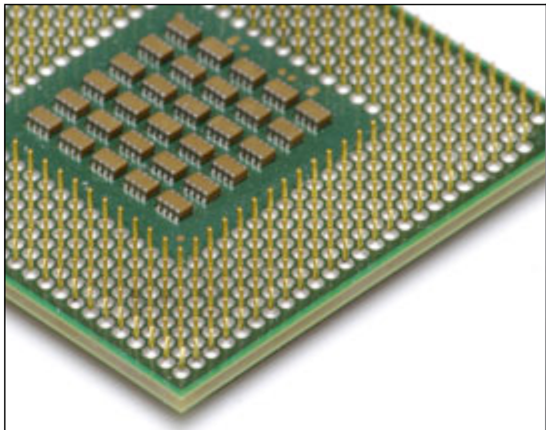
O.C.

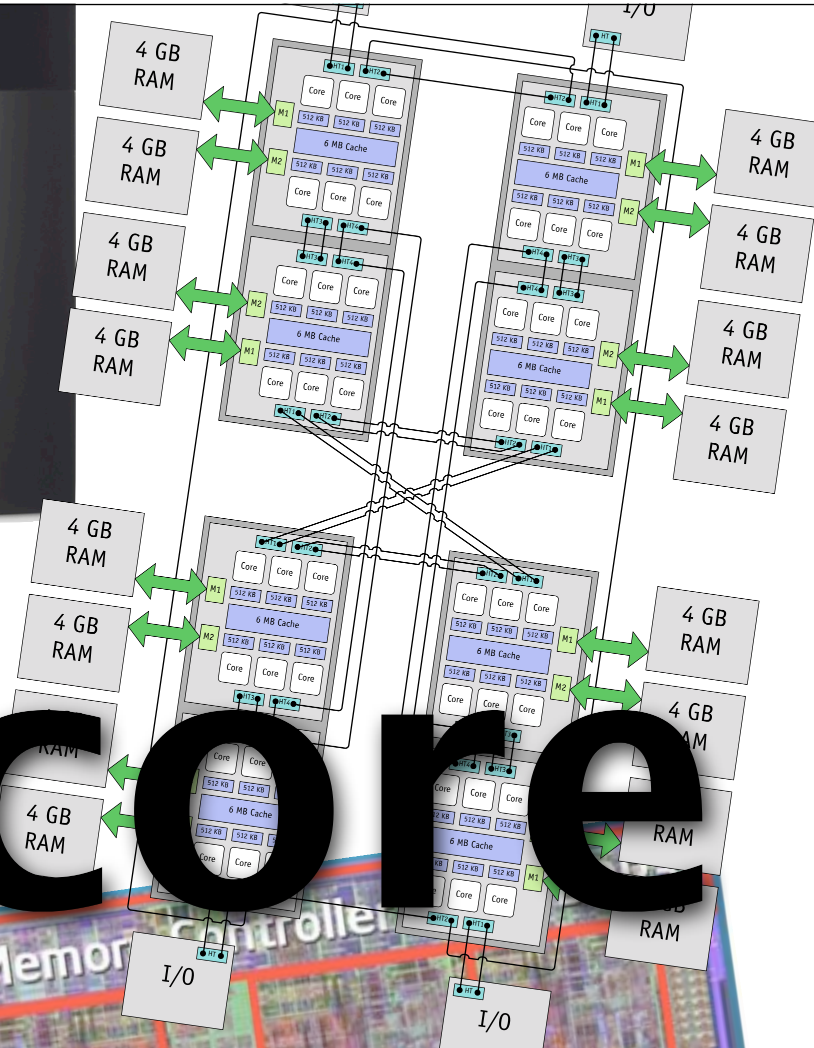
Observationally Cooperative

M.

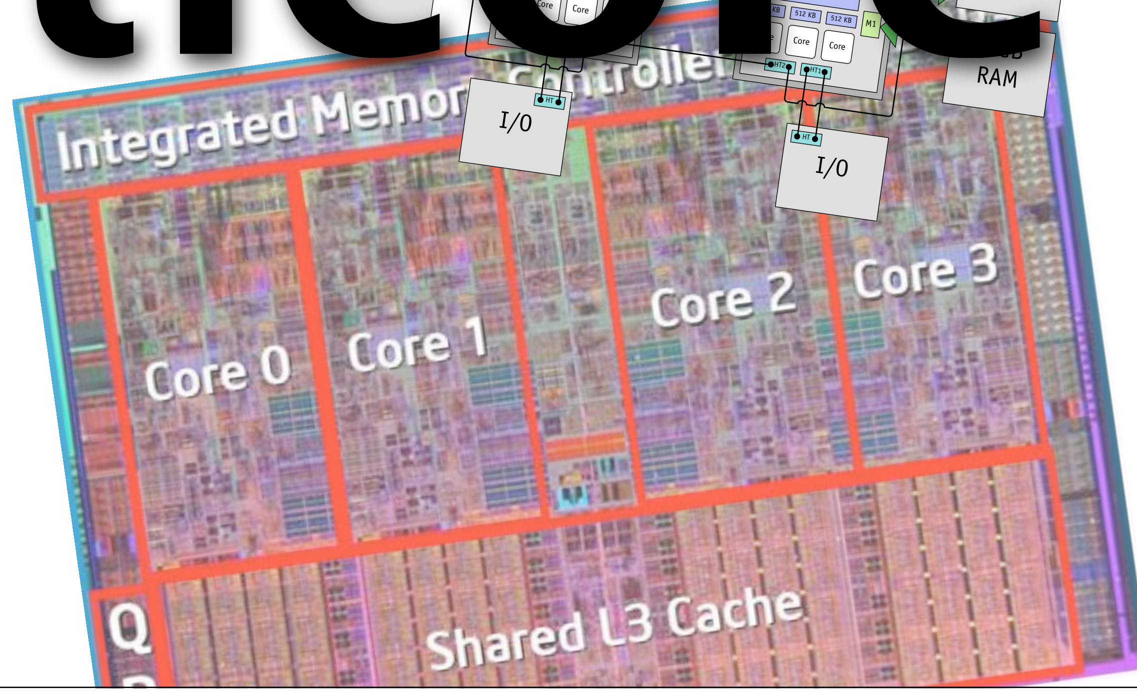
Melissa O’Neill
Chris Stone
lots of summer students




PLAYSTATION 3
SONY


4 GB RAM
Core
512 KB
6 MB Cache
M1
M2
I/O

Multicore


Integrated Memor
Core 0
Core 1
Core 2
Core 3
Shared L3 Cache
Q

Parallel programming is

Parallel programming is

Familiar Correct

Understandable

Performant

Broadly Applicable

Choose one, maybe

Familiar Correct

Understandable

Performant

Broadly Applicable

OCM

Multicore programming for the masses

Goal: a shared-memory model that

- is easy to learn and use
- supports irregular problems
- values correctness, ease-of-use

Race Conditions

```
// move $5
acct[x] = acct[x] - 5;
acct[y] = acct[y] + 5;
```

```
// move $10
acct[i] = acct[i] - 10;
acct[j] = acct[j] + 10;
```

Explicit Locks (?)

```
lock(acct[x]);
lock(acct[y]);
   // move $5
   acct[x] = acct[x] - 5;
   acct[y] = acct[y] + 5;
unlock(acct[y]);
unlock(acct[x]);
```

```
lock(acct[i]);
lock(acct[j]);
   // move $10
   acct[i] = acct[i] - 10;
   acct[j] = acct[j] + 10;
unlock(acct[j]);
unlock(acct[i]);
```

Atomic Blocks

```
atomic {
   // move $5
   acct[x] = acct[x] - 5;
   acct[y] = acct[y] + 5;
}
```

```
atomic {
   // move $10
   acct[i] = acct[i] - 10;
   acct[j] = acct[j] + 10;
}
```

Atomic Blocks

```
while (acct[x] >= 5) {
   // move $5
   acct[x] = acct[x] - 5;
   acct[y] = acct[y] + 5;
}
```

Atomic Blocks

```
while (acct[x] >= 5) {
   // move $5
   acct[x] = acct[x] - 5;
   acct[y] = acct[y] + 5;
}
```

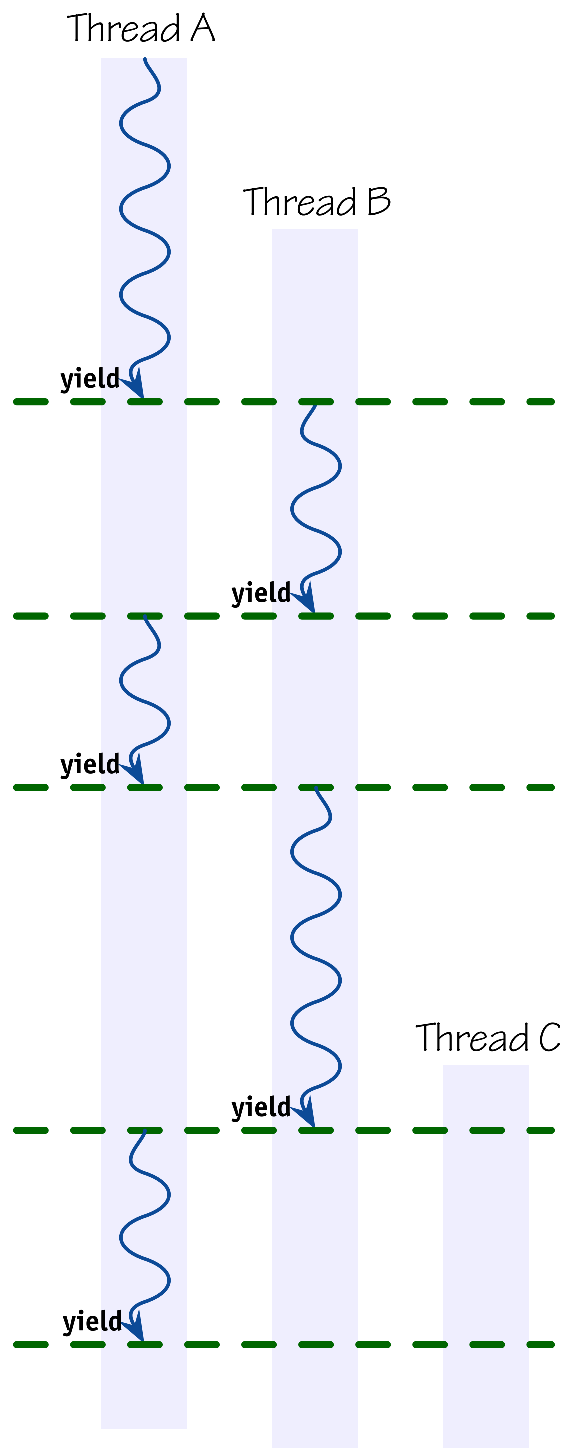
```
bool loop1;
do {
   atomic {
      loop1 = acct[x] >= 5;
      if (loop1) {
         // move $5
         acct[x] = acct[x] - 5;
         acct[y] = acct[y] + 5;
      }
   }
} while(loop1);
```

Cooperative Multithreading (for Uniprocessors)

- Only one thread runs at a time.
- `yield` switches threads; no preemption.

Cooperative Multithreading

- Only one thread runs at a time
- **yield** statements switch threads



Cooperative

```
while (acct[x] >= 5) {
    // move $5
    acct[x] = acct[x] - 5;
    acct[y] = acct[y] + 5;
}
```

```
while (acct[i] >= 10) {
    // move $10
    acct[i] = acct[i] - 10;
    acct[j] = acct[j] + 10;
}
```

Cooperative

```
while (acct[x] >= 5) {
    // move $5
    acct[x] = acct[x] - 5;
    acct[y] = acct[y] + 5;
}
```

```
while (acct[i] >= 10) {
   // move $10
   acct[i] = acct[i] - 10;
   acct[j] = acct[j] + 10;
}
```

```
while (acct[x] >= 5) {
  // move $5
  acct[x] = acct[x] - 5;
  acct[y] = acct[y] + 5;
  yield;
}
```

```
while (acct[i] >= 10) {
  // move $10
  acct[i] = acct[i] - 10;
  acct[j] = acct[j] + 10;
  yield;
}
```

OCM: A Model for Parallel Computation

- CM code = OCM code
- System may run threads simultaneously
- Fundamental guarantee: **CM-Serializability**
  - Result is consistent with some uniprocessor CM execution

Observationally Cooperative Multithreading

```
while (acct[x] >= 5) {
  // move $5
  acct[x] = acct[x] - 5;
  acct[y] = acct[y] + 5;
  yield;
}
```

```
while (acct[i] >= 10) {
  // move $10
  acct[i] = acct[i] - 10;
  acct[j] = acct[j] + 10;
  yield;
}
```

Let’s Try It…

A Parallel Perspective on `yield`

Threads primarily execute in isolation.

When a thread `yields`:

- Its changes are visible to the world
- Changes in the world become visible to it

Advantages of OCM

- We can reason sequentially between `yields`
- Fewer opportunities for deadlock
- Implementation-agnostic

That’s nice…
But how do you
implement it?

You don’t need to care.
“It just works.”

You don’t need to care.

“It just works.”

In theory!

What would programmers do without OCM?

What would programmers do without OCM?

It does that, automatically!

Classic idea: Locks

Implementing OCM with Locks

```
                      release_locks();
yield;      ⟶
                      acquire_locks();
```

- Need locks for data accessed through next `yield`
  - Lock inference
  - Programmer annotations
- OCM is responsible for avoiding deadlock.
- Optimizations: Lazy Acquire, Eager Release

Newer idea:
Atomic Transactions

Implementing OCM with STM

```
                          end_transaction();
yield;       ⟶
                          begin_transaction();
```

- One subtlety: "unreturning" from functions

Unreturning from Functions

```
void caller() {
  callee();
  ...
  yield;
}
```

```
void callee() {
  yield;
  ...
}
```

Unreturning from Functions

```
void caller() {              void callee() {
  callee();                    yield;
  ...                          ...
  yield;                     }
}
```

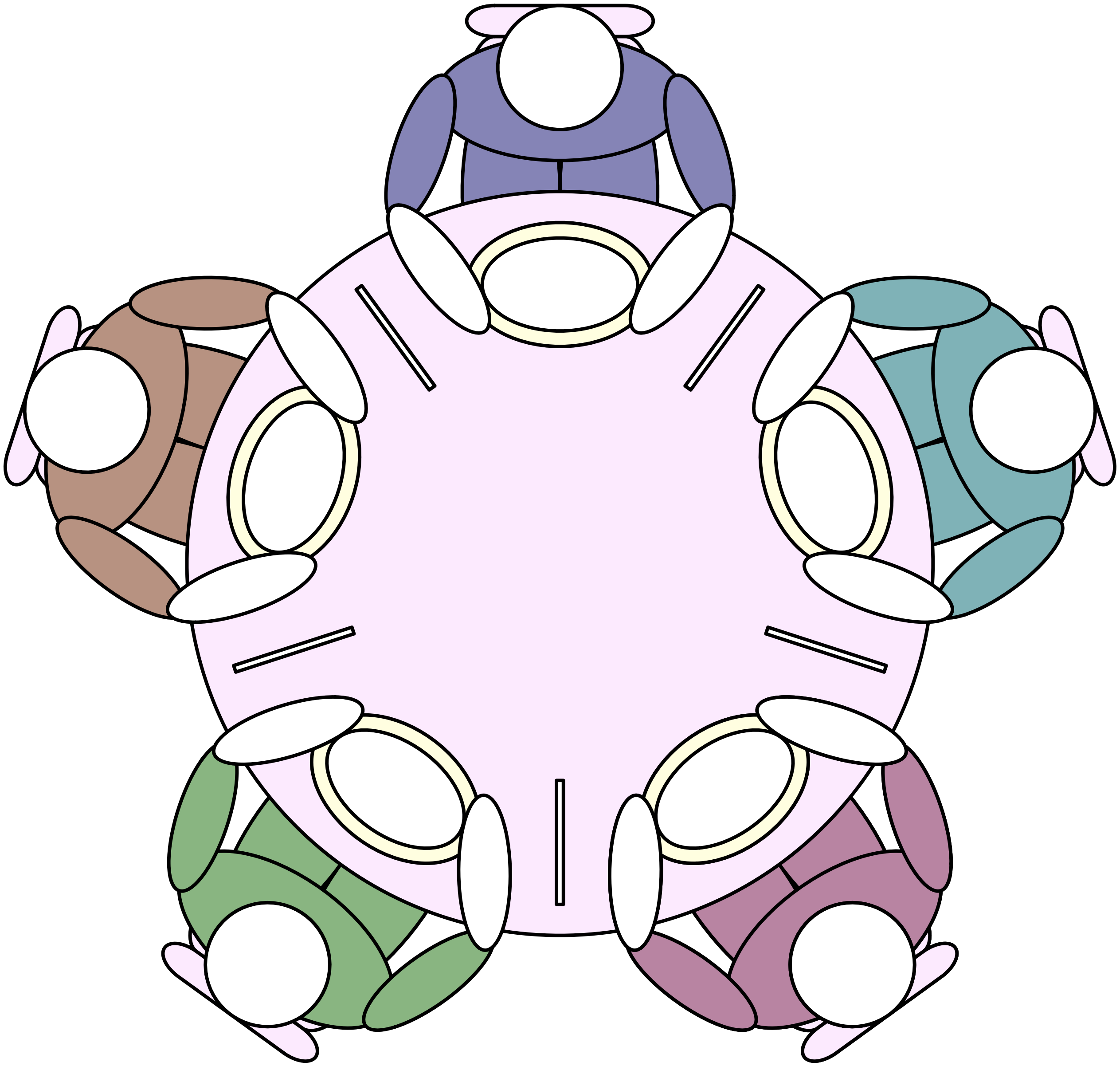
Solutions:

- Access the stack through STM
- Or, save and restore stack segments

Proof of Concept Implementations

- Uniprocessor CM
- Pthreads + Big Lock
- Pthreads + Big Lazy Lock
- Explicit Locks
  - Lua (proxy objects)
  - C subset (lock inference)
- Software Transactional Memory
  - Lua (TinySTM)
  - C++ (wrapper objects, TinySTM/TL2)

Example: Dijkstra's Dining Philosophers



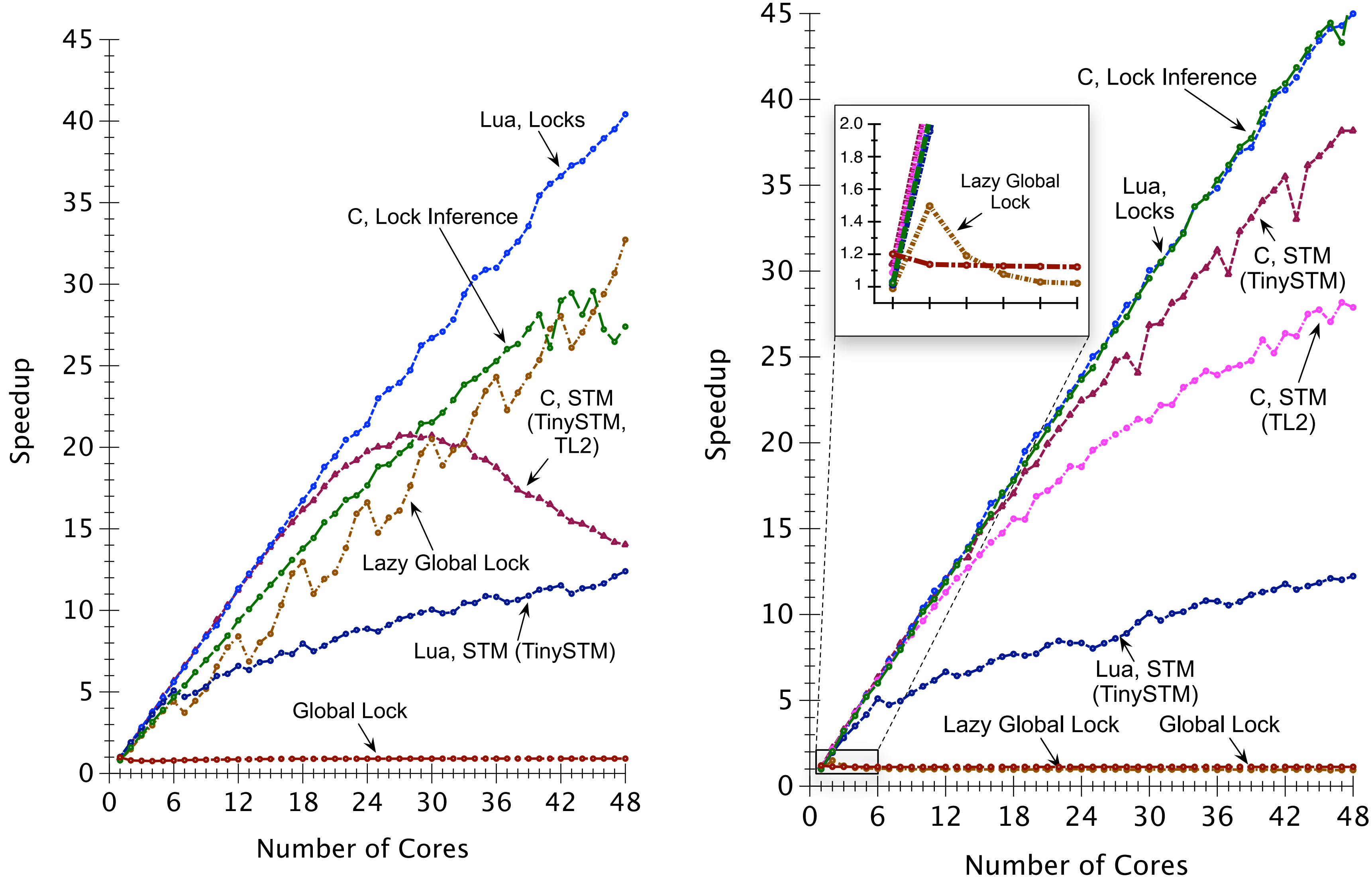
Traditional Philosophers

```
philosopher(int i):
  for iter in (1..ITERS):
     think();

     yieldUntil (isFree[i] && isFree[(i+1) % N]);

     isFree[i]           = false;
     isFree[(i+1) % N] = false;
     yield;

     eat();

     isFree[i]           = true;
     isFree[(i+1) % N] = true;
     yield;
```

True OCM Philosophers

```
philosopher(int i):
  for iter in (1..ITERS):
    think();
    yield;

    eat(fork[i], fork[(i+1) % N]);
    yield;
```

Speedup: Traditional & True OCM Philosophers



Debugging and Profiling

- OCM guarantees CM-Serializability.
  - Run in parallel, record serial equivalent
  - "Replay" the trace in uniprocessor CM.
- Implemented in 2 proof-of-concept implementations.

Conclusion

- OCM appears promising
  - Simple programming model
  - Supports "irregular" problems
  - Debugging support
  - Many possible implementations
- Future Work
  - Larger benchmark suite
  - More examples
  - Better/different OCM implementations
  - Study "ease of programming"

We’d love your help!

Be our Guinea Pigs!