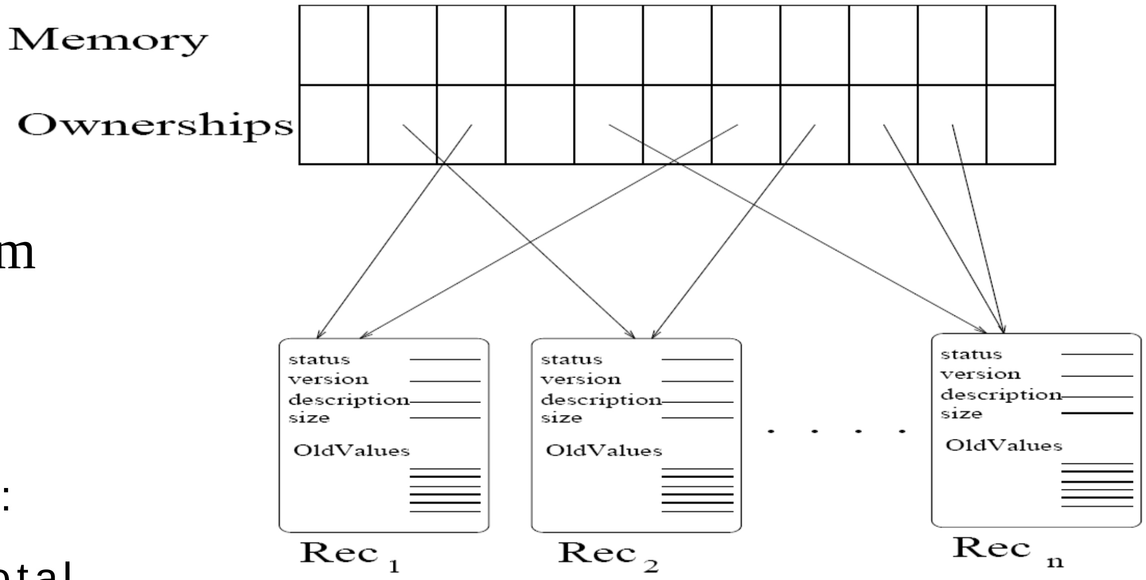
# Transactional Memory

## Part 2: Software-Based Approaches

# Word-based STM (Shavit&Touitou)

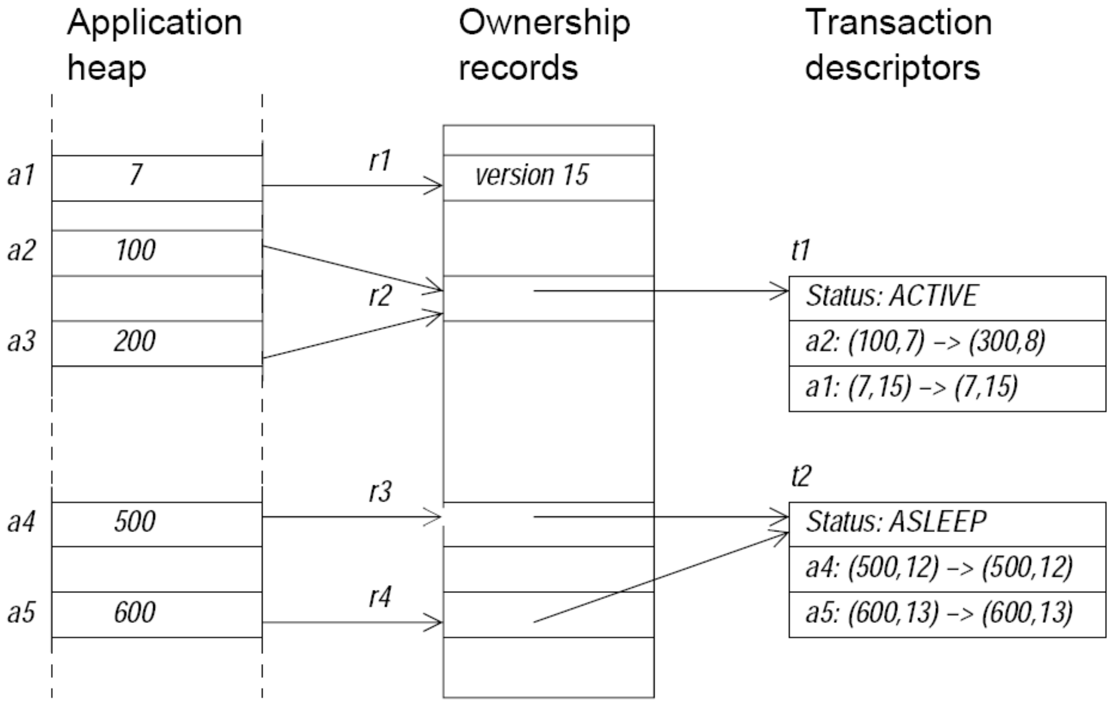


- Guarantees lock-freedom
- Uses a non-recursive "helping" strategy
- Limitations
  - Static transactions: ownership must be acquired in some total order to avoid livelock
  - Memory costs
  - Helping requires transaction to yield same results under multiple (partial) executions

Basic transaction process:

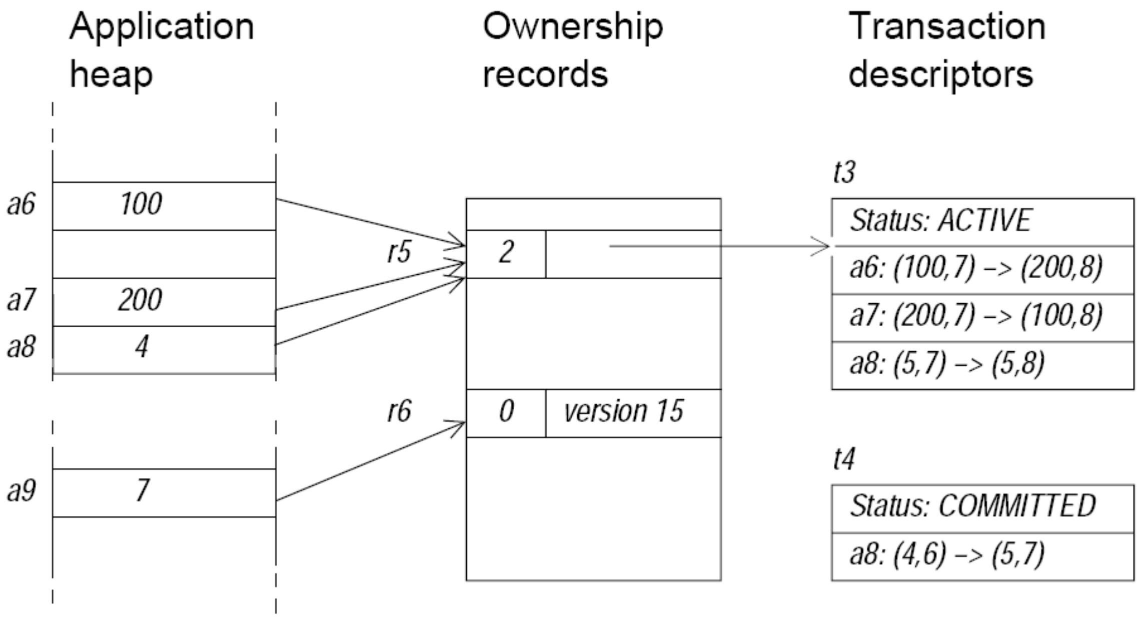
1. Read old values into transaction record
2. Acquire ownership of memory location for each value
   a. Succeed: Perform transaction; update memory; release ownership.
   b. Fail: release ownership; help if not already helping (non-recursive); abort.

# Word-based STM (WSTM): Harris&Fraser



- Multiple addresses map to the same ownership record.
- Logical state: a (value, version) pair representing the contents of a memory location.
- Ownership record stores either version number of address or transaction descriptor.
- Read/write operations create entries in a transaction descriptor.
- Commit operation attempts to gain ownership of the locations it reads/writes by placing the address of its transaction descriptor in the ownership records.
- Guarantees obstruction-free execution.

# Stealing



- Transaction attempting to commit, “steals” transaction entry from conflicting transaction
- Provides non-blocking commit operation (guarantee of obstruction-free execution)
- Requires ownership record to store the number of transaction holding a transaction record for a location mapping to the ownership record

# Language Support

## Conditional Critical Region (CCR)

**Syntax**:

```
atomic (condition) {
   statements;
}
```

- conditional critical region syntax added to Java
- source-to-bytecode compiler handles translation of atomic blocks and creates separate method of each atomic block
- methods of data access provide STMRead and STMWrite for methods defined for atomic blocks

**Translation:**

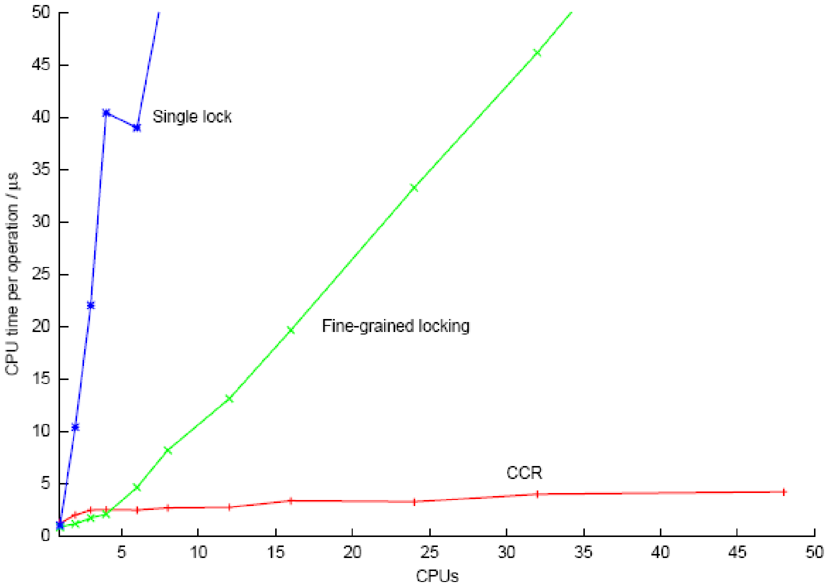
```
boolean done = false;
while (!done) {
  STMStart();
  try {
     if (condition) {
        statements;
        done = STMCommit();
     } else {
        STMWait();
    } catch (Throwable t) {
        done = STMCommit();
        if (done) {
            throw t;
         }
       }
 }
```

# Performance

$\mu s$ per operation

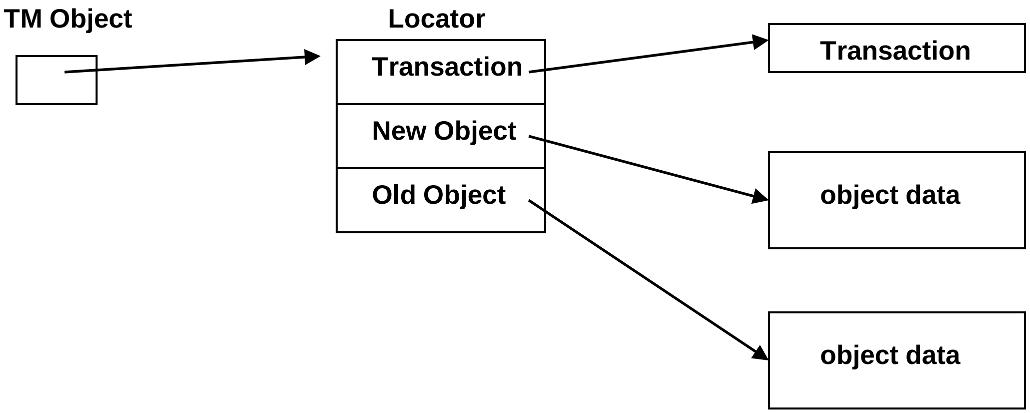
| | 1% updates | | | 16% updates | | |
|---|---|---|---|---|---|---|
| CPUs | CCR | S-1 | FG-1 | CCR | S-1 | FG-1 |
| 1 | 1.8 | 1.1 | 0.9 | 1.9 | 1.1 | 0.9 |
| 2 | 1.8 | 3.3 | 0.9 | 2.0 | 7.9 | 1.0 |
| 3 | 2.1 | 25 | 1.3 | 2.4 | 23 | 1.1 |
| 4 | 1.8 | 30 | 1.1 | 2.4 | 30 | 1.4 |

| | size=256 | | | size=4096 | | |
|---|---|---|---|---|---|---|
| CPUs | CCR | S-1 | FG-1 | CCR | S-1 | FG-1 |
| 1 | 4.8 | 2.1 | 2.6 | 5.1 | 2.3 | 2.7 |
| 2 | 6.2 | 17 | 5.0 | 6.3 | 17 | 4.4 |
| 3 | 7.2 | 27 | 6.4 | 7.2 | 28 | 6.3 |
| 4 | 7.4 | 37 | 8.3 | 7.5 | 40 | 6.9 |



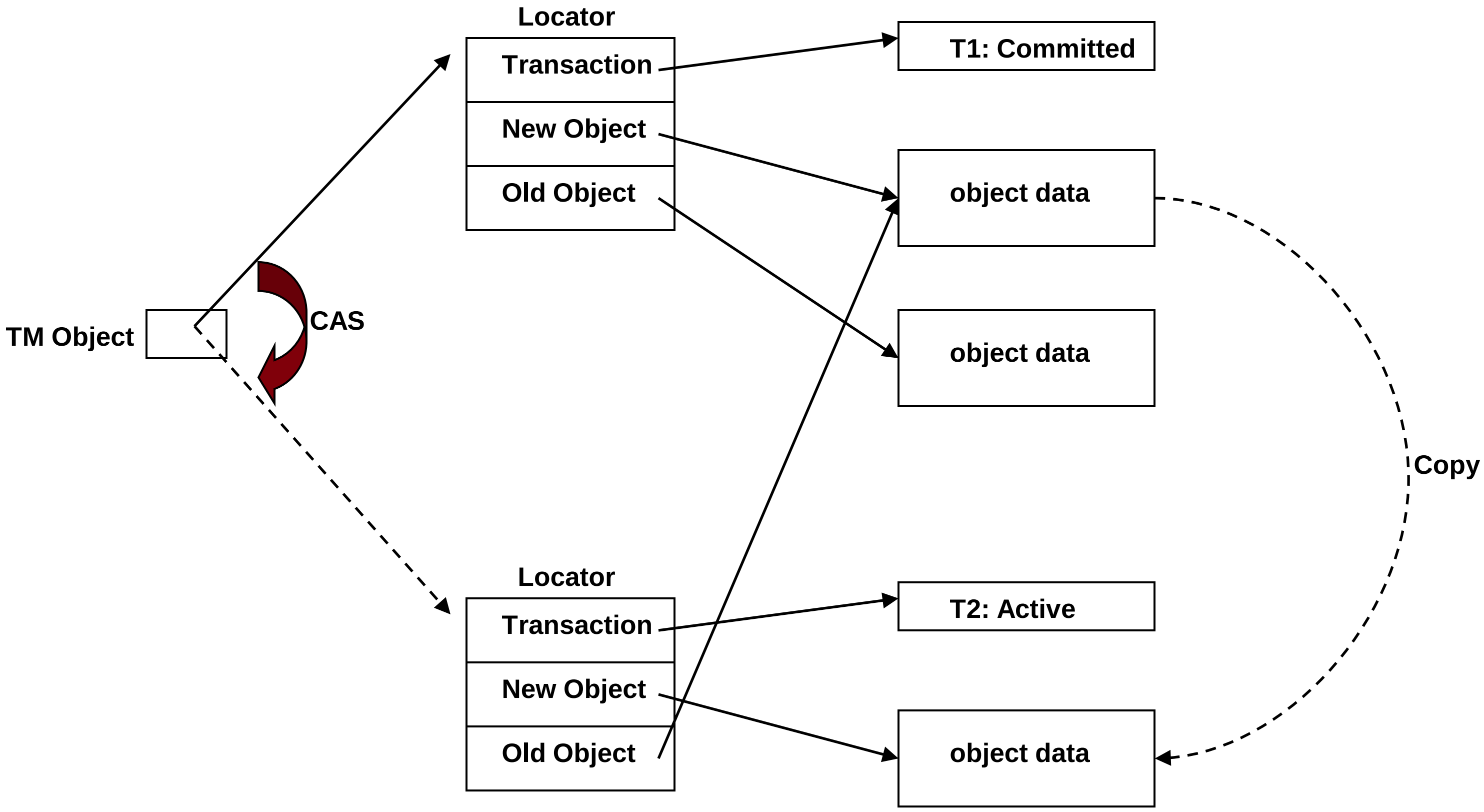
- WSTM is superior to simple synchronization schemes (CCR vs. S-1) on few processors
- WSTM is competitive with sophisticated synchronization schemes (CCR vs. FG-1) on few processors
- WSTM is superior to other synchronization schemes on large number of processors

# Dynamic STM (DTSM): Herlihy et.al.

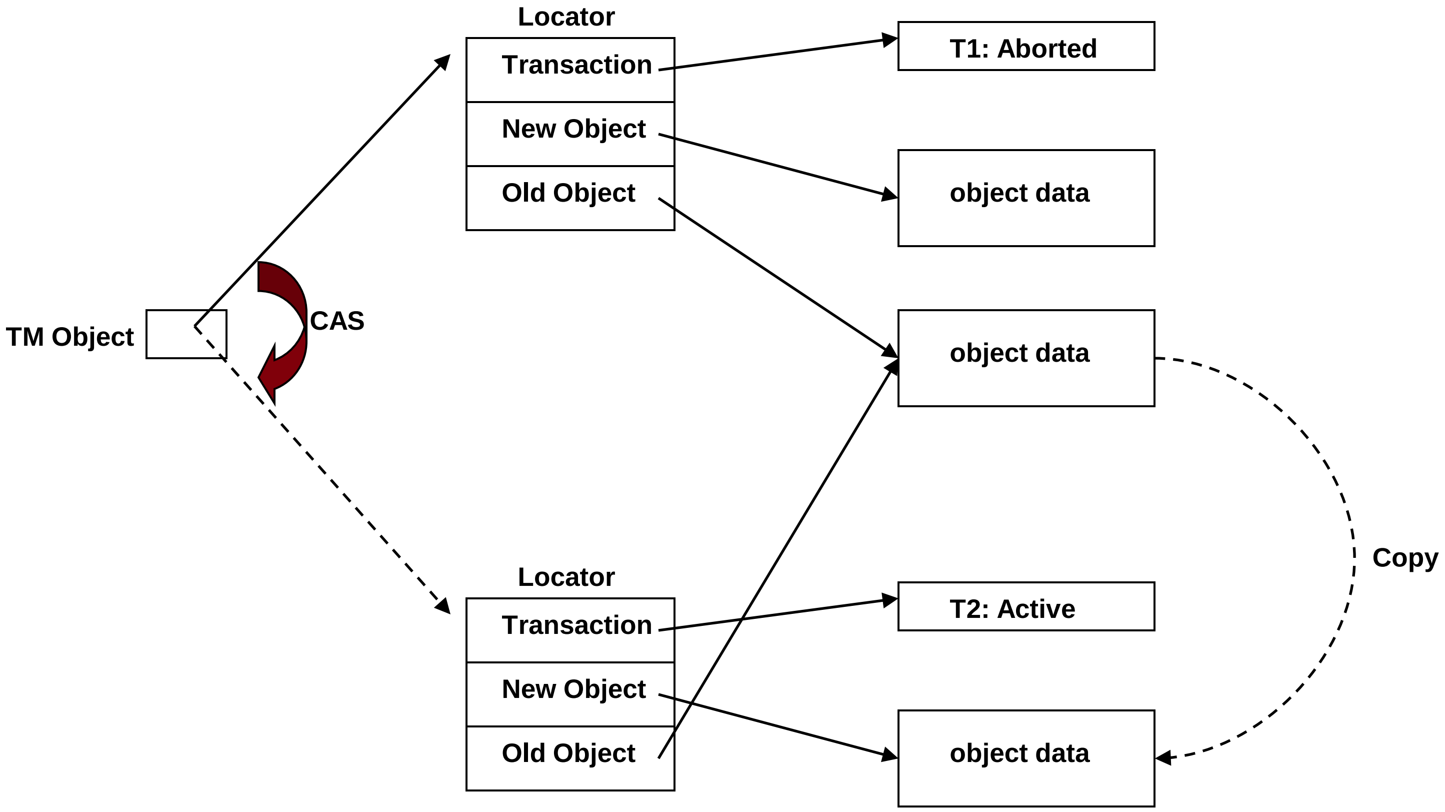


- TMObject is a handle for an object.
- An “open” operation on the TMObject is required before object can be accessed.
- Transaction state may be: ACTIVE, COMMITTED, ABORTED.
- The “current” form of the object data is maintained (Old Object).
- A shadow copy of to-be-committed updates to the object is also maintained.

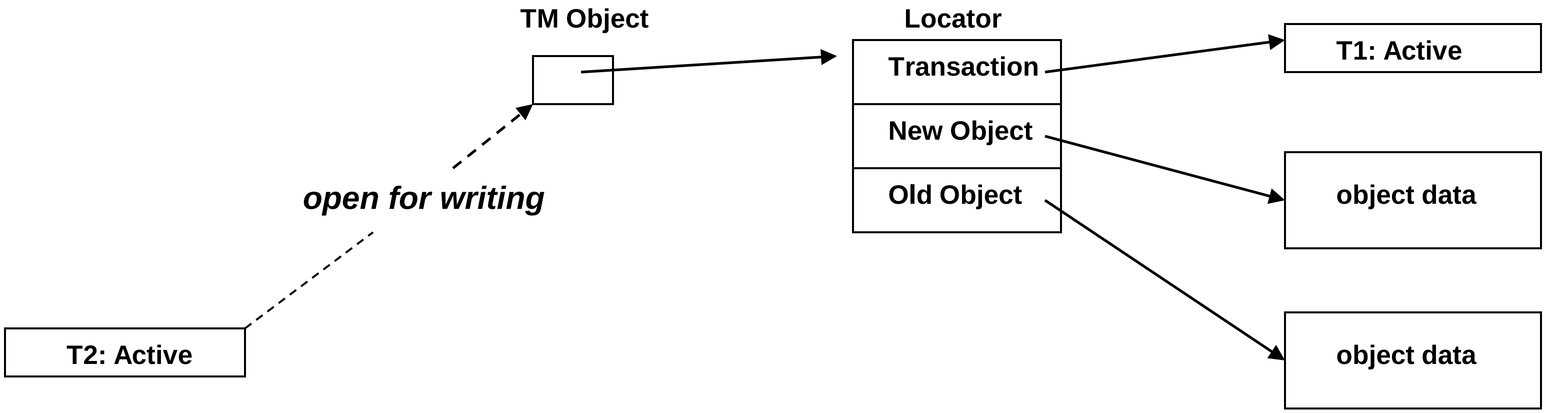
# Opening a TMObject for Writing



# Opening a TMObject for Writing

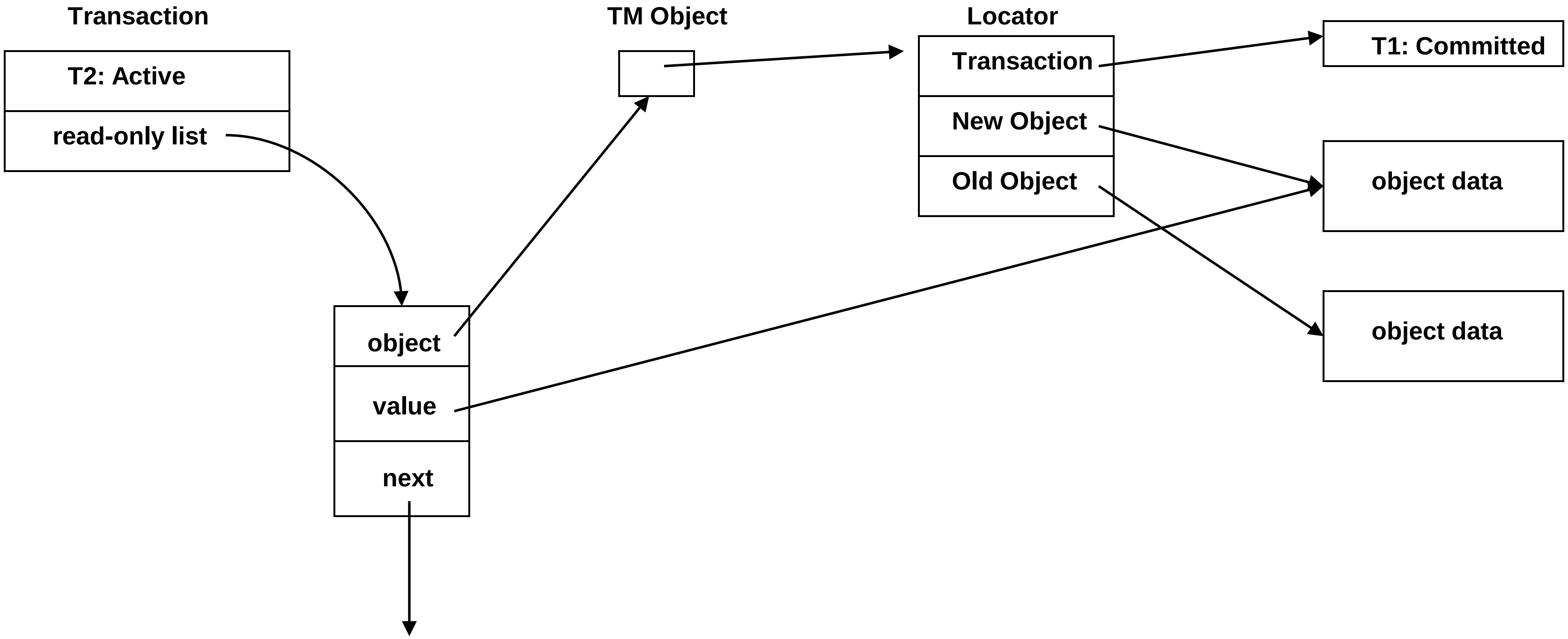


# Opening a TMObject for Writing

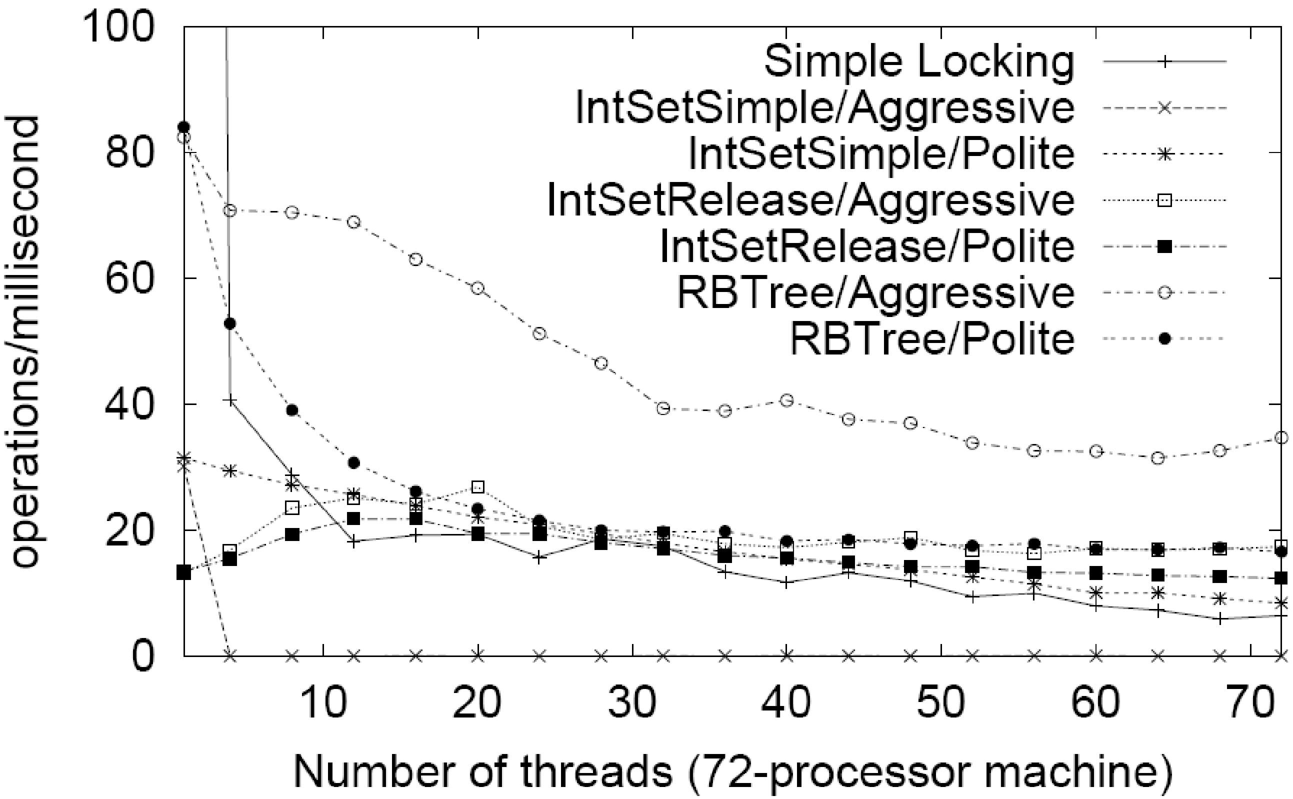


- one of T1 or T2 must abort to resolve conflict without blocking
- each thread has a ContentionManager
  - □ aggressive – always/immediately aborts conflicting transaction
  - □ polite – adaptive back-off
- contention reduced by “early release”
  - □ reference to object dropped before transaction commits
  - □ releasing transaction must insure that subsequent changes to the released object does not jeopardize consistency

# Opening a TMObject for Reading

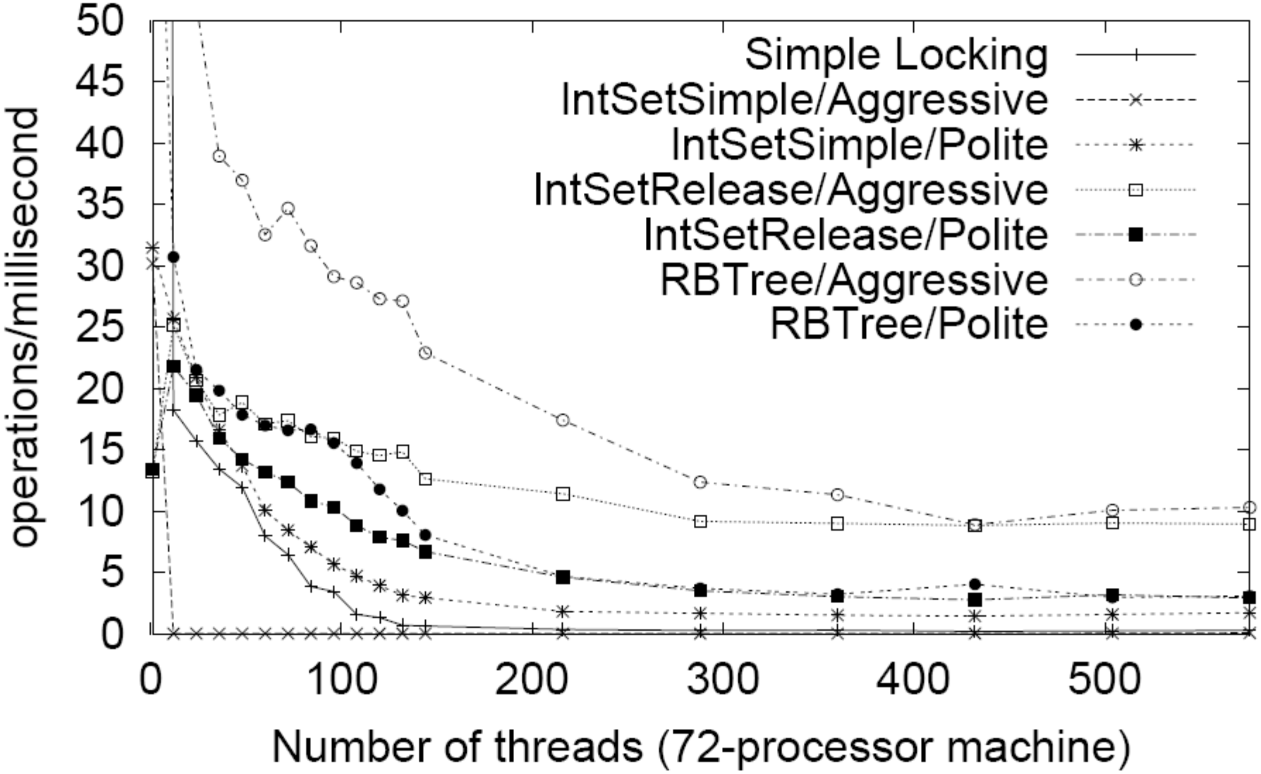


# Performance



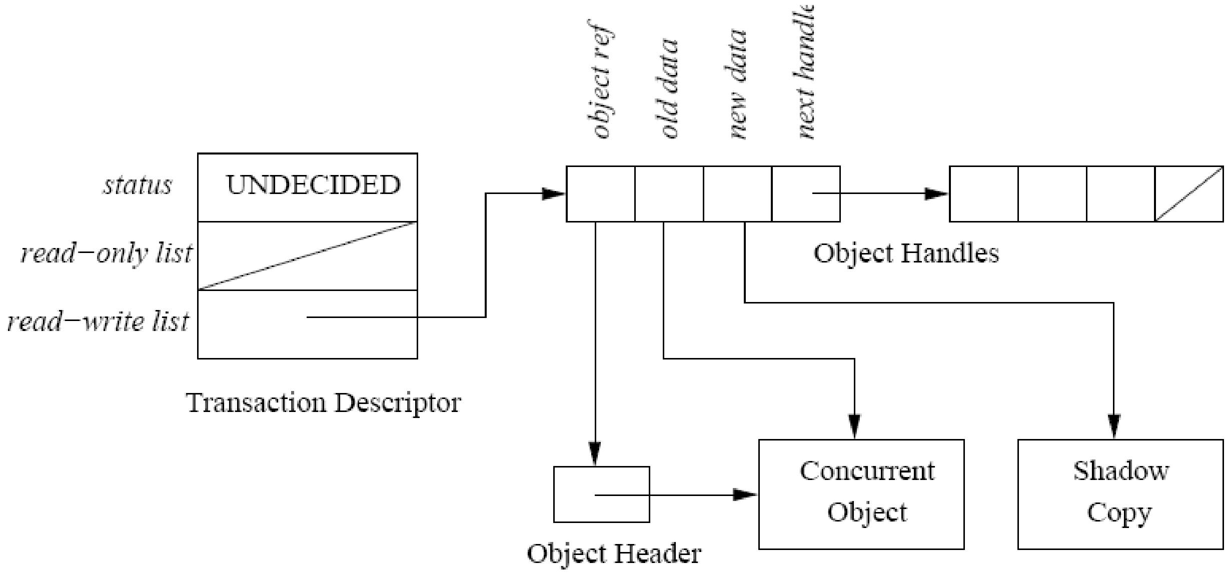
- STM versions competitive with simple locking scheme
- Aggressive contention management can cause performance to collapse under high contention

# Performance



- By lowering contention, early release sustains performance of aggressive contention management.
- Contention management useful and has possibly complex relationship to data structure design.

# FSTM: Fraser



- Objects are accessed by an *open* operation on the *object header*
- An object may be open in multiple transactions at the same time
- Transaction maintains an *object handle* for each open object
- Object handles are organized into two lists: a *read-only list* and a *read-write list*
- For each writeable object the transaction maintains a *shadow copy* of the object private to the transaction
- Conflicts among transactions are detected and resolved at commit-time
- Guarantees lock-freedom

# Commit operation in FTSM

| Phase | Description |
|---|---|
| *Acquire* | Action: Acquire each object in the read-write list in global total order using atomic CAS for each object<br>Outcomes:<br>■ Abort if conflict with committed transaction detected<br>■ Help if conflict with uncommitted transaction detected |
| *Read-checking* | Action: Verify consistency of each object in the read-only list<br>Outcomes:<br>■ Abort if change is detected in object held by Undecided transaction<br>■ If conflict detected with Read-checking transaction:<br>□ Help if other transaction precedes current transaction<br>□ Abort if current transaction precedes other transaction |
| *Release* | Release each acquired object |

# Comparison Criteria*

- Strong or Weak Isolation
  - Weak isolation: conflicting operation outside of a transaction may not follow the STM protocols
  - Strong isolation: all conflicting operations are (converted to) execute in transactions
- Transaction Granularity
  - Word: conflicts detected at word level
  - Block: conflicts detected at block level
- Direct of Deferred Update
  - Direct: memory is updated by transaction and restored to original value on abort
  - Deferred: updates are stored privately and applied to memory on commit
    - Update in place: private values copied to memory
    - Cloned replacement: private copy replaces original memory
- Concurrency control
  - Pessimistic: conflict is immediately detected and resolved
  - Optimistic: conflict detection and/or resolution deferred
- Synchronization
  - Blocking
  - Non-blocking (wait-, lock-, obstruction-freedom)

* *From*: Transactional Memory, James Larus and Ravi Rajwar

# Comparison Criteria* (cont.)

- Conflict Detection
  - Early: conflicts detected on open/acquire or by explicit validation
  - Late: conflicts detected at time of commit operation
- Inconsistent reads
  - Validation: check for updates to memory being read
  - Invalidation: abort reading transaction when update is made
  - Toleration: allow inconsistency (expecting subsequent validation/abort)
- Conflict resolution
  - System-defined: help or abort conflicting transactions
  - Application-defined: contention manager resolves conflicts
- Nested Transactions
  - Flattened: aborting inner transaction aborts outer transaction - inner transaction only commits when outer transaction commits
  - Not-Flattened: aborting inner transaction does not cause outer transaction to abort
    - Closed: effects of inner transaction not visible to other transaction until outer transaction commits (rollback possible)
    - Open: effects of inner transaction visible to other transaction when inner transaction commits (rollback not possible)
- Exceptions
  - Terminate: a commit operation is attempted when an exception occurs in the transaction before propagating the exception
  - Abort: the transaction is aborted

* *From*: Transactional Memory, James Larus and Ravi Rajwar

# Comparison

| **Characteristic** | **System** | | | |
|---|---|---|---|---|
| | STM-1 | WSTM | DSTM | FSTM |
| Strong/Weak Isolation | N/A | Weak | Weak | Weak |
| Granularity | Word | Word | Object | Object |
| Direct/Deferred Update | Direct | Deferred<br>(update in place) | Deferred<br>(clone replacement) | Deferred<br>(clone replacement) |
| Concurrency Control | Pessimistic | Optimistic | Optimistic | Optimistic |
| Synchronization | Lock-free | Obstruction-free | Obstruction-free | Lock-free |
| Conflict Detection | Early | Late | Early | Late |
| Inconsistent Reads | None | Toleration | Validation | Validation |
| Conflict Resolution | Helping | Helping/aborting | Contention manager | Abort |
| Nested Transactions | | Flattened | Flattened | Closed |
| Exceptions | | Terminate | | |