# SAFER: Efficient and Error-Tolerant Binary Instrumentation†

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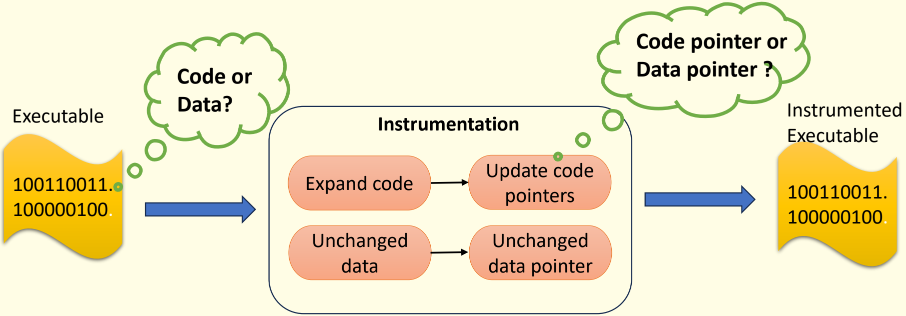
# Why binary instrumentation?

- *Binary instrumentation* $\rightarrow$ Modify program without source code.
- Enables unique capabilities:
    - *Security* without source code:
        - Harden deployed software (almost always binary code)
        - Detect vulnerabilities (fuzzing)
        - Analyze malware
    - *Program profiling:* Identify performance bottlenecks.
    - *Debugging:* Bugs that manifest only at runtime (e.g., *Valgrind*)

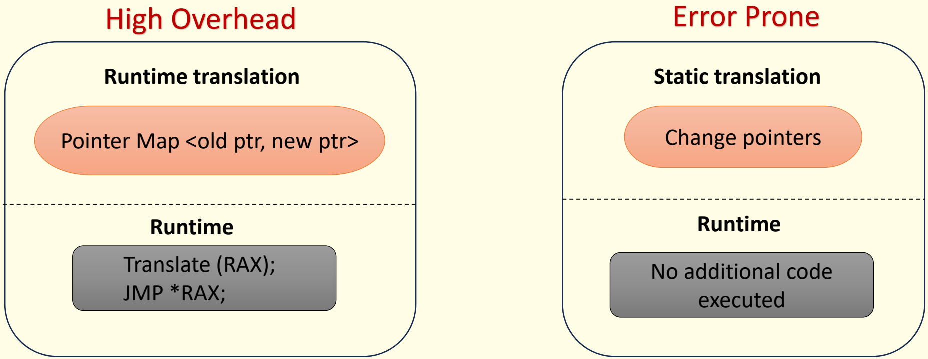
# Key challenges

- *Robustness*: Handling complex binaries



# Key challenges

- *Performance*



# Can we combine above two?

*Yes!*

SAFER: Static pointer encoding + runtime translation $\approx 2\%$ overhead

# SAFER's pointer translation

- **Pre-translate** high confidence code pointers
- **Runtime AT** for others.
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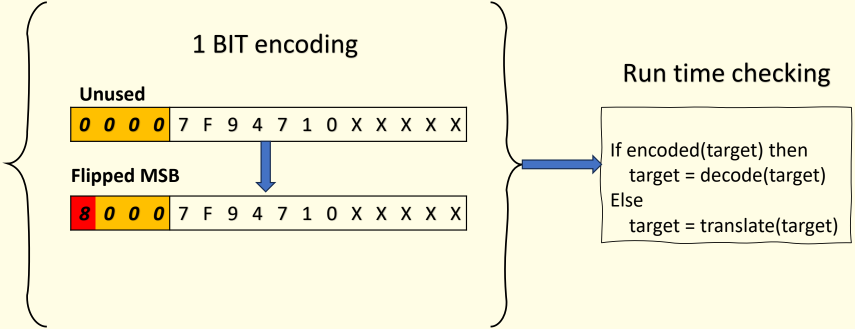

# Error handling

- *Data pointer misclassified as code pointer?*
  - Flipped MSB $\implies$ *crash* on read

# Error handling

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- New multiplicative encoding:
  - A, B: 64 bit odd numbers
  - A x B = 1

Encode

$P_{enc} = P \times A \xrightarrow{\text{Direct use}} P_{enc} \times B = P$ ✓

Decode

$\Downarrow$ Arithmetic

$P_{enc} + X \Longrightarrow (P_{enc} + X) \times B = \text{invalid}$

Crash

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Jump_table:

| | | | |
|---|---|---|---|
| **100** | **200** | **500** | **300** |

```
target = Jump_table[idx];
Jmp *target;
```

- *Identify:* static analysis (Dyninst, Egalito, Ddisasm, etc).

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*Our Contribution:* Safe jump table translation

- As opposed to best effort

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  - Change jump table access.

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  - **Runtime translation** $\Longrightarrow$ high overhead
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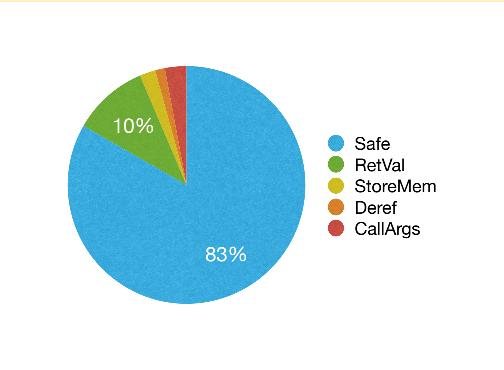
  - Change jump table access.
  - *challenge:* Other use of jump table.
  - **Example:** Jump table address used for accessing other data

# Safe jump table analysis

- Taint analysis to detect other use:
  - Memory dereferencing
  - Move to heap
  - call argument
  - return value
- 83% jump tables *SAFE* → avoid runtime translation



# Evaluation overview

- Experimental evaluation
  - *fail-crash:* Can SAFER detect errors at runtime?
  - *Performance:* What is the performance cost of SAFER's pointer translation approach?
  - *Functionality:* Can SAFER instrument real world applications?

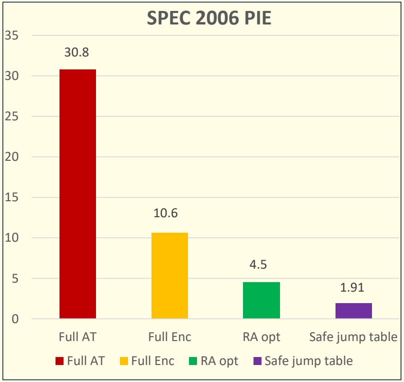
# Fail crash evaluation: Coreutils with embedded data

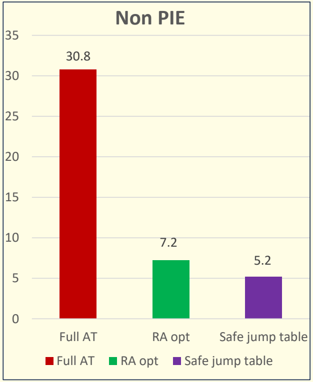
- Linux coreutils: ls, cat, cp, etc.

| Code pointer validation method | Success rate | Safe failure |
|---|---|---|
| None (always use AT) | 105/105 | NA |
| + Instruction boundary | 43/105 | 62/105 |
| + ABI validation | 74/105 | 31/105 |
| + Function prologue matching | 105/105 | NA |

# SAFER optimizations

- **Full AT**: Fully compatible.
  - No pointers changed (including **return addresses)**
- **Full enc**: All pointers encoded.
- **RA opt**: Use current **return addresses**.
  - C++ exception incompatible
  - **Update exception metadata**
- **Safe jump table**: Recreate jump tables



# Functionality evaluation

- 16 real world applications with 500+ shared libraries *(Size: 473MB)*.
  - gimp, evince, gedit, ffmpeg, clang, Python, etc
- 6 applications use libraries with *embedded data*.
  - libgcrypt, libgnutls, libavcodec, libcrypto

# Summary

- SAFER effectively combines **pointer encoding** with **runtime address translation** to get low overhead of $\approx 2\%$.
- SAFER's novel *pointer encoding* facilitiates runtime error detection (*fail-crash*).
- SAFER's *safe jump table* analysis helps improve performance without compromising correctness and safety.

*Artifact URL:* http://seclab.cs.sunysb.edu/soumyakant/safer

# THANK YOU!!!

# Error handling

- *What if we have error?*

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- *What if we have error?*
- Encoding $\Longrightarrow$ *crash* when used.
- *fail-crash* over unexpected behavior
  - Prevent data loss or security failure
  - Identify error prone module
  - *FIX:* full address translation on the module

# Why multiplicative encoding?

- Why not a 15 bit *checksum* in leading 16 bits?
  - Time-consuming to compute
  - Requires many unused bits
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  - Time-consuming to compute
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  - Non-negligible rate of undetected failures
- Benefits of our approach
  - Faster: Just one instruction: `MULX`
    - Does not affect CPU flags
  - Negligible rate of undetected arithmetic

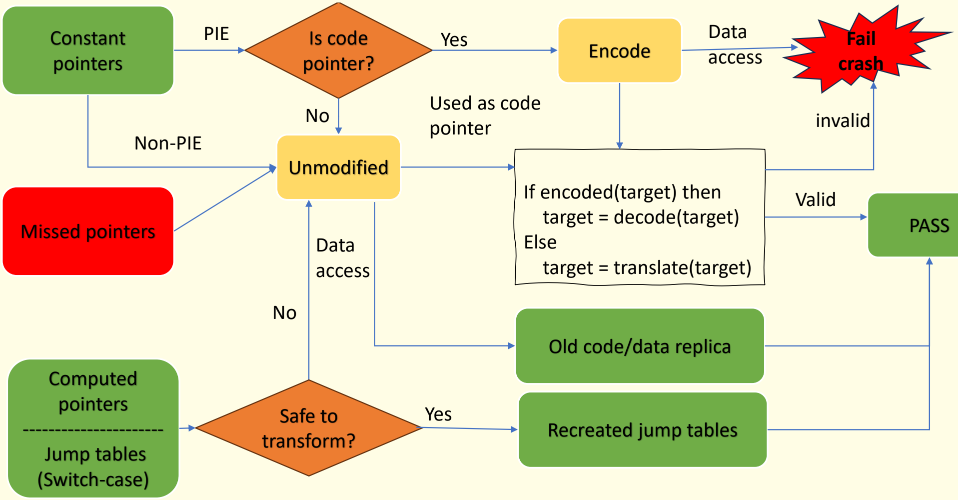
# Safe jump table analysis improvement

- No analysis...all jump tables marked safe: 1.2% overhead.
- Without function signature analysis: 55% safe (reported in paper)
  - Approx. 2% overhead
- Function signature analysis:
  - Helps improve call argument identification accuracy
  - More jump tables marked as safe: 83%
  - Approx. 1.5% performance overhead

# Pointer classification

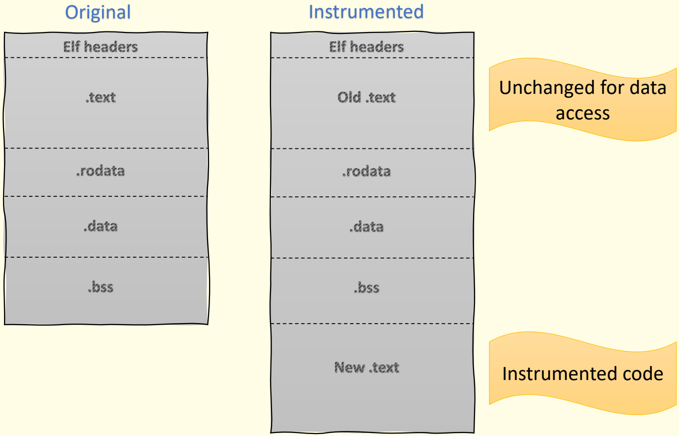
- SAFER's default: ABI validation (2% overhead)
- Function prologue matching: $\approx$5% overhead.

# Instrumentation overview



# Tolerating disassembly false positives

- *Data misinterpreted as code*
  - Replication based instrumentation (PSI, BinStir, etc)



# Identifying constant pointers

- Address taken functions
    - *PIE:* Relocation.
    - *Non-PIE:* Scan code/data sections for 4/8 byte constants

# Address translation

- Two level hashing scheme:
  - Global hash (GTT): <4K aligned Page, LTT>
    - Runtime construction
  - Local hash (LTT): Per-module translation <Old Pointer, New Pointer>
- *Customized loader* for above.

# Exceptional cases!!

- *Return addresses used as indirect jump target*
  - Longjmp, C++ exception handling
  - *Handling:* Return addresses added to translation table
- *Supporting stack unwinding*
  - *Special metadata:* Return address dependent
  - push old RA on stack $\Longrightarrow$ performance heavy
  - *Our approach:* Sync metadata with new RA

# Effect of compiler optimizations

- Average across all 6 optimizations: 2.3%