Stumping the Mobile Chipset

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Agenda

- Android chipsets overview in ecosystem
- Qualcomm chipset subsystem’s overview
- New kernel vulnerabilities
- Exploitation of a new kernel vulnerability
- Conclusions

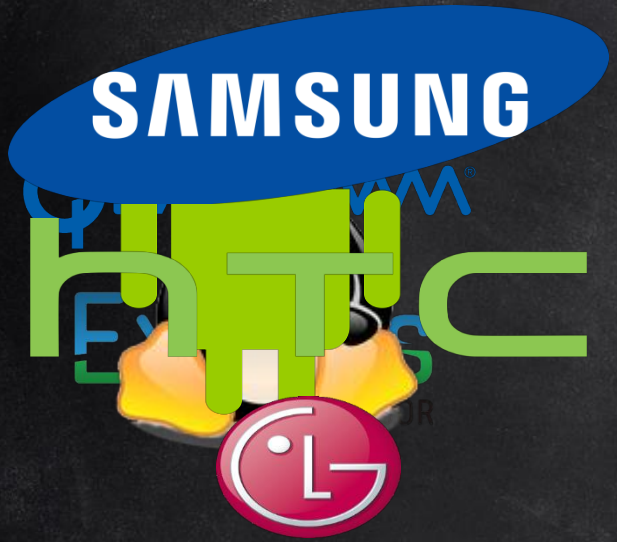
~ $ man Adam

ADAM DONENFELD

- Years of experience in research (both PC and mobile)
- Vulnerability assessment
- Vulnerability exploitation
- Senior security researcher at Check Point
- In meiner Freizeit, lerne ich Deutsch gern ☺

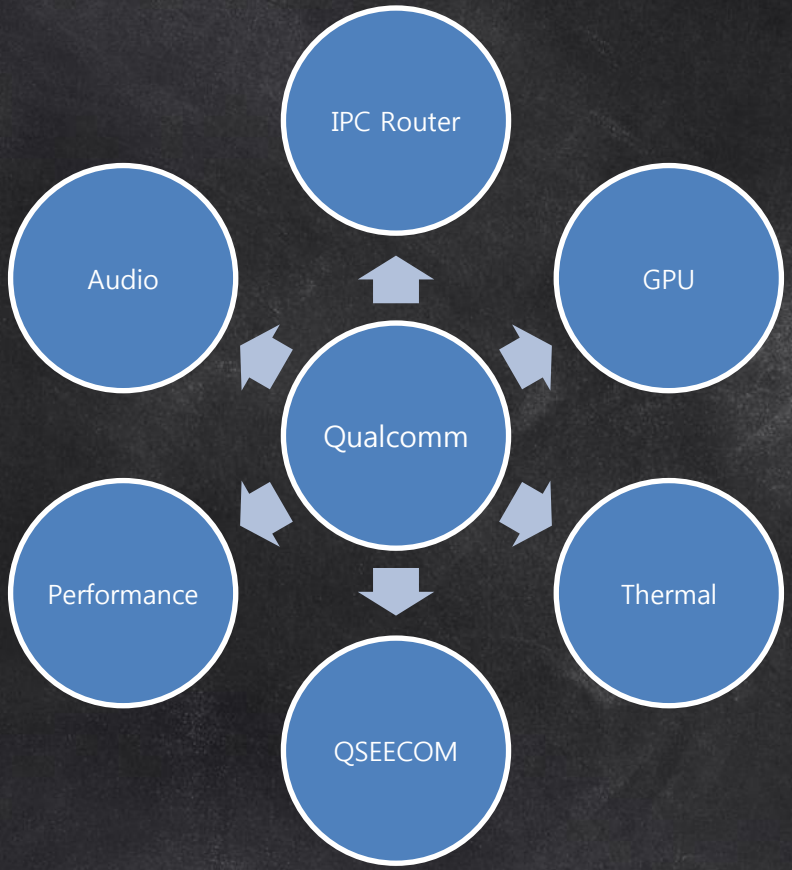
Special thanks to Avi Bashan, Daniel Brodie and Pavel Berengoltz for helping with the research

Android Architecture

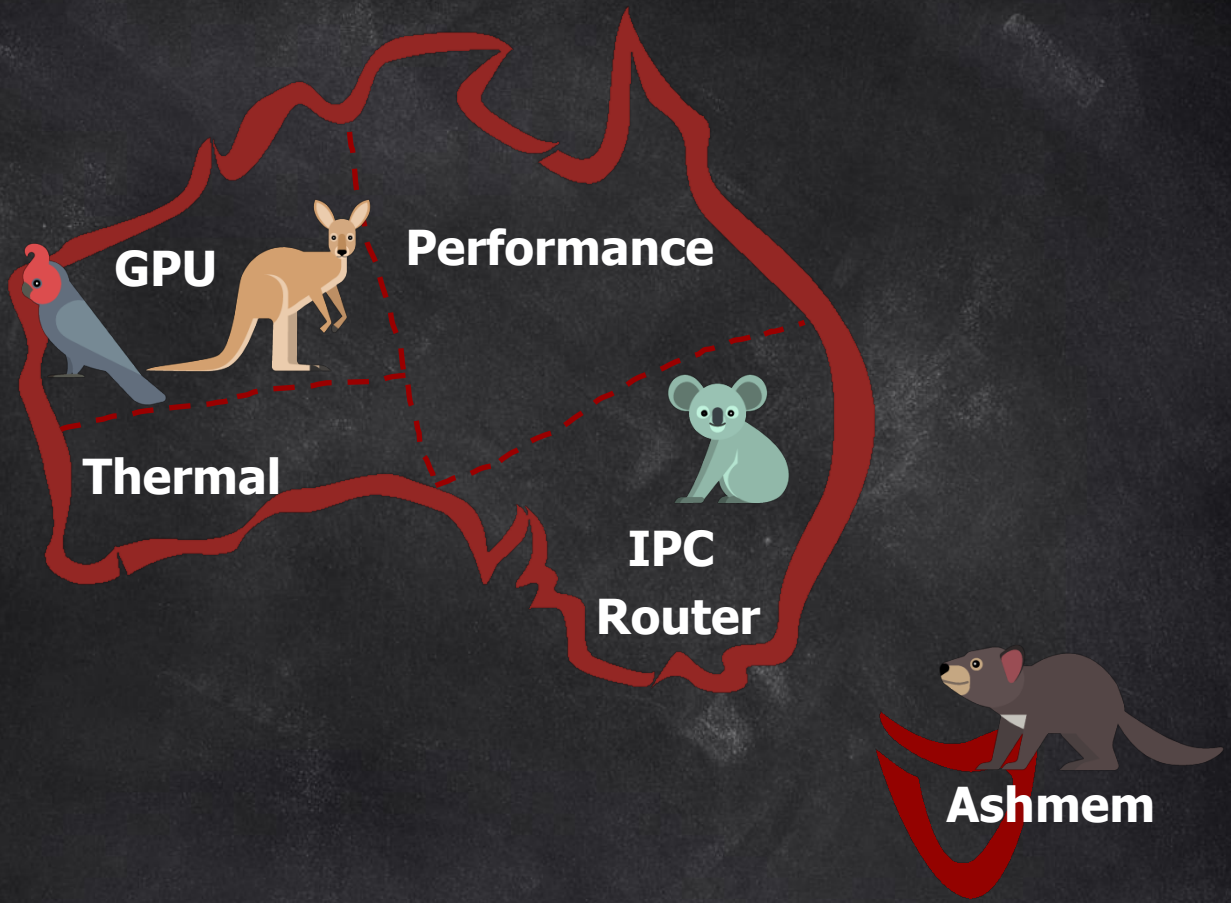


- OEM
- Chipset code
- Android Open Source Project
- Linux Kernel

Qualcomm's chipset subsystems



Welcome to Qualand



ASHmenian Devil (ashmem vulnerability)

CVE-2016-5340

- Ashmem – Android's propriety memory allocation subsystem
- Qualcomm devices uses a modified version
  - Simplifies access to *ashmem* by Qualcomm modules



```
int get_ashmem_file(int fd,
 struct file **filp,
  struct file **vm_file,
     unsigned long *len)
{
     int ret = -1;
     struct ashmem_area *asma;
     struct file *file = fget(fd);
     if (is_ashmem_file(file)) {
          asma = file->private_data;
          *filp = file;
          *vm_file = asma->file;
          *len = asma->size;
          ret = 0;
     } else {
          fput(file);
     }
     return ret;
}
```

Is our fd an ashmem file descriptor?



ASHmenian Devil (ashmem vulnerability)

CVE-2016-5340

- Obtain a file struct from file descriptor
- Compare file operation handlers to expected handler struct
  - If it matches → file type is valid



```c
static int is_ashmem_file(struct file *file)
{
	char fname[256], *name;
	name = dentry_path(file->f_dentry, fname, 256);
	return strcmp(name, "/ashmem") ? 0 : 1; /* Oh my god */
}
```



ASHmenian Devil (ashmem vulnerability)

CVE-2016-5340

- Exploitation requires –
  - Creation of file named “ashmem” on root mount point (“/”)
- / is read-only ☹



ASHmenian Devil - POC

CVE-2016-5340

- Opaque Binary Blob
  - APK Expansion File
  - Support APKs > 100MB
  - Deprecated (still works!)
- A mountable file system

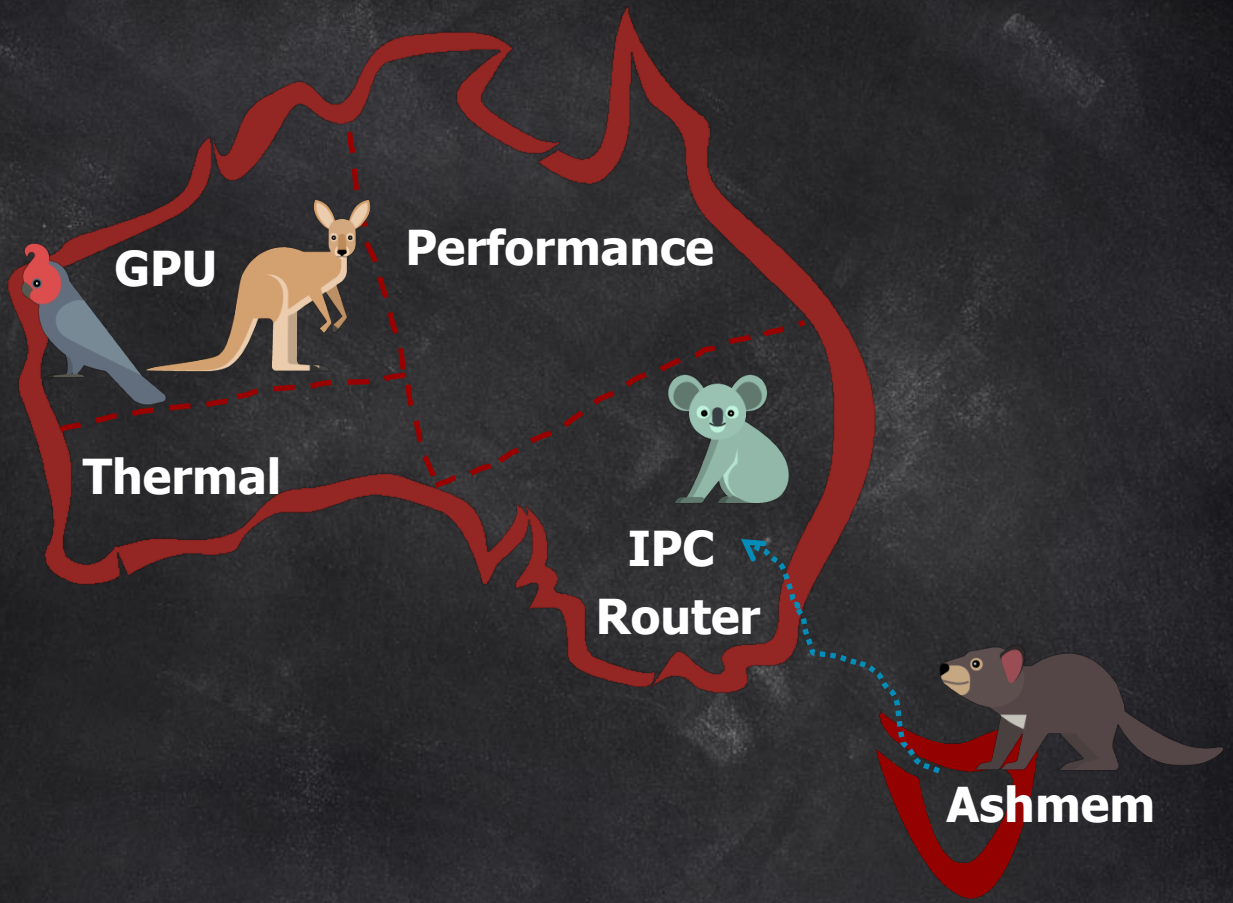


ASHmenian Devil - POC

CVE-2016-5340

- Create an OBB
- Create “ashmem” in it’s root directory
- Mount the OBB
- Map “ashmem” memory to the GPU
  - Pass a fd to the fake ashmem file




GPU
Performance
Thermal
IPC
Router
Ashmem

Qualaroot (IPC Router vulnerability)

CVE-2016-2059

- Qualcomm's IPC router
- Special socket family
  - *AF_MSM_IPC* (27)
- Unique features
  - Whitelist specific endpoints
  - Everyone gets an "address" for communication
  - Creation/destruction can be monitored by anyone
- Requires no permission ☺



Qualaroot (IPC Router vulnerability)

CVE-2016-2059

- *AF_MSM_IPC* socket types
  - *CLIENT_PORT*
  - *CONTROL_PORT*
  - *IRSC_PORT*
  - *SERVER_PORT*

- Each new socket is a *CLIENT_PORT* socket



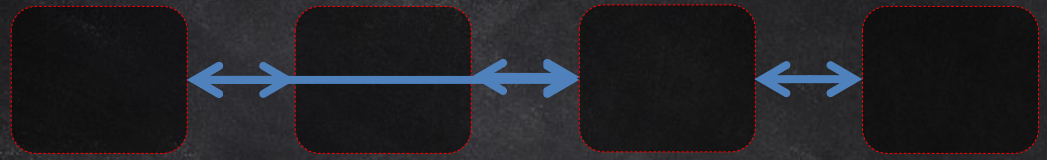
```
static int msm_ipc_router_ioctl(
     struct socket *sock,
     unsigned int cmd,
     unsigned long arg)
{
     struct sock *sk = sock->sk;
     struct msm_ipc_port *port_ptr;

     lock_sock(sk);
     port_ptr = msm_ipc_sk_port(sock->sk);
     switch (cmd) {
     ....
     case IPC_ROUTER_IOCTL_BIND_CONTROL_PORT:
          msm_ipc_router_bind_control_port(
          port_ptr)
     ....
     }
     release_sock(sk);
     ....
}
```



```
int msm_ipc_router_bind_control_port(
struct msm_ipc_port  *port_ptr)
{
     if (!port_ptr)
          return -EINVAL;

     down_write(&local_ports_lock_lhc2);

     list_del(&port_ptr->list);

     up_write(&local_ports_lock_lhc2);

     down_write(&control_ports_lock_lha5);

     list_add_tail(&port_ptr->list, &control_ports);

     up_write(&control_ports_lock_lha5);
     return 0;
}
```



Client list



```
down_write(&local_ports_lock_lhc2);
list_del(&port_ptr->list);
up_write(&local_ports_lock_lhc2);
down_write(&control_ports_lock_lha5);
list_add_tail(&port_ptr->list, &control_ports);
up_write(&control_ports_lock_lha5);
```

Control list





Client list



```
down_write(&local_ports_lock_lhc2);
list_del(&port_ptr->list);
up_write(&local_ports_lock_lhc2);
down_write(&control_ports_lock_lha5);
list_add_tail(&port_ptr->list, &control_ports);
up_write(&control_ports_lock_lha5);
```

Control list





Qualaroot (IPC Router vulnerability)

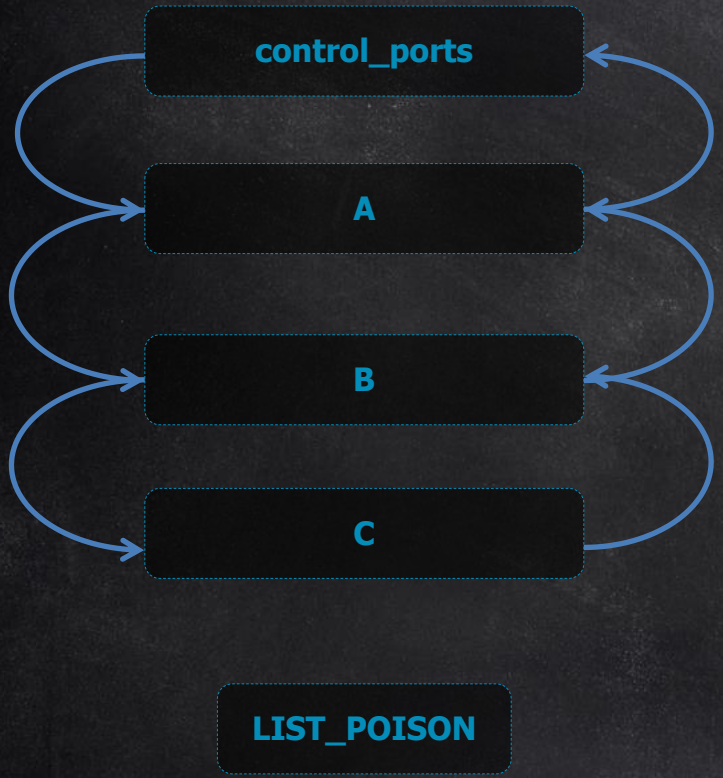
CVE-2016-2059

- *control_ports* list is modified without a lock
- Deleting 2 objects from *control_ports* simultaneously!



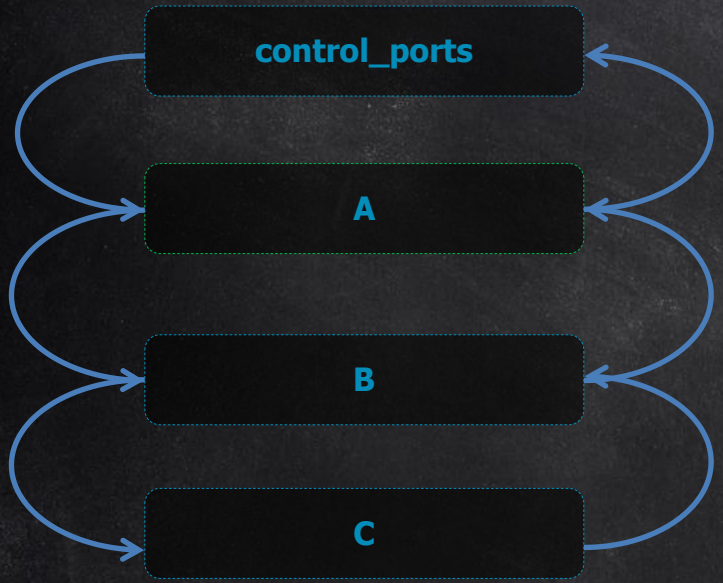


Qualaroot (implementation)




```
static inline void list_del(
      struct list_head * entry)
{
      next = entry->next;
      prev = entry->prev
      next->prev = prev;
      prev->next = next;
      entry->next = LIST_POISON1;
      entry->prev = LIST_POISON2;
}
```

Qualaroot (implementation)



LIST_POISON

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      entry->next = LIST_POISON1;
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}
```

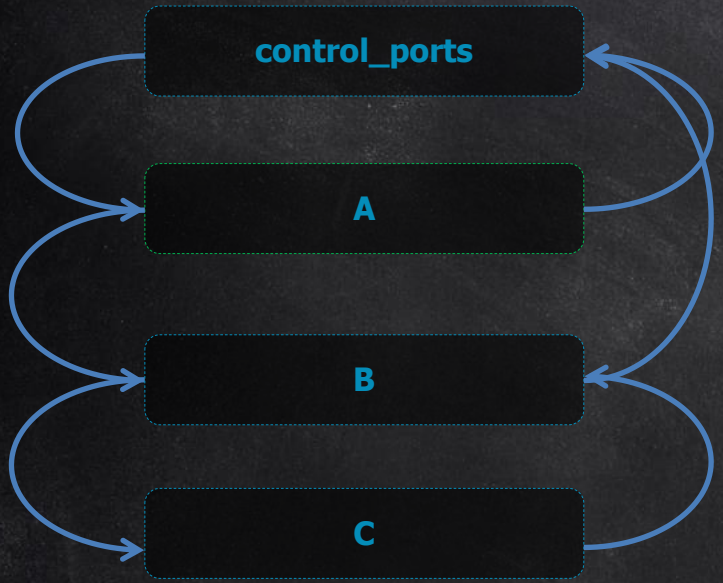
entry = A

next = B

prev = control_ports

B->prev = control_ports

Qualaroot (implementation)



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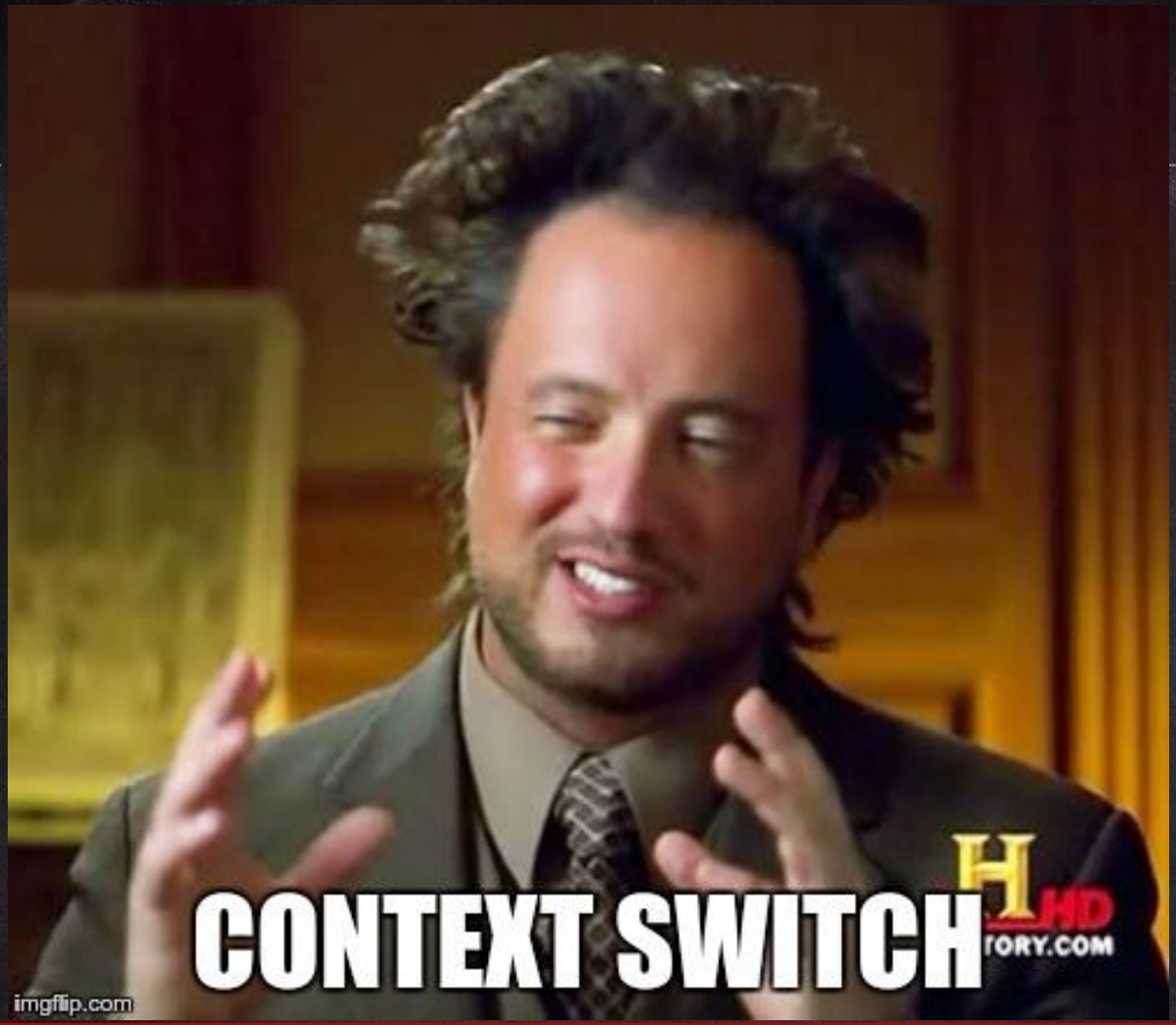
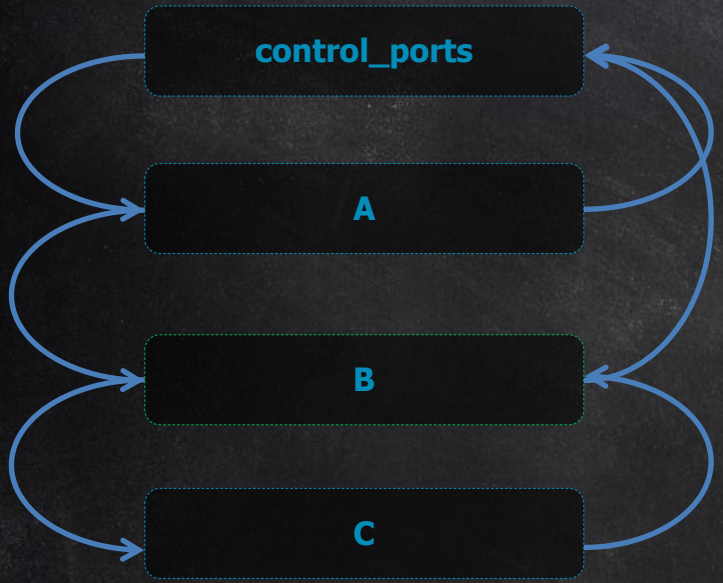

CONTEXT SWITCH
HD
TORY.COM
imgflip.com

Qualaroot (implementation)



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}
```

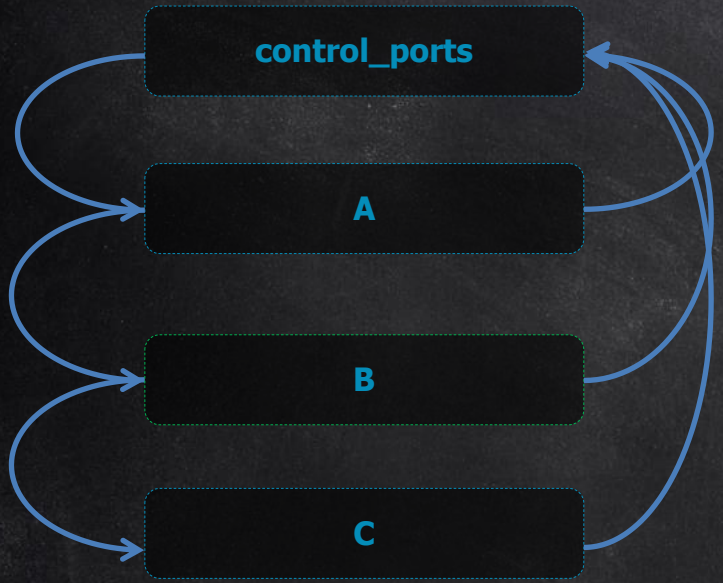
entry = B

next = C

prev = control_ports

C->prev = control_ports

Qualaroot (implementation)



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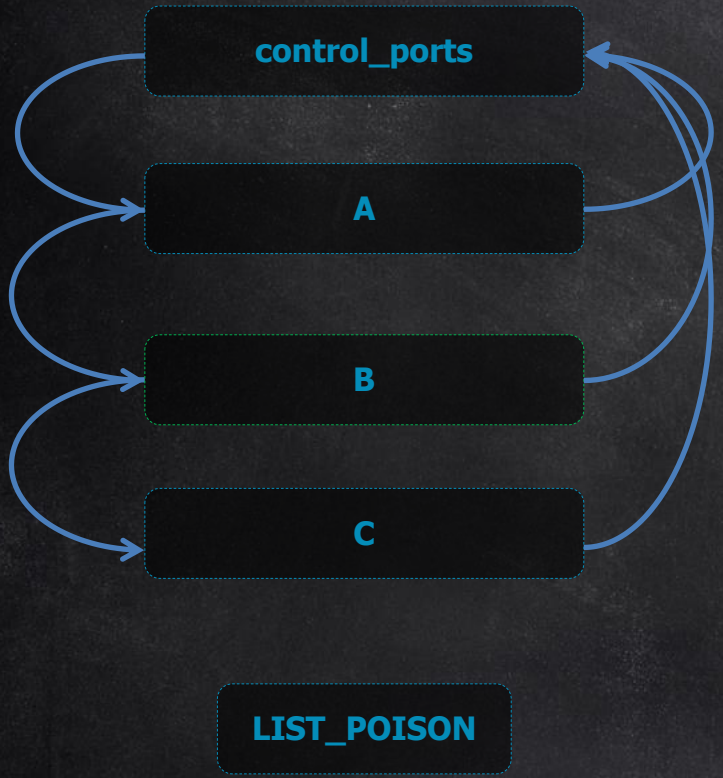


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}
```

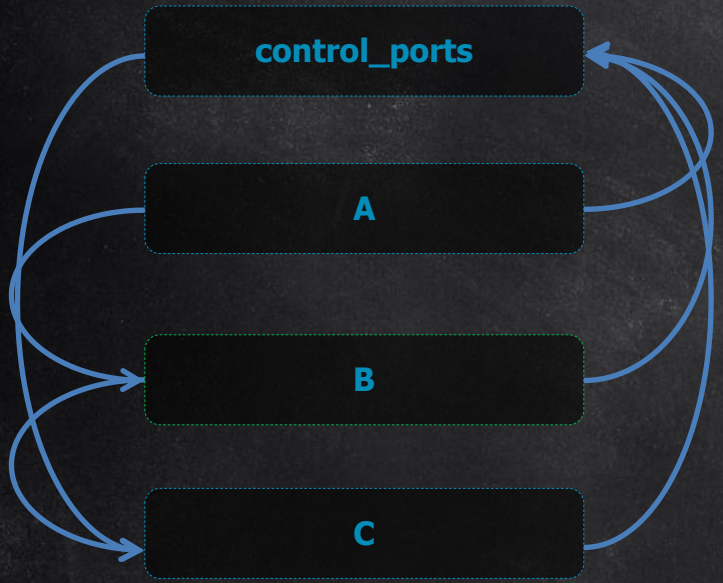
entry = B

next = C

prev = control_ports

control_ports->next = C

Qualaroot (implementation)



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control_ports->next = C

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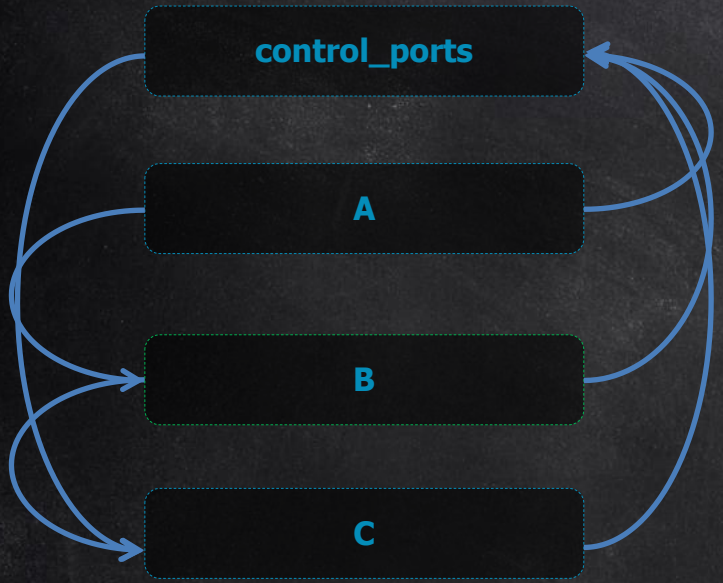

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}
```

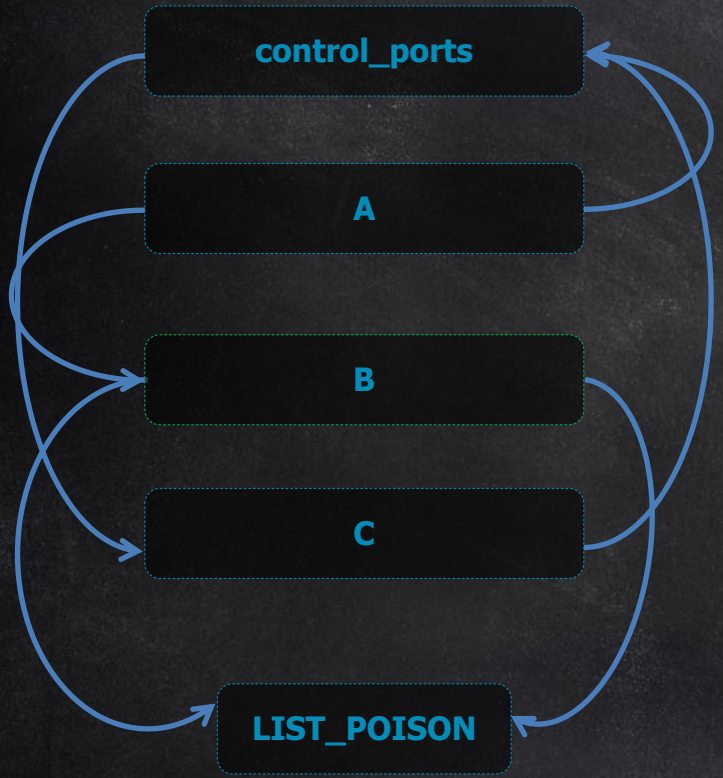
entry = B

next = C

prev = control_ports

B->prev = B->next = POISON

Qualaroot (implementation)

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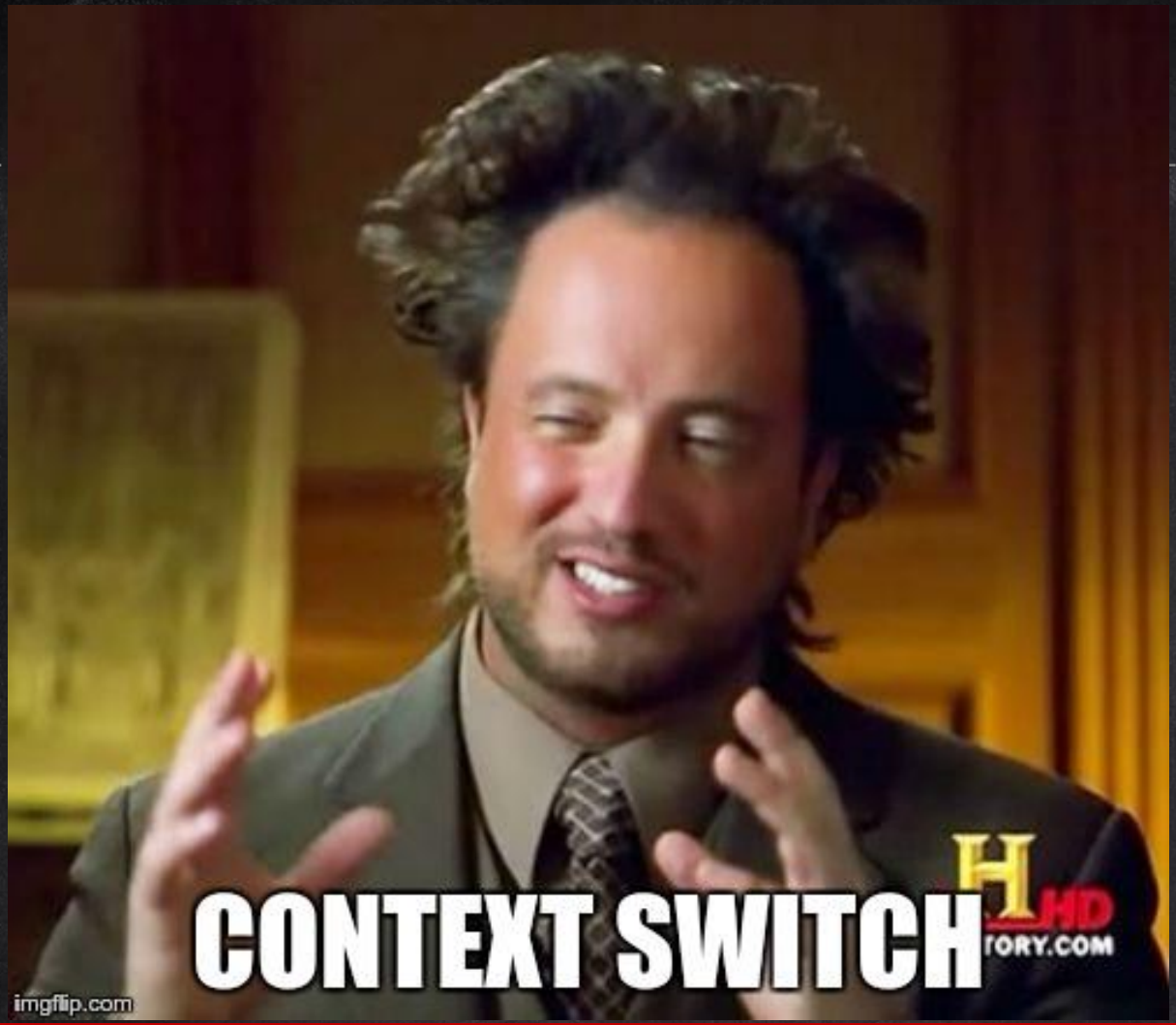
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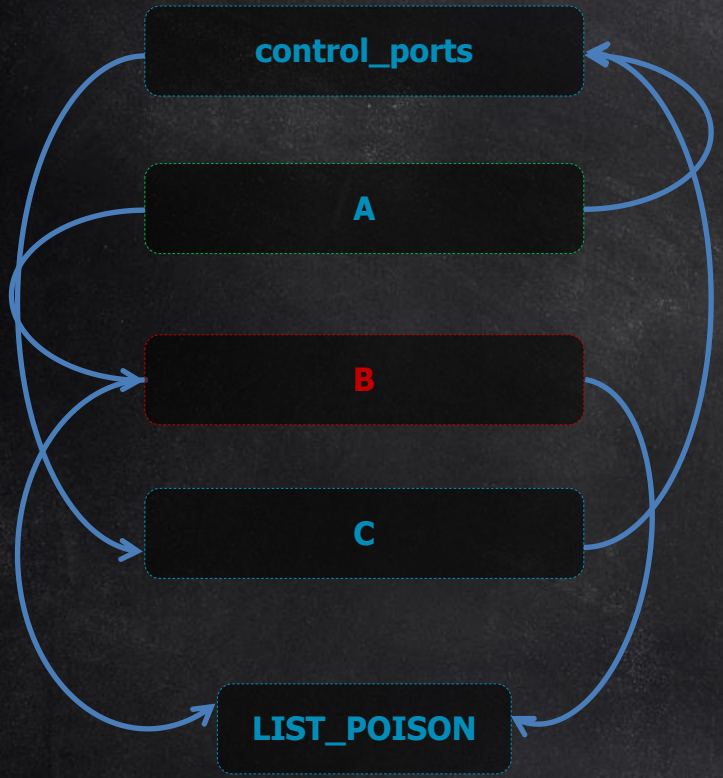
Qualaroot (implementation)

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}
```

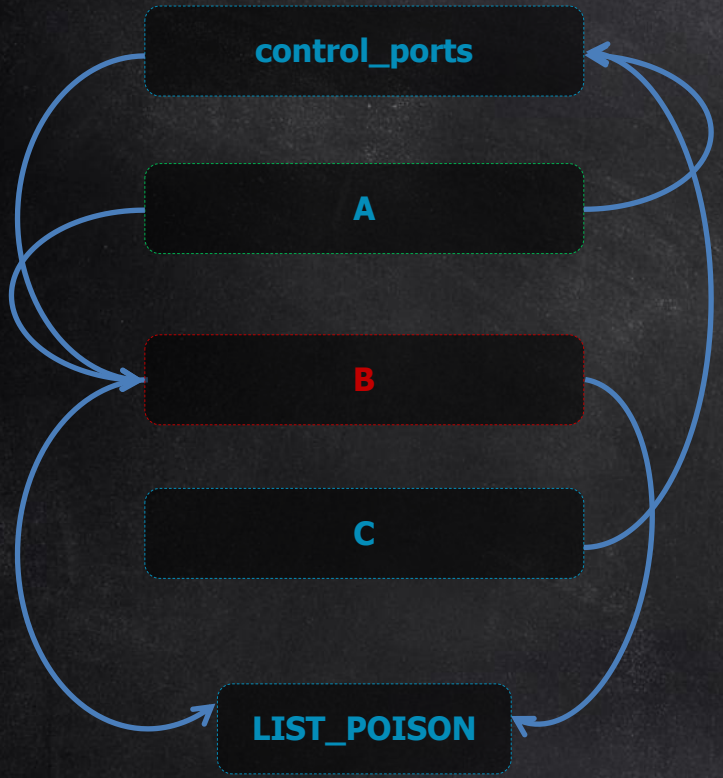
entry = A

next = B

prev = control_ports

control_ports->next = B

Qualaroot (implementation)

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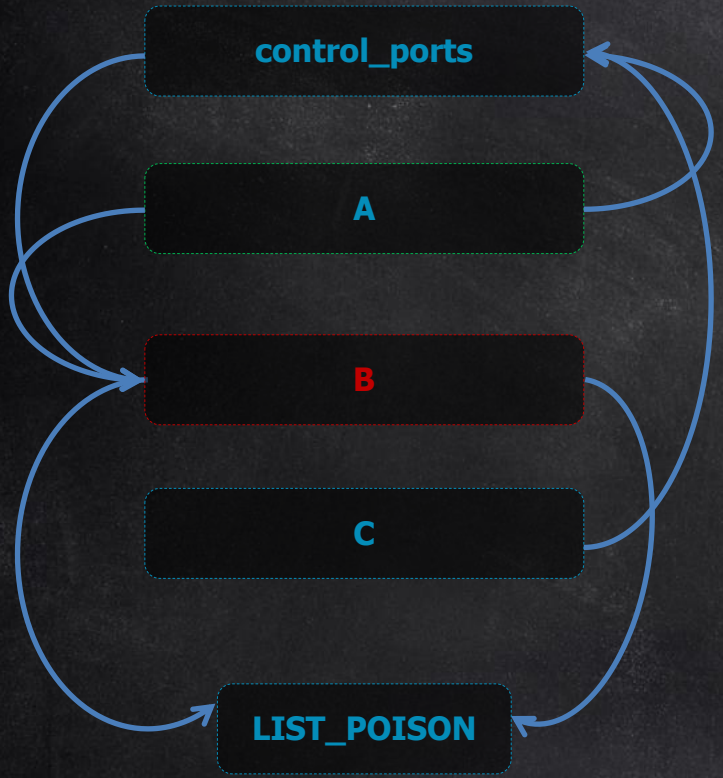


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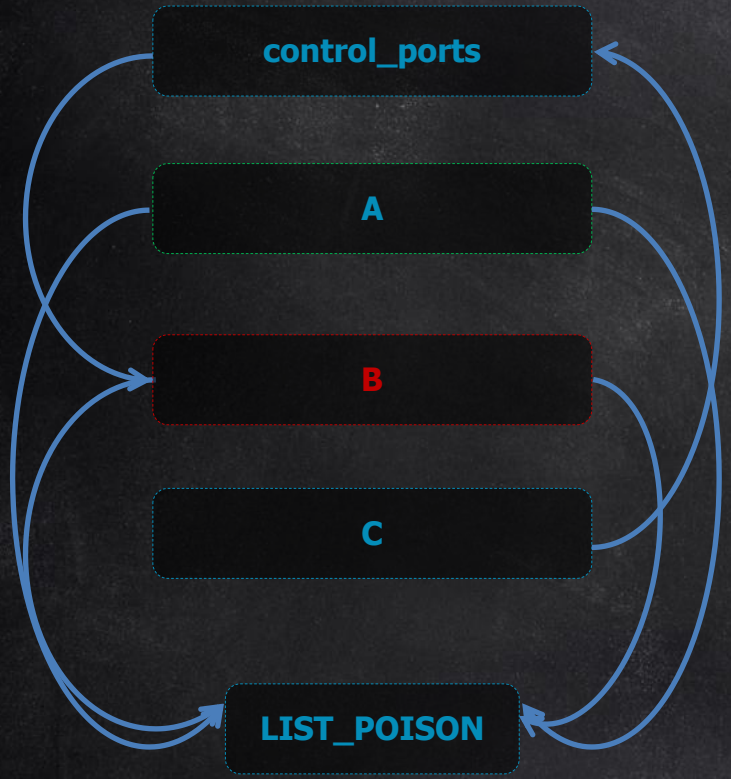
A->prev = A->next = POISON

Qualaroot (implementation)

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      entry->next = LIST_POISON1;
      entry->prev = LIST_POISON2;
}
```

entry = A

next = B

prev = control_ports

A->prev = A->next = POISON

Qualaroot - Implementation

- Two following objects are deleted
  - Simultaneously!
- control_ports points to a FREE data
  - LIST_POISON worked – No longer mappable
  - Spraying af_unix_dgram works
- Iterations on control_ports?
  - Just close a client_port!
  - Notification to all control_ports with *post_pkt_to_port*



```c
static int post_pkt_to_port(struct msm_ipc_port *UAF_OBJECT,
                            struct rr_packet *pkt, int clone)
{
        struct rr_packet *temp_pkt = pkt;
        void (*notify)(unsigned event, void *oob_data,
                       size_t oob_data_len, void *priv);
        void (*data_ready)(struct sock *sk, int bytes) = NULL;
        struct sock *sk;

        mutex_lock(&UAF_OBJECT->port_rx_q_lock_lhc3);
        __pm_stay_awake(UAF_OBJECT->port_rx_ws);
        list_add_tail(&temp_pkt->list, &UAF_OBJECT->port_rx_q);
        wake_up(&UAF_OBJECT->port_rx_wait_q);
        notify = UAF_OBJECT->notify;
        sk = (struct sock *)UAF_OBJECT->endpoint;
        if (sk) {
                read_lock(&sk->sk_callback_lock);
                data_ready = sk->sk_data_ready;
                read_unlock(&sk->sk_callback_lock);
        }
        mutex_unlock(&UAF_OBJECT->port_rx_q_lock_lhc3);
        if (notify)
                notify(pkt->hdr.type, NULL, 0, UAF_OBJECT->priv);
        else if (sk && data_ready)
                data_ready(sk, pkt->hdr.size);

        return 0;
}
```



Qualaroot - Implementation

- *wake_up* function
  - Macros to *__wake_up_common*

```
static void __wake_up_common(
        wait_queue_head_t *q
        .......)
{
        wait_queue_t *curr, *next;

        list_for_each_entry_safe(curr, next,
         &q->task_list, task_list) {
                ...
                if (curr->func(curr, mode,
                 wake_flags, key))
                        break;
        }
}
```



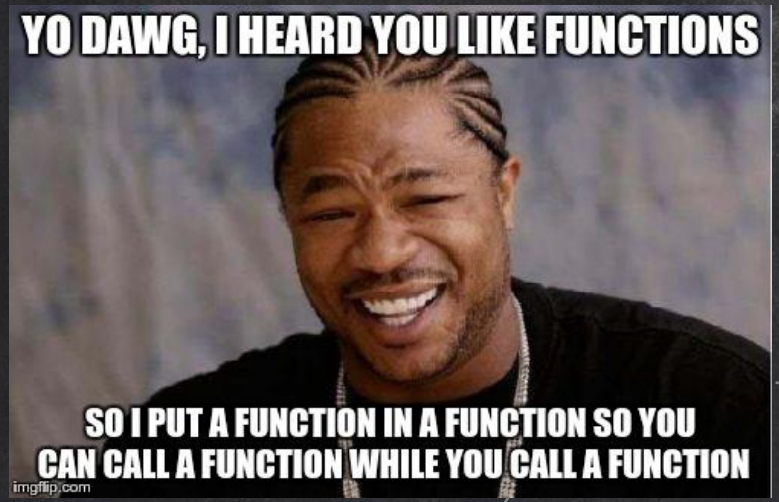
Qualaroot - Implementation

- *wake_up* function
  - Macros to *__wake_up_common*
- New primitive!
  - A call to function with first controllable param
- *Not good enough for commit_creds*



Qualaroot - Implmenetation

- Upgrade primitives
- Find a function that can call an arbitrary function with address-controlled parameters





Qualaroot - Implementation

- *usb_read_done_work_fn* receives a function pointer and a function argument

```
static void usb_read_done_work_fn(
        struct work_struct *work)
{
        struct diag_request *req = NULL;
        struct diag_usb_info *ch = container_of(
                work, struct diag_usb_info,
                read_done_work);
        ...
        req = ch->read_ptr;
        ...
        ch->ops->read_done(req->buf,
                req->actual,
                ch->ctxt);
}
```



Qualaroot - Implementation

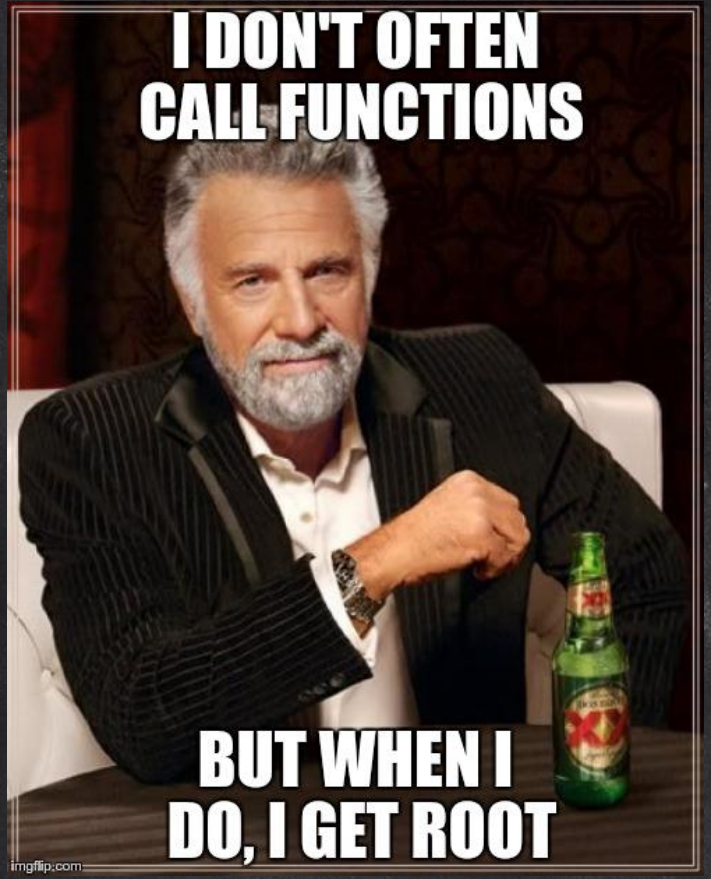
- Chaining function calls –

  __wake_up_common → usb_read_done_work_fn → any function

```
static void __wake_up_common(
        wait_queue_head_t *q
        .......)
{
        wait_queue_t *curr, *next;

        list_for_each_entry_safe(curr, next,
         &q->task_list, task_list) {
                ...
                if (curr->func(curr, mode,
                 wake_flags, key))
                        break;
        }
}
```



Qualaroot - Implementation





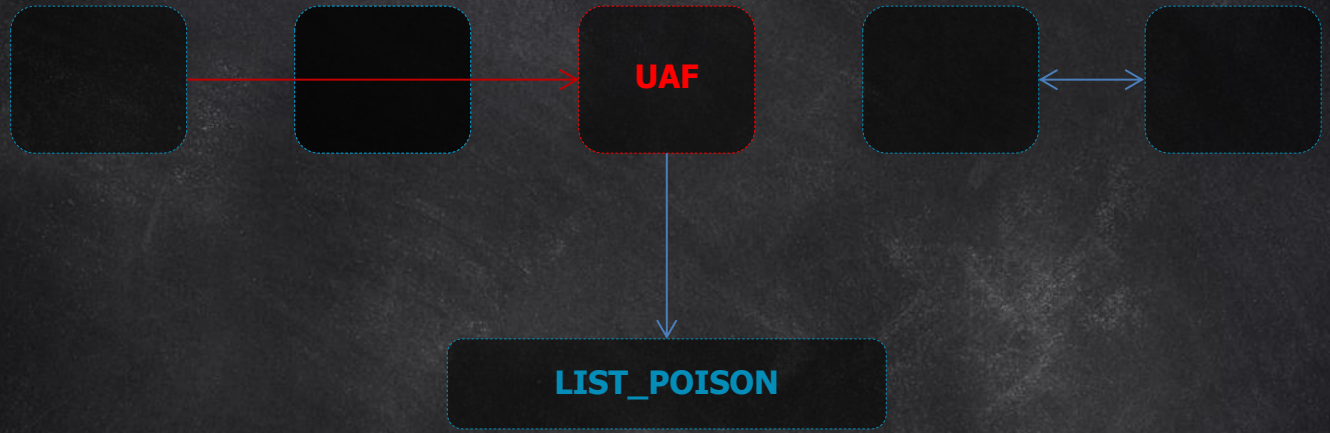
Qualaroot – Exploitation Flow



Create UAF situation using the vulnerability



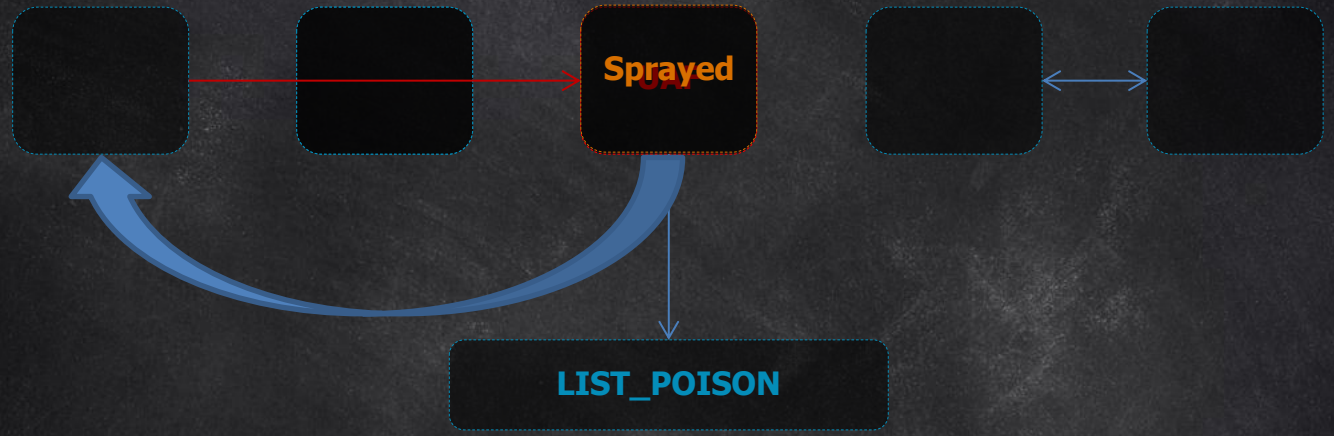
Qualaroot – Exploitation Flow



Spray unix_dgrams to catch the UAF



Qualaroot – Exploitation Flow

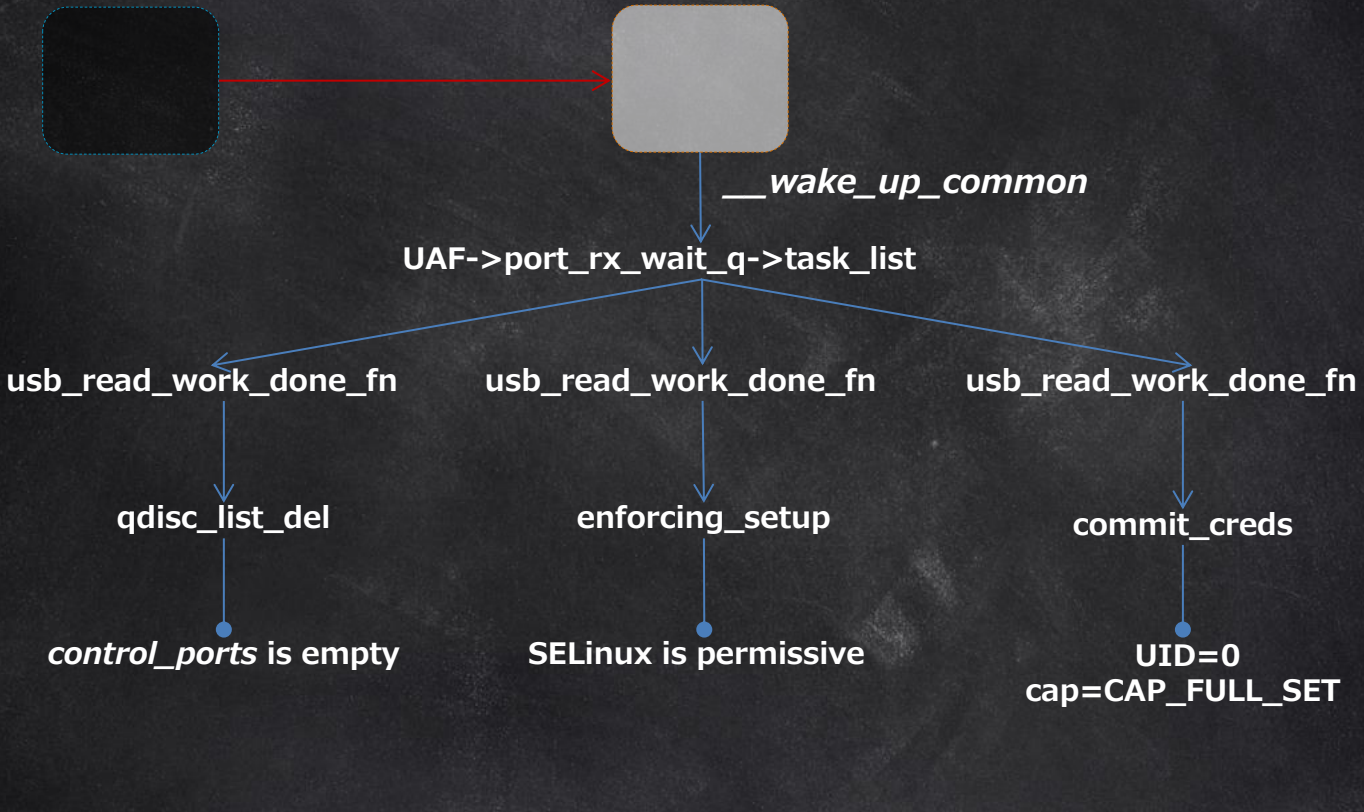


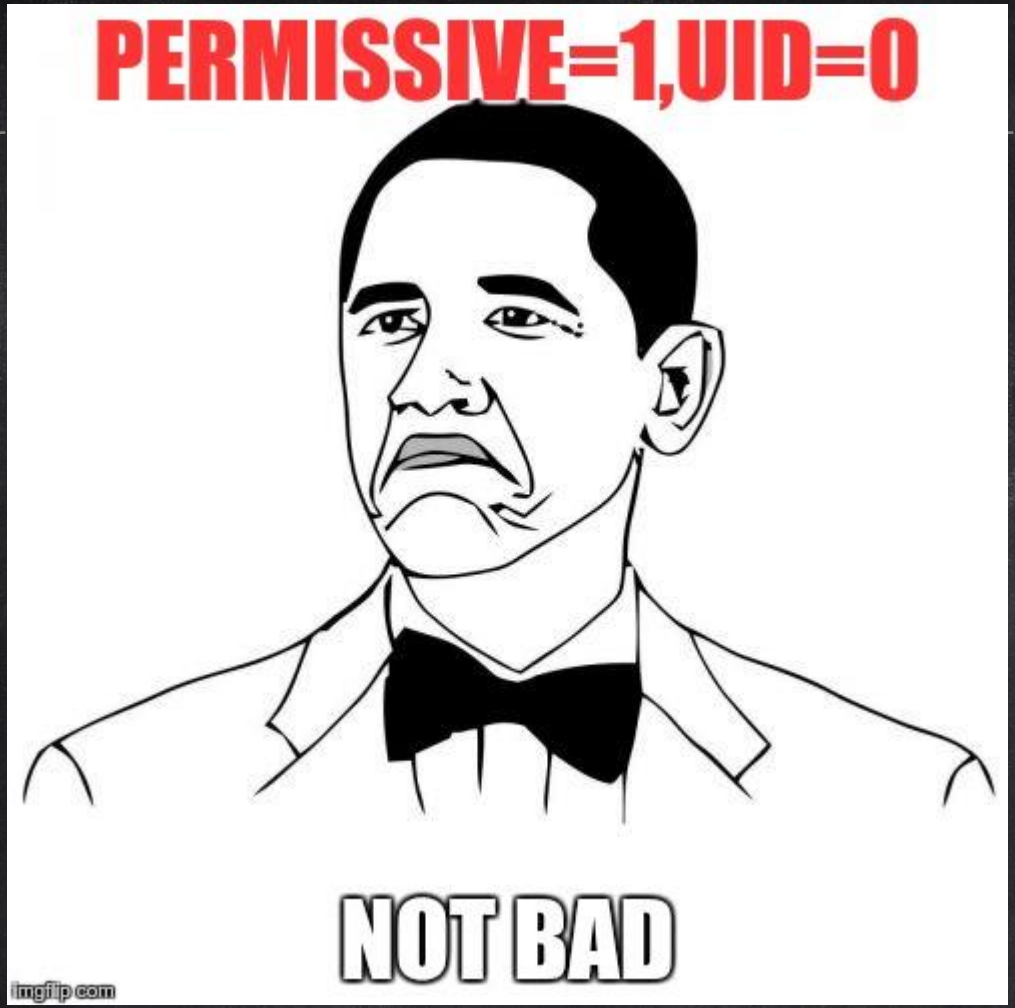
Spray unix_genlist to catch the UAF

Trigger list iteration



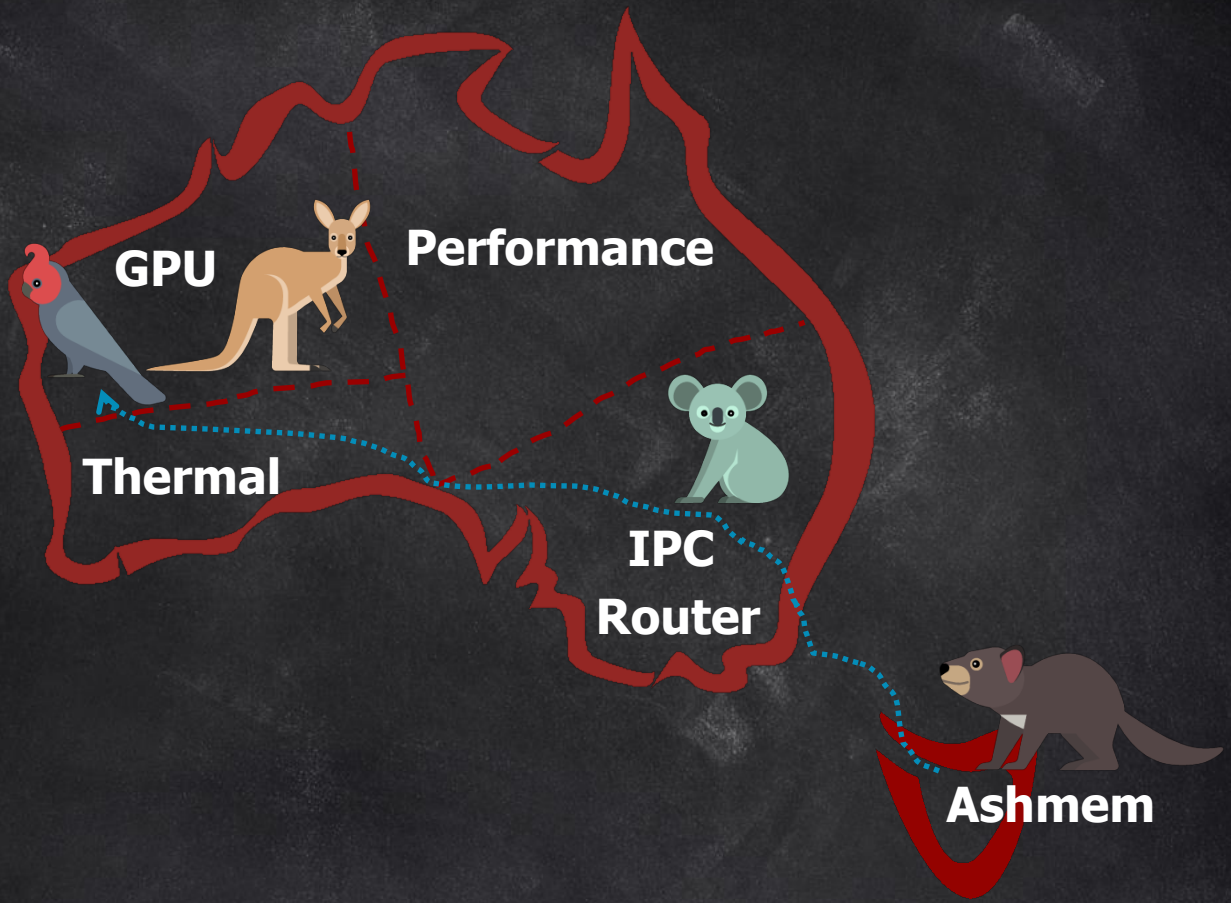
Qualaroot – Exploitation Flow




PERMISSIVE=1,UID=0
NOT BAD
imgflip.com

Demo Time!

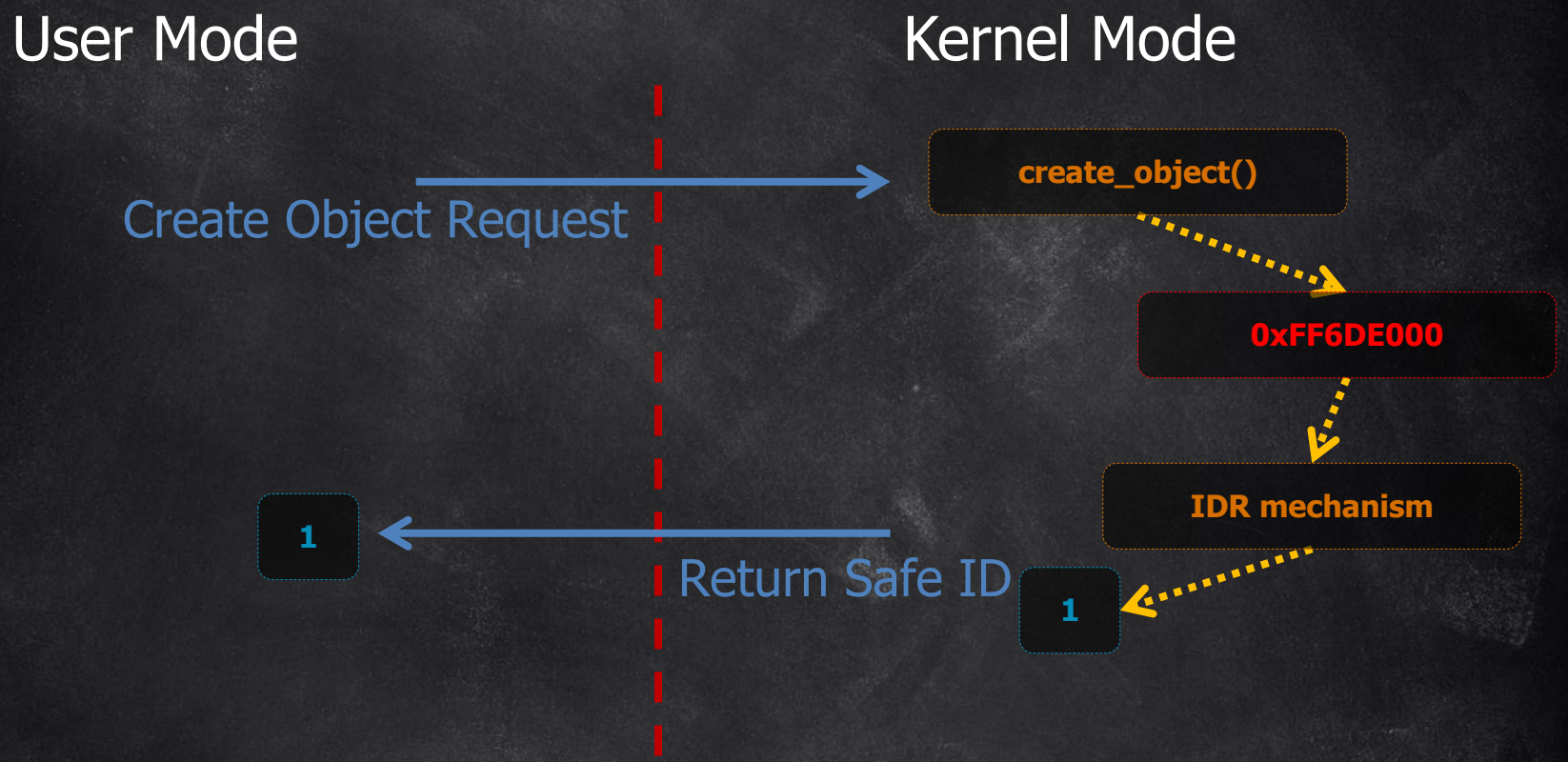



GPU
Performance
Thermal
IPC
Router
Ashmem

IDR mechanism

- ID to pointer translation service
- Handle to kernel objects from user mode without using pointers

IDR mechanism



Syncockaroot (syncsource vulnerability)

CVE-2016-2503

- SyncSource objects
  - Used to synchronize activity between the GPU and the application
- Can be created using IOCTLs to the GPU
  - IOCTL_KGSL_SYNCSOURCE_CREATE
  - IOCTL_KGSL_SYNCSOURCE_DESTROY
- Referenced with the IDR mechanism



```
long kgsl_ioctl_syncsource_destroy(
        struct kgsl_device_private *dev_priv,
        unsigned int cmd, void *data)
{
        struct kgsl_syncsource_destroy *param = data;
        struct kgsl_syncsource *syncsource = NULL;

1

        syncsource = kgsl_syncsource_get(
                dev_priv->process_priv,
                 param->id);
        if (!syncsource)
                goto done;
2       /* put reference from syncsource creation */
        kgsl_syncsource_put(syncsource);
1       /* put reference from getting the syncsource above */
        kgsl_syncsource_put(syncsource);
done:
0       return 0;
```



```
long kgsl_ioctl_syncsource_destroy(
        struct kgsl_device_private *dev_priv,
        unsigned int cmd, void *data)
{
        struct kgsl_syncsource_destroy *param = data;
        struct kgsl_syncsource *syncsource = NULL;

        syncsource = kgsl_syncsource_get(
                dev_priv->process_priv,
                 param->id);
        if (!syncsource)
                goto done;
        /* put reference from syncsource creation */
        kgsl_syncsource_put(syncsource);
        /* put reference from getting the syncsource above */
        kgsl_syncsource_put(syncsource);
done:
        return 0;
```

Any “pending free” check here?



Syncockaroot (syncsource vulnerability)

CVE-2016-2503

free, sprayable data

REFCOUNT == -1

Thread A

```
syncsource = kgsl_syncsource_get(id);
…
…
kgsl_syncsource_put(syncsource);
…
…
kgsl_syncsource_put(syncsource);
```

Thread B

```
syncsource = kgsl_syncsource_get(id);
…
…
kgsl_syncsource_put(syncsource);
…
…
kgsl_syncsource_put(syncsource);
```

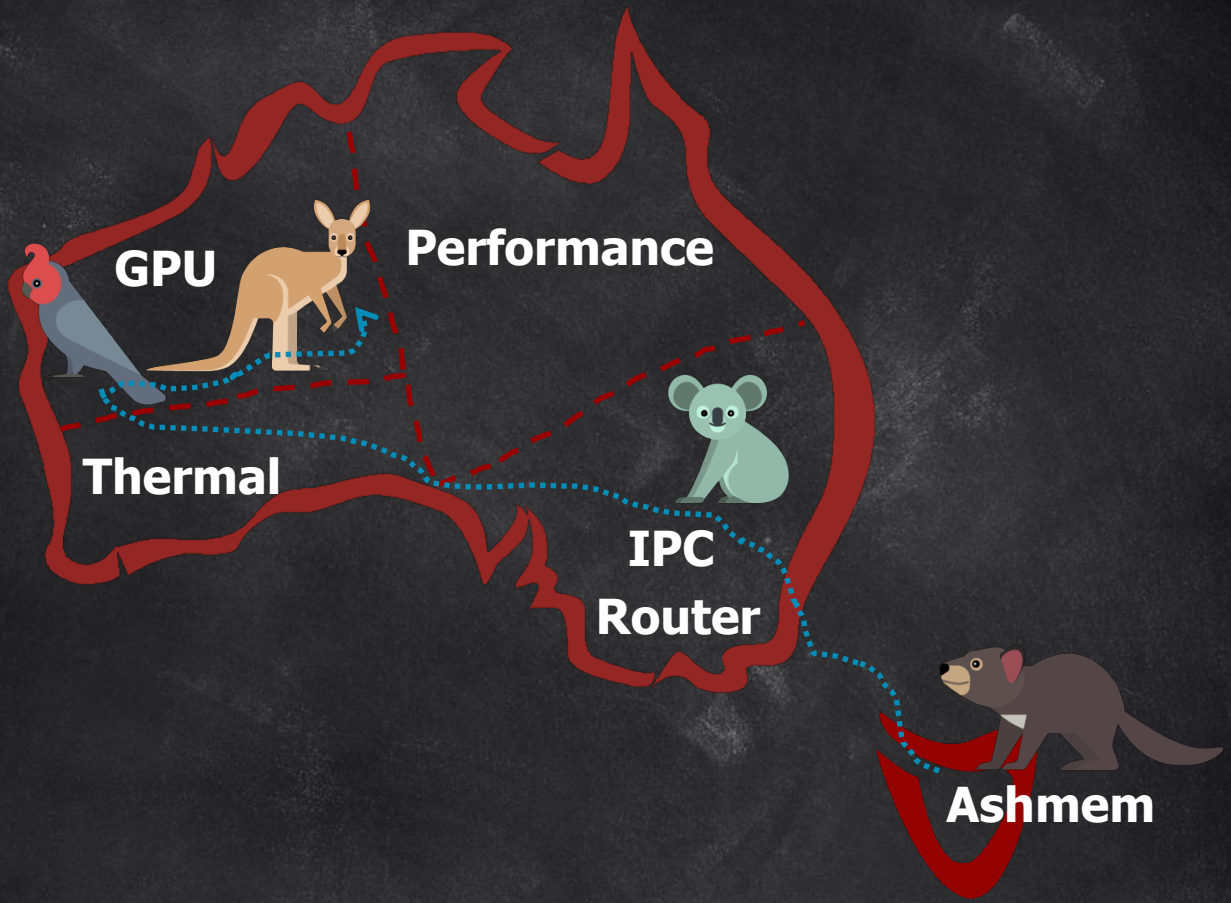
Syncockaroot – PoC

CVE-2016-2503

- Create a syncsource object
  - A predictable IDR number is allocated
- Create 2 threads constantly destroying the same IDR number
- Ref-count will be reduced to -1
  - Right after getting to zero, object can be sprayed

Use After Free ☺




GPU
Performance
Thermal
IPC
Router
Ashmem

KanGaroot (KGsl vulnerability)

CVE-2016-2504

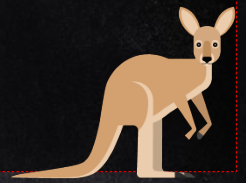
- GPU main module (kgsl-3d0)
- Map user memory to the GPU
  - IOCTL_KGSL_MAP_USER_MEM
  - IOCTL_KGSL_GPUMEM_FREE_ID
- Referenced by a predictable ID
  - IDR mechanism



```
long kgsl_ioctl_gpumem_free_id(
        struct kgsl_device_private *dev_priv,
        unsigned int cmd, void *data)
{
        struct kgsl_gpumem_free_id *param = data;
        struct kgsl_mem_entry *entry = NULL;

        entry = kgsl_sharedmem_find_id(private,
                param->id);

        if (!entry) {
                return -EINVAL;
        }

        return _sharedmem_free_entry(entry);
}
```



```
static long _sharedmem_free_entry(
        struct kgsl_mem_entry *entry)
{
        bool should_free = atomic_compare_exchange(
                entry->pending_free,
                 0, /* if pending_free == 0 */
                  1); /* then set pending_free = 1 */
        kgsl_mem_entry_put(entry);
        if(should_free)
                kgsl_mem_entry_put(entry);

        return 0;
}
```



```
static int
kgsl_mem_entry_attach_process(
        struct kgsl_mem_entry *entry,
        struct kgsl_device_private *dev_priv)
{
        id = idr_alloc(&process->mem_idr,
         entry, 1, 0, GFP_NOWAIT);

        ...
        ret = kgsl_mem_entry_track_gpuaddr(
                process, entry);
        ...

        ret = kgsl_mmu_map(pagetable,
         &entry->memdesc);
        if (ret)
                kgsl_mem_entry_detach_process(entry);
        return ret;
}
```



KanGaroot (KGsl vulnerability)

CVE-2016-2504



IDR items



Thread A - allocator

```
entry = kgsl_mem_entry_create();
…
…
id = idr_alloc(…, entry, …);
…
…
initialize_entry(entry);
```

Thread B - releaser

```
entry = kgsl_sharedmem_find_id(id);
…
…
if(!entry)
     return -EINVAL;
…
…
 sharedmem_safe_free_entry(entry);
```

KanGaroot (KGsl vulnerability)

CVE-2016-2504

free, sprayable data



IDR items



Thread A - allocator

```
entry = kgsl_mem_entry_create();
…
…
id = idr_alloc(…, entry, …);
…
…
initialize_entry(entry);
```

Thread B - releaser

```
entry = kgsl_sharedmem_find_id(id);
…
…
if(!entry)
     return -EINVAL;
…
…
 sharedmem_safe_free_entry(entry);
```

KanGaroot - POC

CVE-2016-2504

- Map memory
- Save the IDR
  - Always get the first free IDR – predictable
- Another thread frees the IDR
  - Before the first thread returns from the IOCTL

UAF in kgsl_mem_entry_attach_process on 'entry' parameter



Disclosure

Syncockaroot (CVE-2016-2503)



4th April, 2016

Vulnerability disclosure to Qualcomm



2nd May, 2016

Qualcomm confirmed the vulnerability



6th July, 2016

Qualcomm released a public patch



6th July

Google deployed the patch to their Android devices



Disclosure

Kangaroot (CVE-2016-2504)



4th April, 2016

Vulnerability disclosure to Qualcomm



2nd May, 2016

Qualcomm confirmed the vulnerability



6th July, 2016

Qualcomm released a public patch



1st August, 2016

Google deployed the patch to their Android devices



Disclosure

ASHmenian Devil (CVE-2016-5340)



10th April, 2016

Vulnerability disclosure to Qualcomm



02nd May, 2016

Qualcomm confirmed the vulnerability



28th July, 2016

Qualcomm released a public patch



TBD

Google deployed the patch to their Android devices



Disclosure

Qualaroot (CVE-2016-2059)



2nd February, 2016

Vulnerability disclosure to Qualcomm



10th February, 2016

Qualcomm confirmed the vulnerability



29th April, 2016

Qualcomm released a public patch

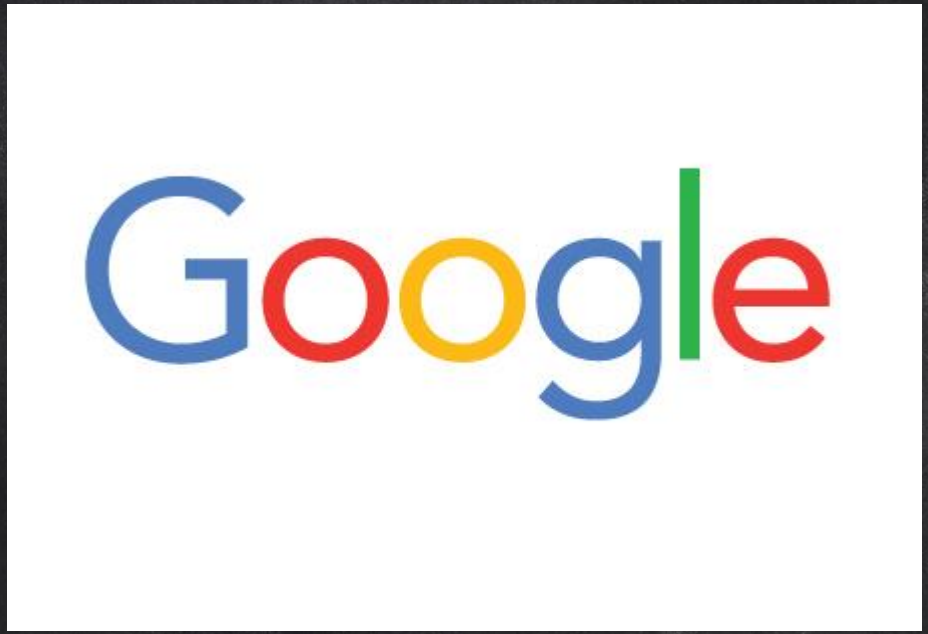


TBD

Google deployed the patch to their Android devices



- Disclosure





#3 ad...@lacoon.com

Hey,

Attached is a full exploit for Nexus 6 devices running Android Marshmallow, build MRA58K.
The binary itself should be run from an application context, i.e. from an APK, (otherwise SELinux prevents the exploitation) and no extra privileges are required in order to successfully exploit the vulnerability.
Please note that on other Qualcomm based devices or versions it might still cause a kernel panic, however the current exploitation requires a modification for each device.

The exploit currently sets SELinux to permissive mode, grants root privileges to the process, modifies the system partition to read-write and writes a suid file there named "zugang" (full path /system/zugang).
The payload can easily be changed in the function do_root, file qualroot.c.

If you wish to test the exploit without creating an extra APK for that, let me know, and I will supply you with an APK.

To build, extract the NDK using the make-standalone-toolchain.sh to the same directory with the qualroot exploit, and run build_and_strip.sh.

---

qualroot.tar.gz
8.6 KB Download

Delete

Project Member #4 qua...@google.com

Thanks Adam.

Qualcomm also notified us that they received this report as well and they have assigned an ID for it: QPSIIR-170.

Quan

Project Member #5 qua...@google.com

Hello,

Thank you for submitting this vulnerability report.
The engineering team has reviewed the issue and set the severity to Low.

For reference, the severity classification is documented here:
https://source.android.com/security/overview/updates-resources.html

Quan

Labels: Severity-Low Triaged-yes

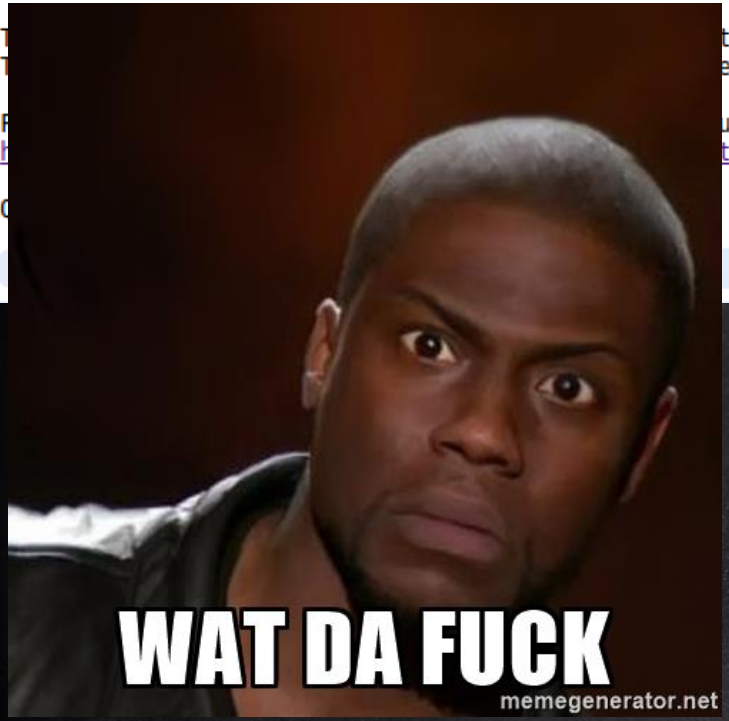


Project Member #5 qua...@google.com

Hello,

t.
et the severity to Low.

umented here:
tes-resources.html





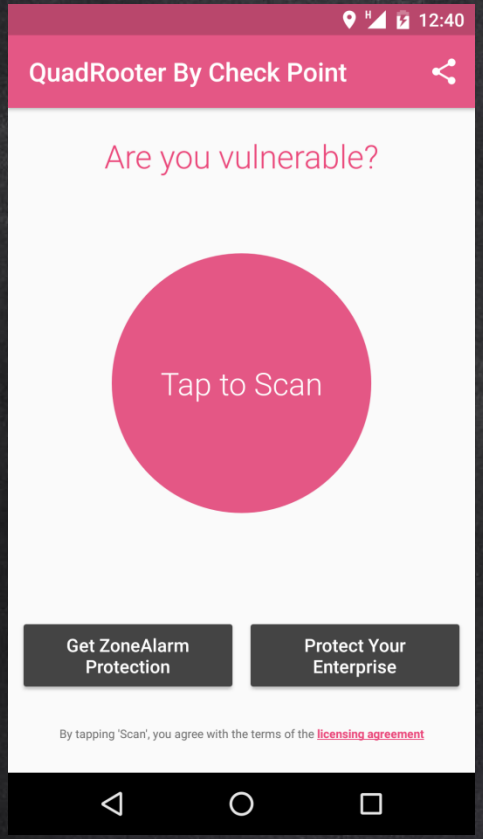
Suggestions/Special Thanks

commit_creds for always being there for me

Absense of kASLR,
for not breaking me and commit_creds apart

SELinux, for being liberal,
letting anyone access mechanisms like Qualcomm’s IPC

Am I Vulnerable?



Google Play

QuadRooter Scanner

Adam Donenfeld
doadam@gmail.com

Thank You!



Check Point
SOFTWARE TECHNOLOGIES LTD.