A Platform for Secure Static Binary Instrumentation

Mingwei Zhang, Rui Qiao, Niranjan Hasabnis
and R. Sekar
Stony Brook University

VEE 2014

Work supported in part by grants from AFOSR, NSF and ONR

Motivation

Why Binary Instrumentation (rewriting)?

- Forms the basis of many software security defenses.
- Binary code broadly available

Dynamic binary instrumentation (DBI) is the de facto choice. *(easy-to-use API, can handle large binaries, non-bypassable)*

Issues with DBI: **performance**

- Start up overhead
- System call
- State maintenance

static binary rewriting can do much better in these situations!

Talk Outline

Background

System Overview and Highlights

Instrumentation Applications

Evaluation

Conclusion

Static Binary Disassembly (Background)

Binary disassembly is a critical issue for SBI. Previous work has shown various solutions

- **ILR [S&P ‘12]**: IDA-pro + objdump
- **Reins [ACSAC ‘12]**: IDApython
- **binCFI [USENIX ‘13]**: objdump+static analysis
- **CCFIR [S&P ‘13]**: IDA-pro + relocation

Issues in Current SBI System

Cannot guarantee all code transformation, ie. dynamically loaded libraries cannot be found at static rewriting time.

- dlopen? configuration/plugin
- environment variable? LD_LIBRARY_PATH=...

Fact of dynamic libraries: wireshark (45/144), gedit(17/74), acroread9 (21/82), gimp-2.6 (151/206)

No general purpose SBI system

- Control Flow Integrity (CFI)
- Software based Fault Isolation (SFI)

System Overview and Highlights

PSI is a general purpose binary rewriting platform that has the advantages:

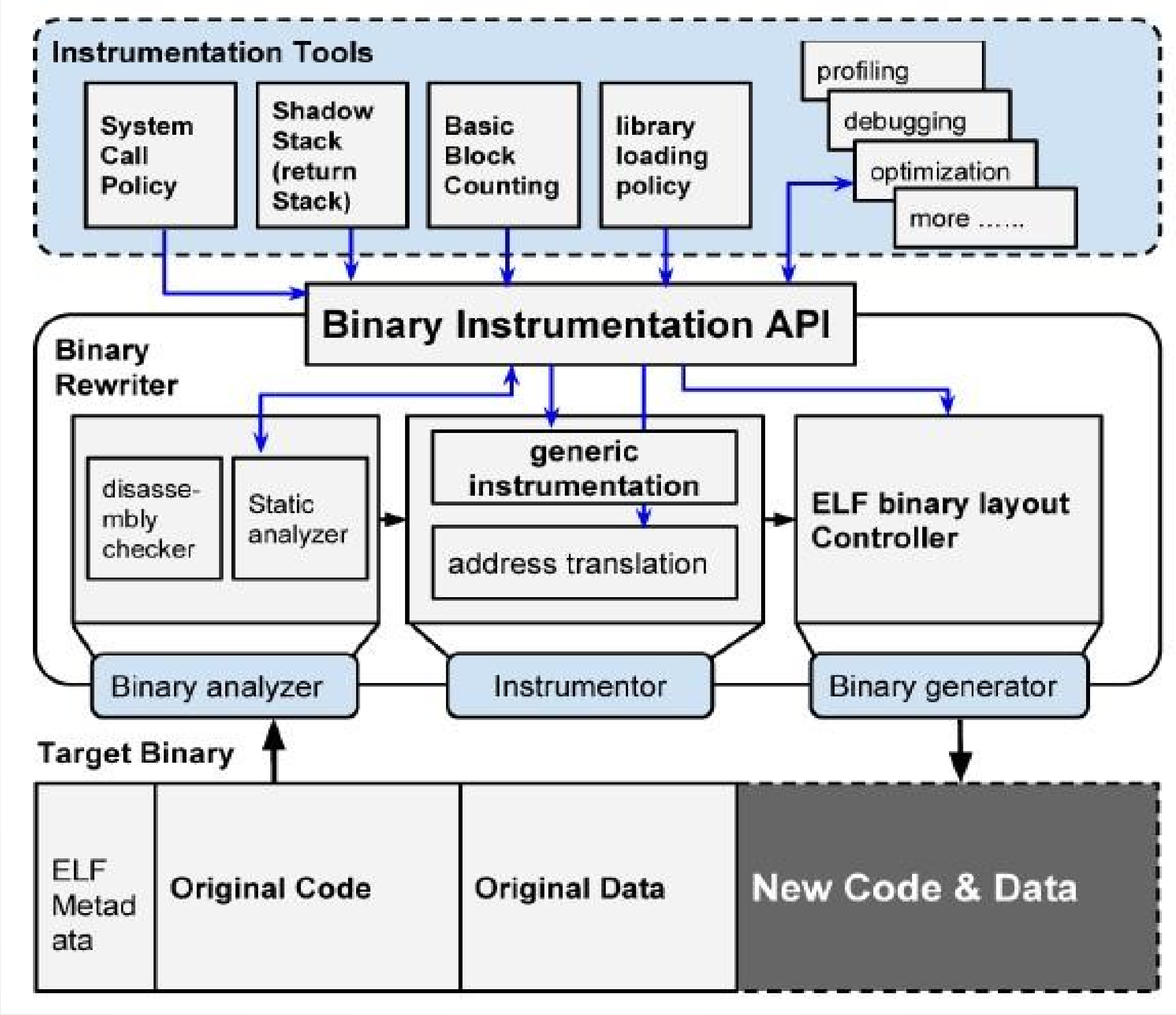
- **All program transformation**
  - transform exes, libs and loader
- **Secure instrumentation**
  - instrumentation code is non-bypassable
- **Versatile, easy-to-use API**
  - low level API + high level API
- **Good performance**
  - 7x ~ 13x lower overhead on many real world programs

All Program Transformation

PSI supports offline rewriting and on-the-fly rewriting

- Offline rewriting
  - psi_rewriter -t instrument.src /bin/ls -o ./ls_trans

Offline Rewriting



All Program Transformation

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Offline rewriting can transform known dependencies, but some dependencies might not be known until runtime.

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- Offline rewriting
  - psi_rewriter -t instrument.src /bin/ls -o ./ls_trans

Offline rewriting can transform known dependencies, but some dependencies might not be known until runtime.

- On-the-fly rewriting
  - psi_loader -t instrument.src -- /bin/ls

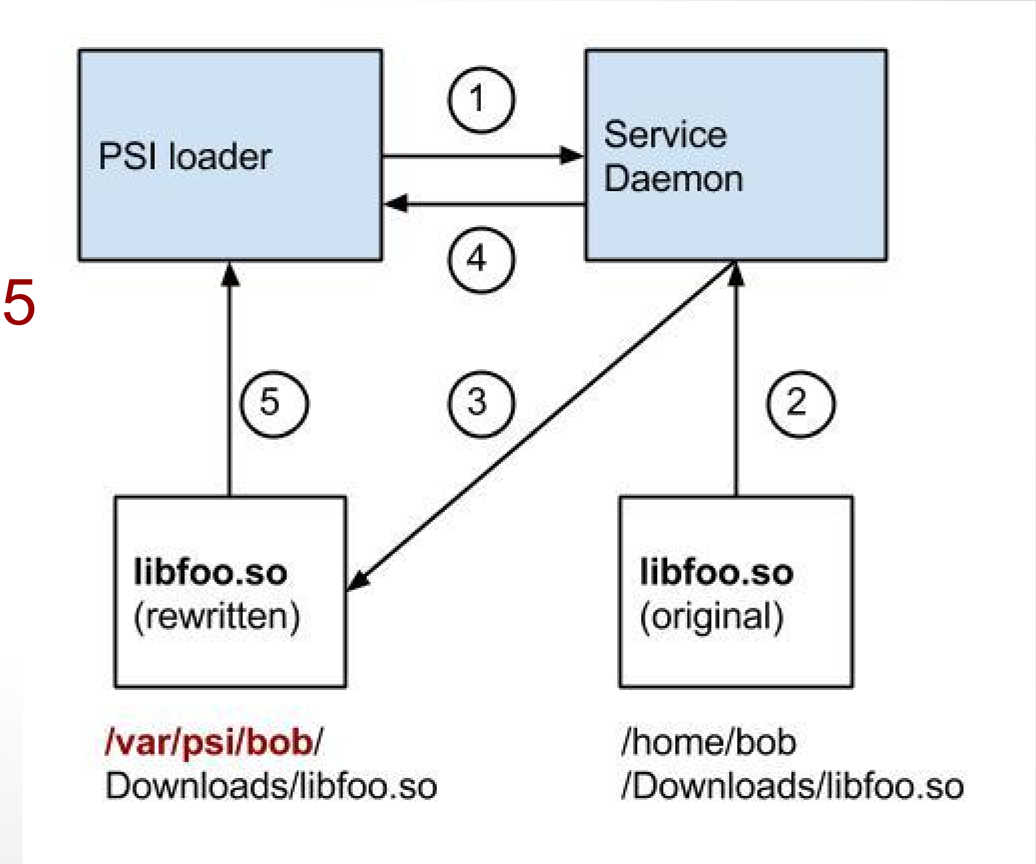
    (invokes psi_rewriter for each library)

On-the-fly rewriting transforms the binary and all dependent libraries at runtime

On-the-fly Binary Rewriting

Implementation mechanism:

- step1:
  send msg to daemon
- step 2:
  if lib is transformed goto 5
- step 3:
  perform rewriting
- step 4:
  ack msg to psi loader
- step 5:
  perform loading



Secure Instrumentation

Why? Security Instrumentation become useless if can be bypassed

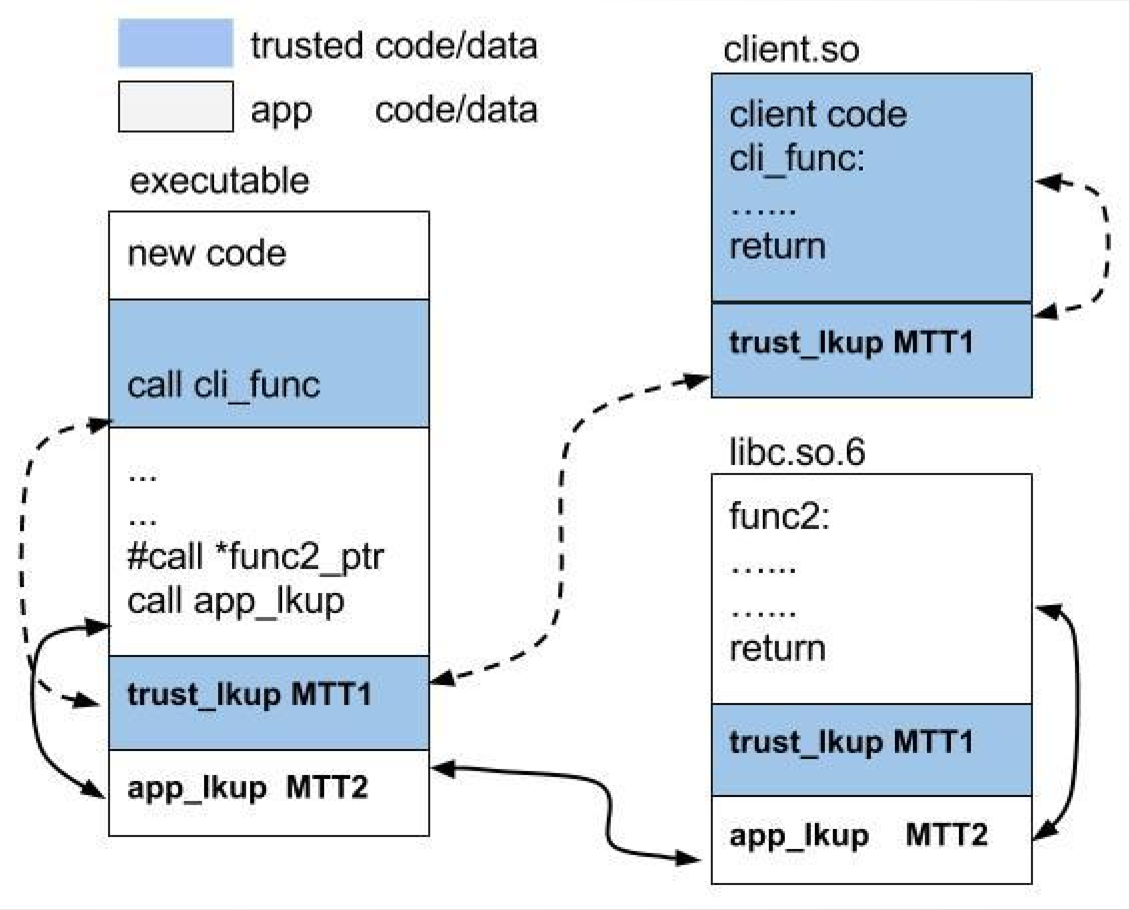
How? All indirect transfer => Table Lookup

```
/* original code */

jump *%ecx
```

```
/* translated code */

mov %eax, %gs:0x40
mov %ecx, %eax
jump table_lookup
```

Secure Instrumentation

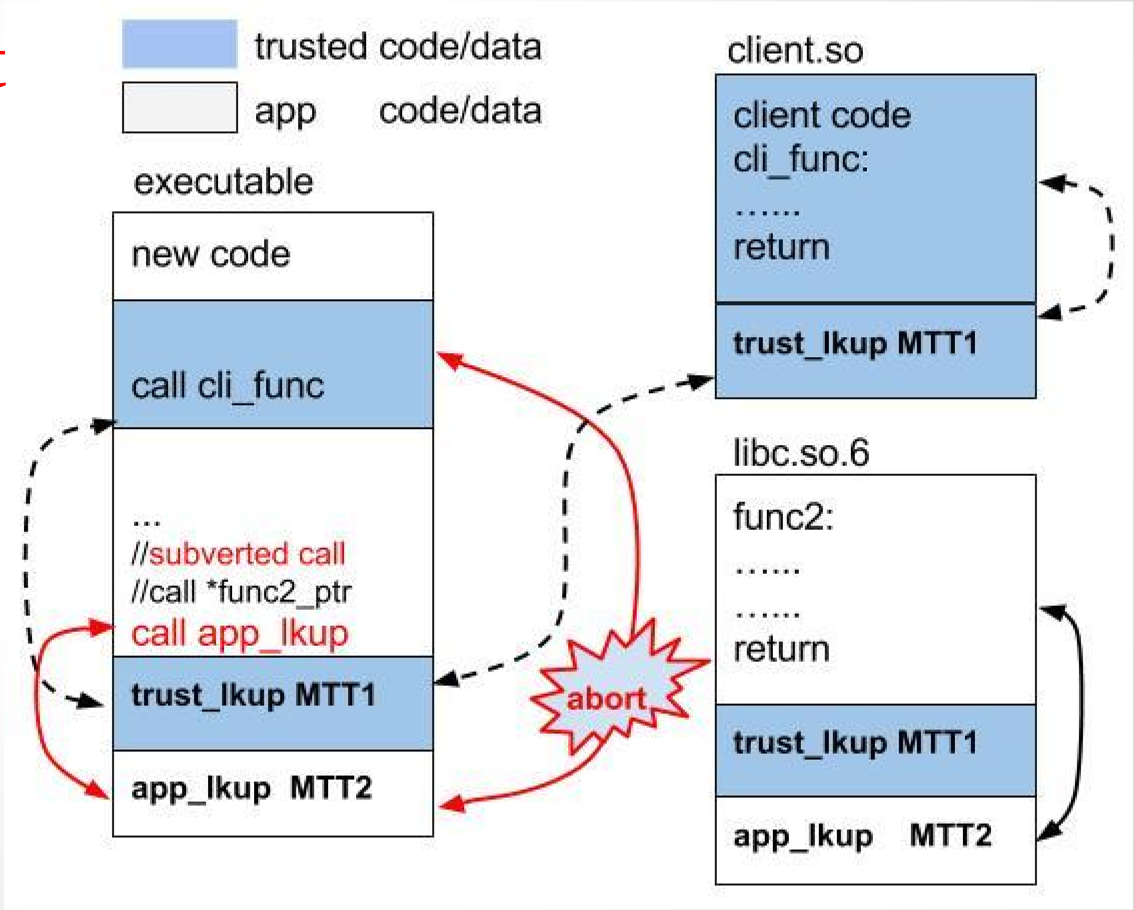
- *All indirect branch targets are checked by table lookup*
- *Control flows application code cannot interfere instrumentation*



Secure Instrumentation

Subverted indirect branch to inline instrumentation code is defeated

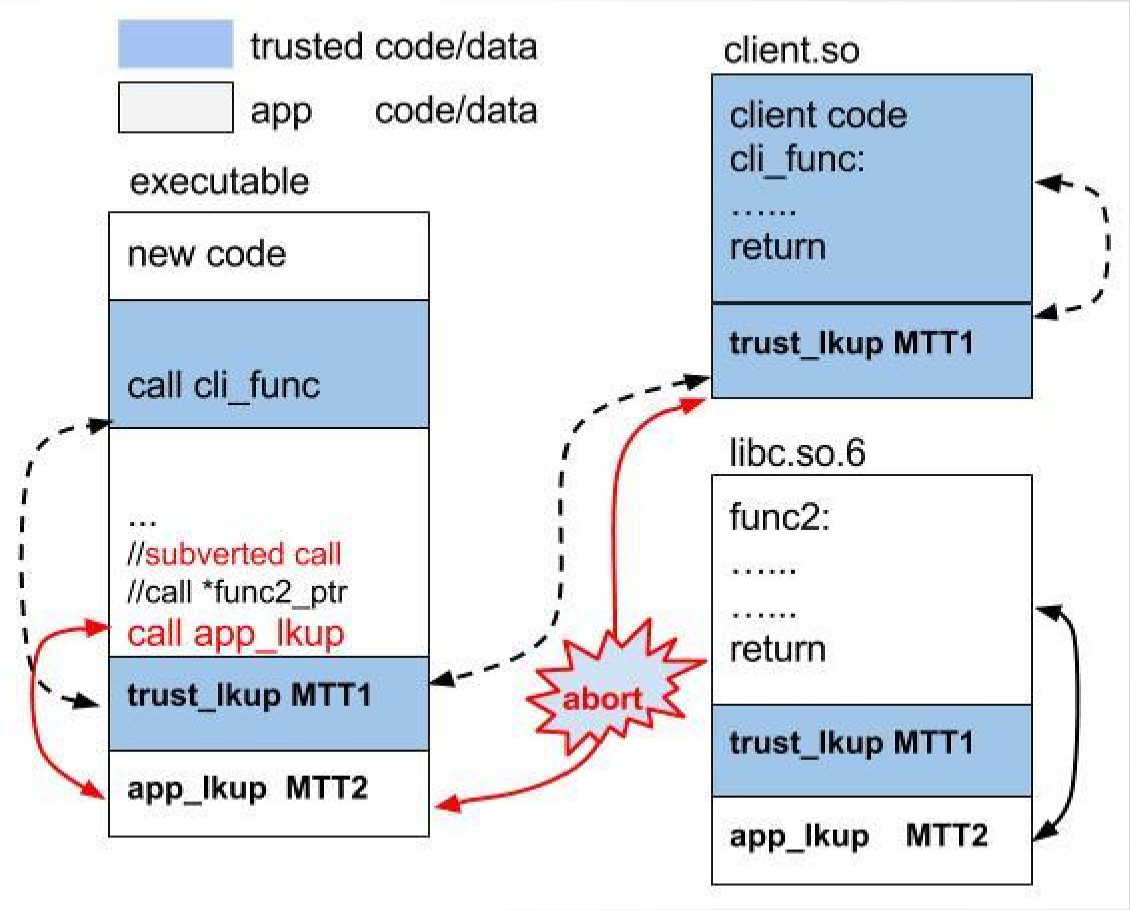
table lookup fail



Secure Instrumentation

Subverted indirect branch to instrumentation client is defeated

empty table in client.s



Instrumentation Applications

- **Basic block counting (in-line)**
- **Shadow stack (in-line + out-of-line)**
- System call policy enforcement
- Library load policy enforcement

Basic Block Counting

```
/********* Binary Rewriting code *********/

foreach bb in getBBs() {
        found = false
        foreach insn in bb {
            if isTest(insn) or isCmp(insn) {
                found = true
                ins_snippet(insn, BEFORE, opt)
                break
            }
        }
        if !found
            ins_snippet(bb, BEGIN, unopt)
}
```

Basic Block Counting

```
/*****Added Instrumentation (Inline)*****/



unopt = “mov %eax, TS_0;
          lahf;
          incl TS_1;
          sahf;
          mov TS_0, %eax”
opt = “incl TS_1”
```

Shadow Stack

A classic security defense against buffer overflow and return-oriented programming (ROP)

Main idea:

- maintain a 2nd stack containing return addresses
- All calls push return address both stacks
- All returns check the consistency of two stacks

Shadow Stack

Low level API
High level API

```
/*Instrumentation (Inline )**/

/* shadow stack pointer is
 * stored in TS_2 */
chk_init_shadowstk= "
            cmp $0x0, TS_2;
            jnz L001;
            call $alloc_stack;
      L001: ";


push_shadowstk = "
      mov %eax, TS_0;
      mov %ebx, TS_1;
      subl $4, TS_2;
      mov TS_2, %eax;
      mov (%esp), %ebx;
      mov %ebx, (%eax);
      mov TS_0, %eax;
      mov TS_1, %ebx;"
```

```
/***** Out-of-line Instrumentation code ********/

void check_return(Context *ctxt) {
      uint shadow_sp = ctxt−>TS[2];
      uint ret = getmem(ctxt−>ESP);
      while (!empty(shadow_sp)){
            if (pop(shadow_sp) == ret) {
                  ctxt−>TS[2] = shadow_sp;
                  return;
            }
      abort();
}

/********* Binary Rewriting code *************/

foreach insn in getInsns()
      if isCall(insn) {
            ins_snippet(insn, BEFORE, chk_init_shadowstk)
            ins_snippet(insn, BEFORE, push_shadowstk)
      }
      else if isRet(insn)
            ins_call(insn, AFTER_CALL, check_return)
```

Shadow Stack

Low level API

High level API

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/**In-line Instrumentation**/

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 * stored in TS_2 */
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Evaluation

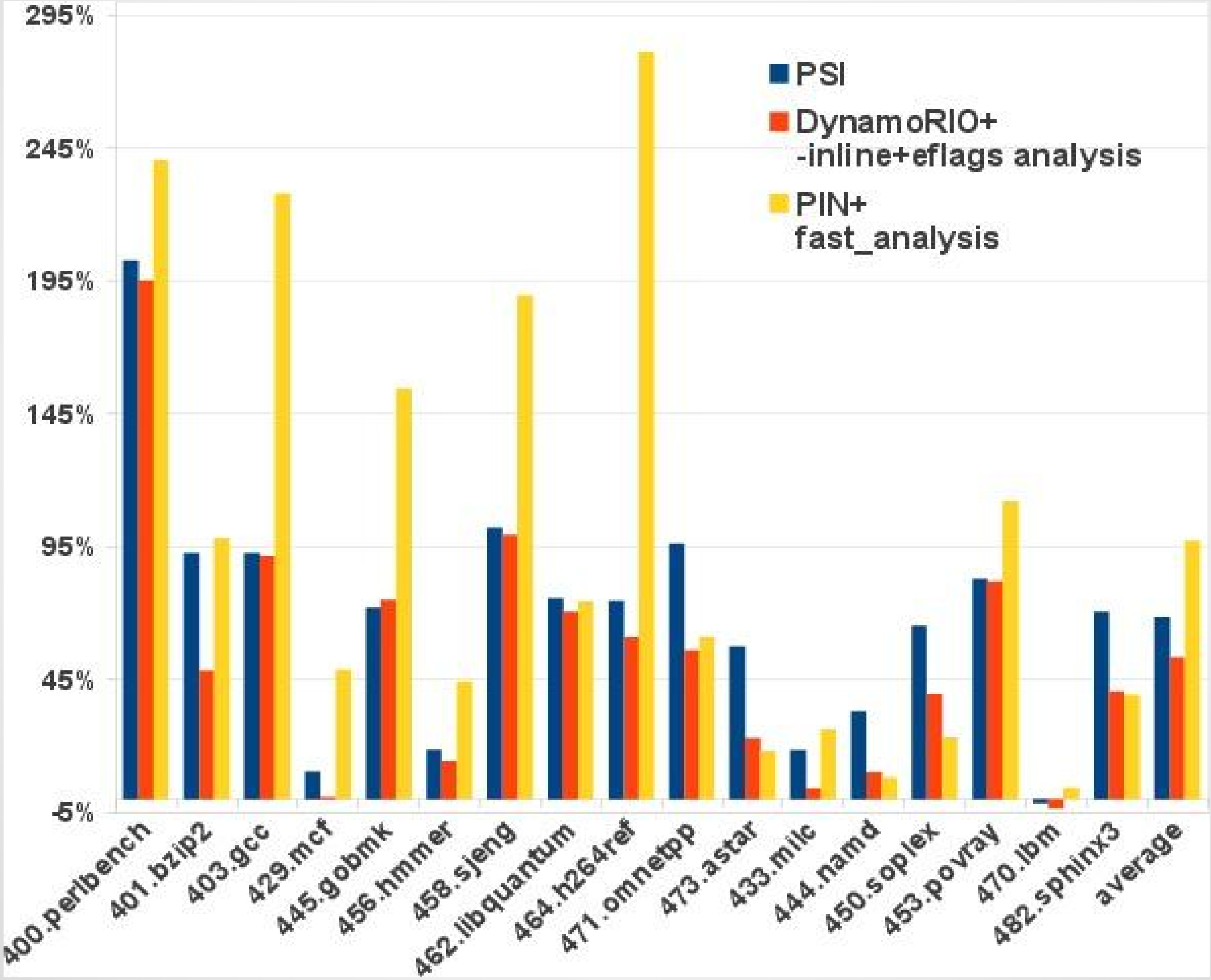
Basic block counting in SPEC2006

Shadow stack

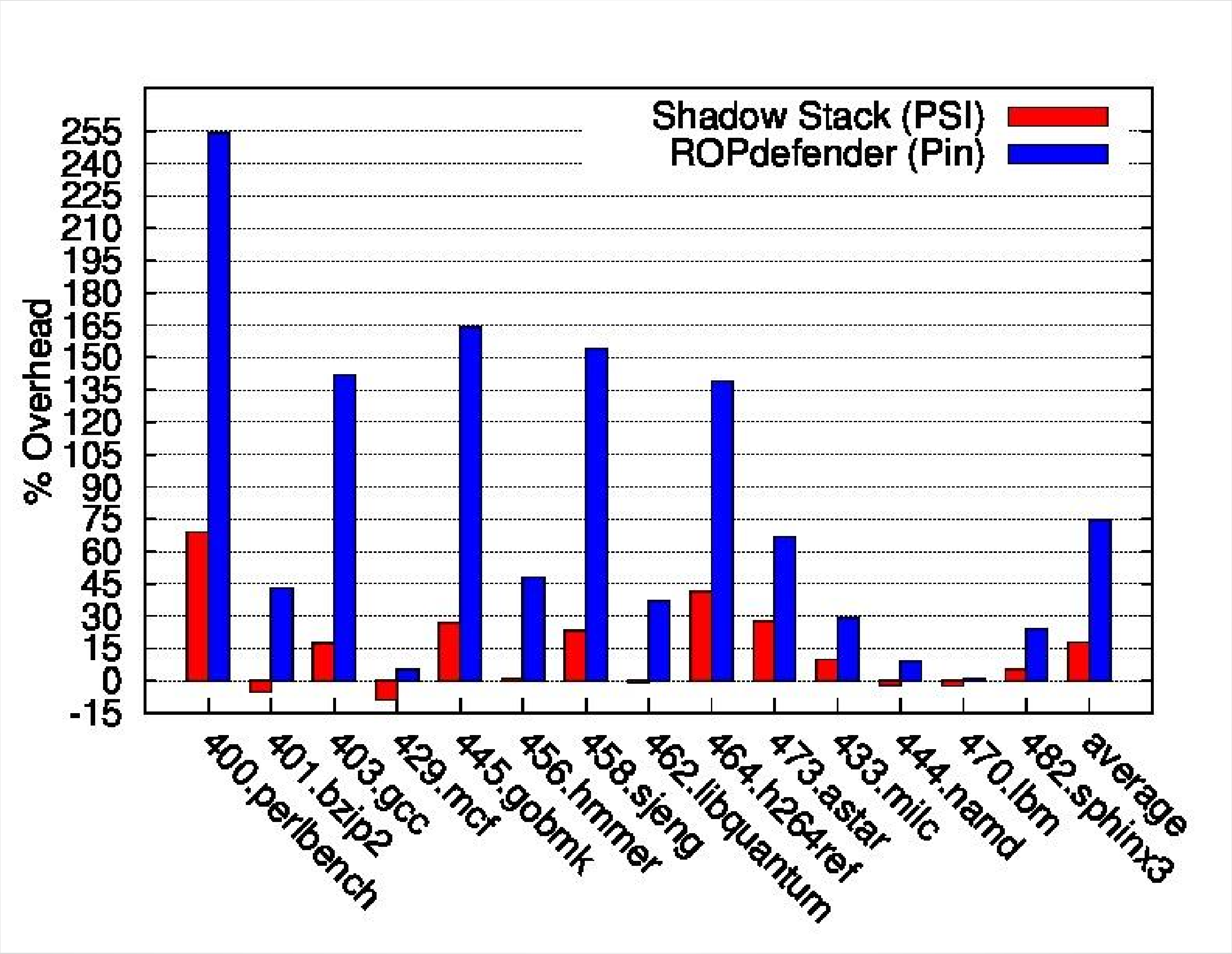
Micro benchmark

Real world applications

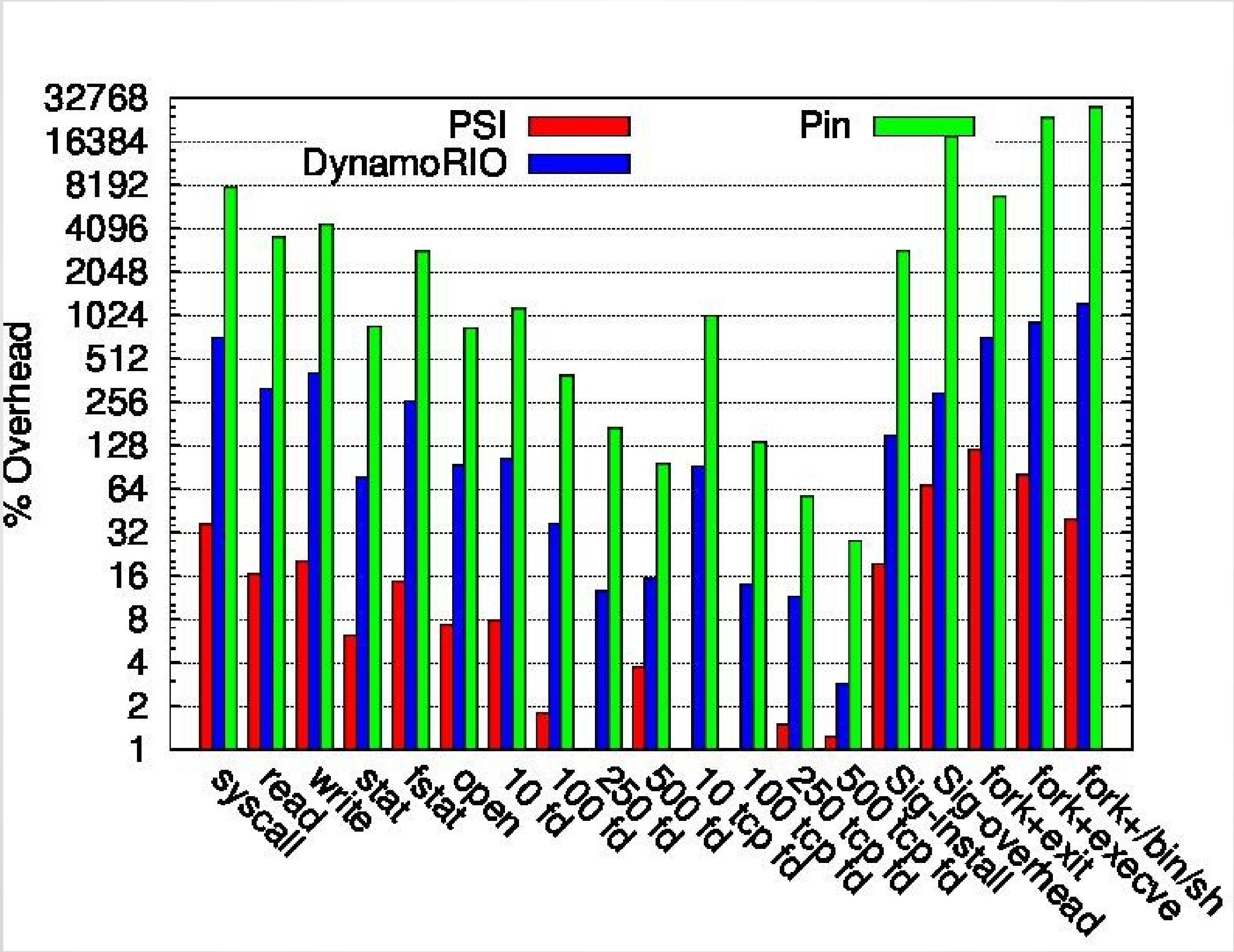
Basic Block Counting for SPEC2006



Shadow Stack



Micro Benchmark: lmbench



Real World Application Evaluation

Program	PSI	DynamoRIO	Pin	Benchmark
coreutils	**97%**	1922%	3509%	coreutils testsuite
gcc	**63%**	1376%	10250%	openssh compilation
apt-get update	**2%**	326%	411%	run cmd 5 times and get median.
latex	**51%**	185%	1806%	compile 17KB tex file into dvi
python	**33%**	85%	96%	pystone 1.1 bench
……	**...**	...	...	…..
average	**53%**	887%	3412%	

Related Work

- Static Binary Rewriting
  - Most previous works require compiler support, symbol, debugging, or relocation information: Native Client [S&P 2009], SFI [Security 2006], G-Free [ACSAC 2010], CFI [TISSEC 2009], XFI [OSDI 2006], CCFIR [S&P 2013] ...
  - Systems targeting COTS binaries
    - SecondWrite [EuroSys 2013] emphasizes binary analysis; no non-bypassable instrumentation support
    - Reins [ACSAC 2012]: Windows executables, not library support
- Dynamic Binary Instrumentation
  - Frameworks:

    Pin [PLDI 2005], DynamoRIO [PhD Thesis 2004]
  - Security Instrumentation:

    Program Sheperding [Security 2002], libdetox [VEE 2011]

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Questions?