Empirical Evaluation of an Approach to Resource Constrained Test Suite Execution

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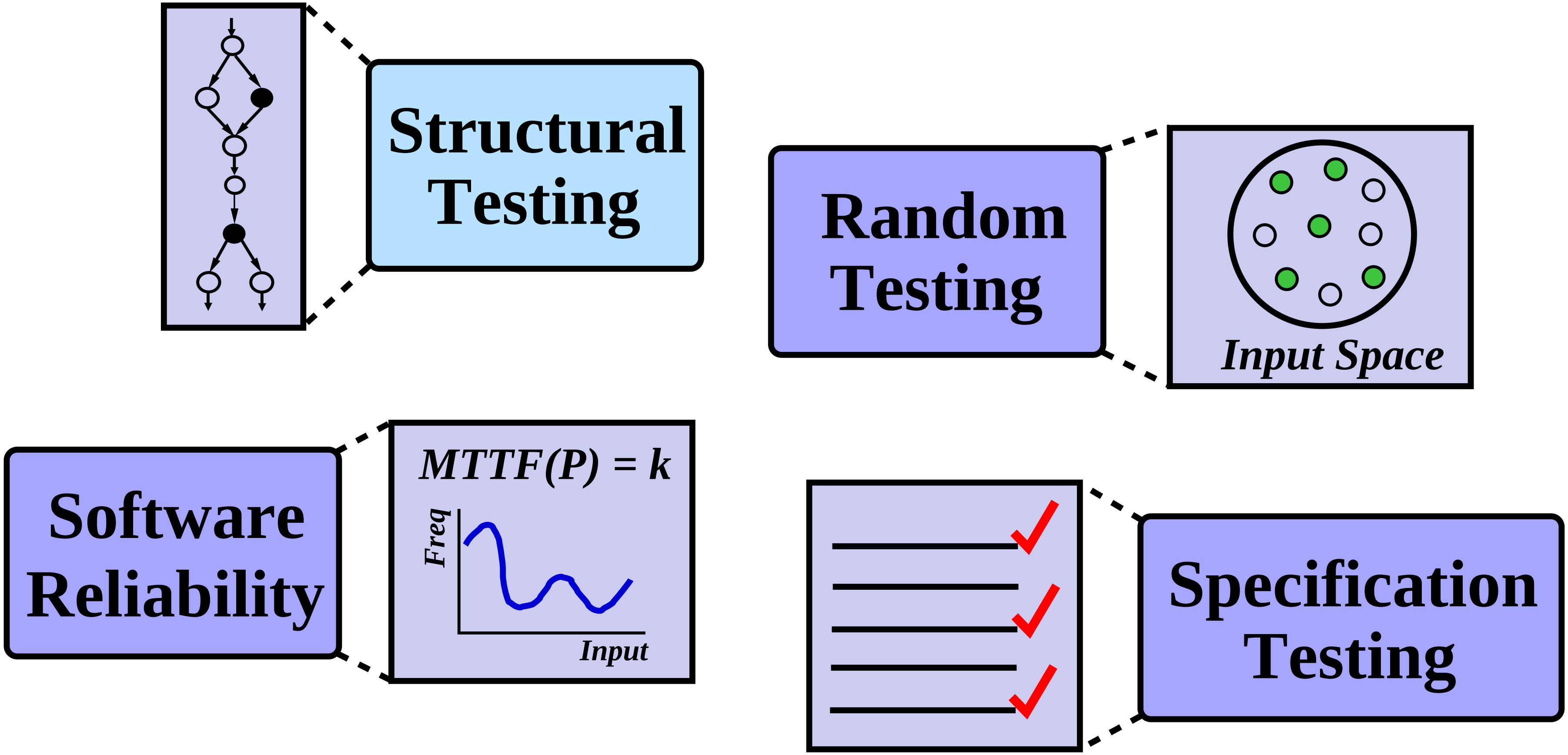
Looking Ahead

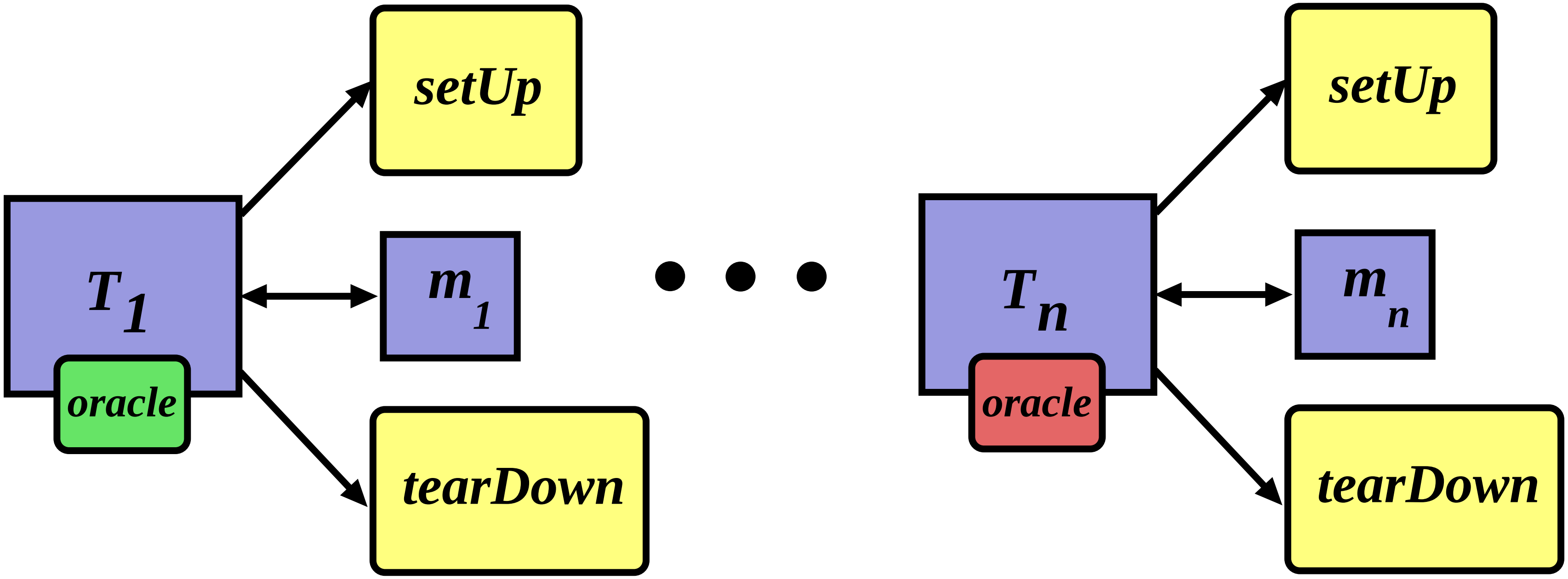
- Use of native code unloading during test suite execution in a resource constrained environment
- Identification of the testing techniques that yield the greatest reduction in execution time and native code size
- Characterization of how software applications and test suites restrict and/or support resource constrained testing
- Cost-benefit analysis for the use of sample-based and exhaustive profiles of program testing behavior
- **Executes test suites faster when memory resources are limited!**

Traditional Testing Techniques



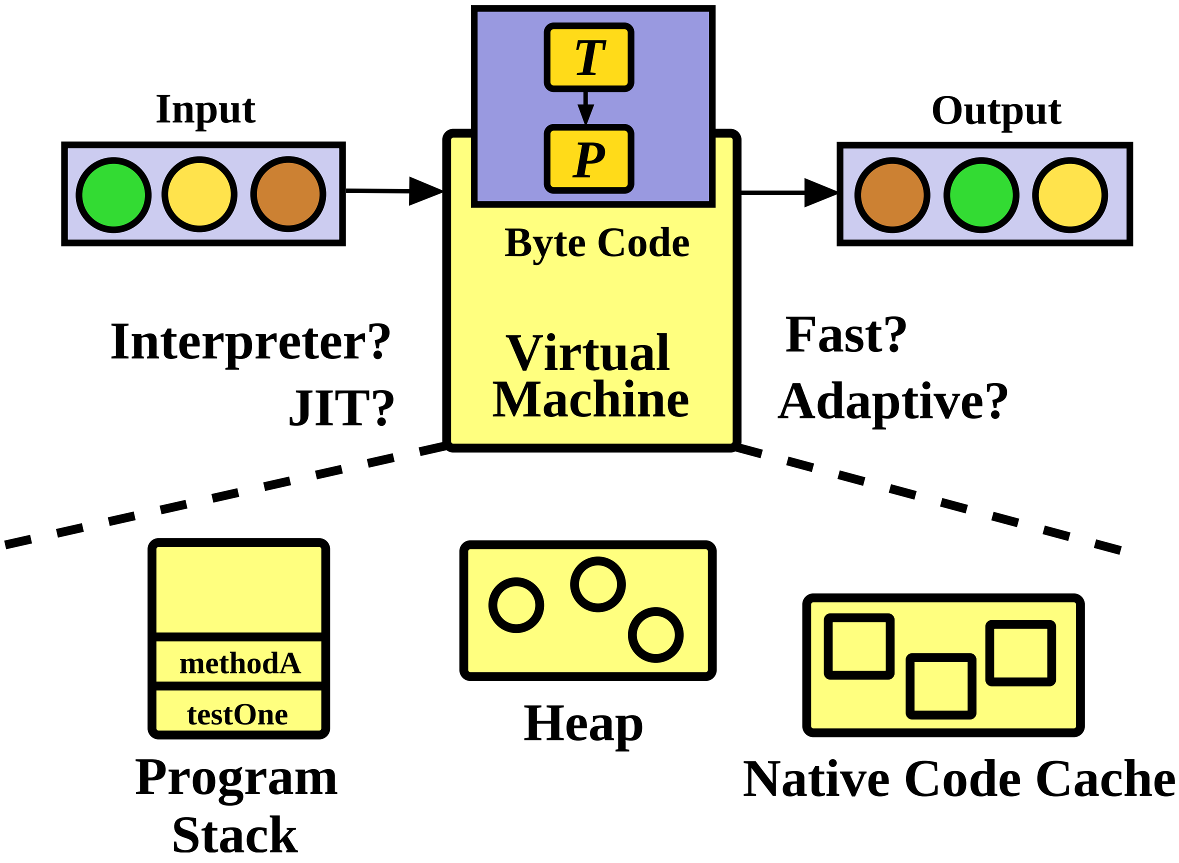
- Different approaches to establishing a confidence in the correctness of and finding faults within software

Test Suite Execution



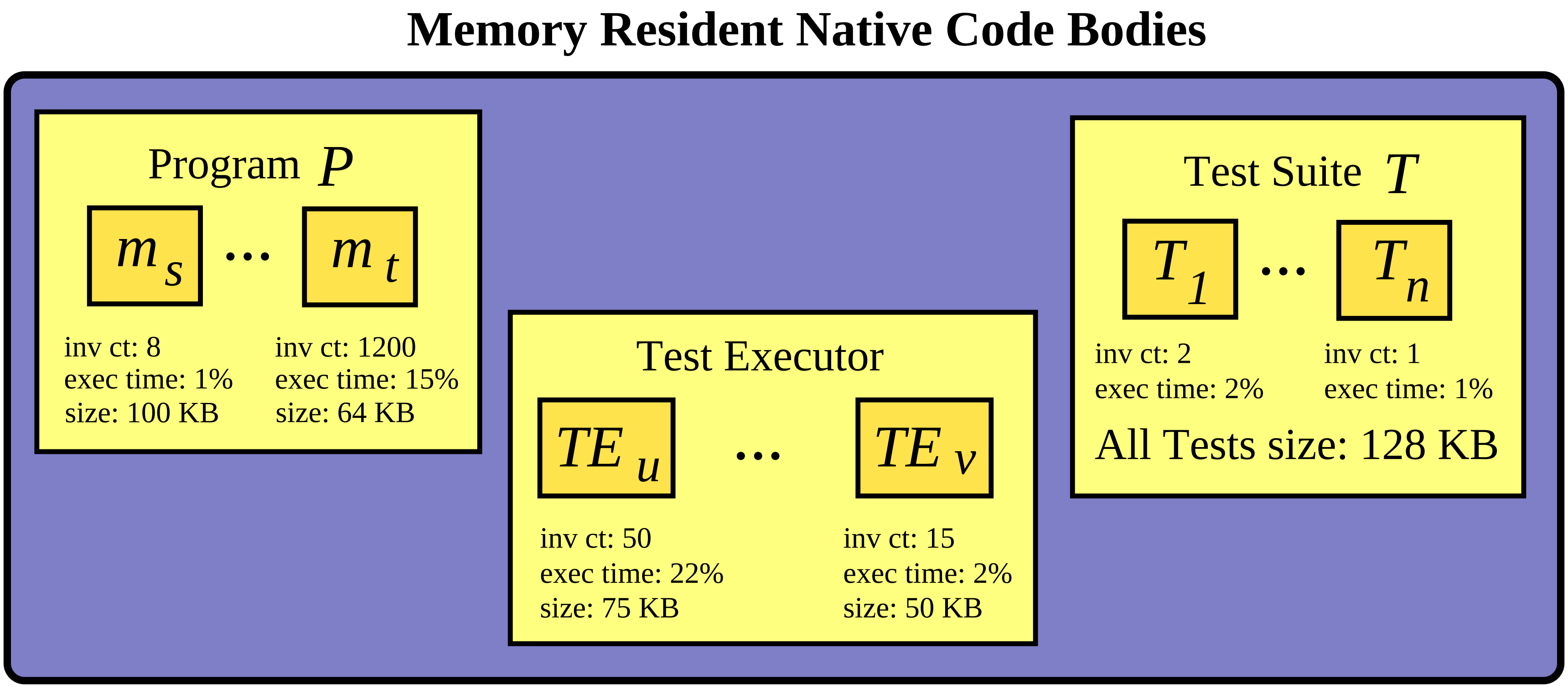
- A test executes a method and uses an oracle to determine if the method's output is correct
- Test suite execution frameworks exist for many different programming languages (e.g., JUnit for Java)

Test Suite Execution with a JVM



- During testing the JVM must manage limited resources

Resource Constrained Testing

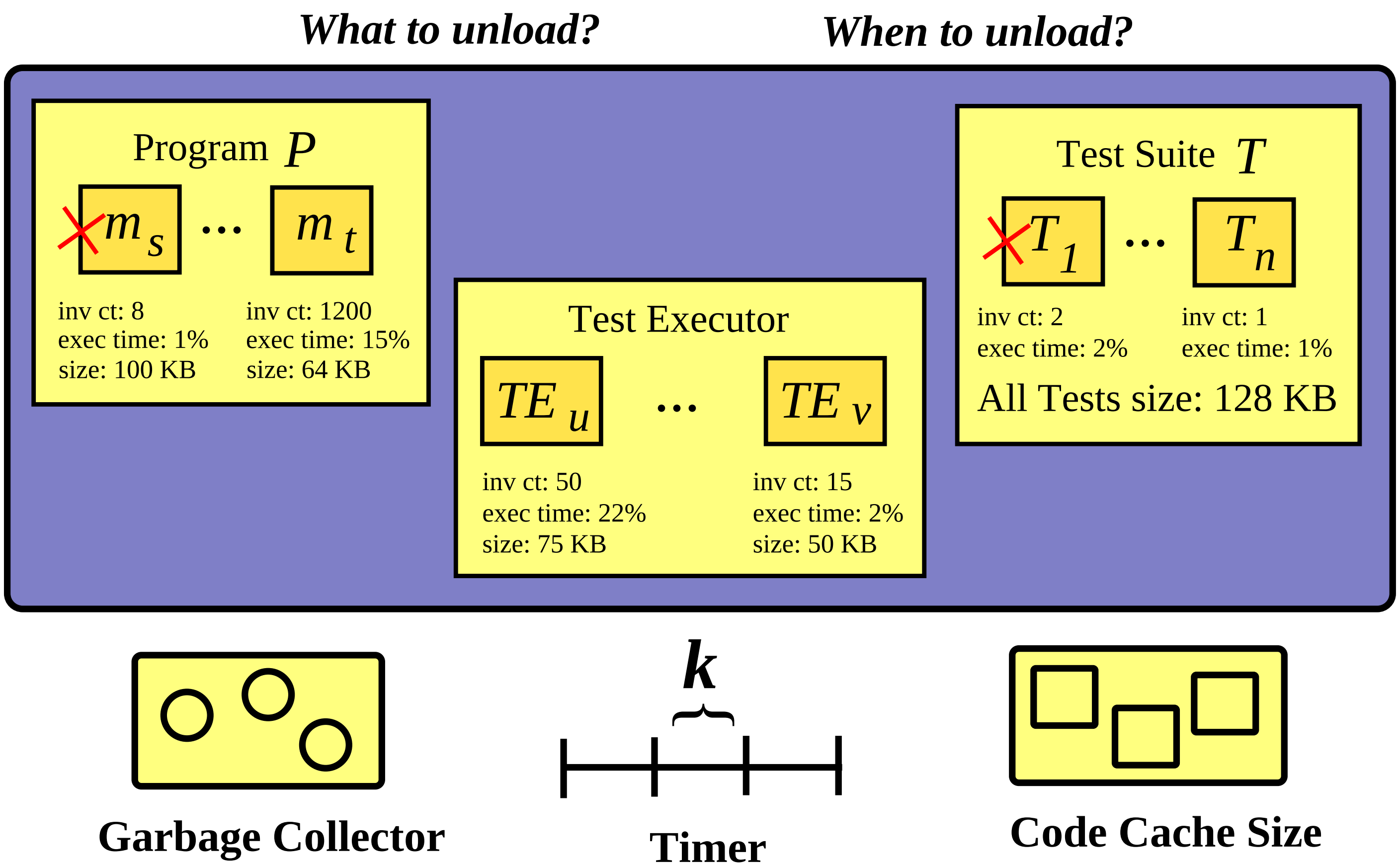


- JIT compiler produces native code that exhausts limited memory resources
- Frequent invocation of GC increases testing time

Test Suite Execution Strategies

- **Omit tests?** - Could reduce overall confi dence in the correctness of P
- **Use non-constrained environment?** - Defects related to P's interaction with environment might not be isolated
- **Execute tests individually?** - Might increase overall testing time and violate test order dependencies
- **Unload with offline profile?** - Not useful if P and T change frequently during regression testing
- **Our Approach**: Use online behavior profi les to guide the unloading of native code

Testing with Native Code Unloading



- *When* - three separate techniques and *What* - behavior profile stored in code body (Zhang and Krintz)

Unloading Configurations: *GC* and *TM*

$$\{S, X\} - \{GC, TM\} = \langle C, UC, U, H \rangle$$

Parameter	**Meaning**
C	init period (GC cycles, secs)
UC	init unload freq (GC cycles, secs)
U	non-init unload freq (GC cycles, secs)
H	heap residency threshold ($\%$)

- Use GC execution or timer expiration to trigger code unloading

Unloading Configuration: *CS*

$$\{S, X\} - CS = \langle Z_{init}, Z_{incr}, U_{CS} \rangle$$

Parameter	**Meaning**
Z_{init}	init code cache size (bytes)
Z_{incr}	code cache increment size (bytes)
U_{CS}	unload session resize trigger (count)

- Unload when native code cache is full

Experiment Goals and Design

- **Research Question:** Can an adaptive code unloading JVM reduce time and space overheads associated with memory constrained testing?
- **Experiment Metrics**: percent reduction in time, $\mathcal{T}_R^{\%}(P, T)$ and space, $\mathcal{S}_R^{\%}(P, T)$
- Jikes RVM 2.2.1, JUnit 3.8.1, GNU/Linux 2.4.18
- Sample-based (*S*) and exhaustive (*X*) program profi les
- Timer (*TM*), garbage collection (*GC*), and code cache size (*CS*) triggers the unloading technique

Case Study Applications

Name	*Min* Size (MB)	# Tests	NCSS
`UniqueBoundedStack` (UBS)	8	24	362
`Library` (L)	8	53	551
`ShoppingCart` (SC)	8	20	229
`Stack` (S)	8	58	624
`JDepend` (JD)	10	53	2124
`IDTable` (ID)	11	24	315

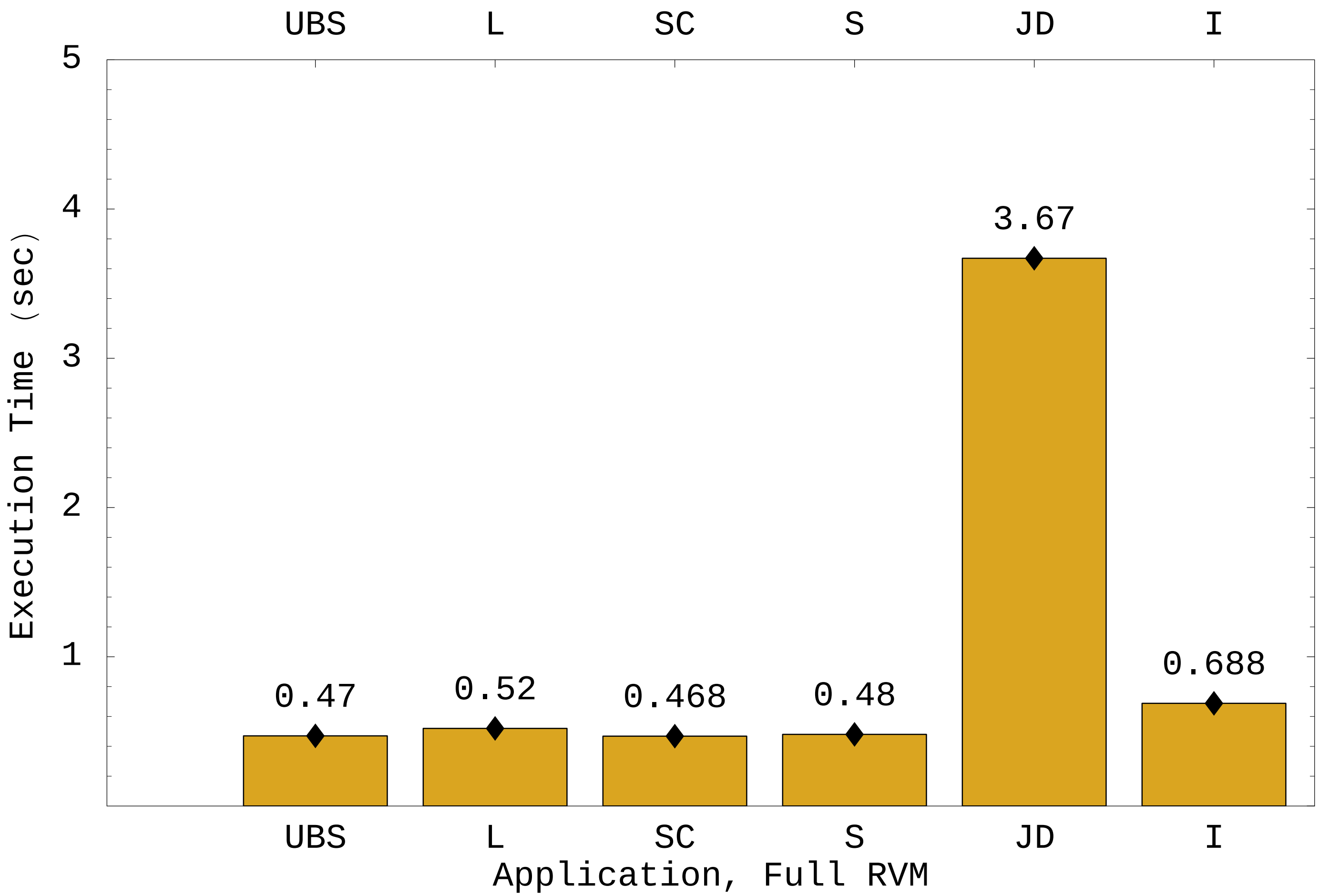
- Empirically determined the *MIN* Jikes RVM heap size

Native Code Unloading Configurations

Name	***GC***	***CS***	***TM***
UBS	$\langle 4, 1, 1, 0.0 \rangle$	$\langle 49370, 512, 5 \rangle$	$\langle 3, .5, 1, 0.0 \rangle$
L	$\langle 5, 1, 3, 0.0 \rangle$	$\langle 49370, 512, 5 \rangle$	$\langle 3, .5, 1, 0.0 \rangle$
SC	$\langle 3, 1, 1, 0.0 \rangle$	$\langle 49370, 512, 5 \rangle$	$\langle 2, .5, 1, 0.0 \rangle$
S	$\langle 4, 1, 1, 0.0 \rangle$	$\langle 49370, 512, 5 \rangle$	$\langle 3, .5, 1, 0.0 \rangle$
JD	$\langle 8, 1, 4, 0.0 \rangle$	$\langle 49370, 512, 5 \rangle$	$\langle 3, .5, 1, 0.0 \rangle$
ID	$\langle 1, 1, 3, 0.0 \rangle$	$\langle 65536, 8192, 5 \rangle$	$\langle 2, .5, 1, 0.0 \rangle$

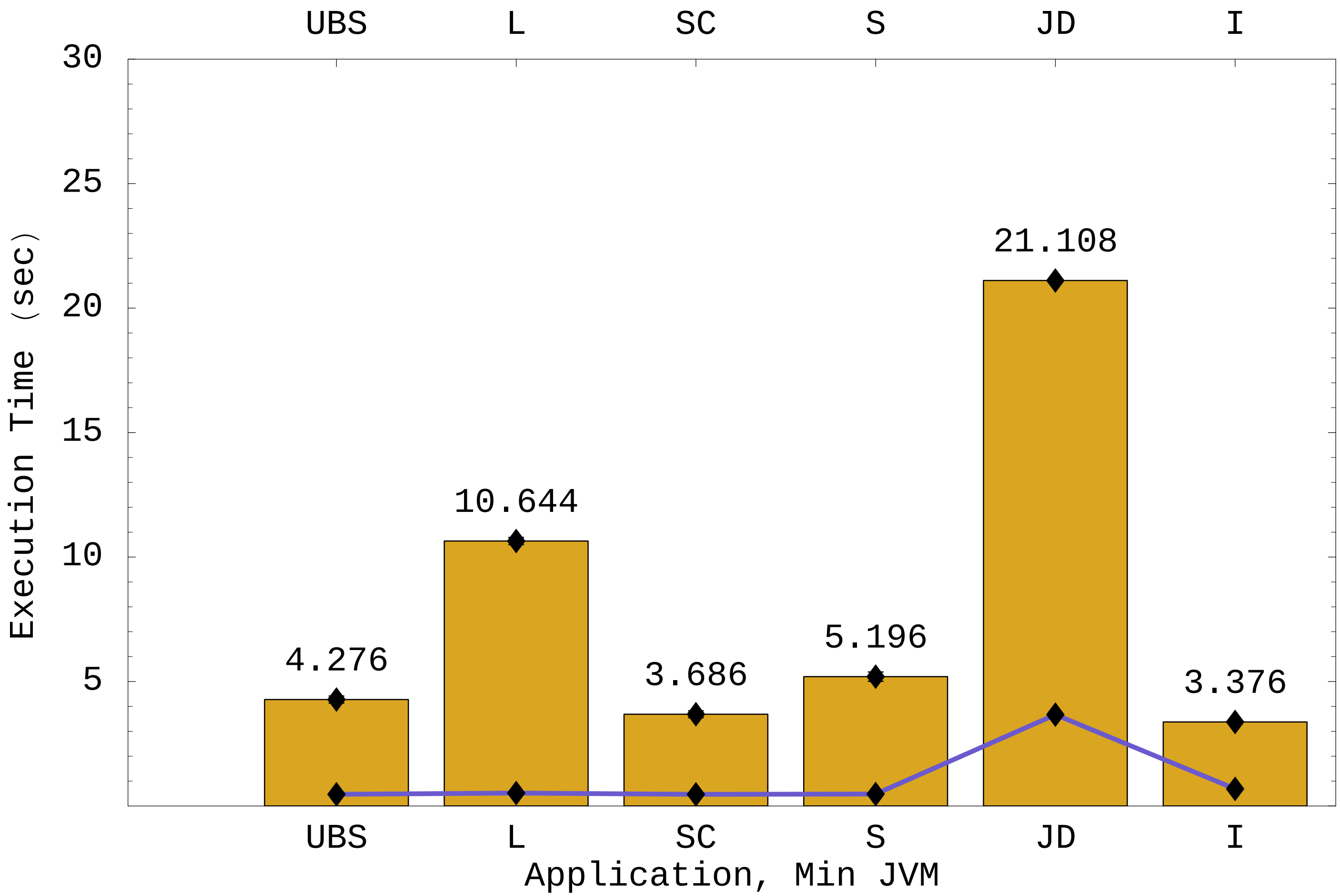
- Ten minutes (or less) of configuration time for each technique
- *S* and *X* use same configuration to a ensure fair comparison

Testing Time Overhead: *Full* RVM



- When memory is not constrained, testing time is acceptable

Testing Time Overhead: *Min* RVM



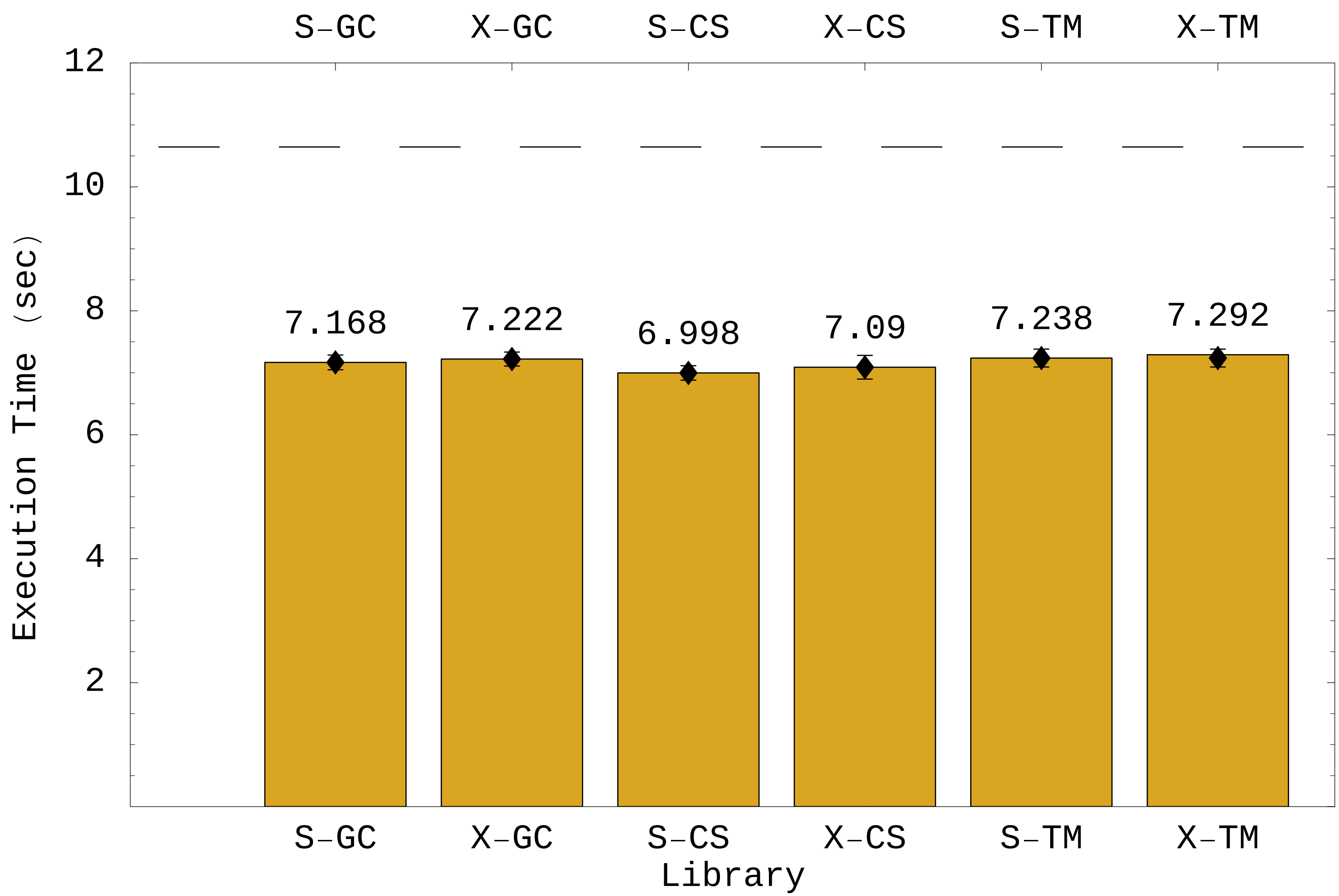
- Testing time increases signifi cantly when memory is *Min*

Summary of Reductions for `Library`

Name	$\mathcal{T}_R^{\%}(P,T)$	$\mathcal{S}_R^{\%}(P,T)$
S-GC	32.7	78.8 ✓
X-GC	32.1	65.0
S-TM	32.0	72.8
X-TM	31.5	62.3
S-CS	34.3 ✓	61.4
X-CS	33.4	59.8

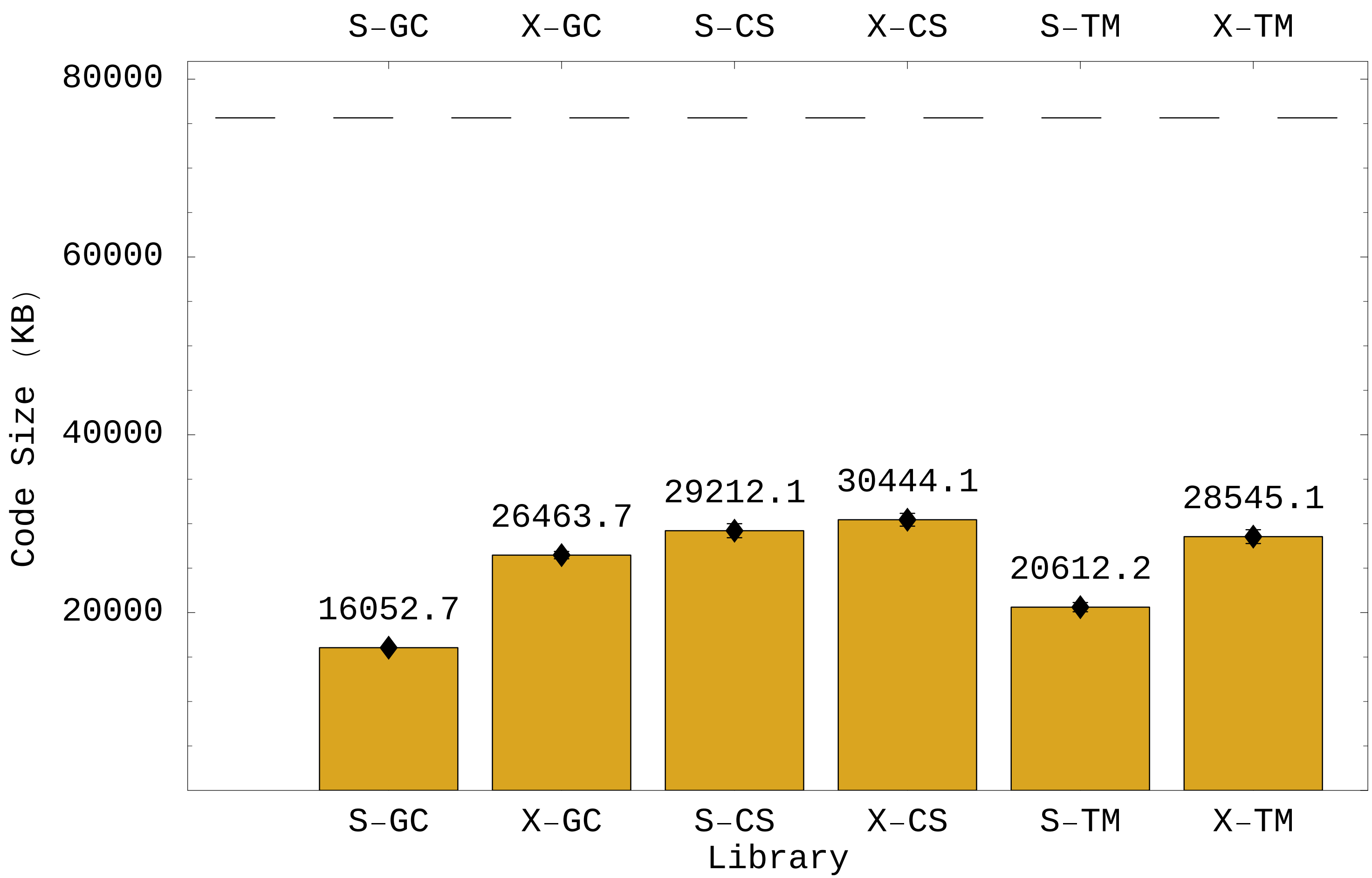
- Signifi cant reductions in time and space required for testing

Testing Time Overhead: Library



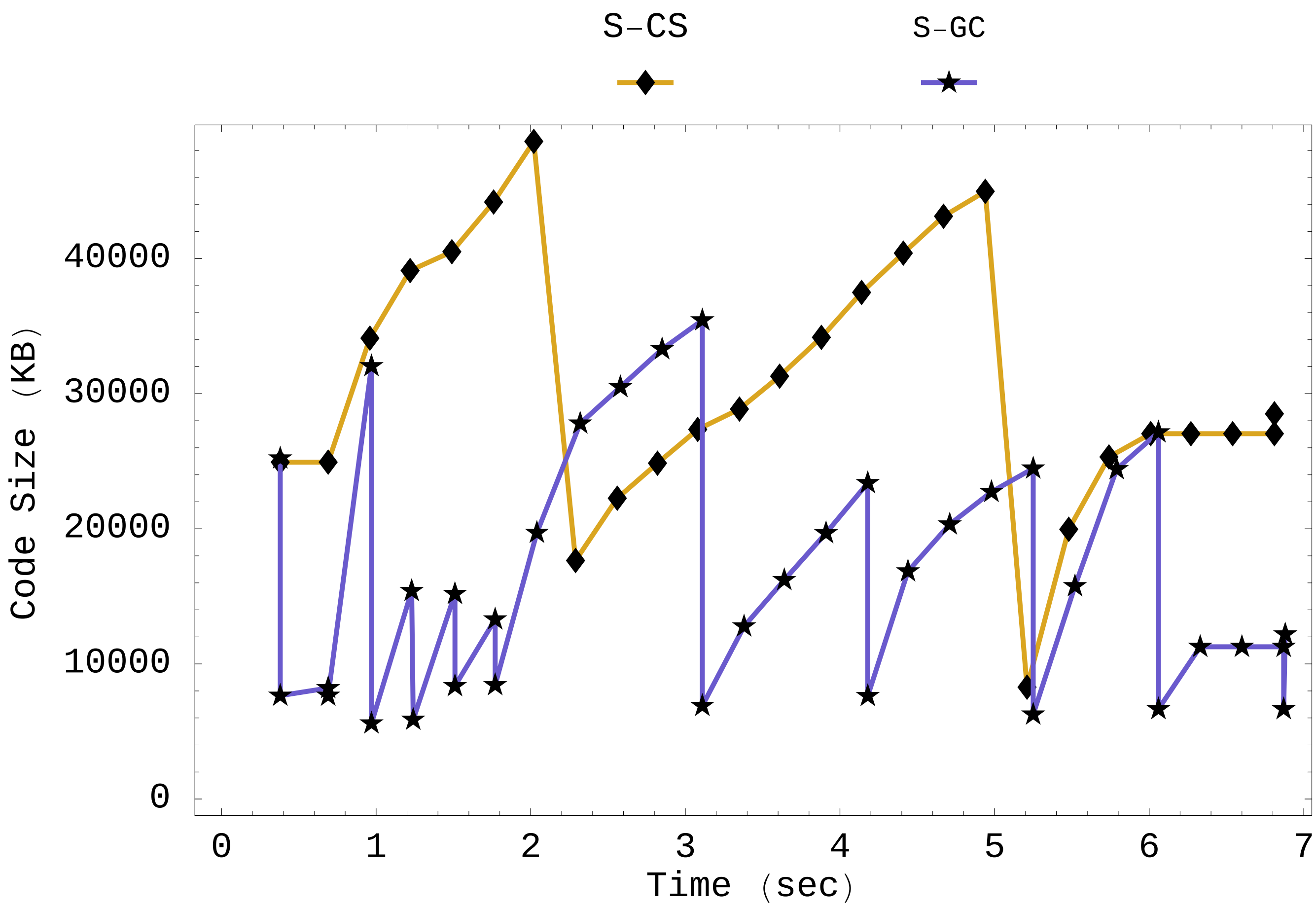
- *S* vs. *X*: Similar reductions for all code unloading techniques

Testing Space Overhead: Library



- Code size reduction does not always yield best testing time

Code Size Fluctuation: `Library`



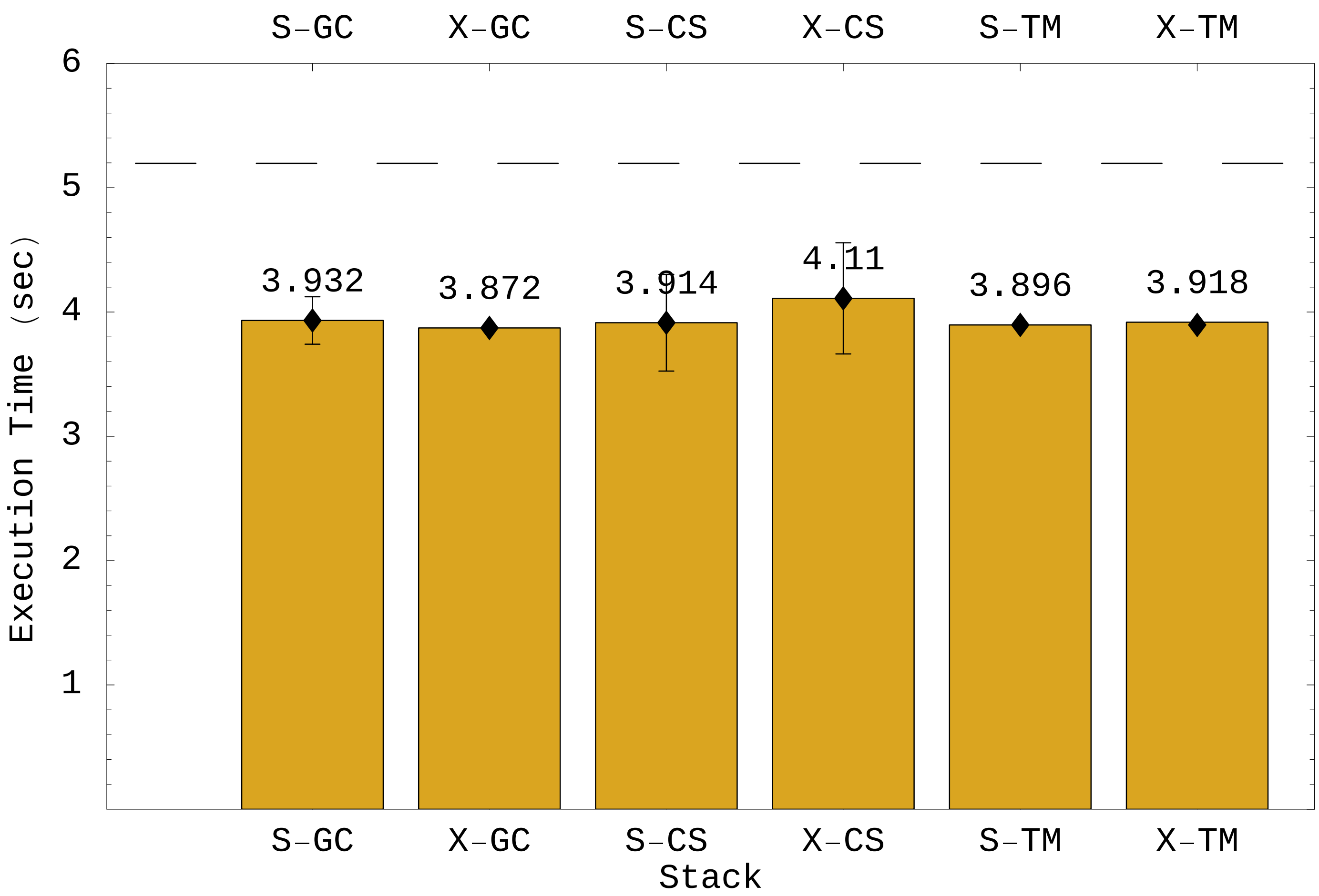
- *S-GC* causes code size fluctuation that increases testing time

Summary of Reductions for `Stack`

Name	$\mathcal{T}_R^{\%}(P,T)$	$\mathcal{S}_R^{\%}(P,T)$
S-GC	24.3	79.0 ✓
X-GC	25.4	63.4
S-TM	25.0 ✓	64.9
X-TM	24.6	47.8
S-CS	24.7	61.6
X-CS	20.9	46.9

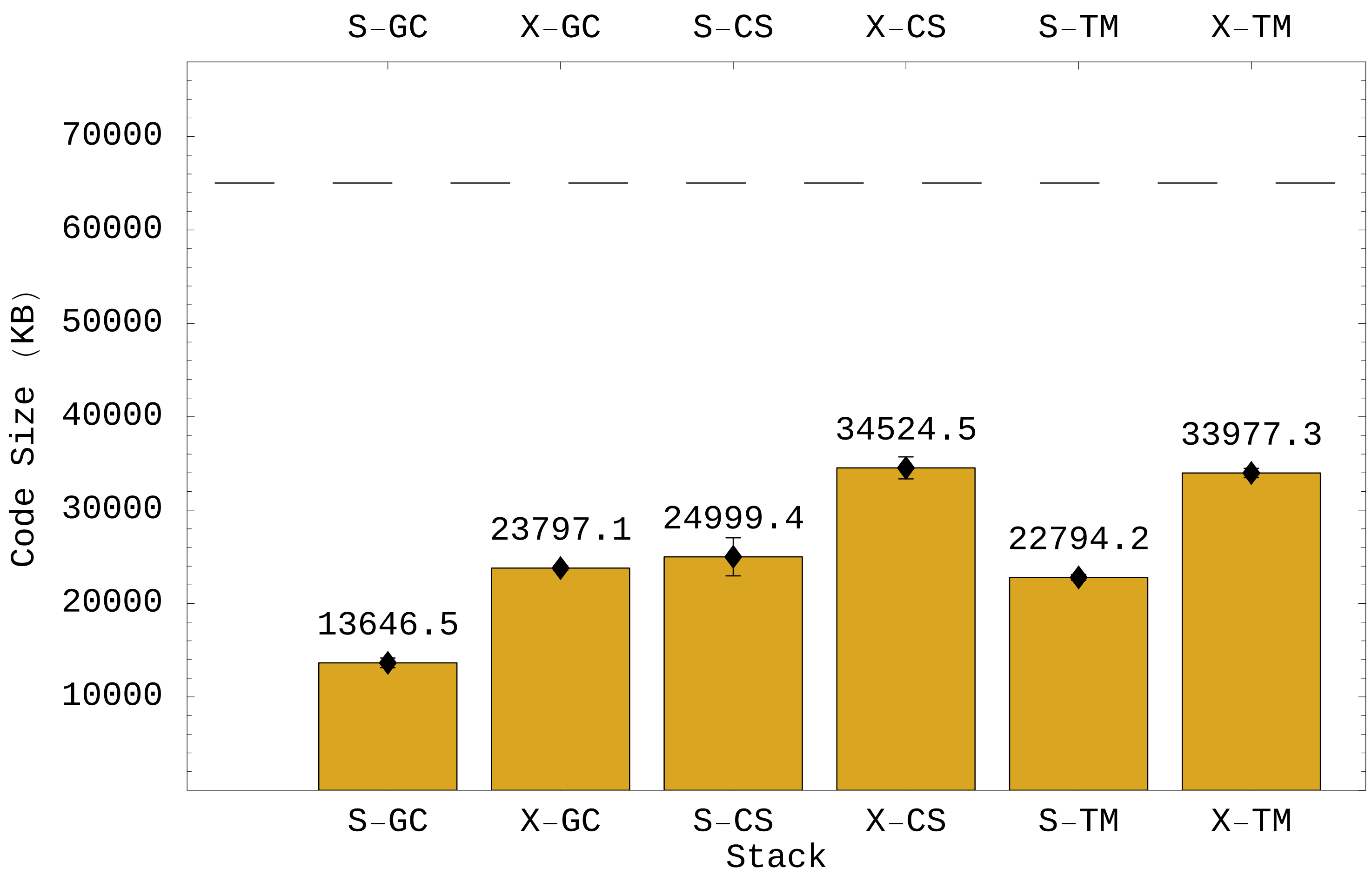
- Across all applications: *S-TM* or *S-CS* normally produce the largest reduction in testing time overhead

Testing Time Overhead: `Stack`



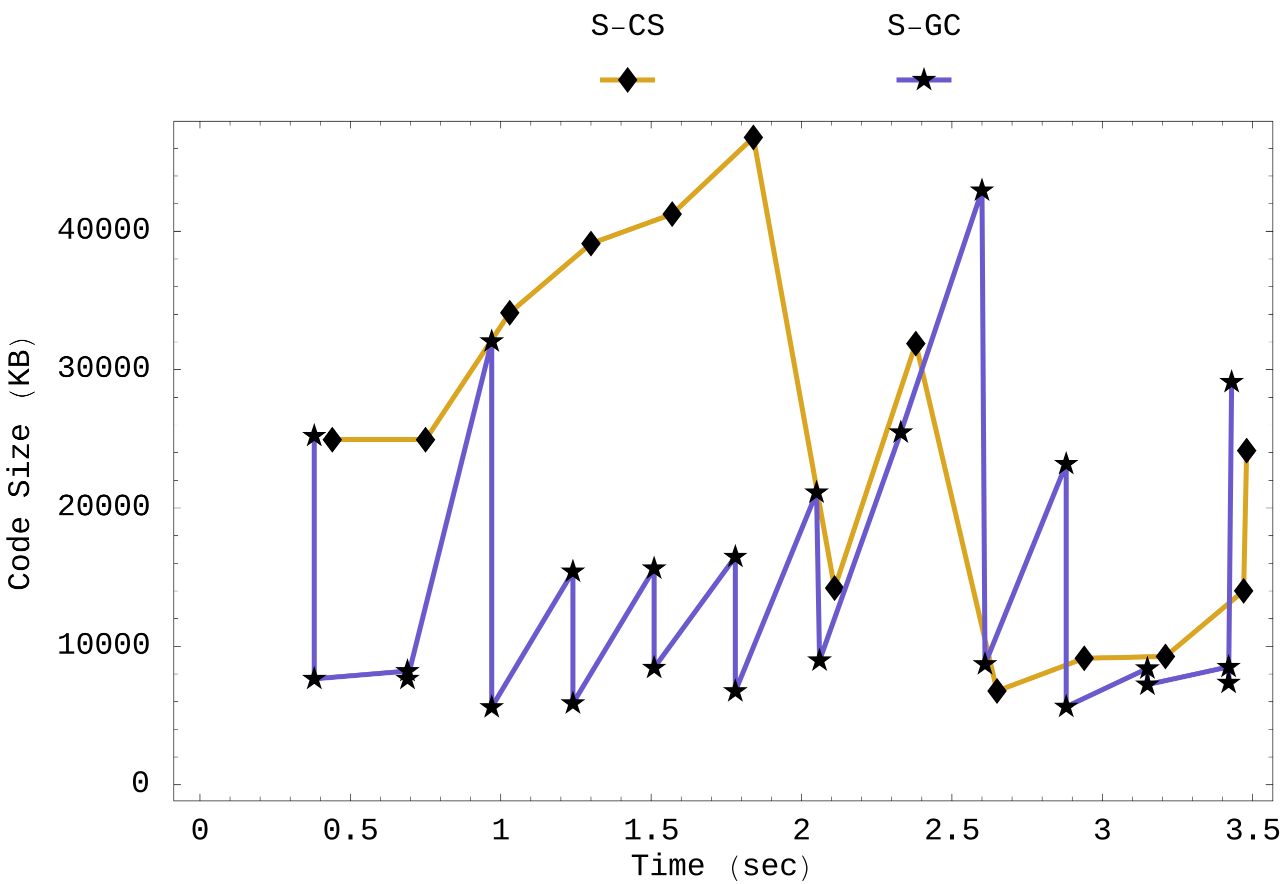
- *S* vs. *X*: Similar time reductions for another application

Testing Space Overhead: Stack



- *S-GC* also produces best code size reduction without creating greatest reduction in testing time

Code Size Fluctuation: `Stack`



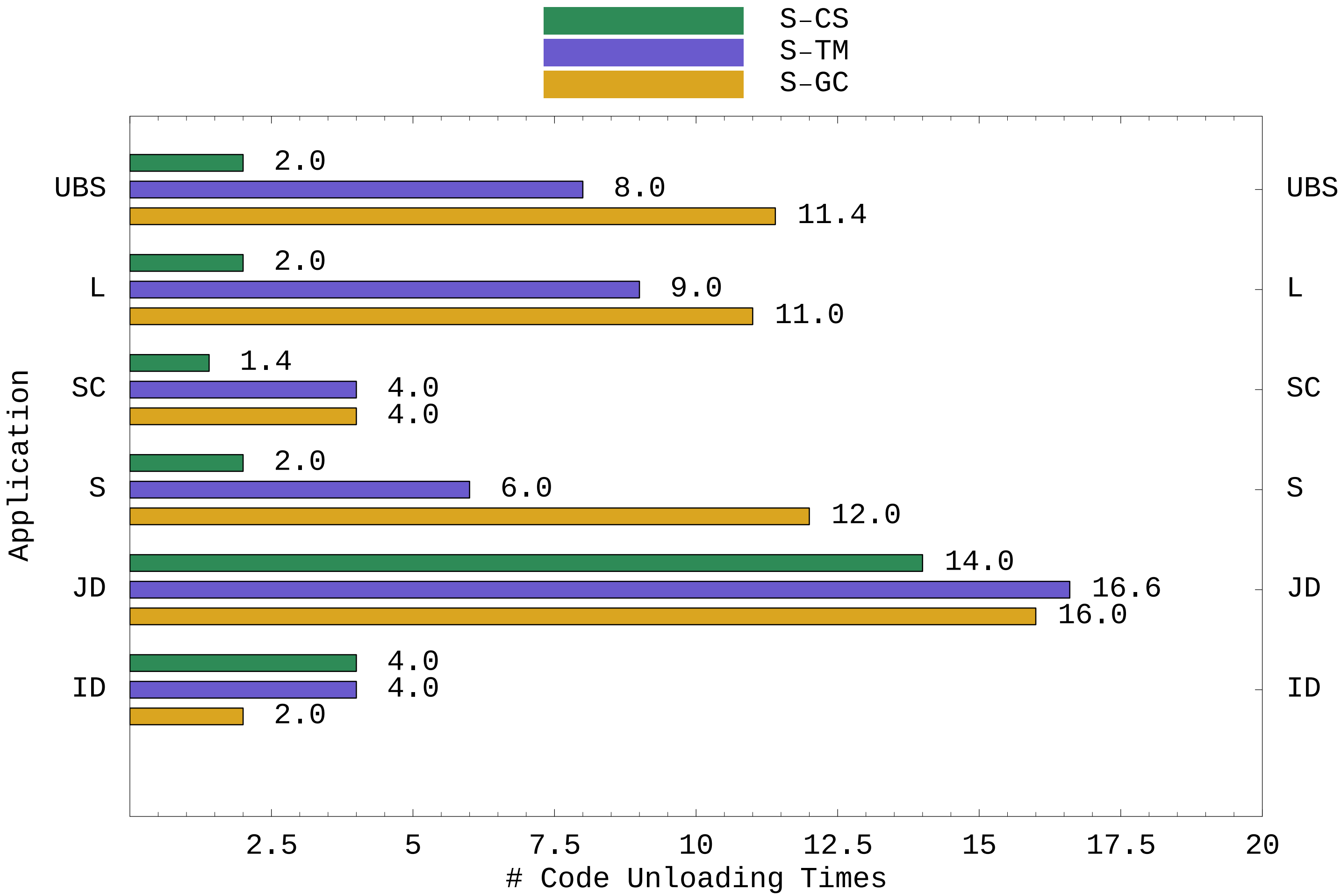
- *S-GC* also causes code size fluctuations in other applications

Summary of Reductions for `ID`

Name	$\mathcal{T}_R^{\%}(P,T)$	$\mathcal{S}_R^{\%}(P,T)$
S-GC	-1.1	42.5
X-GC	-1.1	26.7
S-TM	-1.2	44.5
X-TM	-.29 ✓	28.8
S-CS	-.77	51.4
X-CS	-1.4	61.4 ✓

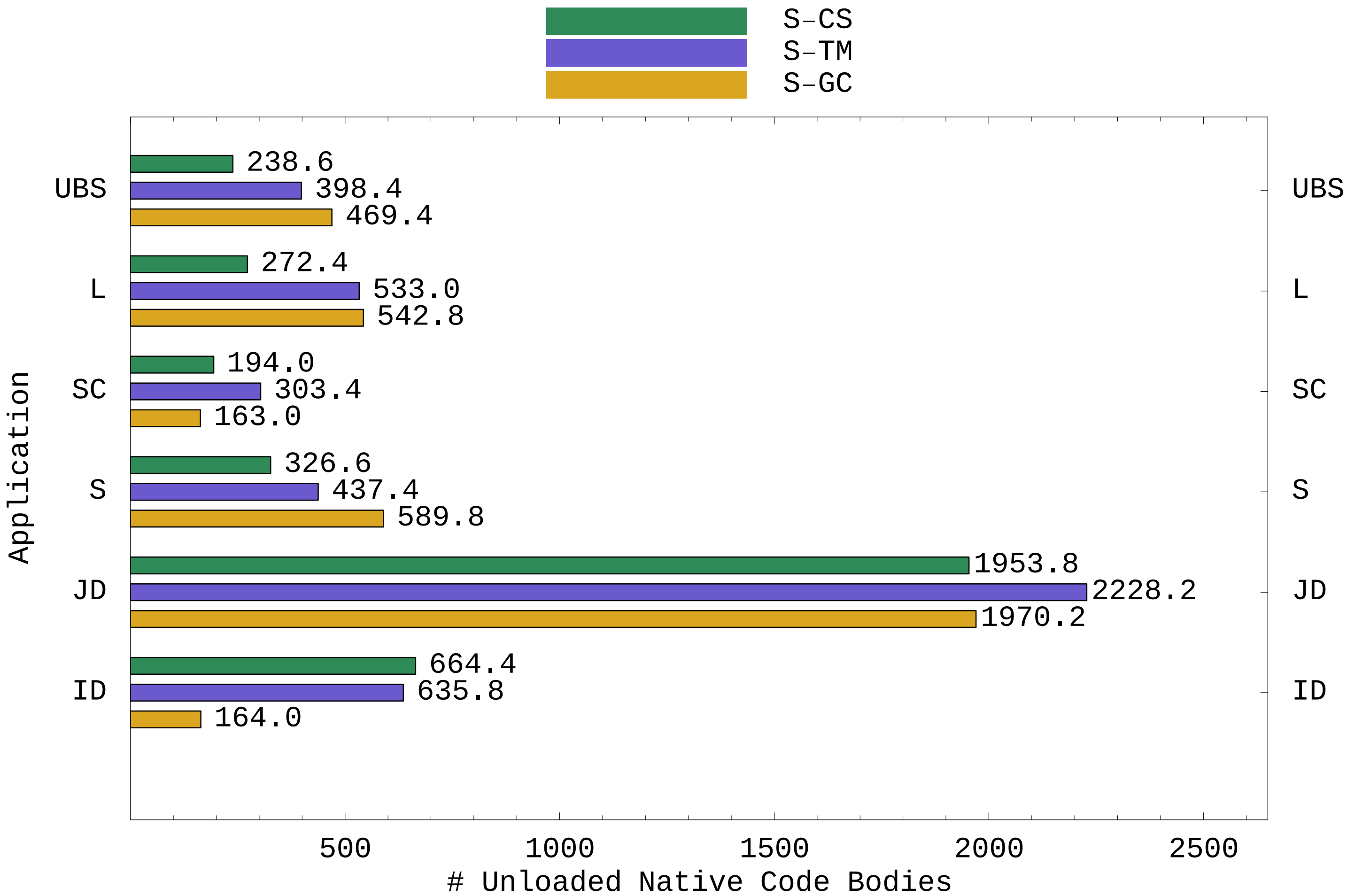
- Unloading can decrease native code size while still creating an overall increase in testing time

Number of Code Unloads



- All techniques cause `ID` to perform few unloading sessions

Number of Unloaded Code Bodies



- ID's large working set forces unloading of many code bodies

Summary of Reductions

Name	$\mathcal{T}_R^{\%}(P,T)$	$\mathcal{S}_R^{\%}(P,T)$
S-GC	16.1	68.4 ✓
X-GC	16.4	52.8
S-TM	17.1	62.6
X-TM	16.4	45.9
S-CS	17.6 ✓	58.8
X-CS	15.3	54.8

- Across all applications, adaptive code unloading techniques reduce both testing time and space overhead

Conclusions

- Dynamic compilation in JVMs can increase testing time if memory is constrained
- Adaptive unloading of native code often reduces memory overhead, avoids GC invocation, and reduces testing time
- Impact of unloading varies with respect to size of application's working set and program testing behavior
- Code unloading JVM can be rapidly configured to produce useful reductions in the time and space overheads of testing

Future Work

- Include new case study applications and test suites
- Experiments to measure the impact of garbage collection and heap compression algorithms (e.g., Jikes RVM MMTk)
- Regression test suite prioritization and reduction techniques that consider structural coverage *and* time or space overheads
- Real testing framework for emerging operating systems that support Java in ad hoc networks (e.g., MagnetOS)

Additional Resources

- Kapfhammer et al. Testing in Resource Constrained Execution Environments. In *IEEE/ACM Automated Software Engineering*. November 7 - 11, 2005.

http://cs.allegheny.edu/~gkapfham/research/juggernaut/