# Software Transactions: A Programming-Languages Perspective

Dan Grossman
University of Washington

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# A big deal

Research on software transactions broad…

- Programming languages
  PLDI, POPL, ICFP, OOPSLA, ECOOP, HASKELL, …
- Architecture
  ISCA, HPCA, ASPLOS, MSPC, …
- Parallel programming
  PPoPP, PODC, …

… and coming together
TRANSACT (at PLDI06 and PODC07)

# Why now?

Small-scale multiprocessors unleashed on the programming masses

Threads and shared memory remains a key model

Locks + condition-variables cumbersome & error-prone

Transactions should be a hot area

An easier to use and harder-to-implement synchronization primitive:

```
atomic { s }
```

# PL Perspective

Key complement to the focus on "transaction engines" and low-level optimizations

Language design:

interaction with rest of the language

- Not just I/O and exceptions (not this talk)

Language implementation:

interaction with the compiler and today's hardware

- Plus new needs for high-level optimizations

# Today

Issues in language design and semantics

1. Transactions for software evolution
2. Transactions for strong isolation [Nov06]*
3. The need for a memory model [MSPC06a]**

Software-implementation techniques

1. On one core [ICFP05]
2. Without changing the virtual machine [MSPC06b]
3. Static optimizations for strong isolation [Nov06]*

* Joint work with Intel PSL

** Joint work with Manson and Pugh

# Code evolution

Having chosen “self-locking” today, hard to add a correct transfer method tomorrow

```
void deposit(…)  { synchronized(this) { … }}
void withdraw(…) { synchronized(this) { … }}
int  balance(…)  { synchronized(this) { … }}

void transfer(Acct from, int amt) {
  synchronized(this) {
   //race
   if(from.balance()>=amt && amt < maxXfer) {
     from.withdraw(amt);
     this.deposit(amt);
   }
  }
}
```

# Code evolution

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```
void deposit(…)  { synchronized(this) { … }}
void withdraw(…) { synchronized(this) { … }}
int  balance(…)  { synchronized(this) { … }}

void transfer(Acct from, int amt) {
  synchronized(this) {
  synchronized(from) { //deadlock (still)
   if(from.balance()>=amt && amt < maxXfer) {
     from.withdraw(amt);
     this.deposit(amt);
   }
  }}
}
```

# Code evolution

Having chosen “self-locking” today, hard to add a correct transfer method tomorrow

```
void deposit(…)  { atomic { … }}
void withdraw(…) { atomic { … }}
int  balance(…)  { atomic { … }}

void transfer(Acct from, int amt) {

   //race
   if(from.balance()>=amt && amt < maxXfer) {
      from.withdraw(amt);
      this.deposit(amt);
   }

}
```

# Code evolution

Having chosen "self-locking" today, hard to add a correct transfer method tomorrow

```
void deposit(…)  { atomic { … }}
void withdraw(…) { atomic { … }}
int  balance(…)  { atomic { … }}

void transfer(Acct from, int amt) {
  atomic {
    //correct
    if(from.balance()>=amt && amt < maxXfer){
      from.withdraw(amt);
      this.deposit(amt);
    }
  }
}
```

# Lesson

Locks do not compose; transactions do

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# “Weak” atomicity

Widespread misconception:

“Weak” atomicity violates the “all-at-once” property of transactions only when the corresponding lock code has a data race

(May still be a bad thing, but smart people disagree.)

```
initially y==0
```

```
atomic {
  y = 1;
  x = 3;
  y = x;
}
```

```
x = 2;
print(y); //1? 2?
```

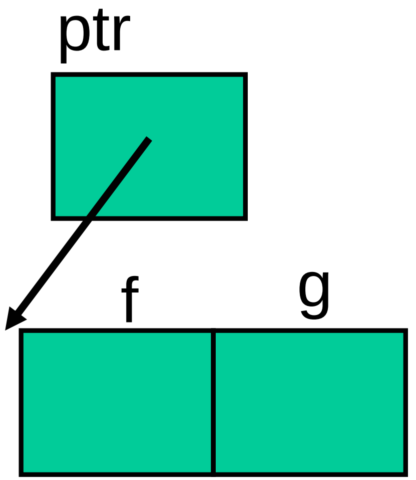
# It’s worse

This lock-based code is correct in Java

```
initially ptr.f == ptr.g
```

```
sync(lk) {
  r = ptr;
  ptr = new C();
}
assert(r.f==r.g);
```

```
sync(lk) {
  ++ptr.f;
  ++ptr.g;
}
```




(Example from [Rajwar/Larus] and [Hudson et al])

# It’s worse

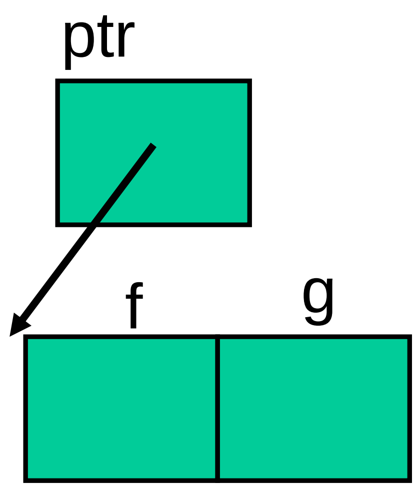
But every published weak-atomicity system allows the assertion to fail!

- Eager- or lazy-update

```
initially ptr.f == ptr.g
```

```
atomic {
  r = ptr;
  ptr = new C();
}
assert(r.f==r.g);
```

```
atomic {
  ++ptr.f;
  ++ptr.g;
}
```




(Example from [Rajwar/Larus] and [Hudson et al])

# Lesson

"Weak" is worse than most think

and sometimes worse than locks

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# Relaxed memory models

Modern languages don't provide sequential consistency

1. Lack of hardware support
2. Prevents otherwise sensible & ubiquitous compiler transformations (e.g., copy propagation)

One tough issue: When do transactions impose ordering constraints?

# Ordering

Can get "strange results" for bad code

- Need rules for what is "good code"

```
initially x==y==0
```

```
x = 1;

y = 1;
```

```
r = y;

s = x;
assert(s>=r);//invalid
```

# Ordering

Can get "strange results" for bad code

- Need rules for what is "good code"

```
initially x==y==0
```

```
x = 1;
sync(lk){}
y = 1;
```

```
r = y;
sync(lk){} //same lock
s = x;
assert(s>=r);//valid
```

# Ordering

Can get “strange results” for bad code

- Need rules for what is “good code”

```
initially x==y==0
```

```
x = 1;
atomic{}
y = 1;
```

```
r = y;
atomic{}
s = x;
assert(s>=r);//???
```

If this is good code, existing STMs are wrong

# Ordering

Can get “strange results” for bad code

- Need rules for what is “good code”

```
initially x==y==0
```

```
x = 1;
atomic{z=1;}
y = 1;
```

```
r = y;
atomic{tmp=0*z;}
s = x;
assert(s>=r);//???
```

“Conflicting memory” a slippery ill-defined slope

# Lesson

It is unclear when transactions should be ordered, but languages need memory models

Corollary: Could/should delay adoption of transactions in real languages

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# Interleaved execution

The “uniprocessor (and then some)” assumption:

*Threads communicating via shared memory don't execute in “true parallel”*

Important special case:

- Uniprocessors still exist
- Many language implementations assume it (e.g., OCaml, DrScheme)
- Multicore may assign one core to an application

# Uniprocessor implementation

- Execution of an atomic block logs updates
  - No overhead outside transaction nor for reads nor for initialization writes
- If scheduler preempts midtransaction, rollback
  - Else commit is trivial
- Duplicate code to avoid logging overhead outside transactions
  - Closures/objects need double code pointers
- Smooth interaction with GC
  - The log is a root
  - No need to log/rollback the GC (unlike hardware)

# Evaluation

Strong atomicity for Caml at little cost

– Already assumes a uniprocessor

– See the paper for “in the noise” performance

- Mutable data overhead

| | not in atomic | in atomic |
|---|---|---|
| read | none | none |
| write | none | log (2 more writes) |

- Rare rollback

# Lesson

Implementing (strong) atomicity in software for a uniprocessor is so efficient it deserves special-casing

Note: The O/S and GC special-case uniprocessors too

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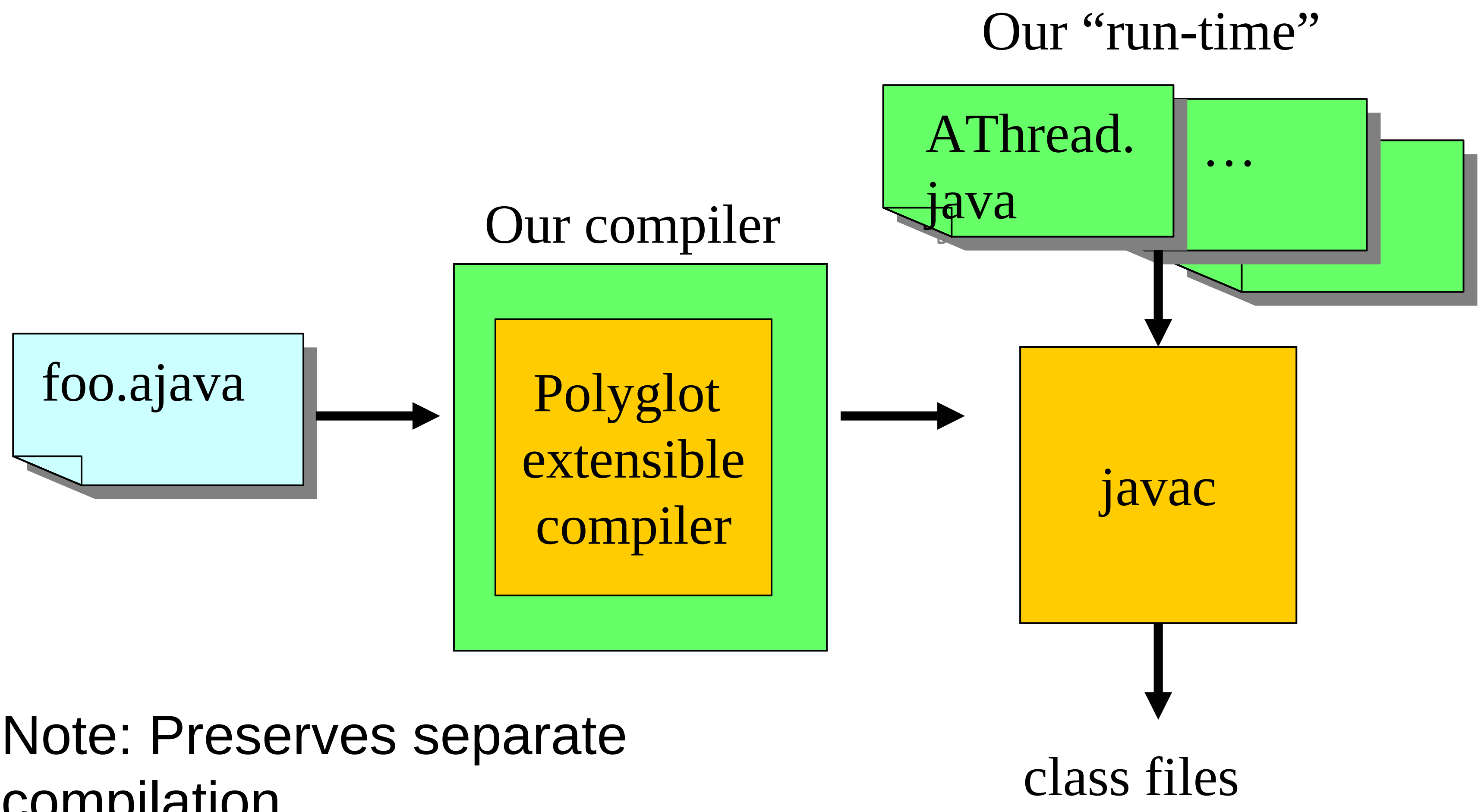
# System Architecture




Note: Preserves separate compilation

# Key pieces

- A field read/write first *acquires ownership* of object
- *Polling* for releasing ownership
  - Transactions rollback before releasing
- In transaction, a write also *logs the old value*
- Read/write barriers via method calls

  (JIT can inline them later)
- Some Java cleverness for efficient logging
- Lots of details for other Java features

# Acquiring ownership

All objects have an **`owner`** field

```
class AObject extends Object {
  Thread owner; //who owns the object
  void acq(){   //owner=caller (blocking)
   if(owner==currentThread())
      return;
   … // complicated slow-path
  }
}
```

- Synchronization only when contention
- With “owner=currentThread()” in constructor, thread-local objects *never* incur synchronization

# Lesson

Transactions for high-level programming languages do not need low-level implementations

But good performance often needs parallel readers, which is future work. ☹

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# Strong performance problem

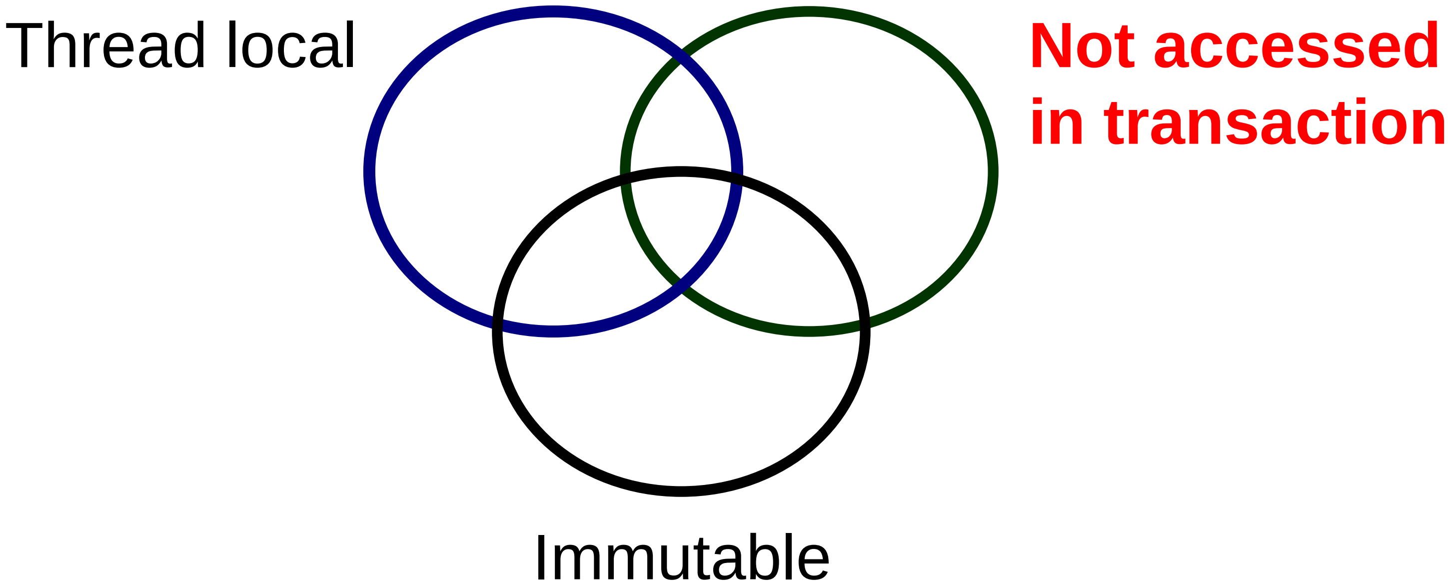
Recall uniprocessor overhead:

| | not in atomic | in atomic |
|---|---|---|
| read | none | none |
| write | none | some |

With parallelism:

| | not in atomic | in atomic |
|---|---|---|
| read | none iff weak | some |
| write | none iff weak | some |

# Optimizing away barriers




New: static analysis for not-accessed-in-transaction …

# Experimental Setup

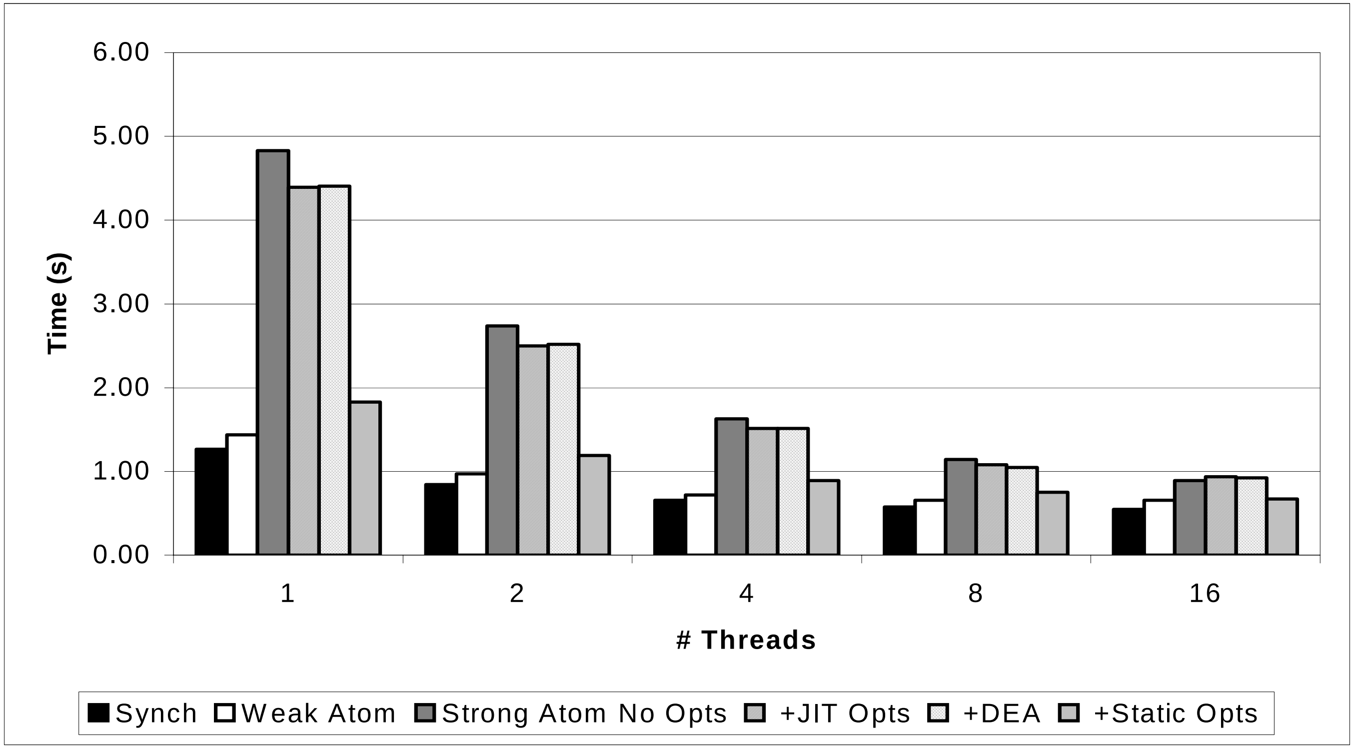
UW: static analysis using whole-program pointer analysis

- Scalable (context- and flow-insensitive) using Paddle/Soot

Intel PSL: high-performance strong STM via compler and run-time

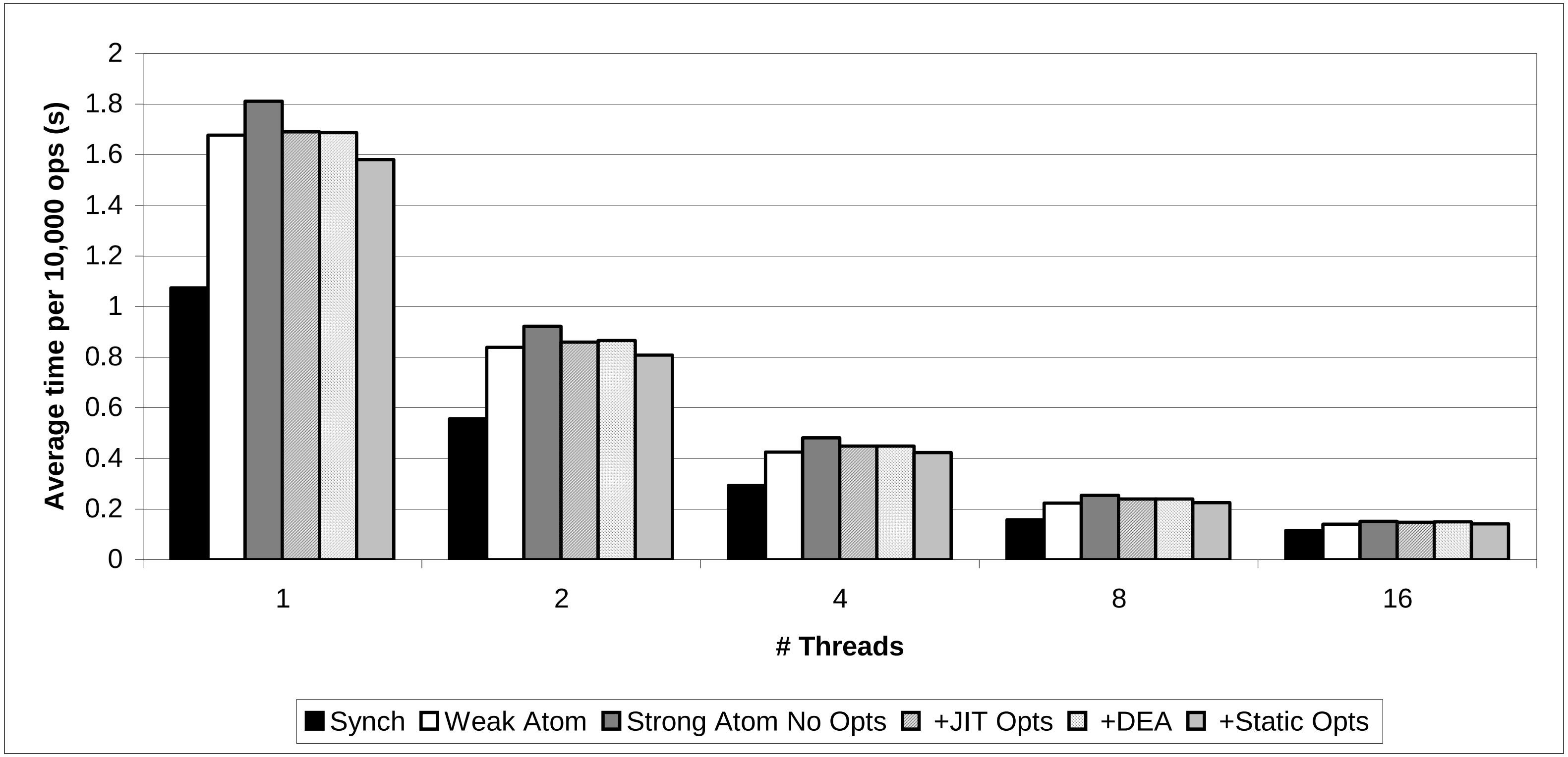
- StarJIT
  - IR and optimizations for transactions and isolation barriers
  - Inlined isolation barriers
- ORP
  - Transactional method cloning
  - Run-time optimizations for strong isolation
- McRT
  - Run-time for weak and strong STM

# Benchmarks




Tsp

# Benchmarks




JBB

# Lesson

The cost of strong isolation is in nontransactional barriers and compiler optimizations help a lot

Note: The first high-performance strong software transaction implementation for a multiprocessor

# Credit

Uniprocessor: Michael Ringenburg

Source-to-source: Benjamin Hindman (undergrad)

Barrier-removal: Steve Balensiefer, Kate Moore

Memory-model issues: Jeremy Manson, Bill Pugh

High-performance strong STM: Tatiana Shpeisman, Vijay Menon, Ali-Reza Adl-Tabatabai, Richard Hudson, Bratin Saha

wasp.cs.washington.edu

# Lessons

1. Locks do not compose; transactions do
2. "Weak" is worse than most think and sometimes worse than locks
3. It is unclear when transactions should be ordered, but languages need memory models

---

4. Implementing atomicity in software for a uniprocessor is so efficient it deserves special-casing
5. Transactions for high-level programming languages do not need low-level implementations
6. The cost of strong isolation is in nontransactional barriers and compiler optimizations help a lot