Direct Map Management

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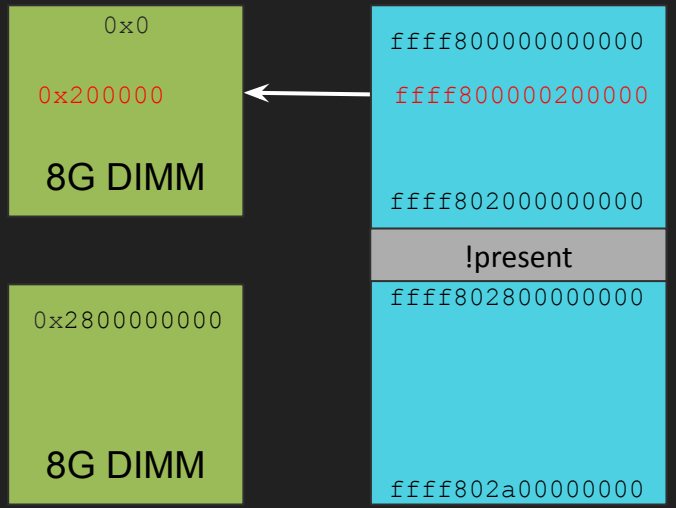
Direct map recap

- 1x1 mapping of the physical memory
  - Up to randomisation offsets with KASLR
- Direct map is the kernel page table
  - alloc_pages(), kmalloc() return addresses in the direct map



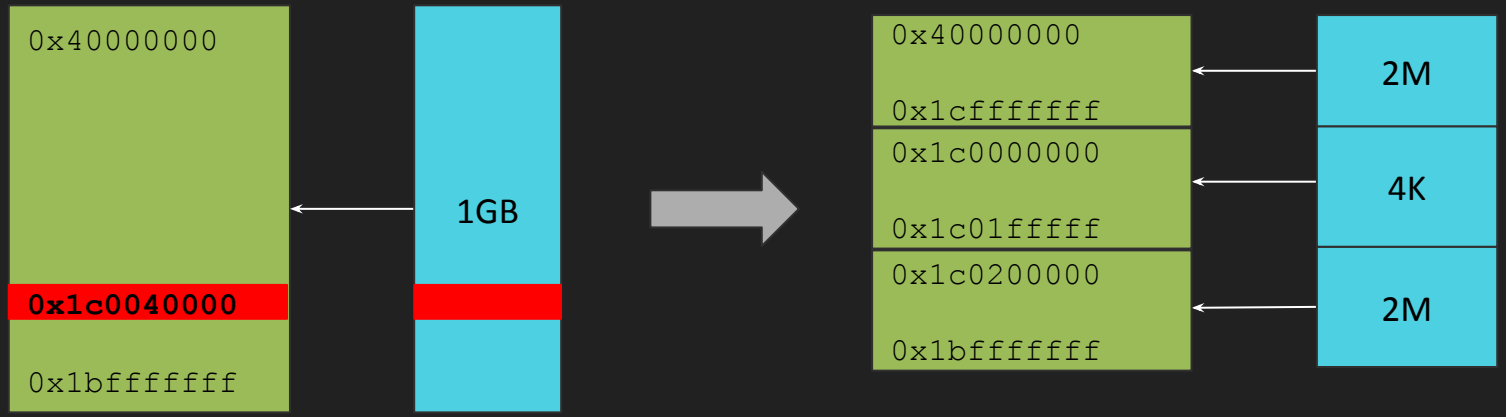
Direct map fragmentation

- Direct map uses large pages
  - 1GB and 2MB on x86
- Changes at 4k granularity fragment the large pages
  - Unmapping some 4k page
  - Changing protection to RO
  - Performance degradation
  - Need to allocate page tables for the 4KB or 2MB levels

Direct map fragmentation

```
struct page *page = alloc_page(GFP_KERNEL);

/* physical address of the page is 0x1c004000 */
set_direct_map_invalid_noflush(page);
```



Example use-cases

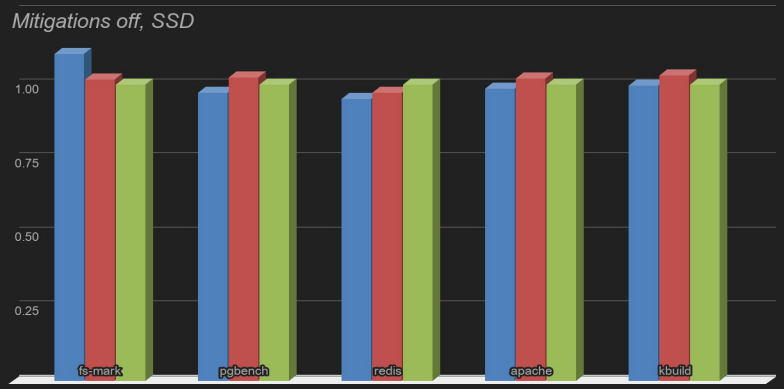
- Modules/BPF/ftrace/kprobes
  - `set_memory_ro()` callers today
- memfd_secret
  - https://git.kernel.org/torvalds/c/1507f51255c9ff07d75909a84e7c0d7f3c4b2f49
- Protecting page tables with PKS
  - https://lore.kernel.org/all/20210830235927.6443-1-rick.p.edgecombe@intel.com
- AMD Secure Nested Paging (SEV-SNP) Hypervisor Support
  - https://lore.kernel.org/all/20210820155918.7518-1-brijesh.singh@amd.com

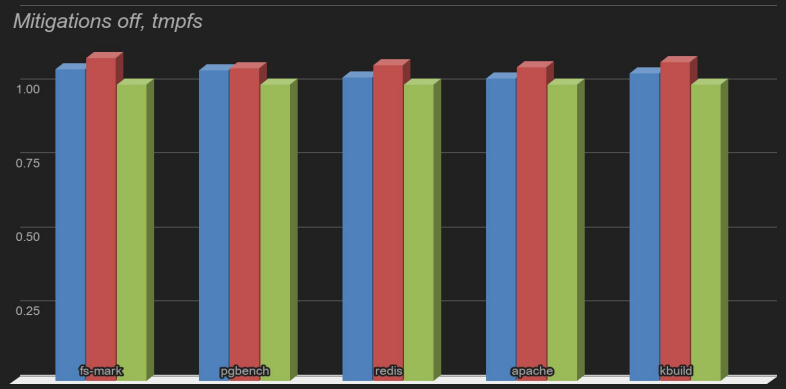
Direct map fragmentation benchmarks

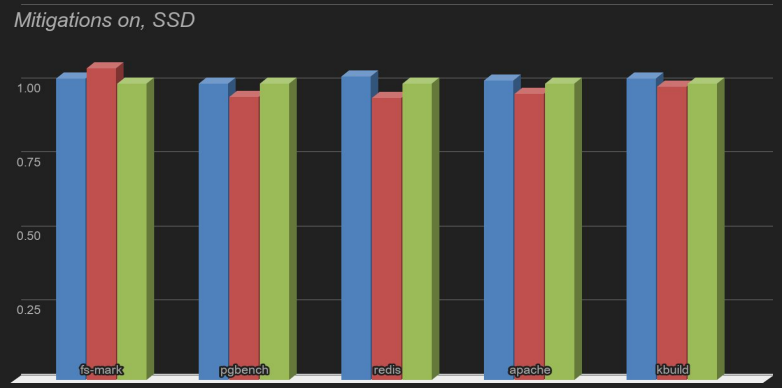
- System: ThinkPad T480, Intel i7-8650U CPU, 32 GBytes of RAM
- Benchmarks: fs-mark, pgbench, redis, apache, kbuild
- Variants:
  - SSD vs tmpfs
  - HW vulnerabilities mitigations on vs off

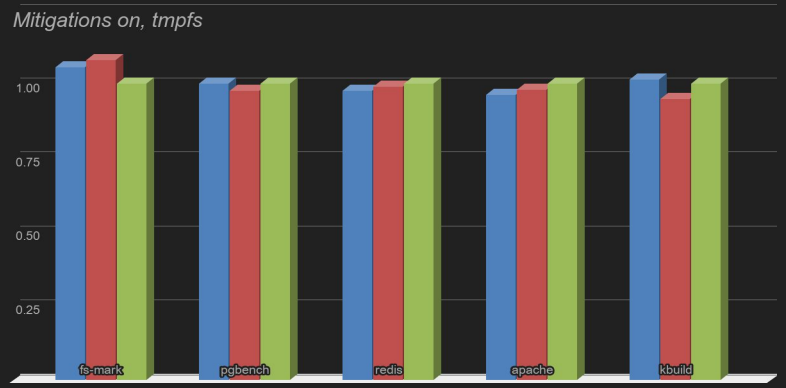
- More comprehensive tests:
  https://lore.kernel.org/linux-mm/213b4567-46ce-f116-9cdf-bbd0c884eb3c@linux.intel.com/

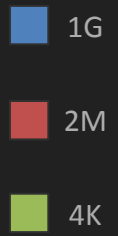
Direct map fragmentation benchmarks











Direct map management

- Reuse split large pages that are split anyway
  - Allocate large physically contiguous page
  - Cache large pages removed from the direct map
  - Resort to base page allocations as a fallback
- Cache design alternatives:
  - A cache (per user?) on top of page allocator
  - An extension to page allocator

  RFC: https://lore.kernel.org/all/20210823132513.15836-1-rppt@kernel.org/

Cache design alternatives

Per-user caches

+ Simpler implementation
+ Better access control
  - Easier cache management

– Larger memory overhead
– Higher fragmentation
– Freeing via dedicated API

Page allocator extension

– More intrusive changes
– Cache is a black box
  - Allocations are unmovable

+ More memory efficient
+ Lower fragmentation
+ Core MM integration

Thank you!