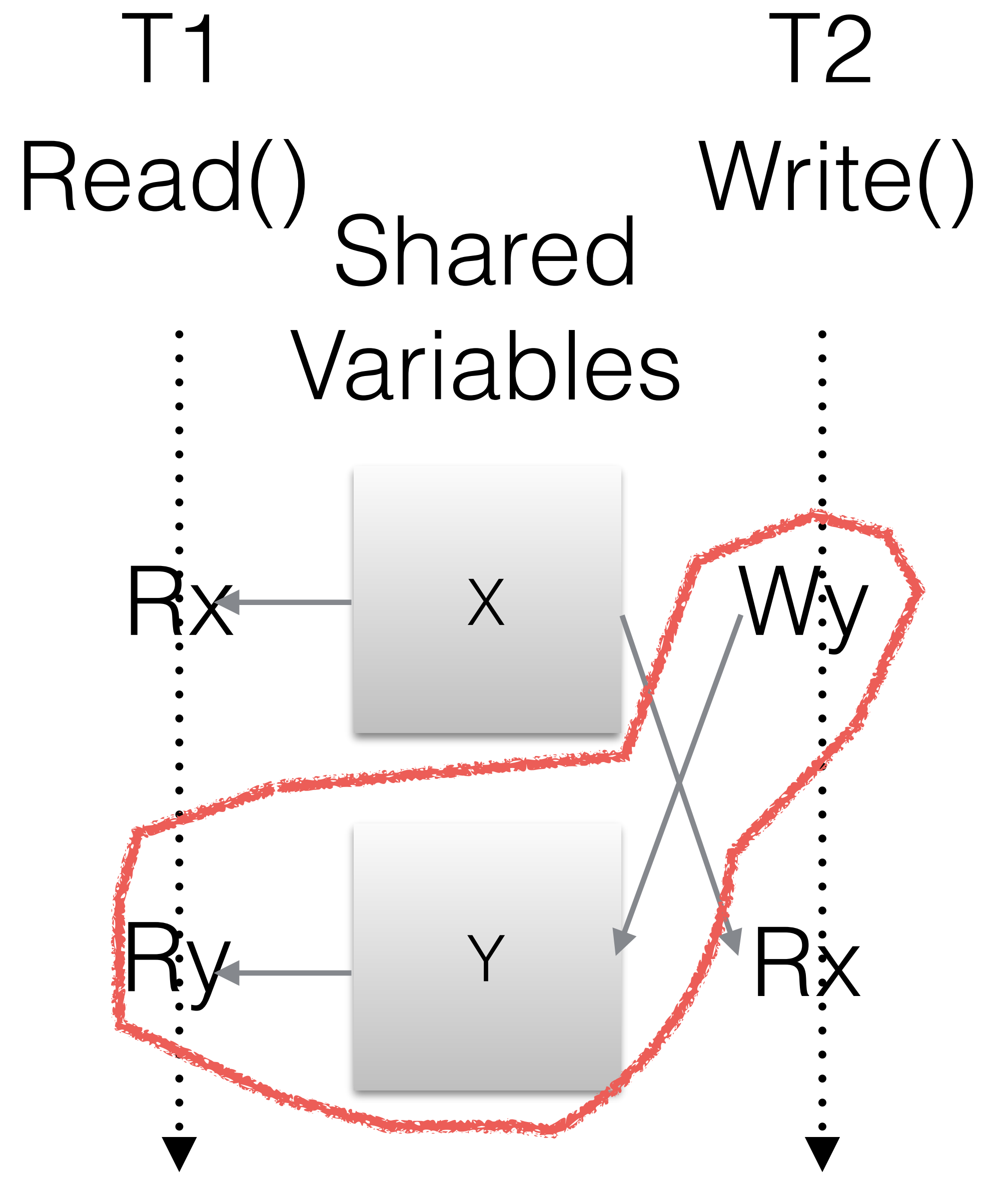


State Space Explosion

[1] “Generalized Symbolic Execution for Model Checking and Testing ” Khurshid, TACAS, 2003
[2] “Dynamic Partial-order Reduction for Model Checking Software”, Flanagan, POPL, 2005

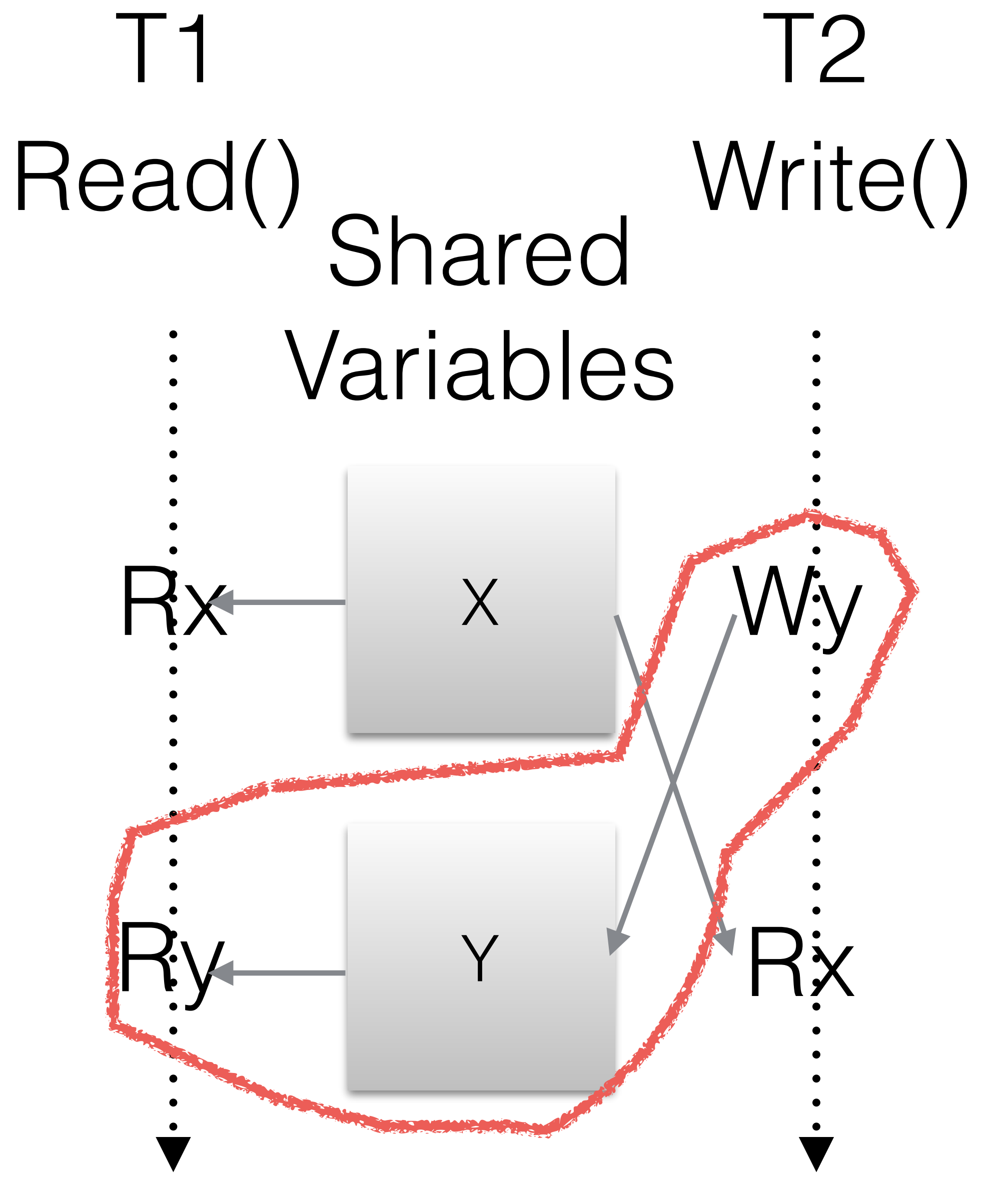
Symbolic Execution for Multithreaded Application
Our Approach I

- Insight: We just want to test the library calls and their invocation
  - library calls contain small and finite number of steps
  - library calls are typically symmetric across threads
- Goals:
  First, we go for coverage;
  Second, we go for TM correctness



Symbolic Execution for Multithreaded Application
Our Approach II

- start with all interleavings of sequential execution of threads without symbols
    - only one path is taken through the code
    - register read and write operations to shared data structures per thread
- re-execute function under observation with values symbolised restricted to the concrete values observed
    - new code paths are taken
    - interferences between threads are tract and incorporated (e.g. breaking busy loops)



Current Prototype

- Extension of Symbolic Execution Engine KLEE [1] (which is based on LLVM [2] Compiler framework 3.4)
  - exercises TM ABI used by TM compiler (GCC, ICC, DTMC)
  - partial support for inline assembler (e.g. support libatomic_ops on x86)
  - multithreading extension

[1] “KLEE: unassisted and automatic generation of high-coverage tests for complex systems programs”Cadar et al., OSDI, 2008
[2] “LLVM: a compilation framework for lifelong program analysis transformation”, Lattner et al.,CGO, 2004

Results for TM TinySTM++

- Bugs we found:
    - Timing issue in Txn-Initialisation per thread -> wrongly protected access might lead to lost update operation
    - Bug in read operation returning wrong value with write operation by other thread

- Modifications we made to TinySTM++ [1]
    - replace assembler-based setjmp/longjmp version with C-code based solution

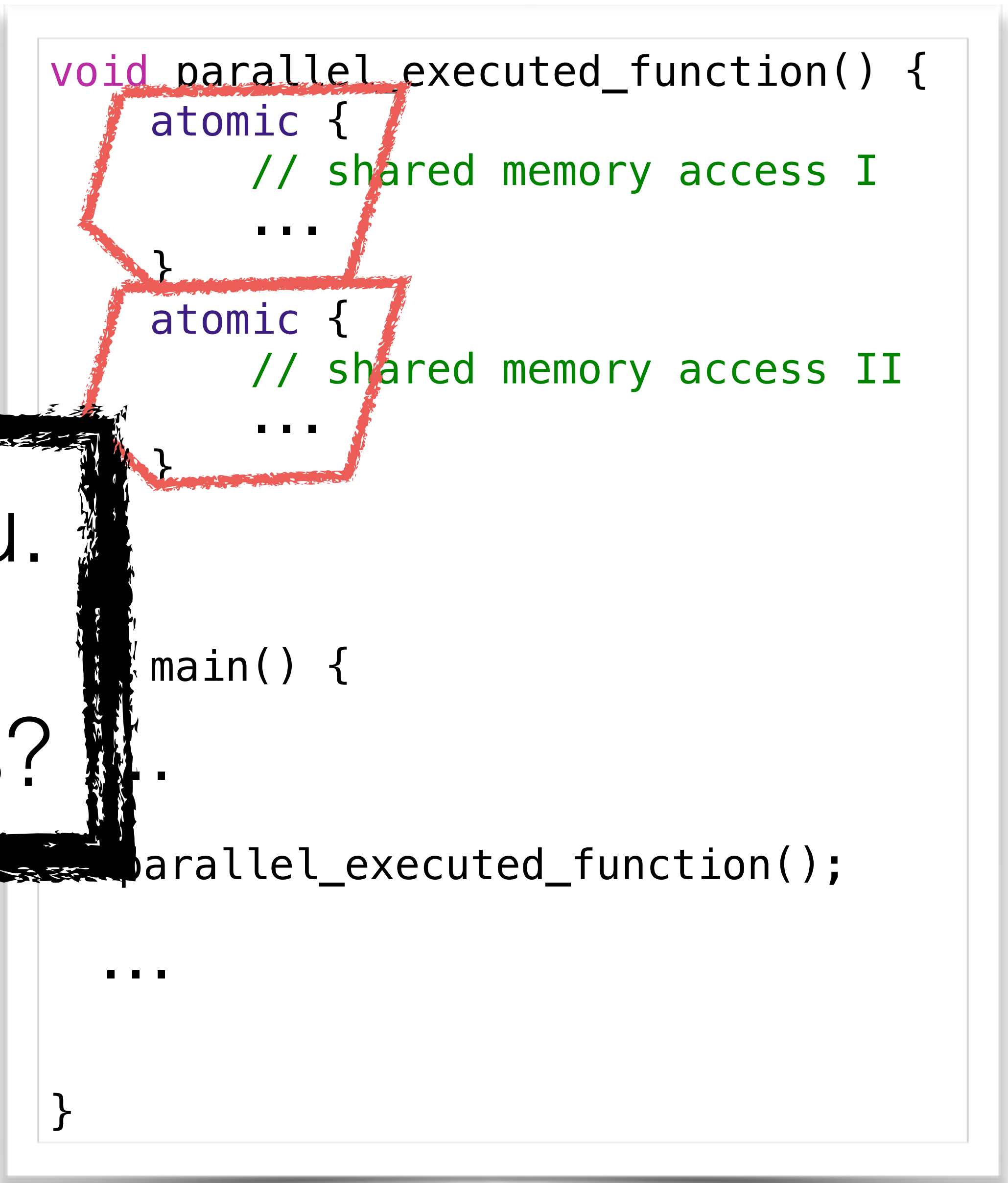
[1] “Dynamic performance tuning of word-based software transactional memory” Felber et al., PPOPP, 2008

WIP/ Future Work

- Exercising different protocol operations more thoroughly - in an automated way
- Independent execution allows to test on cluster of machines

Summary & Outlook

Whole Application



```
void parallel_executed_function() {
    atomic {
        // shared memory access I
        ...
    }
    atomic {
        // shared memory access II
        ...
    }


    main() {
    ...
    arallel_executed_function();

  ...

}
```

- Developed tool based o
  symbolic execution whi
  allows to exercise TM li
  in a systematic way

Thank you.

Questions?

Example

```
Error: memory error: out of bound pointer
File: /home/martin/tinystmplusplus/src/transaction.h: 82
Stack:
   #0 00007638 in tinystm::TransactionBase::getPublicState (this=0) at src/transaction.h:82
   #1 00009090 in tinystm::TransactionBaseSTMBound<tinystm::wt::STMTraits>::isActive (this=0) at src/transaction.h:181
   #2 00009020 in tinystm::TransactionBaseSTMBound<tinystm::wt::STMTraits>::begin (this=0, abiCodeProps=1) at src/transaction.h:157
   #3 00007251 in tinystm::TransactionBaseABI<tinystm::wt::STMTraits, tinystm::TxnalMemMgmnt<tinystm::wt::STMTraits,
                          tinystm::wt::STMTraits>, true>::begin (this=0, flags=1, jmpbuf=105699145786208) at /home/martin/tinystmplusplus/src/
                          transaction.h:227
   #4 00005067 in GTM_begin_transaction (flags=1, jmpbuf=105699145786208) at /home/martin/tinystmplusplus/src/c-interface.h:69
   #5 00005419 in _ITM_beginTransaction (nr=1) at /home/martin/tinystmplusplus/src/stm-wt.cpp:263
   #6 00000184 in simple_read () at /home/martin/tinystmplusplus/test/simple/simple.c:20
Info:
   address: 104 (0x68)
   next: object at 47974457809056 (0x2ba1ec8418a0) of size 4
          MO30[4] (no allocation info)
```