Post Memory Corruption Memory Analysis

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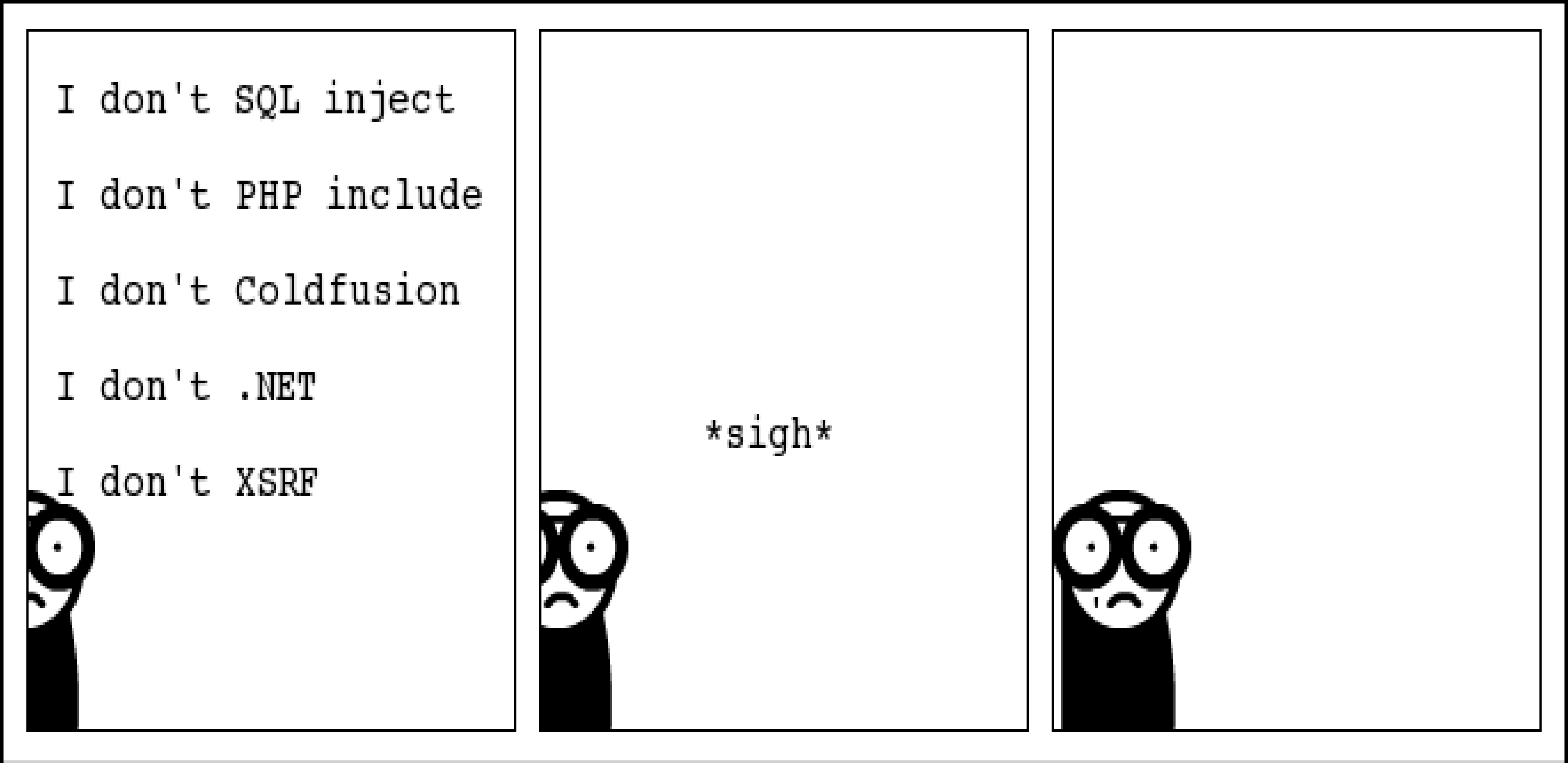
Who am I ?

- Security Research Engineer at Toucan System
- Speaker at Blackhat, Defcon, HITB, H2HC, Kiwicon, Ruxcon.
- Organiser of the Hackito Ergo Sum conference (Paris).
- I'm the guy who comes to CCC with 90+ slides...

I don't reverse plain text



Agenda

- A few basics
- Being environment aware
- PMCMA Design
- Extending Pmcma
- Stack desynchronization

Tool available at http://www.pmcma.org

We got 10k downloads+ in 2 less than months...

... and every email we get is questioning exploitation of remote stack overflows instead of invalid memory writes... ;(

What's pmcma ?

It's a debugger, for Linux (maybe one day *NIX) ptrace() based.

Pmcma allows to find and test exploitation scenarios.

Pmcma's output is a roadmap to exploitation, not exploit code.

Tells you if a given bug triggering an invalid memory access is a vulnerability, if it is exploitable with the state of the art, and how to exploit it.

What's pmcma ?

DEMO

Coz you asked for it…

Remote stack overflow automated exploitation

NX/SSP (stack cookies)/ASLR/PIE/STATIC GOT/Ascii Armoring...

=> No problem, easy cheesy : can be done with static analysis (of the libc/binary) only.

Remote stack overflow automated exploitation

SSP :

cookies can be bruteforced remotely
(cf Ben Hawks @ Ruxcon 2006).

Remote stack overflow automated exploitation

FORTIFY :
- Doesn't apply all the time.
- Fails silently (this is bad !!)
- Is consistent under Linux (but not Apple...)

Remote stack overflow automated exploitation

PIE :

- The bug new thing (every deamon compiled with PIE under ubuntu 10.10)
- No public exploits (untill today ;)
- We can bruteforce the saved EIP, then get back to ret2plt or ROP.

DEMO

Now, let's move to the real thing…

A FEW BASICS

Seriously, can we skip this section ?

How do applications crash ?

* Stack corruptions -> stack overflows, usually now detected because of SSP | studied a LOT
* Signal 6 -> assert(),abort(): unexpected execution paths (assert() in particular), heap corruptions
* Segfault (Signal 11) -> Invalid memory access

How do applications crash ?

* Stack corruptions -> stack overflows, usually now detected because of SSP | studied a LOT
* Signal 6 -> assert(),abort(): unexpected execution paths (assert() in particular), heap corruptions
* Segfault (Signal 11) -> Invalid memory access

Invalid memory access

- trying to read a page not readable. often not mapped at all.
- trying to write to a page not writable. often not mapped at all.
- trying to execute a page not executable. often not mapped at all.

Why do they happen ?

Because of any kind of miscomputation, really :

- integer overflows in loop counters or destination registers when copying/initializing data, casting errors when extending registers or
- uninitialised memory, dangling pointers
- variable misuse
- heap overflows (when inadvertently overwriting a function ptr)
- missing format strings
- overflows in heap, .data, .bss, or any other writable section (including shared libraries).
- stack overflows when no stack cookies are present...

Exploiting invalid exec

Trivial, really. Eg :

call eax

with eax fully user controled

Invalid memory reads (1/2)

Eg :

CVE-2011-0761 (Perl)

```
cmp    BYTE PTR [ebx+0x8],0x9
```

Invalid memory reads (2/2)

Eg :

CVE-2011-0764 (t1lib)

```
fld    QWORD PTR [eax+0x8]
```

Exploiting invalid memory reads ?

- usually plain not exploitable
- won't allow us to modify the memory of the mapping directly
- in theory : we could perform a user controled read, to trigger a second (better) bug.

Invalid memory writes

Eg :

CVE-2011-1824 (Opera)

```
mov    DWORD PTR [ebx+edx*1],eax
```

How to...

To exploit invalid writes, we need to find ways to transform an arbitray write into an arbitrary exec.

The most obvious targets are function pointers.

Exploiting invalid memory writes : scenario

- Target a known function pointer (typically : .dtors, GOT entry...).

Can be prevented at compile time : no .dtors, static GOT...

- Target function pointers in the whole binary ?
- Overwrite a given location to trigger an other bug (eg : stack overflow)

Being environment aware

Problems to take into account

- Kernel : ASLR ? NX ?
- Compilation/linking : RELRO (partial/full) ? no .dtors section ? SSP ? FORTIFY_SOURCE ?

=> Pmcma needs to mesure/detect those features

ASLR

Major problem when chosing an exploitation strategy.

ASLR : not perfect

- Prelinking (default on Fedora) breaks ASLR
- All kernels don't have the same randomization strength.
- Non PIE binaries

=> Truth is : we need better tools to test it !

Testing ASLR

-Run a binary X times (say X=100)

  -Stop execution after loading

-Record mappings.

=> Compare mappings, deduce randomization

DEMO : being environment aware

PMCMA DESIGN

GOALS

- We want to test overwriting different memory locations inside a process and see if they have an influence over the flow of execution
- We want to scale to big applications (web browsers, network deamons...)
- We want a decent execution time

mk_fork()

The idea :

-We start analysing after a SEGFAULT
-We make the process fork() (many many times)
-Inside each offspring, we overwrite a different memory location

mk_fork() : benefits

Mapping looks « just like » it will when actually exploiting a binary

No ASLR/mapping replication problem

Exhaustive and hopefully fast

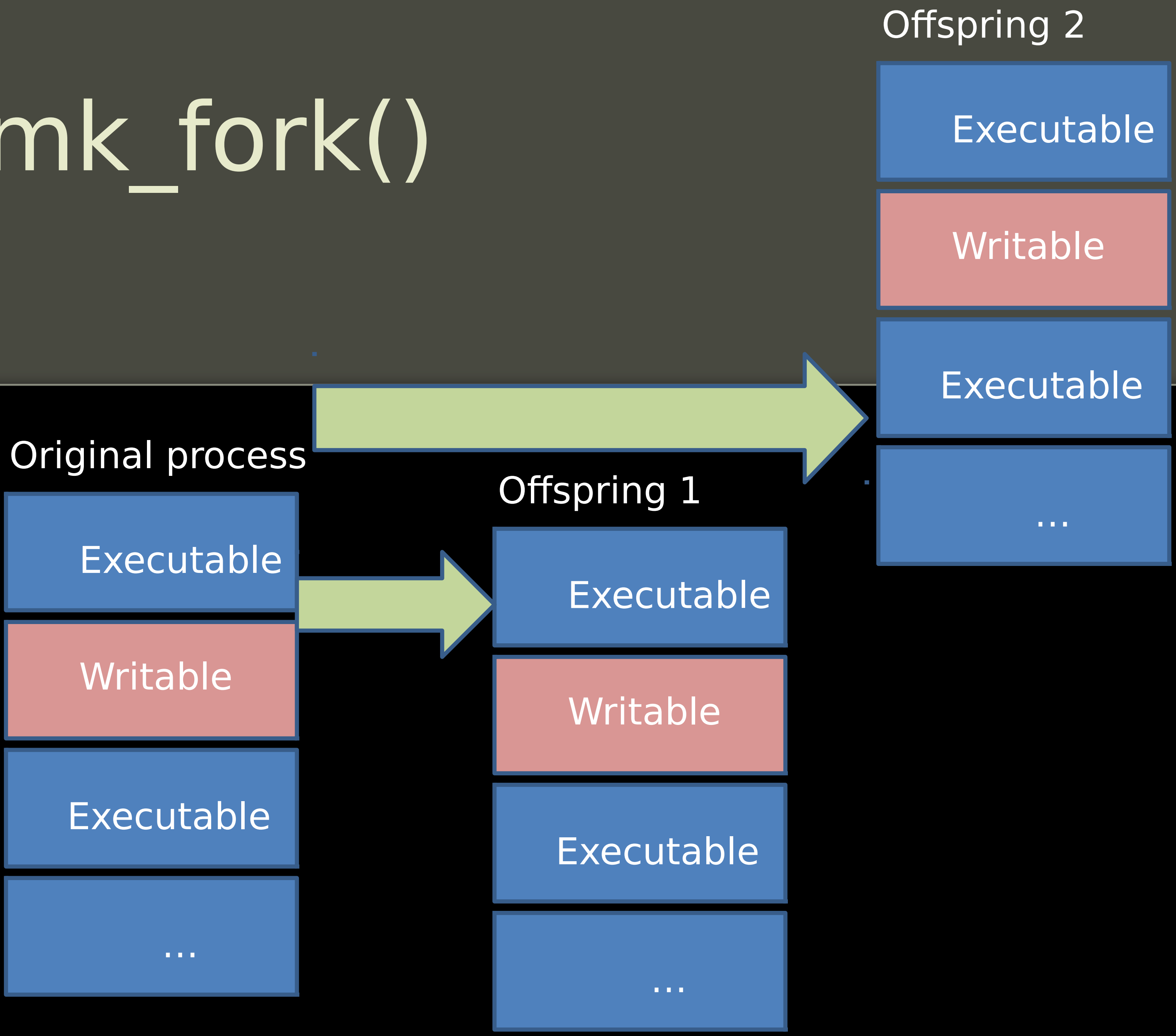
How to force a process to fork ?

1) Find a +X location mapped in memory.
2) Save registers
3) Use ptrace() to inject fork() shellcode.
4) Modify registers so eip points to shellcode.
5) Execute shellcode.
6) Wait() for both original process and offspring.
7) Restore bytes in both processes.
8) Restore registers in both processes.

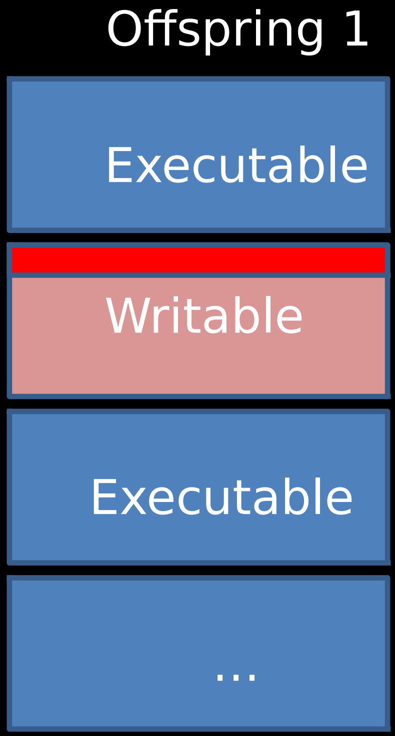
Forking shellcode

```
;forking shellcode:
00000000  6631C0          xor eax,eax
00000003  B002            mov al,0x2
00000005  CD80            int 0x80
```

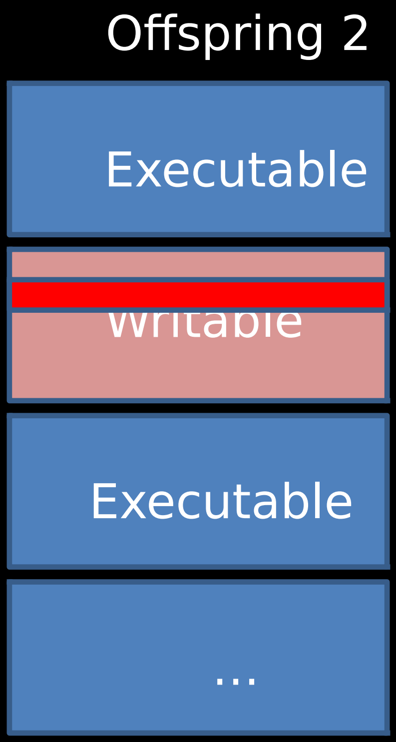
mk_fork()


Offspring 2
Executable
Writable
Executable
...
Original process
Executable
Writable
Executable
...
Offspring 1
Executable
Writable
Executable
...

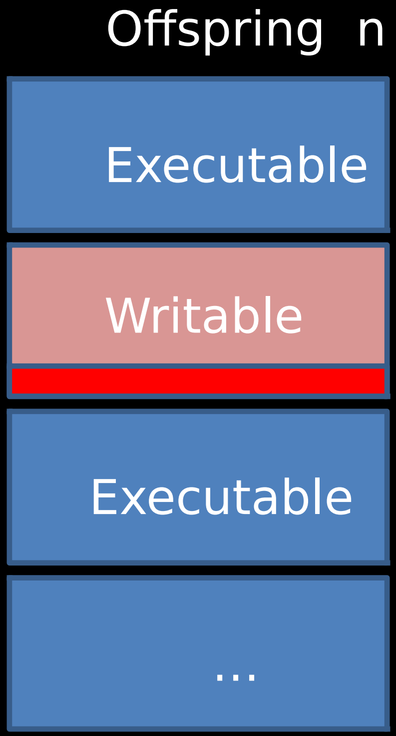
mk_fork()



mk_fork()



mk_fork()



mk_fork() : PROS

- allows for multiple tests out of a single process
- fast, efficient (no recording of memory snapshots)
- no need to use breakpoints
- no single stepping

mk_fork() : CONS

- Dealing with offsprings termination ? (Zombie processes)
- I/O, IPC, network sockets will be in unpredictable state
- Hence syscalls will get wrong too (!!)

Zombie reaping

- Avoid the wait() for a SIGCHILD in the parent process.
- Kill processes after a given timeout, including all of their children.

Zombie reaping : the SIGCHILD problem

If we can have the parent process ignore SIGCHILD signals, we won't create Zombies.

=> We inject a small shellcode to perform this via sigaction()

Zombie reaping : the SIGCHILD problem

1) Find a +X location mapped in memory.
2) Save registers
3) Use ptrace() to inject sigaction() shellcode.
4) Modify registers so eip points to shellcode.
5) Execute shellcode.
6) Wait() for the process while executing shellcode.
7) Restore bytes in +X location.
8) Restore registers in the process.

Force process grouping : shellcode

; Sigaction shellcode: // Zombie reaper
; struct sigaction sa = {.sa_handler = SIG_IGN};
; sigaction(SIGCHLD, &sa, NULL);

```
_start:
        nop
        nop
        nop
        nop
        call fake
fake:
        pop ecx
        add ecx,0x18    ; delta to sigaction structure

        xor eax,eax
        mov al,0x43     ; sigaction
        mov ebx,0x11    ; SIGCHLD
        xor edx,edx     ; 0x00
        int 0x80

        db 0xcc, 0xcc,0xcc,0xcc

; struct sigaction sa = {.sa_handler = SIG_IGN};
        db 01, 00, 00, 00, 00, 00, 00, 00, 00, 00, 00, 00, 00, 00
        db 00, 00, 00, 00, 00, 00, 00, 00, 00, 00, 00, 00, 00, 00
        db 00, 00, 00, 00, 00, 00, 00, 00, 00, 00, 00, 00, 00, 00
        db 00, 00, 00, 00, 00, 00, 00, 00, 00, 00, 00, 00, 00, 00
        db 00, 00, 00, 00, 00, 00, 00, 00, 00, 00, 00, 00, 00, 00
        db 00, 00, 00, 00, 00, 00, 00, 00, 00, 00, 00, 00, 00, 00
        db 00, 00, 00, 00, 00, 00, 00, 00, 00, 00, 00, 00, 00, 00
        db 00, 00, 00, 00, 00, 00, 00, 00, 00, 00, 00, 00, 00, 00
        db 00, 00, 00, 00, 00, 00, 00, 00, 00, 00, 00, 00, 00, 00
        db 00, 00, 00, 00, 00, 00, 00, 00, 00, 00, 00, 00, 00, 00
```

Zombie reaping : killing the offsprings and their children

Fortunatly, this is possible using « process grouping »...

Process grouping

setpgid() sets the PGID of the process specified by pid to pgid. If pid is zero, then the process ID of the calling process is used. If pgid is zero, then the PGID of the process specified by pid is made the same as its process ID. If setpgid() is used to move a process from one process group to another (as is done by some shells when creating pipelines), both process groups must be part of the same session (see setsid(2) and credentials(7)). In this case, the pgid specifies an existing process group to be joined and the session ID of that group must match the session ID of the joining process.

Zombie reaping : forcing process grouping

1) Find a +X location mapped in memory.
2) Save registers
3) Use ptrace() to inject setpgid() shellcode.
4) Modify registers so eip points to shellcode.
5) Execute shellcode.
6) Wait() for the process while executing shellcode.
7) Restore bytes in +X location.
8) Restore registers in the process.

Force process grouping…

```
;
; setpgid(0,0); shellcode
;

_start:
    nop
    nop
    nop
    nop
    mov eax,0x39  ; setpgid
    xor ebx,ebx
    xor ecx,ecx
    int 0x80

    db 0xcc, 0xcc
```

Zombie reaping : final details

From now on, to kill a process and all of its children :

```
kill (-pid, SIGTERM) ;
```

IPC, I/O, invalid syscalls

One possibility is to recode correct execution on the original process (after clearing signals and ignoring the SEGFAULT).
Then replay/fake the syscalls on the offsprings.

=> Minimal userland « virtualization ».

PMCMA : FEATURES

Exploiting invalid memory writes via function pointers

We now want to find all the function pointers called by the application from the instruction which triggered the SEGFAULT until it actually halts.

(including pointers in shared libraries!!)

Finding all the function pointers actually called

1) Parse all the +W memory, look for possible pointers to any section
1 bis) optionally disassemble the destination and see if it is a proper prologue.
2) use mk_fork() to create many children
3) in each children, overwrite a different possible function pointer with a canari value (0xf1f2f3f4).
4) Monitor execution of the offsprings

Finding all the function pointers actually called

Overwritten pointer leads to execution of canari address 0xf1f2f3f4

<=> We found a called function pointer.

Finding all the function pointers actually called

DEMO

So what can we test now ?

Invalid write anything anywhere :

attacker has full control over data written and destination where written

=> GAME OVER

So what can we test now ?

Overflows (in any writtable section but the stack) :
Simply limit the results of pmcma to this section.

So what can we test now ?

What if the attacker has little or no control over the data being written (arbitrary write non controled data, anywhere) ?

Partial overwrites and pointers truncation

If we can't properly overwrite a function pointer, maybe we can still truncate one (with the data we don't control) so that it transfers execution to a controled memory zone ?

Exemple :

--[Function pointers exploitable by truncation with 0x41424344:
At 0xb70ce070 : 0xb70c63c2 will become 0xb70c4142 (lower truncated by 16 bits, dest perms:RW)
At 0xb70e40a4 : 0xb70ca8f2 will become 0xb70c4142 (lower truncated by 16 bits, dest perms:RW)
At 0xb70ec080 : 0xb70e5e02 will become 0xb70e4142 (lower truncated by 16 bits, dest perms:RW)
At 0xb731a030 : 0xb7315da2 will become 0xb7314142 (lower truncated by 16 bits, dest perms:RW)
At 0xb73230a4 : 0xb732003a will become 0xb7324142 (lower truncated by 16 bits, dest perms:RW)
At 0xb732803c : 0xb7325a36 will become 0xb7324142 (lower truncated by 16 bits, dest perms:RW)
At 0xb76a80d8 : 0xb7325bf0 will become 0xb7324142 (lower truncated by 16 bits, dest perms:RW)

One more situation…

Sometimes, an attacker has limited control over the destination of the write (wether he controls the data being written or not).

Eg : 4b aligned memory writes.

Exploiting 4b aligned memory writes

We can't attack a function pointer directly, unless it is unaligned (rare because of compiler internals).

Pmcma will still let you know if this happens ;)

Exploiting 4b aligned memory writes : plan B

Find all « normal » variables we can overwrite/truncate, and attempt to trigger a second bug because of this overwrite.

Finding all unaligned memory accesses

Setting the unaligned flag in the EFLAGS register will trigger a signal 7 uppon next access of unaligned memory (read/write).

Finding all unaligned memory accesses

DEMO

Finding all unaligned memory accesses

DEMO x86_64

Defeating ASLR : Automated memory mapping leakage

How does WTFuzz did it at CansecWest 2010 to win the pwn2own contest against IE8/Windows 7 ?

Overwrite the null terminator of a JS string to perform a mem leak uppon usage (trailing bytes).

Defeating ASLR with an arbitrary write ?

In the original process :
- use ptrace() PTRACE_SYSCALL
- record the calls to sys_write() and sys_socketall() (wrapper to sys_send() or sys_sendto()...), including :
    where is the data sent ? How many bytes ?

Defeating ASLR with an arbitrary write ?

Create many offsprings using mk_fork().
-In each of them : overwrite a different location with dummy data.
-Follow execution using PTRACE_SYSCALL
-Monitor differences : a different address or a bigger size means a memory leak :)

Extending Pmcma

Means of modifying the flow of execution without function pointers

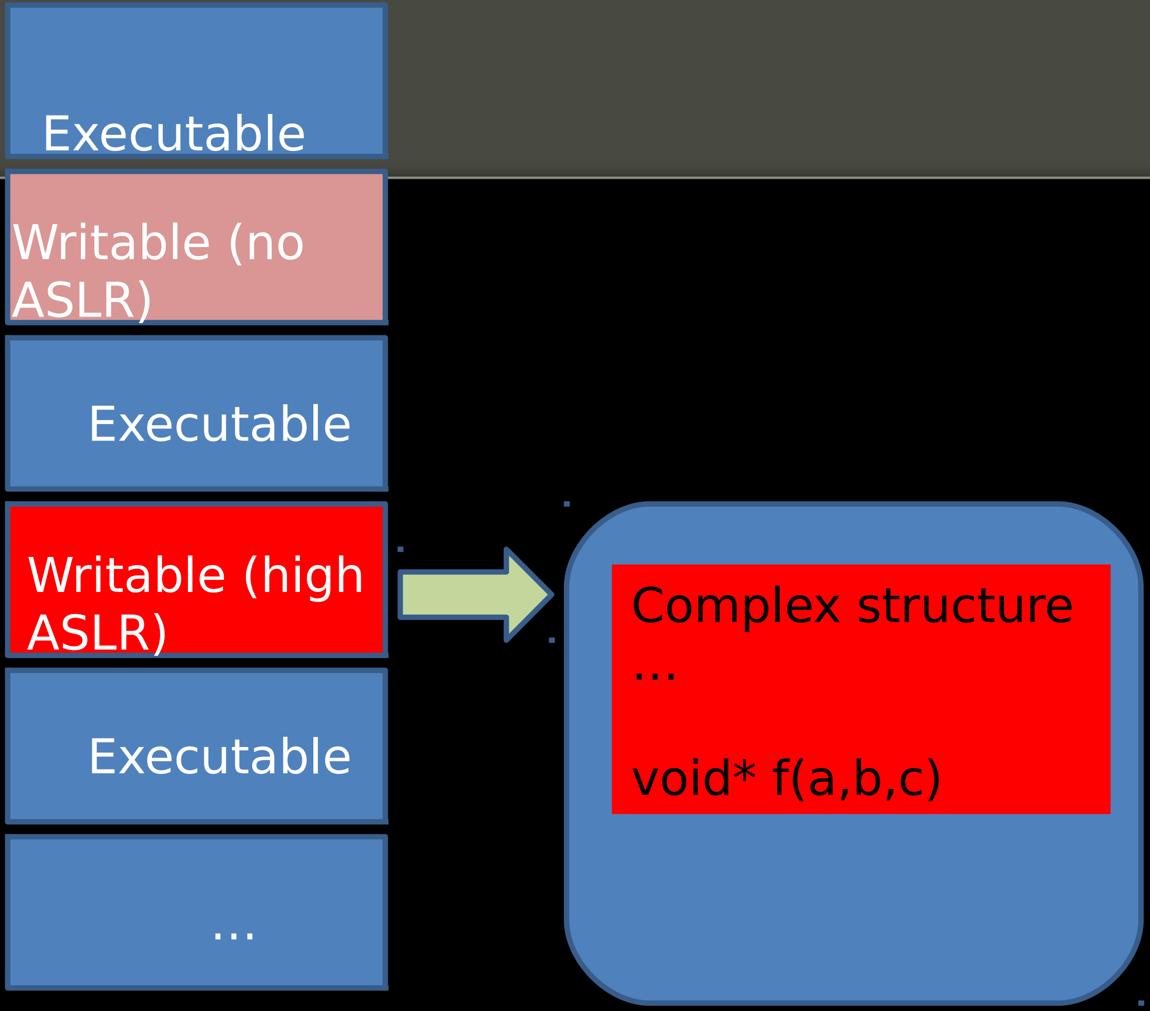
Call tables.
Calling [Offset+register]

=> This is also already performed automatically using pmcma.

Pointers and ASLR

If overwritting a given function pointer isn't practical because of ASLR : is it possible to overwrite a pointer (in an other section) to a structure containing this function pointer ? Would this « other section » be less randomised ?

Finding pointers to structures containing function pointers



Finding pointers to structures containing function pointers

We'd like to have the debugged process create a new section, with a given mapping (to ease identify).

Modify a possible pointer per offspring (use mk_fork()).

Monitor execution : is the offspring calling a function pointer from our custom mapping ?

Forcing a process to create a new mapping :

1) Find a +X location mapped in memory.
2) Save registers
3) Use ptrace() to inject mmap() shellcode.
4) Modify registers so eip points to shellcode.
5) Execute shellcode.
6) Wait() for the process while executing shellcode.
7) Restore bytes in +X location.
8) Restore registers in the process.

```
;
; old_mmap(NULL, 4096, PROT_READ|PROT_WRITE, MAP_SHARED|MAP_ANONYMOUS, 0, 0) shellcode:
;

_start:
        nop
        nop
        nop
        nop

        xor eax, eax
        xor ebx, ebx
        xor ecx, ecx
        xor edx, edx
        xor esi, esi
        xor edi, edi

        mov bx, 0x1000          ; 1 page
        mov cl, 0x3             ; PROT_READ|PROT_WRITE
        mov dl, 0x21            ; MAP_SHARED|MAP_ANON

        push eax
        push eax
        push edx
        push ecx
        push ebx
        push eax

        mov ebx, esp
        mov al, 0x5a            ; sys_mmap
        int 0x80

        ; eax contains address of new mapping

        db 0xcc, 0xcc, 0xcc, 0xcc
```

Testing exhaustively arbitrary writes

In case all of the above failed...

Can we trigger secondary bugs by overwritting specific memory locations ?

Testing exhaustively arbitrary writes

Complexity is huge !

Still doable with Pmcma, with no guaranty over the time of execution.

Testing exhaustively arbitrary reads

In the same veine, attacker controled invalid reads can trigger secondary bugs, which will be exploitable.

=> We can test the whole 4+ billions search space (under x86 Intel architecture), or just a few evenly chosen ones.

Stack desynchronization

W^X is a problem.

Even if we can overwrite fully a function pointer and modify the flow of execution... what do we want to execute in 2011 ?

Stack desynchronization

Instead of returning directly to shellcode in +W section (hence probably not +X) :

-Return to a function epilogue chosen so that esp will be set to user controled data in the stack.
- Fake stack frames in the stack itself.
- Use your favorite ROP/ret2plt shellcode

Stack desynchronization : Exemple : sudo

- stack is ~1000 big (at analysis time)
- we find a function pointer to overwrite (at 0x0806700c)
- we overwrite it with a carefully chosen prologue (inc esp by more than 1000)

Stack desynchronization : Exemple : sudo

```
jonathan@blackbox:~$ objdump -Mintel -d
   /usr/bin/sudo
...
 805277a:       81 c4 20 20 00 00       add esp,0x2020
 8052780:       5b                      pop    ebx
 8052781:       5e                      pop    esi
 8052782:       5d                      pop    ebp
 8052783:       c3                      ret
```

Stack desynchronization : Exemple : sudo

We can control the destination where esp is going to point : simply use an environment variable

TOTO=mydata sudo

Stack desynchronization : Exemple : sudo

We then forge fake stack frames in the stack itself

- « Nop sled » : any pointer to 'ret'

Eg :804997b: c3   ret

- Then copy shellcode to .bss byte per byte using memcpy via ret2plt
- Use GOT overwrite to get pointer to mprotect() in the GOT (ROP)
- call mprotect to make .bss +X via ret2plt
- return to shellcode in .bss

DEMOS

Future Work

- port to more architectures (Linux x86_64 on the way, arm...)
- port to more OS (Mac OSX, *BSD)
- port to Windows (hard)
- add tests for other bug classes

Thank you for coming

Questions ?