Open Nesting in Software Transactional Memories

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Tony Hosking

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Tony Hosking

Eliot Moss

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Yang Ni   Vijay Menon   Ali-Reza Adl-Tabatabai
Tony Hosking   Rick Hudson   Eliot Moss
Bratin Saha   Tatiana Shpeisman

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Abstract v. physical serializability

```
Set s;
```

Txn T_1:

```
atomic {
  s.add(x);
  s.add(y);
}
```

Txn T_2:

```
atomic {
  s.add(z);
}
```

- Linked list set implementation adds element to end of list
- Physical schedule results in (x,y,z) or (z,x,y)
- (x,z,y) violates atomicity of T_1
- However, (x,z,y) is consistent with "abstract" serializabilty: both transactions insert their elements; the result, in terms of s.contains, is the same
- Permitting the "abstractly" serializable result can increase concurrency

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Abstract serializability

- Still need:
  - conflict detection
  - conflict resolution
- Set insertions must themselves happen atomically: (x,z) is not serializable either way
- Abstract conflicts must still be prevented

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Abstract v. physical serializability

```
Set s;
```

Txn T_1:

```
atomic {
  s.add(x);
  if (!s.contains(z))
    s.add(y);
}
```

Txn T_2:

```
atomic {
  s.add(w);
  if (!s.contains(y))
    s.add(z);
}
```

- Abstract serializability allows (unordered) {w,x,y} or {w,x,z}
- If T_1 sees z not in s, t2 must not insert z without serializing with T_1
- T_2 must either wait for T_1 to complete or one of them must abort

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Open nesting

- Supports abstract serializability
- Set operations implemented as openatomic actions that execute at a lower level of abstraction
- Individual set operations physically serializable, but once committed release memory resources to enhance concurrency
- Conflict detection via *abstract* locks:
  - T_1 must use abstract lock to assert absence of z
  - T_2 will try to obtain lock to insert z
- If both get past "if" at least one must abort

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Abort

- To abort an open nested action programmers provide a *compensation* action
- In the example, T_1 must run an action that removes `x`

Atomic actions: syntax

(cf. Harris & Fraser)

`atomic` in place of `synchronized`

- succeeds: effects committed
- aborts: effects undone, action retried
- fails: effects undone, action not retried (for exceptions)
  - (others vary in semantics of exceptions)

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Open atomic

Open atomicity as a property of *classes*:

- Can have `openatomic` methods; all public methods are implicitly so
- `openatomic` is inherited
- No public fields (else no access control)
- All fields implicitly `openatomic`, accessible only in `openatomic` methods

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Open atomic methods

Signified by one of following handler blocks:

- `onabort`: undo global effects of committed child when parent fails
- `oncommit`: cleanup action for committed child when parent succeeds
- `onvalidation`: high-level checking for committed child when parent commits
- `ontopcommit`: finalisation action for all committed descendents of a committing top-level action

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Handler syntax

MethodBody:

Block OpenAtomicHandlers$_{opt}$

OpenAtomicHandler:

onabort *Block*

oncommit *Block*

onvalidation *Block*

ontopcommit *Block*

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Open atomic methods

May also have a `locks` clause:

- abstract locks that open atomic method must acquire before it can return

MethodDeclaration:

MethodHeader LocksClause$_{opt}$ *MethodBody*

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Example

```
import java.util.*;
import java.openatomic.SXModes.*;
public openatomic class OpenMap implements Map {
  private final Map map;
  private final Object lock = new Object();
  public OpenMap(Map map) { this.map = map; }
  public Object get(Object key)
    locks(key:S) { return map.get(key); }
  public Object put(Object key, Object value)
    locks(key:X, lock:IX) { return map.put(key, value); }
    onabort {
      if (@result == null) map.remove(key);
      else map.put(key, @result);
    }
  public Object remove (Object key)
    locks(key:X, lock:IX) { return map.remove(key); }
    onabort { if (@result != null) map.put(key, @result); }
  public int size() locks(lock:S) { return map.size(); }
}
```

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Log semantics: closed nesting

- New transaction starts with a clean log
- Log reads/writes + old values for writes
- Closed nested commit appends log to parent
- Top-level commit discards log
- Abort processes log in reverse, restores writes

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Log semantics: conflicts

- Neither action an ancestor of the other and both access a location in conflicting modes (i.e., at least one writes)
- Conflicting actions must not both commit and must never write same locations

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Log semantics: open nesting

- Add handlers and abstract locks to logs
- Nested commit:
  - invokes handlers (from children) in its log, in order, as open nested actions: `onvalidation` then `oncommit`
  - `ontopcommit` handlers appended to parent log (invoked on top-level commit)
  - appends own handlers/locks to parent log

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Log semantics: nested abort

- Process log entries in reverse order:
  - invoke `onabort` handlers (from children)
  - undo writes
    - writes to same location may be undone more than once to preserve view for interleaved handlers

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Log semantics: abstract locks

Lock consists of:

- *context* object (or class) whose method was run as openatomic
- *Locked* object mentioned in lock expression
- Lock *mode*

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Log semantics: lock conflict

- Same context (==)
- Same locked object (`.equals`)
- Conflicting modes, as defined by lock class

Action T_a acquiring lock conflicts with T_h if T_h is not an ancestor of T_a and lock by T_a conflicts with some lock in T_h's log

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Caveat Emptor

- Programmer errors bite!
  - programmer must specify conflicts and compensations
  - open nested aborts can deadlock
- Most problems arise because of mistakes in abstraction layering: accessing objects at different abstraction levels
- Avoiding mistakes can be achieved by observing guidelines that we hope to formalize (see paper)

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Experiments

- Wrap `HashMap` and `TreeMap` using `synchronized`, `atomic`, `openatomic`
- 16 "transactions", each performing 4K puts:
  - partitioned across available threads
- All keys are different (so no logical conflicts)
- 16-way (4x4) Xeon
- "Transaction":

```
atomic {
  for (int i = 0; i < 4096; i++)
    map.put(key[i], value[i]);
}
```

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Closed nested

- map is an `AtomicMap`:

```
import java.util.*;
public class AtomicMap implements Map {
    private final Map map;
    public AtomicMap(Map map) { this.map = map; }
    public Object put(Object key, Object value) {
        atomic { return map.put(key,value); }
    }
    ...
}
```

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Open nested

- `map` is an `OpenMap`, defined earlier

Synchronized

- `map` is unmodified `TreeMap/HashMap`
- `synchronized(map)` instead of `atomic`:

```
synchronized (map) {
                for (int i = 0; i < 4096; i++)
                  map.put(key[i], value[i]);
              }
```

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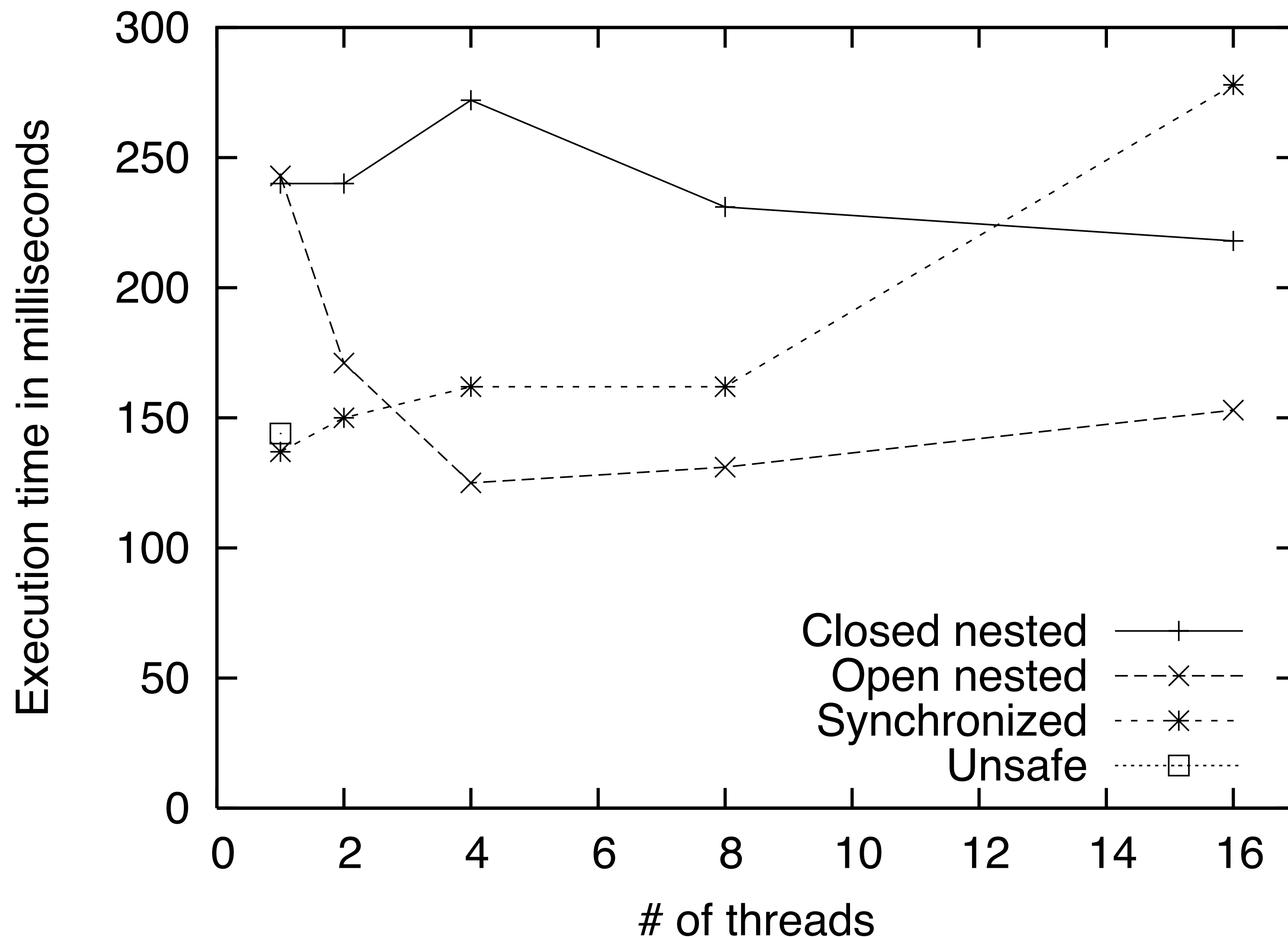
64K puts on a TreeMap



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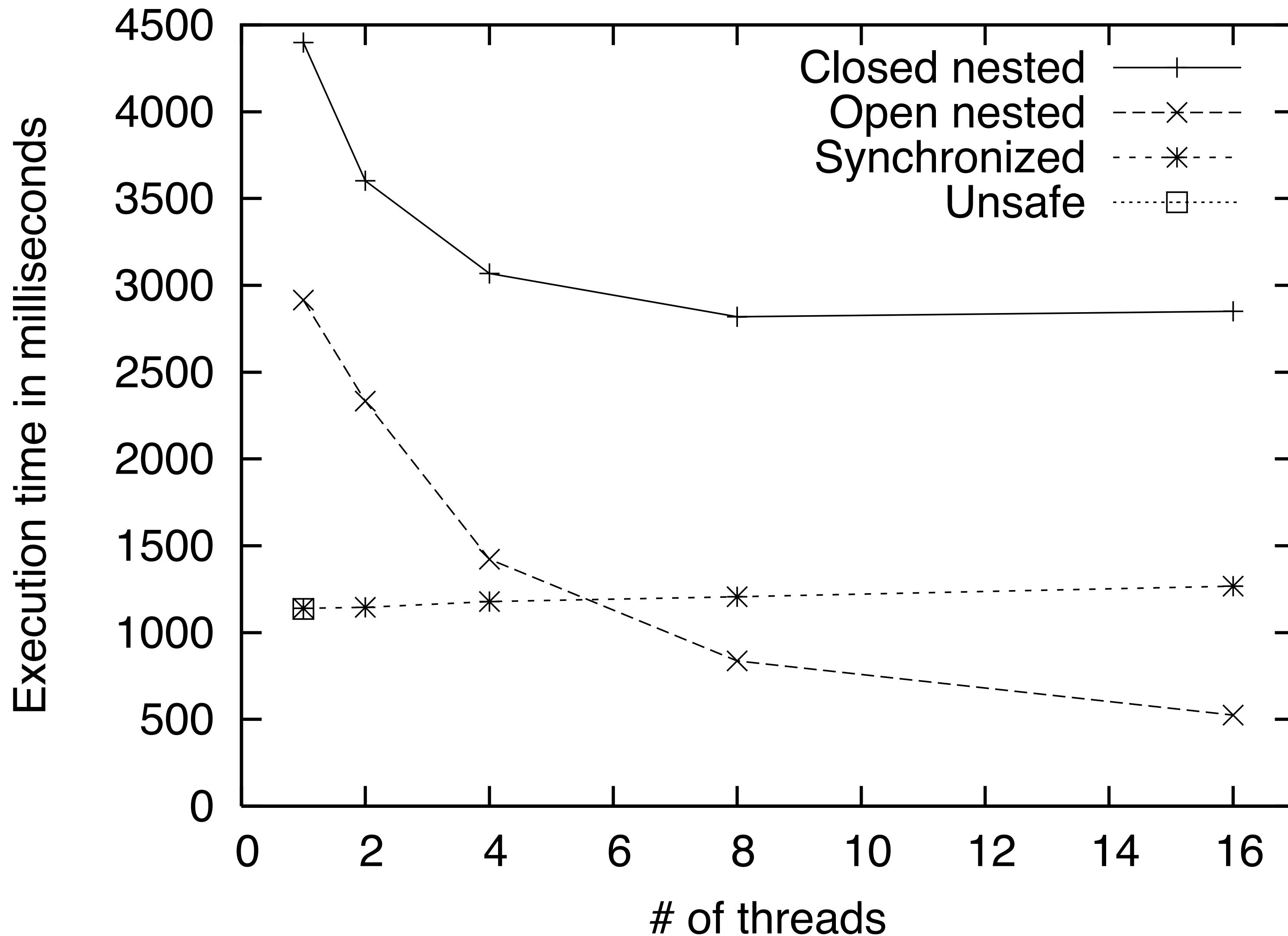
64K puts on a HashMap



128 buckets

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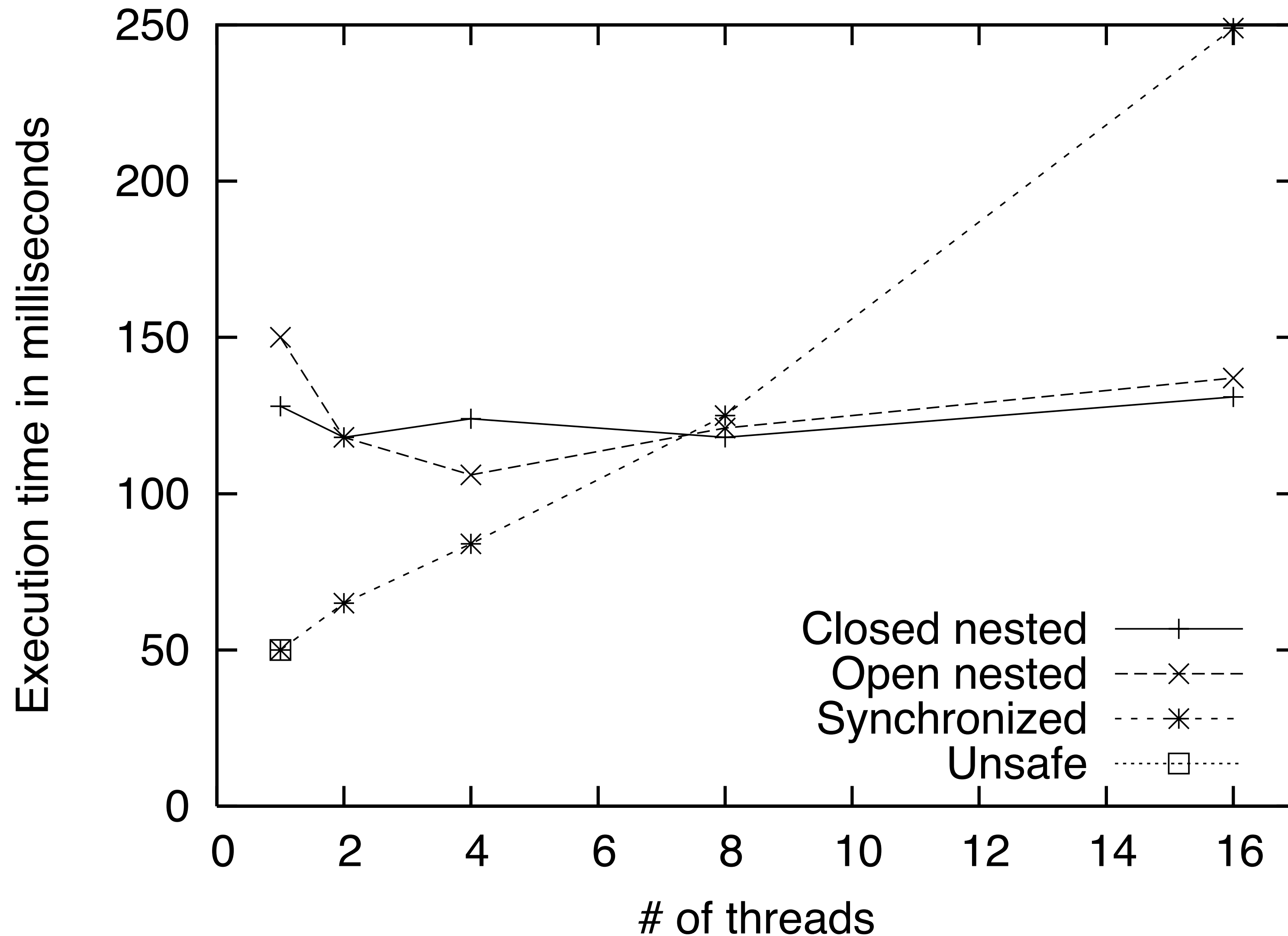
64K puts on a HashMap



64K buckets

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