Exploiting Task-Order Information

for Optimizing Sequentially Consistent Java Programs

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Sequential Consistency

- Easy-to-understand memory model
- Conceptually:
  - All memory accesses are visible immediately
  - All tasks agree on same legal sequential history of memory events
  - No re-ordering

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`Inefficient without optimizations!`

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Initially, x == y == 0

1: r1 = x;	3: r2 = y;
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No, if “sequentially consistent”

SC Example

Initially, x == y == 0

`2: y = 2;`	`4: x = 1;`
`1: r1 = x;`	`3: r2 = y;`

Is r1 == 1 AND r2 == 2 possible?

Yes, if the compiler reorders 1/2 and/or 3/4

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  - Guard every memory access with `barriers` (fields and array elements)
- Drawbacks:
  - `Barriers` introduce overhead
  - Prevents many standard optimizations
- Optimize to re-gain performance:
  - Remove `barriers` where no parallel task may interfere

Optimization Question

- Can memory access `m1` interfere with `m2`?

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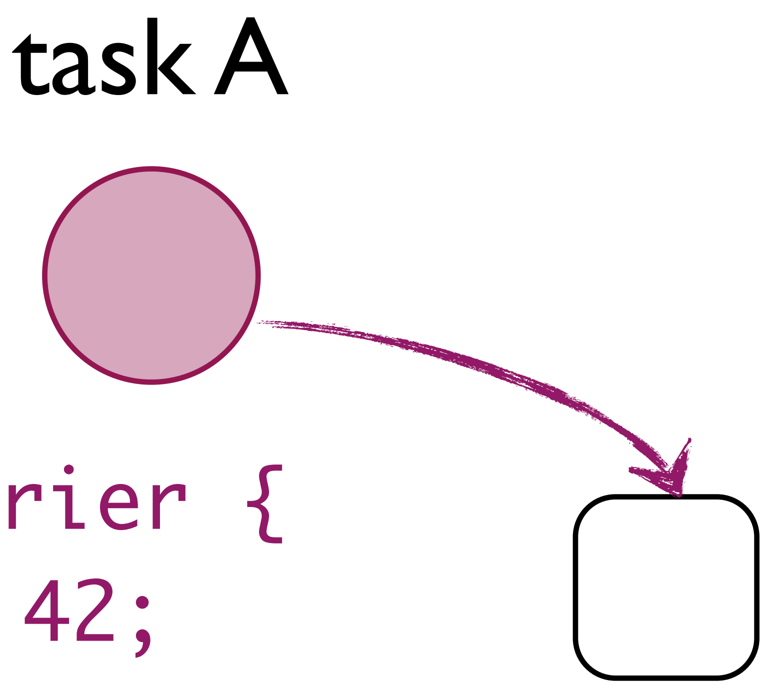


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m1: barrier {
  x.f = 42;
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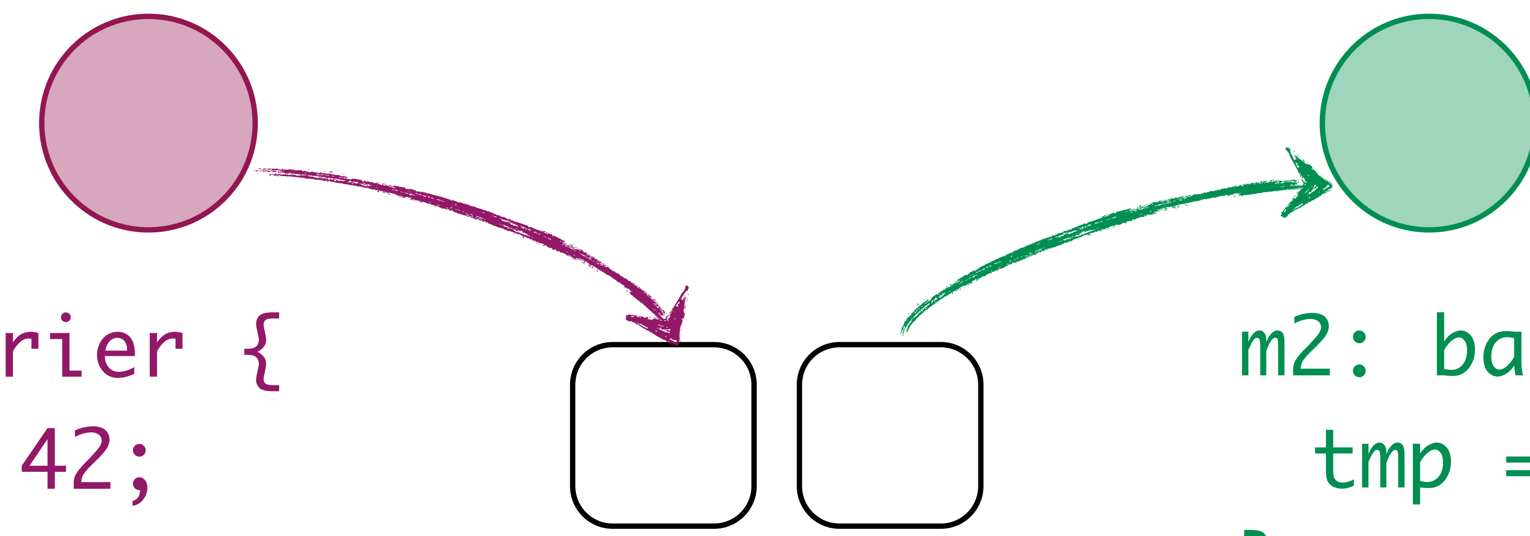
Optimization Question

- Can memory access `m1` interfere with `m2`?

task A

task B



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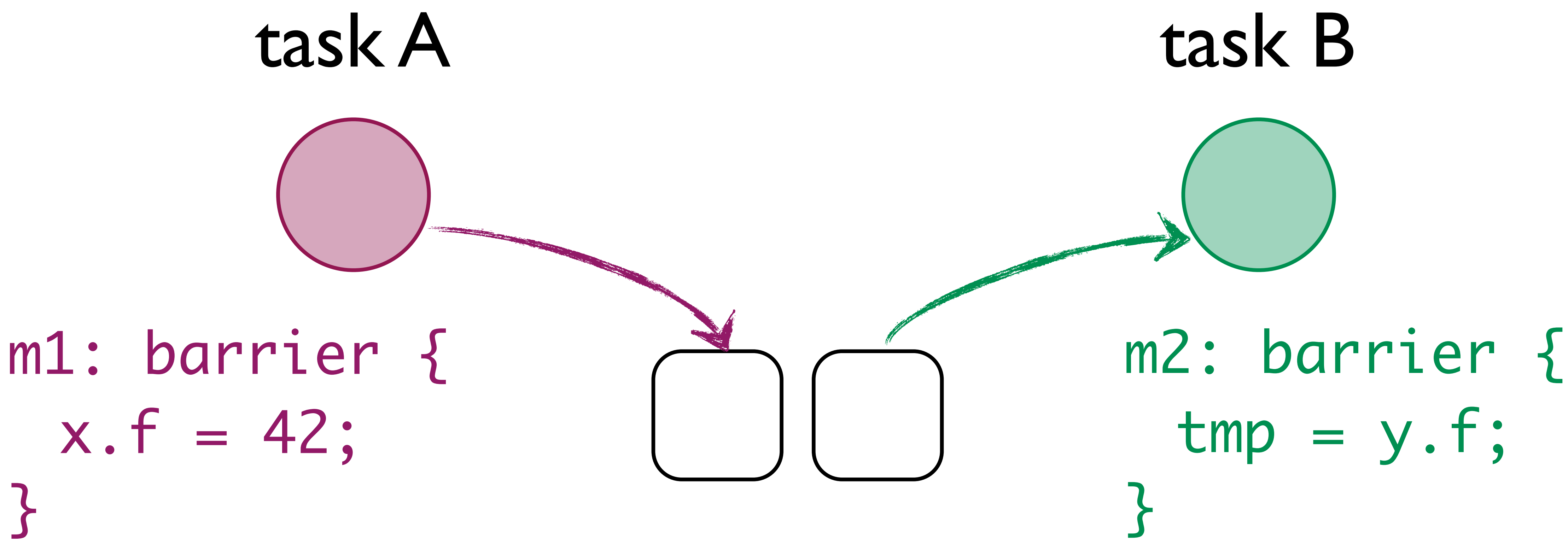

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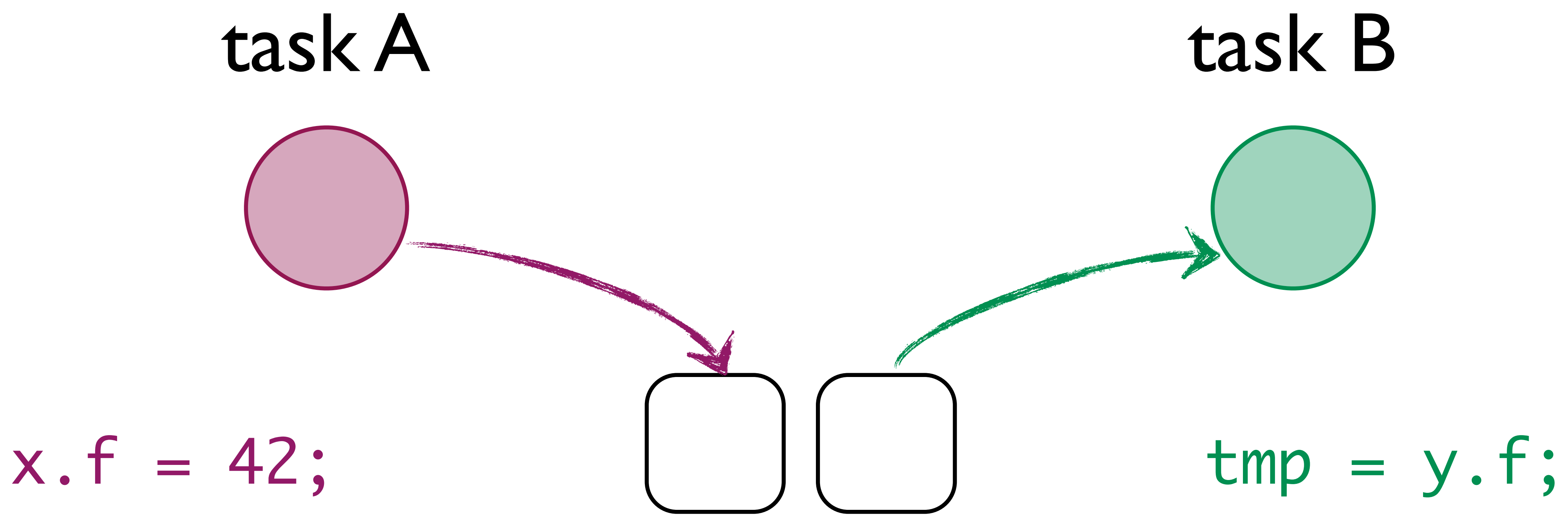

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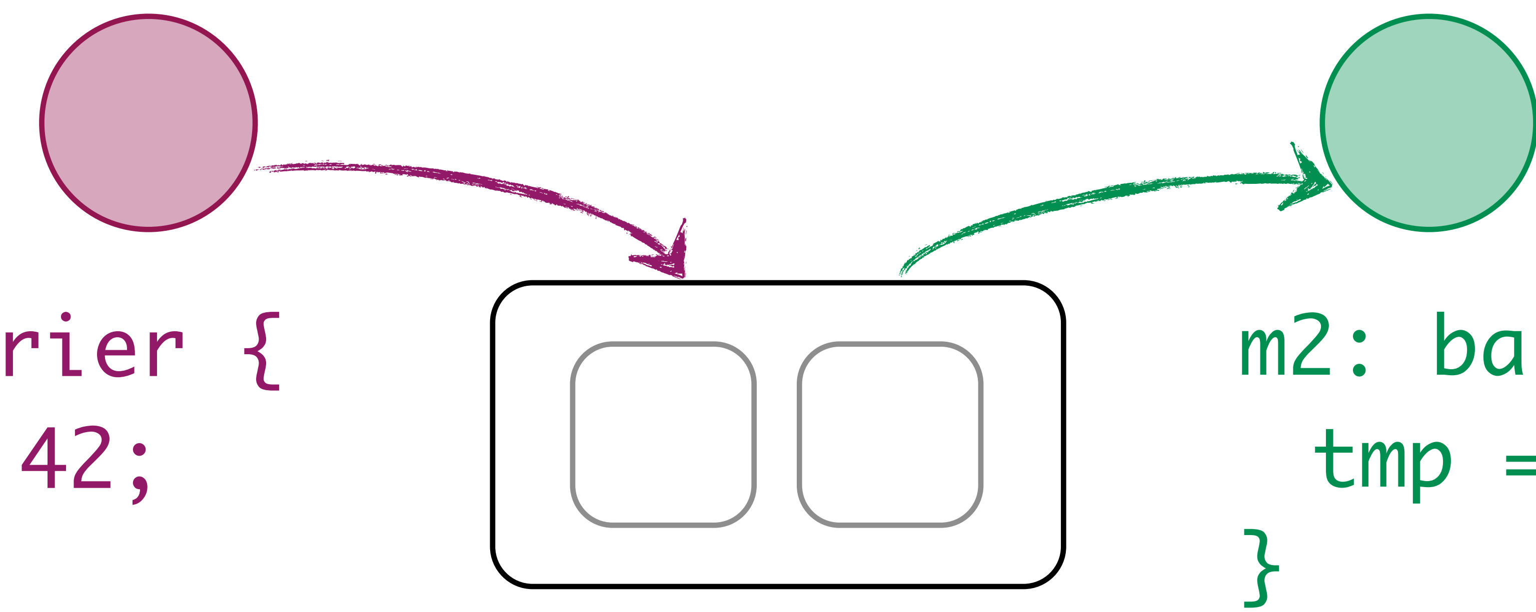

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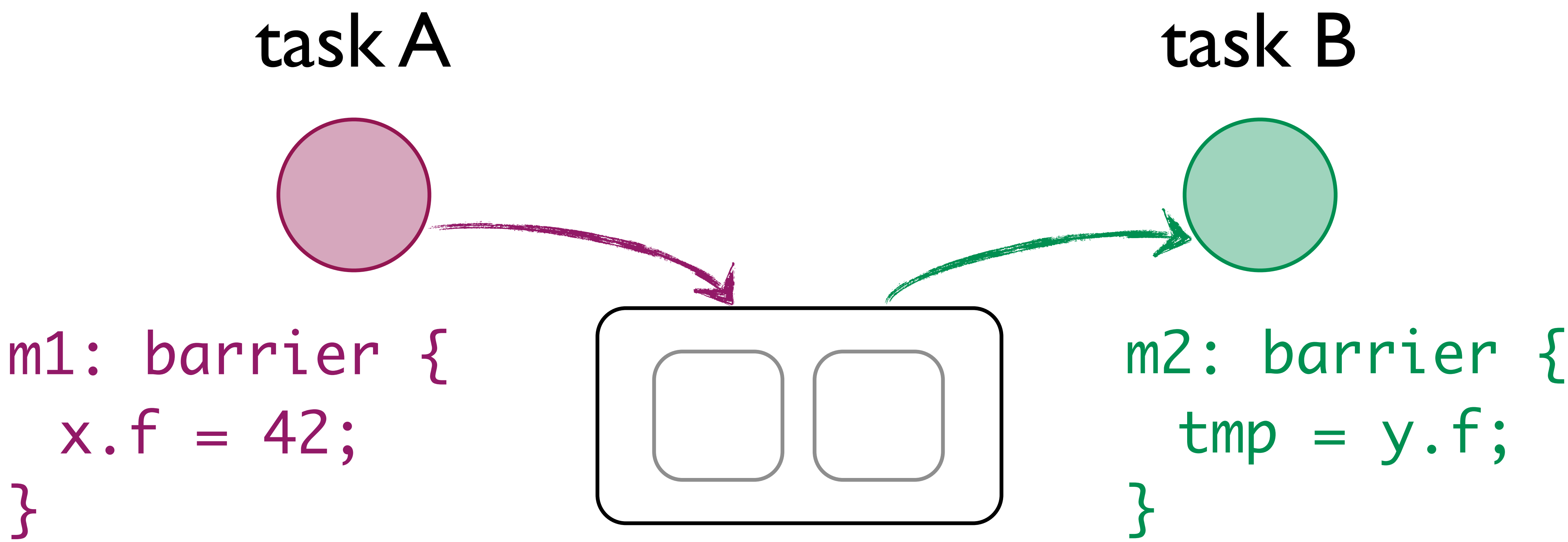

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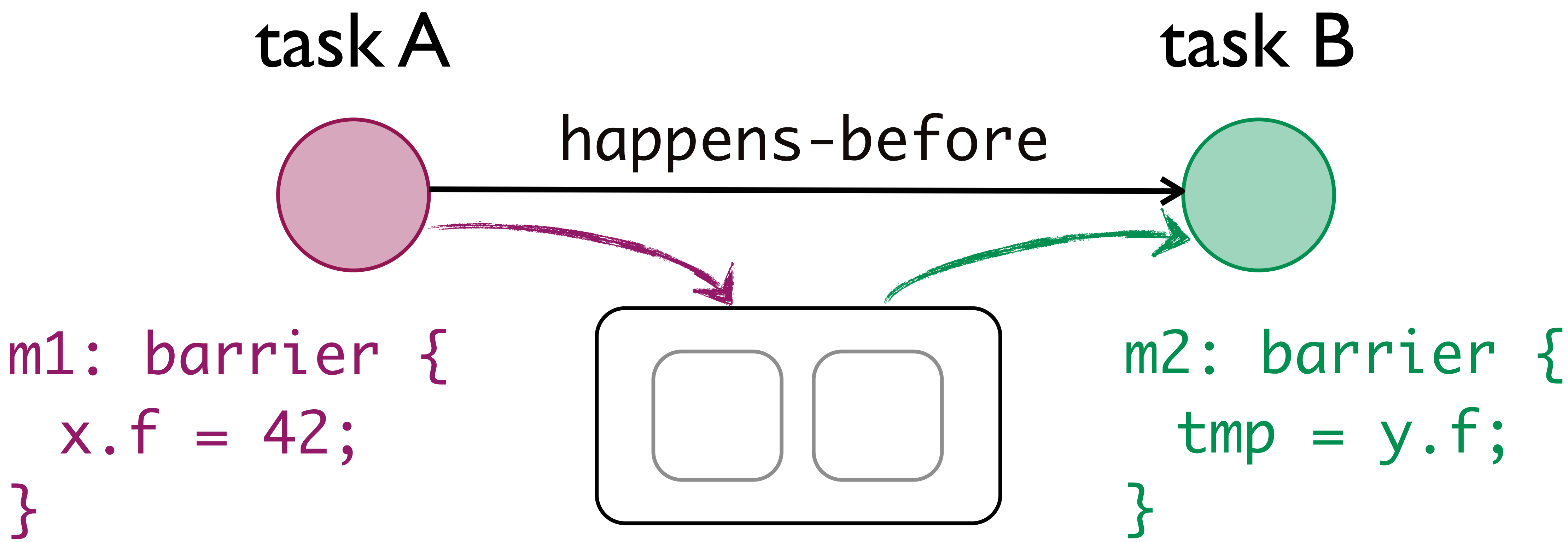

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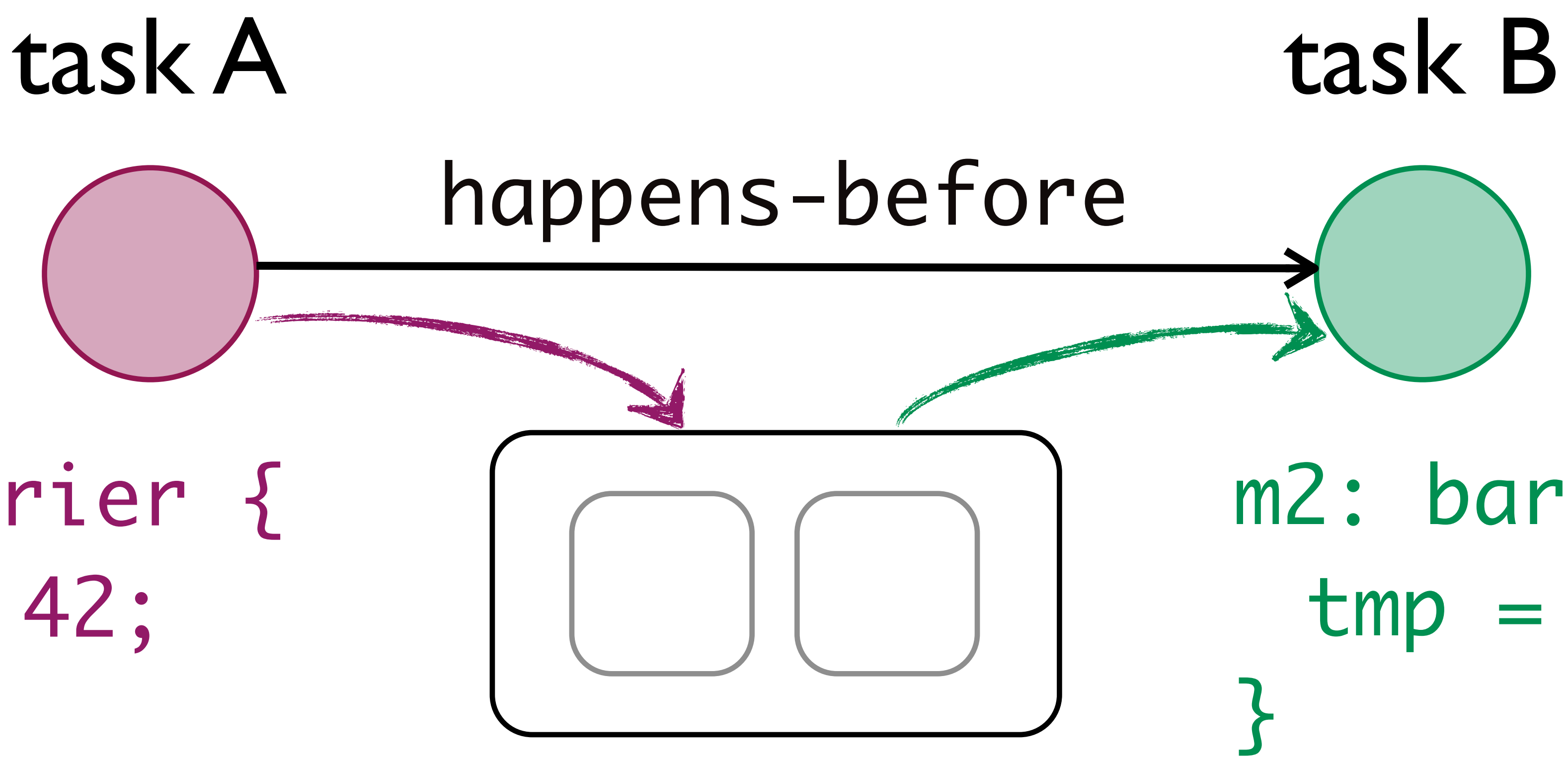


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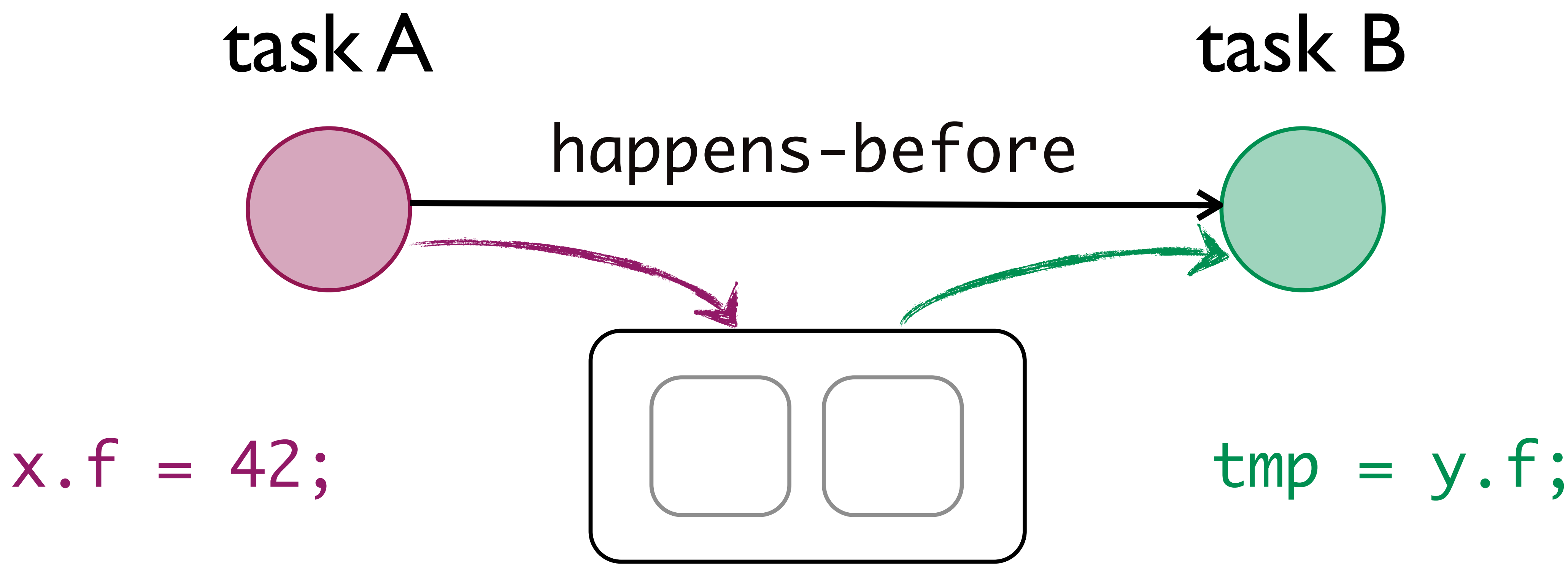

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Ordering in OpenMP

```
/*A*/

//#omp parallel for
for(int i=0; i<3; i++) {
  /*B*/
}

/*C*/
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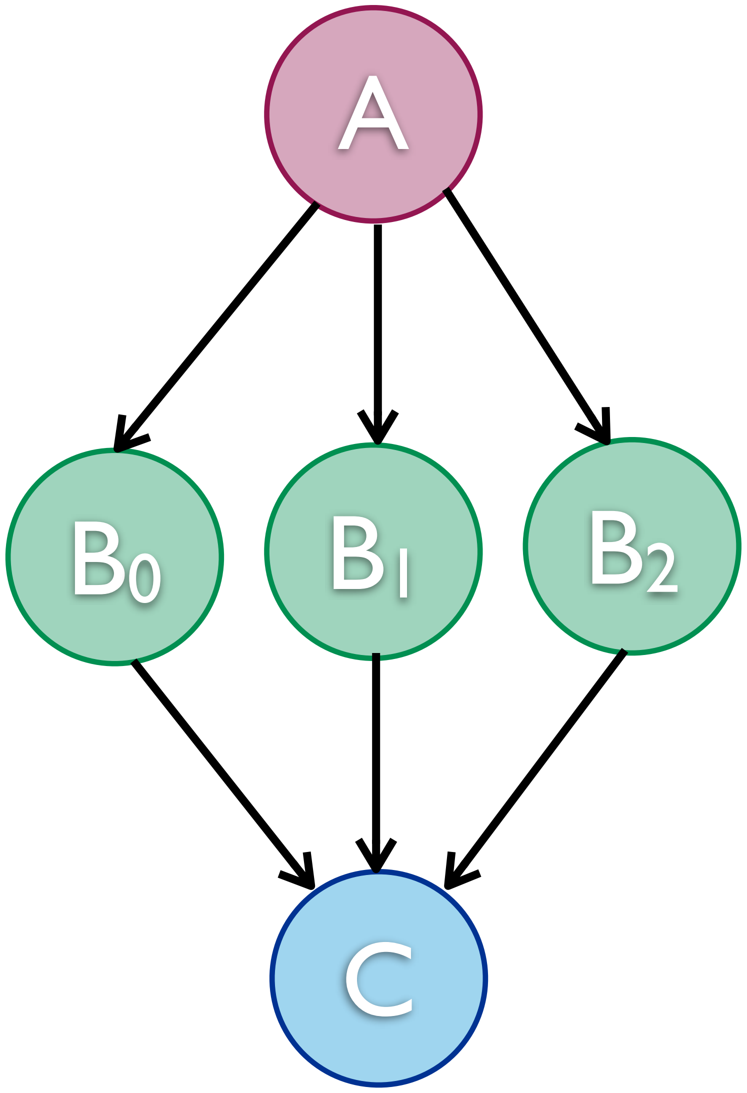

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  - Feature explicit task ordering
  - Not much previous work here

Ordering in Microsoft TPL

```
Task tA = Task.StartNew(/*A*/);

for(int i=0; i<3; i++) {
  tA.ContinueWith(/*B*/,
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/*C*/
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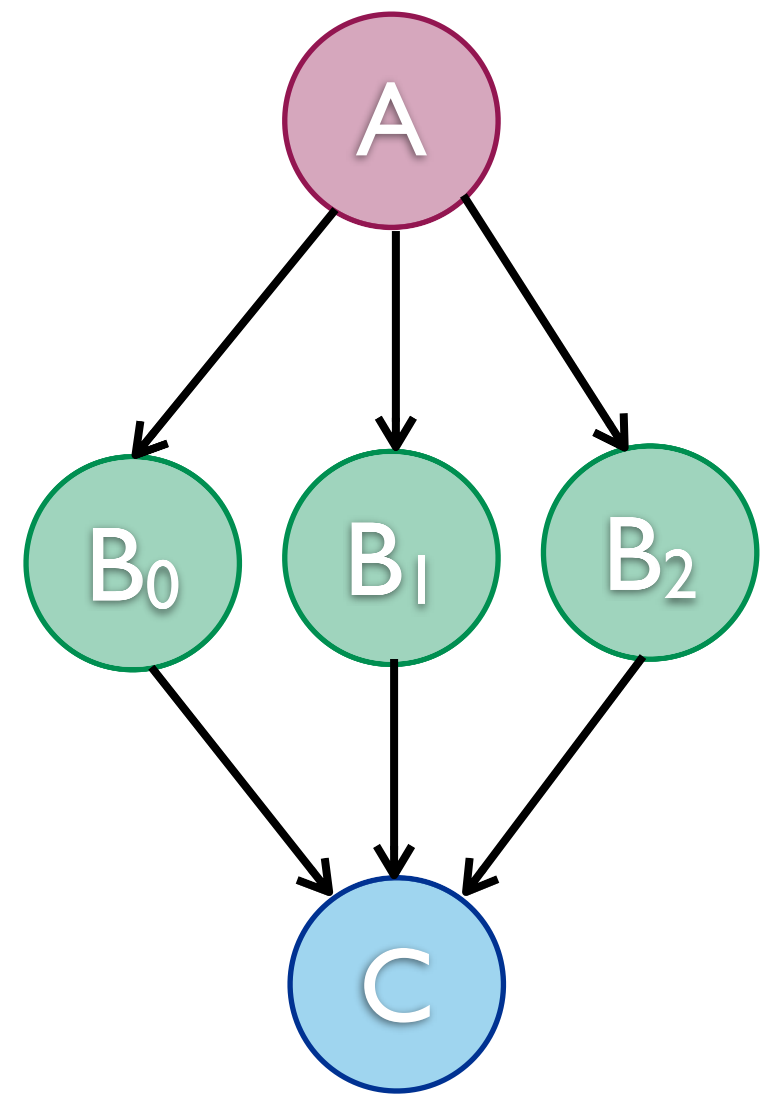

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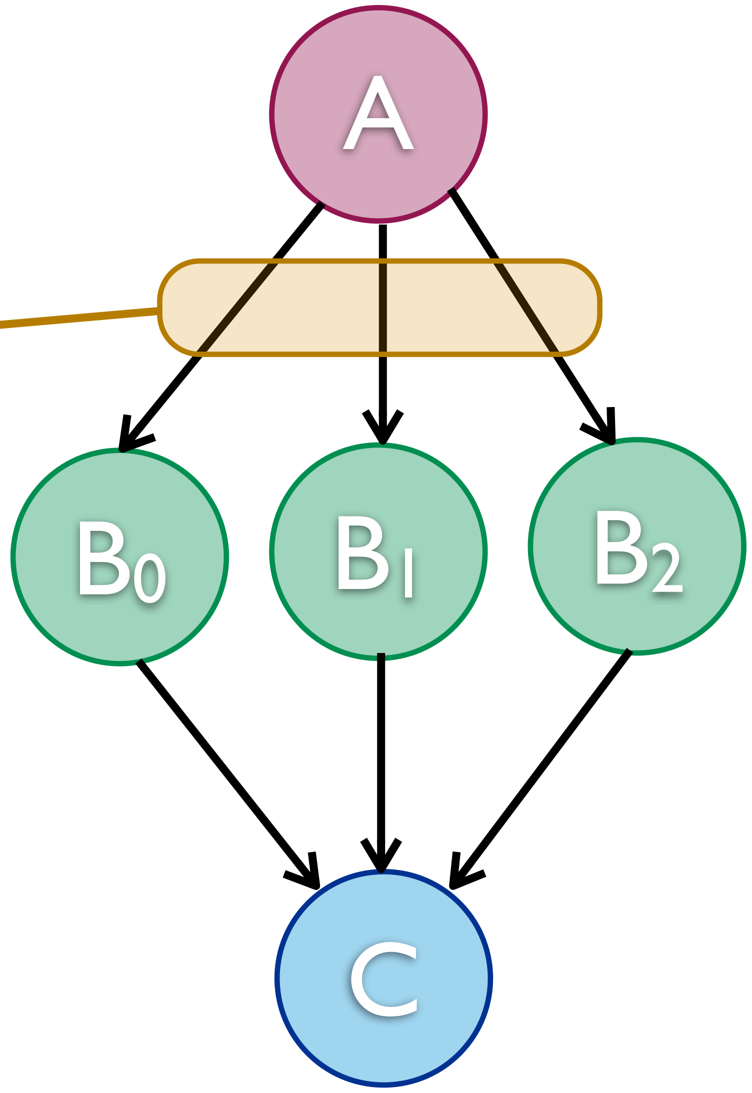

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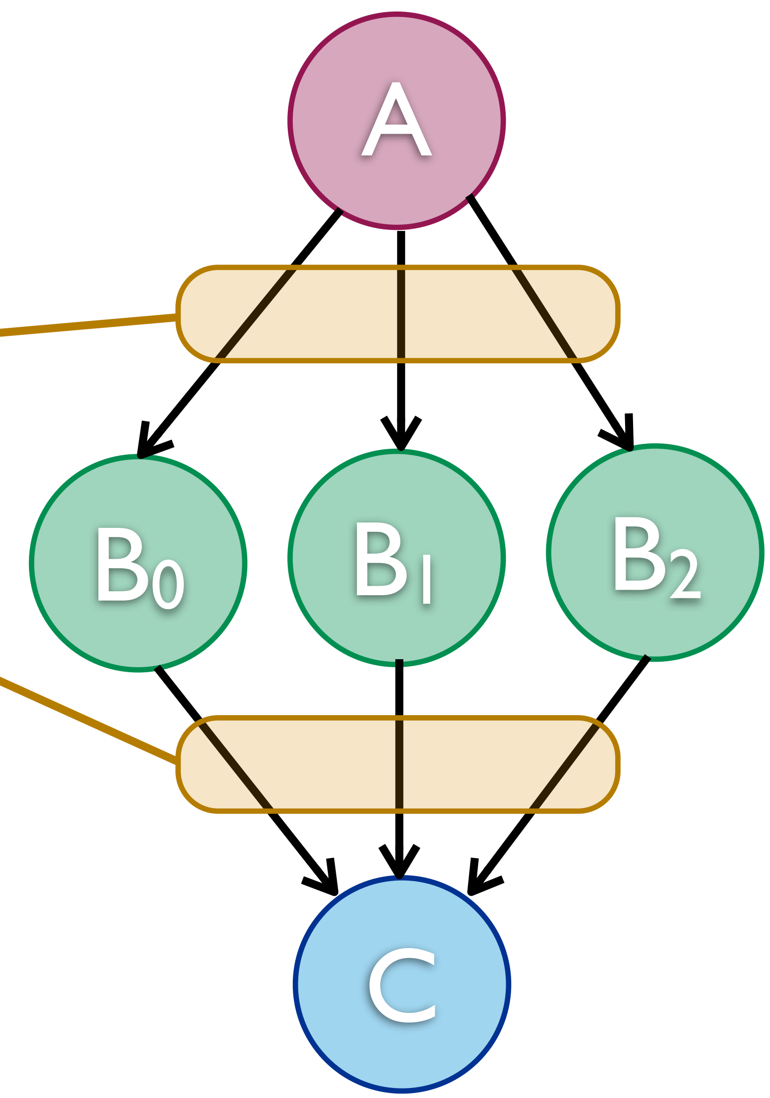

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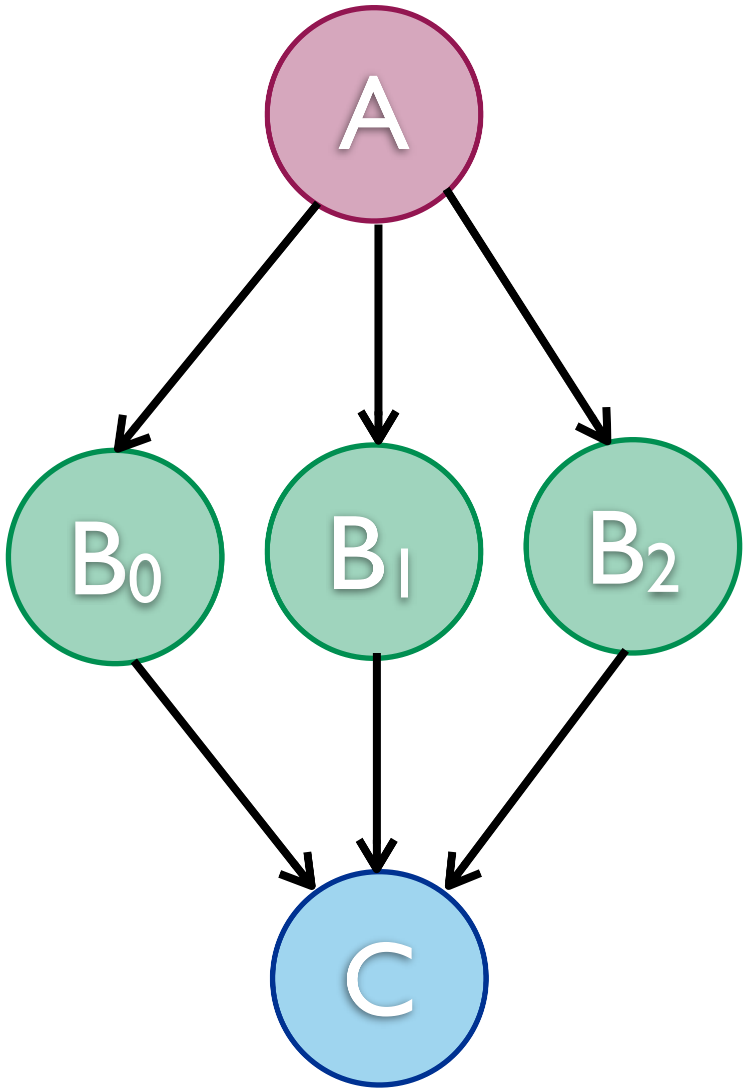
Abstraction:

Tasks with explicit happens-before relationships

Our Model: Explicit Scheduling

```
Task a = schedule /*A*/;
Task c = schedule /*C*/;

for(int i=0; i<3; i++) {
  Task b = schedule /*B*/;
  a → b;
  b → c;
}
```



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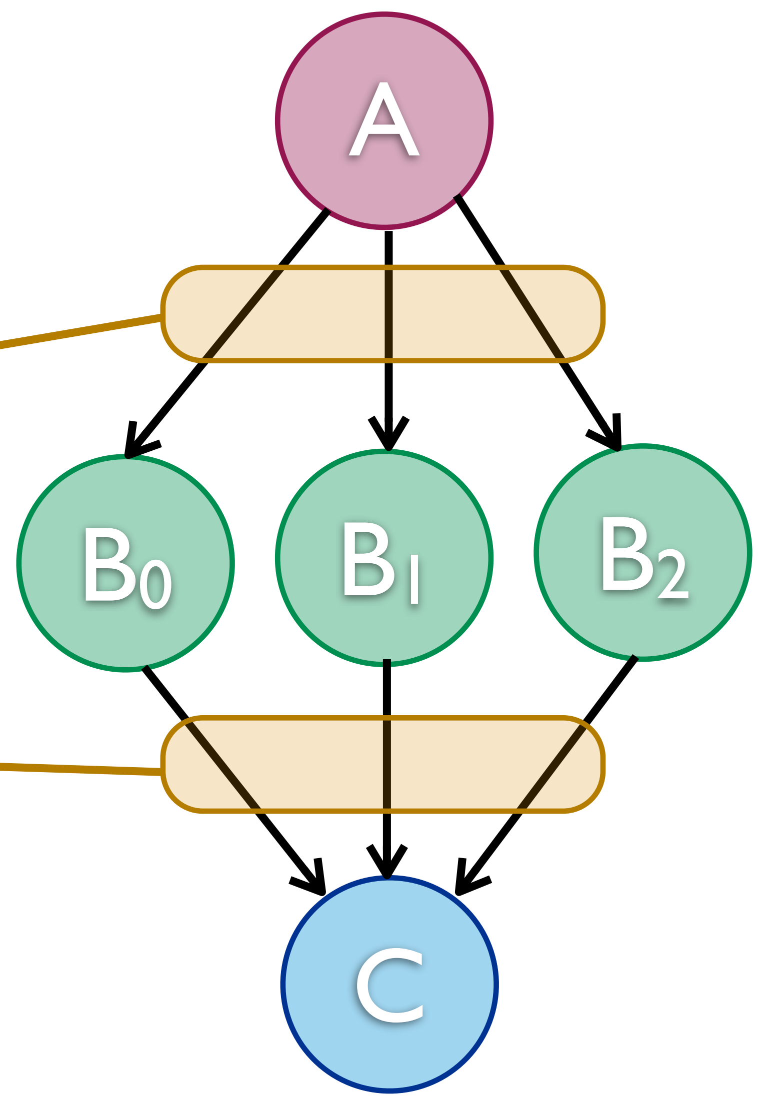

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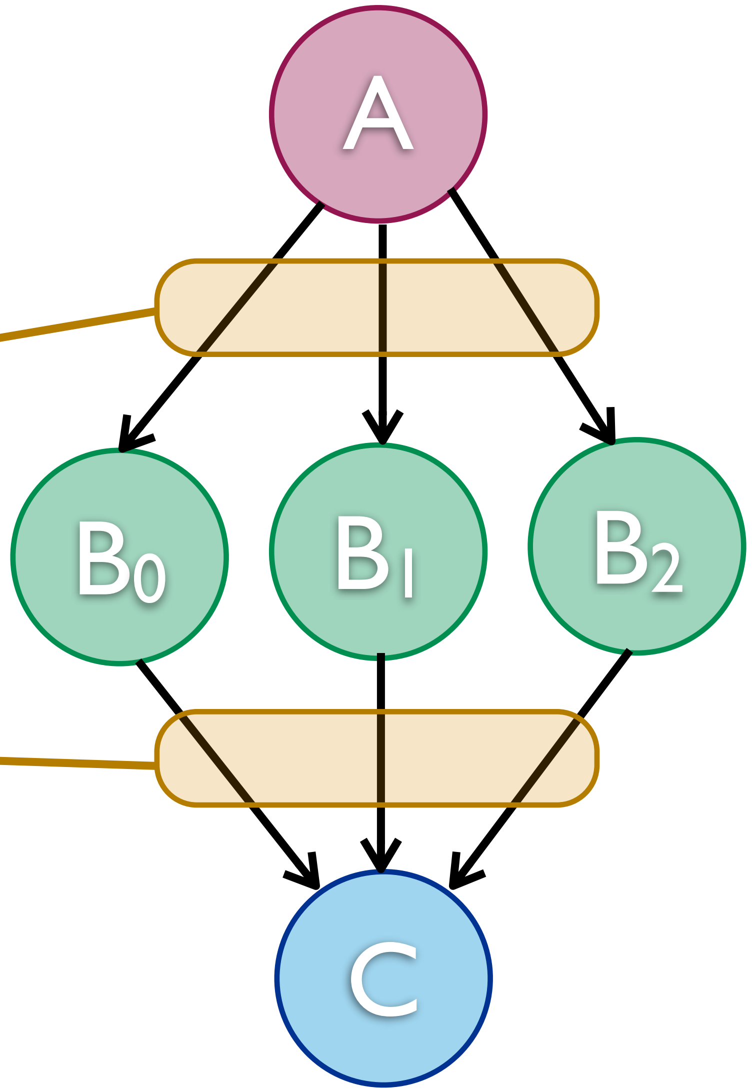

General enough to express threads, fork/join, thread libraries, ...

Schedule Analysis

- Static bytecode analysis
- Computes relation:
  `mayBeParallel(task1, task2)`
- If `!mayBeParallel(task1, task2)` then `task1` and `task2` are guaranteed to be ordered

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3. Find tasks that may be created directly or indirectly `without ordering`

- Key insight:
  - We look for `unordered-ness` not `ordered-ness`
  - Unordered-ness is monotonic!

On Monotonicity

```
task T1
  schedules A and B
  with A → B


task T2
  schedules A and B
```

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Ordered-ness:

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@T1: A → B

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not monotonic

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@T2: A || B

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not monotonic

Unordered-ness:

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@T2: A || B

monotonic

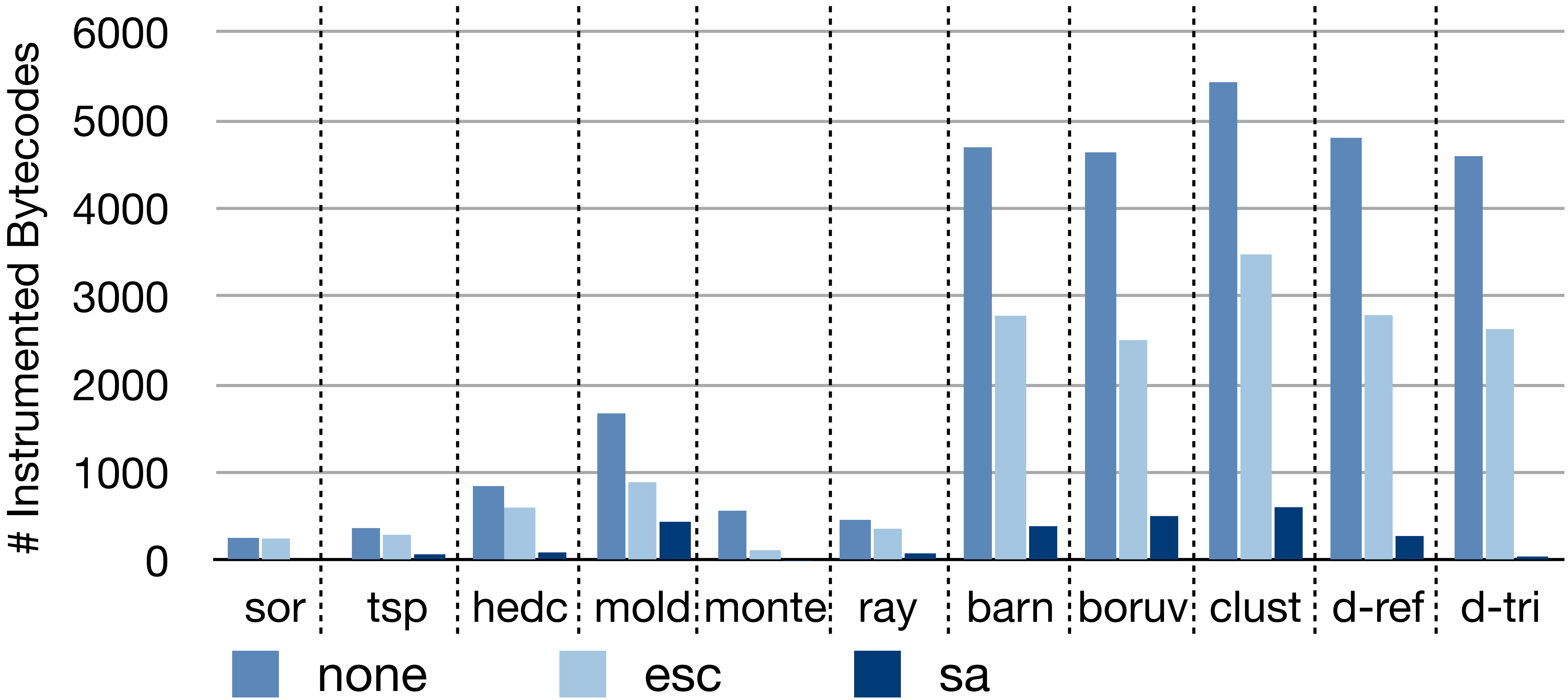
Evaluation Setup

- Bytecode-to-bytecode translation using `sun.misc.Unsafe.getXYVolatile()` and `sun.mist.Unsafe.putXYVolatile()` intrinsics
- Analyzes bytecode in SSA form
- Wala framework for analysis, Javassist for code generation
- Intel Core 2 Duo, 2.8 GHz, 4Gb RAM
  - ➡ 2 Java Threads
- Java 1.6.0 (Mac)

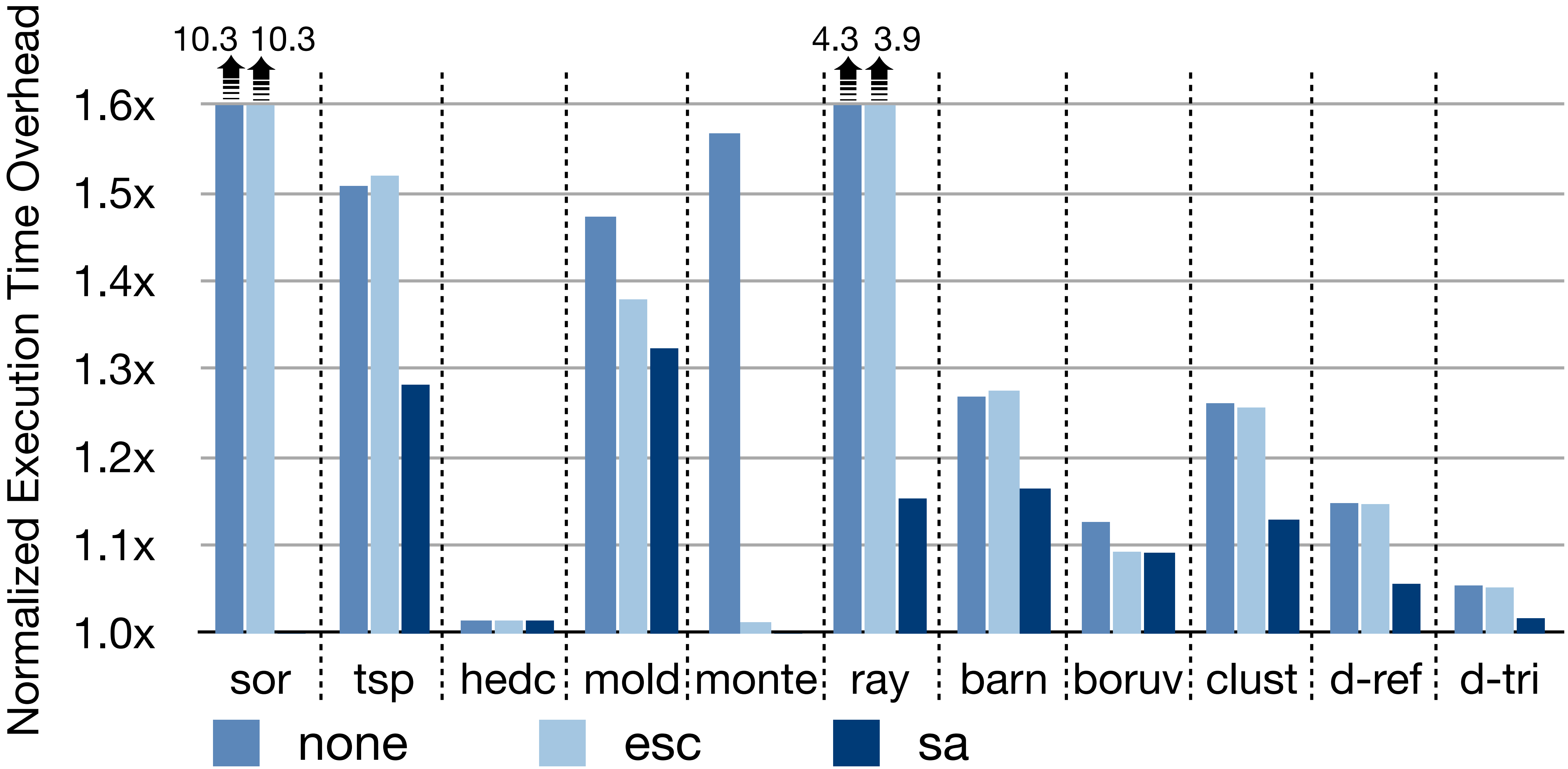
Benchmarks

- Erco Benchmarks: `sor`, `tsp`, `hedc`
- Java Grande (numeric apps): `mold`, `ray`, `monte`
- Lonestar (Galois): `barn`, `boruv`, `clust`, `d-tri`, `d-ref`
- Configurations:
  - Hand-optimized (`baseline`)
  - No optimizations (`none`)
  - Escape analysis only (`esc`)
  - Schedule analysis + escape analysis (`sa`)

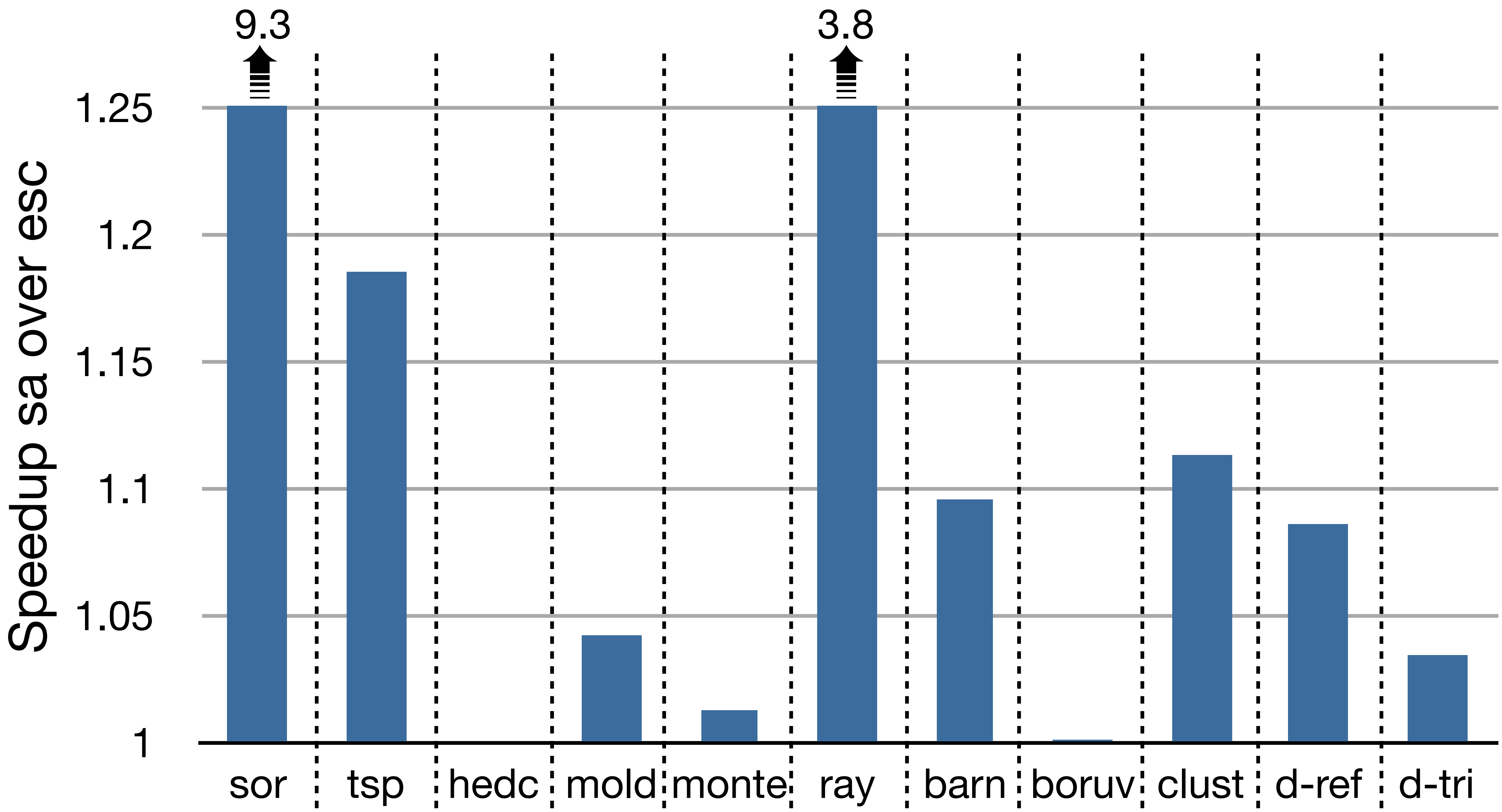
Instrumentation Overhead



Execution Time



Speedup sa vs. esc



Related Work

- **Compiler techniques for high performance sequentially consistent java programs.** Z. Sura et al, PPoPP'05
- **A case for an SC-preserving compiler.** D. Marino et al, PLDI'11
- **Efficient sequential consistency using conditional fences.** C. Lin, V Nagarajan, R. Gupta, PACT'10
- **BulkCompiler: high-performance sequential consistency through cooperative compiler and hardware support.** W. Ahn et al, MICRO'09
- **MHP Analysis.** (Agarwal et al)

Concluding Remarks

- Optimizations for `shared-memory` parallel programs need `task-order information` to be effective
- `Schedule analysis` is an approach that
  - can extract task-order information from `real-world` programs
  - provides starting point for optimizations
- Modest overhead over hand-optimized sequentially consistent programs