# KASan in a Bare-Metal Hypervisor

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# Motivation

- C and C++ are not memory safe
- Buffer overflow and use-after-free bugs can be maliciously exploited
- We want to get rid of such bugs in our C code
- KASan is a great technology, let's use it for PT hypervisor!

# Agenda

- Basic ideas behind KASan
- What is a bare-metal hypervisor
- Porting KASan to a bare-metal hypervisor:
  - Main steps
  - Pitfalls
  - How to make KASan checks much more strict and multi-purposed

# KASan (Kernel Address Sanitizer)

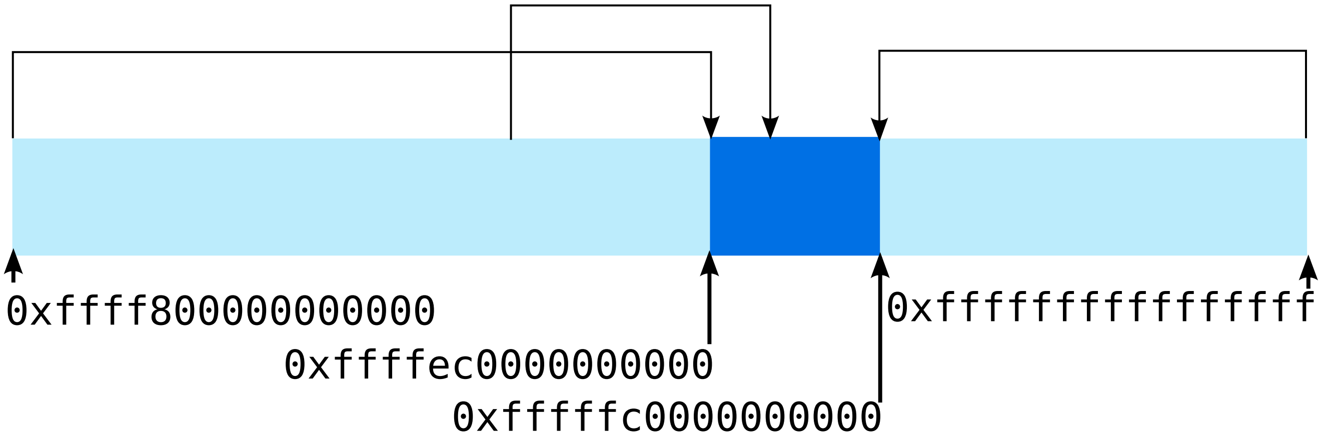
- KASan is a **dynamic** memory error detector for Linux kernel
- Based on work by Andrey Konovalov and others at AddressSanitizer project. The KASan patch set came to Linux kernel from Andrey Ryabinin.
- **Trophies:** more than 65 memory errors found in Linux kernel
- KASan is a **debug tool** giving maximum profit with fuzzing
- **Low penalty:** ~1.5x slowdown, ~2x memory usage
- Can be used in bare-metal software

# KASan shadow memory legend

Every aligned 8 bytes can have 9 states. KASan shadow encoding:

- 0 if access to all 8 bytes is valid
- N if access only to first N bytes is valid (1 <= N <= 7)
- Negative value (poison) if access to all 8 bytes is invalid

# Mapping to KASan shadow (x86-64)



0xffff800000000000

0xffffec0000000000

0xfffffc0000000000

0xffffffffffffffff

▢ Kernel address space (47 bits, 128 TB)

🟦 KASan shadow memory (44 bits, 16 TB)

Mappinng:

```
shadow_addr = KASAN_SHADOW_OFFSET + (addr >> 3)
```

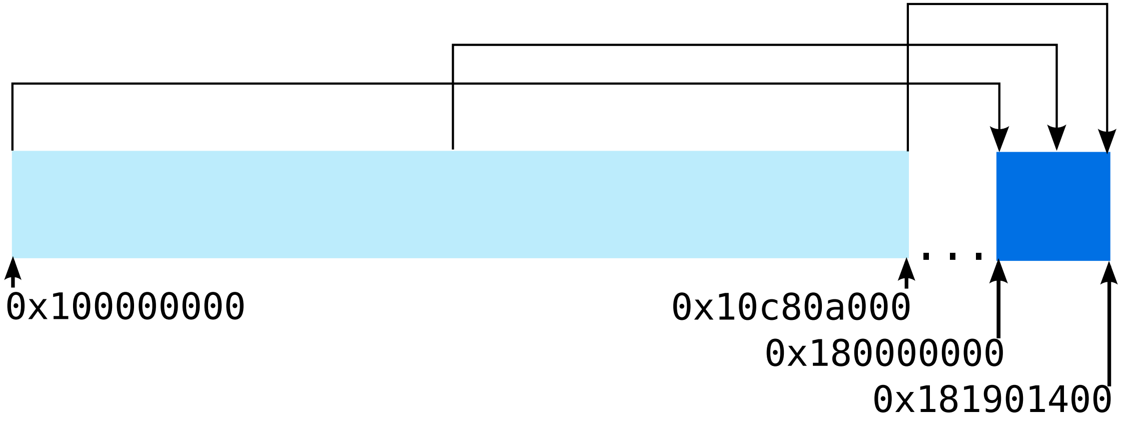
# Compile-time instrumentation

- gcc adds calling of `__asan_load##size()` or `__asan_store##size()` before memory access
- gcc adds redzones around stack buffers and globals

# A bare-metal hypervisor

- What is a hypervisor
- What does “bare-metal” mean
- How does it work with memory

# Step 1: Page tables for shadow



▭ Hypervisor memory (~200 MB)

🟦 KASan shadow memory (~25 MB)

**N.B.** Choosing KASAN_SHADOW_OFFSET is tricky

**N.B.** Ability to check whether hypervisor code touches foreign memory

# Step 2: Sanitize a single source file

- Specify these gcc flags:

  `-fsanitize=kernel-address`

  `-fasan-shadow-offset=...`

  **N.B.** The build system should support specifying different flags for different source files

- Add KASan implementation from `mm/kasan/kasan.c` little by little

  **N.B.** KASan is GPL

- Experiment till shadow works fine

# Step 3: Track global variables

- Additionally specify `--param asan-globals=1`
- Take care of `.ctors` section in the linker script
- Add `do_ctors()` looking at `init/main.c`
- Add `struct kasan_global` dictated by gcc
- Poison redzones of globals by negative `KASAN_GLOBAL_REDZONE` in `__asan_register_globals()`
- **N.B.** gcc does not create a KASan constructor for globals declared in assembler

# Step 4: Track heap

- Make allocator add redzones around every allocation
- Introduce `kasan_alloc()` and `kasan_free()` which poison redzones by `KASAN_HEAP_REDZONE`
- Delayed freeing decreases the probability of missing use-after-free

# Step 5: Poison shadow by default

- Fill whole shadow memory by `KASAN_GENERAL_POISON` in `kasan_init()`
- Different from KASan in Linux kernel
- Whitelist instead of blacklist
- A perfectionist sleeps better now :)

# Step 6: Track stack

- Additionally specify `--param asan-stack=1`
- When GCC sanitizes stack accesses it works with KASan shadow on its own
- **Pitfall 1:** GCC expects that shadow is filled by `0`. So don't make GCC sad with poisoning the stack shadow by default.
- **Pitfall 2:** Don't put `kasan_init()` call into a function with local variables.

# Step 7: Design a noKASan API

- Allows memory access without KASan checks
  - `nokasan_r64()` , `nokasan_w64()` and others
  - `nokasan_memset()` , `nokasan_memcmp()` and others
    - check the whole region at once
    - avoid copying the code

  **N.B.** `nokasan_snprintf()` is an uninstrumented copy: tracking accesses to arglist is a useless complication
- Now we can **very carefully** apply this API to the hypervisor code which legitimately works with foreign memory

# Steps 8,9,10: Apply to the whole project

- Cover files by KASan gradually
  - Fix memory access bugs
  - Apply noKASan API very carefully

    **N.B.** Changed memory layout and timings trigger new bugs too

    **N.B.** Thorough code review by the code authors is **vital**
- Move `kasan_init()` as early as possible
- This took me 3 months to do (project size is 55000 SLOC)

# Summary

- KASan has been successfully ported to a bare-metal hypervisor and has found some very tricky memory errors in it

- The new environment allowed to add new features to KASan

- Using KASan in new environments make it better:

  patch to the Linux kernel mainline

  ```
  commit 5d5aa3cfca5cf74cd928daf3674642e6004328d1
  x86/kasan: Fix KASAN shadow region page tables
  ```

- KASan is very helpful for developing

# Thanks. Questions?

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