# Cracking the Pixel 8: Exploiting the Undocumented DSP to Bypass MTE

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# About us

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# Agenda

- **Backgrounds**
- Bug analysis
- DSP exploit
- MTE on Android
- Conclusion

# Android Kernel mitigations

- Android 14 kernel (5.4/5.10/5.15/6.1/6.6)
- PAN/PXN
- UAO
- CFI
- PAC
- MTE
- KASLR
- CONFIG_INIT_STACK_ALL_ZERO
- CONFIG_INIT_ON_ALLOC_DEFAULT_ON
- CONFIG_DEBUG_LIST/CONFIG_SLAB_FREELIST_RANDOM/…
- Vendor independent mitigations (KNOX/DEFEX/PhysASLR/…)

# Android exploits

- Universal exploit
- Chipset specific exploit
- Vendor specific exploit
- Model specific exploit

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  - Linux kernel bugs: net, binder, etc…
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  - Pixel X driver A, Samsung [A/S/Z] XX driver B, etc…

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  - Pixel X driver A, Samsung [A/S/Z] XX driver B, etc…

# Pixel Driver Attack Surfaces

- Pixel TPU(edgeTPU)
- Pixel LWIS(Lightweight image processing)
- Pixel GXP(DSP)
- Pixel GPU(Mali Pixel)

# Why Pixel GXP?

- First introduced in Pixel 7 (2022)
- No public informations
- No developer toolchains
- No past CVEs or exploits

# Why Pixel GXP?

- GXP can be used by untrusted_app context
- sesearch --allow policy -s untrusted_app -t gxp_device
- allow untrusted_app_all gxp_device:chr_file { getattr ioctl map read write };

# Why Pixel GXP?

- If you look carefully, you will find untrusted_app context do not have open permissions
- allow untrusted_app_all edgetpu_app_service:service_manager find;
- allow edgetpu_app_server gxp_device:chr_file { append getattr ioctl lock map open read watch watch_reads write };

# Why Pixel GXP?

- We can make edgetpu service send driver fd back
- untrusted_app open /vendor/lib64/libedgetpu_client.google.so to call GetDspFd that interact with com.google.edgetpu.IEdgeTpuAppService
- Everything looks fine here.

```
v19[1] = *(_QWORD *)(_ReadStatusReg(ARM64_SYSREG(3, 3, 13, 0, 2)) + 40);
v16 = 0LL;
v17 = 0LL;
v18[0] = AServiceManager_getService("com.google.edgetpu.IEdgeTpuAppService/default");
aidl::com::google::edgetpu::IEdgeTpuAppService::fromBinder(&v16, v18);
v3 = v18[0];
if ( v18[0] )
  AIBinder_decStrong(v18[0]);
```

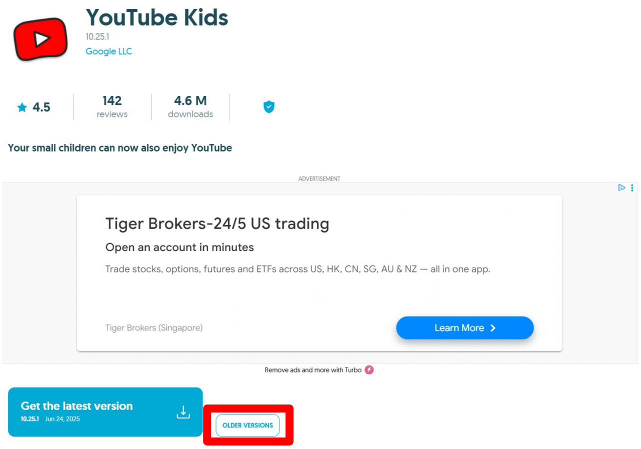
# Why Pixel GXP?

- But edgetpu_app_server won't simply pass the fd to us xD
- It will check the calling process's signature, only those in allowlist will get fd

```
((void (__fastcall *)(void **, char *, __int64))loc_E5E0)(&v377, v515, 1LL);
((void (__fastcall *)(char *, const char *))loc_9170)(
  v513,
  "10:39:38:EE:45:37:E5:9E:8E:E7:92:F6:54:50:4F:B8:34:6F:C6:B3:46:D0:BB:C4:41:5F:C3:39:FC:FC:8E:C1");
((void (__fastcall *)(void **, char *, __int64))loc_E5E0)(&v379, v513, 1LL);
((void (__fastcall *)(_BYTE *, const char *, void **))loc_E670)(v603, "com.google.android.apps.youtube.kids", &v377);
((void (__fastcall *)(char *, const char *))loc_9170)(
  v509,
  "A2:A1:AD:7B:A7:F4:1D:FC:A4:51:4E:2A:FE:B9:06:91:71:9A:F6:D0:FD:BE:D4:B0:9B:BF:0E:D8:97:70:1C:EB");
((void (__fastcall *)(char *, const char *))loc_9170)(
  v511,
  "6A:2F:65:EC:69:4A:6A:63:2A:CD:CB:50:80:91:2A:56:5F:90:3D:4B:8D:83:F0:EB:8E:44:FB:DF:26:60:D8:E1");
((void (__fastcall *)(void **, char *, __int64))loc_E5E0)(&v373, v509, 2LL);
((void (__fastcall *)(char *, const char *))loc_9170)(
  v505,
  "CA:7C:DF:89:09:2B:2C:18:5F:D3:41:35:C2:7A:F8:90:36:48:90:06:3D:88:47:47:80:DF:65:A5:68:5C:D3:11");
((void (__fastcall *)(char *, const char *))loc_9170)(
  v507,
  "A0:E1:39:06:55:CB:DC:4A:77:FC:0E:50:9F:BC:0E:80:6B:A4:4F:93:C5:2D:63:62:C2:EC:17:BF:97:C4:67:97");
((void (__fastcall *)(void **, char *, __int64))loc_E5E0)(&v375, v505, 2LL);
((void (__fastcall *)(_BYTE *, const char *, void **))loc_E670)(v604, "com.google.android.apps.youtube.music", &v373);
((void (__fastcall *)(char *, const char *))loc_9170)(
```

# Why Pixel GXP?

- But with code execution in those apps we can still reach the attack surface
- The Signature check do not prevent us from installing Older/Vulnerable versions of allow list apps
- A lot of apps in the allowlist are not installed by default, which means the “Downgrade mitigation” also not work for us.



# Pixel GXP Introduce

- GXP replaces the GPU in many common image processing steps, such as deblurring and local tone mapping
- It closely collaborates with the existing EdgeTPU on Pixel devices to optimize performance and efficiency.

```c
/* get tpu mailbox register base */
ret = of_property_read_u64_index(np, "reg", 0, &base_addr);
of_node_put(np);
if (ret) {
    dev_warn(dev, "Unable to get tpu-device base address\n");
    goto out_not_found;
}
/* get gxp-tpu mailbox register offset */
ret = of_property_read_u64(dev->of_node, "gxp-tpu-mbx-offset", &offset);
if (ret) {
    dev_warn(dev, "Unable to get tpu-device mailbox offset\n");
    goto out_not_found;
}
gxp->tpu_dev.dev = get_device(&tpu_pdev->dev);
gxp->tpu_dev.mbx_paddr = base_addr + offset;
return;
```

# Pixel GXP Introduce

- Google's Camera app can directly take advantage of GXP to do acceleration
  - allow google_camera_app gxp_device:chr_file { append getattr ioctl lock map open read watch watch_reads write };
- Interestingly, the Google TPU share exactly the same policy as GXP
  - allow google_camera_app edgetpu_device:chr_file { getattr ioctl map read write };
  - allow appdomain binderservicedomain:binder { call transfer };
  - allow appdomain binderservicedomain:fd use;
  - allow untrusted_app_all edgetpu_device:chr_file { getattr ioctl map read write };

# Pixel GXP Introduce

- For edgeTPU and GXP, the difference is edgeTPU has **one** reported bug
  - CVE-2023-35645

EdgeTpu

Pixel Update Bulletin—October 2023 | Android Open Source Project

Android Open Source Project › docs › security › bulletin › pixel

1 Oct 2023 ... **Edgetpu**. CVE-2023-35654, A-272492131 *, EoP, Moderate, vl53l1 driver. CVE-2023-35655, A-264509020*, EoP, Moderate, Darwinn. CVE-2023-35660, A- ...

Search for **EdgeTpu** on Google

# Pixel GXP Introduce

- For edgeTPU and GXP, the difference is edgeTPU has one reported bug
  - [CVE-2023-35645]()

```
+#if LINUX_VERSION_CODE < KERNEL_VERSION(5, 8, 0)
+       down_read(&current->mm->mmap_sem);
+#else
+       mmap_read_lock(current->mm);
+#endif
        ret = pin_user_pages(host_addr & PAGE_MASK, num_pages, foll_flags,
                             pages, vmas);
+#if LINUX_VERSION_CODE < KERNEL_VERSION(5, 8, 0)
+       up_read(&current->mm->mmap_sem);
+#else
+       mmap_read_unlock(current->mm);
+#endif
```

# XPU Attach Surfaces

- We didn’t find this kind of bug in GXP
- But there’s many research on other different coprocessors
  - Mali GPU
  - Qualcomm GPU
  - Qualcomm DSP
  - Lwis (Pixel light weight image processing)
  - Samsung Exynos NPU
  - Samsung Exynos GPU
  - …
- Can we migrate ideas from “XPU” attack to get easy win?

# XPU Attach Surfaces

- Write to Read-Only Files
  - E.g: CVE-2022-0847 (dirtypipe)

```
diff --git a/lib/iov_iter.c b/lib/iov_iter.c
index b364231..1b0a349 100644
--- a/lib/iov_iter.c
+++ b/lib/iov_iter.c
@@ -407,6 +407,7 @@ static size_t copy_page_to_iter_pipe(struct page *page, size_t offset, size_t by
 		return 0;

 	buf->ops = &page_cache_pipe_buf_ops;
+	buf->flags = 0;
 	get_page(page);
 	buf->page = page;
 	buf->offset = offset;
@@ -543,6 +544,7 @@ static size_t push_pipe(struct iov_iter *i, size_t size,
 			break;

 		buf->ops = &default_pipe_buf_ops;
+		buf->flags = 0;
 		buf->page = page;
 		buf->offset = 0;
 		buf->len = min_t(ssize_t, left, PAGE_SIZE);
```

# XPU Attach Surfaces

- Write on Read-Only memory
    - E.g: [CVE-2021-28664](CVE-2021-28664)

```
#if KERNEL_VERSION(4, 6, 0) > LINUX_VERSION_CODE
    faulted_pages = get_user_pages(current, current->mm, address, *va_pages,
#if KERNEL_VERSION(4, 4, 168) <= LINUX_VERSION_CODE && \
KERNEL_VERSION(4, 5, 0) > LINUX_VERSION_CODE
            reg->flags & KBASE_REG_CPU_WR ? FOLL_WRITE : 0,
            pages, NULL);
#else
            reg->flags & KBASE_REG_CPU_WR, 0, pages, NULL);
#endif
#elif KERNEL_VERSION(4, 9, 0) > LINUX_VERSION_CODE
    faulted_pages = get_user_pages(address, *va_pages,
            reg->flags & KBASE_REG_CPU_WR, 0, pages, NULL);
#else
    faulted_pages = get_user_pages(address, *va_pages,
            reg->flags & KBASE_REG_CPU_WR ? FOLL_WRITE : 0,
            pages, NULL);
#endif
```

```
    write = reg->flags & (KBASE_REG_CPU_WR | KBASE_REG_GPU_WR);

#if KERNEL_VERSION(4, 6, 0) > LINUX_VERSION_CODE
    faulted_pages = get_user_pages(current, current->mm, address, *va_pages,
#if KERNEL_VERSION(4, 4, 168) <= LINUX_VERSION_CODE && \
KERNEL_VERSION(4, 5, 0) > LINUX_VERSION_CODE
            write ? FOLL_WRITE : 0, pages, NULL);
#else
            write, 0, pages, NULL);
#endif
#elif KERNEL_VERSION(4, 9, 0) > LINUX_VERSION_CODE
    faulted_pages = get_user_pages(address, *va_pages,
            write, 0, pages, NULL);
#else
    faulted_pages = get_user_pages(address, *va_pages,
            write ? FOLL_WRITE : 0, pages, NULL);
#endif
```

# XPU Attach Surfaces

- Dangling PTE Page UaF
  - E.g: CVE-2022-36449

```
if (ioctl(mali_fd, KBASE_IOCTL_MEM_IMPORT, &mi) < 0) {
    err(1, "[!] mem_import failed %lx\n", cpu_rw);
}

uint64_t gpu_mapping = (uint64_t)mmap(NULL, MAP_SIZE, PROT_READ | PROT_WRITE, MAP_SHARED, mali_fd, mi.out.gpu_va);
if ((void *)gpu_mapping == MAP_FAILED) {
    err(1, "[!] gpu mapping failed\n");
}

uint64_t jc = map_resource_job(mali_fd, atom_number++, (uint64_t)gpu_mapping);
// access it
printf("[+] access mapping and trigger page fault: 0x%lx\n", *(uint64_t *)gpu_mapping);

/*
    unmap cpu_rw and release softjob, then trigger shrinker, CVE-2022-22706
    gpu mapping being shrinked, but cpu mapping not handled, physical page could be reclaimed
*/
munmap((void *)cpu_rw, MAP_SIZE);
release_resource_job(mali_fd, atom_number++, jc);
```

# XPU Attach Surfaces

- Shrinker Page UaF
  - E.g: CVE-2024-32929

```
for (i = 0; i < info->live_ranges_count; ++i)
{
        struct kbase_va_region *reg;
        u64 size;
        u64 va;
        u32 index = info->live_ranges[i].index;

        if (unlikely(index >= info->buffer_count))
                continue;

        size = info->buffer_sizes[index];
        va = info->buffer_va[index];

        reg = gpu_slc_get_region(kctx, va);
        if(!reg)
                continue;
```

# XPU Attach Surfaces

- Shrinker Page UaF
  - E.g: CVE-2024-32929

```diff
 /**
@@ -59,7 +59,7 @@
  */
 static void gpu_slc_unlock_as(struct kbase_context *kctx)
 {
-	kbase_gpu_vm_unlock(kctx);
+	kbase_gpu_vm_unlock_with_pmode_sync(kctx);
 	up_write(kbase_mem_get_process_mmap_lock());
 }

@@ -97,6 +97,12 @@
 	/* Validate the region */
 	if (kbase_is_region_invalid_or_free(reg))
 		goto invalid;
+	/* Might be shrunk */
+	if (kbase_is_region_shrinkable(reg))
+		goto invalid;
+	/* Driver internal alloc */
+	if (kbase_va_region_is_no_user_free(reg))
+		goto invalid;
```

# Agenda

- Backgrounds
- **Bug analysis**
- DSP exploit
- MTE on Android
- Conclusion

# Bug analysis

- In function gxp_mapping_create, the foll_flags not associated with the dir user passed

```c
struct gxp_mapping *gxp_mapping_create(struct gxp_dev *gxp,
                                       struct gcip_iommu_domain *domain,
                                       u64 user_address, size_t size, u32 flags,
                                       enum dma_data_direction dir)
{
```

```c
	vma = find_extend_vma(current->mm, user_address & PAGE_MASK);
	if (vma) {
		if (!(vma->vm_flags & VM_WRITE))
			foll_flags &= ~FOLL_WRITE;
	} else {
		dev_dbg(gxp->dev,
			"unable to find address in VMA, assuming buffer writable");
	}
	mmap_read_unlock(current->mm);

```

```c
	mapping->dir = dir;
	ret = sg_alloc_table_from_pages(&mapping->sgt, pages, num_pages, 0,
					num_pages * PAGE_SIZE, GFP_KERNEL);
```

# Bug analysis

- which means device might can still write to this device, thus we can write a read-only region in AP by device.

```c
struct gxp_mapping *gxp_mapping_create(struct gxp_dev *gxp,
                                        struct gcip_iommu_domain *domain,
                                        u64 user_address, size_t size, u32 flags,
                                        enum dma_data_direction dir)
{
```

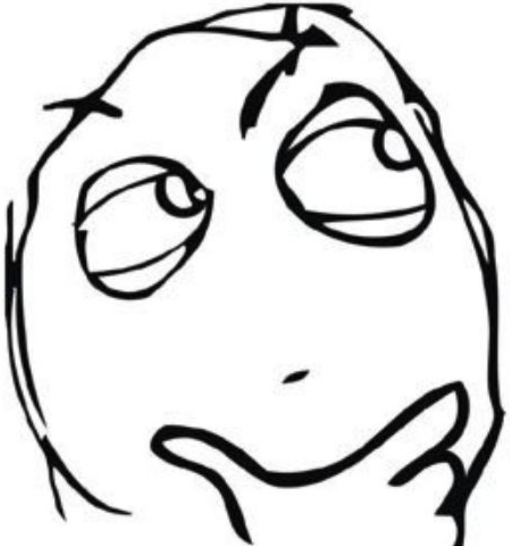
```c
        vma = find_extend_vma(current->mm, user_address & PAGE_MASK);
        if (vma) {
                if (!(vma->vm_flags & VM_WRITE))
                        foll_flags &= ~FOLL_WRITE;
        } else {
                dev_dbg(gxp->dev,
                        "unable to find address in VMA, assuming buffer writable");
        }
        mmap_read_unlock(current->mm);

```

```c
        mapping->dir = dir;
        ret = sg_alloc_table_from_pages(&mapping->sgt, pages, num_pages, 0,
                                        num_pages * PAGE_SIZE, GFP_KERNEL);
```

# Proof-Of-Concept

- We have an “in theory” write read-only bug now
- But how to prove?



# Proof-Of-Concept

- Let’s take a step back
- If we have a write read-only bug on GPU, how to verify?

# Proof-Of-Concept

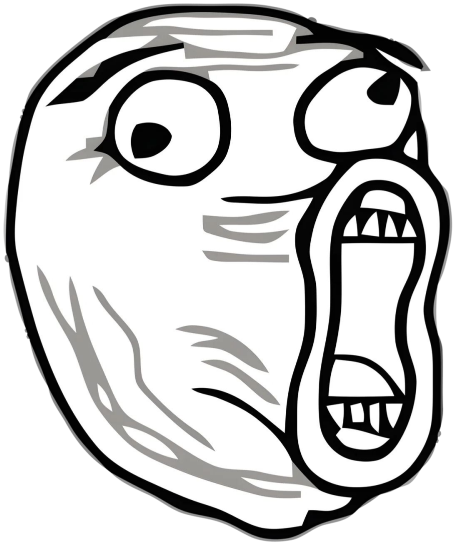
- Write read-only on import memory from CPU side
  - Create a CPU read-only memory cpu_ro
  - Import to GPU side and create cpu_rw mapping by bug
  - Directly write to cpu_rw

# Proof-Of-Concept

- Write read-only on import memory from GPU side
  - Create a CPU read-only memory cpu_ro
  - Import to GPU side and it’s marked as rw in GPU MMU
  - Use OpenCL/Reversed ioctl to submit GPU write request (a bit more complex, but not much)

# Proof-Of-Concept

- How about our case?
  - Gxp support import pages, but it won't remap to another CPU address
  - Gxp don't have public infos or toolchains, there's no OpenCL for Gxp to use



# First Attempt

- Emulation
  - Even if there’s no OpenCL, maybe we can find the firmware of the GXP
  - Use qemu to emulate the GXP firmware
  - Reverse firmware to find the place of write memory handler
  - Use qemu to verify our test.
  - Let’s go!

# First Attempt

- Emulation
- The firmware init by init_mcu_firmware_buf

```c
int gxp_mcu_firmware_init(struct gxp_dev *gxp, struct gxp_mcu_firmware *mcu_fw)
{
    static const struct gcip_image_config_ops image_config_parser_ops = {
        .map = image_config_map,
        .unmap = image_config_unmap,
    };
    int ret;

    ret = gcip_image_config_parser_init(
        &mcu_fw->cfg_parser, &image_config_parser_ops, gxp->dev, gxp);
    if (unlikely(ret)) {
        dev_err(gxp->dev, "failed to init config parser: %d", ret);
        return ret;
    }
    ret = init_mcu_firmware_buf(gxp, &mcu_fw->image_buf);
    if (ret) {
        dev_err(gxp->dev, "failed to init MCU firmware buffer: %d",
            ret);
        return ret;
    }
```

# First Attempt

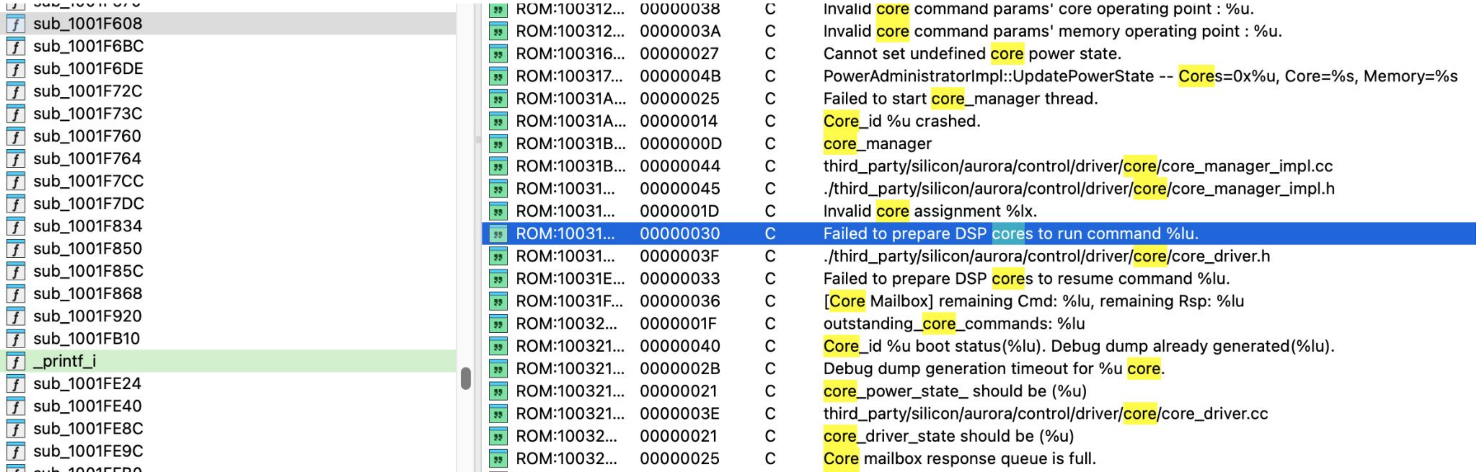
- Emulation
- By dumping the buf->vaddr, we can get the firmware

```
static int init_mcu_firmware_buf(struct gxp_dev *gxp,
				 struct gxp_mapped_resource *buf)
{
	struct resource r;
	int ret;

	ret = gxp_acquire_rmem_resource(gxp, &r, "gxp-mcu-fw-region");
	if (ret)
		return ret;
	buf->size = resource_size(&r);
	buf->paddr = r.start;
	buf->daddr = GXP_IREMAP_CODE_BASE;
	buf->vaddr =
		devm_memremap(gxp->dev, buf->paddr, buf->size, MEMREMAP_WC);
	if (IS_ERR(buf->vaddr))
		ret = PTR_ERR(buf->vaddr);
	return ret;
```

# First Attempt

- Emulation
- After load it into IDA, seems this one is what we want, let’s emulate and reverse to get it work!



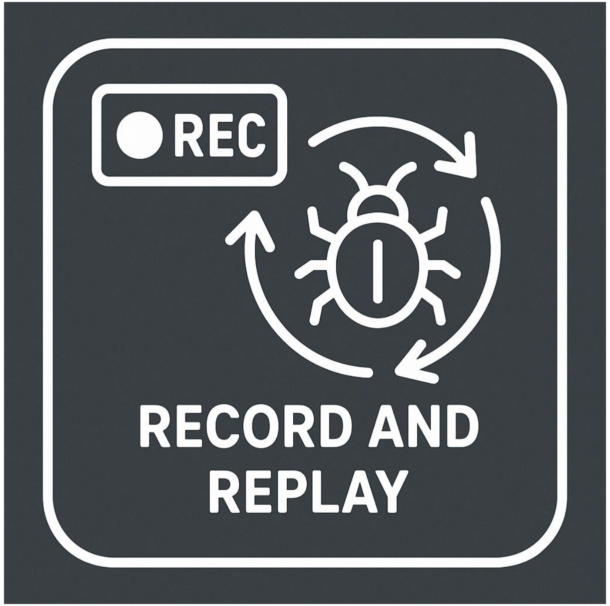
# First Attempt

# Failed First Attempt

- Qemu didn’t support this arch, many instructions just failed or didn’t work as expected even after some patch
- We are a bit lazy to reverse the no symbol firmware xD

# Second Attempt

- Record and Replay
  - Basic idea is using some tool to hook the process using the GXP driver and observe how it send the ioctl to write the memory



# Second Attempt

- Record and Replay
  - First to figure out which app can use gxp device.
  - From previous explore, we already know it's Google Camera and those apps in allow list
  - But to perform record and replay, we better choose the one do the heavy usage on it
  - allow google_camera_app gxp_device:chr_file { append getattr ioctl lock map open read watch watch_reads write }

# Second Attempt

- Record and Replay
  - From google_camera_app process's maps, there is a interesting library named libgxp.so
    **r-xp 00000000 fe:0b 3854 /vendor/lib64/libgxp.so**
  - It should be the core library to use gxp device driver

# Second Attempt

- Record and Replay
  - In libgxp.so, we can roughly know something from function name

| | | |
|---|---|---|
| sub_C6D8C | .text | 0000000000C6D8C |
| GxpCapi_DeviceSpec_SetPrivateMemoryKBPerCore | .text | 0000000000C6DC4 |
| GxpCapi_DeviceSpec_SetSharedMemoryKBPerCore | .text | 0000000000C6DD0 |
| GxpCapi_DeviceSpec_SetCacheableSharedMemoryKBAl... | .text | 0000000000C6DDC |
| GxpCapi_DeviceSpec_SetStackLocation | .text | 0000000000C6DE8 |
| GxpCapi_DeviceSpec_SetDefaultMallocPolicy | .text | 0000000000C6DF4 |
| GxpCapi_DeviceSpec_SetStackSize | .text | 0000000000C6E08 |
| GxpCapi_DeviceSpec_SetMaxMemoryAllocationBlocks | .text | 0000000000C6E14 |
| GxpCapi_DeviceSpec_GetCoreCount | .text | 0000000000C6E20 |
| GxpCapi_DeviceSpec_GetThreadsPerCore | .text | 0000000000C6E2C |
| GxpCapi_DeviceSpec_GetTcmMemoryKBPerCore | .text | 0000000000C6E38 |
| GxpCapi_DeviceSpec_GetPrivateMemoryKBPerCore | .text | 0000000000C6E44 |
| GxpCapi_DeviceSpec_GetSharedMemoryKBPerCore | .text | 0000000000C6E50 |
| GxpCapi_DeviceSpec_GetCacheableSharedMemoryKBA... | .text | 0000000000C6E5C |
| GxpCapi_DeviceSpec_GetMaxMemoryAllocationBlocks | .text | 0000000000C6E68 |
| GxpCapi_Wakelock_GetDevicePowerState | .text | 0000000000C6E74 |
| GxpCapi_Wakelock_GetMemoryPowerState | .text | 0000000000C6E90 |
| GxpCapi_Wakelock_GetCoherentFabricPowerState | .text | 0000000000C6EA0 |
| GxpCapi_Wakelock_GetPowerStateFlags | .text | 0000000000C6EBC |
| GxpCapi_DeviceSpec_GetStackLocation | .text | 0000000000C6ECC |
| GxpCapi_DeviceSpec_GetDefaultMallocPolicy | .text | 0000000000C6EDC |
| GxpCapi_DeviceSpec_GetStackSize | .text | 0000000000C6EE8 |
| GxpCapi_DeviceSpec_GetDeviceFamily | .text | 0000000000C6EF4 |
| GxpCapi_DeviceSpec_SetQoS | .text | 0000000000C6F04 |
| GxpCapi_DeviceSpec_GetQoS | .text | 0000000000C6F10 |
| GxpCapi_DeviceSpec_SetCacheableLibraryDataSection | .text | 0000000000C6F1C |
| GxpCapi_DeviceSpec_GetBufferCoherencySupport | .text | 0000000000C6F2C |
| GxpCapi_DeviceSpec_GetVirtualizationSupport | .text | 0000000000C6F3C |
| GxpCapi_DeviceSpec_GetMaxVirtualDeviceCount | .text | 0000000000C6F4C |
| GxpCapi_DeviceSpec_GetMaxConcurrentVirtualDeviceC... | .text | 0000000000C6F58 |
| GxpCapi_DeviceSpec_SetShared | .text | 0000000000C6F64 |
| GxpCapi_DeviceSpec_GetShared | .text | 0000000000C6F74 |
| GxpCapi_DeviceSpec_SetDeviceId | .text | 0000000000C6F88 |
| GxpCapi_DeviceSpec_SetMcuCoreThrottling | .text | 0000000000C6F94 |
| GxpCapi_DeviceSpec_SetTachyonDevice | .text | 0000000000C6FB8 |
| GxpCapi_QueryDeviceSpec | .text | 0000000000C6FDC |
| GxpCapi_CreateDevice | .text | 0000000000C70D8 |
| GxpCapi_CreateSharedVirtualDevice | .text | 0000000000C712C |
| GxpCapi_ReleaseDevice | .text | 0000000000C717C |
| GxpCapi_CreateBufferOptions | .text | 0000000000C71A8 |

# Second Attempt

- Record and Replay
  - Use Frida to trace the function usage
  - Frida is a dynamic instrumentation toolkit for developers, reverse-engineers, and security researchers

# Second Attempt

- Record and Replay
  - Hook target process's ioctl function call
  - Interceptor.attach(Module.getExportByName(null,  'ioctl')

### Interceptor

- `Interceptor.attach(target, callbacks[, data])`: intercept calls to function at `target`. This is a `NativePointer` specifying the address of the function you would like to intercept calls to. Note that on 32-bit ARM this address must have its least significant bit set to 0 for ARM functions, and 1 for Thumb functions. Frida takes care of this detail for you if you get the address from a Frida API (for example `Module#getExportByName()`).

# Second Attempt

- Record and Replay
  - Hook process's libgxp.so external function call
  - var m = Process.findModuleByName("libgxp.so")
  - for (var i = 0; i < Ex.length; i++) {
    - Interceptor.attach(Module.getExportByName("libgxp.so", Ex[i].name)

### Interceptor

- `Interceptor.attach(target, callbacks[, data])`: intercept calls to function at `target`. This is a `NativePointer` specifying the address of the function you would like to intercept calls to. Note that on 32-bit ARM this address must have its least significant bit set to 0 for ARM functions, and 1 for Thumb functions. Frida takes care of this detail for you if you get the address from a Frida API (for example `Module#getExportByName()`).

# Second Attempt

- Record and Replay
  - With Frida, we can trace how app using ioctl to interact with gxp device
  - With Frida, we can know the correct function sequence to interact with gxp device
  - We just record a successful function calls pattern to reach our vulnerable driver code, which is from GxpCapi_OpenNamedLibraryFromBuffer

```
if( name.indexOf("GxpCapi_OpenNamedLibraryFromBuffer")!=-1){
        //console.log(arg[1].readCString());
            var f = new File("/data/local/tmp/lib8", "wb");
            f.write(arg[1].readByteArray(arg[2].toInt32()));
            console.log("Write lib done");
            trace_ioctl = 1;

} else {
        trace_ioctl = 0;

}
```

# Verify the bug

- Record and Replay
  - Pass read-only memory to GxpCapi_OpenNamedLibraryFromBuffer, we can successfully write our PoC to reproduce write read-only files.

```
shiba:/data/local/tmp # ./poc
Read data before exploit
00000000  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  |................|
00000010  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  |................|
Target host: b400007895a4f080
Read data after exploit
00000000  61 61 61 61 61 61 61 61 61 61 61 61 61 61 61 61  |aaaaaaaaaaaaaaaa|
00000010  61 61 61 61 61 61 61 61 61 61 61 61 61 61 61 61  |aaaaaaaaaaaaaaaa|
shiba:/data/local/tmp #
```

# Bug patch

- Google refactored the whole code in GXP, the driver now will first get the gup_flags from host_address's vma

```
static unsigned int gcip_iommu_get_gup_flags(u64 host_addr, struct device *dev)
{
	struct vm_area_struct *vma;
	unsigned int gup_flags;

	mmap_read_lock(current->mm);
	vma = vma_lookup(current->mm, host_addr & PAGE_MASK);
	mmap_read_unlock(current->mm);

	if (!vma) {
		dev_dbg(dev, "unable to find address in VMA, assuming buffer writable");
		gup_flags = FOLL_LONGTERM | FOLL_WRITE;
	} else if (vma->vm_flags & VM_WRITE) {
		gup_flags = FOLL_LONGTERM | FOLL_WRITE;
	} else {
		gup_flags = FOLL_LONGTERM;
	}

	return gup_flags;
}
```

# Bug patch

- Then it will setup gcip_map_flags based on the gup_flags and pass to gxp mmu setup function

```
if (!(gup_flags & FOLL_WRITE)) {
        gcip_map_flags &= ~(((BIT(GCIP_MAP_FLAGS_DMA_DIRECTION_BIT_SIZE) - 1)
                            << GCIP_MAP_FLAGS_DMA_DIRECTION_OFFSET));
        gcip_map_flags |= GCIP_MAP_FLAGS_DMA_DIRECTION_TO_FLAGS(DMA_TO_DEVICE);
}

sgt = kzalloc(sizeof(*sgt), GFP_KERNEL);
if (!sgt) {
        ret = -ENOMEM;
        goto err_unpin_page;
}

ret = sg_alloc_table_from_pages(sgt, pages, num_pages, 0, num_pages * PAGE_SIZE,
                                GFP_KERNEL);
if (ret) {
        dev_err(domain->dev, "Failed to alloc sgt for mapping (ret=%d)\n", ret);
        goto err_free_table;
}

mapping = gcip_iommu_domain_map_buffer_sgt(domain, sgt, orig_dir, offset, iova,
                                           gcip_map_flags);
```

# Agenda

- Backgrounds
- Bug analysis
- **DSP exploit**
- MTE on Android
- Conclusion

# DSP Exploit

- Write read-only files exploits is already very strong exploit primitive, we can follow the DirtyPipe exploit path on Android
    - Trigger write-ro to overwrite libc++.so
    - Hijack init by setprop and trigger write-ro again to write kernel module payload
    - Fork from init and change context to modprobe and load kernel module
    - Use kernel module to bypass selinux and get root

# DSP Exploit

- Trigger write-ro to overwrite libc++.so
- Hijack init by setprop and trigger write-ro again to write kernel module payload
- 🙅

# DSP Exploit

- In DirtyPipe the bug resides in syscall, and init do not have seccomp
- In our case, the policy is allow init gxp_device:chr_file setattr;

# DSP Exploit

- After some time exploring the selinux policy, we found another path
  - allow hal_camera_default gxp_device:chr_file { append getattr ioctl lock map open read watch watch_reads write };
  - type_transition init hal_camera_default_exec:process hal_camera_default;
  - allow hal_camera_default vendor_file_type:dir { getattr ioctl lock open read search watch watch_reads };
  - allow hal_camera_default vendor_file_type:file { execute getattr map open read };

# DSP Exploit

- So we now need hijack android.hardware.camera.provider to exploit write-ro again to put kernel module payload
  - Android.hardware.camera.provider (hal_camera_default) not like init can be stably triggered by setprop
  - We found that it will automatically do some log when it restarts
  - Maybe we can force restart it and use liblog.so to hijack it?

# DSP Exploit

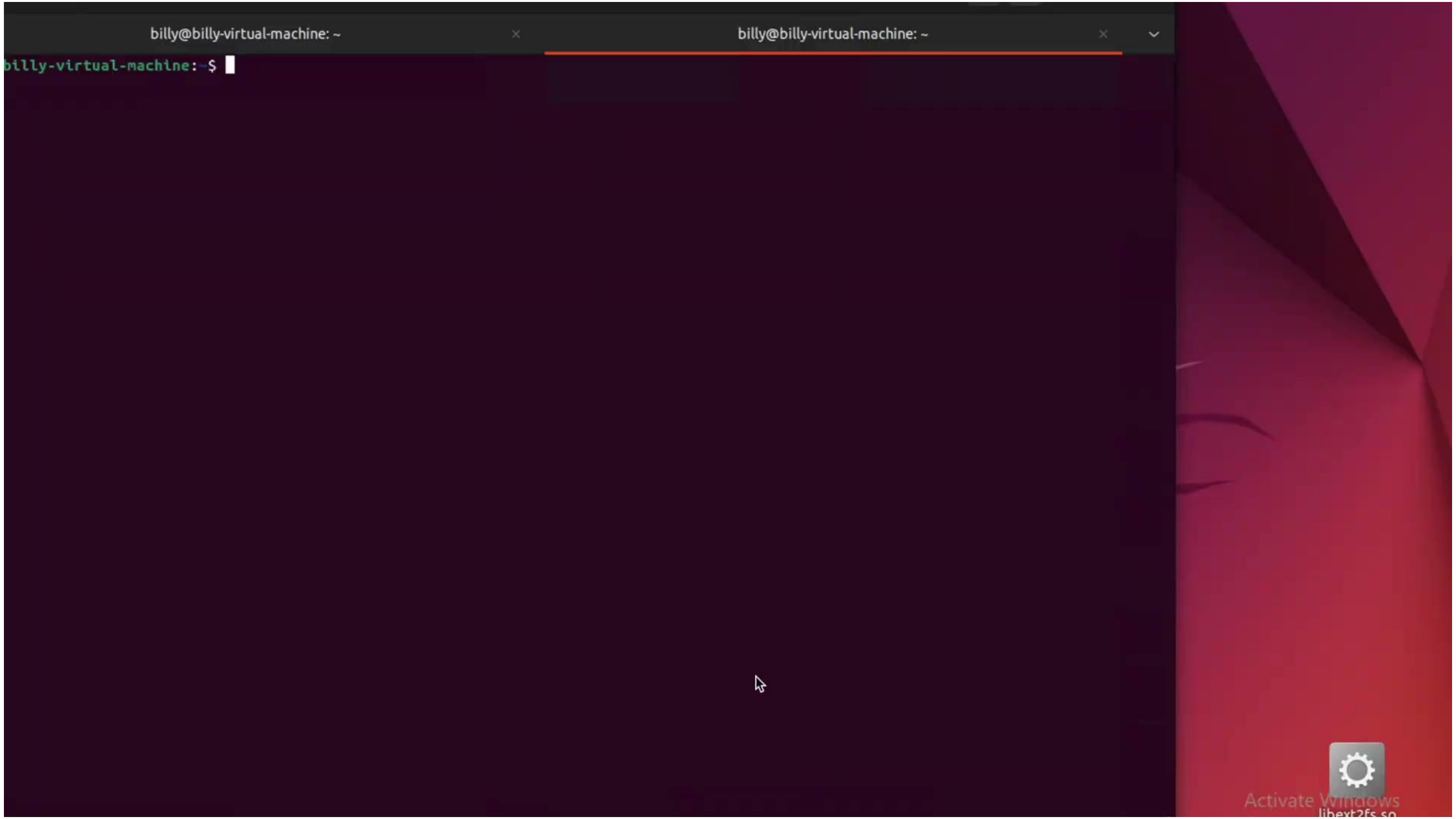
- Force restart android.hardware.camera.provider
  - If attack from untrusted_app, we won't know the pid of it
  - In the hijacked init process, we have namespace isolation, also can't use pidof to get it
- But we found android.hardware.camera.provider is a system service which launched at the early boot stage
- Because of that, the pid of it is in a small range across each boot
- After forcing init to kill the pid range, we can successfully hijack android.hardware.camera.provider to do the second stage attack

# DSP Exploit

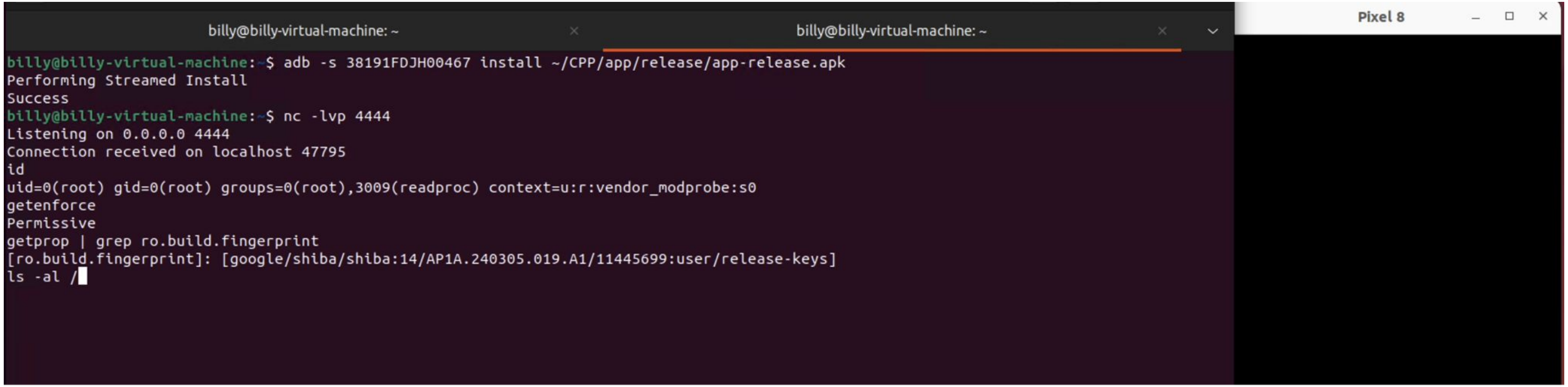
Summary the exploit flow

- Overwrite libext2fs.so with our library's content
- Overwrite libc++.so to hijack init and android.hardware.camera.provider@2.7-service-google
- init kill android.hardware.camera.provider@2.7-service-google to trigger the hijack, the hijack will dlopen libext2fs.so
- android.hardware.camera.provider@2.7-service-google exploit the bug again to overwrite /vendor/bin/modprobe(reverse shell payload) and /vendor/lib64/libExynosC2Vp9Dec.so(kernel module payload)
- Init then execute modprobe to load ko to disable selinux and launch reverse shell

# DSP Exploit Demo



# DSP Exploit Demo



# Agenda

- Backgrounds
- Bug analysis
- DSP exploit
- **MTE on Android**
- Conclusion

# Arm Memory Tagging Extension (MTE)

- The Memory Tagging Extension (MTE) is a security feature on newer Arm processors(Armv8.5a) that uses hardware implementations to check for memory corruptions or other bug types.
- For Android, it first introduced in Pixel8 as a non default feature.
- adb shell setprop arm64.memtag.bootctl memtag,memtag-kernel

# Arm Memory Tagging Extension (MTE)

- It’s been a hot topic for security researchers since first out

The GitHub Blog
https://github.blog › Security › Vulnerability research

**Bypassing MTE with CVE-2025-0072**

23 May 2025 — See how a vulnerability in the Arm Mali GPU can be exploited to gain kernel code execution even when Memory Tagging Extension (**MTE**) is ...

An AI Overview is not available for this search

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The GitHub Blog
https://github.blog › Security › Vulnerability research

**Gaining kernel code execution on an MTE-enabled Pixel 8**

18 Mar 2024 — How does this **bypass MTE**? So far, I've not mentioned any specific measures to **bypass MTE**. In fact, **MTE** does not affect the exploit flow of ...

arXiv
https://arxiv.org › html

**TikTag: Breaking ARM's Memory Tagging Extension with ...**

13 Jun 2024 — We demonstrate that **TikTag gadgets can be used to bypass MTE-based mitigations** in real-world systems, Google Chrome and the Linux kernel.

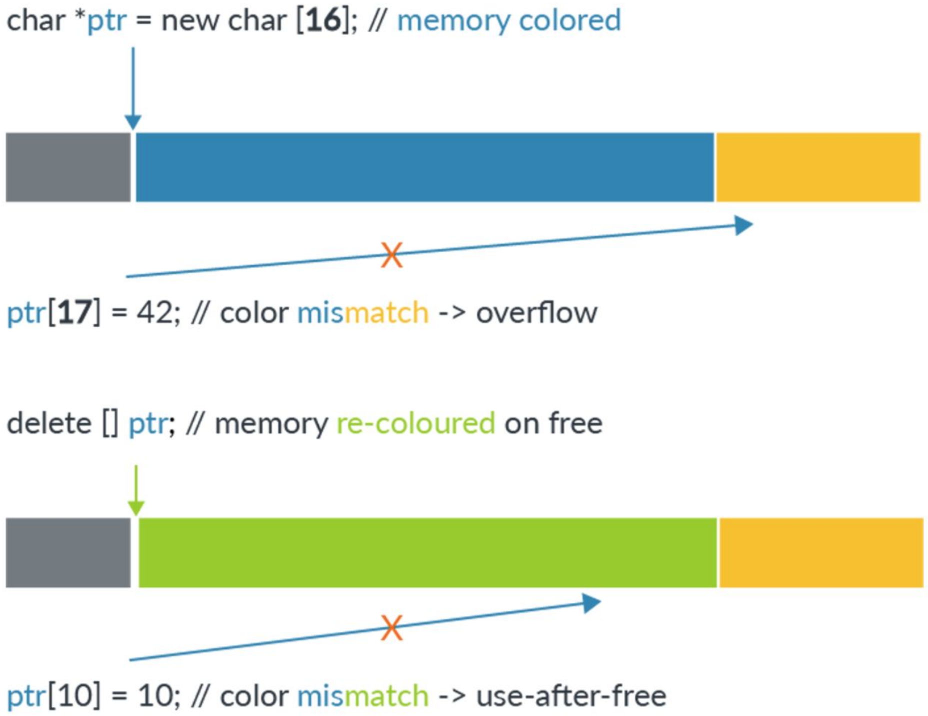
Reddit · r/netsec
2 comments · 11 months ago

**Memory Tag Extensions(MTE) Bypassed In Real World ...**

**MTE is powerful** but it is not intended to be a flawless defense nor is it incredibly widely deployed either in the mobile or server context.

# Arm Memory Tagging Extension (MTE)

- MTE store tags in unused higher bits in address space



# Will MTE end the game in Real World?

- For memory corruption bugs, it seems the end of the game
- But Android is famous for the Lego Ecosystem. Besides Google, there’s Samsung/Xiaomi/Huawei/Vivo/Oppo/Oneplus/…
- Most vendors will choose not open it by default for better performance

# MTE bypass

- MTE is born for memory corruption bugs
- For logic vulnerabilities, MTE can not prevent attacker to do privilege escalate

# Agenda

- Backgrounds
- Bug analysis
- DSP exploit
- MTE on Android
- **Conclusion**

# Conclusion

- Record and replay to break closed source devices
- Page level memory corrupt with coprocessor or logic bugs are also “born to bypass MTE”
- Logic bugs like write read-only will always win if there’s no runtime signature check

# Timeline

- Found bug and write exploit at mid 2024
- Report to Google at Sep 2, 2024
- Asked for non pre-compiled lib at Oct 17, 2024
- Send back new one to Google at Oct 19, 2024
- Google announced bug bounty reward at Nov 9, 2024
- Bug addressed in 25Q1 update of Android release

# Timeline

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- Send back new one to Google at Oct 19, 2024
- Google announced bug bounty reward at Nov 9, 2024
- Bug addressed in 25Q1 update of Android release
- …
- Not the end of story~

# References


- HITCON 2022 - How we use Dirty Pipe to get reverse root shell on Android Emulator and Pixel 6
- Memory Tagging Extension: Enhancing memory safety through architecture
- Two Bugs With One PoC: Rooting Pixel 6 From Android 12 to Android 13
- Dynamic instrumentation toolkit for developers, reverse-engineers, and security researchers.
- Project Zero Race conditions issues for edgeTPU

# Q & A

Thanks for listening