Stumping the Mobile Chipset

Adam Donenfeld & Yaniv Mordekhay

Check Point
SOFTWARE TECHNOLOGIES LTD.

Agenda

- Chipsets and security
- Kernel vulnerabilities and exploitation
  - ASHmenian Devil
  - Qualaroot
  - Syncockaroot
  - Kangaroot
- Disclosure process
- Conclusions

~ $ cat AUTHORS|xargs -n 1 man

Adam Donenfeld

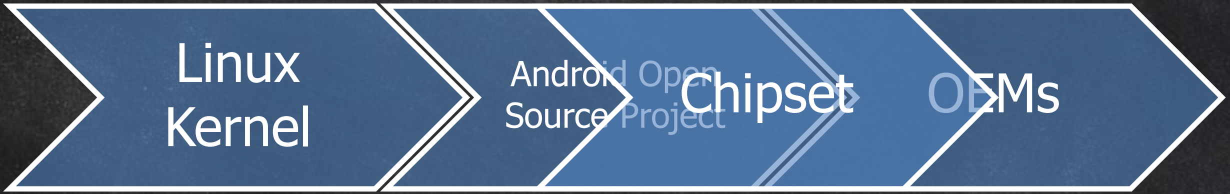
- Years of experience in research
- Vulnerability assessment
- Vulnerability exploitation
- In meiner Freizeit, lerne ich Deutsch gern ☺

Yaniv Mordekhay

- Veteran developer and researcher
- Specialization in behavioral analysis
- Specialization in statistical analysis
- Avid hiker

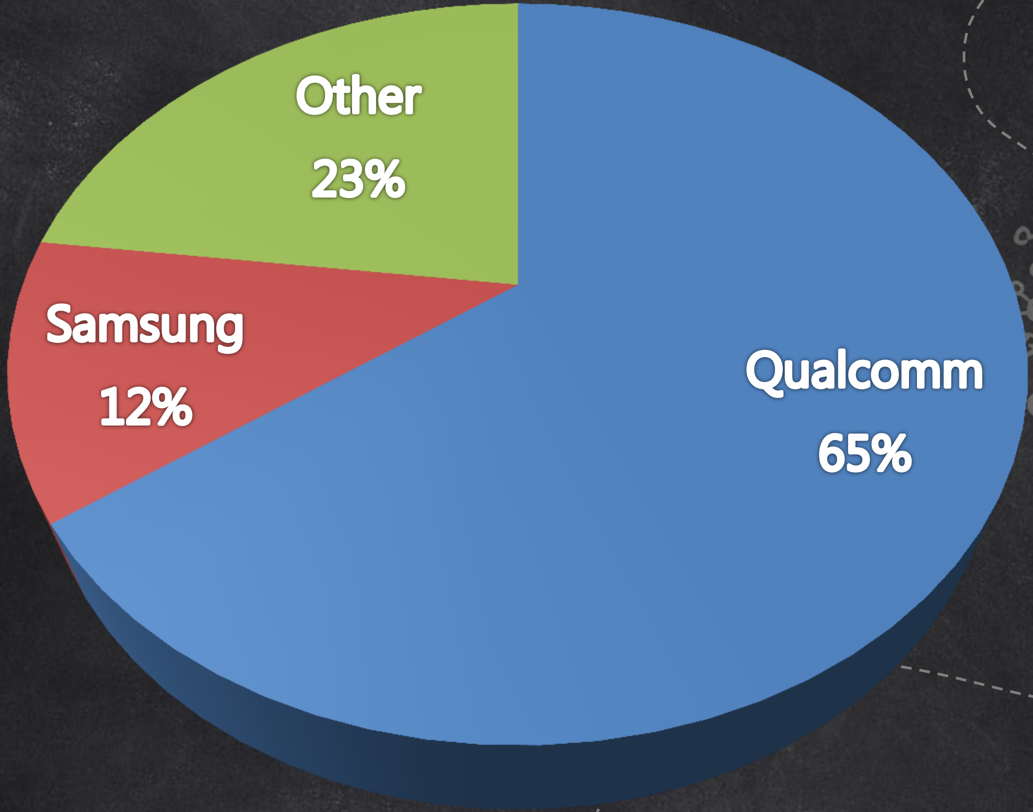
Special thanks to Avi Bashan, Daniel Brodie and Pavel Berengoltz for helping with the research

Android Architecture



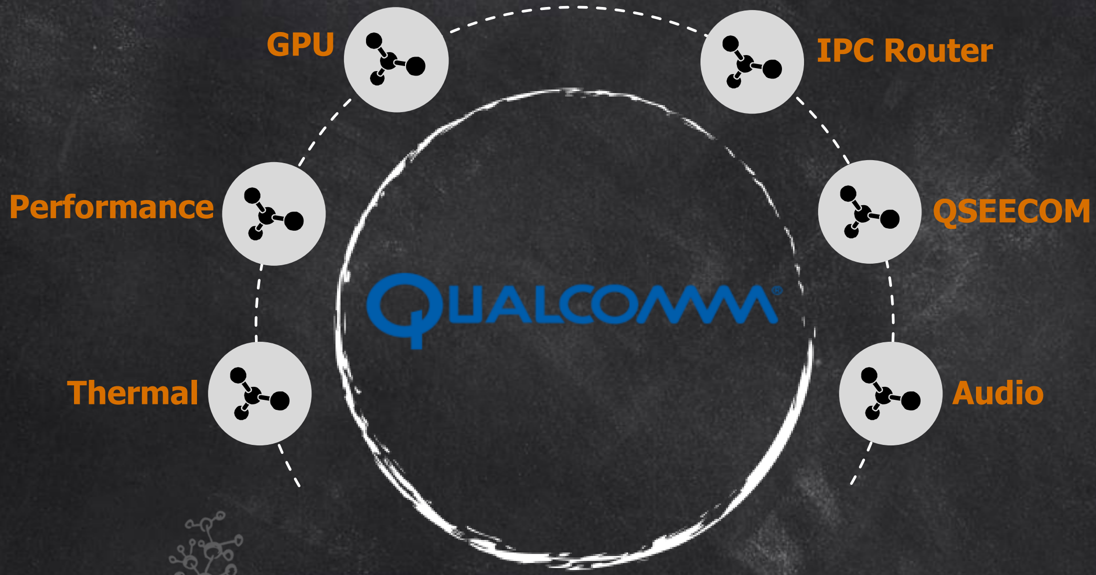
Qualcomm Chipsets

The dangers of chipset vulnerabilities

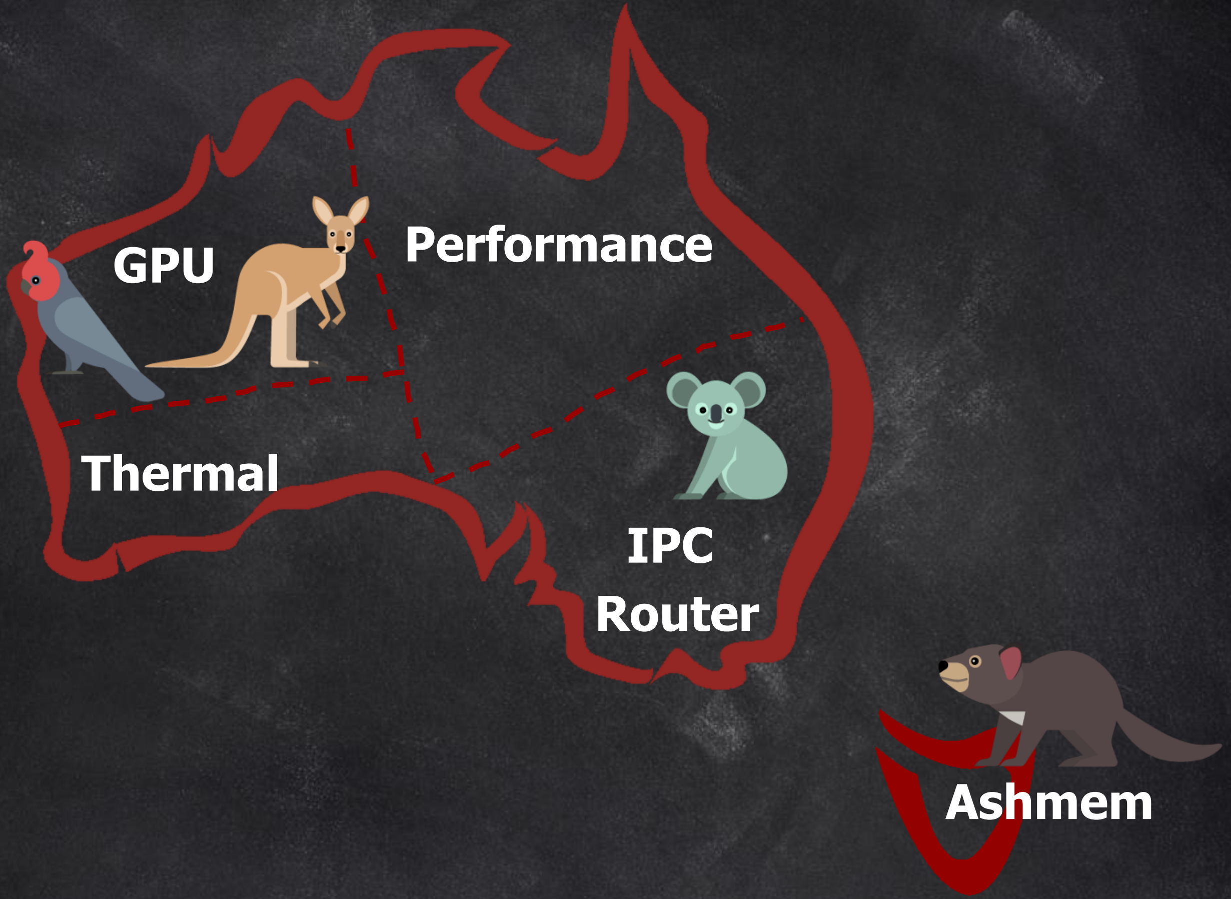


* ABI Research, February 2016

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

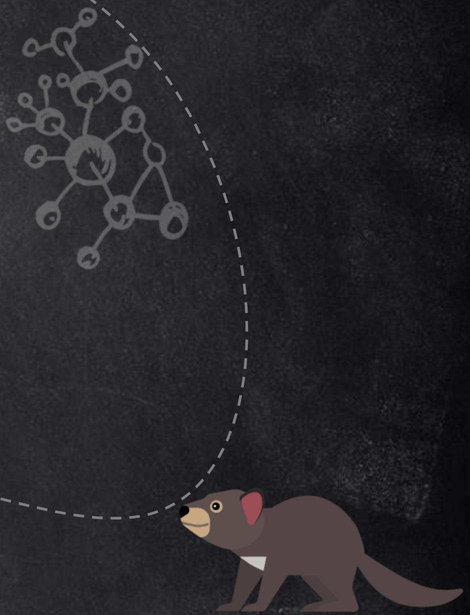
```c
int get_ashmem_file(int fd,
 struct file **filp,
  struct file **vm_file,
     unsigned long *len)
{
     int ret = -1;
     struct ashmem_area *asma;
     struct file *file = fget(fd);
     if (is_ashmem_file(file)) {
          asma = file->private_data;
          *filp = file;
          *vm_file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

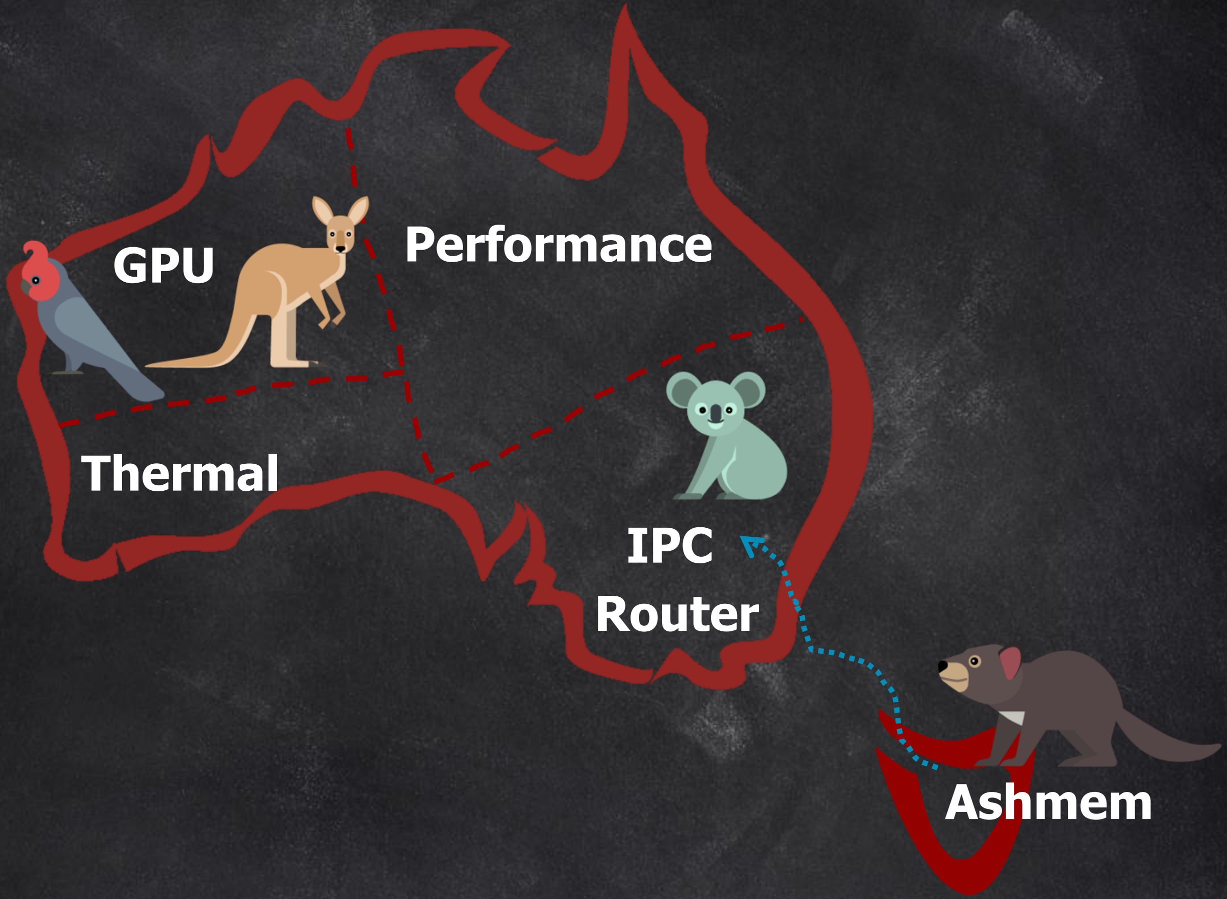
CVE-2016-5340

- 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);
     ....
}
```

```c
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);

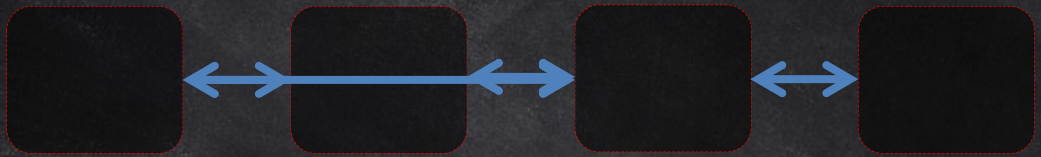
     up_write(&local_ports_lock_lhc2);

     down_write(&control_ports_lock_lha5);

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

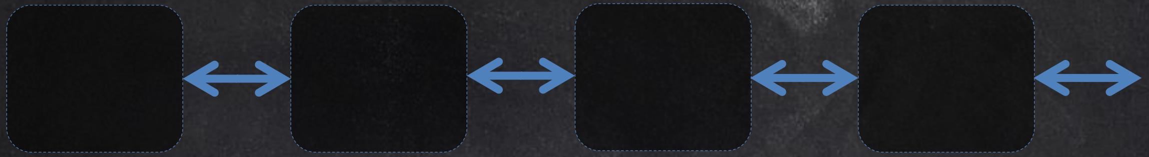
     up_write(&control_ports_lock_lha5);
     return 0;
}
```

Client list

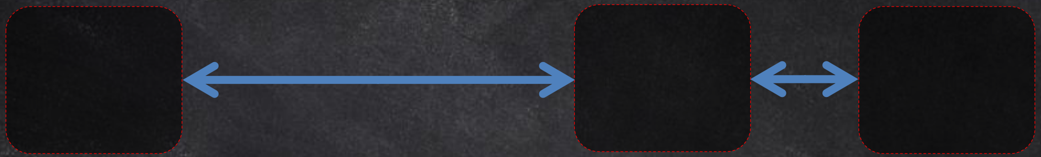


```
down_write(&local_ports_lock_lhc2);
list_del(&port_ptr->list);
up_write(&local_ports_lock_lhc2);
down_write(&control_ports_lock_lha5);
list_add_tail(&port_ptr->list, &control_ports);
up_write(&control_ports_lock_lha5);
```

Control list



Client list



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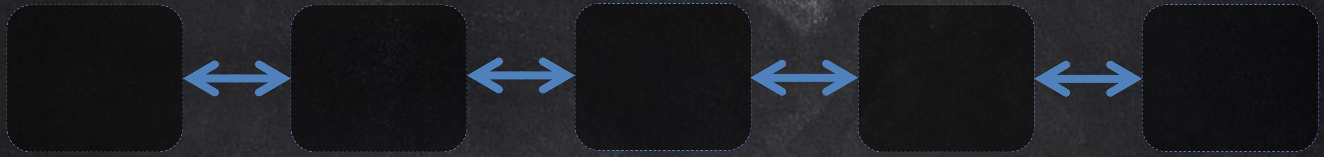
```

Control list

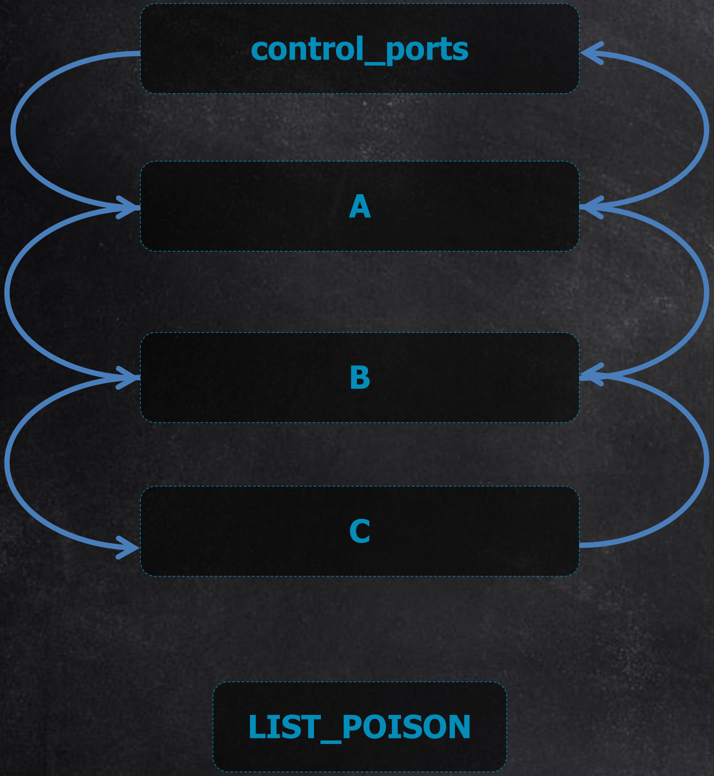


Qualaroot (IPC Router vulnerability)

CVE-2016-2059

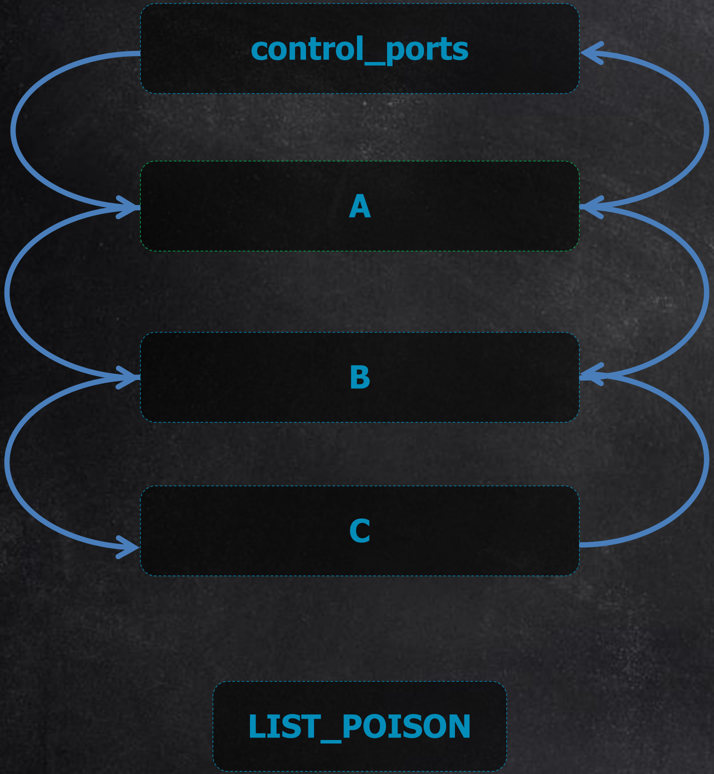
- *control_ports* list is modified without a lock
- Deleting 2 objects from *control_ports* simultaneously!

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)



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}
```

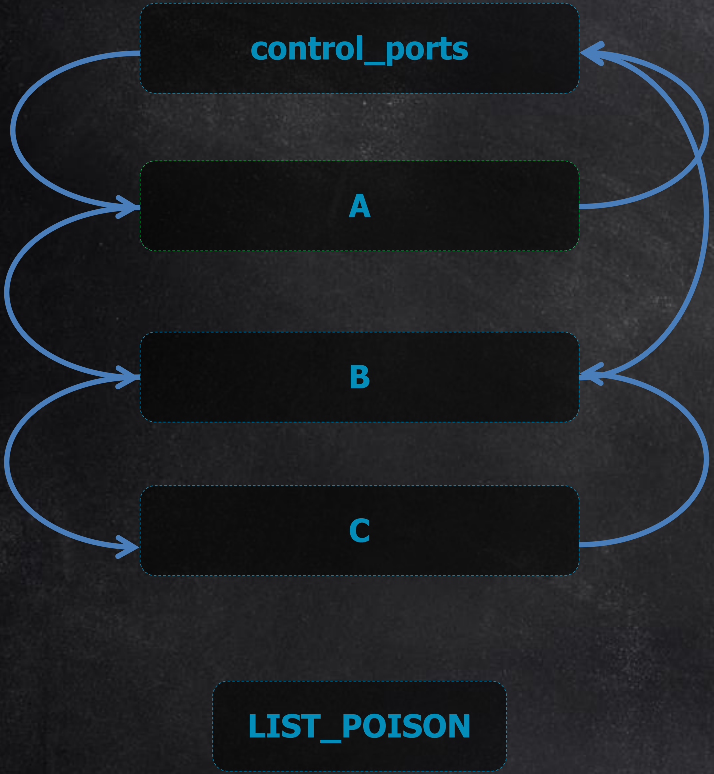
entry = A

next = B

prev = control_ports

B->prev = control_ports

Qualaroot (implementation)



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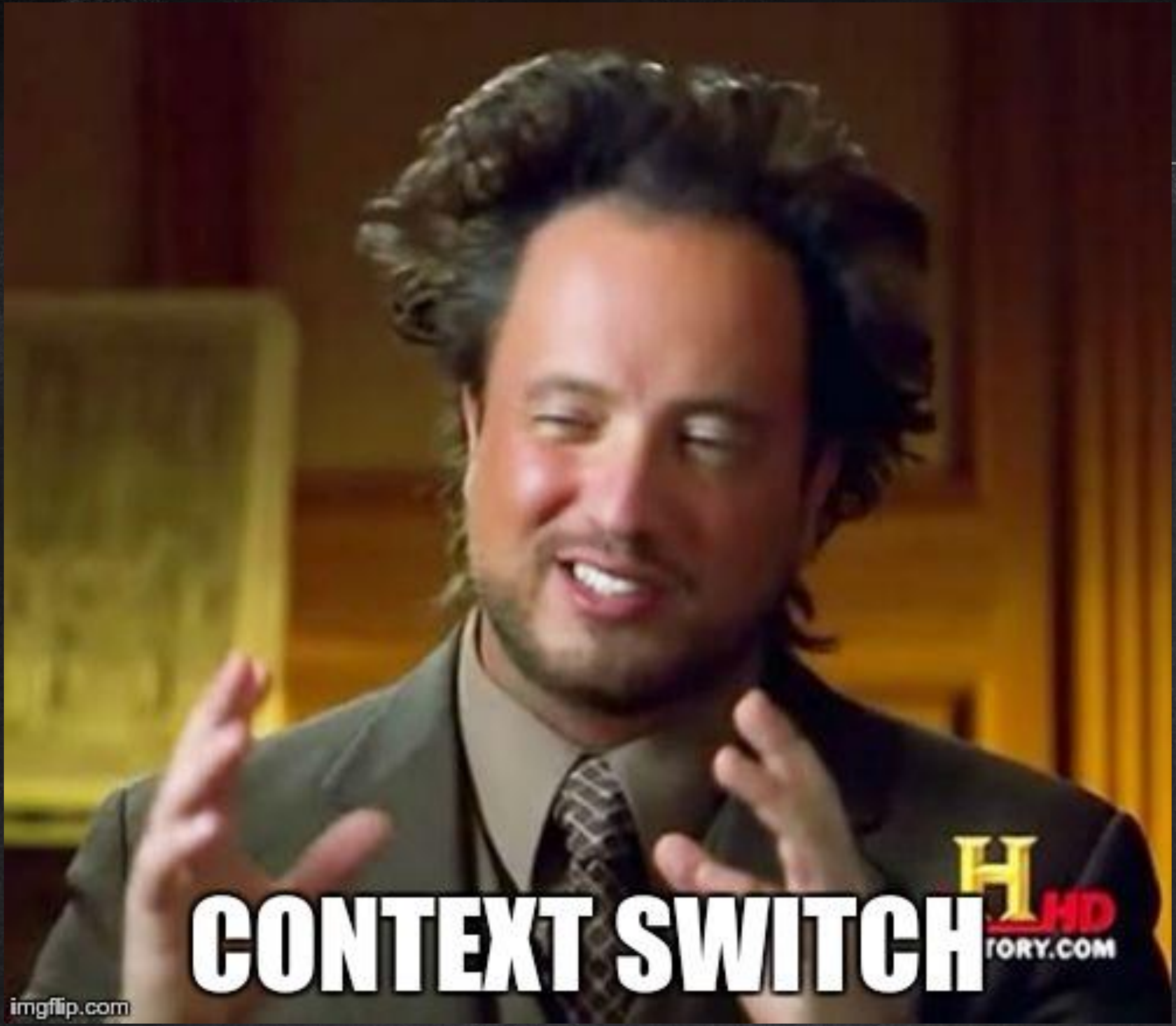
```

entry = A

next = B

prev = control_ports

B->prev = control_ports


CONTEXT SWITCH
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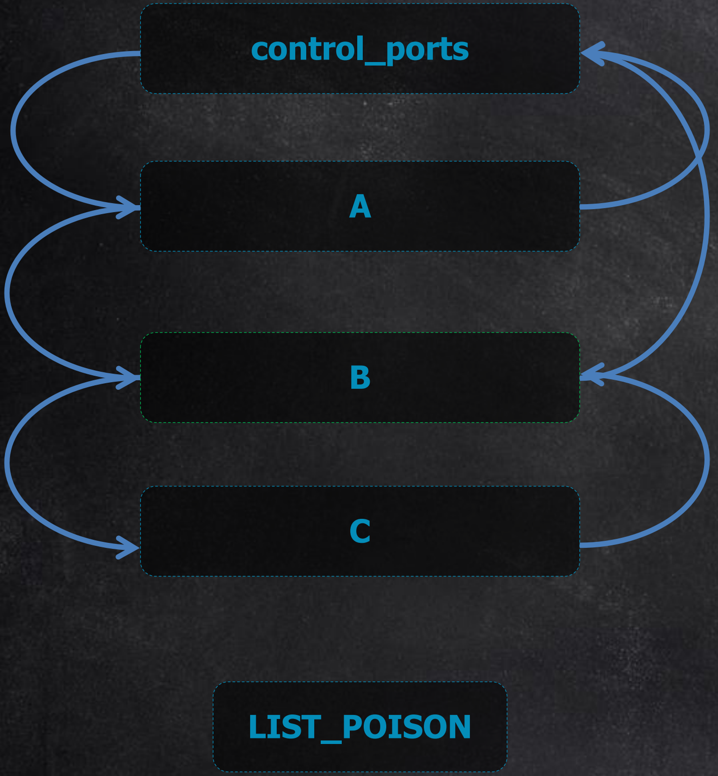
H HD
TORY.COM

Qualaroot (implementation)



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}
```

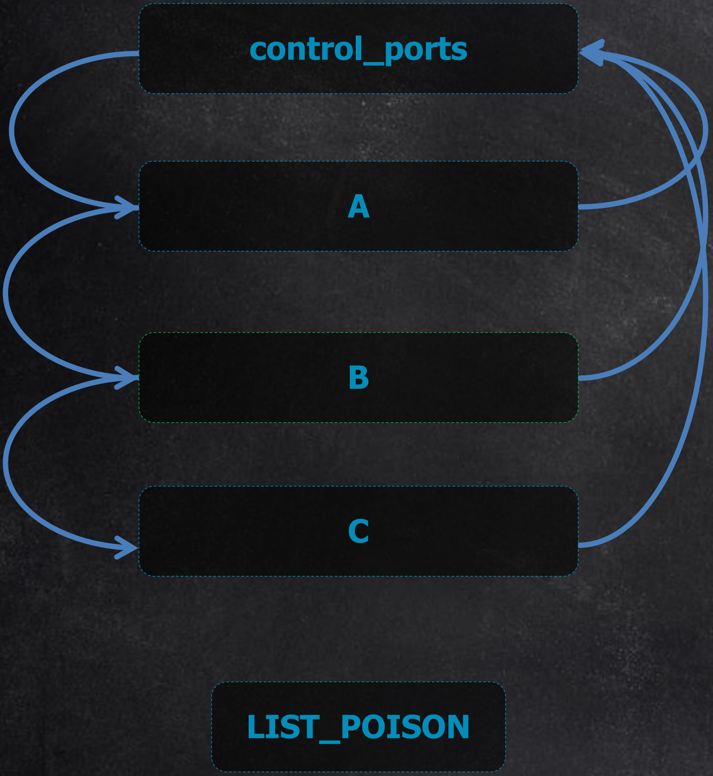
entry = B

next = C

prev = control_ports

C->prev = control_ports

Qualaroot (implementation)



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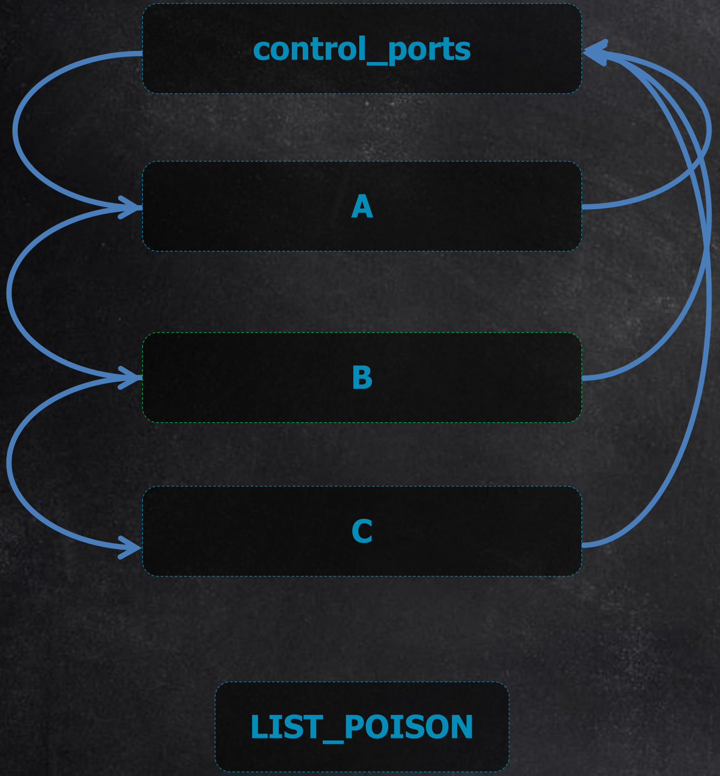

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      prev->next = next;
      entry->next = LIST_POISON1;
      entry->prev = LIST_POISON2;
}
```

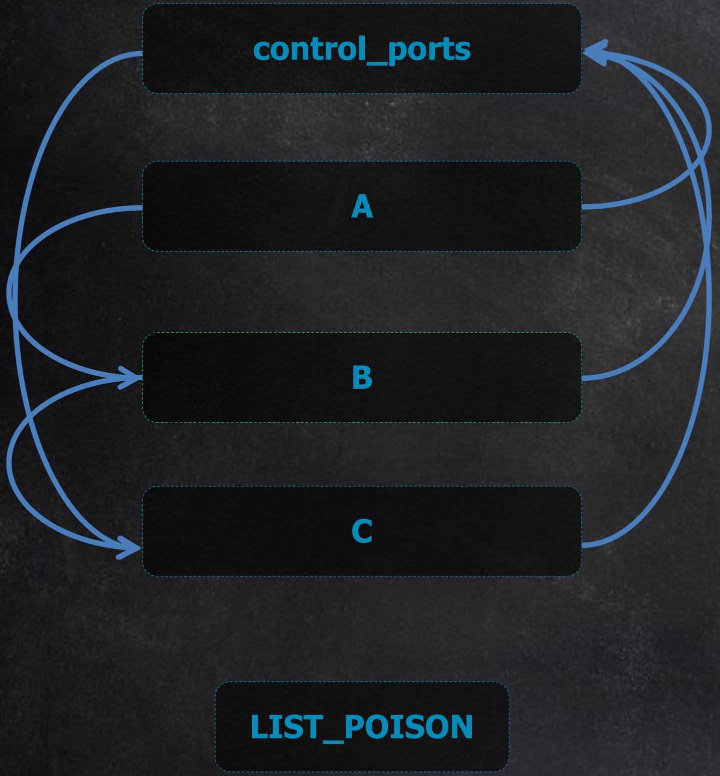
entry = B

next = C

prev = control_ports

control_ports->next = C

Qualaroot (implementation)



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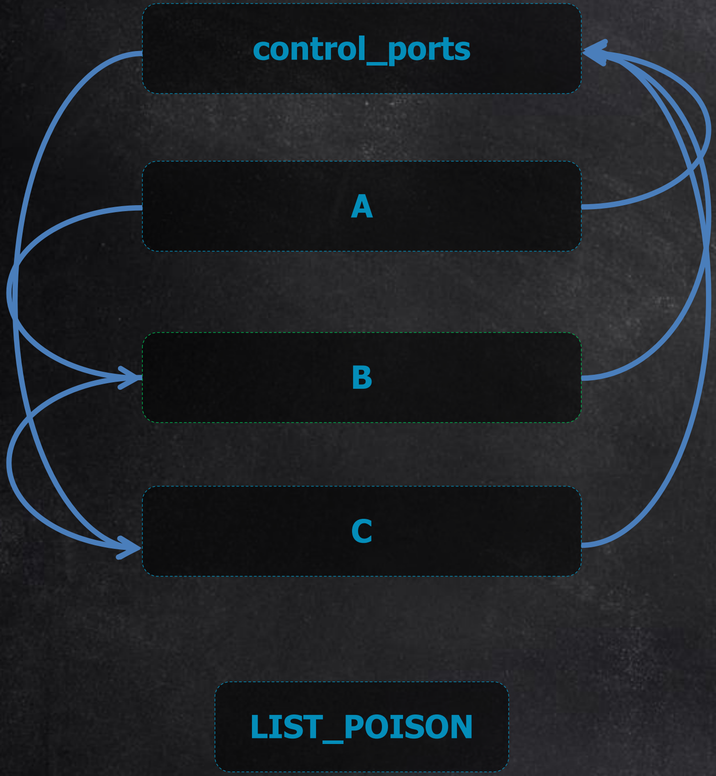
entry = B

next = C

prev = control_ports

control_ports->next = C

Qualaroot (implementation)



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}
```

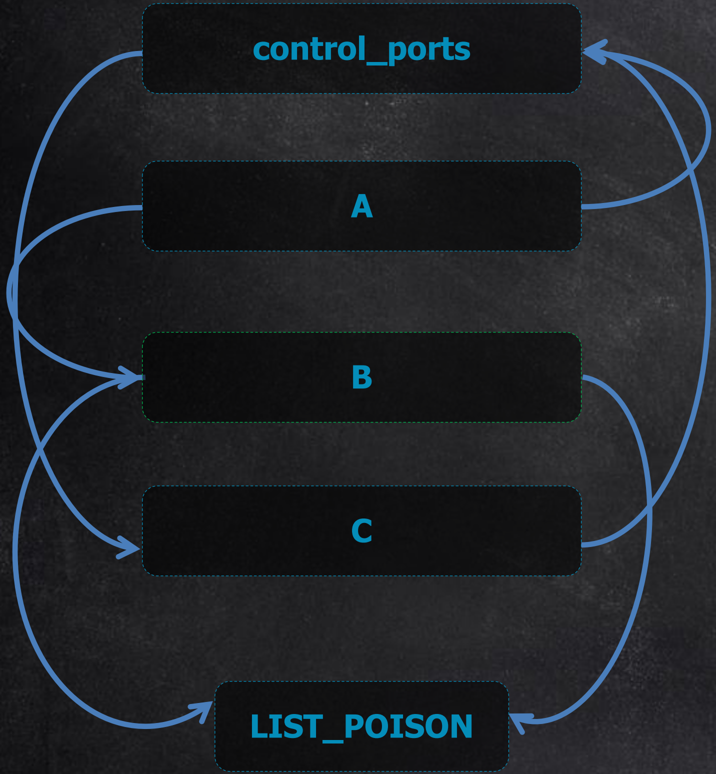
entry = B

next = C

prev = control_ports

B->prev = B->next = POISON

Qualaroot (implementation)



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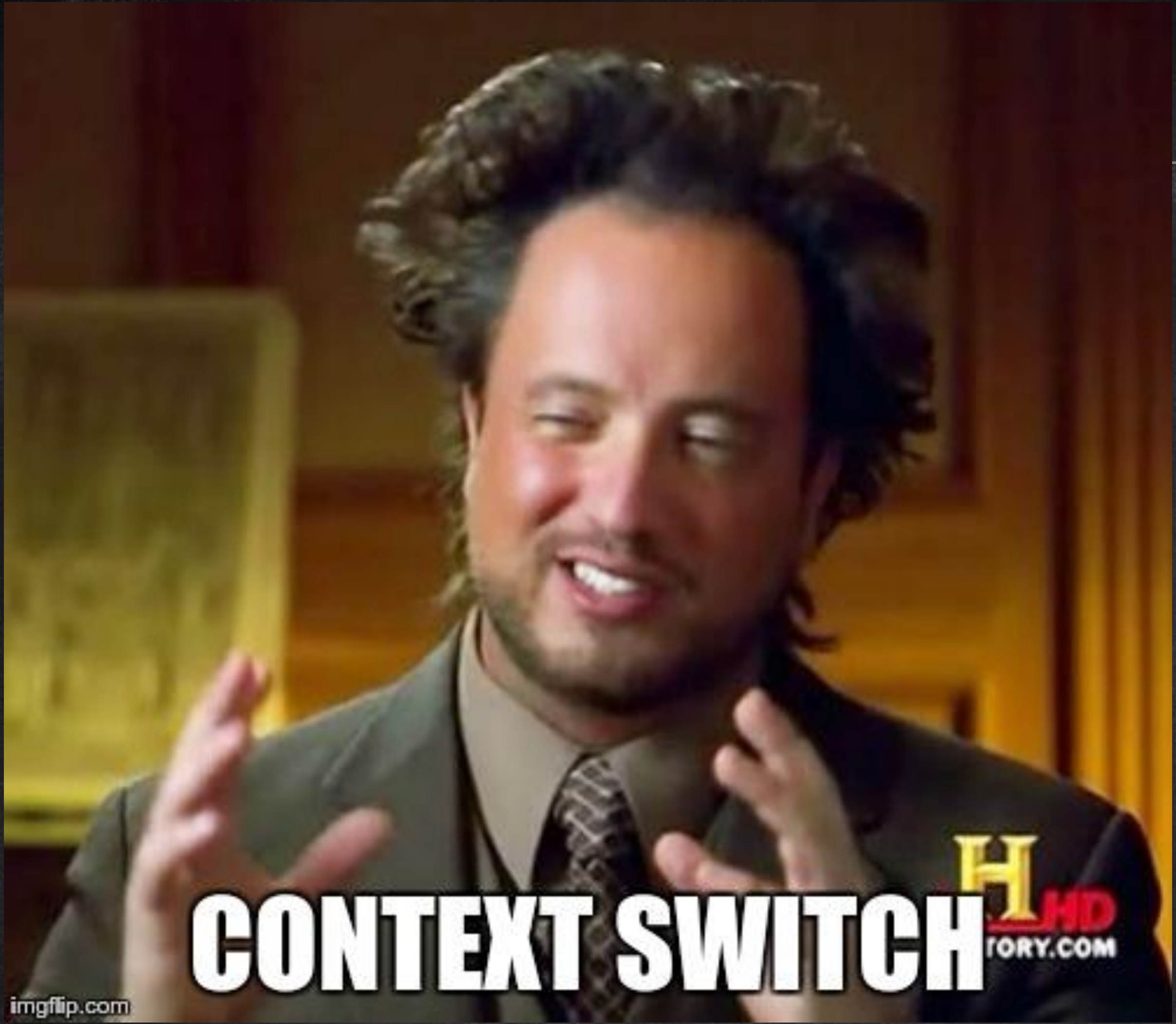
}
```

entry = B

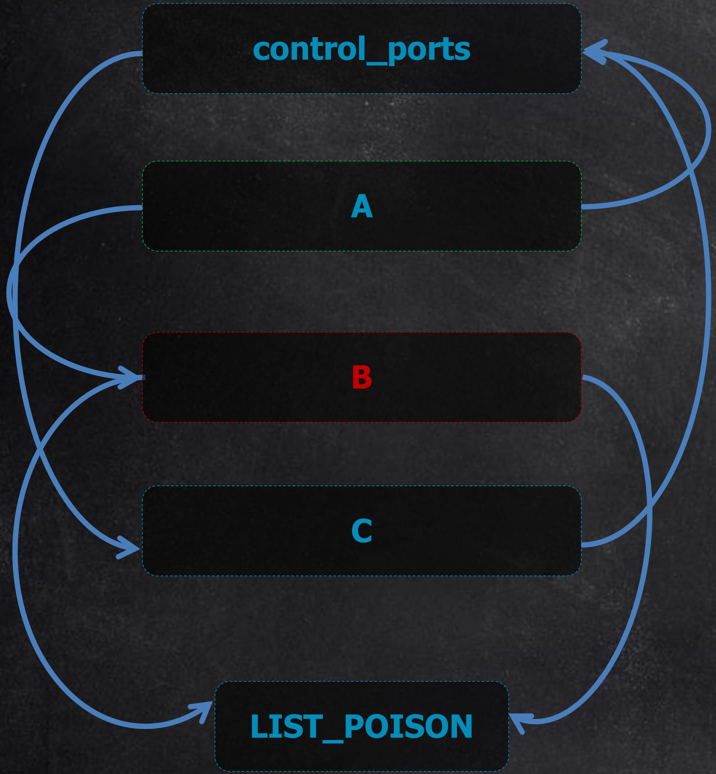
next = C

prev = control_ports

B->prev = B->next = POISON


CONTEXT SWITCH
HD
TORY.COM
imgflip.com

Qualaroot (implementation)



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

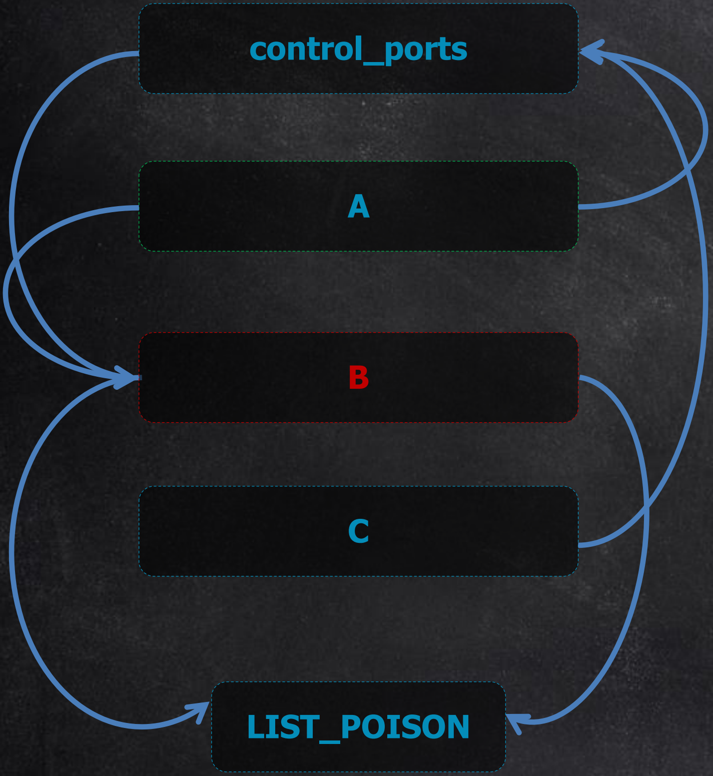
entry = A

next = B

prev = control_ports

control_ports->next = B

Qualaroot (implementation)



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entry = A

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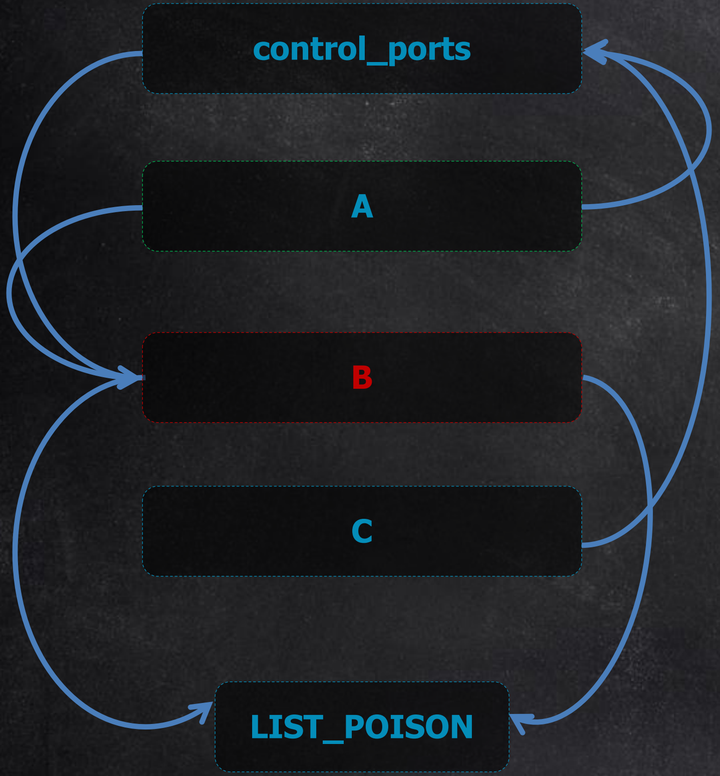
control_ports->next = B

Qualaroot (implementation)



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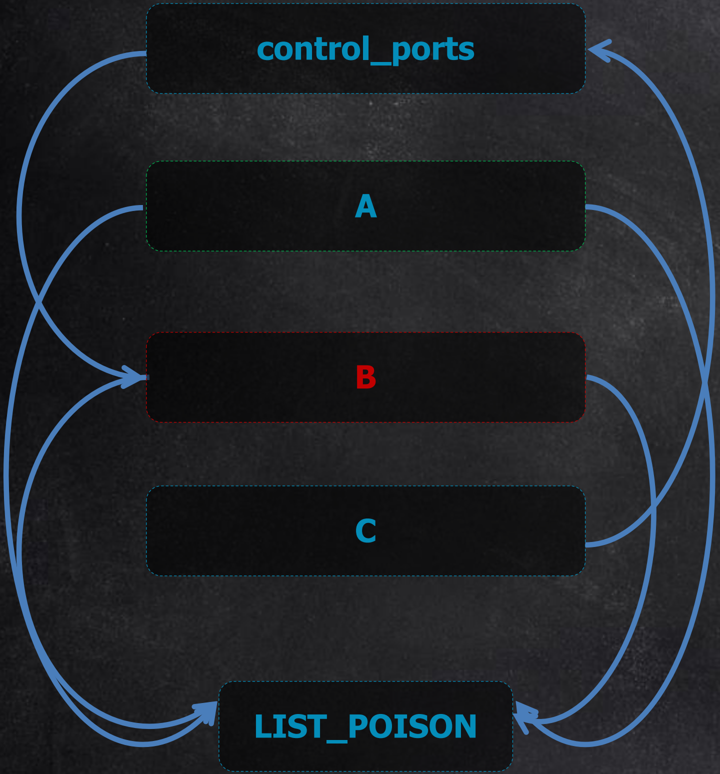
A->prev = A->next = POISON

Qualaroot (implementation)



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        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*

```
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;

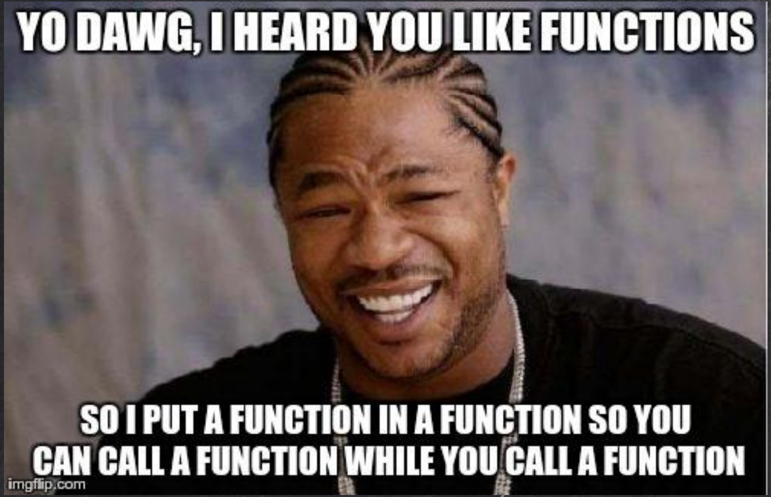
     list_for_each_entry_safe(curr, next,
      &q->task_list, task_list) {
          ...
          if (curr->func(curr, mode,
           wake_flags, key))
               break;
     }
}
```

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


YO DAWG, I HEARD YOU LIKE FUNCTIONS
SO I PUT A FUNCTION IN A FUNCTION SO YOU CAN CALL A FUNCTION WHILE YOU CALL A FUNCTION
imgflip.com

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

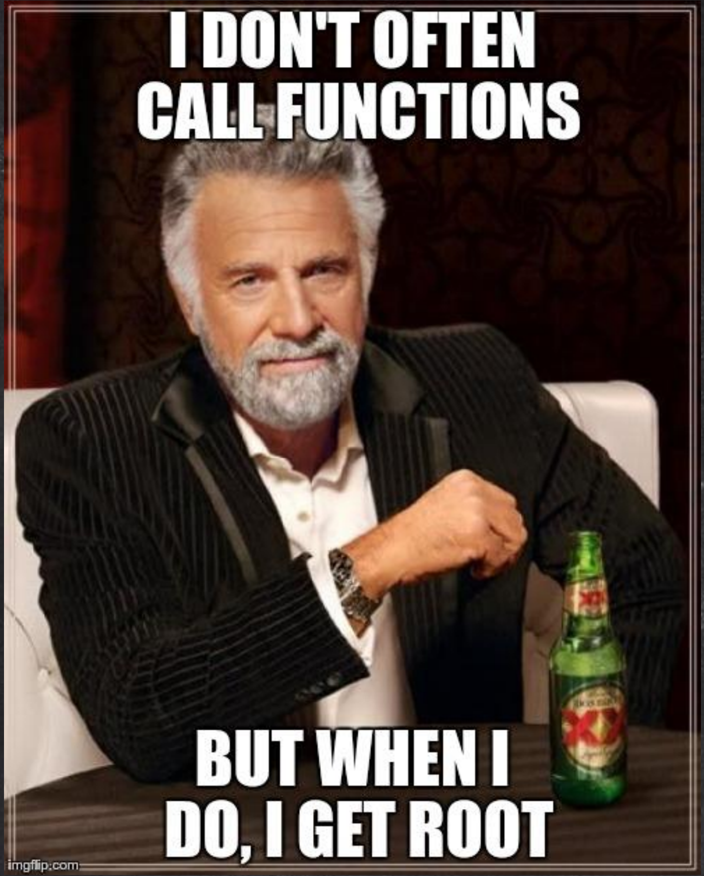
- Chaining function calls –

  __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;
      }
}
```

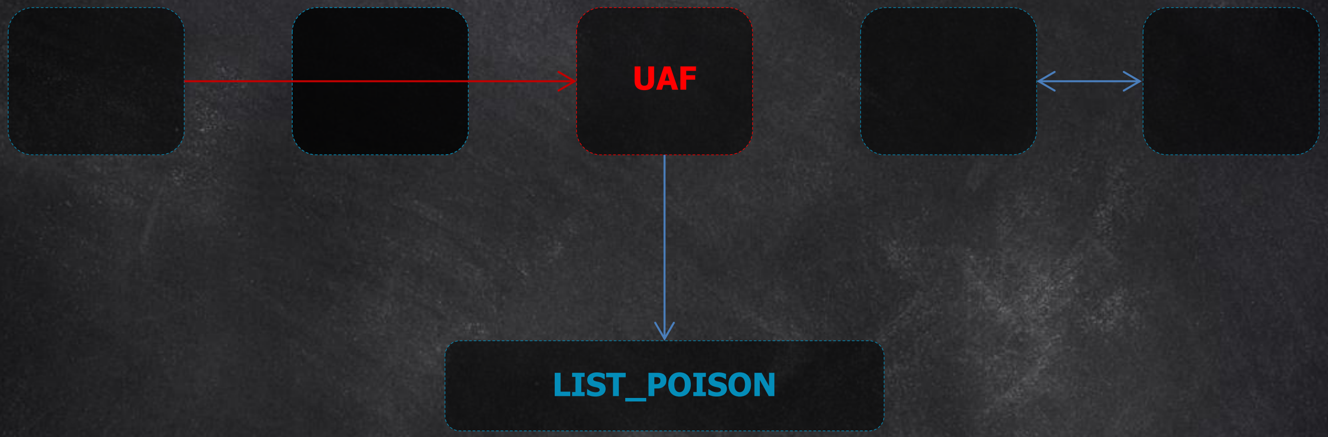
Qualaroot - Implementation



Qualaroot – Exploitation Flow

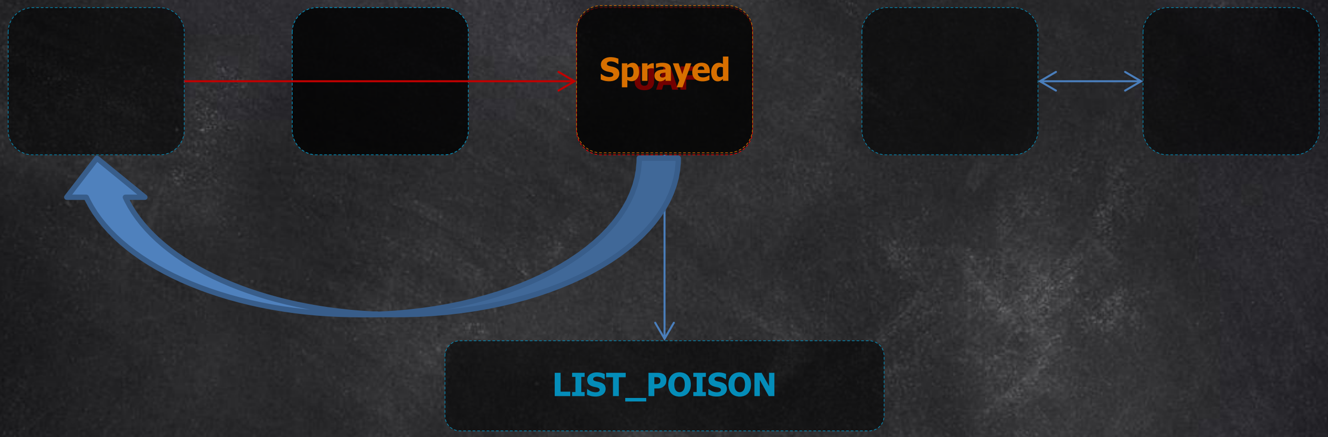
Create UAF situation using the vulnerability

Qualaroot – Exploitation Flow



Spray unix_dgrams to catch the UAF

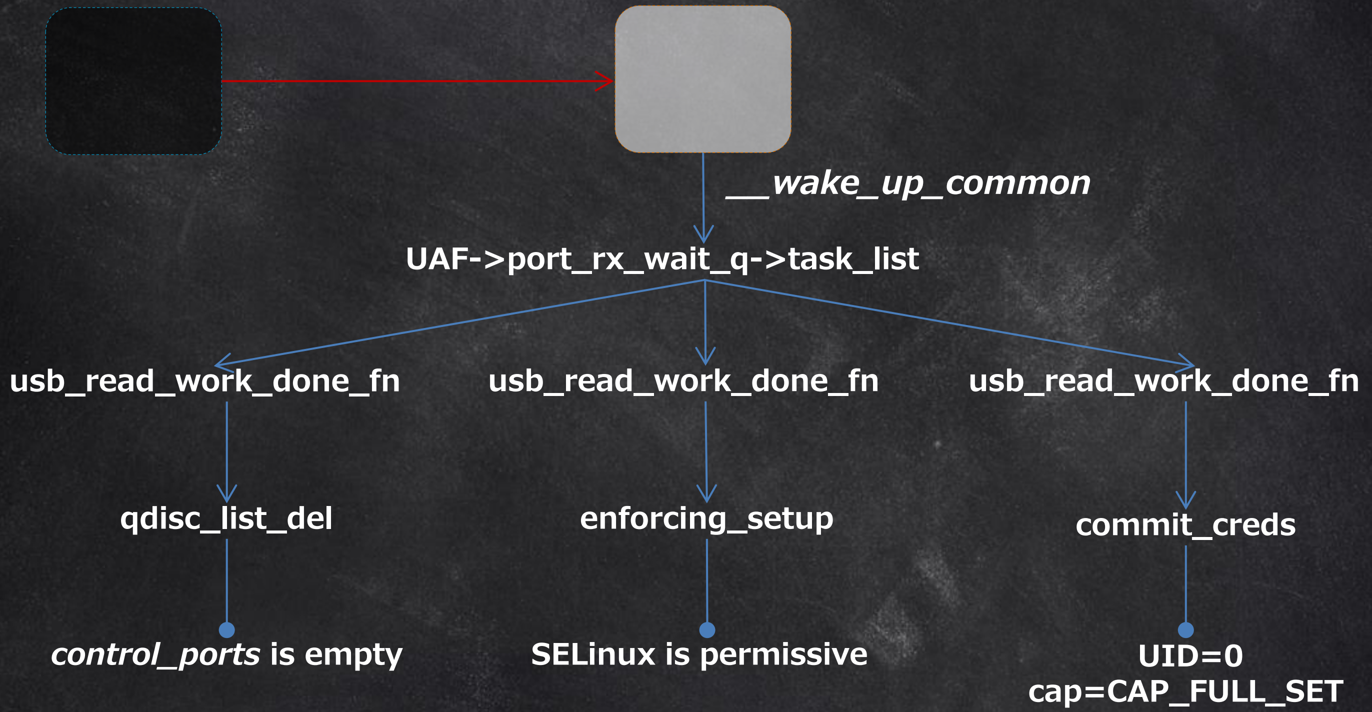
Qualaroot – Exploitation Flow

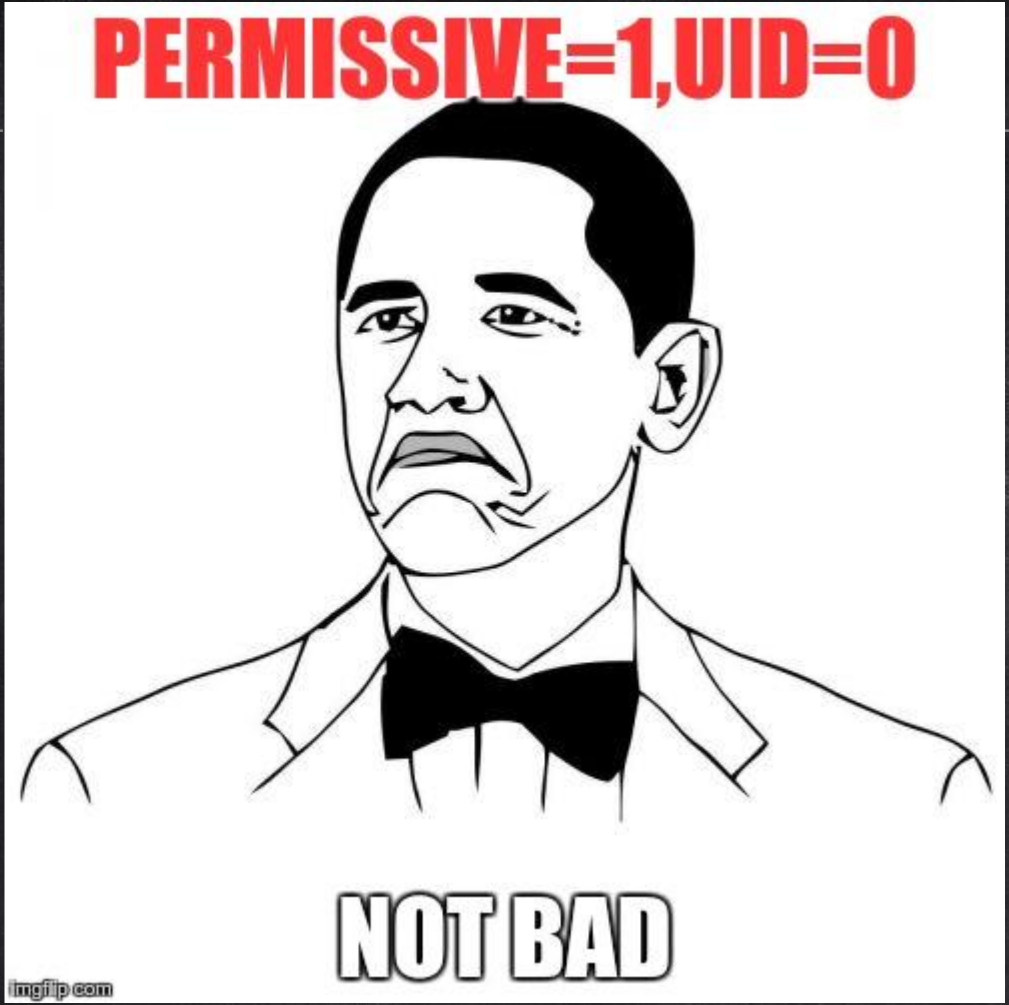


Spray until [illegible] to catch the UAF

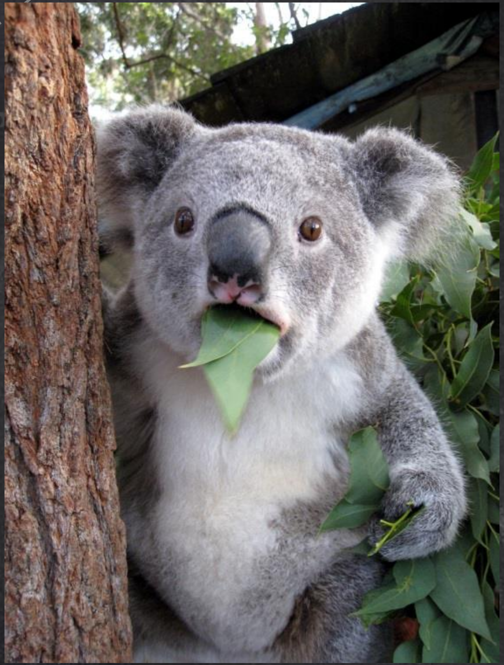
Trigger list iteration

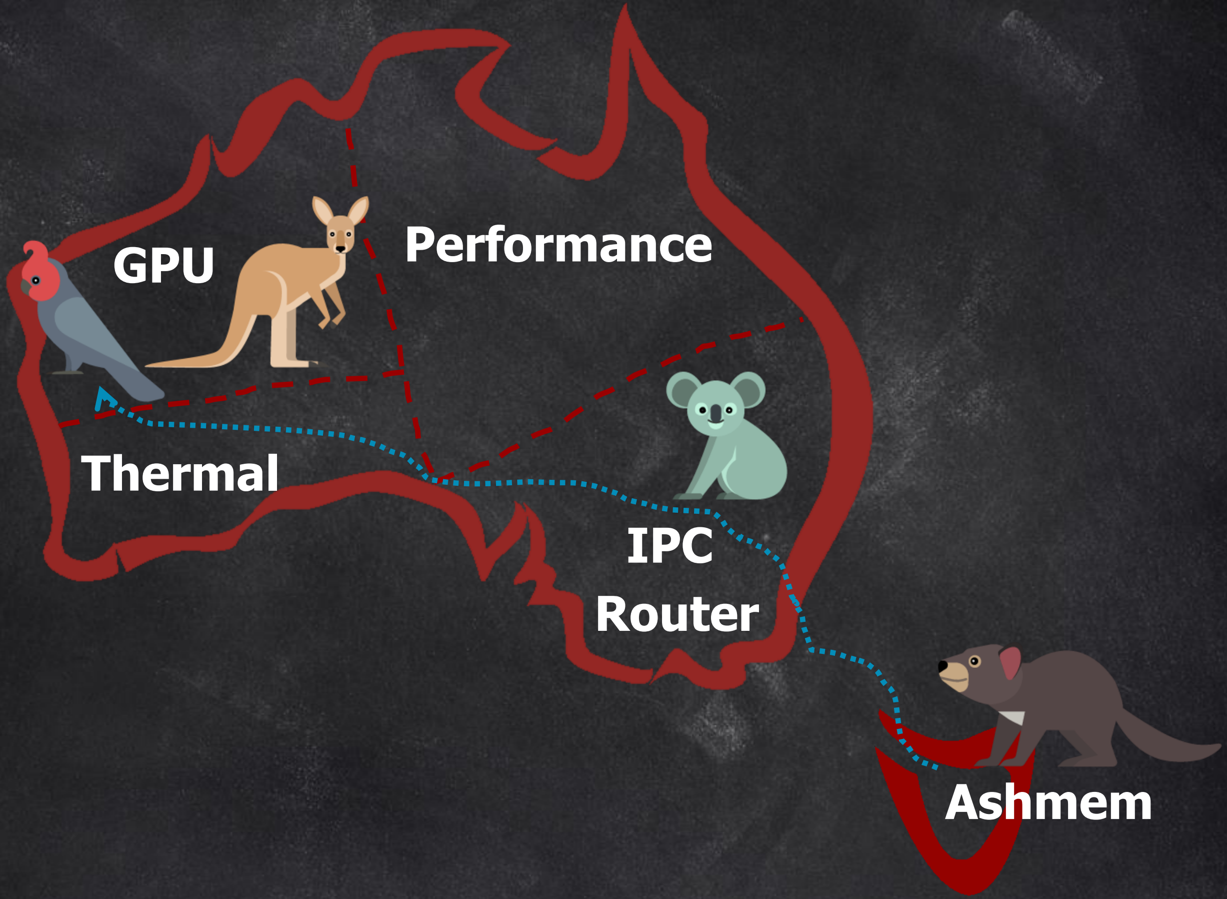
Qualaroot – Exploitation Flow




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

Demo Time!

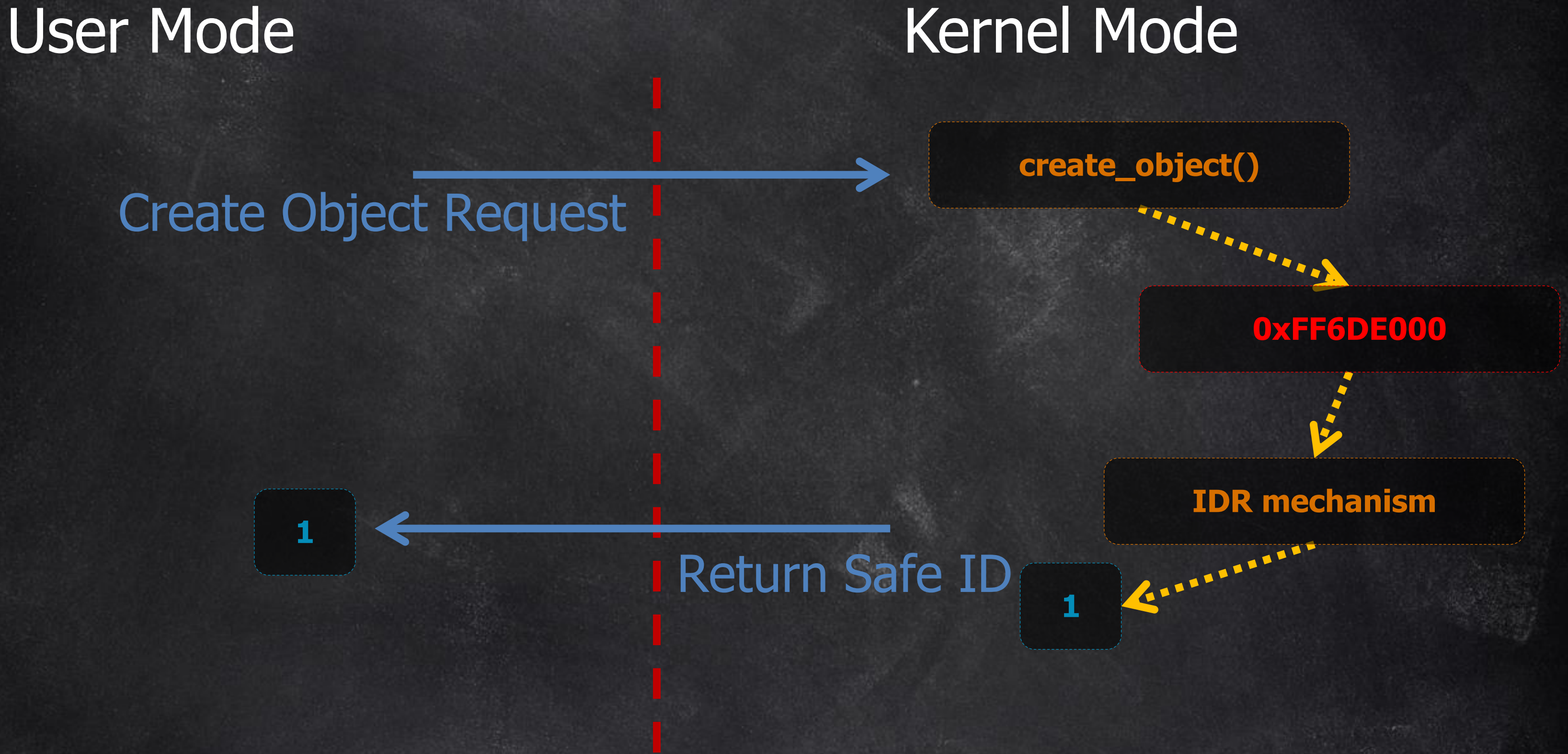



GPU
Performance
Thermal
IPC
Router
Ashmem

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;
```

```c
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

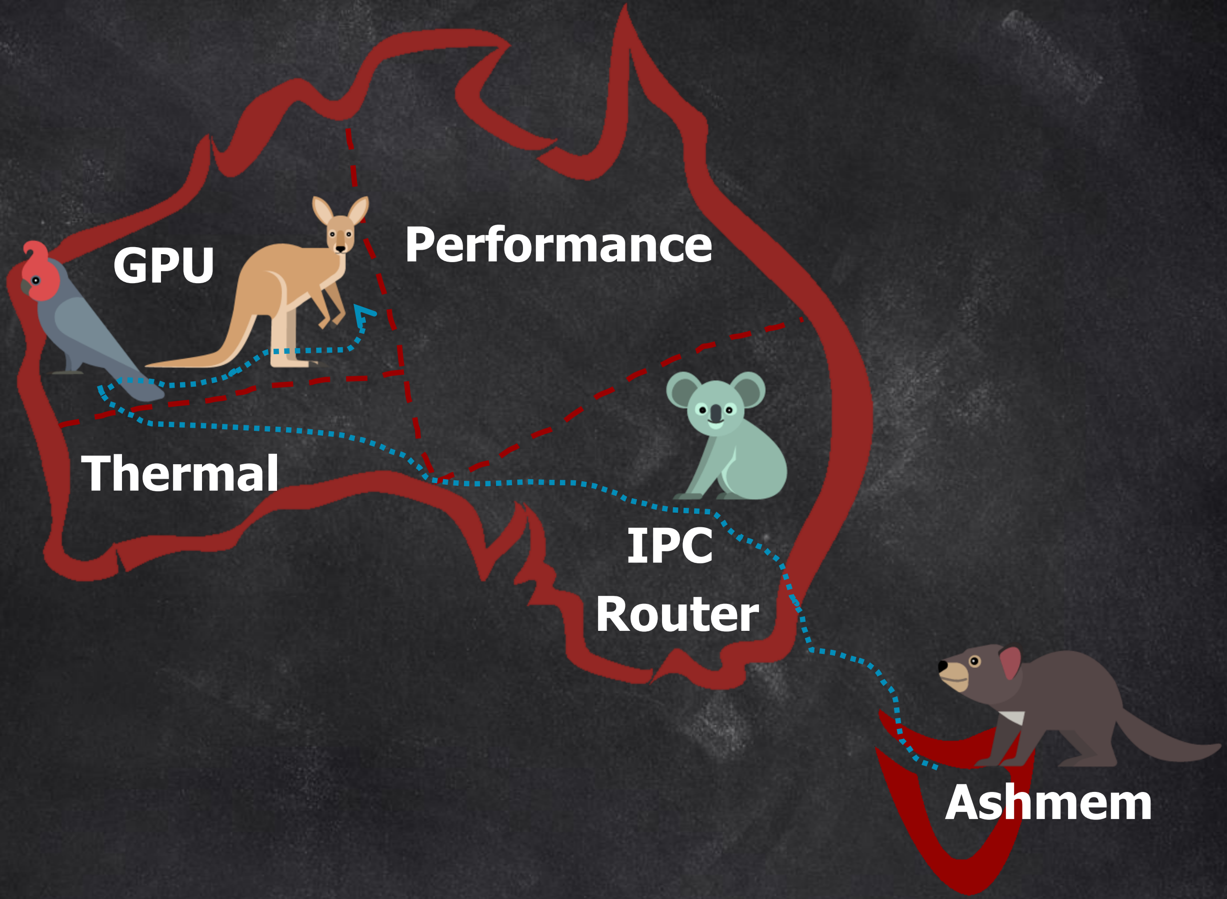
```
syncsource = kgsl_syncsource_get(id);
…
…
kgsl_syncsource_put(syncsource);
…
…
kgsl_syncsource_put(syncsource);
```

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 ☺

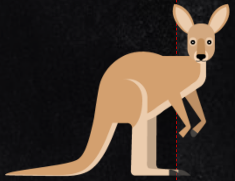

GPU
Performance
Thermal
IPC
Router
Ashmem

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;
}
```

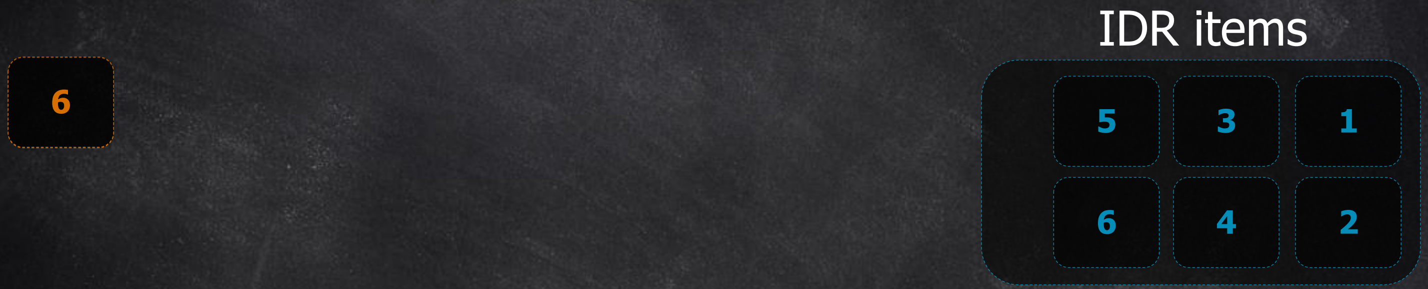
LOCKED APPROPRIATELY

```
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;
}
```

LOCKED INAPPROPRIATELY

KanGaroot (KGsl vulnerability)

CVE-2016-2504



Thread A - allocator

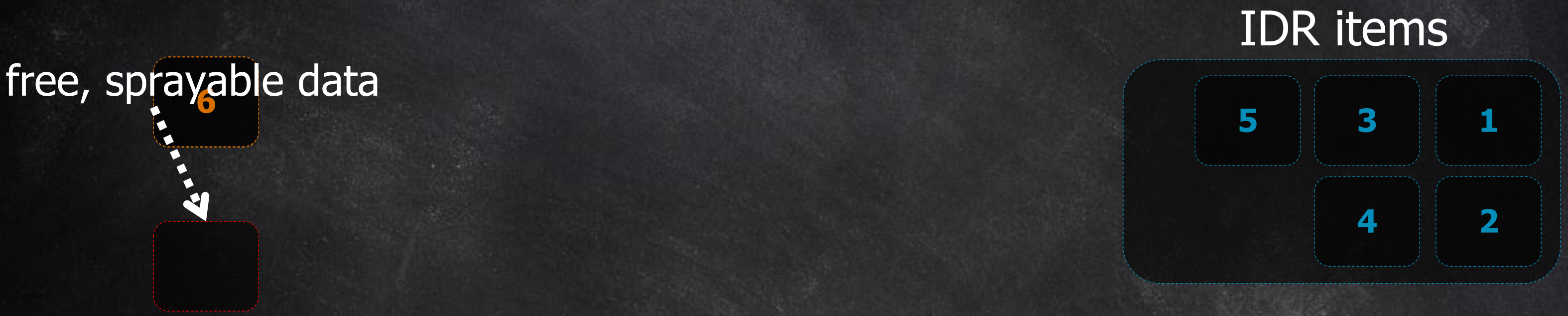
```
entry = kgsl_mem_entry_create();
…
…
id = idr_alloc(…, entry, …);
…
…
initialize_entry(entry);
```

Thread B - releaser

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

KanGaroot (KGsl vulnerability)

CVE-2016-2504



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

OUT OF BAND PATCH BY SEVERAL OEMS

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

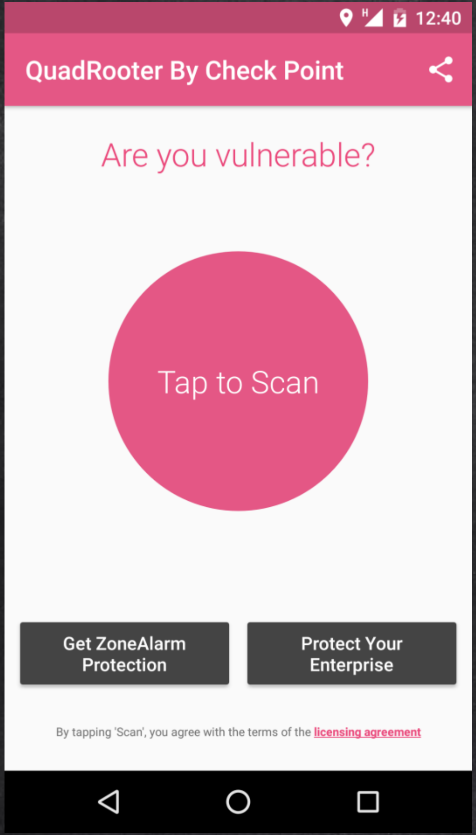
Suggestions/Special Thanks

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?


12:40

QuadRooter By Check Point

Are you vulnerable?

Tap to Scan

Get ZoneAlarm Protection

Protect Your Enterprise

By tapping 'Scan', you agree with the terms of the licensing agreement

Google Play

QuadRooter Scanner

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Thank You!

Check Point
SOFTWARE TECHNOLOGIES LTD.