Code-Pointer Integrity

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R. Sekar, Dawn Song

Outline

- Problem Statement
- Existing solutions and their weaknesses
- Code-Pointer Integrity
- Implementation-dependant weakness (Related Paper)
- Discussion

Problem Statement

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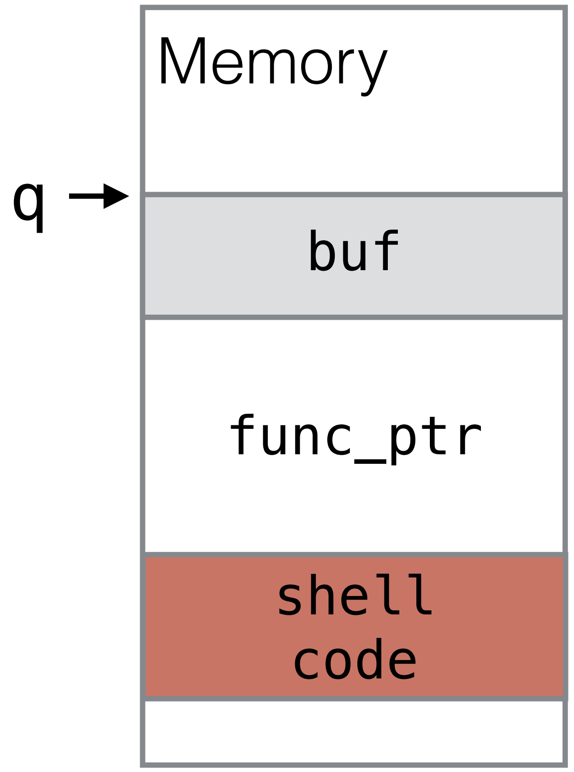

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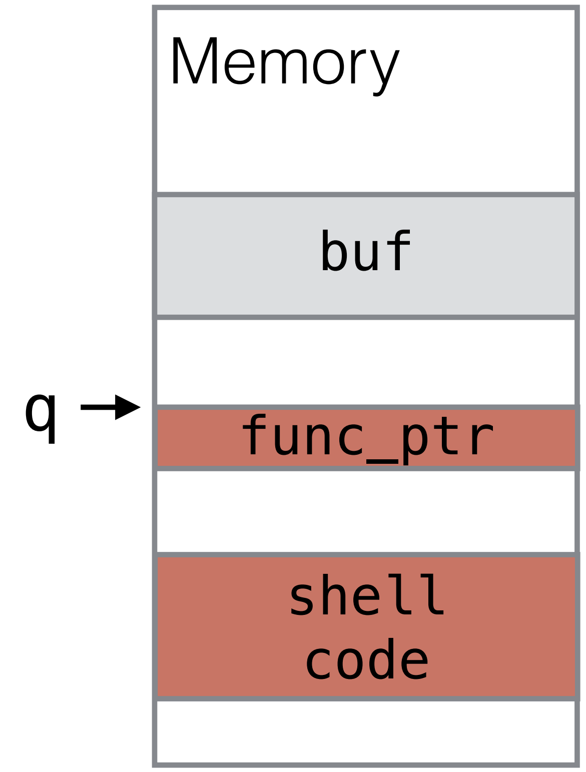

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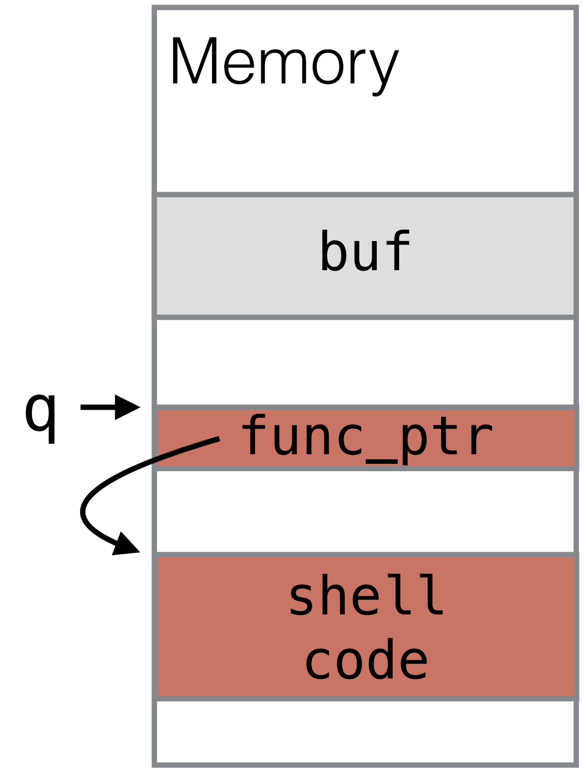

Existing Solutions

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- Adress Space Layout Randomisation (ASLR)

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  - Places code and data segments at random addresses
  - Complicates code-reuse (ROP)
  - Defeated by pointer leaks and side channel attacks

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  - Protect return addresses on the stack
  - Only protect against continuous buffer overflows

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- Finest-grained CFI has 10-21% performance overhead

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- Requires rewriting code in memory-safe languages or retrofitting memory safety onto existing code
- Requires runtime checks to verify correctness of pointer computations
  - ➡ Introduces significant performance overhead (≥2x when retrofitted)

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  - Significantly less performance overhead than state-of-the-art
- Idea:
  - Use memory-safety but only protect code-pointers

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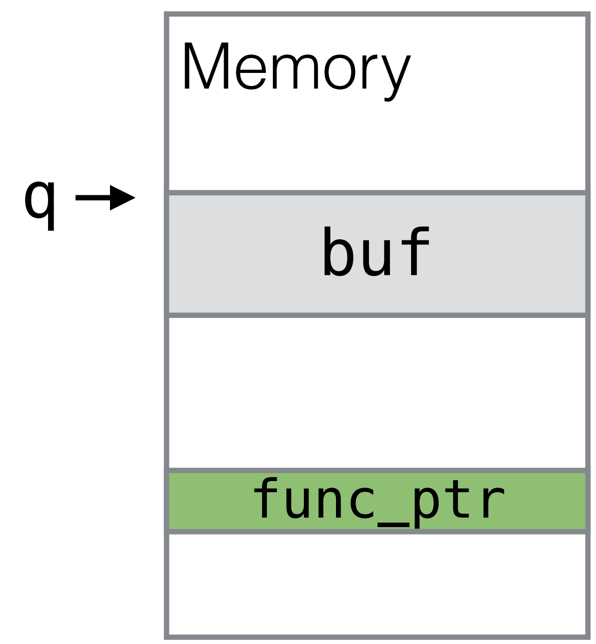

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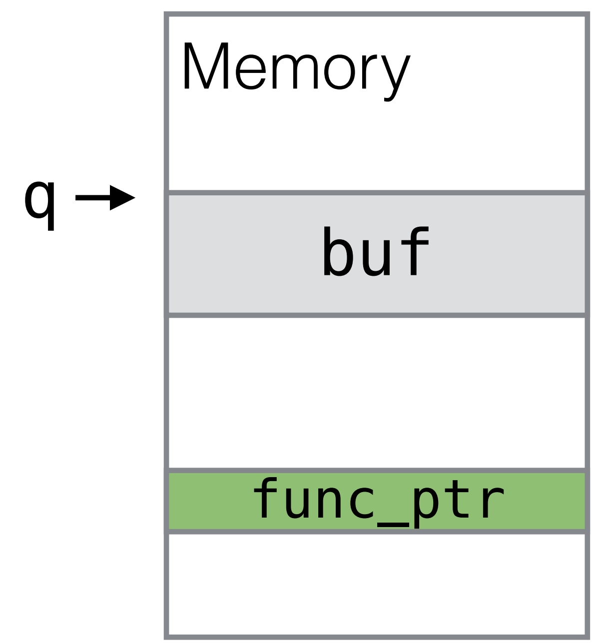

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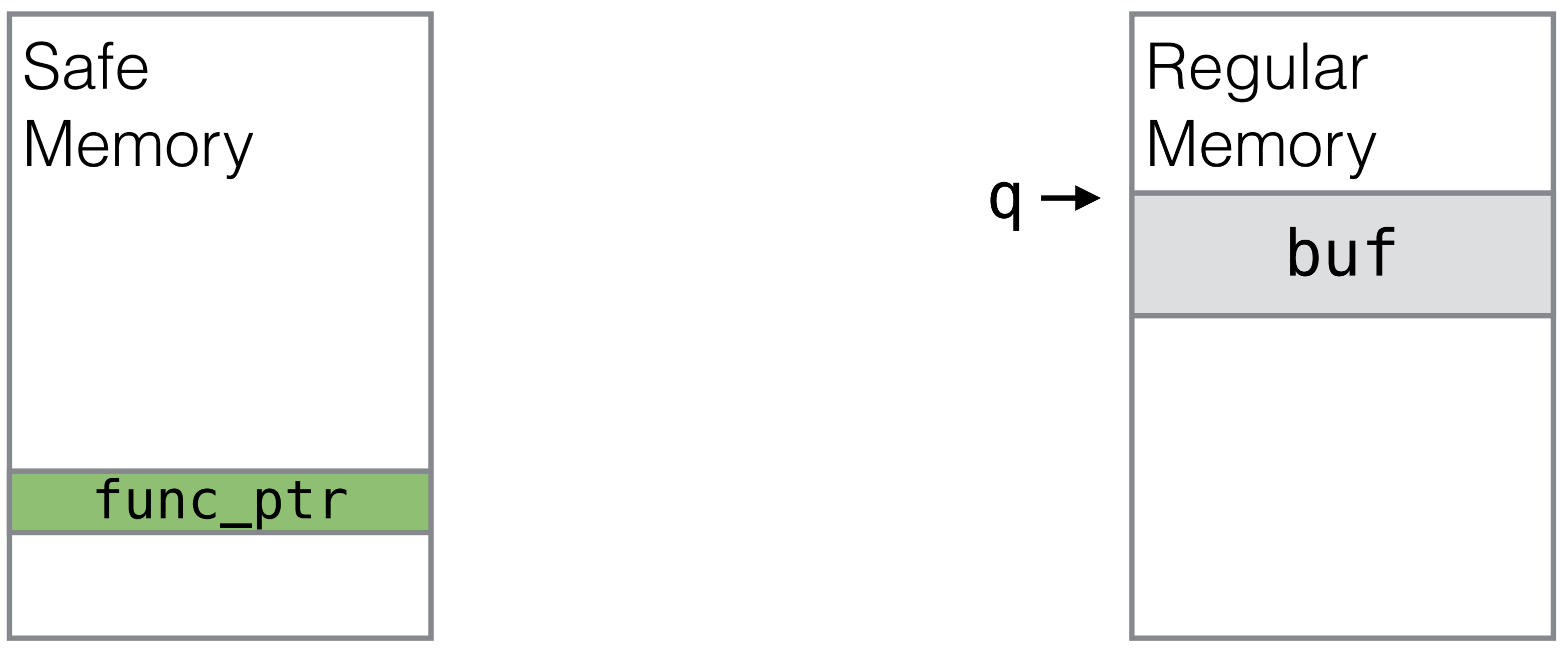
- Move only code pointers to safe memory
  - ➡ Isolate safe memory on instruction level



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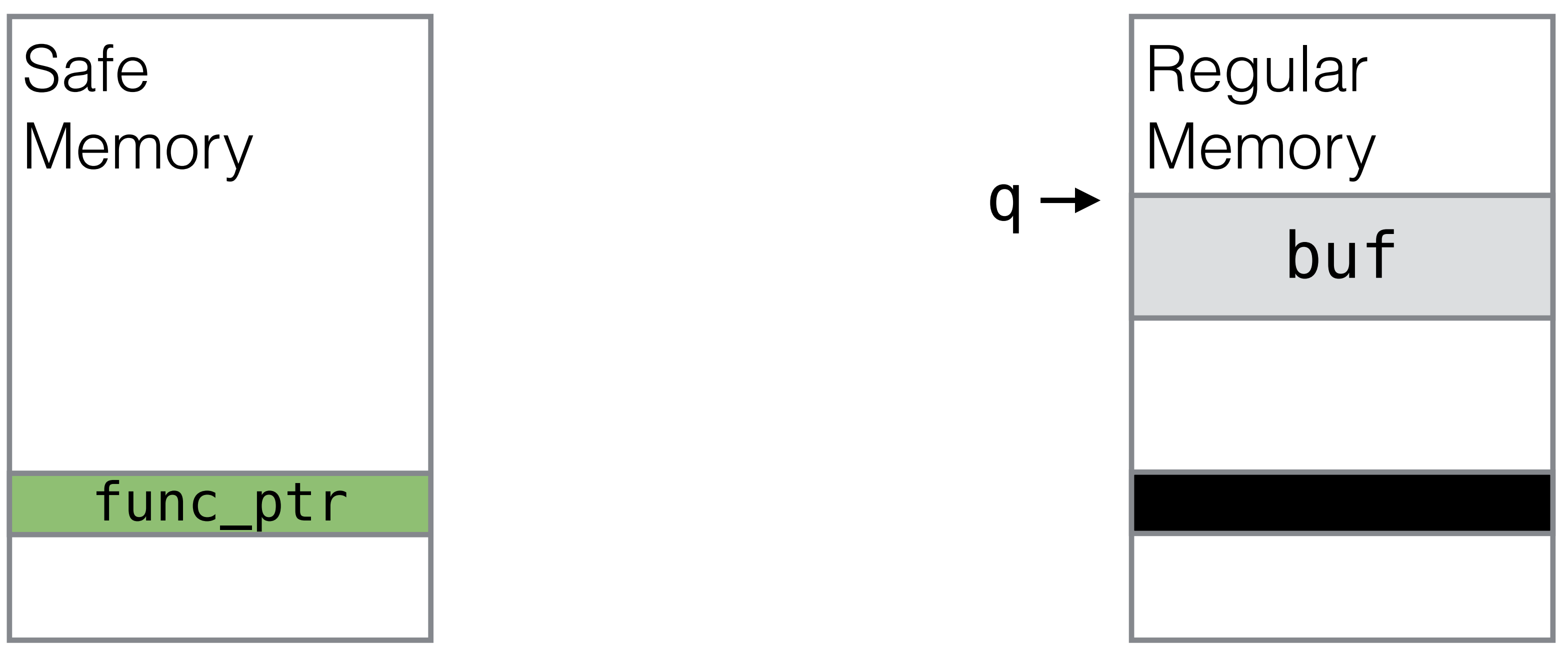

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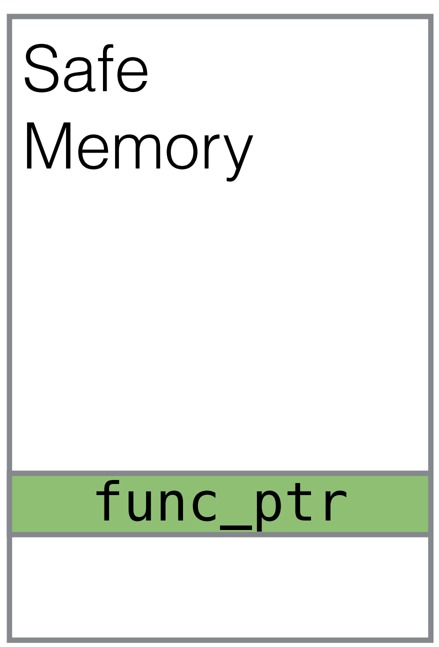

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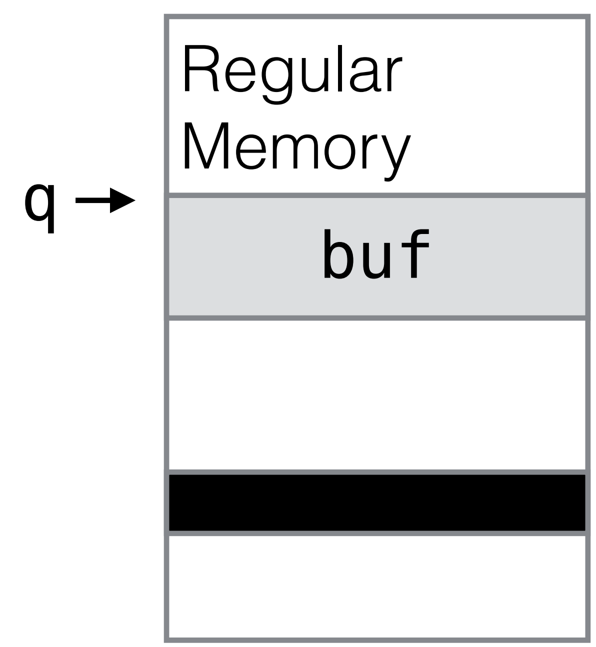
memory accesses



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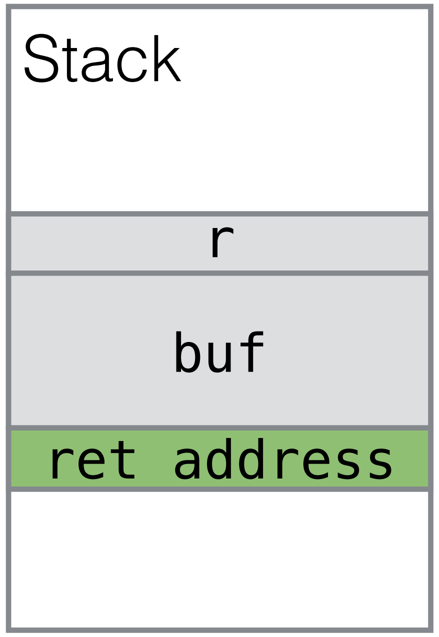

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- Split into regular and safe stack
- Statical check during compile which objects are safe
- Only keep unsafe objects on the regular stack (e.g. arrays)

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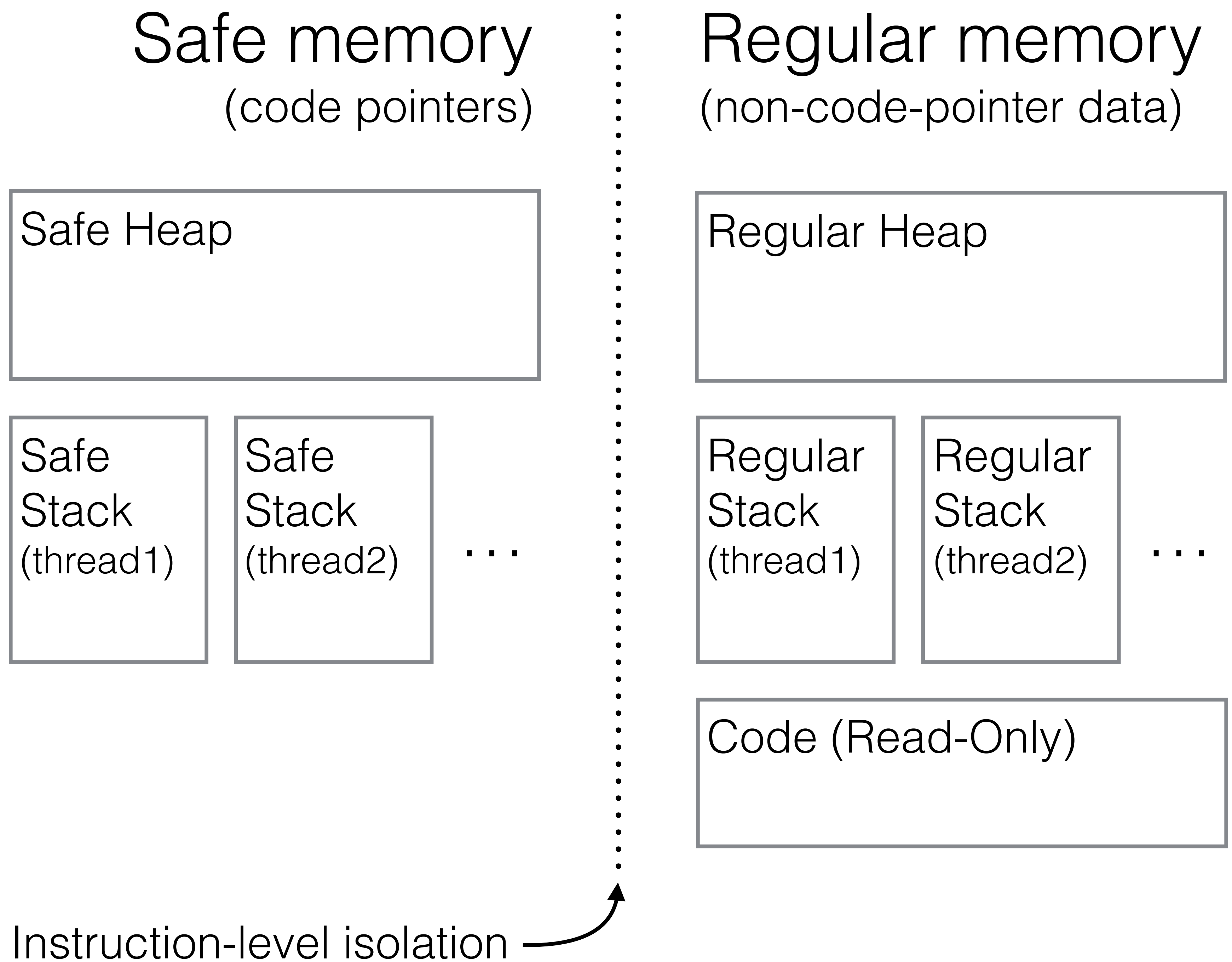

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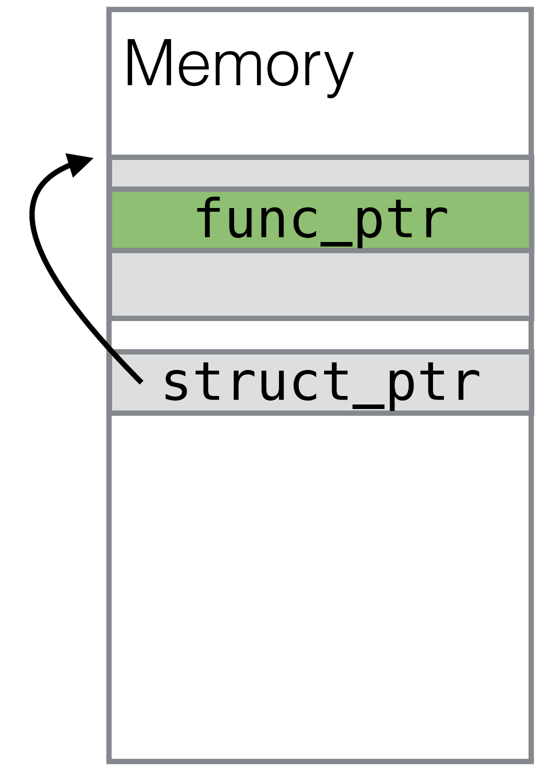

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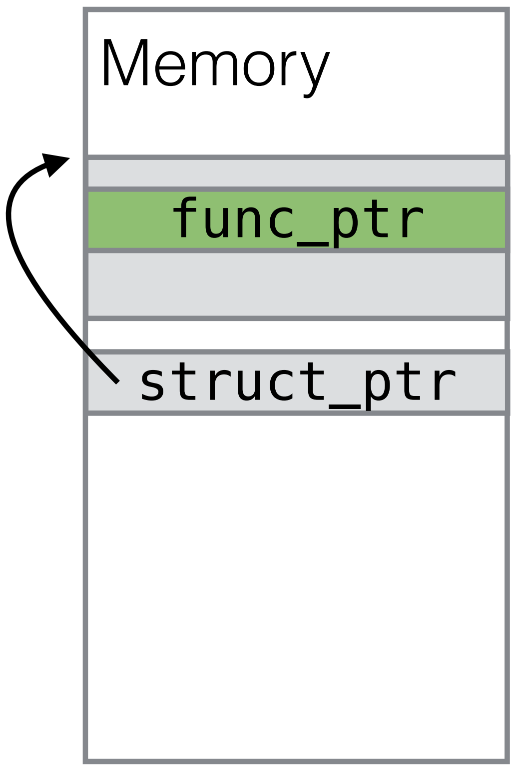

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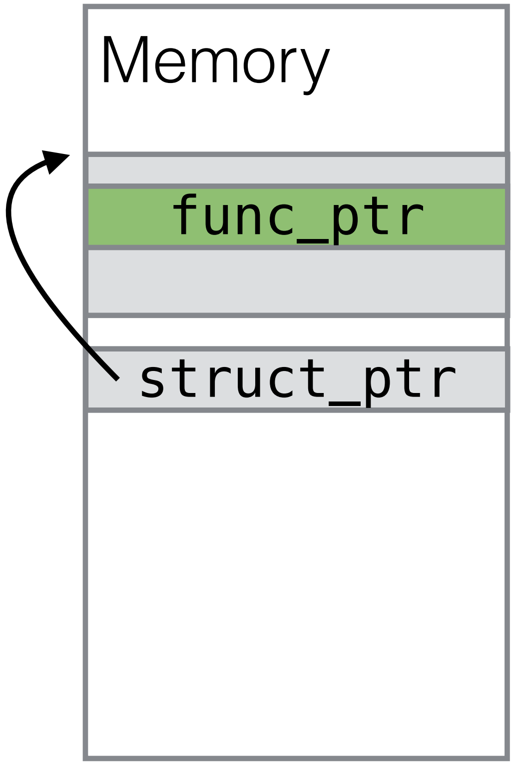

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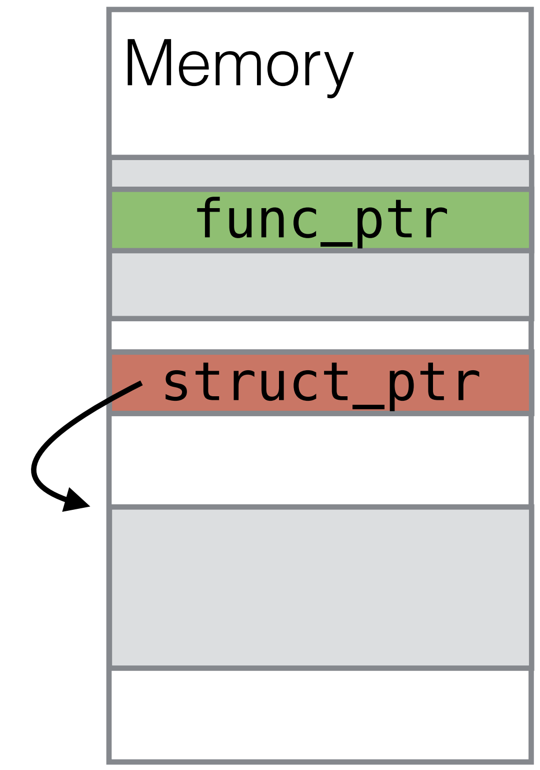

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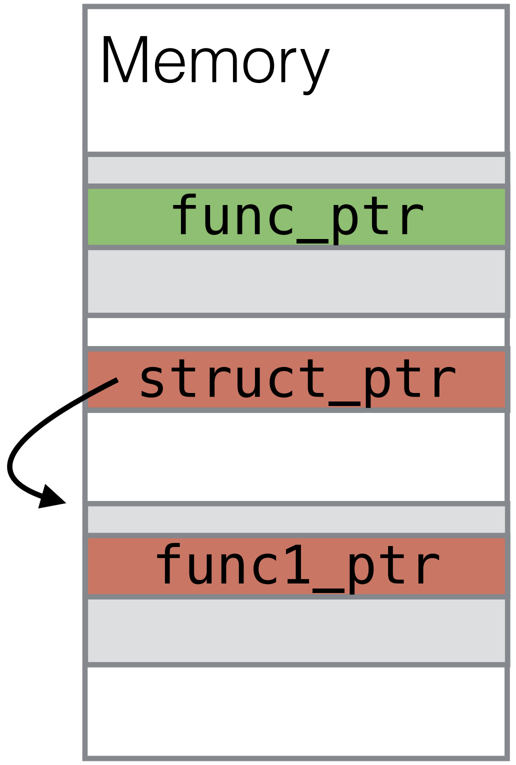

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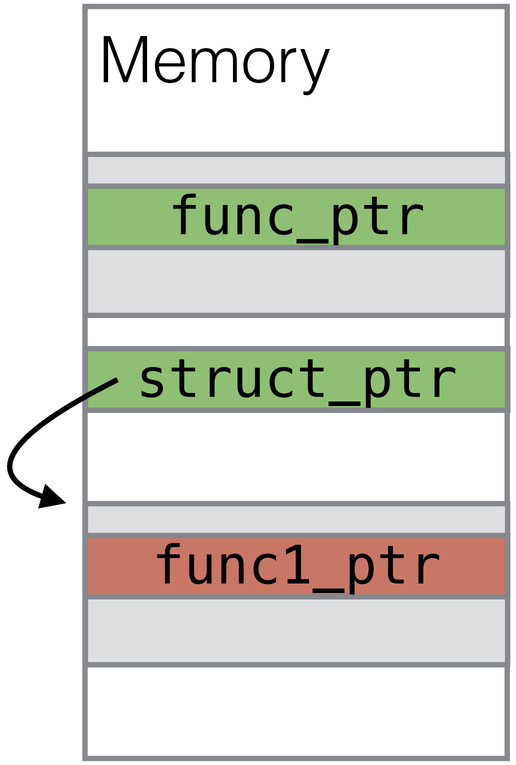

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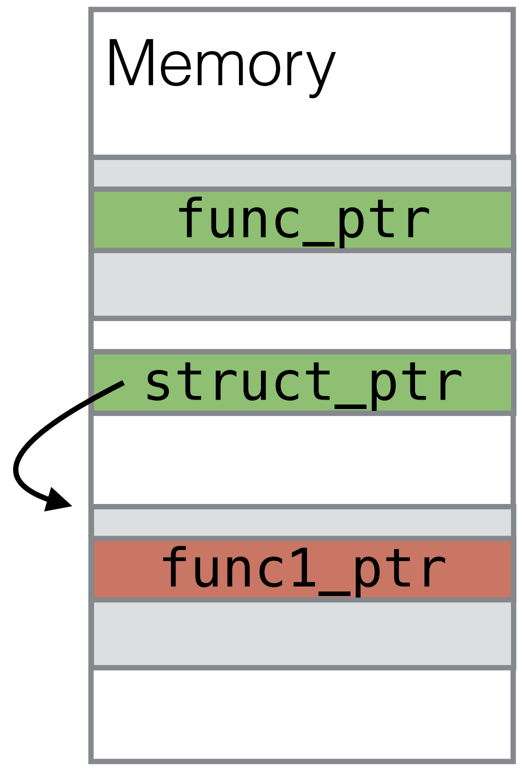

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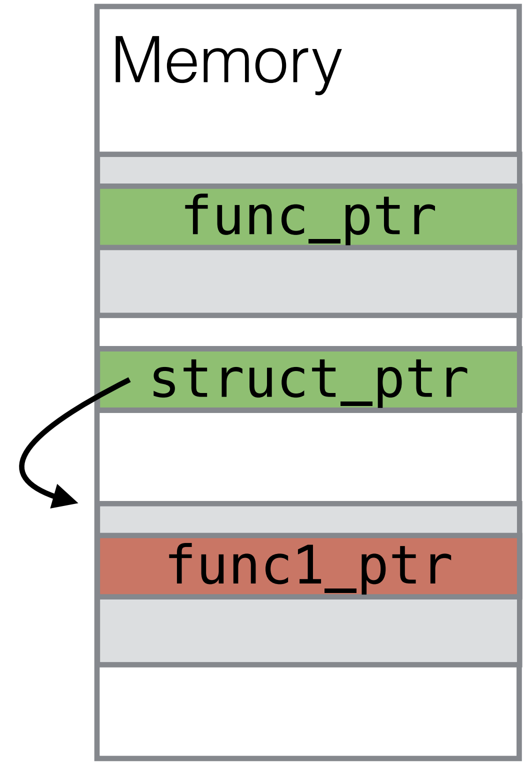
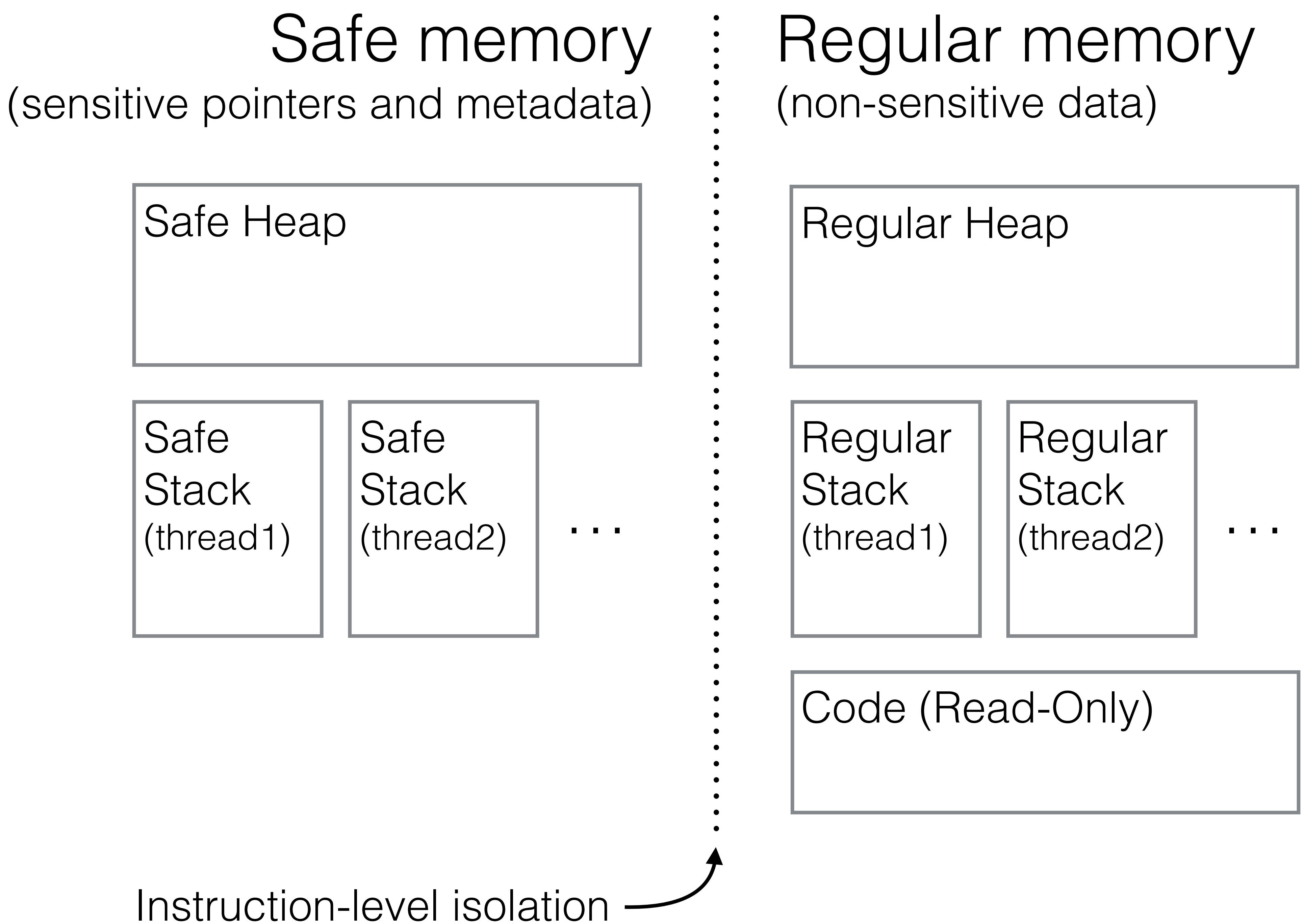


➡ **Indirect Pointers have to be protected as well**

➡ **Extend static analysis to include indirect pointers**

CPI Memory Layout



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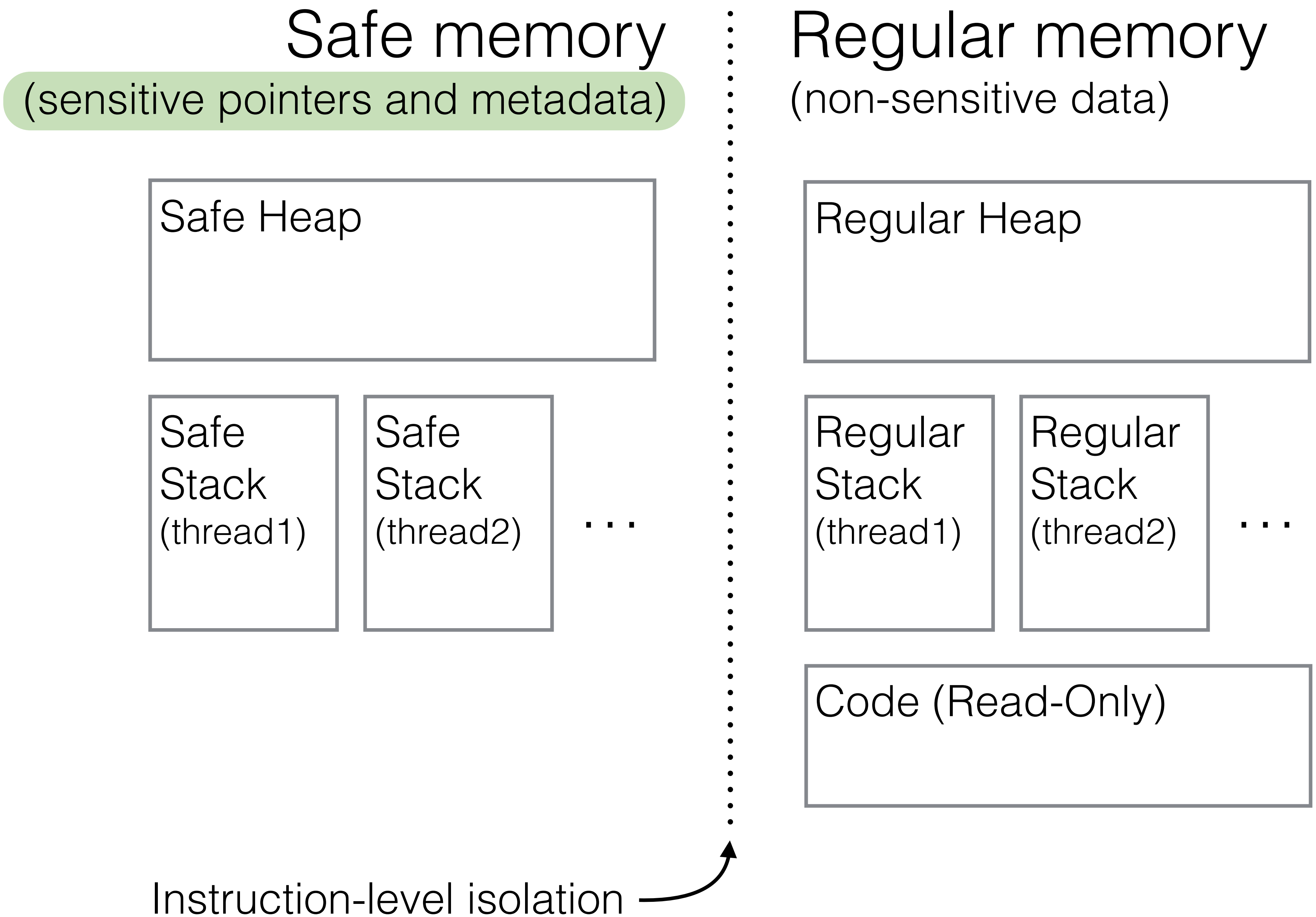

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- Keeps performance overhead low by not protecting data pointers

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- Adding safe memory region while keeping the original memory layout intact
- Separating the safe region from the regular region using instruction level protection:
    - Hardware segment protection on x86-32
    - Information hiding on x86-64 and ARM

Security analysis

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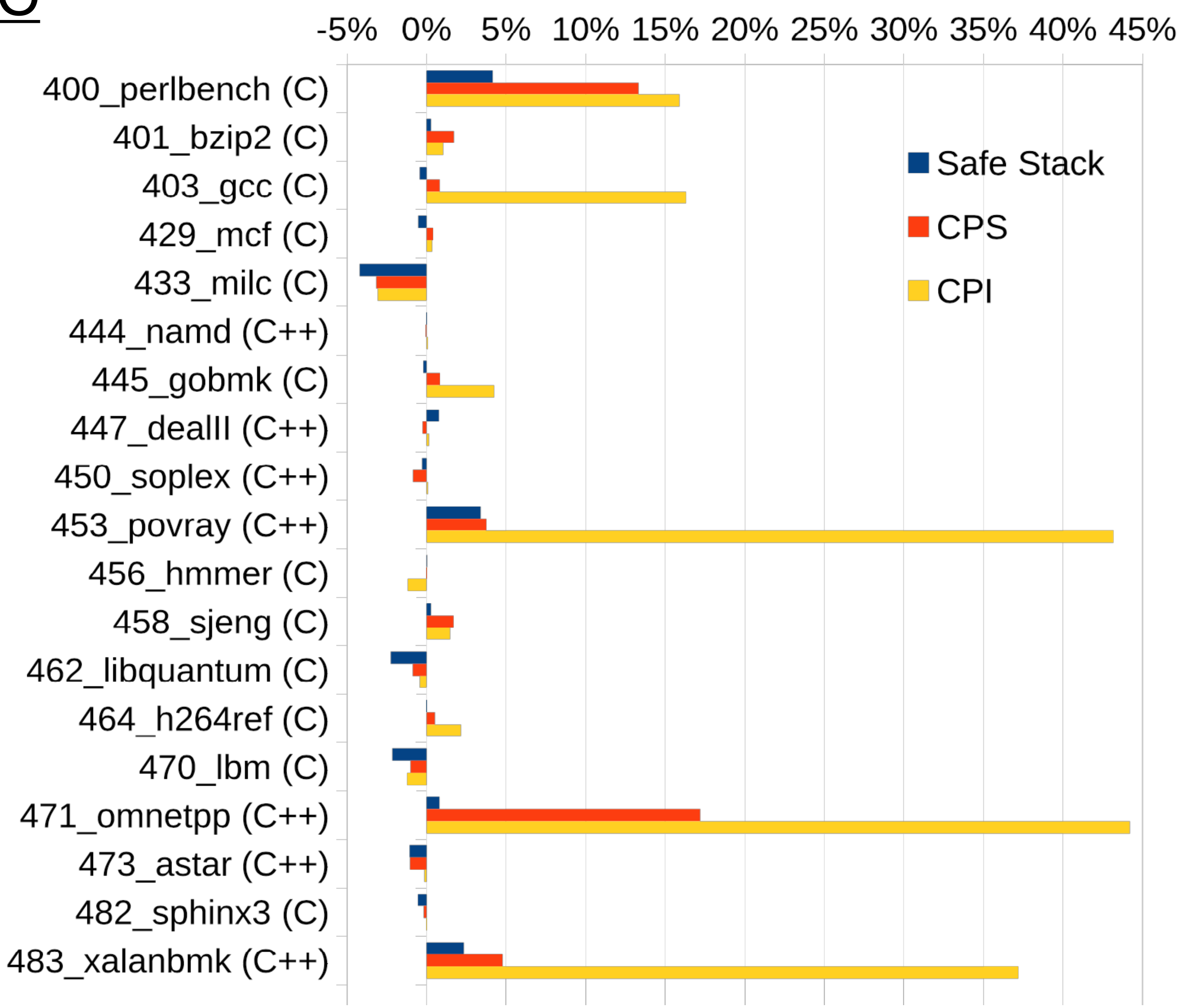
- CPI and CPS protect against all attacks from RIPE (Runtime intrusion prevention evaluator)
- CPI correctness proof in paper guarantees security against future attacks
- Does not protect against data-only attacks

Performance Benchmark

Performance in SPEC CPU2006:



Performance summary

	Safe Stack	CPS	CPI
Average (C/C++)	0.0%	1.9%	8.4%
Median (C/C++)	0.0%	0.4%	0.4%
Maximum (C/C++)	4.1%	17.2%	44.2%
Average (C only)	-0.4%	1.2%	2.9%
Median (C only)	-0.3%	0.5%	0.7%
Maximum (C only)	4.1%	13.3%	16.3%

Performance numbers from SPEC CPU2006 Benchmark

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- Paper by Evans et. al.:

  ➡ Shows there is a way to find the safe area using side channel attack

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➡ 48 bit address space in x64 CPU makes guessing impractical, most guesses would cause crashing

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3) Locate Safe Region

4) Attack Safe Region

Mitigation of the Weakness

- Implement Hardware Segmentation in x86-64
- Switch to software fault isolation

  ➡ Introduces additional performance overhead of ~5%
- Reduce feasibility of side channel attack by changing implementation of information hiding

  ➡ Replace linear table with hash table or two-level lookup table

Discussion

Questions?

References:

- Code-Pointer Integrity - Kuznetsov et. al. (2014)
- Presentation: Code-Pointer Integrity - Kuznetsov (OSDI 2014)
- Missing the Point(er) - Evans et. al. (2015)
- Getting the Point(er) - Kuznetsov et. al. (2015)