The Atomos Transactional Programming Language

Brian D. Carlstrom, Austen McDonald, Hassan Chafi,
JaeWoong Chung, Chi Cao Minh,
Christos Kozyrakis, Kunle Olukotun

Computer Systems Laboratory
Stanford University
http://tcc.stanford.edu

Transactional Memory

- Reasons to use Transactional Memory (TM)
  - Replace mutual exclusion with concurrent transactions
  - Remove challenges to programming with locks
- Challenges
  - Long running transactions without lower level violations
    - Easier to use one big transaction than having to split into chunks
    - Application libraries and runtimes want to update encapsulated state
  - Transactional conditional waiting with hardware support
    - Software transactional memory (STM) systems have an arbitrary number of transactional contexts in memory, allowing some to be idle
    - Hardware transactional memory (HTM) systems have a fixed number of transactional contexts in silicon, don't want to busy wait

The Atomos Programming Language

- Atomos derived from Java
  - `atomic` replaces `synchronized`
  - `retry` replaces `wait/notify/notifyAll`
- Atomos design features
  - Open nested transactions
    - `open` blocks committing nested child transaction before parent
    - Useful for language implementation but also available for applications
  - Watch Sets
    - Extension to `retry` for efficient conditional waiting on HTM systems
- Atomos implementation features
  - Violation handlers
    - Handle expected violations without rolling back in all cases
    - Not part of the language, only used in language implementation

`synchronized` versus `atomic`

Java

```
...
synchronized (hashMap){
  hashMap.put(key,value);
}
...
```

Atomos

```
...
atomic {
  hashMap.put(key,value);
}
...
```

Transactional memory advantages

- No association between a lock and shared data
- Non-conflicting operations can proceed in parallel

The counter problem

Application

```
atomic {
  ...
  this.id = getUID();
  ...
}
static long getUID () {
  atomic {
    globalCounter++;
}}
```

JIT Compiler

```
// method prolog
...
invocationCounter++;
...
// method body
...
// method epilogue
...
```

- Lower-level updates to global data can lead to violations
- General problem not confined to counters:
  - Application level caching
  - Cooperative scheduling in virtual machine

Open nested solution to the counter problem

- Solution
  - Wrap counter update in open nested transaction

```
atomic {
   ...
   this.id = getUID();
   ...
}

static long getUID () {
   open {
     globalCounter++;
   }
}
```

- Benefits
  - Violation of counter just replays open nested transaction
  - Open nested commit discards child's read-set preventing later violations
- Issues
  - What happens if parent rolls back after child commits?
  - Okay for *statistical* counters and UID
  - Not okay for SPECjbb2000 object allocation counters
    - Need to some way to *compensate* if parent rolls back

Transaction Commit and Abort Handlers

- Programs can specify callbacks at end of transaction
  - Separate interfaces for commit and abort outcomes

```
public interface CommitHandler { boolean onCommit();}
public interface AbortHandler  { boolean onAbort ();}
```

  - DB technique for delaying non-transactional operations
  - Harris brought the technique to STM for solving I/O problem
    - See *Exceptions and side-effects in atomic blocks*.
    - Buffer output until commit, rewind input on abort
  - In Atomos, commit of open nested transaction can register abort handler for parent transaction
    - This allows for compensating transaction for object counter example

`wait/notifyAll` versus `retry`

Java

```
public int get (){
  synchronized (this) {
    while (!available)
      wait();
    available = false;
    notifyAll();
    return contents;}}
```

Atomos

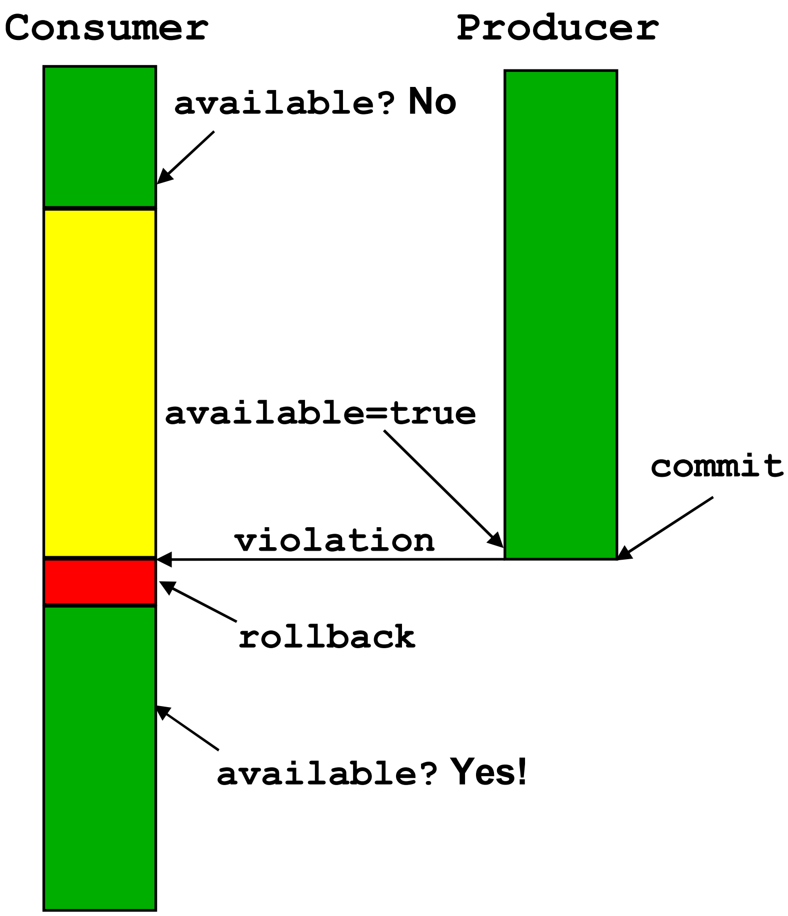
```
public int get (){
  atomic {
    if (!available)
      retry;
    available = false;

    return contents;}}
```

Transactional memory advantages

- Automatic reevaluation of `available` condition
- No need for explicit `notifyAll`

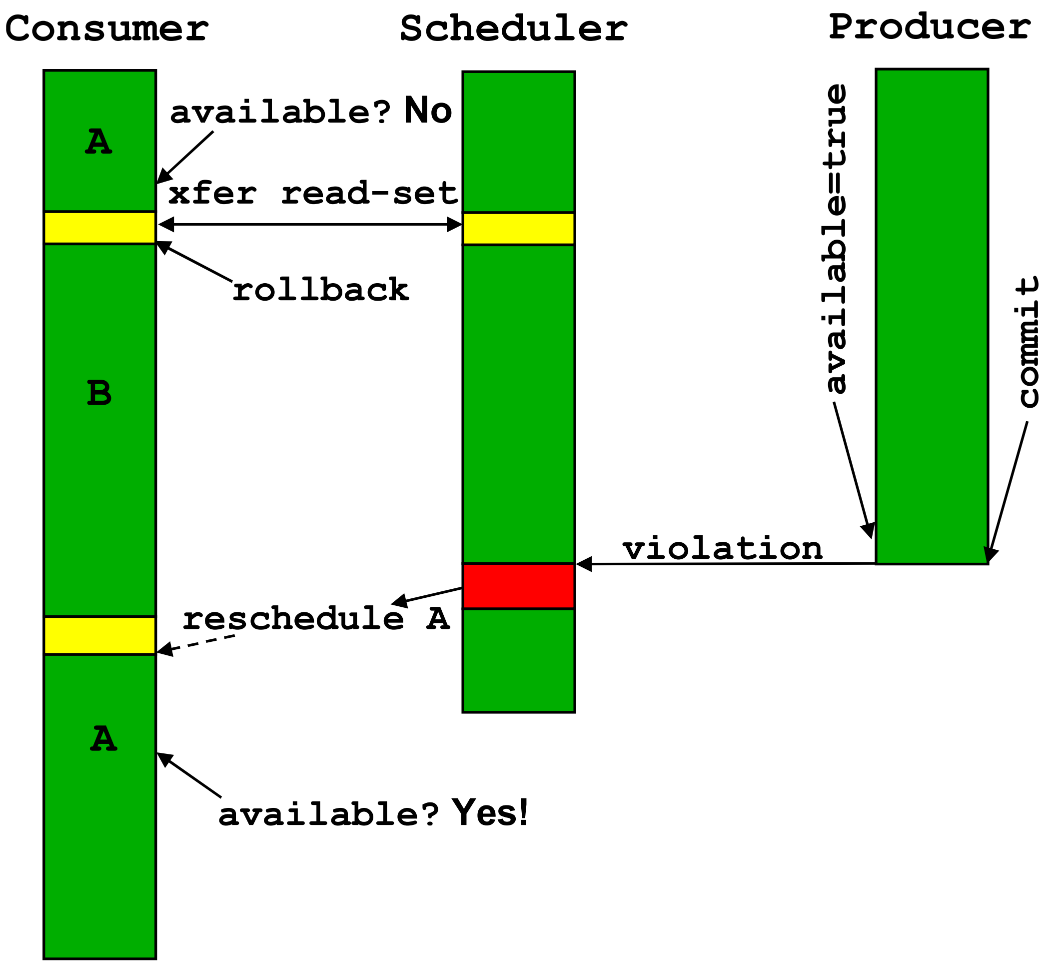
Transactional Conditional Waiting

- When condition false, wait until read set violated
  - Leverage violation detection for efficient wakeup
  - When violation happens
    - Rollback waiting transaction
    - Move thread from waiting to ready
- Approach scales well in STM
  - No practical limit on number of transactional contexts
- However HTM has limited number of hardware contexts
  - Can we overcome this issue?



Hardware Transactional Conditional Waiting

- Instead of using one HW context per waiting transaction
  - Merge waiting read sets into one shared context
- Our VM already has dedicated VM scheduler thread
  - Use as shared context
- Challenges
  - How can we communicate read set between threads?
  - How can shared context handle violations for others?



Violation Handlers

- Violation Handlers solve both challenges
  - Thread can register handler for violation callbacks

```
public interface ViolationHandler {
    boolean onViolation (Address violatedAddress);}
```

- How can we communicate read set between threads?
  - Use open nested transaction to send command to scheduler
  - Scheduler ViolationHandler receives commands
- How can shared context handle violations for others?
  - Scheduler maintains map of addresses to interested threads
  - non-command violation moves threads from waiting to ready

Common case transactional waiting

- Issues with transferring the read-set on retry
  - Need HW interface to enumerate read-set
  - Want to minimize size the number of addresses
  - Want to prevent overflow of HW transactional context
- Solution
  - Program usually only cares about changes to a small subset of its read-set
  - This *watch-set* will usually only be a single address

```
public int get (){
  atomic {
    if (!available){
      watch available;
      retry;}
    available = false;
return contents;}}
```

Hardware and Software Environment

- The simulated chip multiprocessor TCC Hardware (See PACT 2005)

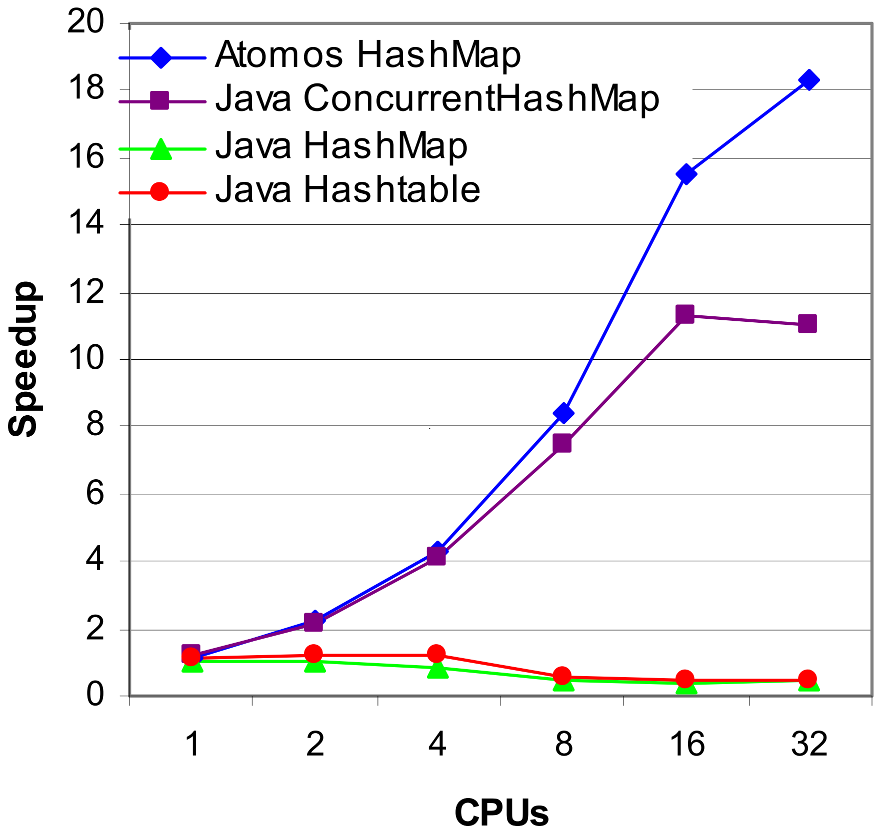
CPU	1-32 single issue PowerPC core
L1	64-KB, 32-byte cache line, 4-way associative, 1 cycle latency
Victim Cache	8 entries fully associative
Bus width	16 bytes
Bus arbitration	3 pipelined cycles
Transfer Latency	3 pipelined cycles
L2 Cache	8MB, 8-way, 16 cycles hit time
Main Memory	100 cycles latency, up to 8 outstanding transfers

For detailed semantics of open nesting, handlers, etc., see ISCA 2006

- Atomos built on top of Jikes RVM
  - Derived from Jikes RVM 2.4.2+CVS using GNU Classpath 0.19
  - All necessary code precompiled before measurement
  - Virtual machine startup excluded from measurement

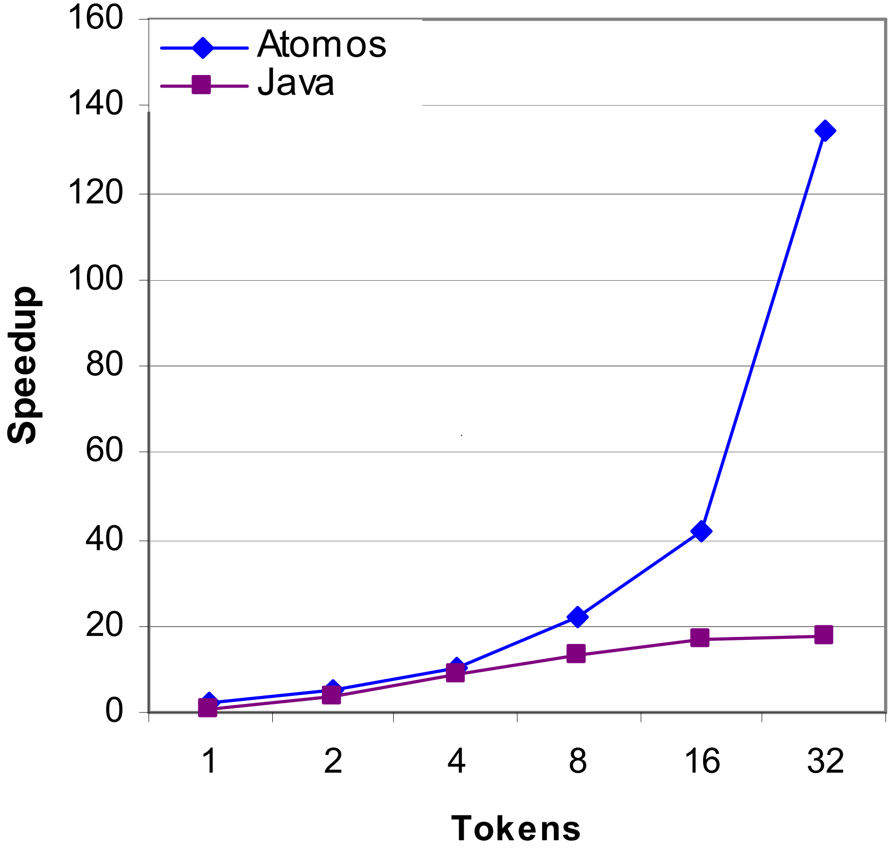
Transactions keep data structures simple

- TestHashtable
  - 50%-50% mix of reads and write to Map implementations
- Comparison of Map performance
  - Java HashMap
    - No built in synchronization
    - Collections.synchronizedMap
  - Java Hashtable
    - Singe coarse lock
  - Java ConcurrentHashMap
    - Fine grained locking
  - Atomos HashMap
    - Simple HashMap with transactions scales better than than ConcurrentHashMap



Transactional conditional waiting evaluation

- TestWait benchmark
  - Pass tokens in circle
  - Uses blocking queues
  - 32 CPUs, vary token count
- Purpose
  - Used by Harris and Fraser to measure Conditional Critical Region (CCR) performance
- Results
  - Atomos similar scalability to Java with few tokens
  - As token count nears CPU count, violation detection short circuits wait code, avoiding context switch overhead



The Atomos Programming Language

- Atomos derived from Java
  - Transactional Memory for concurrency
    - `atomic` blocks define basic nested transactions
    - Removed `synchonized`
  - Transaction based conditional waiting
    - Derivative of Conditional Critical Regions and Harris `retry`
    - Removed `wait`, `notify`, and `notifyAll`
    - *Watch sets* for efficient implementation on HTM systems
  - Open nested transactions
    - `open` blocks committing nested child transaction before parent
    - Useful for language implementation but also available for applications
  - Violation handlers
    - Handle expected violations without rolling back in all cases
    - Not part of the language, only used in language implementation
- Finally, *atomos* is the classical Greek word for indivisible
  - “a” prefix means “not” and “tomos” root means “cuttable”

Questions?