# Enhancing Memory Error Detection for Larg e-Scale Applications and Fuzz testing

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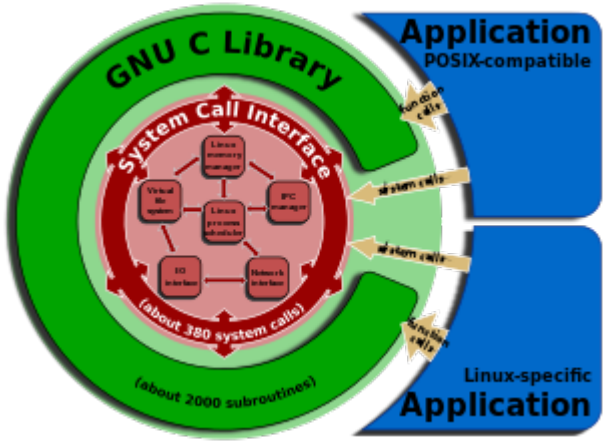
# Memory error

Heartbleed

Shellshock




glibc: getaddrinfo sta
ck-based buffer overf
low

- Information leakage – Heartbleed
- Privilege escalation – Shellshock
- Remote code execution – Shellshock, glibc, Conficker

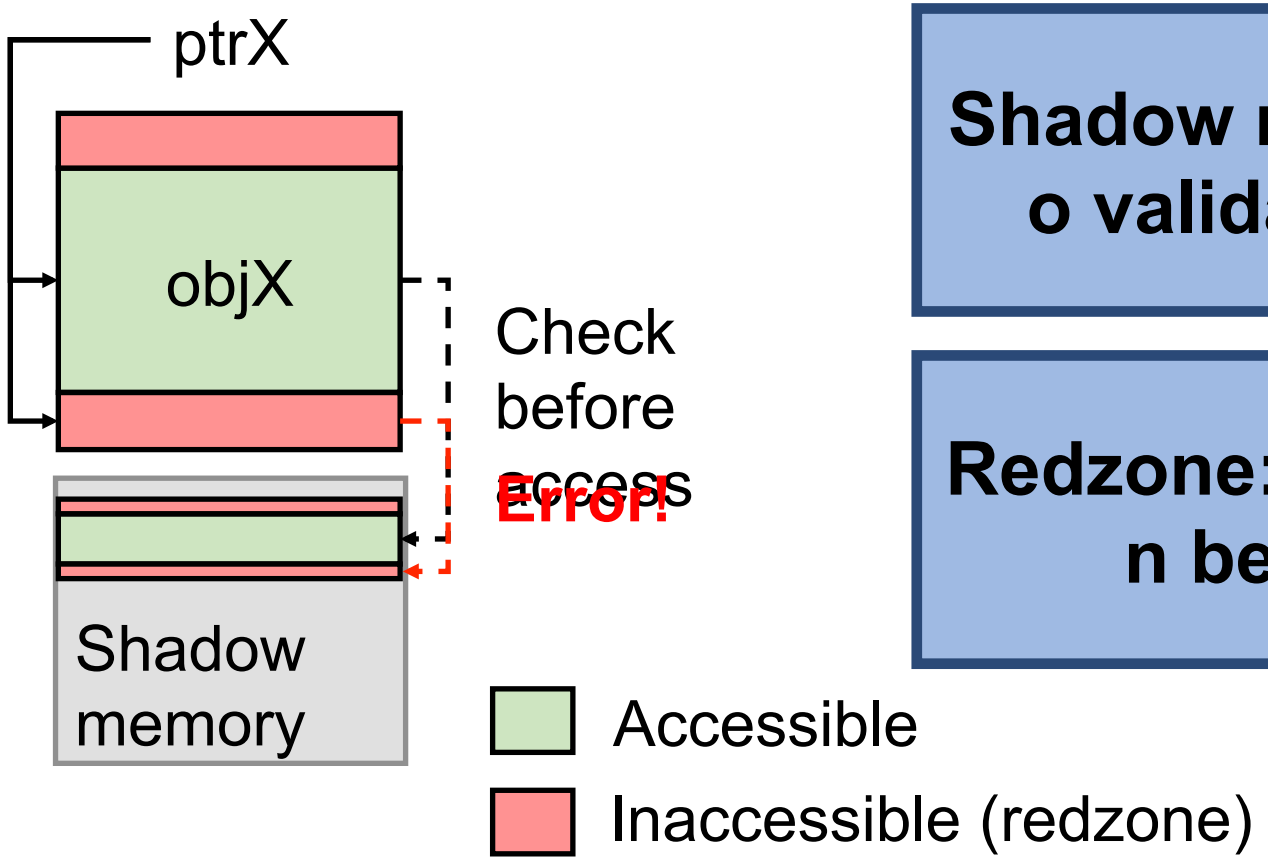
# Memory error detection

- **Pointer-based [SoftBound+CETS, Intel MPX]**
  - Hardware support (cannot detect temporal memory errors)
  - Challenges to support complex applications

- **Redzone-based [AddressSanitizer (ASan)]**
  - **Compatible** to complex applications
  - **Most popular in practice**
    - ➔ Google Chrome, Mozilla Firefox, Linux Kernel
    - ➔ American Fuzzy Lop (AFL), ClusterFuzz, OSS-Fuzz

# Redzone-based memory error detection

- **Buffer overflow (spatial memory errors)**

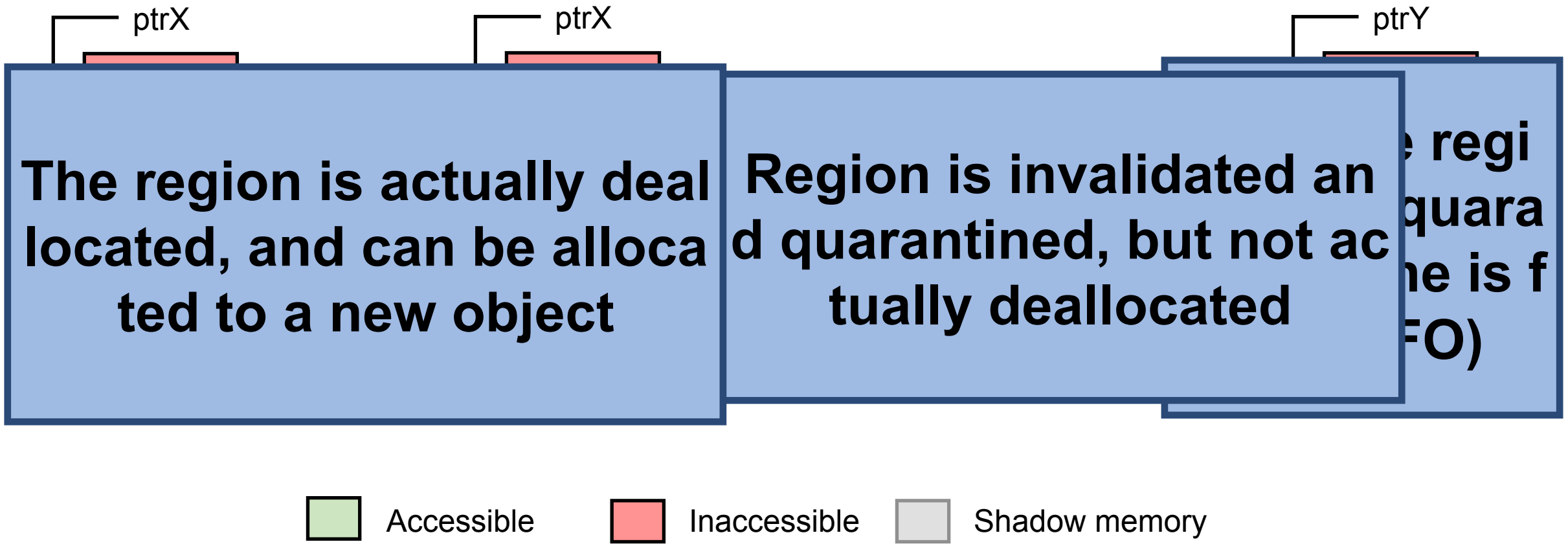



**Shadow memory: a bitmap t o validate all addresses**

**Redzone: inaccessible regio n between objects**

# Redzone-based memory error detection

- **Use-after-free (temporal memory errors)**



# Limitations of redzone-based approach

**1. What if a pointer acce sses *beyond* redzone?**

**2. What if a dangling pointer ac cesses *after* another object is a llocated in the region?**

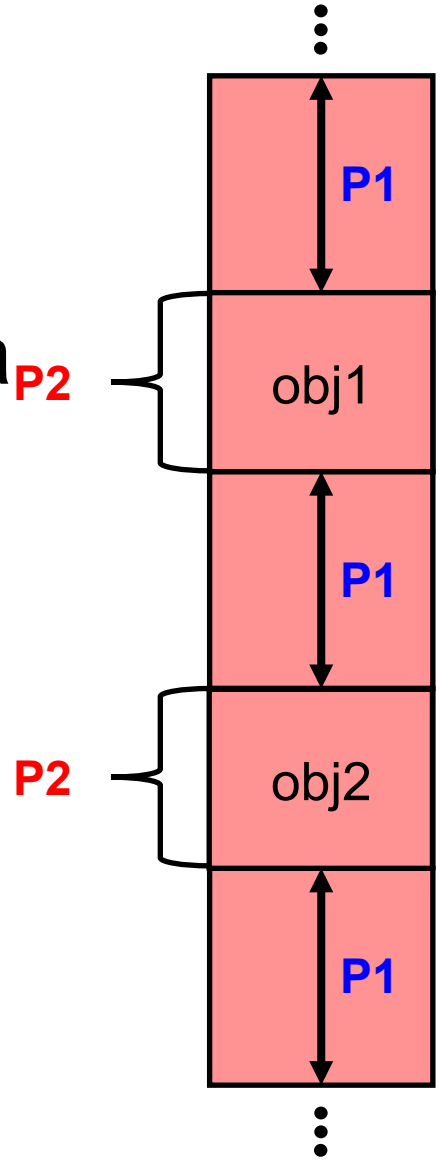

Spatial memory error

Temporal memory error

# Motivation

- To enhance detectability of redzone-based memory error detection
  - **P1. Large gap** to detect spatial memory errors
  - **P2. Large quarantine zone** to detect temporal memory errors

**Huge physical memory required**



# MEDS overview

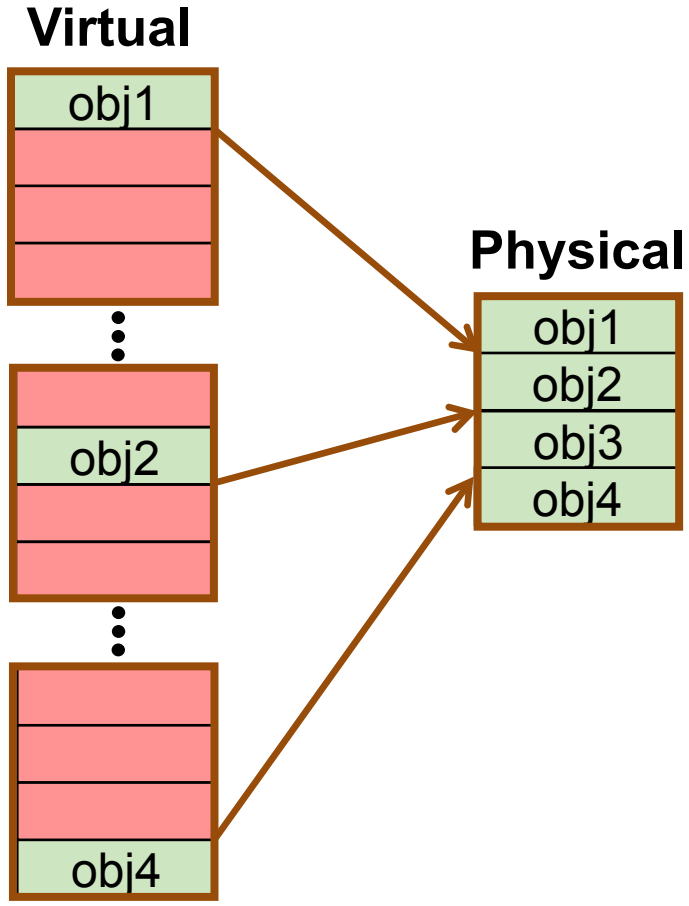
- Enhances detectability of redzone-based memory error detecti on

- **Idea: Fully utilize 64-bit virtual address** space to support
  - **P1. Large gap** to detect spatial error
  - **P2. Large quarantine zone** to detect temporal error

- **Approach**: minimize physical memory use
  - **Page aliasing** allocator and **page protection**
  - **Hierarchical** memory error detection

# Page aliasing (P1)

- Maps multiple virtual pages to single physical page




**Redzone itself does not o ccupy physical memory**

A memory page

Allocated

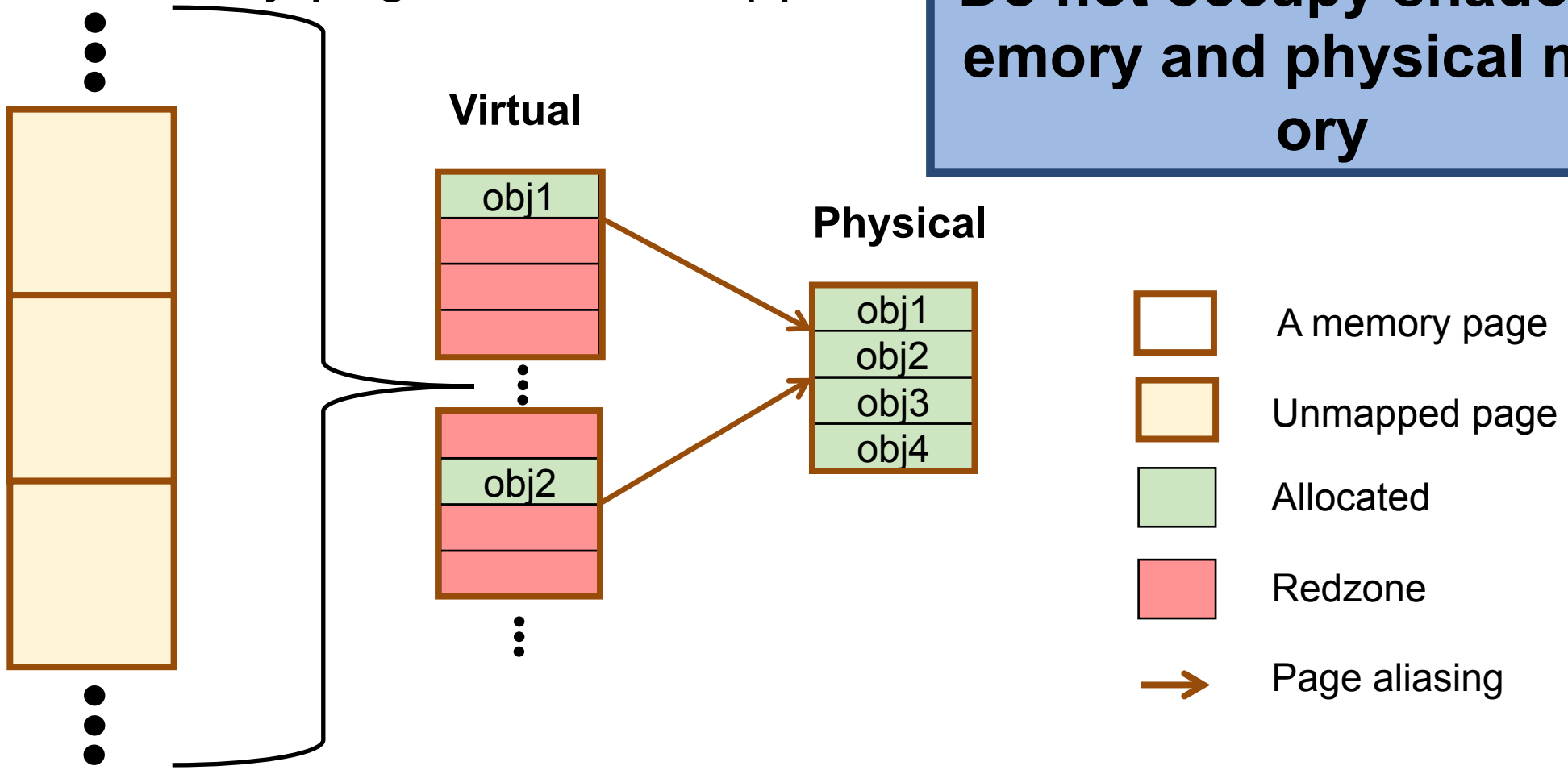
Redzone

Page aliasing

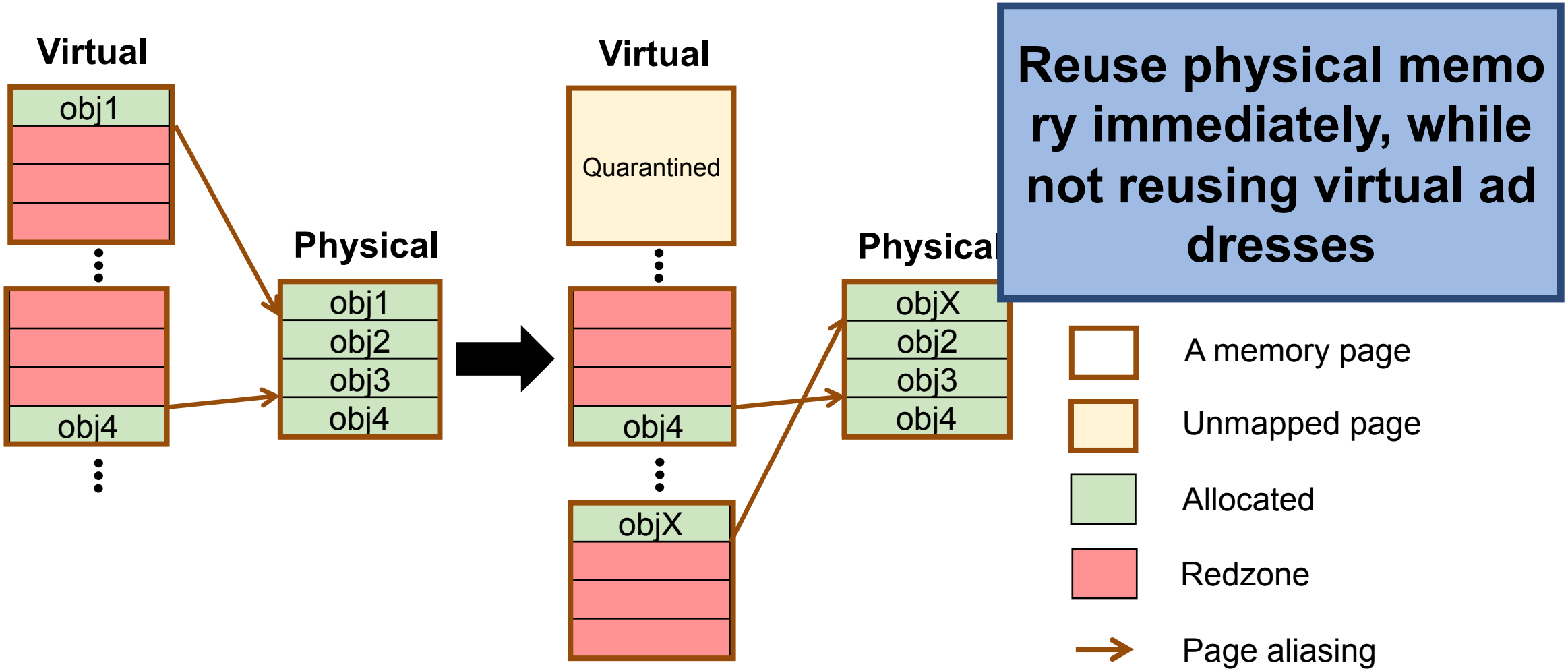
# Page protection (P1)

- Redzone only pages are unmapped

**Do not occupy shadow m emory and physical mem ory**



# Page aliasing & Page protection (P2)



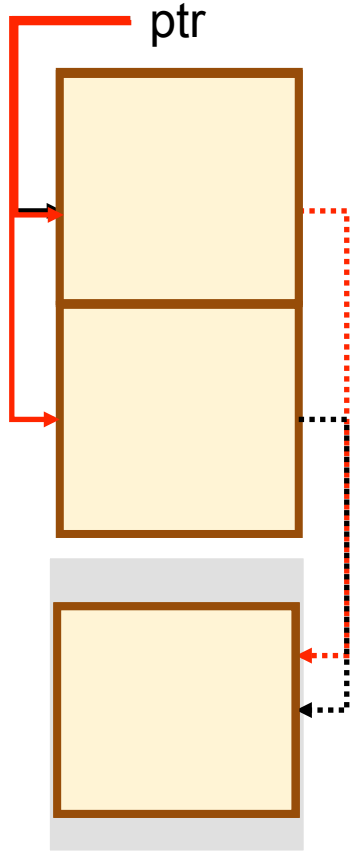
# Hierarchical memory error detection

- Many different ways to represent redzones
  - ➔ Further optimizing physical memory uses

**#1. Shadow memory is invalid**

**#2. Virtual page is unmapped**

**#3. Shadow memory is unmapped**



# Evaluation

- **Configuration**

| | ASan | MEDS | Improv. |
|---|---|---|---|
| **Redzone** | **8-1024 bytes** | **4MB** | **16,384x** |
| **Quarantine** | **128MB** | **80TB** | **65,536x** |

  - ASan cannot use configuration for MEDS (lack of memory)
- **Compatibility**
- **Performance:** 2 times slowdown
- **Detection (fuzz testing):** **68%** more detection

# Compatibility

- **Unit tests from real-world applications**
  - Test cases in Chrome, Firefox, Nginx
    - **All Passed**

- **Memory error unit tests**
  - ASan unit tests
    - **All Passed**
  - NIST Juliet test suites
    - **All Passed** except random access tests

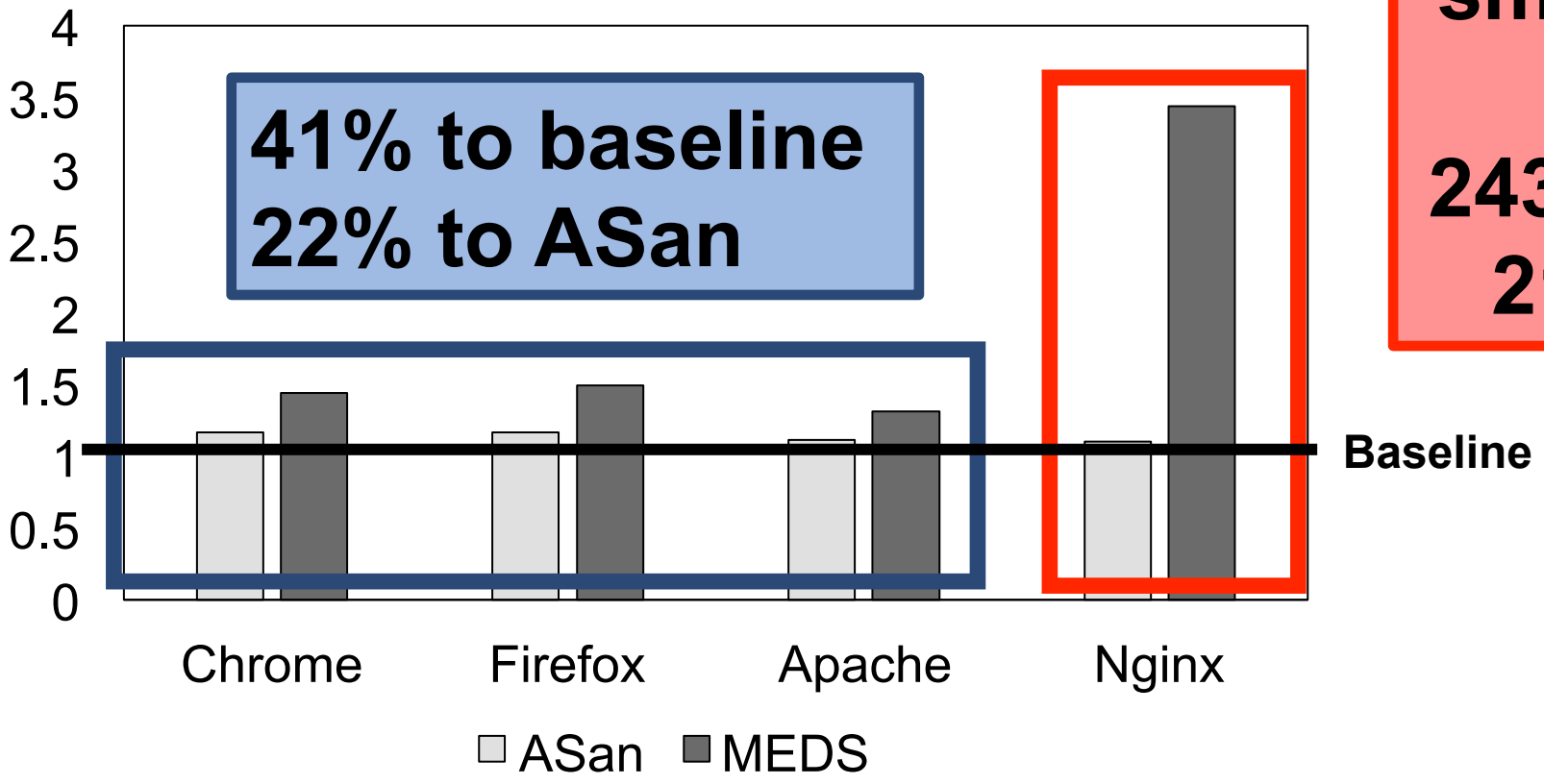
    ➔ ASan: 35% vs. MEDS: 98%

# Micro-scale performance overhead

- **TLB misses**
  - 5 times more than ASan (more **virtual pages** **with** **page aliasing**)
- **Number of system calls**
  - mmap(), munmap(), and mremap()
  - 32 times more than ASan (**page aliasing** and **page protection**)
- **Memory footprint**
  - 218% more than baseline
  - 68% more than ASan (much larger **redzone** and **quarantine**)

# End-to-end performance overhead

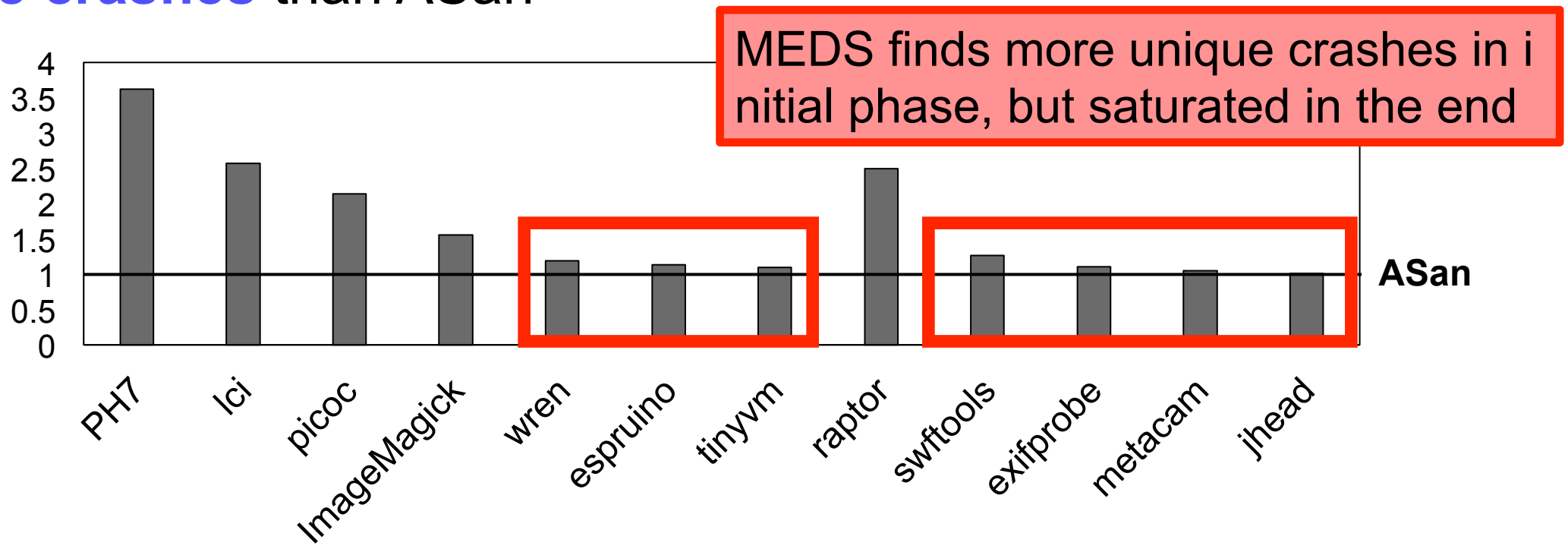
- 108% compared to baseline, 86% to ASan




**Large number of small objects on stack**
**243% to baseline**
**211% to ASan**

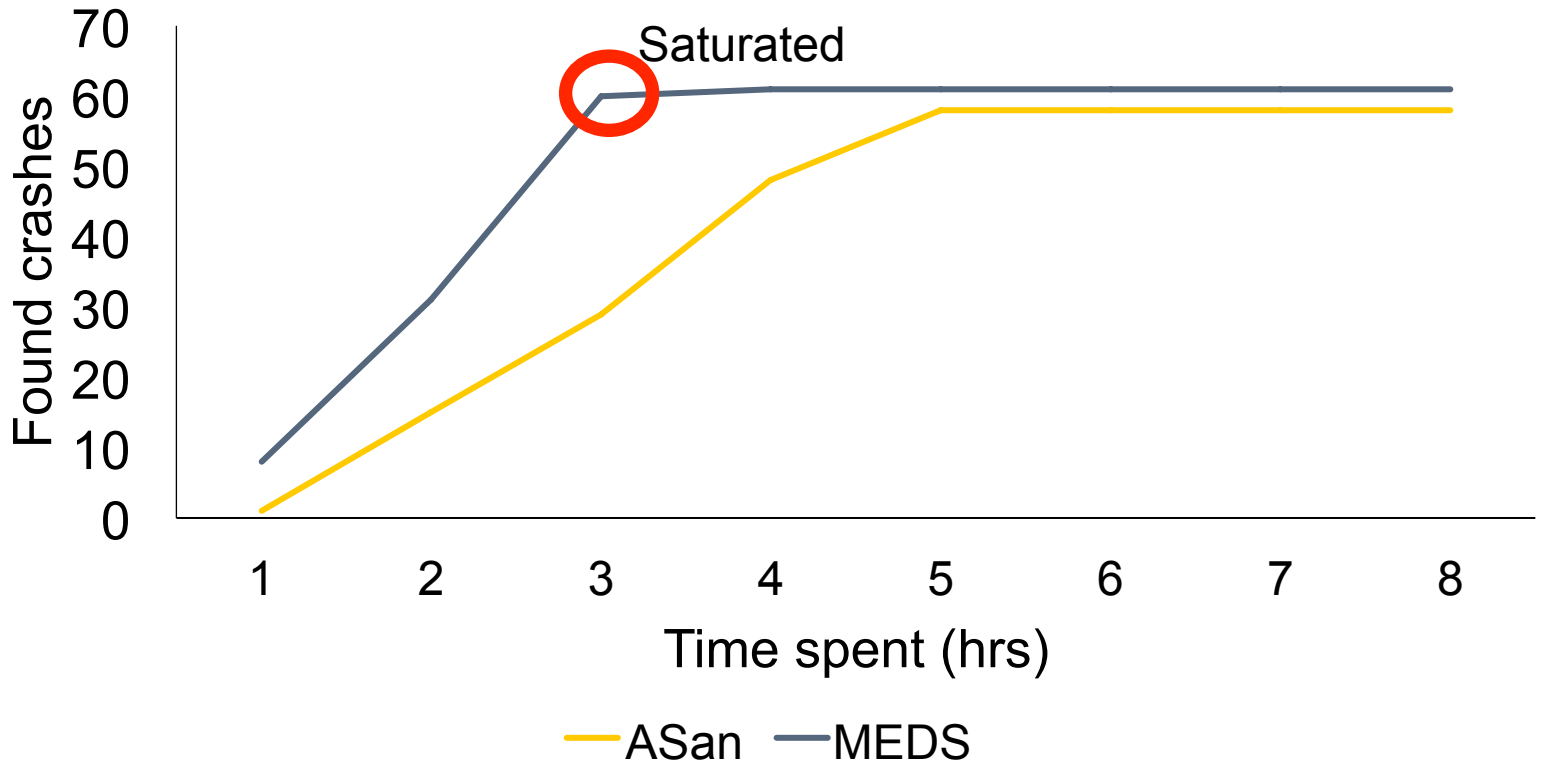
# Detection (fuzz testing)

- Run AFL (8 cores, 6 hours)
- Despite the performance overhead, explore **68.3% more unique crashes** than ASan



# Detection (fuzz testing)

- Number of unique crashes with time spent (metacam)



# How MEDS explores more crashes?

- **More input sets can be detected**
  - **Higher probability** to detect
  - Bugs can be found **earlier** than ASan
  - Fuzzer can focus on **the other paths**

```
int a[10];
a[x] = x;
```

- **MEDS can detect the cases that AS an cannot detect**
  - Always **bypass** redzone
  - e.g., Miscalculation of structure array size
    - Size of the structure is larger than redzone siz e
    - Access to certain element cannot be detected.

```
struct A {
  int num[10];
};
struct A *a = malloc(size
of(struct A));
...
(a+i)->num[8] = i;
```

# Conclusion

- **Idea**
  - Support **large gap** and **large quarantine zone**
- **Approach**
  - **Page aliasing** and **page protection**
  - **Hierarchical** memory error detection
- **Despite overhead (108%), MEDS finds more crashes during fuzz testing (68.3%)**
- **Open source – will be available soon**
  - **https://github.com/purdue-secomp-lab/MEDS**
  - Please use to detect bugs

# Thank you for listening!