Combining Static Analysis and Speculations in JIT Compilers

Innovations in Compiler Technology (IICT-25)

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Brief Introduction

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- Idea: Staged Static+Dynamic analysis for Managed Runtimes.
  - Offload the costly analysis to static time.
  - Use analysis results in the JIT to enable additional optimizations.

Staged Analysis

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- Perform precise (context-, flow-, field-sensitive) escape analysis statically.
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- To handle the functional correctness due to the dynamism offered by the Language/VM — Correctness ensured through run-time checks — Heapification.

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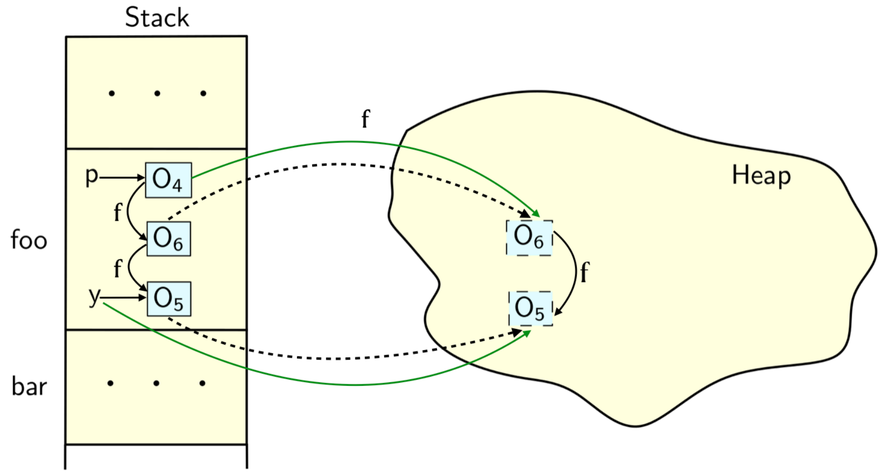

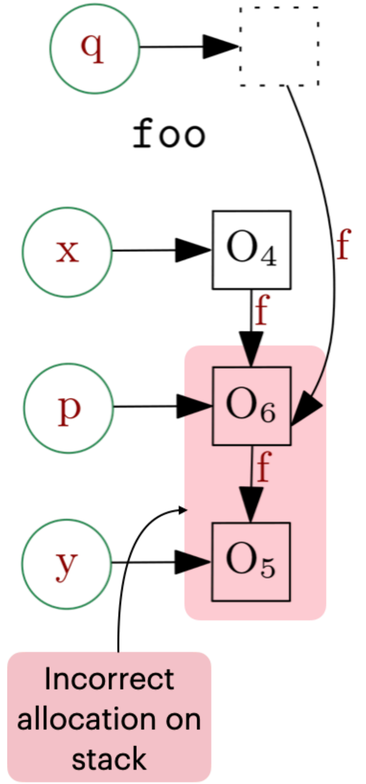

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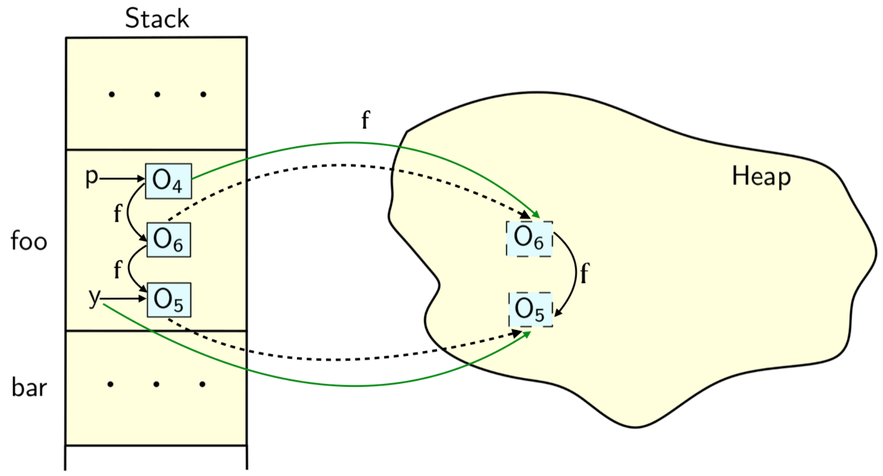

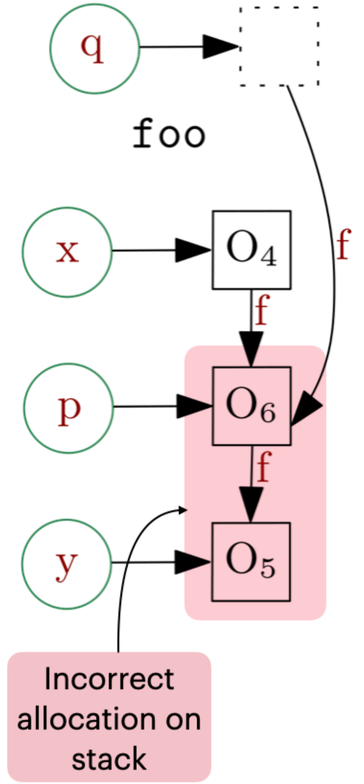

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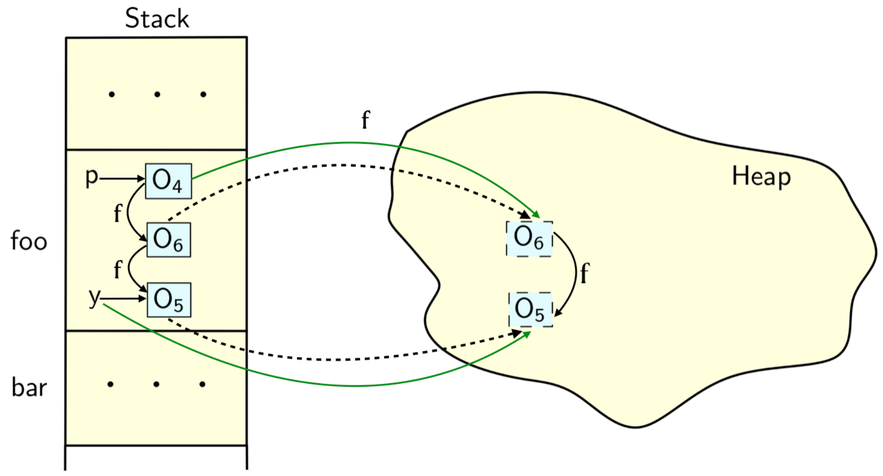

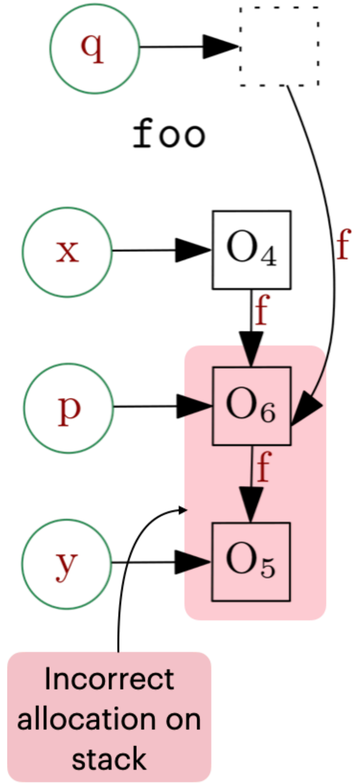

- The first approaches to soundly and efficiently use static (offline) analysis results in a JIT compiler!

Recent Works

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PYE: A Framework for Precise-Yet-Efficient Just-In-Time Analyses for Java Programs

TOPLAS 19

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ZS3: Marrying Static Analyzers and Constraint Solvers to Parallelize Loops in Managed Runtimes

CASCON 22

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Optimistic Stack Allocation and Dynamic Heapification for Managed Runtimes

PLDI 24

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Principles of Staged Static+Dynamic Partial Analysis

SAS 22

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RESEARCH

Partial program analysis for staged compilation systems

FMSD 24

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Static Analysis for JIT Compilers

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Standard Speculative Optimizations

Can we make JIT compiler perform more speculative optimizations ??

CoSSJIT: Combining Static Analysis and Speculation in JIT Compilers

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- Idea:
  - Enrich Static Analysis results with possibility of speculation at run-time.
  - Enable the JIT Compiler to perform speculative optimization based on the static analysis results.

1. PolyMorphic CallSites

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```
1. class A {
      . . .
4.   void foo(A z) {
5.        A x = new A(); // O5
6.        A y = new A(); // O6
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14.       z.bar(x);
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$\sqcap$: {B, C } —> [O_5],[O_7] [Escaping]

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At runtime:

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- Class Hierarchy (CHTable): C is not loaded.

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At runtime:

- Class Hierarchy (CHTable): C is not loaded.
- Most of the times z is of type "B".

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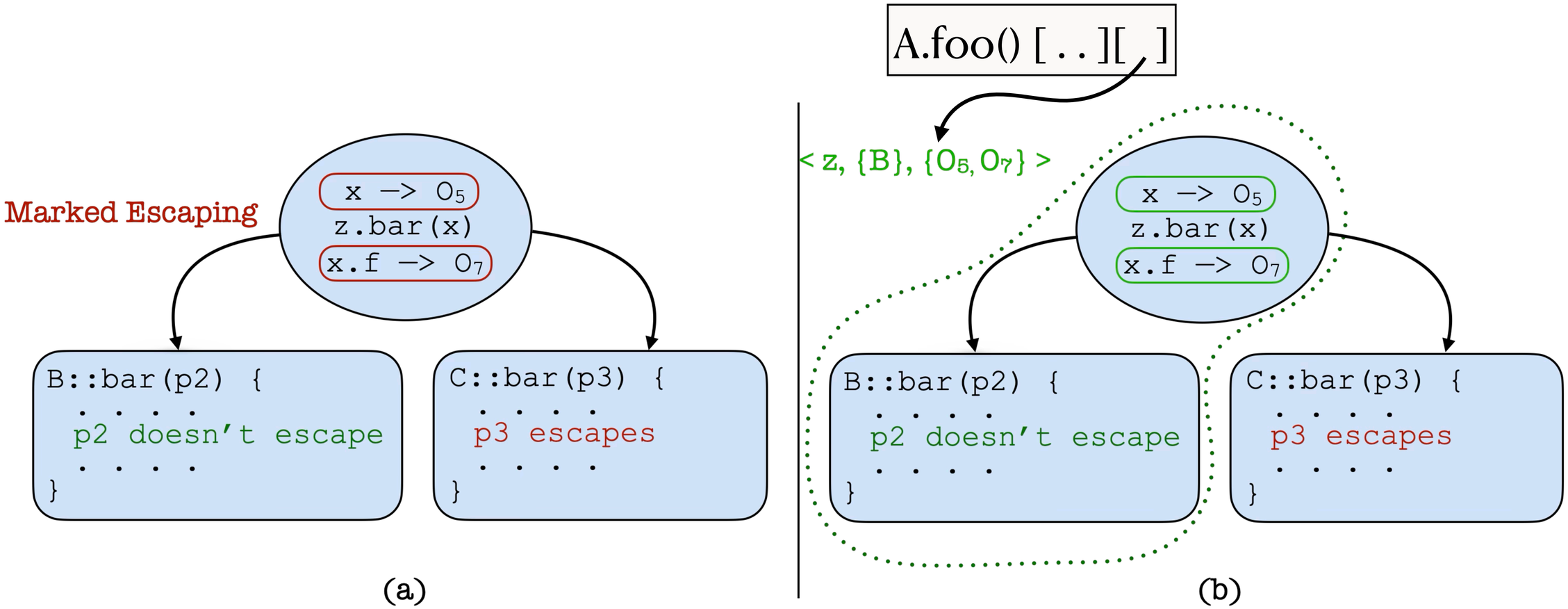

2. Branching

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1. class A {
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6.       A y = new A(); // O6
     . . .
9.       if(p1 instance A) {
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⊓ : —> O_6 (Escaping)

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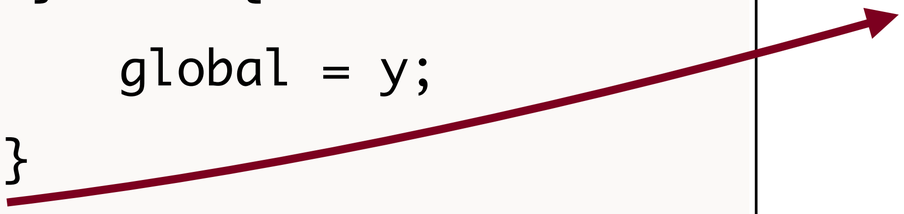

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```

At runtime:

- The “if” branch is taken most number of times.

2. Branching

```
A::foo(p1) {
    . . . .
6. Y = new A(); // O6
9. if(*) {
     . . .
   } else {
     // Object O6 escapes.
   }
 }
```

O_6 Marked Escaping

(a)

```
A::foo(p1) {
    . . . .
6. Y = new A(); // O6
9. if(*) {
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     // Object O6 escapes.
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 }
```

[< {9}, {O_6} >]

A.foo() [. .][ ]

(b)

3. Inlining Based Results

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```
1. class A {
2.    void foo() {
3.        . . .
4.        z.bar(x);
5.        r.foobar(p, q);
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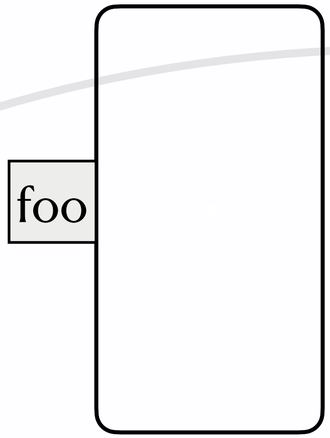

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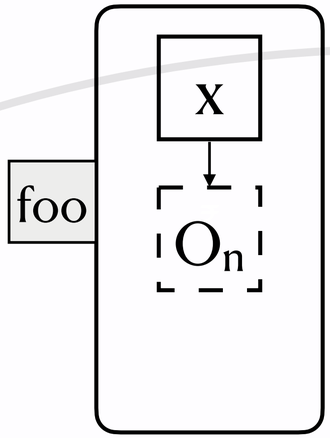

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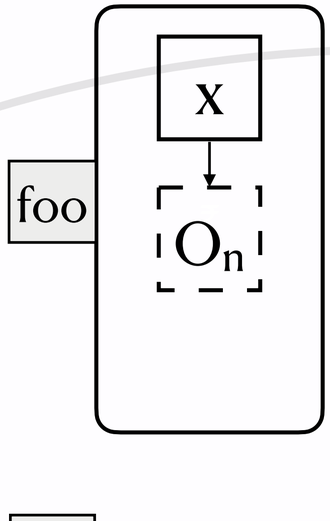

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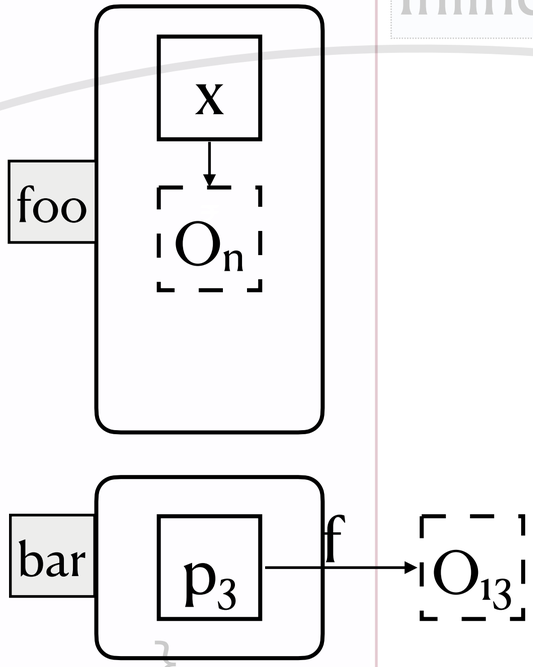


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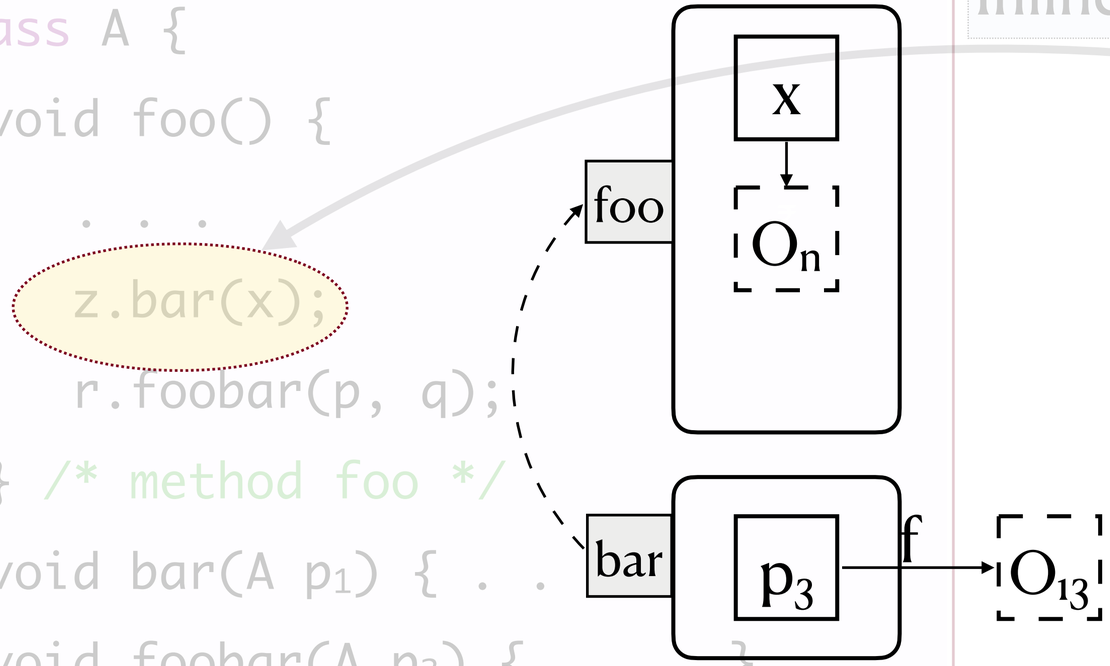

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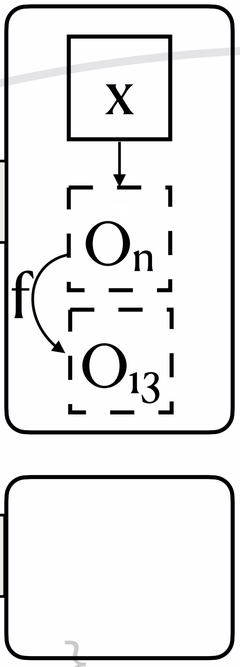

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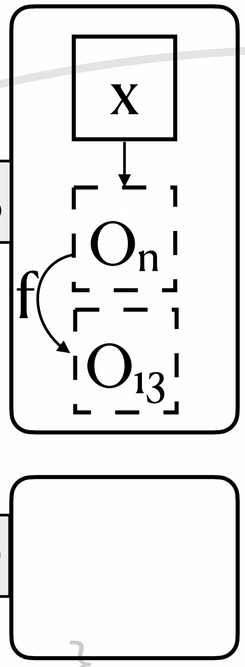

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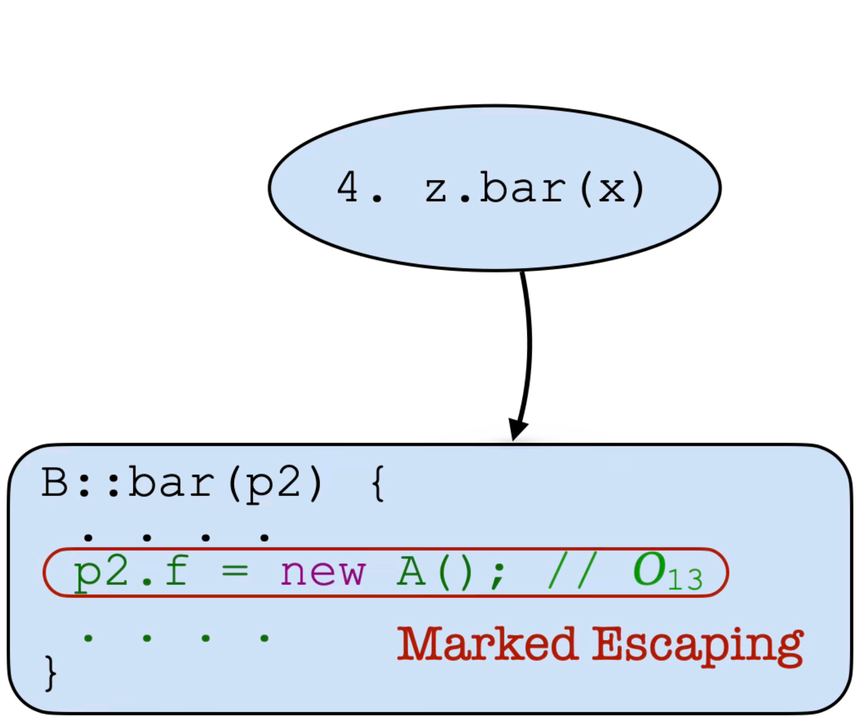
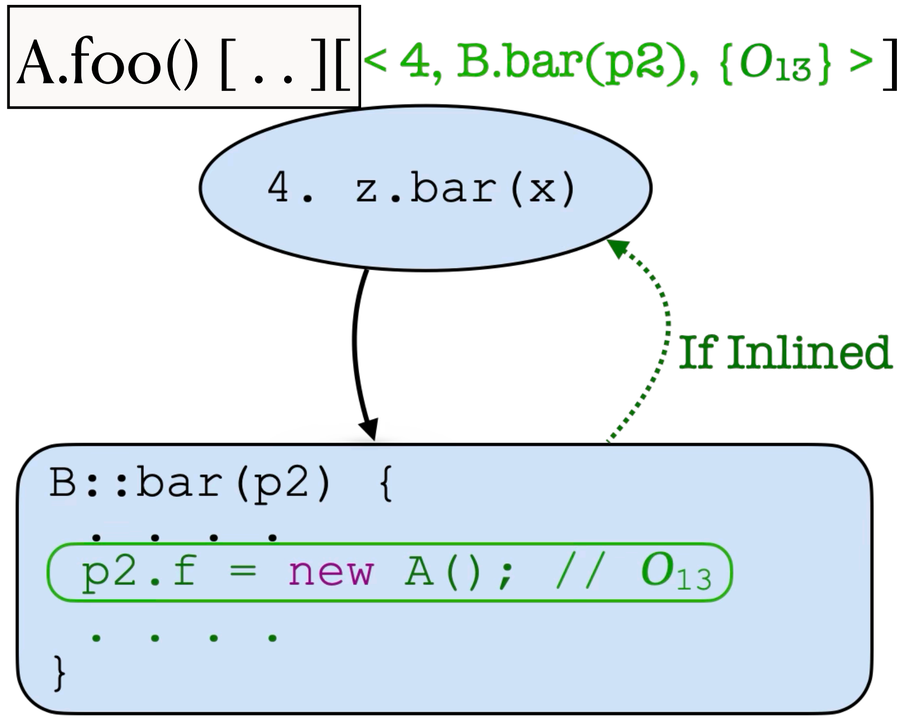
Callee object on caller's stack frame

3. Inlining Based Results



(a)



(b)

Summarize

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- A::foo() [Direct_Allocation] [bci_polymorphic_callsite] [bci_branching][bci_inlining]

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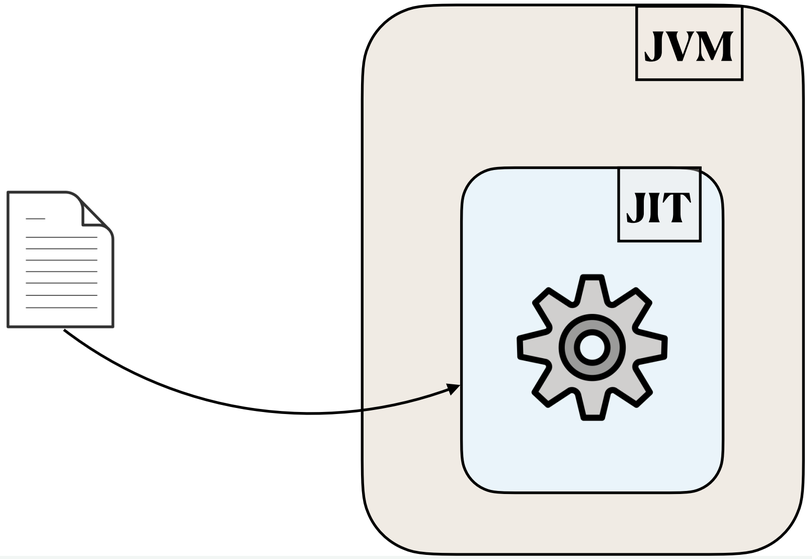

Algo in JIT for Polymorphic Callsites Results

```
Input: SAm, CHm, CPm, ST
Output: Objects marked for stack allocation

for each O in JIT_identified_objects(m):
    if O is non-escaping:
        mark O
    else if O in SAm:
        if ∀ callsite c ∈ SAm[O]:
            (CHm[c] ⊆ SAm[O][c]) v ( ∀ t ∈ SAm[O][c] ∑ CPm(t) > ST):
            mark O
```

Algo in JIT for Branching Results

```
Input: SAm, BPm, ST
Output: Additional objects marked for stack allocation

for each O in Candidatesm not marked:
    if ∀ branch br ∈ SAm[O]:
         (∀ b ∈ SAm[O][br] with Σ BPm(b) > ST):
        mark O
```

Algo in JIT for Inlining Based Results

```
Input: SAm, ITm
Output: Additional objects marked for stack allocation

for each callsite c ∈ CallSitesm:
    Callersc = SAm[c]
    if ∃ n such that (n ∈ ITm[c] ∧ n ∈ Callersc):
        Ostatic = statically_marked_objects(m)
        mark all O ∈ Ostatic
```

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  - Static analysis: **Soot**
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- Compute:
  - Enhancement in stack allocation.
  - Impact on performance and garbage collection.

Evaluation (Stack Allocation)

	Base Scheme (BaseLine)			Conditional Scheme (CoSSJIT)			
Benchmark	Static Count	Dynamic Count	Stack Bytes	Static Count	Dynamic Count	Stack Bytes	Heapify Count
avrora	12	104.2M (38.0%)	3335MB	14	106.5M (39.3%)	3391.4MB	0.4M
compress	8	0.01M (3.29%)	1720MB	18	0.093M (15.5%)	2.75MB	0M
graphchi	12	349M (5.20%)	8327MB	109	1041.1M (14.2%)	20020MB	0.0006M
h2	61	33M (1.02%)	579MB	129	525M (16.2%)	12749MB	6M
luindex	30	4.9M (3.16%)	137MB	84	24.2M (15.4%)	746MB	0.06M
pmd	24	1762M (9.80%)	42295MB	92	1835M (10.2%)	43468MB	0.2M
sunflow	100	1077M (20.0%)	27577MB	243	2286M (34.7%)	56042MB	0.19M
signverify	15	0.24M (0.86%)	6.8MB	40	3.25M (6.34%)	102.2MB	0.5M
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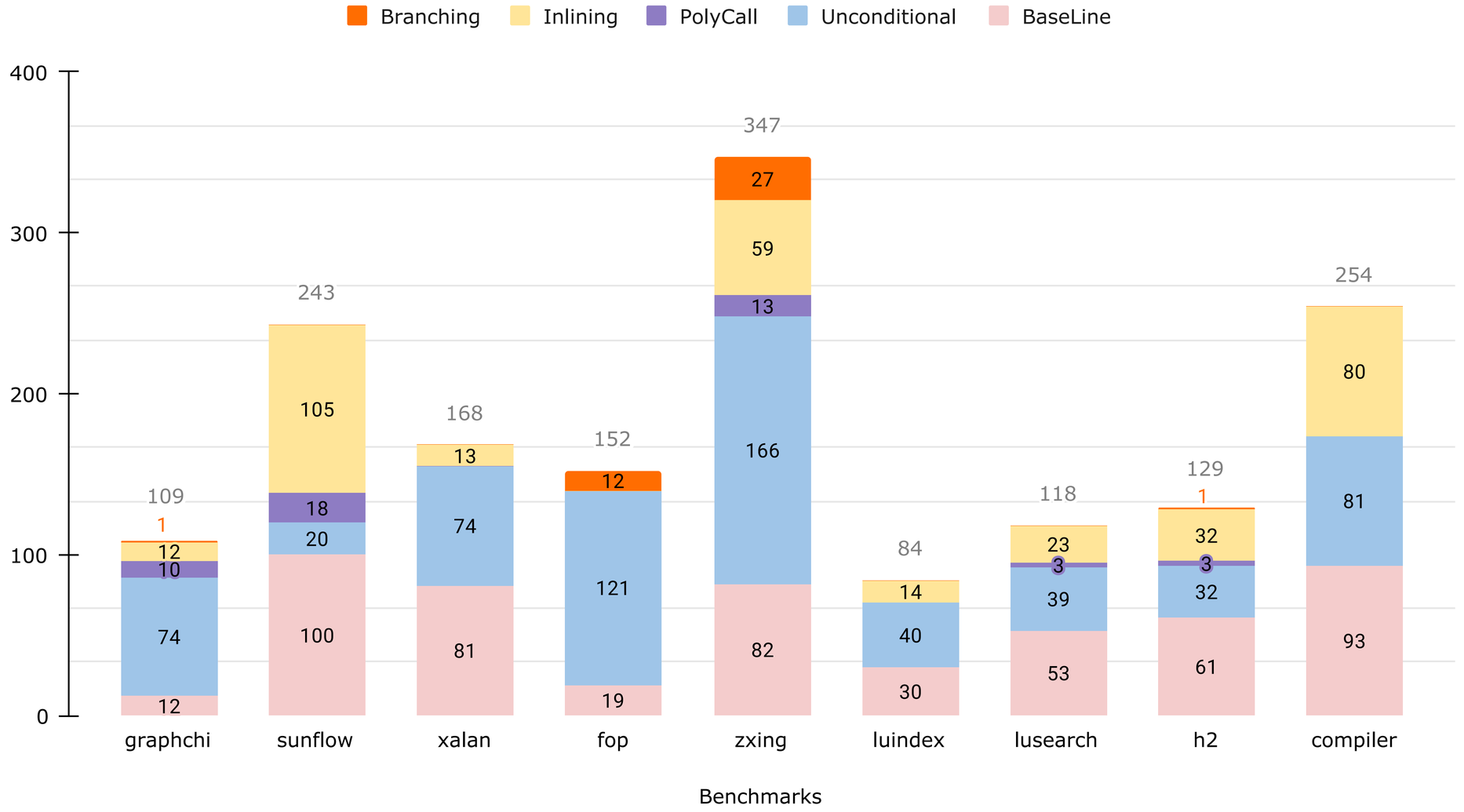
luindex	30	4.9M (3.16%)	137MB	84	24.2M (15.4%)	746MB	0.06M
pmd	24	1762M (9.80%)	42295MB	92	1835M (10.2%)	43468MB	0.2M
sunflow	100	1077M (20.0%)	27577MB	243	2286M (34.7%)	56042MB	0.19M
signverify	15	0.24M (0.86%)	6.8MB	40	3.25M (6.34%)	102.2MB	0.5M
zxing	82	24.2M (2.61%)	987.6MB	347	1539M (16.4%)	52796.7MB	0.4M

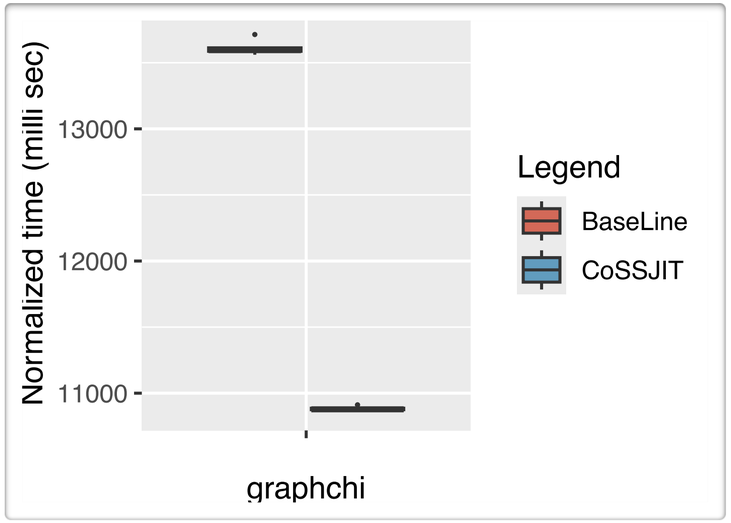
Stack Allocation: 1.4x↑ Stack Bytes: 5.7x↑

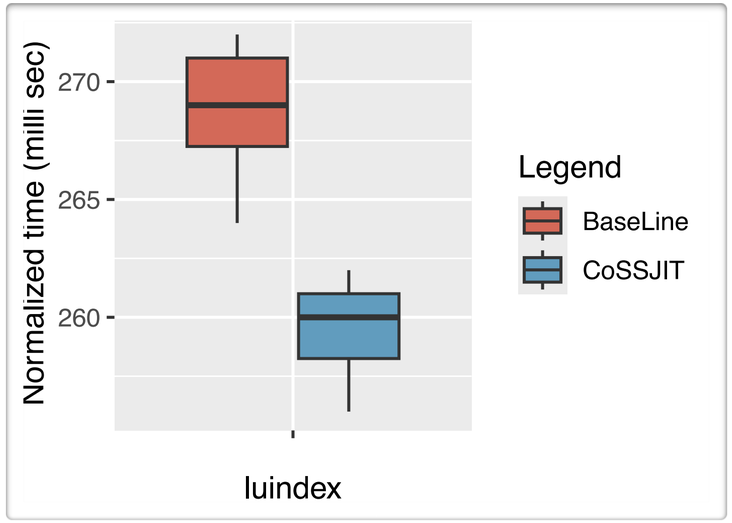
(Less Heap Allocation)

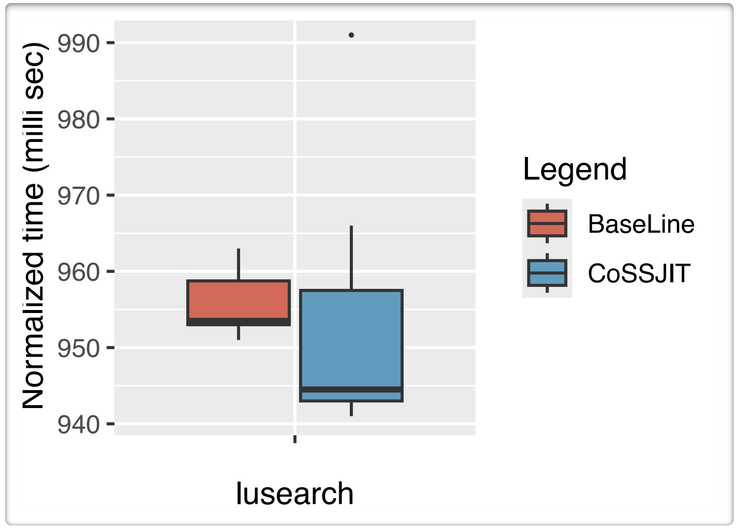
Contributions by different SC

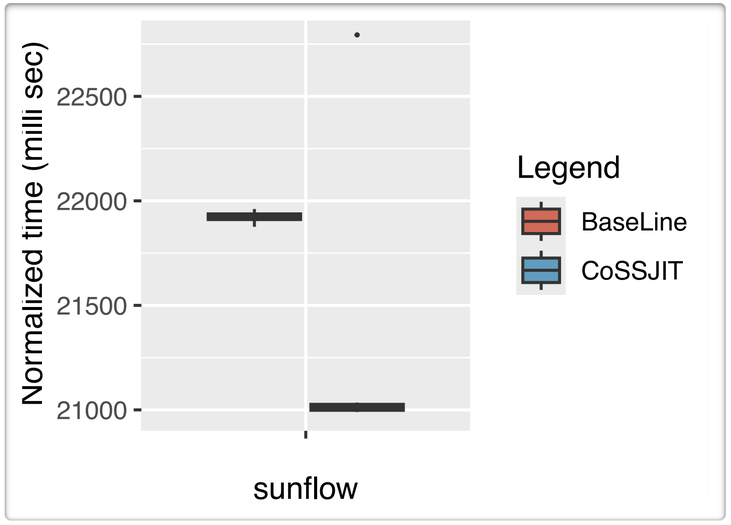


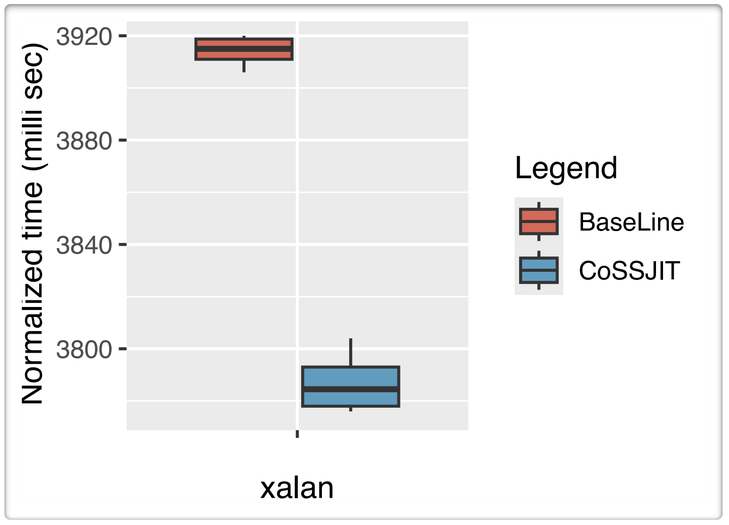
Performance Improvement

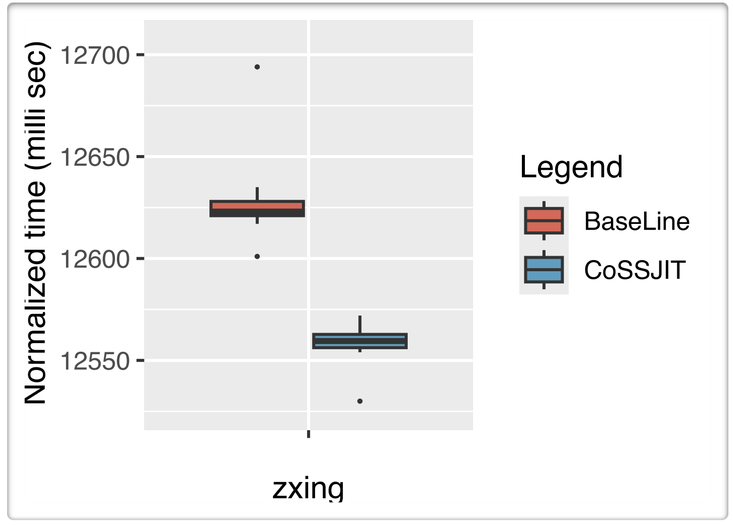




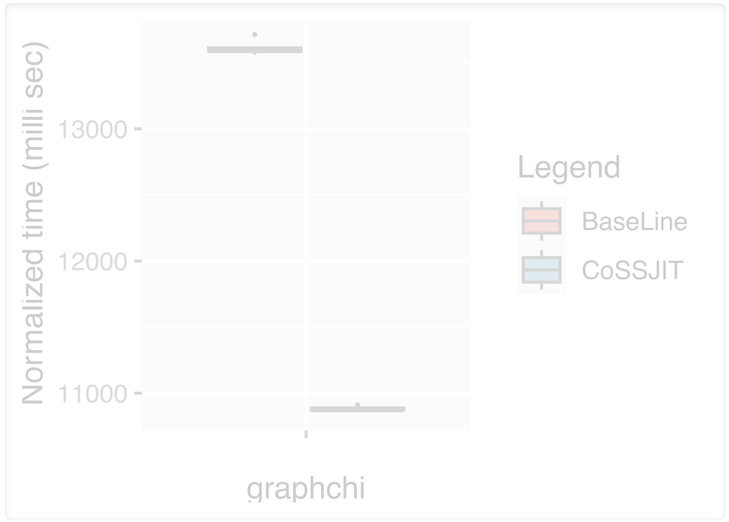


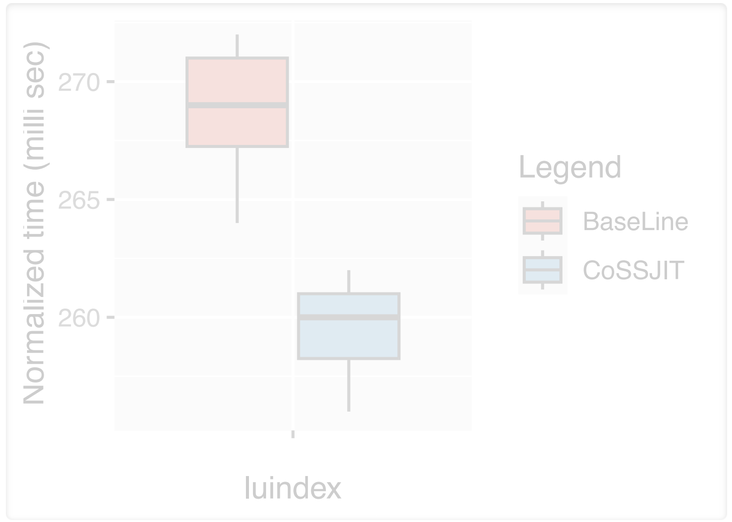


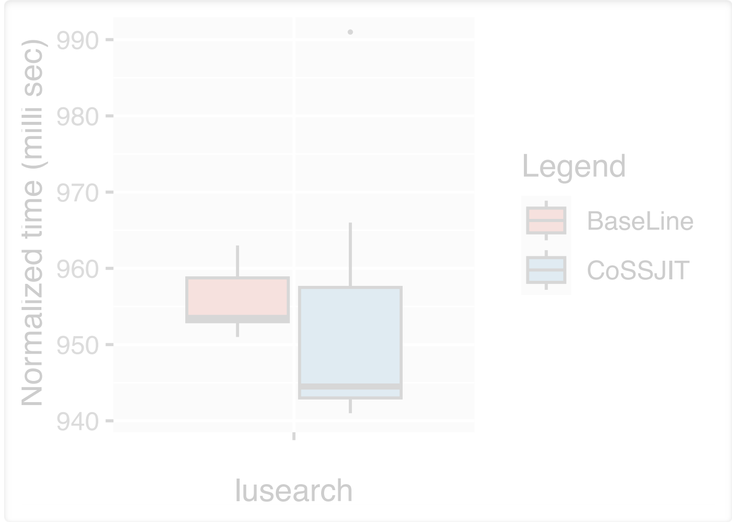


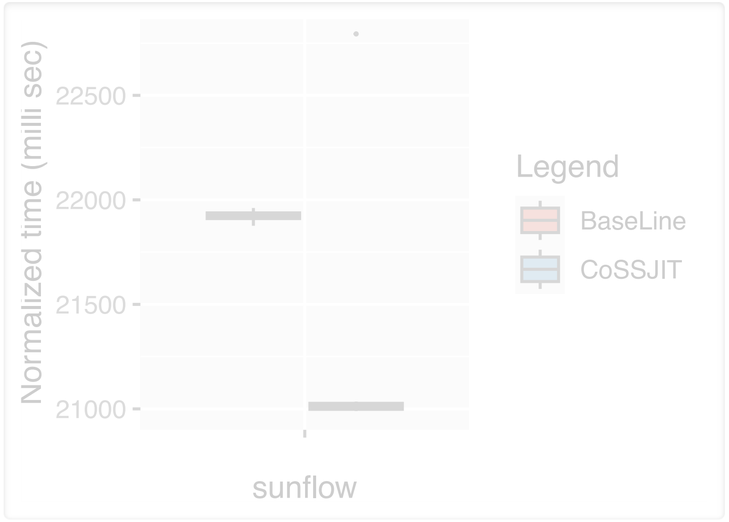


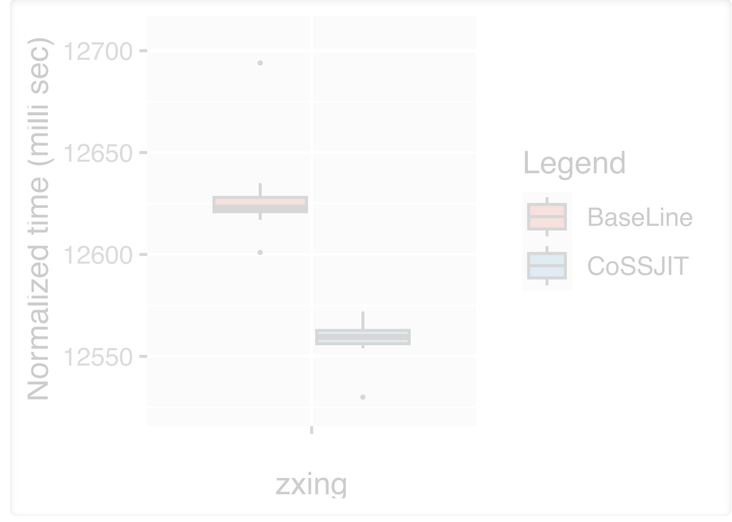
Performance Improvement



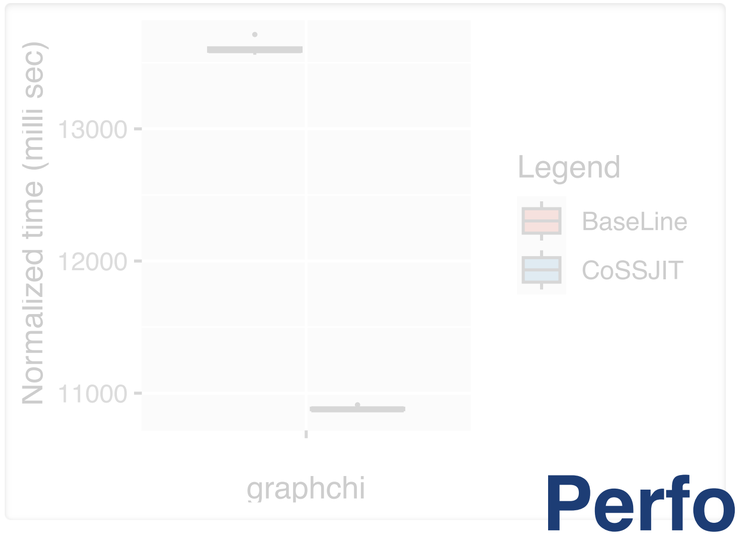


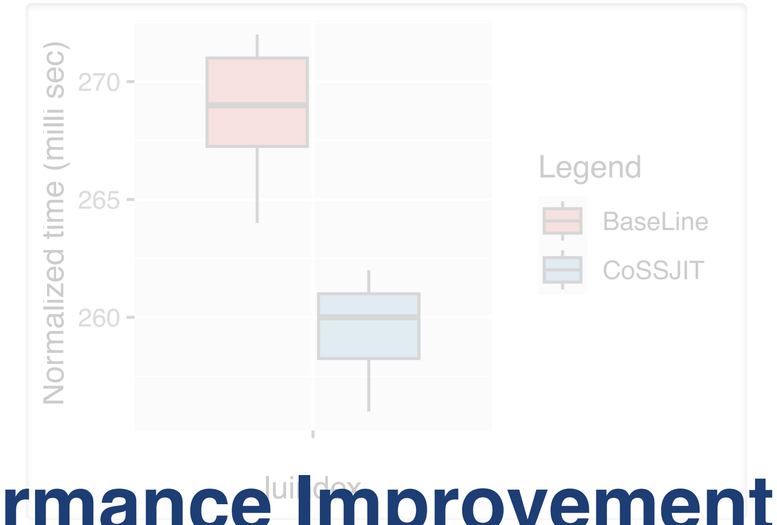


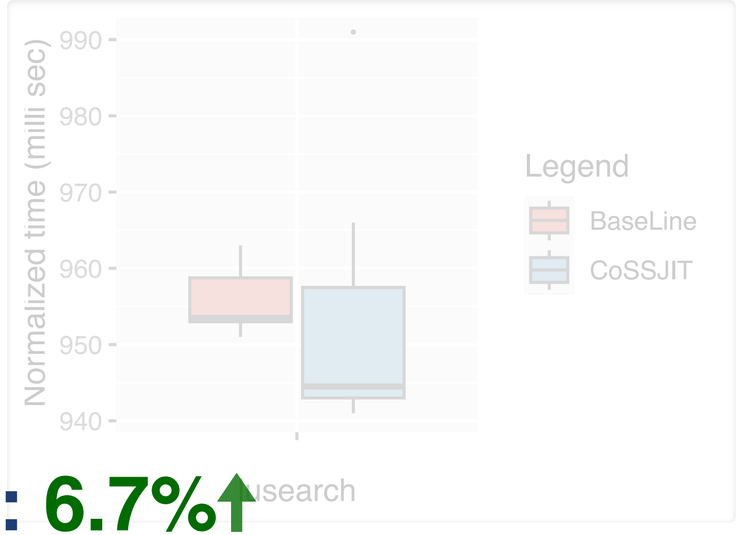




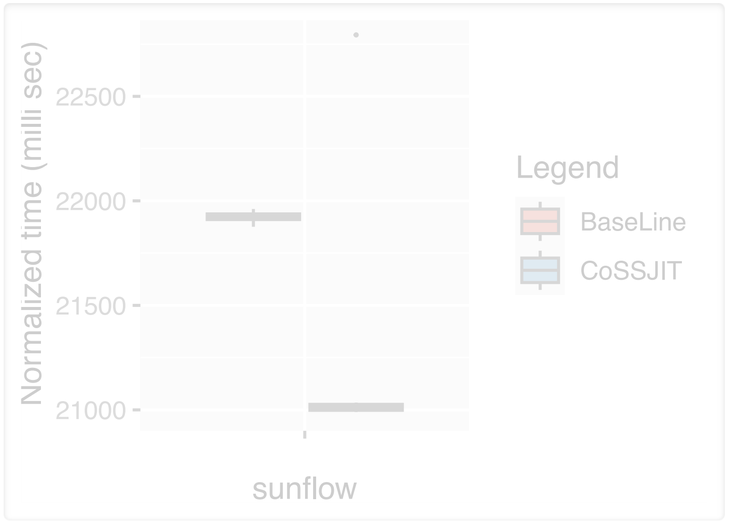
Performance Improvement

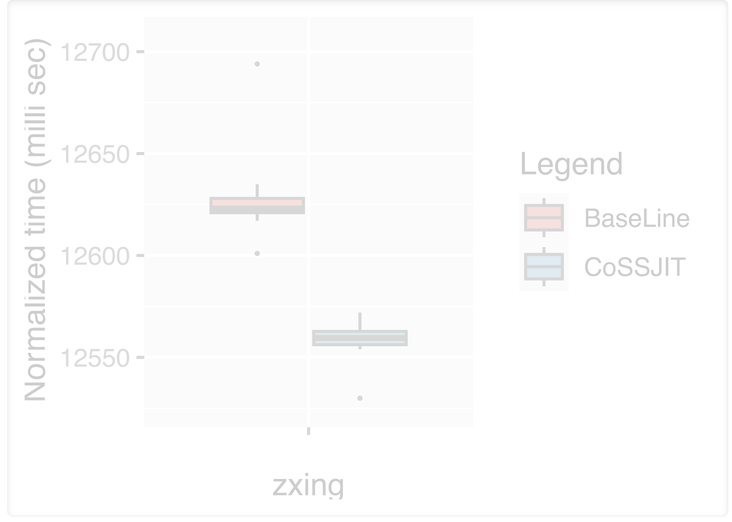




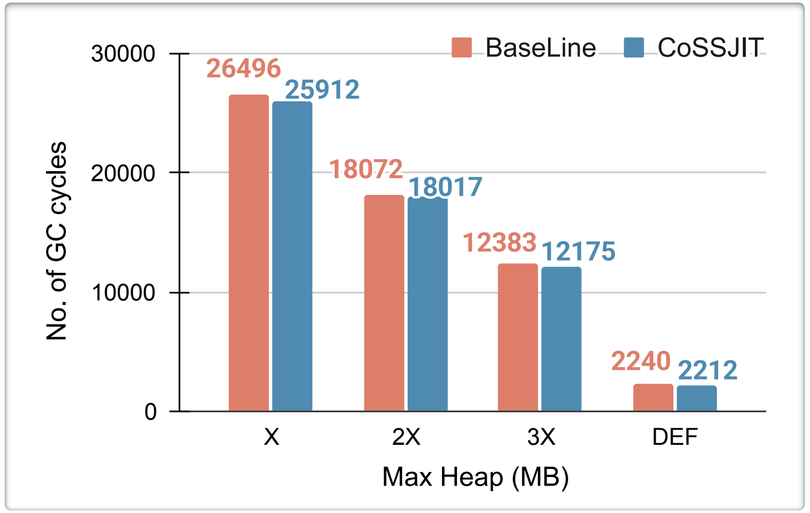


Performance Improvement: 6.7%↑

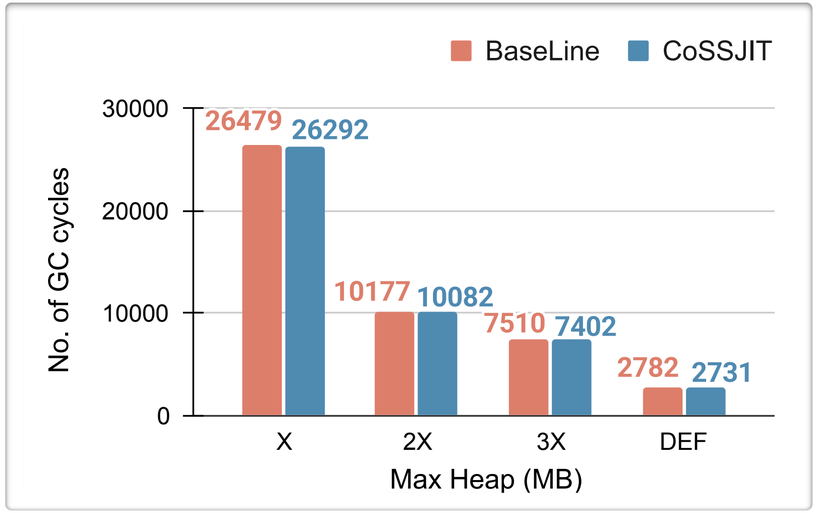




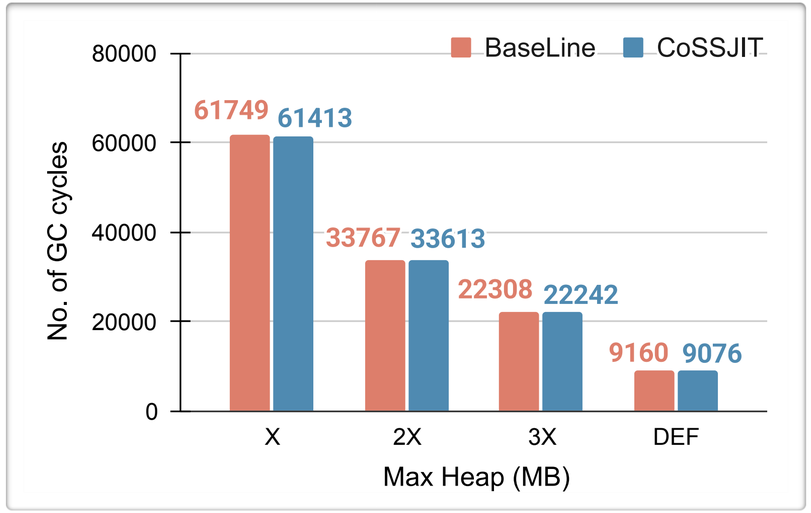
Garbage Collection



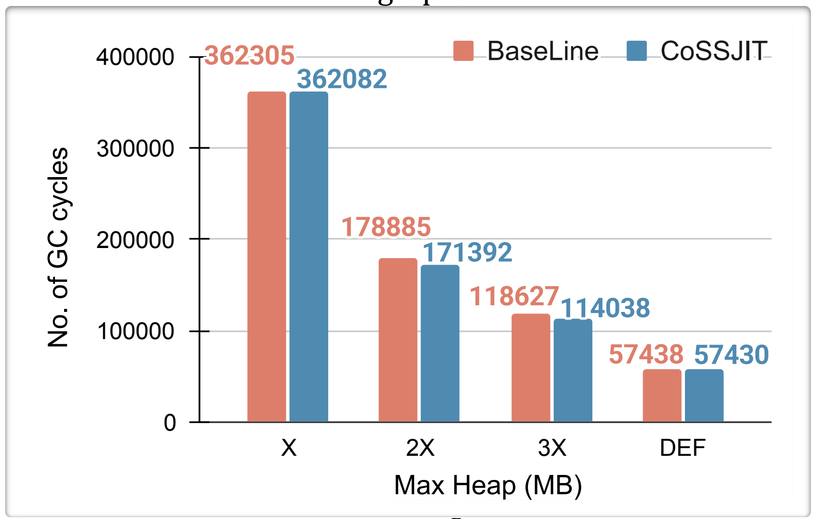
graphchi



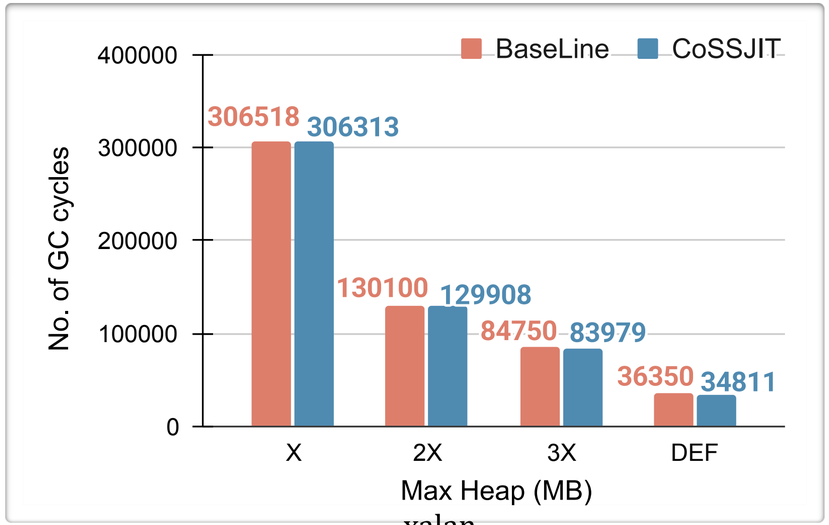
luindex



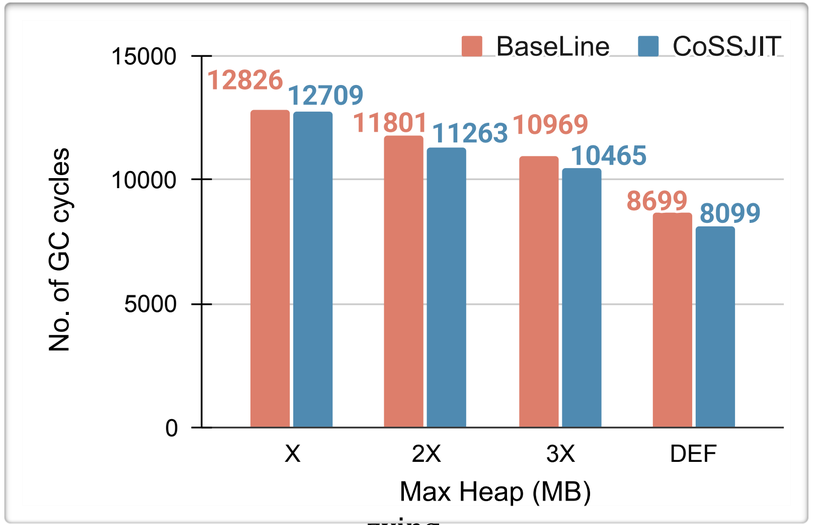
lusearch



sunflow

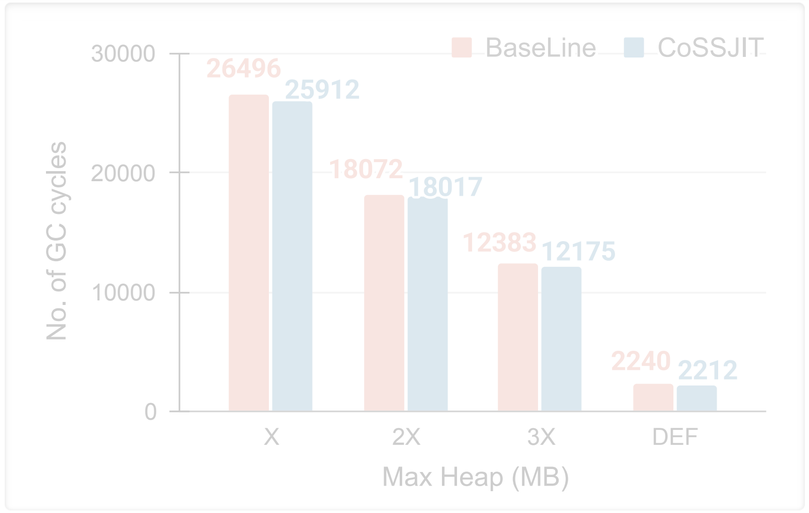


xalan

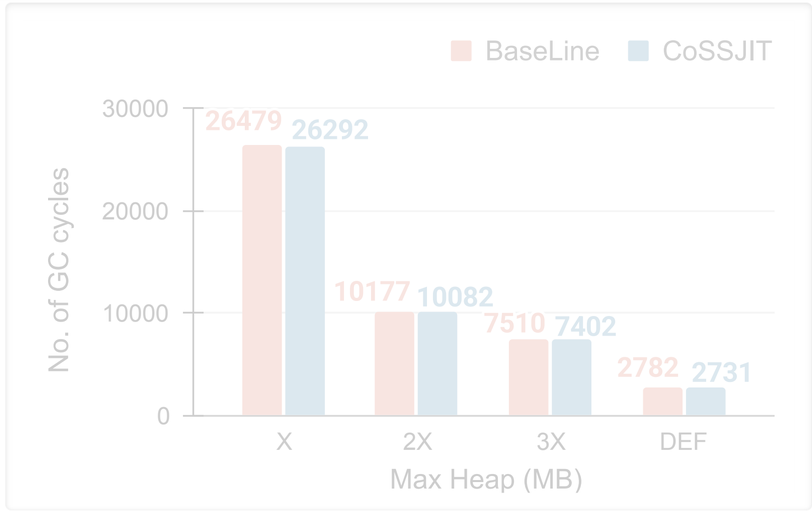


zxing

Garbage Collection



graphchi



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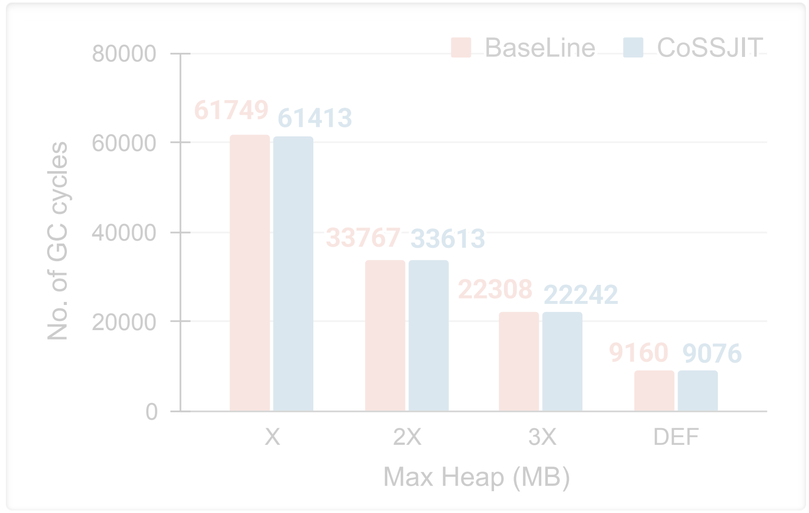

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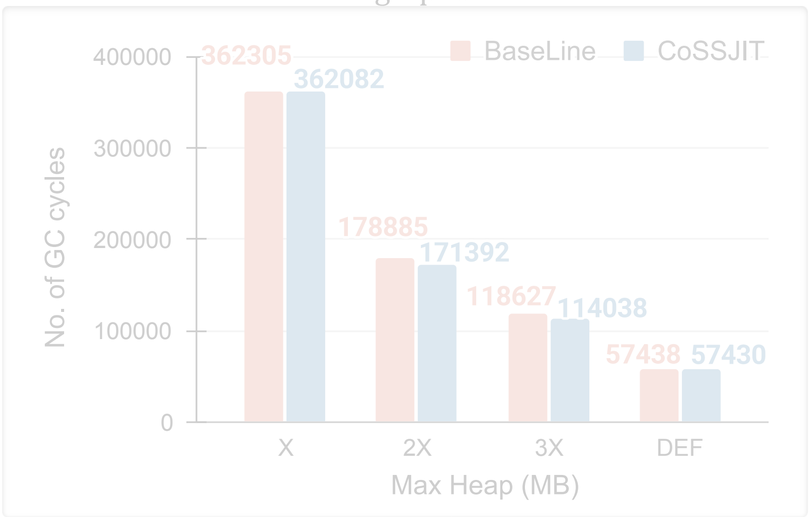

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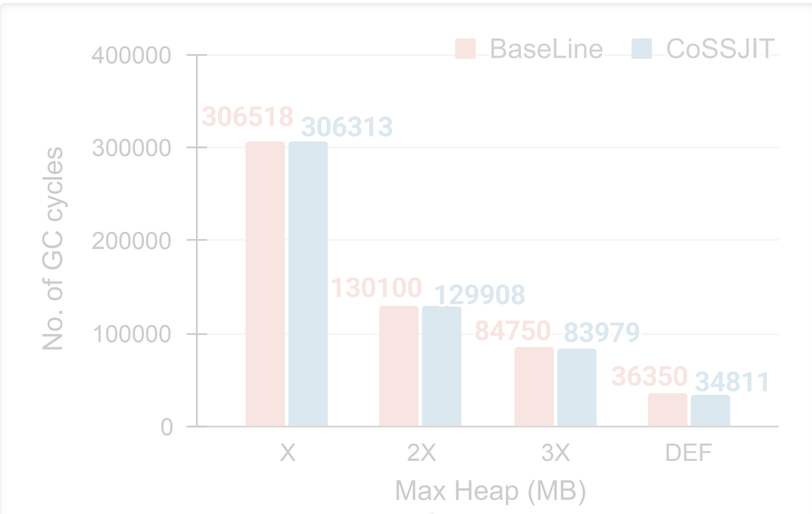

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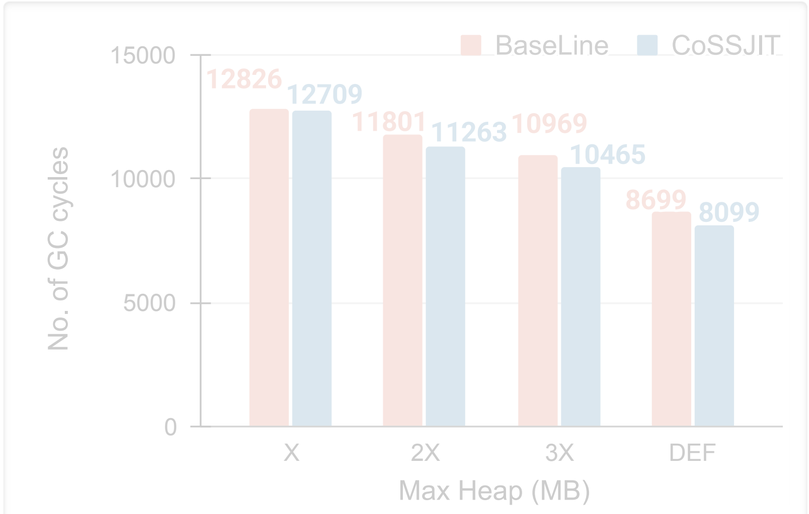

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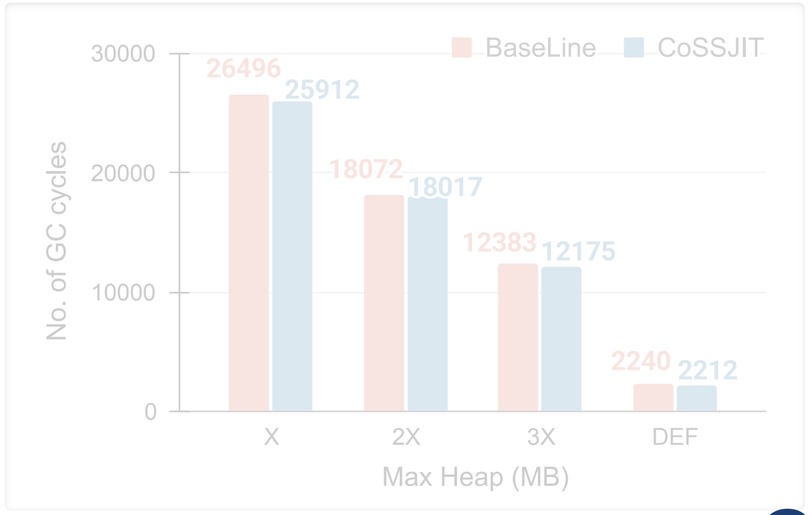
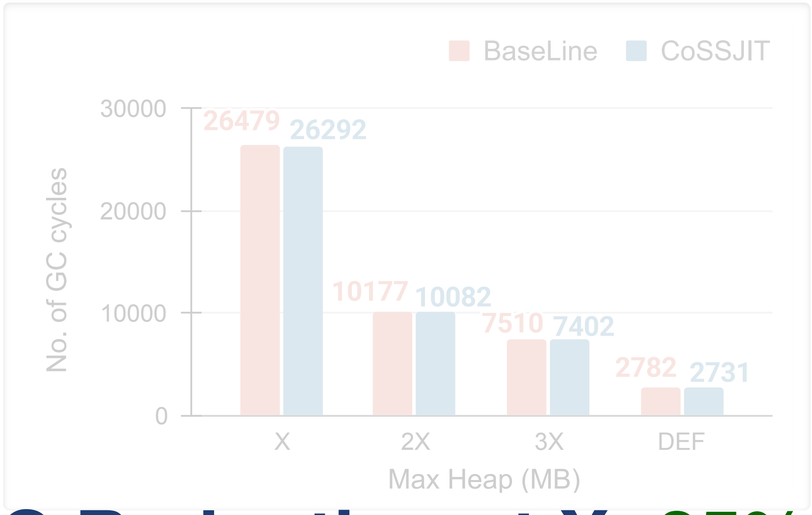
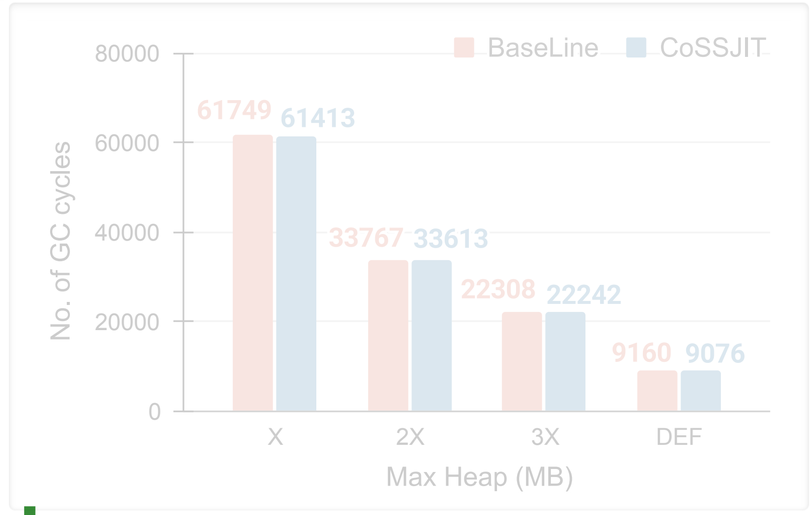
Garbage Collection



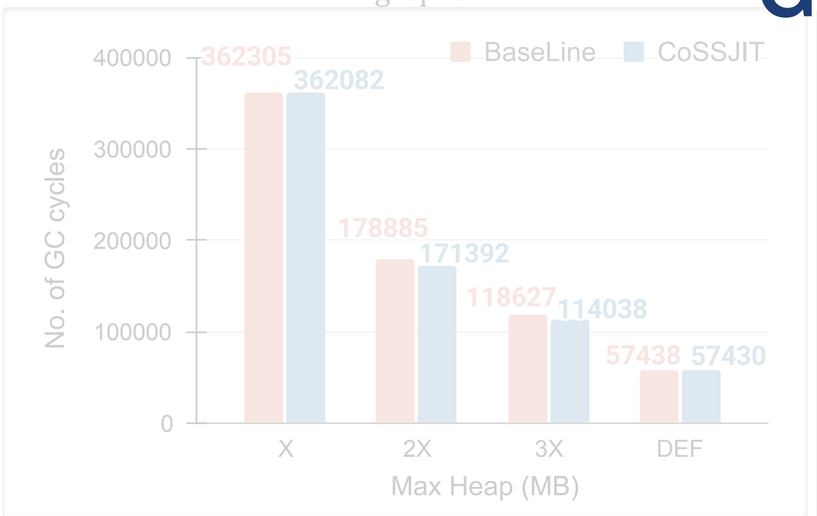
graphchi



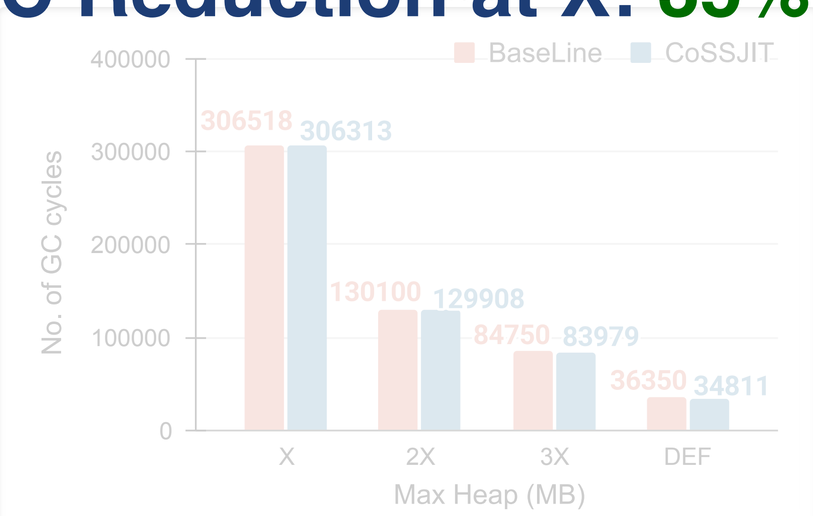


lusearch

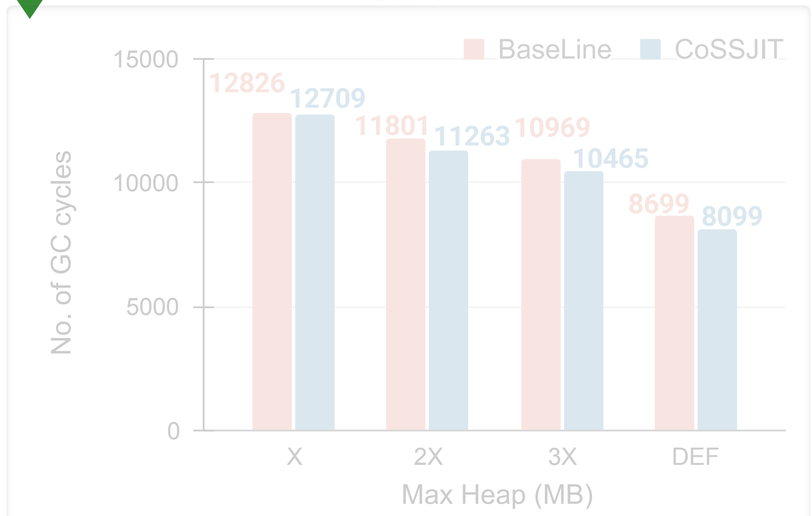
GC Reduction at X: 35% ↓



sunflow



xalan



zxing

Overheads

Benchmark	Static Time(s)	.class size (MB)	.res size (MB)	Total ET (s)	Improvement (s)	JIT Overhead(s)
avrora	92	8.7	0.29	294	1.6	0.2
fop	735	27	1.40	264	1.0	0.9
graphchi	105	9.8	0.34	2524	325.3	0.2
h2	160	2.2	0.35	173	4.0	0.06
luindex	90	1.3	0.28	165	6.0	0.7
pmd	277	27	0.67	570	41.0	0.8
sunflow	131	11	0.37	448	4.1	0.08
xalan	113	11	0.38	415	6.0	0.7
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Take Aways

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To summarize: Proposed an approach to combine the best parts of statically performed AOT analysis and dynamically performed JIT analysis.

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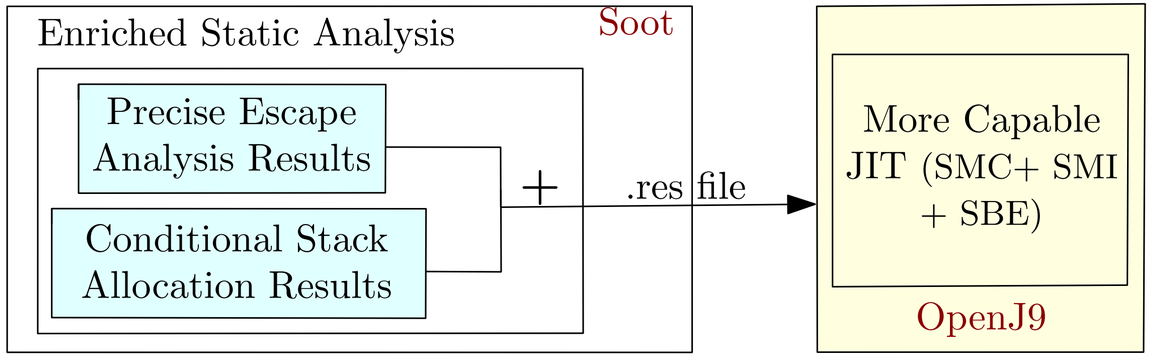
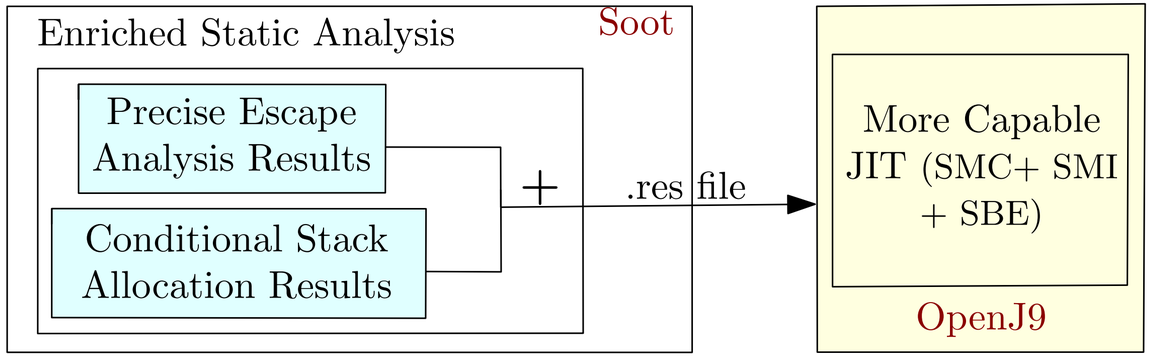


Take Aways

To summarize: Proposed an approach to combine the best parts of statically performed AOT analysis and dynamically performed JIT analysis.



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Take Aways

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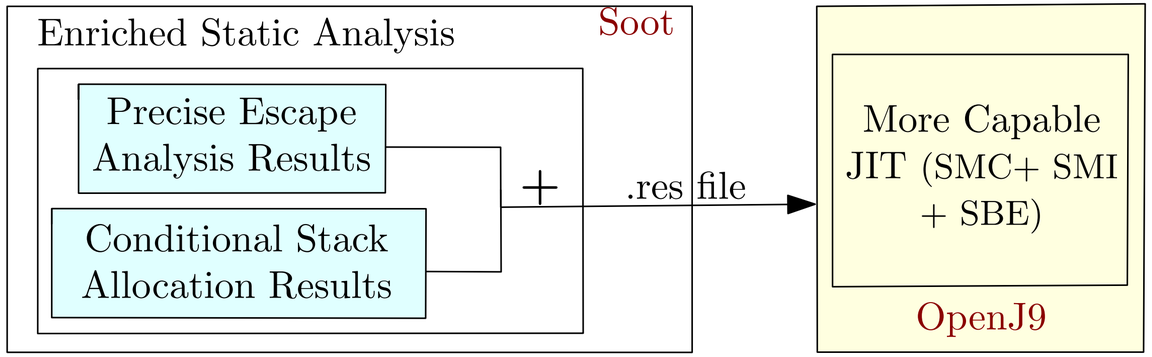

- Enriched the static analysis with the possible run-time based speculative results.
- Mechanism in the JIT compiler to incorporate the conditional static analysis results.

Take Aways

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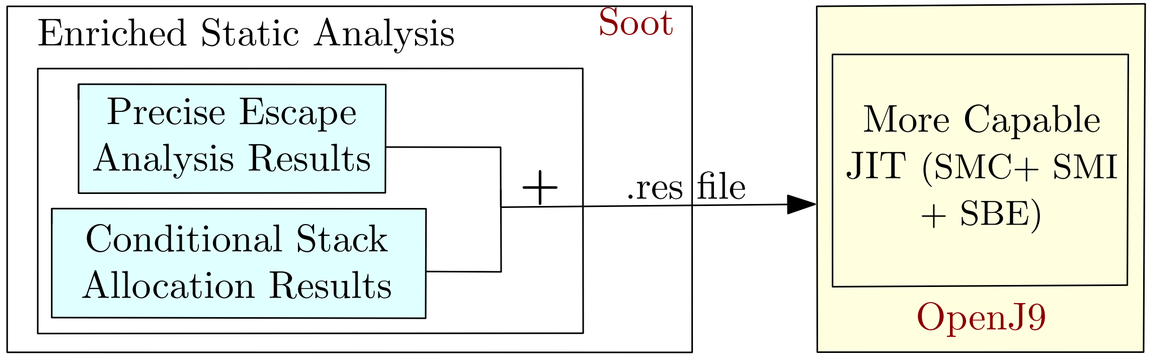
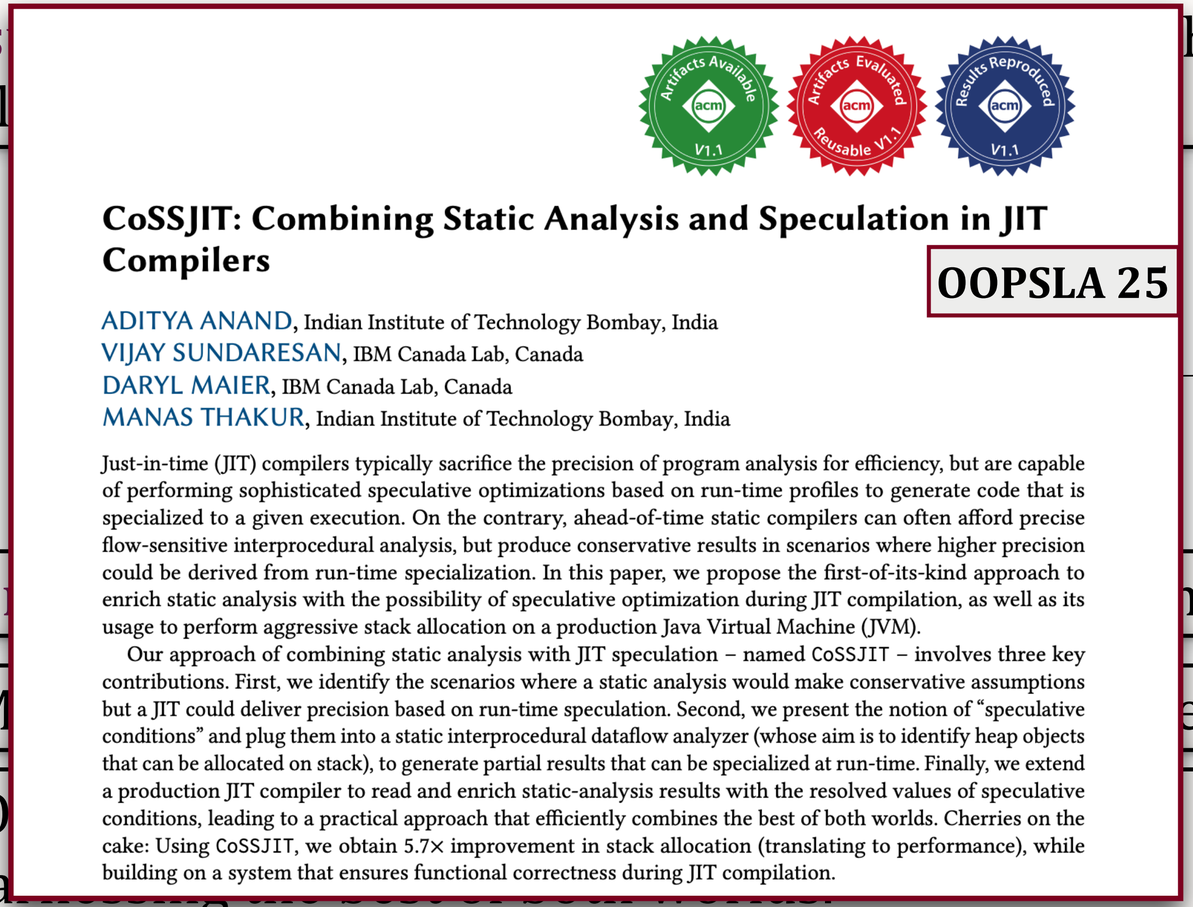


- Enriched the static analysis with the possible run-time based speculative results.
- Mechanism in the JIT compiler to incorporate the conditional static analysis results.
- Overall, one of the first approach that strikes a balance between static analysis and JIT, harnessing the best of both worlds.

Take Aways


Artifacts Available
Artifacts Evaluated
Reusable V1.1
Results Reproduced
V1.1
CoSSJIT: Combining Static Analysis and Speculation in JIT Compilers
OOPSLA 25
ADITYA ANAND, Indian Institute of Technology Bombay, India
VIJAY SUNDARESAN, IBM Canada Lab, Canada
DARYL MAIER, IBM Canada Lab, Canada
MANAS THAKUR, Indian Institute of Technology Bombay, India
Just-in-time (JIT) compilers typically sacrifice the precision of program analysis for efficiency, but are capable of performing sophisticated speculative optimizations based on run-time profiles to generate code that is specialized to a given execution. On the contrary, ahead-of-time static compilers can often afford precise flow-sensitive interprocedural analysis, but produce conservative results in scenarios where higher precision could be derived from run-time specialization. In this paper, we propose the first-of-its-kind approach to enrich static analysis with the possibility of speculative optimization during JIT compilation, as well as its usage to perform aggressive stack allocation on a production Java Virtual Machine (JVM).
Our approach of combining static analysis with JIT speculation – named CoSSJIT – involves three key contributions. First, we identify the scenarios where a static analysis would make conservative assumptions but a JIT could deliver precision based on run-time speculation. Second, we present the notion of "speculative conditions" and plug them into a static interprocedural dataflow analyzer (whose aim is to identify heap objects that can be allocated on stack), to generate partial results that can be specialized at run-time. Finally, we extend a production JIT compiler to read and enrich static-analysis results with the resolved values of speculative conditions, leading to a practical approach that efficiently combines the best of both worlds. Cherries on the cake: Using CoSSJIT, we obtain 5.7× improvement in stack allocation (translating to performance), while building on a system that ensures functional correctness during JIT compilation.

Take Aways

CoSSJIT: Combining Static Analysis and Speculation in JIT Compilers

OOPSLA 25

ADITYA ANAND, Indian Institute of Technology Bombay, India
VIJAY SUNDARESAN, IBM Canada Lab, Canada
DARYL MAIER, IBM Canada Lab, Canada
MANAS THAKUR, Indian Institute of Technology Bombay, India

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Thank You !!