RL-Bin

A Framework for Robust Low-Overhead Binary Instrumentation

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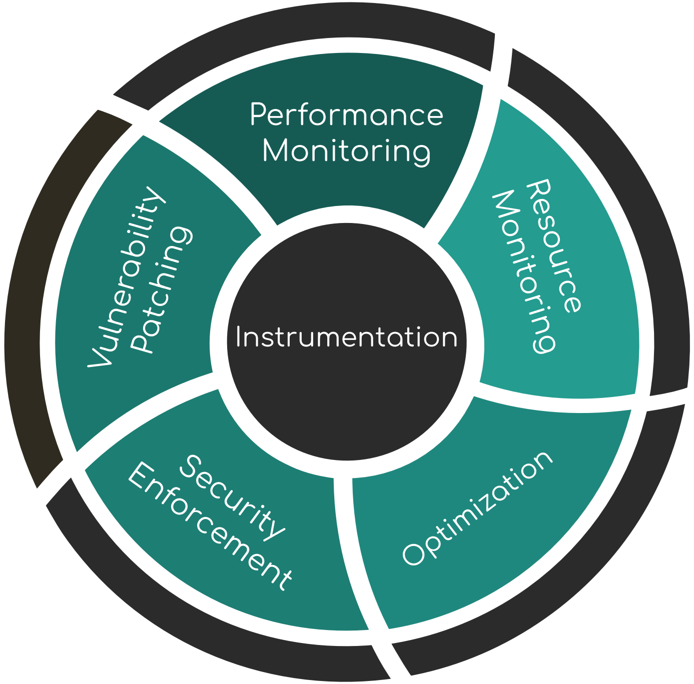
The Problem: Instrumenting programs

Program instrumentation is invaluable for following capabilities:



Instrumenting interpreted vs. binary code

Programming Languages

- Interpreted
  (Python, Java, ...)

  - Relatively easy to instrument!

- Compiled
  (C, C++, Fortran, ...)

  - Instrumentation is very complicated!

Why binary code persists?

1. IP protection
2. High performance

Need a binary rewriter to instrument binary code!

Requirements for Deployment use of a binary rewriter

- Solution must be robust

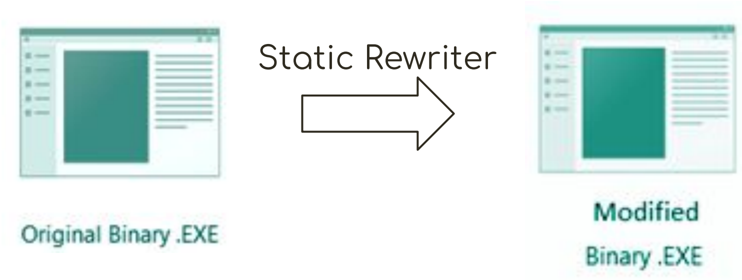
  It should work for all binaries

- It must also be low-overhead

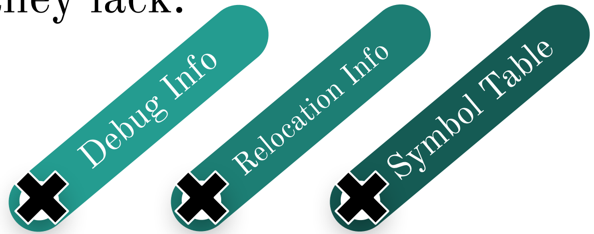
  High overhead is not tolerated in practice

Static binary rewriters

What is a static rewriter?



Most commercial binaries are stripped, so they lack:



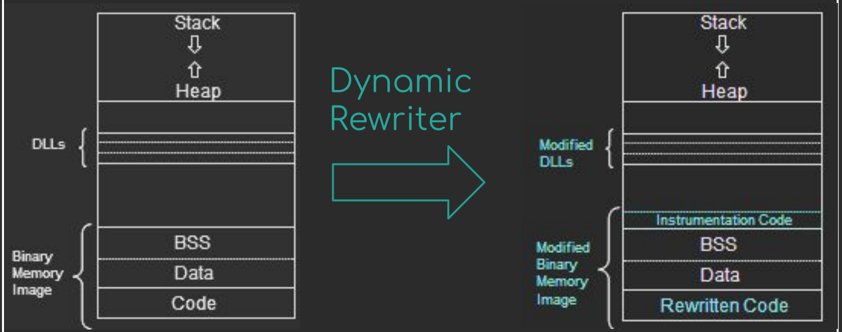
Limitations:

- Error prone for all programs
- Do not support obfuscation
- No support for self-modifying code
- Dynamically-generated code not supported
- Binary file will change => Checksum mismatch

Dynamic Solutions

In-place designs

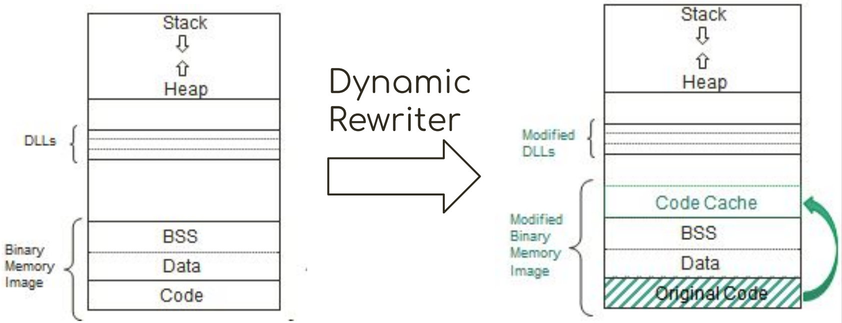
(i.e. Dyninst'06 and BIRD)



- No support for obfuscation, self-modifying and dynamically generated code

Code-cache based designs

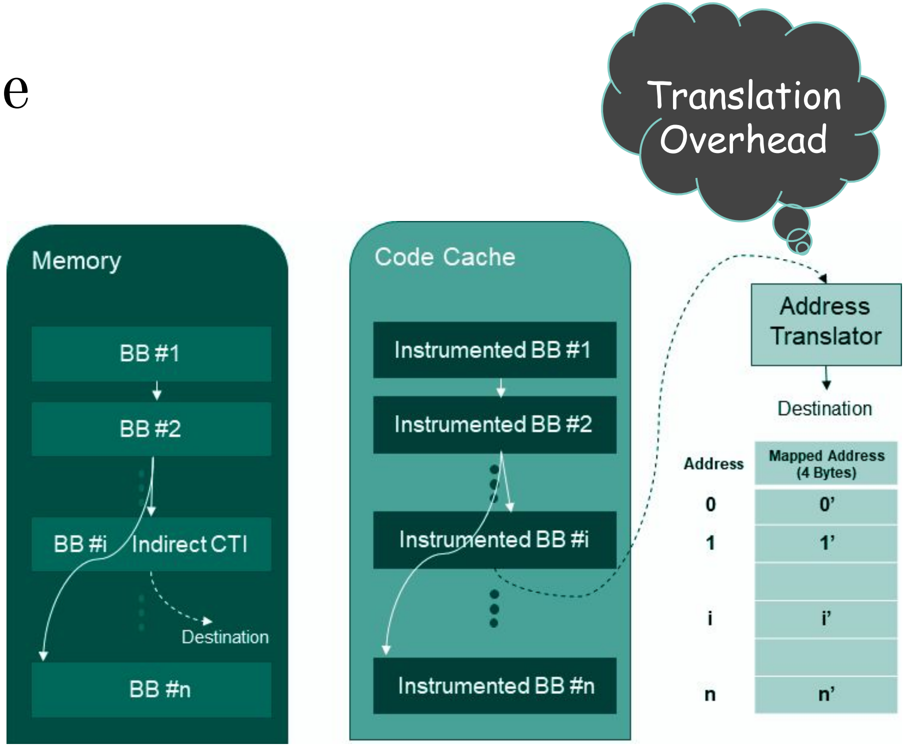
(i.e. Pin and DynamoRIO)



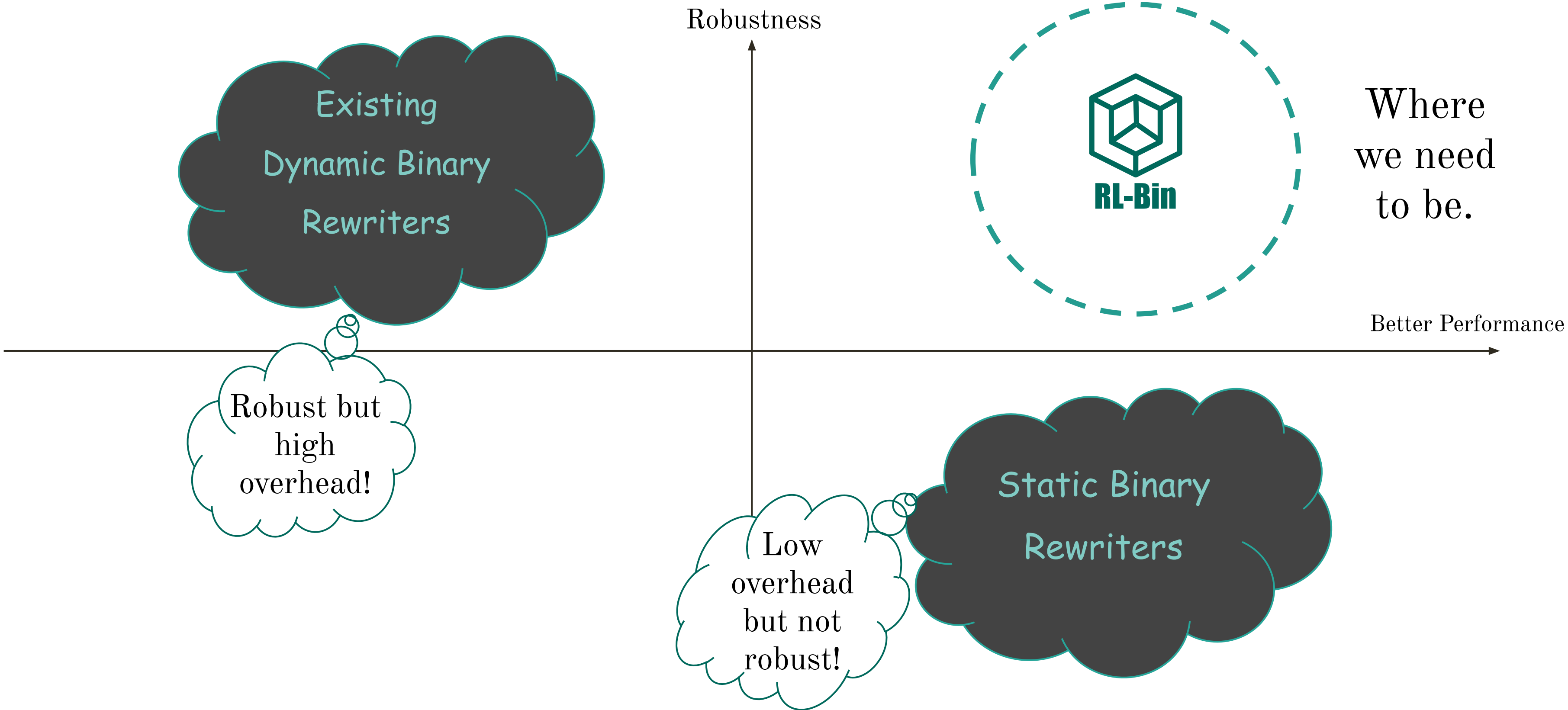
- They are robust but have high overhead!

Why Code-Cache has High Overhead?

- Indirect CTIs are everywhere
- They need to be translated
- Address translation cannot be removed!



Summary of existing solutions



Our Solution (RL-Bin)

RL-Bin

(Robust Low-overhead Binary Rewriter)

RL-Bin has very low overhead,

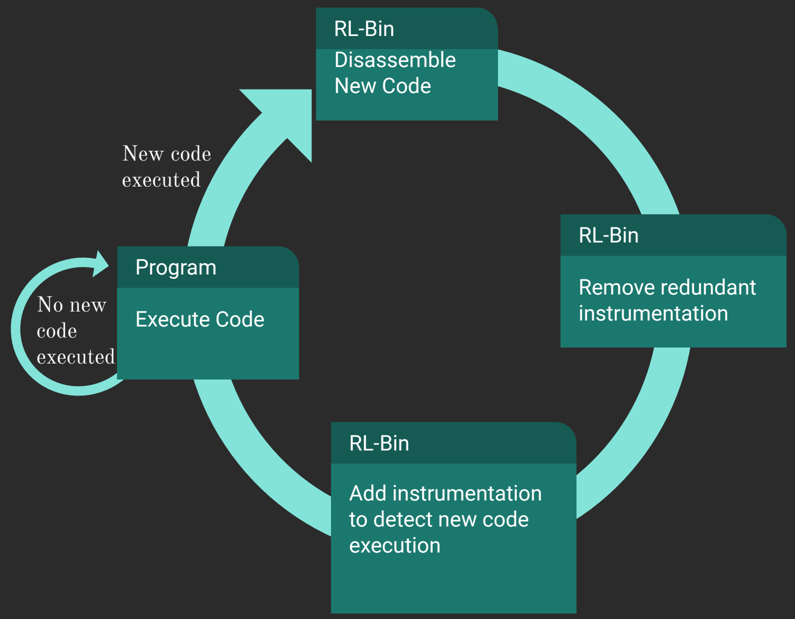
(less than 5%)

- RL-Bin is robust,
  it supports

Obfuscation	✓
Self-modifying code	✓
Dynamically-generated code	✓

RL-Bin's Overall Approach

- Does not rely on static analysis
- Instead, it discovers code dynamically as it executes
- Conceptually, discover every CTI's target as code when that CTI executes

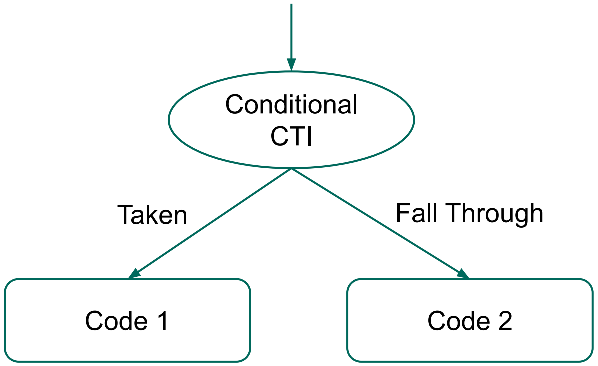


How Far Can We Disassemble New Code?

- When we arrive at a new code location, how far can we continue disassembling code?
- There are four possibilities:
  - Straight-line code (non-CTI instructions)
    - The address of the next instruction is known
  - Unconditional jumps
    - The address of the target is known and fixed
  - Conditional branches
    - Need run-time verification because we cannot assume that both targets are code)
  - Indirect CTIs
    - Must be verified during run-time because targets are discovered dynamically)

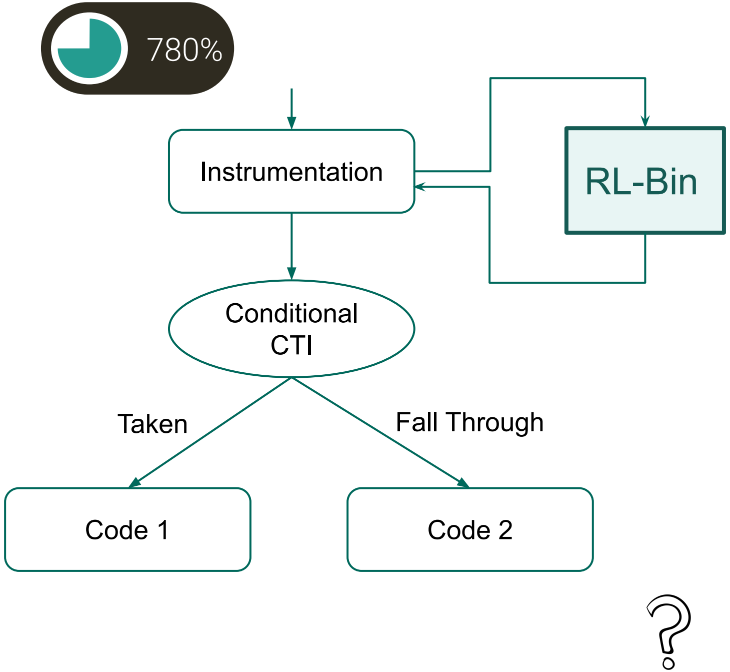
Discovering new code: Conditional CTIs

The problem with conditional branches



For obfuscated code, both targets may not be code!

- Unoptimized solution for conditional CTIs

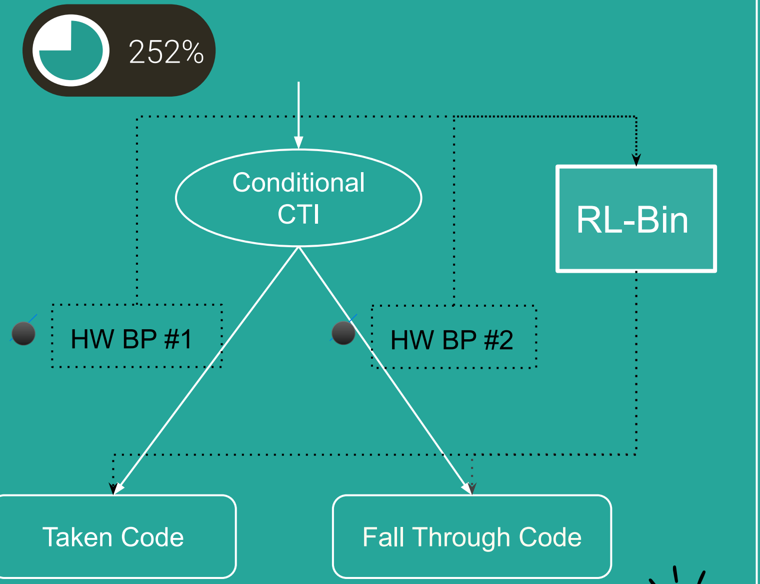


Discovering new code: Conditional CTIs

A lower overhead solution:

- Use Hardware breakpoints instead of instrumentation
- Much lower overhead!

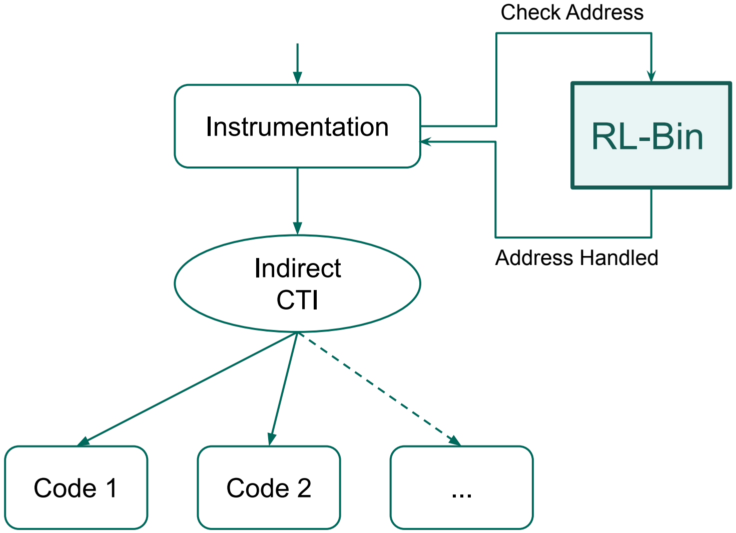
- Optimized handling of conditional CTIs



Breakpoints can be removed if one or both of the targets are executed. Very low overhead!

Discovering new code: Indirect CTIs

- Unoptimized handling of Indirect CTIs



- Indefinite number of run-time computer targets.

- The instrumentation could be optimized and either reduced or removed!

113% — Branch target prediction for common case target specialization

49% — Function cloning to eliminate returns

14% — Safe functions (i.e., those that cannot modify return address)

More Optimizations

9%

Whitelisting Library Modules

- Optionally not monitor Win32 or standard library DLLs
- Only possible when call back functions and call back addresses are known

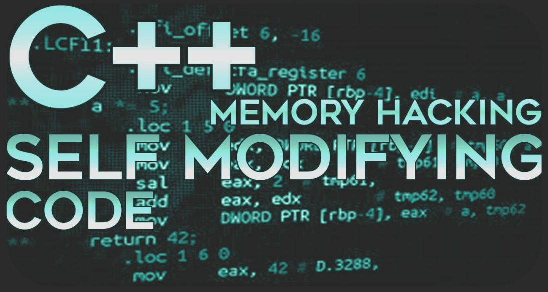
5%

Optimizing Library Calls

- Library Calls done through Import Address Table.
- An indirect call with always one destination!
- Optimize away the check by write-protecting IAT

Handling Self-Modifying Code

To detect self-modifying code,



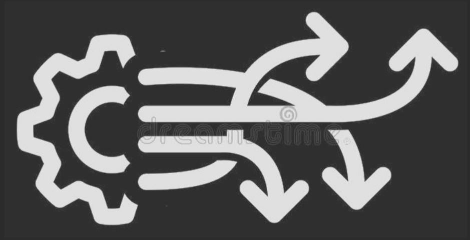
  - Code segment is write-protected
  - Any change to the code segment will trigger an exception
  - Modified code will be disassembled and analyzed again

- The method can be optimized by adding instrumentation before and after instructions that cause self-modification
  (this is a best effort optimization to avoid triggering a lot of exceptions)

Handling Multi-Threaded Code

Handle race conditions from access to shared data structures, such as disassembly table, etc.

- ➢ Thread 1 is instrumenting a piece of code
- ➢ Thread 2 is executing the same code
- ➢ Thread 2 might execute from an address that is the middle of instrumentation instruction added by thread 1. The application will crash!



Handled by using mutually exclusive access to shared data structures

Limitations of RL-Bin

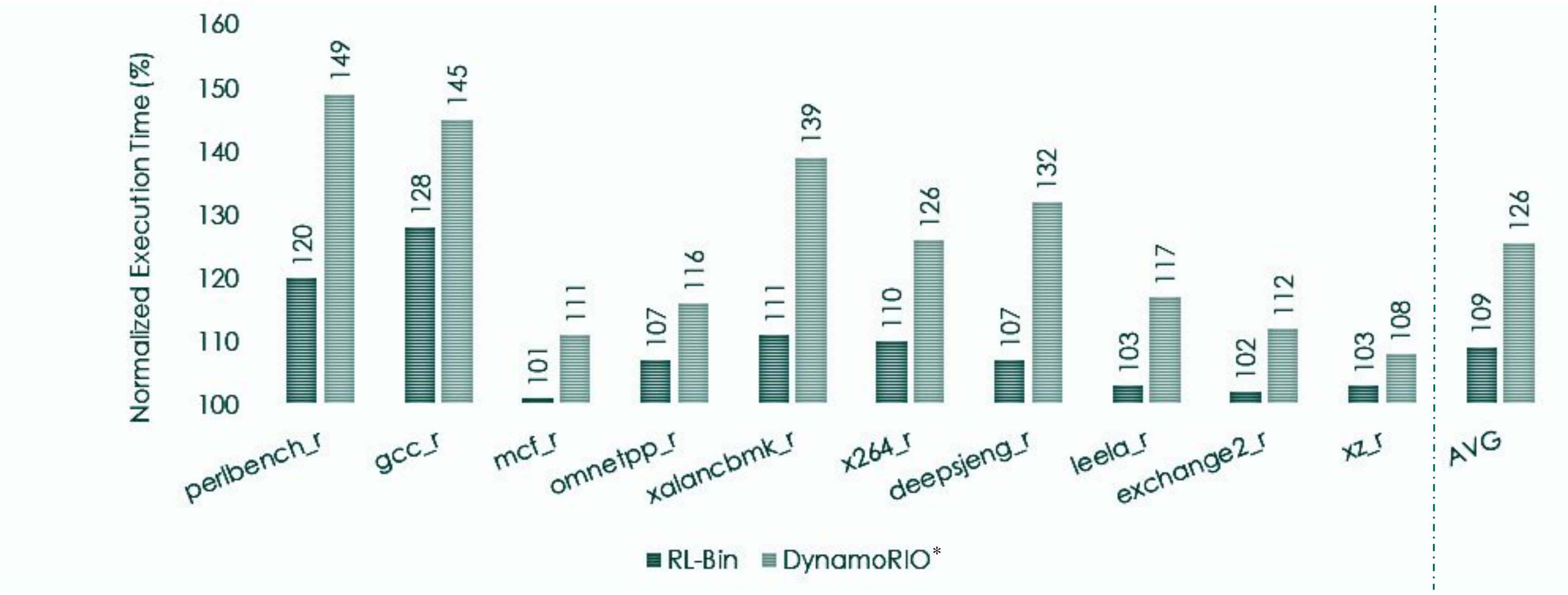
RL-Bin can handle any application that can be debugged by a debugger.

Benign applications are meant to be debugged, so they are supported.

Troublesome feature	Why debuggers would fail too
Self-referencing code	• Detects changes in the code (which debuggers change)
Self-checksumming the memory image	• Debuggers use breakpoints and change memory checksum
Memory layout checking	• Requires no change in memory layout (which debuggers do)

Results (Spec 2017 Integer)

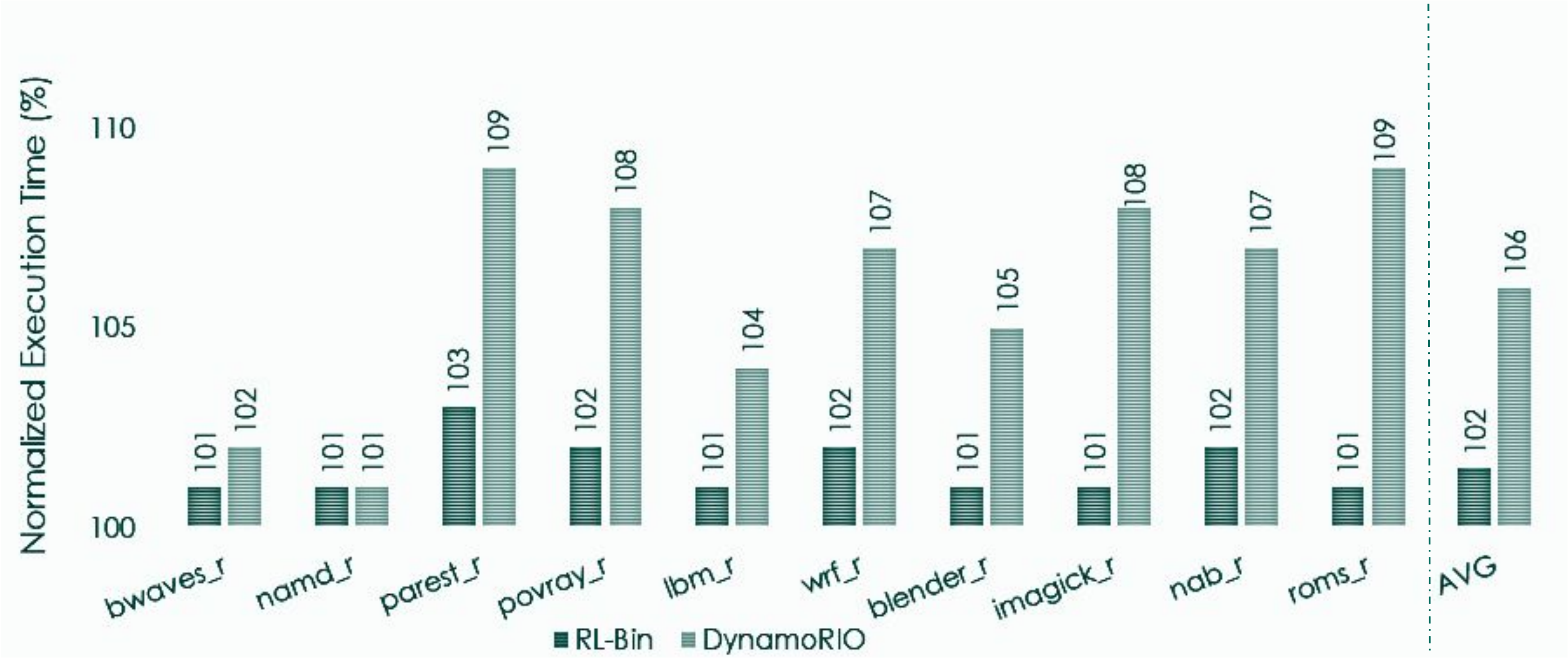
- Normalized run-time overhead of rewriters without added instrumentation



* Pin has higher overhead than DynamoRIO according to ref. C.-K. Luk et al. ACM,2005

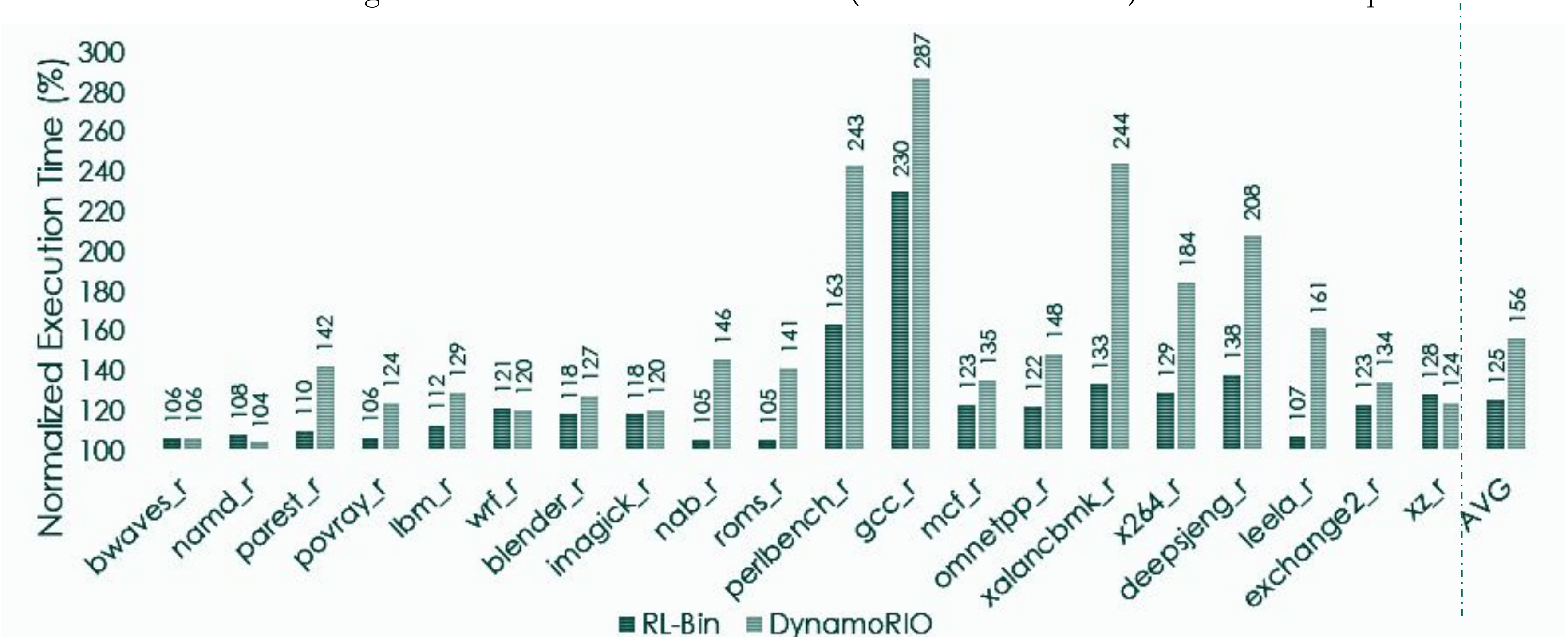
Results (Spec 2017 Floating Point)

- Normalized run-time overhead of rewriters without added instrumentation



Results with example heavyweight instrumentation

- Run-time overhead of rewriters with added instrumentations to count external calls
- The overhead is significant because all indirect calls (which are common) must be intercepted



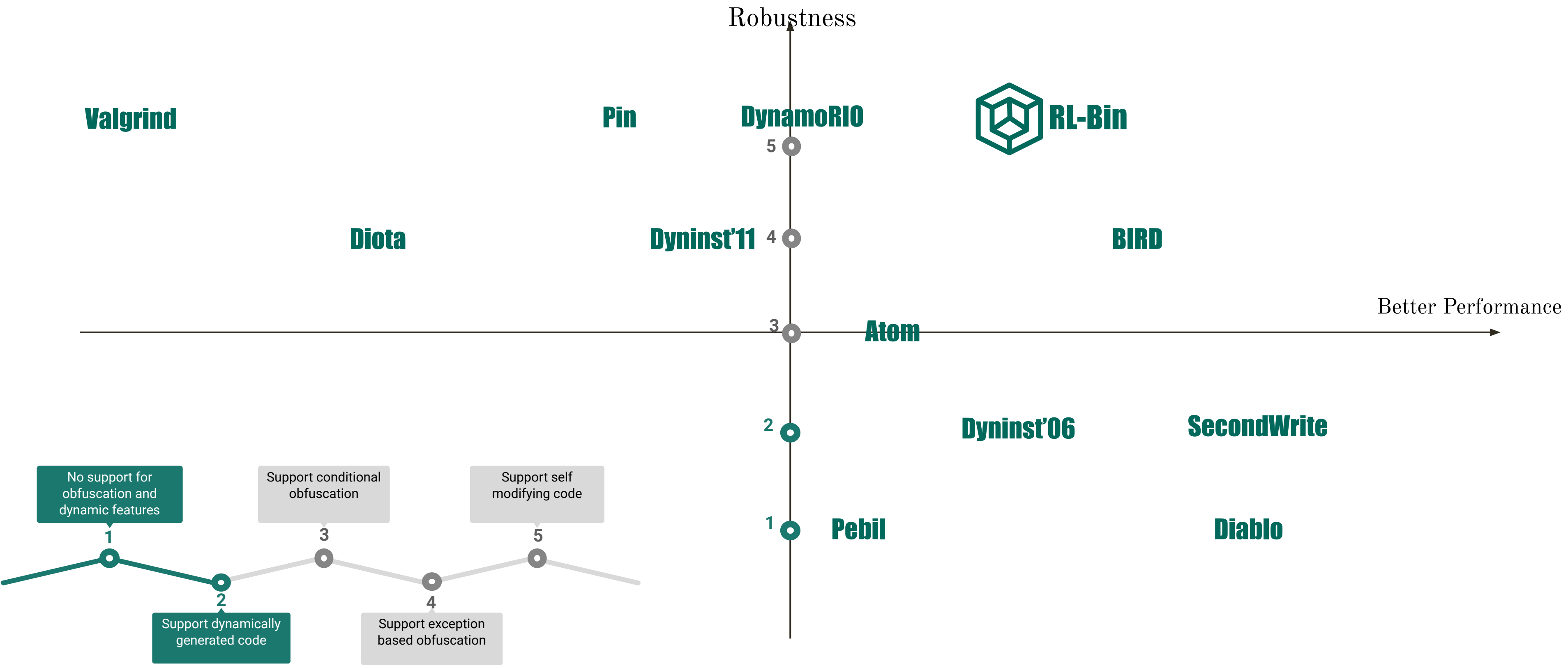
Proving Robustness

- Accuracy and Code Coverage
  - Number of dynamically executed instructions were measured and compared against DynamoRIO.
  - Matched in all cases for SPECrate 2017 benchmarks

- Commercial Applications were tested

Obfuscation	✓
Self-modifying code	✓
Dynamically-generated code	✓

Related Works



Future Work

- Improve robustness by overcoming limitations
- Developing custom instrumentation API
  (User-friendly API for instrumentation)
- Plan to release RL-Bin publicly in late 2020

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Thanks for your time!