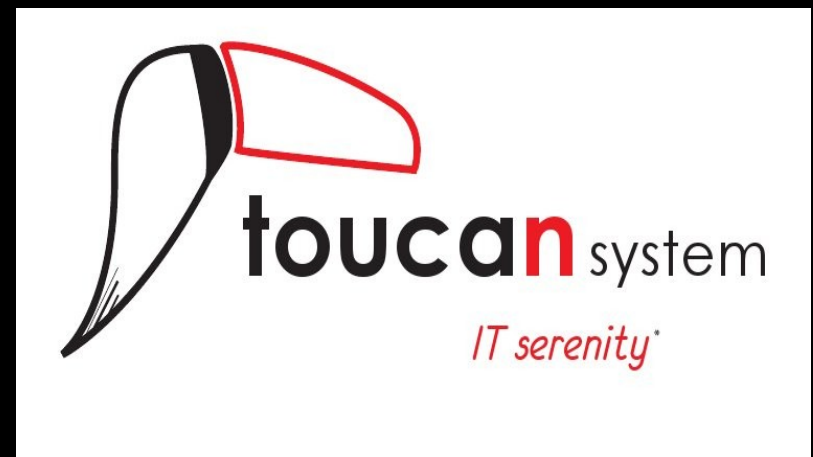


Post Memory Corruption Memory Analysis

Jonathan Brossard
CEO – Toucan System



jonathan@
toucan-system.com



Who am I ?

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

I don't reverse plain text

I don't SQL inject

I don't PHP include

I don't Coldfusion

I don't .NET

I don't XSRF



sigh



Regarding webapps...

For webdev, XSS, CSS, Javascript ... ask
Jeremiah Grossman during Ruxcon ;)

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...

(Note : Andrewg, thanks for your help,
you can stop your bot now...)

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.

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 controlled 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 arbitrary 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 .ctors section ? SSP ? FORTIFY_SOURCE ?

=> Pmcma needs to measure/detect those features

ASLR

Major problem when choosing 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 daemons...)
- 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.

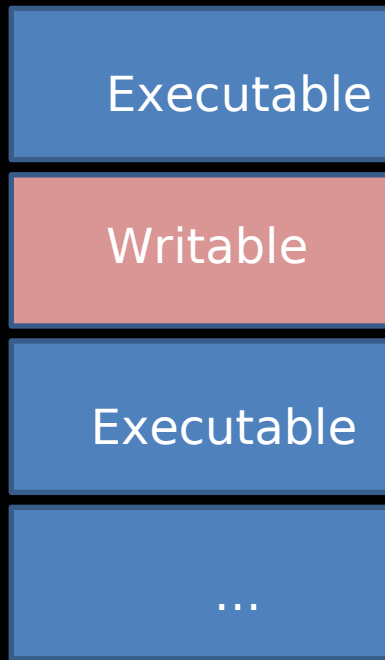
Forking shellcode

;forking shellcode:

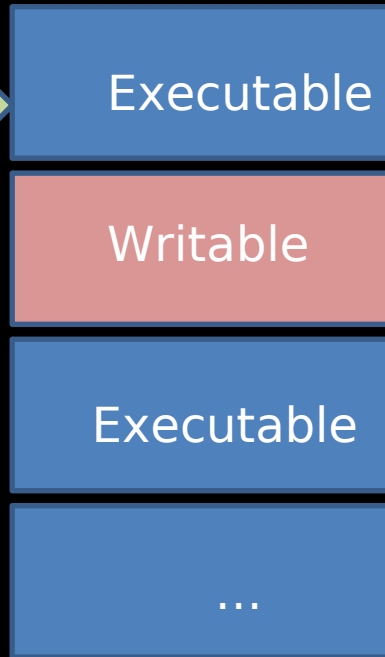
00000000	6631C0	xor eax,eax
00000003	B002	mov al,0x2
00000005	CD80	int 0x80

mk_fork()

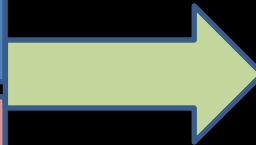
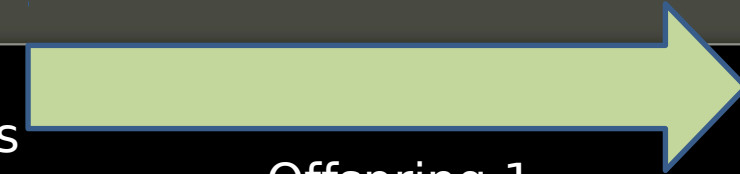
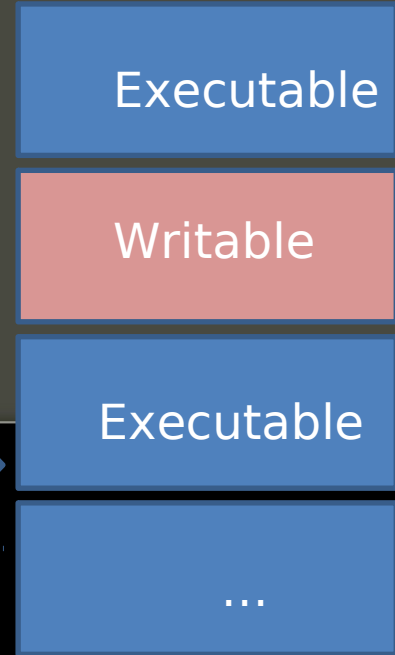
Original process



Offspring 1



Offspring 2



mk_fork()

Offspring 1

Executable

Writable

Executable

...

mk_fork()

Offspring 2

Executable

writable

Executable

...

mk_fork()

Offspring n

Executable

Writable

Executable

...

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 `SIGCHLD` in the parent process.
- Kill processes after a given timeout, including all of their children.

Zombie reaping : the SIGCHLD problem

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

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

Zombie reaping : the SIGCHLD 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.

Zombie reaping : killing
the offsprings and their
children

Fortunately, 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 writable 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 controlled 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 controlled 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 upon 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_socketcall()` (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.

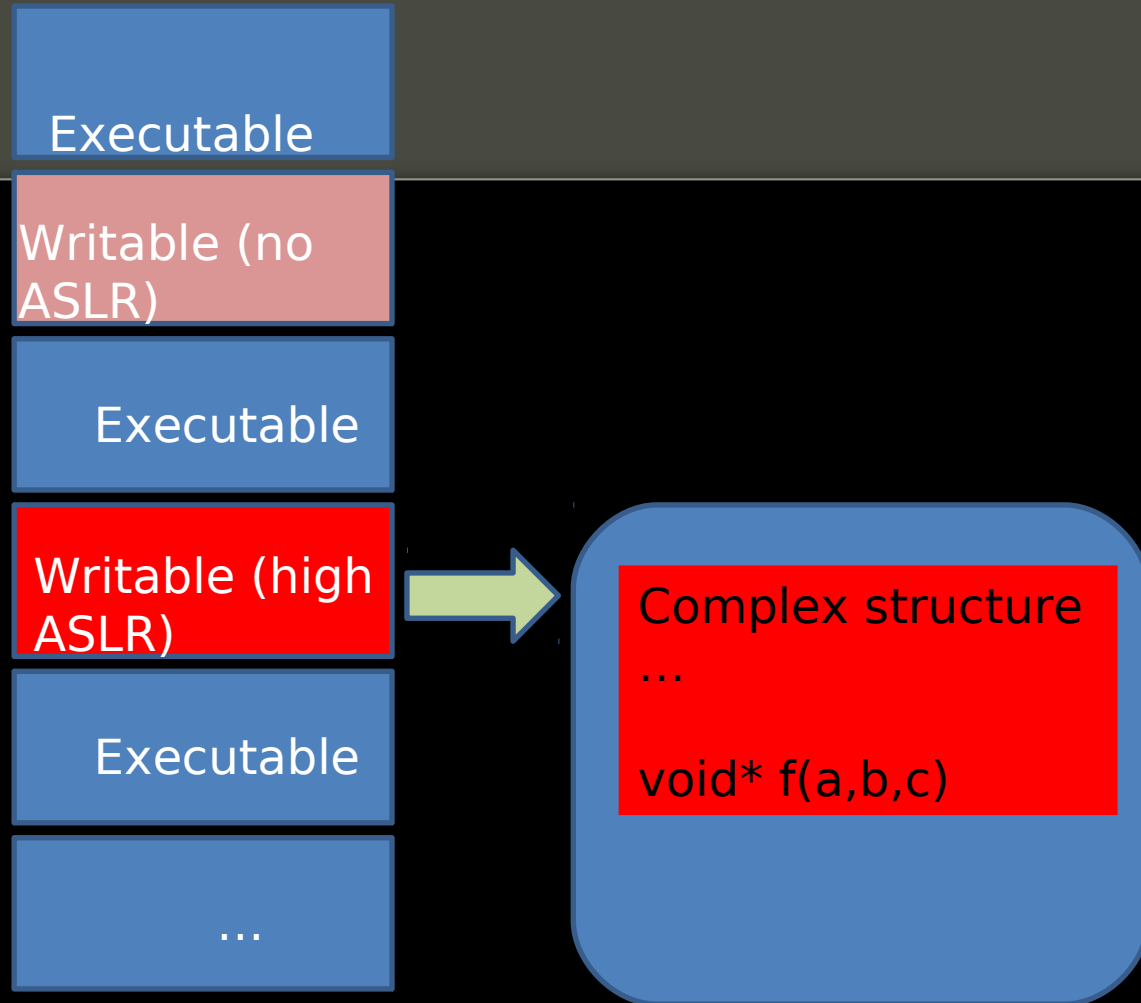
Calling [Offset+register]

=> This is also already performed
automatically using pmcma.

Pointers and ASLR

If overwriting 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
overwriting 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 vein, attacker controlled 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 controlled 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 -Intel -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 ?

