
# Restricting Control Flow During Speculative Execution with Venkman

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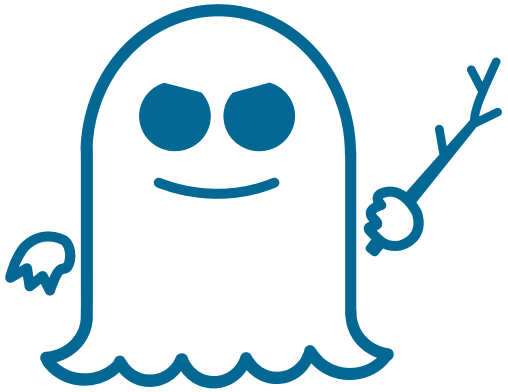
Picture from the Internet

# Speculative Execution

- **Feature to improve processor performance**
  - Equipped in x86, ARM, POWER, etc
- **Execute instructions prior to knowing if they are needed**
  - Restore and re-execute on mis-speculation
  - Leave observable side effects
- **Vulnerable to sophisticated attacks!**



# Spectre Attacks

- **Variant 1: exploit conditional branches**
  - Direction prediction using PHT
  - Mitigations: fence, data dependence

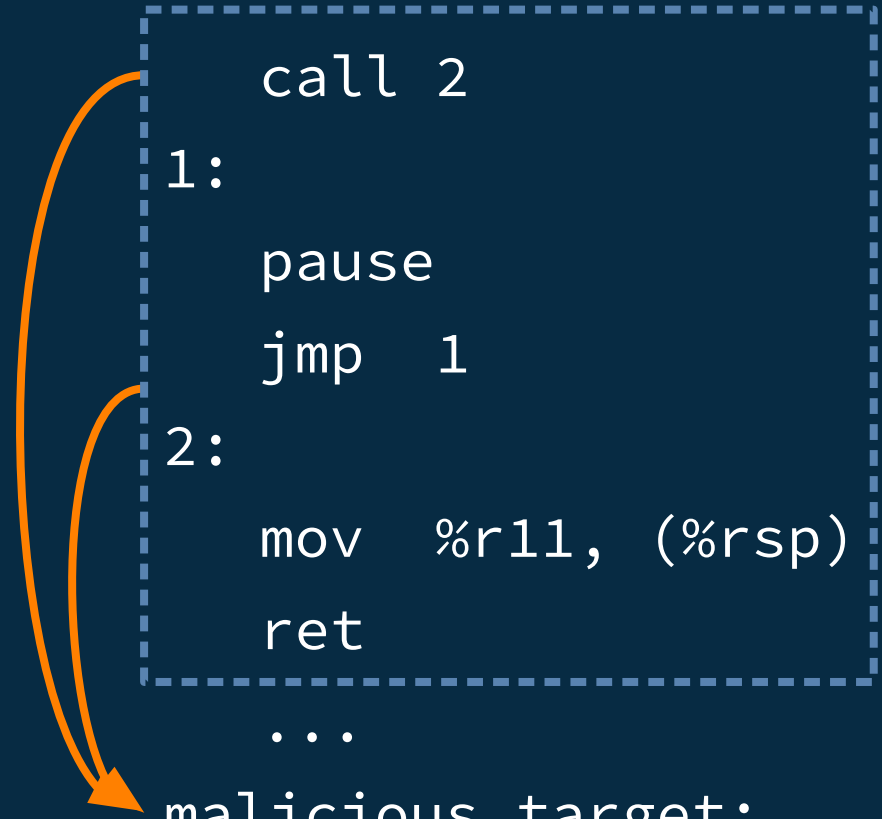
```
if (x < arr1_size) {
  y = arr1[x];
}
```

- **Variant 2: exploit indirect branches**
  - Target prediction using BTB and RSB
  - Mitigations: microcode, Retpoline

```
(*func_ptr)(); // return;

if (x < arr1_size) {
  load_fence();
  y = arr1[x];
}
```

What if **direct branch targets** can also be poisoned?




**Retpoline becomes vulnerable too!**

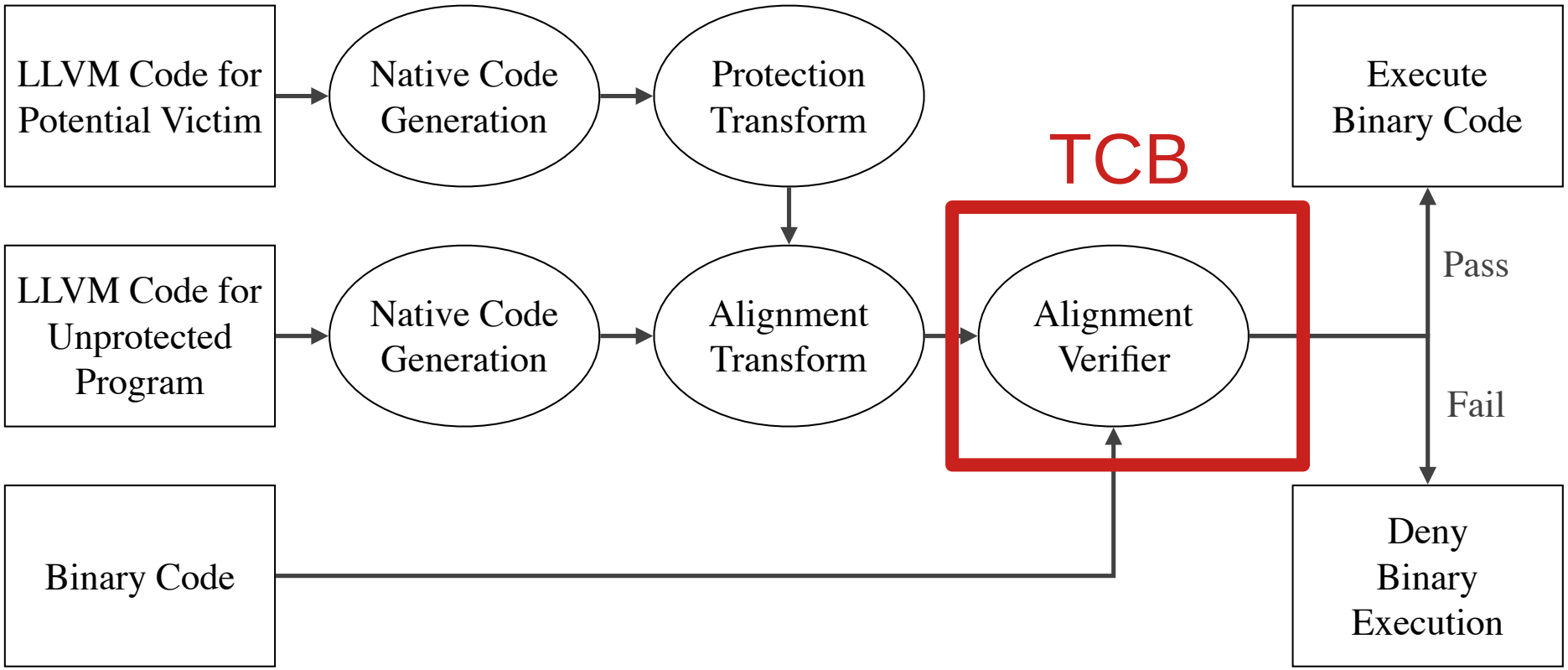
# Venkman: Our Solution!

- **Defense against BTB & RSB poisoning**
  - Aligned control-flow transfer targets
  - Protective instructions not bypassed
- **Broad threat model**
  - Any program can be a potential attacker!
  - Require whole-system instrumentation

# Outline

- **Design**
- Implementation
- Security Evaluation
- Space & Performance Evaluation
- Conclusions & Future Work

# Venkman System Architecture



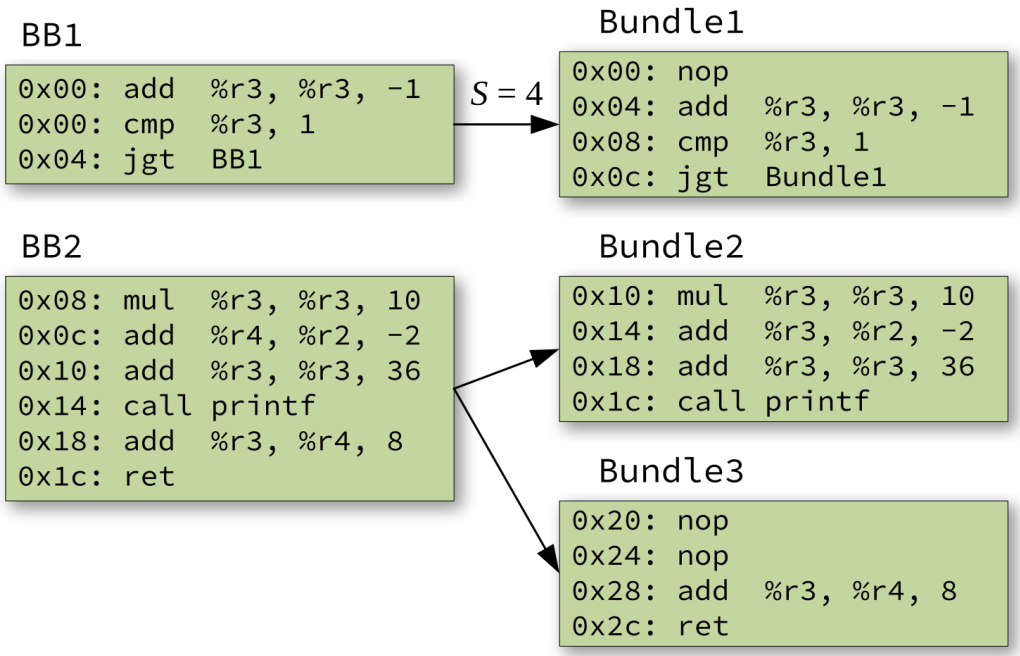
# Venkman Transformations

- **Alignment transformations**
  - Code padding & alignment
  - Bit-masking control data

  } Core of Venkman
- **Protection transformations**
  - Spectre protection

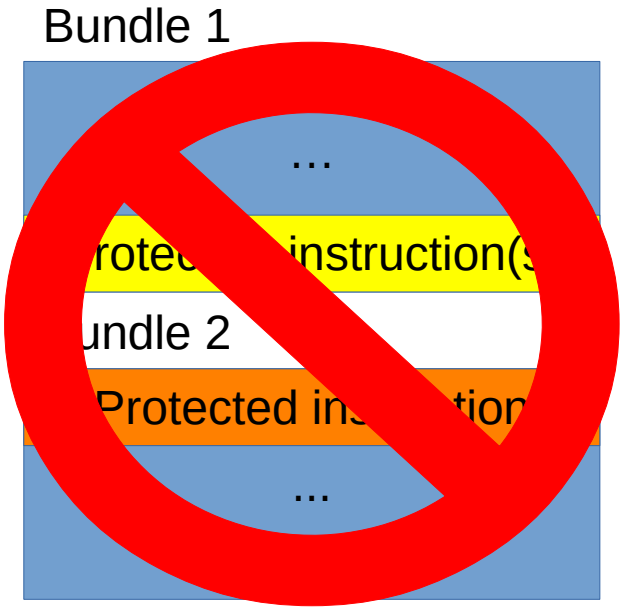
# Code Padding & Alignment

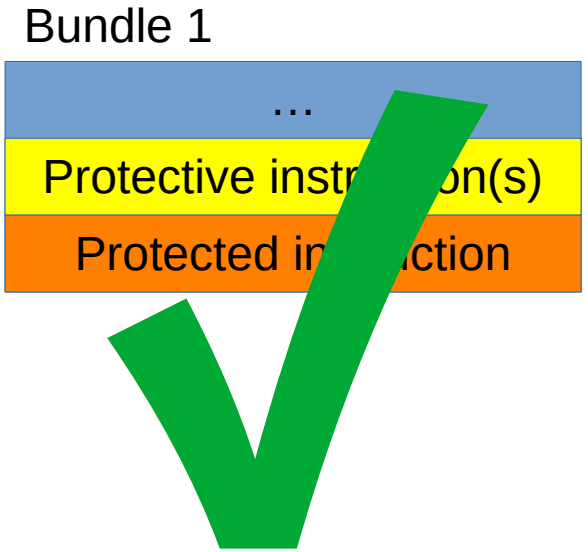
- **Transform basic blocks into *bundles***
  - Groups of Instructions sized and aligned at $2^s$ bytes
  - Split large BBs
  - Pad NOPs to small BBs
- **Function calls at the end of bundle**



# Code Padding & Alignment

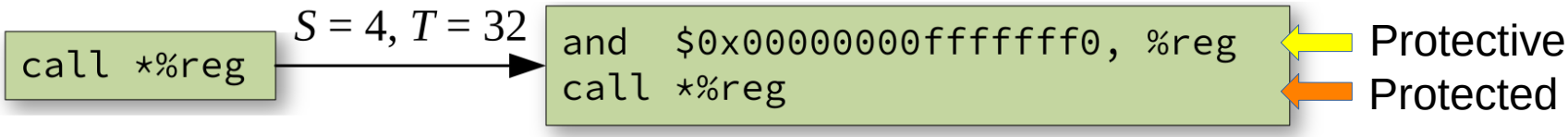
## Honor co-location requirements



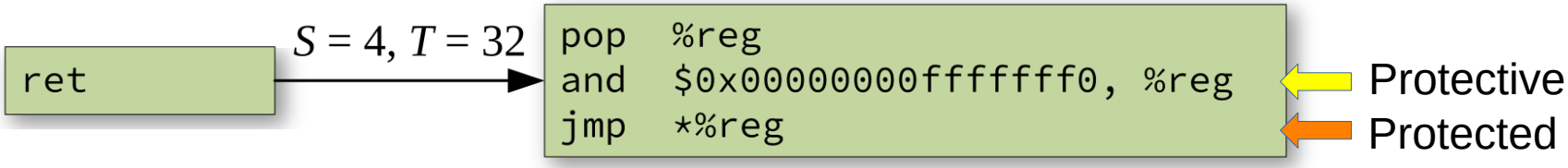



# Bit-Masking Control Data

- **Clear lower $S$ bits**
- **Clear higher $(64 - T)$ bits**

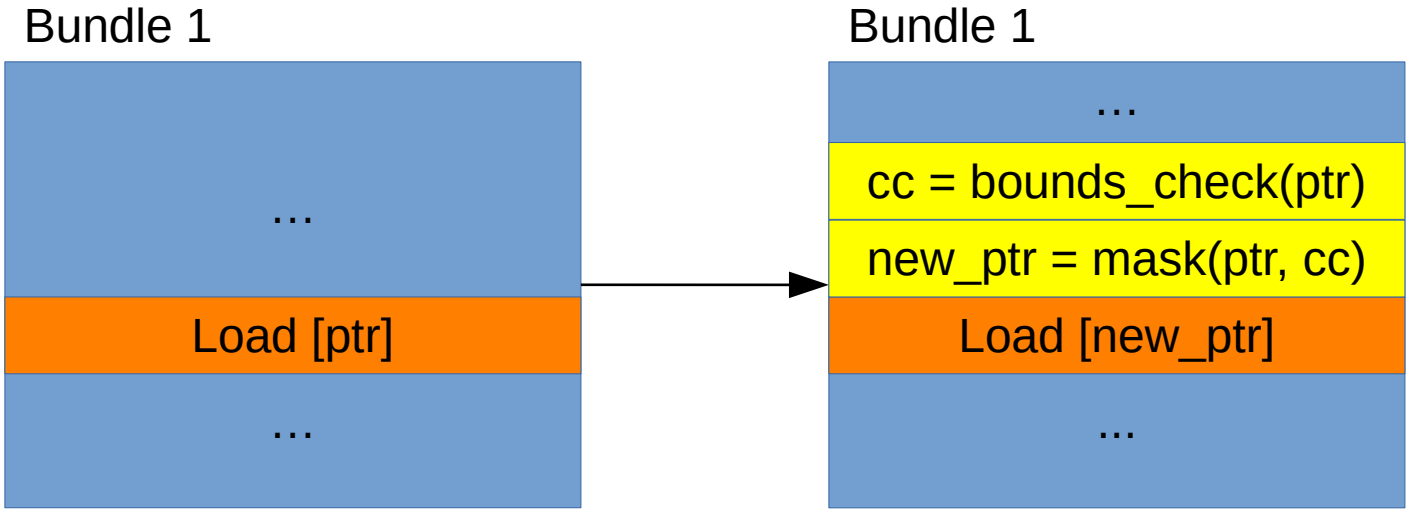



- **Transform branches w/ in-memory target**



# Spectre Protection

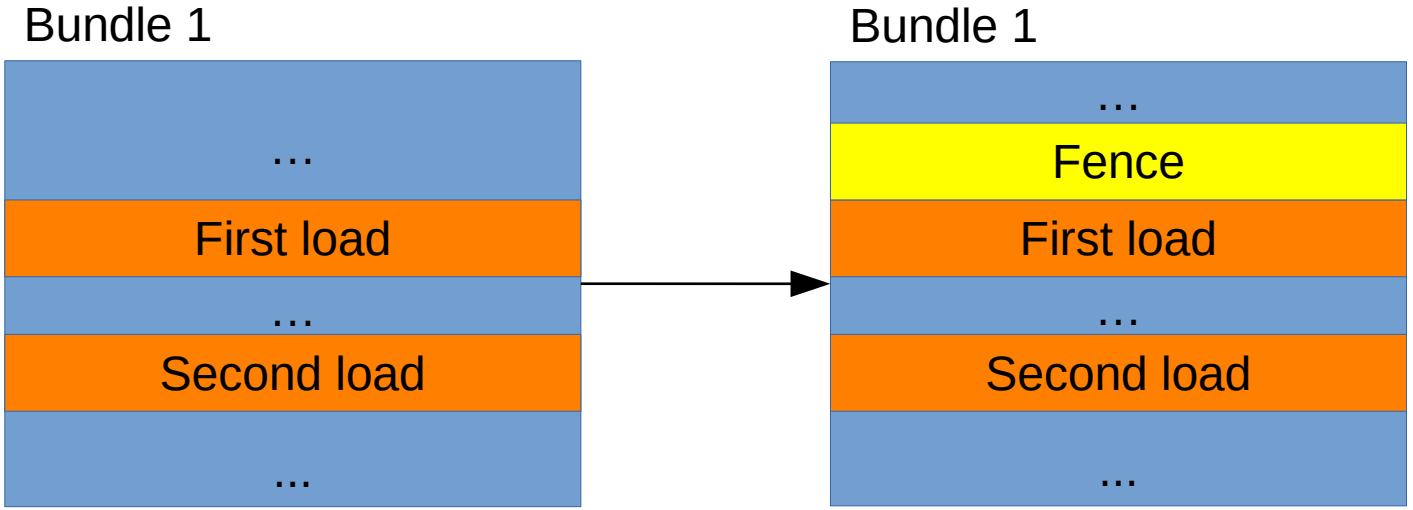
- **Insert Spectre-resistant SFI** [1]




[1] X. Dong *et al*. Spectres, Virtual Ghosts, and Hardware Support. In *HASP*'18.

# Spectre Protection

- **Insert fences**



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# Implementation

- **Implemented on POWER architecture**
- **Extended LLVM with** `MachineFunctionPass`**es**
- **32-byte bundles (**$S = 5$**)**
- **Code segment at first 32 TB (**$T = 45$**)**
- **Use** `EIEIO` **as fence** `Enforce In-order Execution of I/O`
- **Use dummy SFI**

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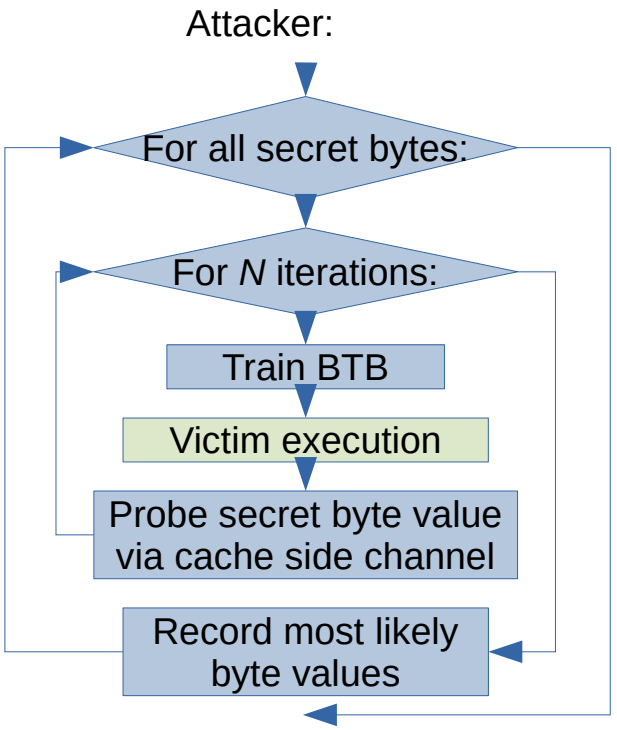
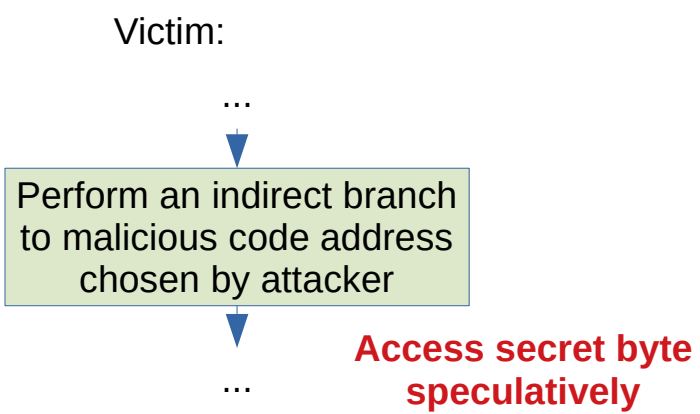
# Security Evaluation

- **Proof-of-concept Spectre V2 attack on POWER**




**With Venkman, such attack no longer works!**

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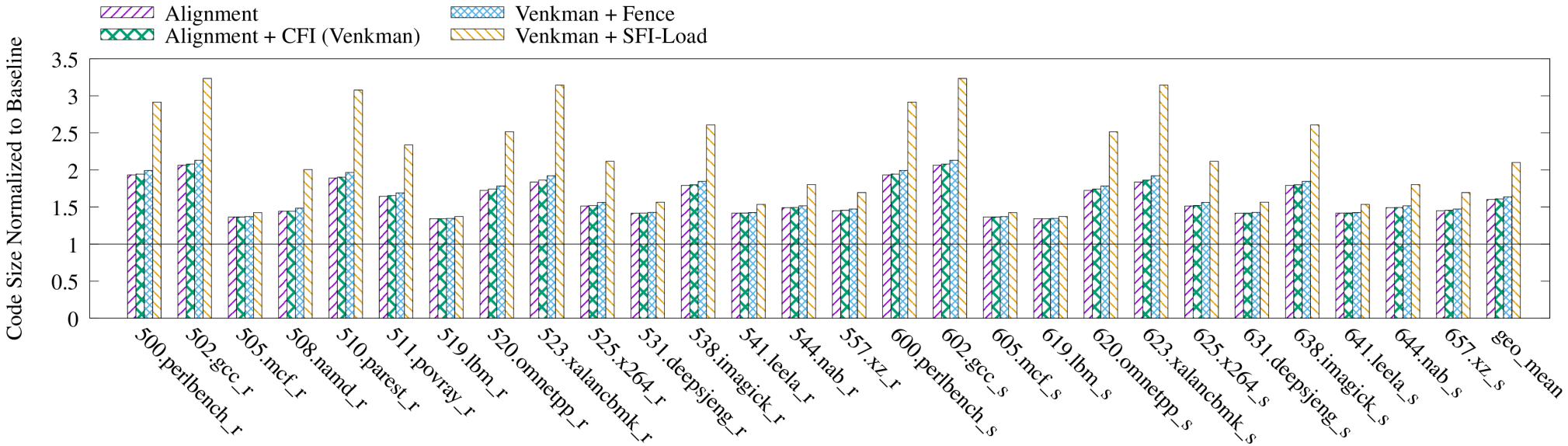
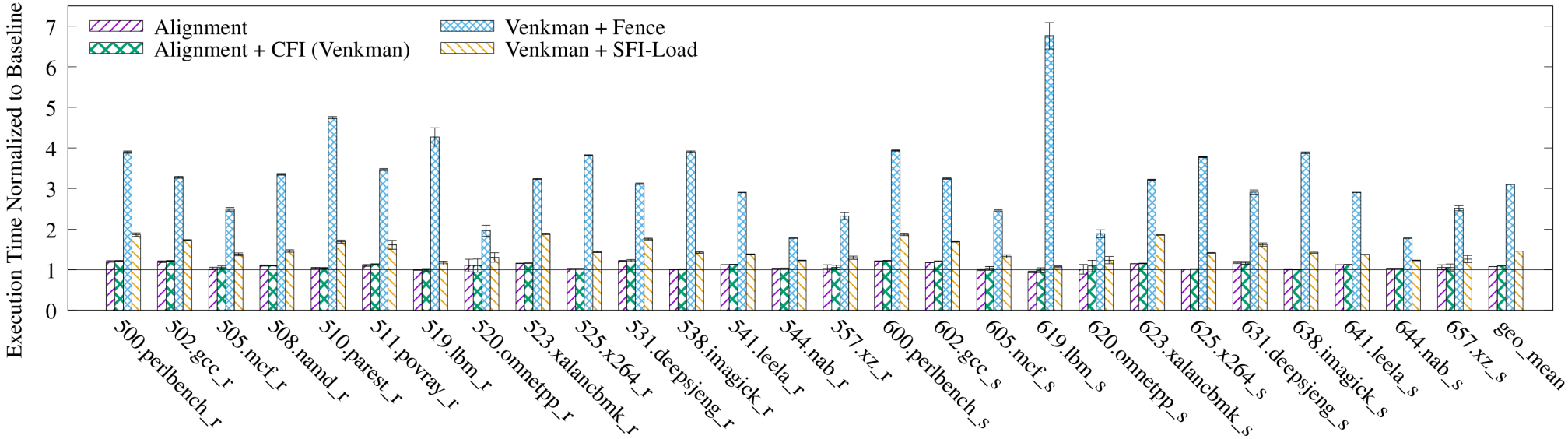
# Experimental Setup

- **Hardware specifications**
  - 64-bit IBM POWER8
  - 20 cores, 8 threads/core
  - 4.1 GHz
  - 64 GB RAM
- **Configurations**
  - Baseline
  - Alignment only
  - Alignment + CFI (Venkman)
  - Venkman + Fence
  - Venkman + SFI-Load
- **Software specifications**
  - CentOS 7 w/ Linux 3.10.0
  - LLVM/Clang 4.0.1
- **Benchmarks & applications**
  - SPEC CPU 2017
  - Nginx 1.15.8
  - GnuPG 1.4.23
  - ClamAV 0.92

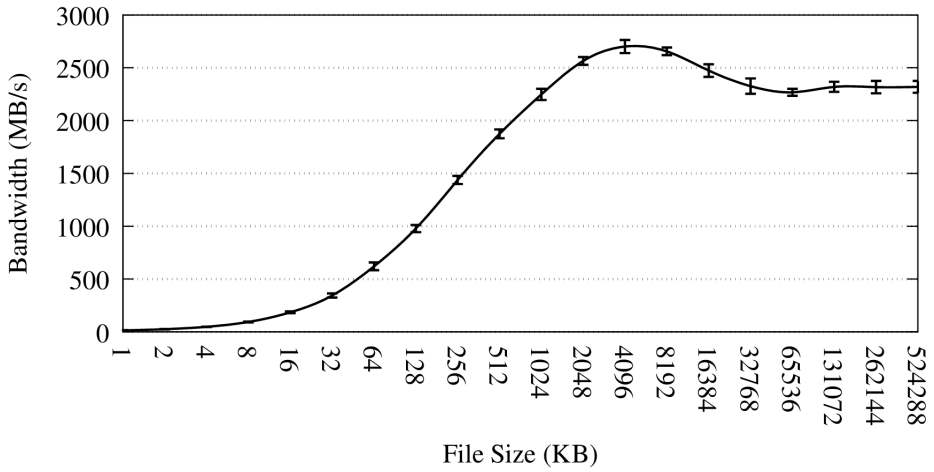
# Code Size Overhead on SPEC CPU 2017



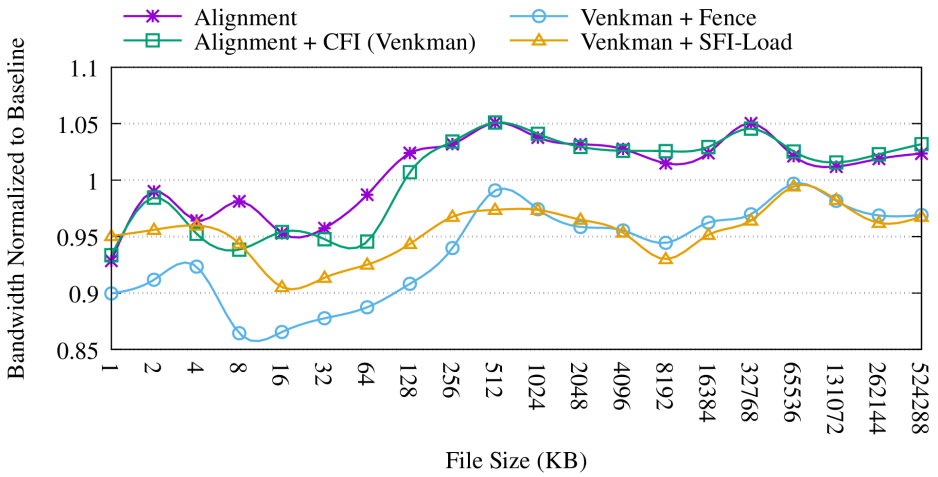
# Performance Overhead on SPEC CPU 2017



# Nginx File Transfer Rate

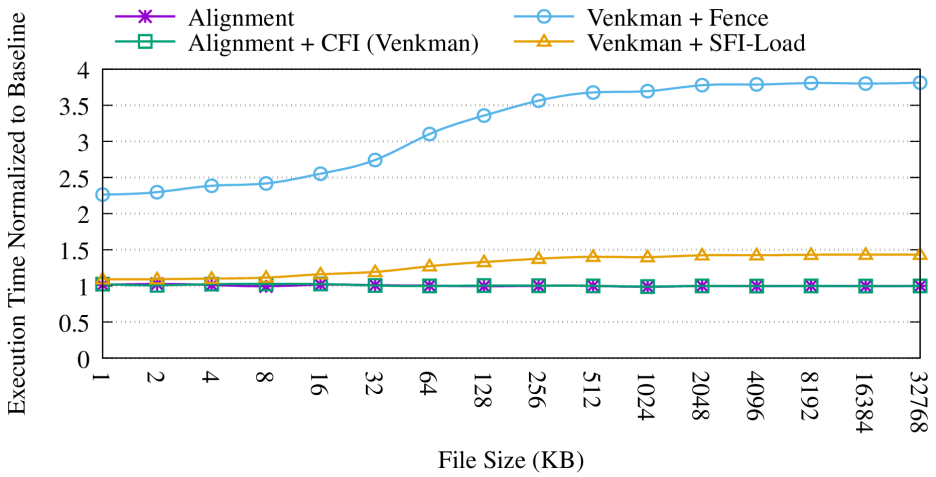



Baseline

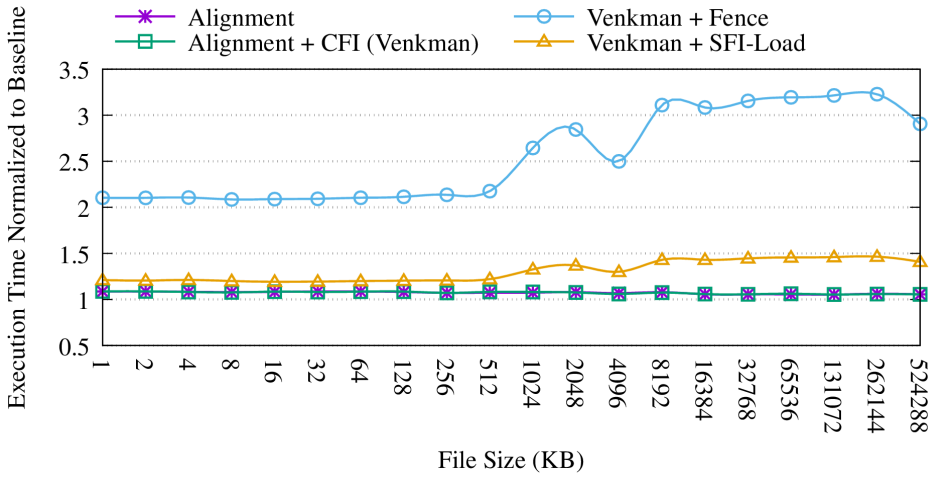



Venkman Normalized to Baseline

# GnuPG & ClamAV Overhead




GnuPG Encryption




ClamAV

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# Conclusions

- **Venkman mitigates BTB & RSB poisoning**
- **When protecting fences, Venkman exhibits**
  - 1.64x average space overhead
  - 2.97x average performance overhead
- **When protecting SFI, Venkman exhibits**
  - 2.13x average space overhead
  - 1.43x average performance overhead
- **61.3% space and 8.6% performance overhead for non-victim programs**

# Future Work

- **Reduce overhead**
- **Port to x86 & ARM**

# Thank you!