Using DISE to Protect Return Addresses from Attack

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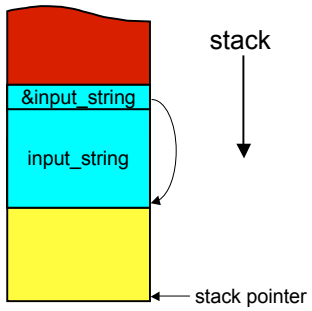
Overview

- Prevent stack-smashing attacks
- Old approach, new implementation
  - Dynamic Instruction Stream Editing (DISE)

Stack-Smashing Attacks




```
strcpy(A, input_string);
```


Stack-Smashing is a Problem

- Some famous stack-smashing attacks
  - Internet worm, 1987
  - NCSA HP-UX 1.3 web server breach, 1994
  - Slammer worm, 2003
  - Blaster worm, 2003

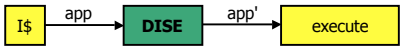
Solutions

- Prevent buffer-overflow in general
  - Safe languages (e.g. Java, ML)
  - Range checks (e.g., libSafe)
- Prevent return address corruption
  - Canary: padding word (e.g., StackGuard)
  - Virtual memory: write protect (e.g., StackGuard)
  - **Shadow stack**

Talk Outline

- Introduction
- DISE background
- DISE return address protection
- Evaluation
- Conclusion

DISE

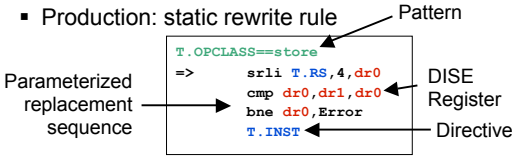


- Programmable instruction macro-expander
  - Like hardware SED (DISE = dynamic instruction SED)
  - Example: memory fault isolation (MFI)

```
store r4,8(r9)  →  srli r9,4,r1
                   cmp r1,r2,r1
                   bne r1,Error
                   store r4,8(r9)
```


DISE Productions

- Production: static rewrite rule



- Expansion: dynamic instantiation of production

```
store r4,8(r9)  →  srli r9,4,dr0
                   cmp dr0,dr1,dr0
                   bne dr0,Error
                   store r4,8(r9)
```

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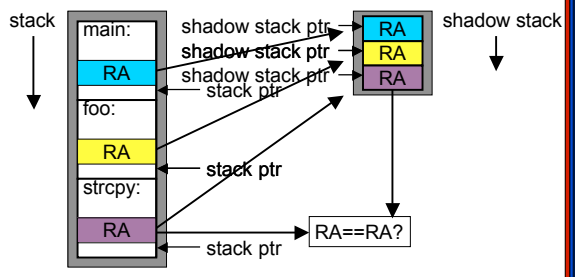
Shadow Stack Approach



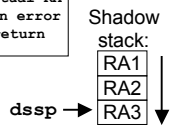
DISE Implementation

- At call instructions
  - Push return address on shadow stack
- At return instructions
  - Pop address from shadow stack
  - Verify shadow address equals return address

Protection Productions

```
T.OPCLASS==call
  =>  add T.PC,4,dr0        # compute RA
      add dssp,8,dssp       # push it on...
      store dr0,-8(dssp)    # ... shadow stack
      T.INST                # perform call
```

```
T.OPCLASS==return
  =>  load dr0,-8(dssp)     # pop RA from...
      add dssp,-8,dssp      # ... shadow stack
      cmpne T.RS,dr0,dr0    # cmp to actual RA
      ccall dr0,Error       # diff? then error
      T.INST                # perform return
```



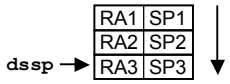
Implementation Issues

- Discussed in this talk
  - Handling non-local returns
  - Protecting shadow stack itself
- Discussed in the paper
  - Expanding DISE memory
  - Protecting DISE productions

Non-Local Returns

- Problem: Exceptions, setjmp/longjmp
  - Cut the stack
- Previous solution: pop shadow stack until match
  - Attacker can simulate longjmp
- Ours: store stack pointer (SP) on shadow stack
  - \+ SP is unique in caller stack, not-smashable
  - Pop shadow stack until RA & SP match

New shadow stack:



New Productions

```
T.OPCLASS==call
  =>  add T.PC,4,dr0          # compute RA
      add dssp,16,dssp        # push it on…
      store dr0,-8(dssp)      # … shadow stack
      store sp,-16(dssp)      # … along w/ stack ptr
      cmp dssp,darp,dr0       # stack full?
      ccall dr0,expand        # yes, expand stack
      T.INST                  # perform call
```

```
T.OPCLASS==return
  =>  load dr0,-8(dssp)       # pop RA from…
      add dssp,-16,dssp       # … shadow stack
      cmpne T.RS,dr0,dr0      # cmp to actual RA
      ccall dr0,AddrChk       # diff? figure out why
      T.INST                  # perform return
```


Protecting the Shadow Stack

- What if attack corrupts shadow stack?
- One approach: encrypt shadow stack (XOR)

```
T.OPCLASS==call
  =>  add T.PC,4,dr0          # compute RA
      xor dr0,dxr,dr0         # encrypt address
      add dssp,16,dssp        # push it on…
      store dr0,-8(dssp)      # … shadow stack
      store sp,-16(dssp)      # … along w/ stack ptr
      T.INST                  # perform call
```

```
T.OPCLASS==return
 =>   load dr0,-8(dssp)       # pop RA from…
      add dssp,-16,dssp       # … shadow stack
      xor dr0,dxr,dr0         # decrypt address
      cmpne T.RS,dr0,dr0      # comp. to actual RA
      ccall dr0,AddrChk       # diff? See what's up
      T.INST                  # perform return
```

Another Approach

- Prevent writes to shadow stack (e.g. MFI)
- Call/return productions don't change
- New productions for stores

```
T.OPCLASS==store
=> srli T.RS,4,dr0
   cmp dr0,dr1,dr0
   beq dr0,Error
   T.INST
```


Virtues of Using DISE

- Versus dedicated hardware
  - + General-purpose: compression, debug., mfi, etc.
  - + Flexible: new attack, new productions
- Versus binary rewriter
  - + Transparent: protect all code inc. DLLs
  - + Declarative interface: security by simplicity
  - + Efficient: in a moment…

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Evaluation

- Correctness
  - False negatives?
  - False positives?
- Performance
  - What's the overhead?
  - How does it compare to alternatives?

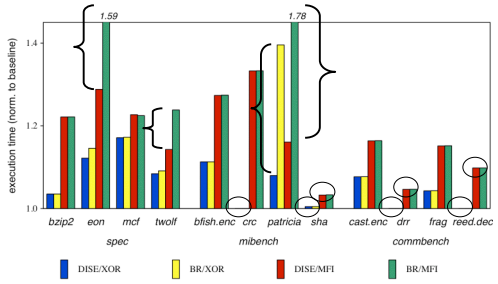
Correctness

- Attacking inputs detected
  - overflow1 (micro-benchmark)
  - sendmail-8.7.5
  - gzip-1.2.4
- No false positives with non-attacking inputs

Performance Methodology

- SimpleScalar Alpha
- Benchmarks
  - SPEC Int 2000, MiBench, CommBench
- Binary rewriter (for comparison)
  - Statically insert DISE instrumentation code
  - ± No optimization, but not a lot of opportunity either

Performance Overhead



- DISE overhead reasonable
  - XOR less than 10%, MFI less than 35%
- DISE outperforms BR
  - BR has additional I$ misses

Conclusion

- DISE return address protection effective
  - + No false negatives, no false positives
- Advantages over binary rewriter
  - + Efficient, transparent, declarative interface
- Advantages over custom hardware
  - + General-purpose, flexible
- Future work
  - Other security-related applications using DISE