A Framework for Automated Architecture-Independent Gadget Search

Thomas Dullien
Tim Kornau
Ralf-Philipp Weinmann

Overview

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Goal

The goal of this research is to be able to use return-oriented programming platform independently across multiple platforms.

Motivation I

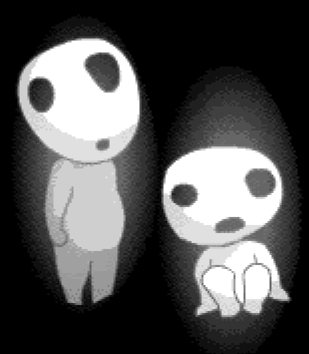
MIPS TECHNOLOGIES

Power™

IA32

ARM POWERED

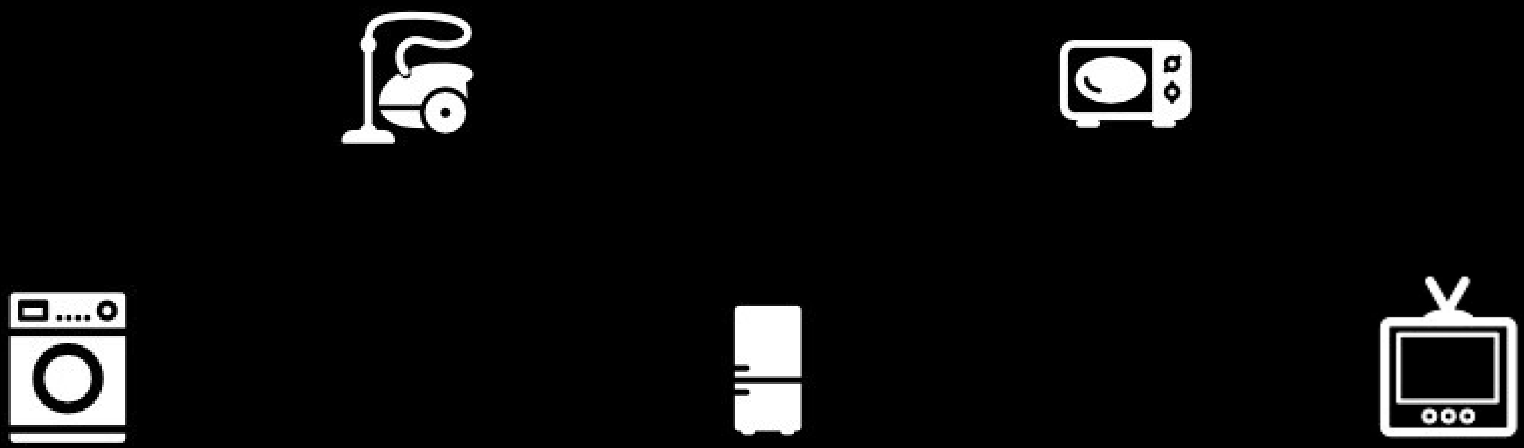
AMD64



Little spirits need access to a wide range of devices.
Because what is a device without a spirit ?

Motivation II

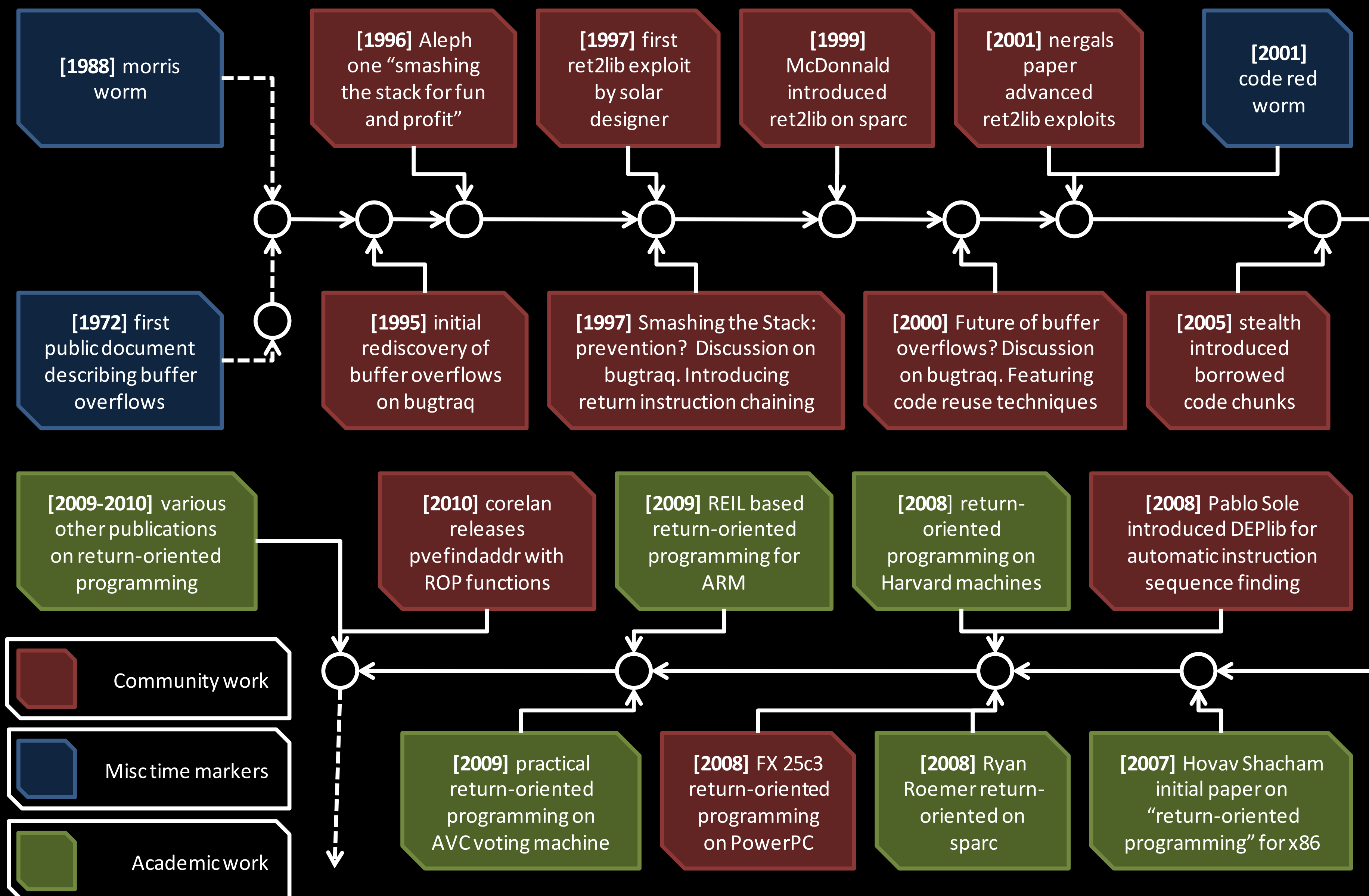
CPU Architecture diversity is increasing.



Motivation III

We want to execute code on machines despite the presence of non-executable memory, but we do not aim for ASLR!

History I


[1972] first public document describing buffer overflows
[1988] morris worm
[1995] initial rediscovery of buffer overflows on bugtraq
[1996] Aleph one “smashing the stack for fun and profit”
[1997] first ret2lib exploit by solar designer
[1997] Smashing the Stack: prevention? Discussion on bugtraq. Introducing return instruction chaining
[1999] McDonnald introduced ret2lib on sparc
[2000] Future of buffer overflows? Discussion on bugtraq. Featuring code reuse techniques
[2001] nergals paper advanced ret2lib exploits
[2001] code red worm
[2005] stealth introduced borrowed code chunks
[2007] Hovav Shacham initial paper on “return-oriented programming” for x86
[2008] Pablo Sole introduced DEPlib for automatic instruction sequence finding
[2008] return-oriented programming on Harvard machines
[2008] Ryan Roemer return-oriented on sparc
[2008] FX 25c3 return-oriented programming on PowerPC
[2009] REIL based return-oriented programming for ARM
[2009] practical return-oriented programming on AVC voting machine
[2010] corelan releases pvefindaddr with ROP functions
[2009-2010] various other publications on return-oriented programming
Community work
Misc time markers
Academic work

History II

```
/* e2.c                                                 *
/* specially crafted to feed your brain by gera */

/* Now, your misson is to make abo1 act like this other program:
 *
        char buf[100];

        while (1) {
                scanf("%100s",buf);
                system(buf);
        }

 * But, you cannot execute code in stack.
 */

int main(int argv,char **argc) {
        char buf[256];

        strcpy(buf,argc[1]);
}
```

Strategy I

- Use only already present code
- No single instruction / return like approach
- Use REIL to be platform independent
- Use “free-branch” instructions rather than ret only
- “Find all first, then filter useful ones” approach
- Keep an eye on side-effects and minimize them

Strategy II

Small RISC instruction set

- 17 instructions for arithmetic, control flow and misc functionality
- Instructions are always side-effect free

Interpreter

- Virtually unlimited memory and temporary registers
- Implemented as a register machine

No support for

- Exceptions, floating point instructions, 64Bit instructions yet

Algorithms

Stage I -> Collect data from the binary

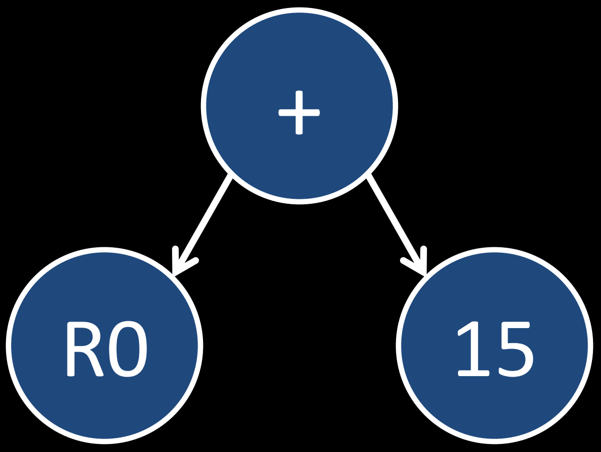
Stage II → Merge the collected data

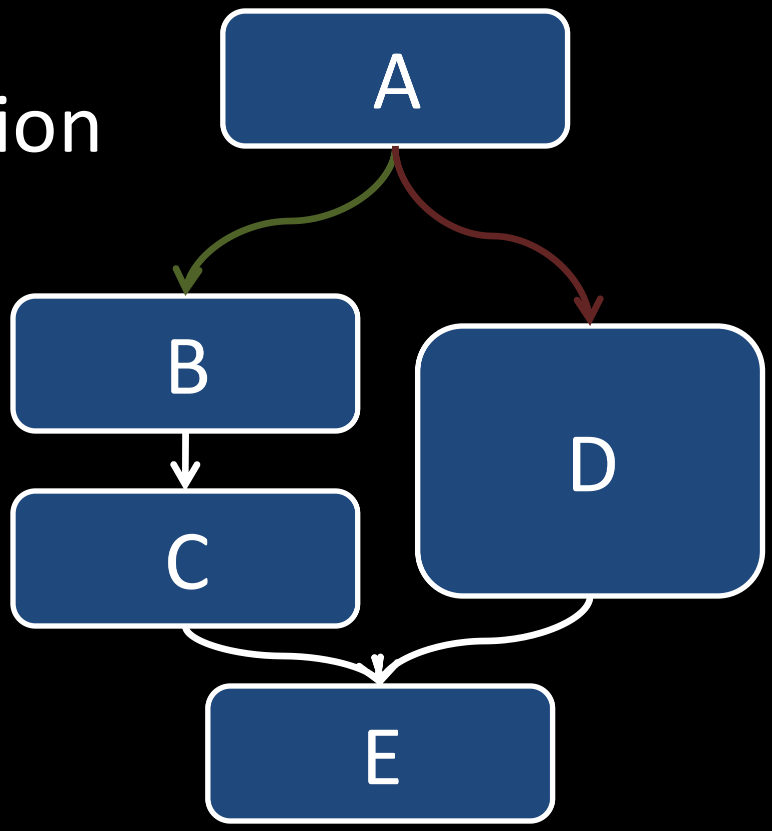
Stage III → Locate useful gadgets in merged data

Algorithms stage I (I)

Goal of the stage I algorithms:

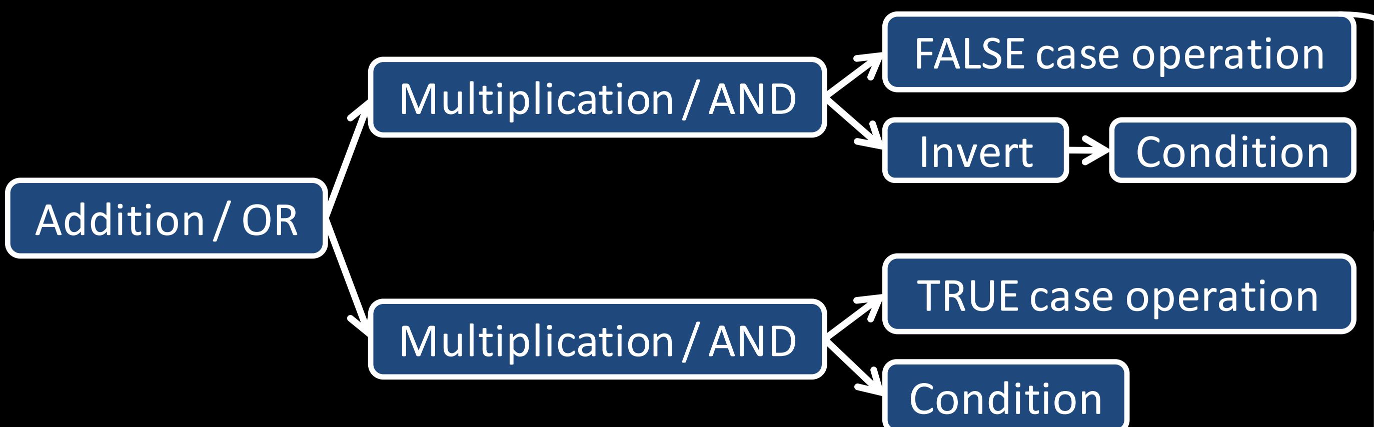
- Collect data from the binary
  1. Extract expression trees from native instructions
  2. Extract path information





Algorithms stage I (II)

1. Expression tree extraction details:
   - Handlers for each possible REIL instruction
     1. Most of the handlers are simple transformations
     2. Memory store and conditional execution need special treatment
2. Path extraction details:
   - Path is extracted in reverse control flow order



We want to have all possible outcomes for a conditional execution in a single expression tree

Algorithms stage II (I)

Goal of the stage II algorithms:

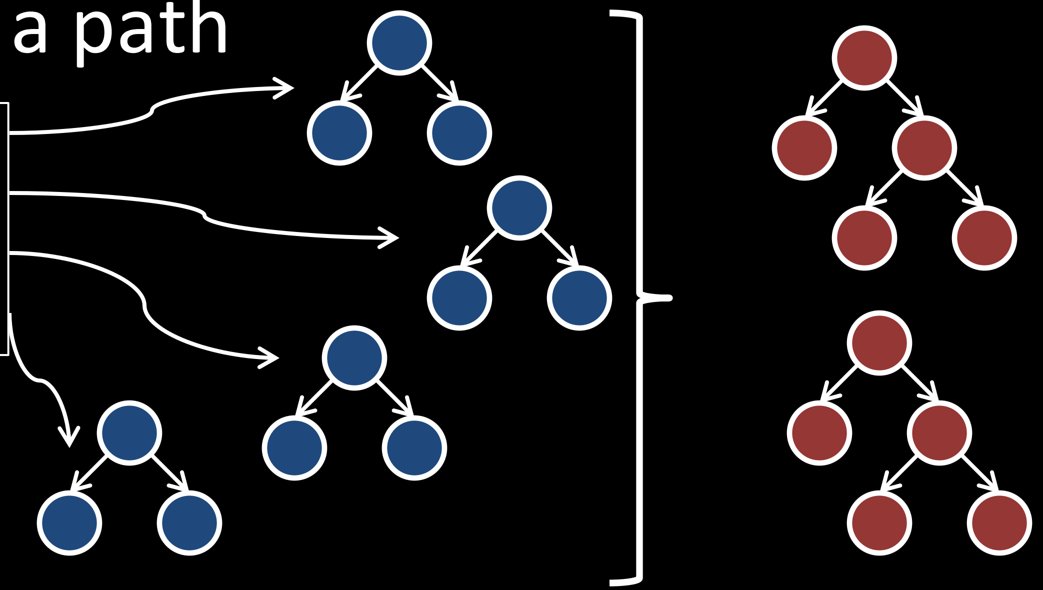
- Merge the collected data from stage I
  1. Combine the expression trees for single native instructions along a path
  2. Determine jump conditions on the path
  3. Simplify the result

Algorithms stage II (II)

Details of the stage II algorithms:

- Combine the expression trees for single native instructions along a path

1. 0x00000001 ADD R0, R1, R2
2. 0x00000002 STR R0, R4
3. 0x00000003 LDMFD SP! {R4,LR}
4. 0x00000004 BX LR



Algorithms stage II (III)

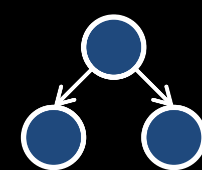
Details of the stage II algorithms:

- Determine jump conditions on the path:

1. 0x00000001 SOME INSTRUCTION
2. 0x00000002 BEQ 0xADDRESS
3. 0x00000003 SOME INSTRUCTION
4. 0x00000004 SOME INSTRUCTION

Z FLAG MUST BE FALSE

Generate condition tree



- Simplify the result:

R0 = ((((((R2+4)+4)+4)+4) OR 0) AND 0xFFFFFFFF)
R0 = R2+16

Algorithms stage III (I)

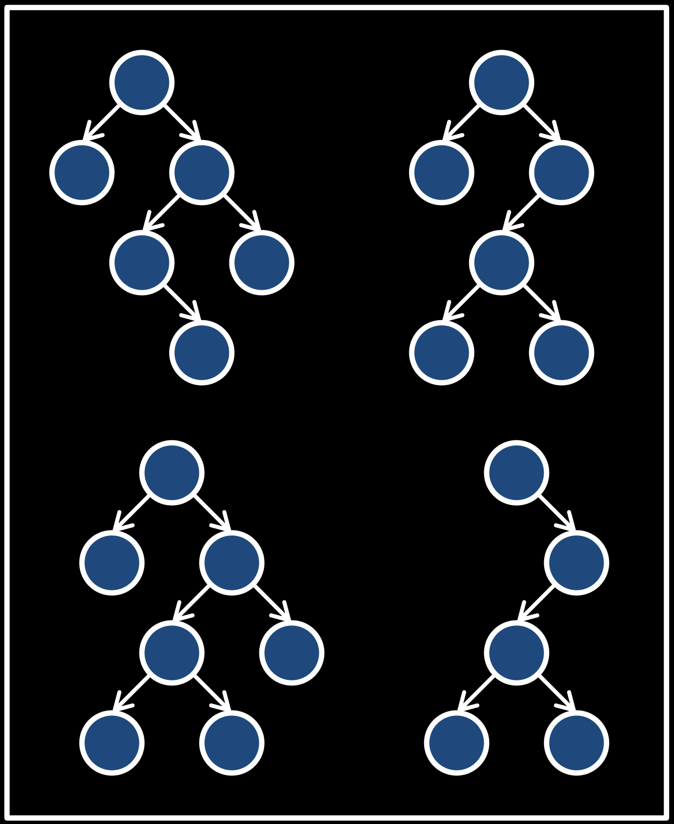
Goal of the stage III algorithms:

- Search for useful gadgets in the merged data
  - Use a tree match handler for each operation.
- Select the simplest gadget for each operation
  - Use a complexity value to determine the gadget which is least complex. (side-effects)

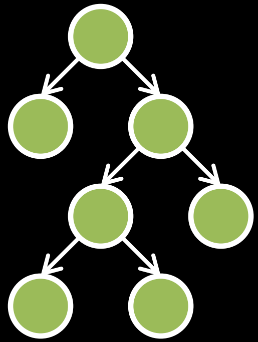
Algorithms stage III (II)

Details of the stage III algorithms:

- Search for useful gadgets in the merged data



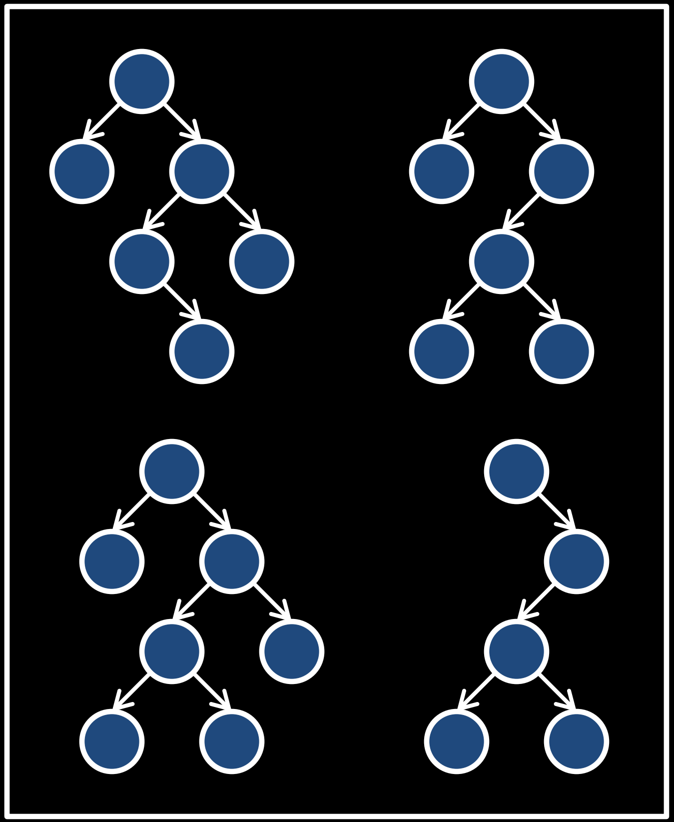
Trees of a gadget candidate are compared to the tree of a specific operation.
Can you spot the match ?

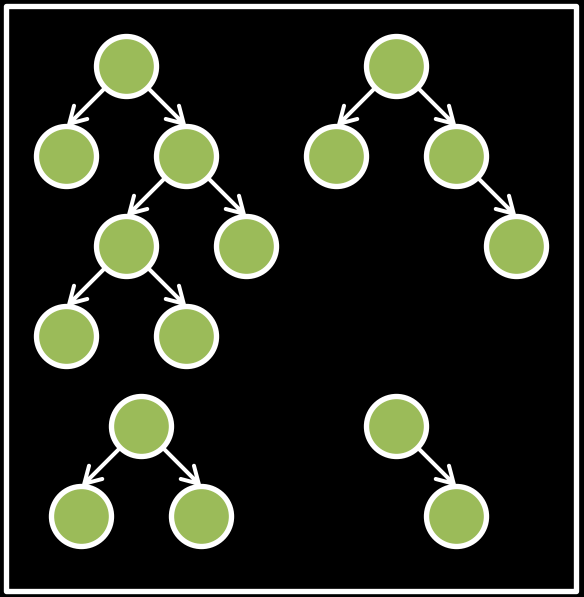


Algorithms stage III (III)

Details of the stage III algorithms:

- Select the simplest gadget for each operation





In most cases there is more than one instruction sequence that provides a specific operation. The overall complexity of all trees is used to determine which gadget is the simplest.

Results

- Algorithms for platform independent return-oriented programming are possible
- We are able to find all necessary gadgets for return-oriented programming using our tool
- Searching for gadgets is not only platform but also very compiler dependent
- Minimizing side-effects is possible if the right approach is chosen

Further work

- Abstract gadget description language
- Automatic gadget compiler for all platforms
- Bring more platforms to REIL
- Better understand the implications of different compilers

Thank you for your time !

Questions ?