Buffer overflows and counter meassures

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2019-03-08

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- code review
- product pentesting

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Joined April 2014, got Heartbleed as signing bonus

Outline

Buffer overflows and protections:

- Stack canaries
- Fortify source
- Address space layout randomization
- No-execute memory (NX, W^X)

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Used by SUSE products, there are other protection mechanisms out there

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Requires some C and assembler background, but I'll explain most on the fly

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Also I will try to keep it at least a bit interactive

General mechanism

We're talking here about **stack** based buffer overflows and counter meassures

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Really simple example:

```
#include <string.h>

int main(int argc, char **argv) {
  char buffer[20];

  strcpy(buffer, argv[1]);

  return EXIT_SUCCESS;
}
```

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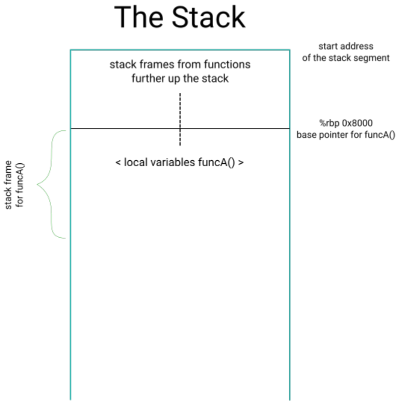
Usually a size check is just missing

Sometimes the check is there but faulty or can be circumvented (think integer overflows)

Why is this a problem?

Because in data of the application and control information about execution is mixed




```
/*
 * some simple, fuzzy code for explaining
 * the stack frame setup
 *
 * hex addresses are just rounded samples
 * for better readability
 */

void funcB(uint32_t num)
{
    uint64_t local_var;
    register uint32_t index;

    /* some more code */
}

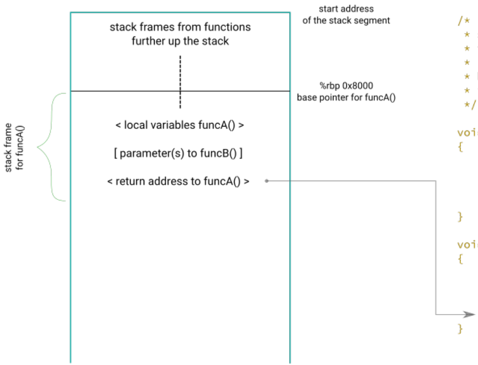
void funcA()
{
    /* some local vars */
    funcB(some_num);

    /* some more code */
}
```

Why is this a problem?

Part of the control information (saved instruction pointer RIP/EIP) is the address where execution will continue after the current function

The Stack

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```

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If a buffer overflow happens this control information can be overwritten

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If this is done carefully arbitrary code can be executed

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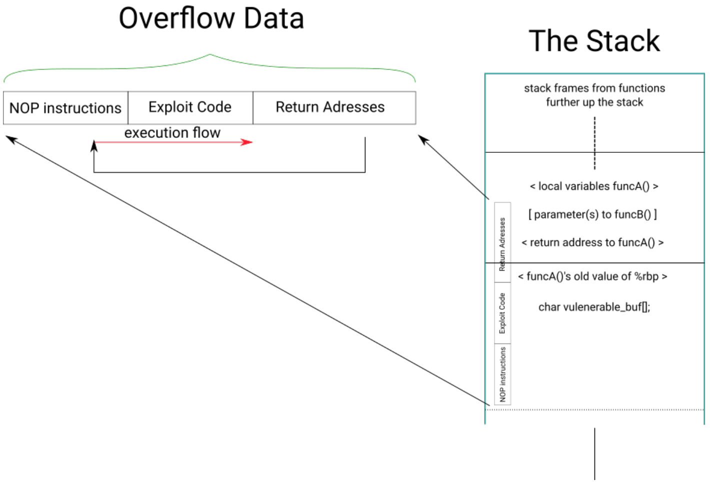

Other overwrites

Not only saved RIP/EIP can be highjacked. Think of

- Function pointers
- Exceptions handlers
- Other application specific data (`is_admin` flag ...)

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Not only saved RIP/EIP can be highjacked. Think of

- Function pointers
- Exceptions handlers
- Other application specific data (`is_admin` flag ...)

So what can be done against these problems?

Just use Java for everything. Done! We're safe ;)

Simple 32 bit exploitation

```c
#include <unistd.h>

void vulnerable( void ) {
  char buffer[256];

  read(0, buffer, 512);

  return;
}

int main(int argc, char **argv) {
  vulnerable();

  return EXIT_SUCCESS;
}
```

Demo time

Mitigations: Stack canaries

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General idea: Compiler generates extra code that puts a *canary* value at predefined locations within a stack frame

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- `-fstack-protector-all`: extra code for each and every function
- `-fstack-protector-explicit`: extra code every function annotated with `stack_protect`

Mitigations: Stack canaries

Short reminder of the example code:

```c
#include <string.h>

int main(int argc, char **argv)
{
  char buffer[20];

  strcpy(buffer, argv[1]);

  return EXIT_SUCCESS;
}
```

Mitigations: Stack canaries

Original code:

```
00000000000006b0 <main>:
 6b0:    55                      push   rbp
 6b1:    48 89 e5                mov    rbp,rsp
 6b4:    48 83 ec 30             sub    rsp,0x30
 6b8:    89 7d dc                mov    DWORD PTR [rbp-0x24],edi
 6bb:    48 89 75 d0             mov    QWORD PTR [rbp-0x30],rsi
 6bf:    48 8b 45 d0             mov    rax,QWORD PTR [rbp-0x30]
 6c3:    48 83 c0 08             add    rax,0x8
 6c7:    48 8b 10                mov    rdx,QWORD PTR [rax]
 6ca:    48 8d 45 e0             lea    rax,[rbp-0x20]
 6ce:    48 89 d6                mov    rsi,rdx
 6d1:    48 89 c7                mov    rdi,rax
 6d4:    e8 87 fe ff ff          call   560 <strcpy@plt>
 6d9:    b8 00 00 00 00          mov    eax,0x0
 6de:    c9                      leave
 6df:    c3                      ret
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Mitigations: Stack canaries

Protected code:

```
0000000000000720 <main>:
 720:    55                      push   rbp
 721:    48 89 e5                mov    rbp,rsp
 724:    48 83 ec 30             sub    rsp,0x30
 728:    89 7d dc                mov    DWORD PTR [rbp-0x24],edi
 72b:    48 89 75 d0             mov    QWORD PTR [rbp-0x30],rsi
 72f:    64 48 8b 04 25 28 00    mov    rax,QWORD PTR fs:0x28
 736:    00 00
 738:    48 89 45 f8             mov    QWORD PTR [rbp-0x8],rax
 73c:    31 c0                   xor    eax,eax
 73e:    48 8b 45 d0             mov    rax,QWORD PTR [rbp-0x30]
 742:    48 83 c0 08             add    rax,0x8
 746:    48 8b 10                mov    rdx,QWORD PTR [rax]
 749:    48 8d 45 e0             lea    rax,[rbp-0x20]
 74d:    48 89 d6                mov    rsi,rdx
 750:    48 89 c7                mov    rdi,rax
 753:    e8 68 fe ff ff          call   5c0 <strcpy@plt>
 758:    b8 00 00 00 00          mov    eax,0x0
 75d:    48 8b 4d f8             mov    rcx,QWORD PTR [rbp-0x8]
 761:    64 48 33 0c 25 28 00    xor    rcx,QWORD PTR fs:0x28
 768:    00 00
 76a:    74 05                   je     771 <main+0x51>
 76c:    e8 5f fe ff ff          call   5d0 <__stack_chk_fail@plt>
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- No protection for inlined functions
- Can be used to cause DoS

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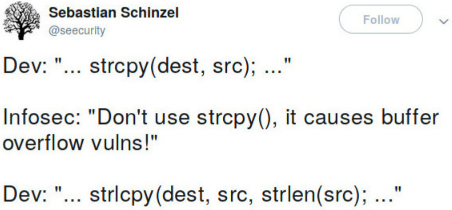

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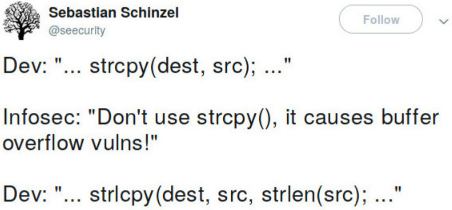

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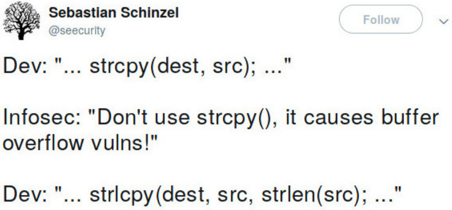

What is checked: For statically sized buffers the compiler can check calls to certain functions.

Enable it with `-DFORTIFY_SOURCE=2` (only with optimization).

Mitigations: Fortify source

```c
void fun(char *s) {
  char buf[0x100];
  strcpy(buf, s);
  /* Don't allow gcc to optimise away the buf */
  asm volatile("" :: "m" (buf));
}

int main(int argc, char **argv)
{
  fun( argv[1] );

  return EXIT_SUCCESS;
}
```

Example based on Matthias' work

Mitigations: Fortify source

```
00000000000006b0 <fun>:
 6b0:    55                      push   rbp
 6b1:    48 89 e5                mov    rbp,rsp
 6b4:    48 81 ec 10 01 00 00    sub    rsp,0x110
 6bb:    48 89 bd f8 fe ff ff    mov    QWORD PTR [rbp-0x108],rdi
 6c2:    48 8b 95 f8 fe ff ff    mov    rdx,QWORD PTR [rbp-0x108]
 6c9:    48 8d 85 00 ff ff ff    lea    rax,[rbp-0x100]
 6d0:    48 89 d6                mov    rsi,rdx
 6d3:    48 89 c7                mov    rdi,rax
 6d6:    e8 85 fe ff ff          call   560 <strcpy@plt>
 6db:    90                      nop
 6dc:    c9                      leave
 6dd:    c3                      ret
```

Mitigations: Fortify source

`gcc -o fortify -O2 -D_FORTIFY_SOURCE=2 fortify.c`

```
0000000000000700 <fun>:
 700:   48 81 ec 08 01 00 00    sub    rsp,0x108
 707:   48 89 fe                mov    rsi,rdi
 70a:   ba 00 01 00 00          mov    edx,0x100
 70f:   48 89 e7                mov    rdi,rsp
 712:   e8 69 fe ff ff          call   580 <__strcpy_chk@plt>
 717:   48 81 c4 08 01 00 00    add    rsp,0x108
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But it comes with almost no cost, so enable it

Mitigations: ASLR

ASLR: Address space layout randomization

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Memory segments (stack, heap and code) are loaded at random locations

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Memory segments (stack, heap and code) are loaded at random locations

Atttackers don't know return addresses into exploit code or C library code reliably any more

Mitigations: ASLR

```
bash -c 'cat /proc/$$/maps'
56392d605000-56392d60d000 r-xp 00000000 fe:01 12058638  /bin/cat
<snip>
56392dd05000-56392dd26000 rw-p 00000000 00:00 0         [heap]
7fb2bd101000-7fb2bd296000 r-xp 00000000 fe:01 4983399
     /lib/x86_64-linux-gnu/libc-2.24.so
<snip>
7fb2bd6b2000-7fb2bd6b3000 r--p 00000000 fe:01 1836878
     /usr/lib/locale/en_AG/LC_MESSAGES/SYS_LC_MESSAGES
<snip>
7fffd5c36000-7fffd5c57000 rw-p 00000000 00:00 0         [stack]
7fffd5ce9000-7fffd5ceb000 r--p 00000000 00:00 0         [vvar]
7fffd5ceb000-7fffd5ced000 r-xp 00000000 00:00 0         [vdso]
ffffffffff600000-ffffffffff601000 r-xp 00000000 00:00 0 [vsyscall]
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7fb2bd6b2000-7fb2bd6b3000 r--p 00000000 fe:01 1836878
     /usr/lib/locale/en_AG/LC_MESSAGES/SYS_LC_MESSAGES
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```

```
for i in `seq 1 5`; do bash -c 'cat /proc/$$/maps | grep stack'; done
7ffcb8e0f000-7ffcb8e30000 rw-p 00000000 00:00 0 [stack]
7fff64dc9000-7fff64dea000 rw-p 00000000 00:00 0 [stack]
7ffc3b408000-7ffc3b429000 rw-p 00000000 00:00 0 [stack]
7ffcee799000-7ffcee7ba000 rw-p 00000000 00:00 0 [stack]
7ffd4b904000-7ffd4b925000 rw-p 00000000 00:00 0 [stack]
```

Mitigations: ASLR

`cat /proc/sys/kernel/randomize_va_space` shows you the current settings for your system.

- **0**: No randomization
- **1**: Randomize positions of the stack, VDSO page, and shared memory regions
- **2**: Randomize positions of the stack, VDSO page, shared memory regions, and the data segment

Mitigations: ASLR

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To get the full benefit you need to compile your binaries with `-fPIE`

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- Brute forcing still an issue if restart is not handled properly.
- Can be circumvented by chaining an information leak into the exploit
- Some exotic software might rely on fixed addresses (think inline assembly)
- Sometimes you have usable memory locations in registers

Mitigations: No-execute memory

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bash -c 'cat /proc/$$/maps | grep stack'
7ffcb8e0f000-7ffcb8e30000 rw-p 00000000 00:00 0 [stack]
```

Mitigations: NX

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- Use existing code in the exploited program

Mitigations: NX

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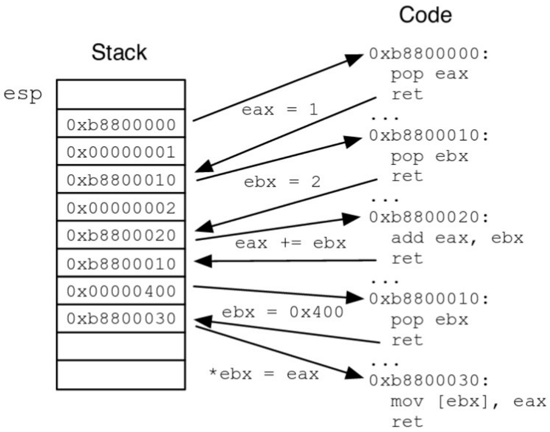
- Use existing code in the exploited program
- Return to libc: Use existing functions

Mitigations: NX

Limitations

- Use existing code in the exploited program
- Return to libc: Use existing functions
- ROP (Return Oriented Programming): Structure the data on the stack so that instruction sequences ending in `ret` can be used

ROP



Graphic taken from https://www.cs.columbia.edu/ angelos/Papers/theses/vpappas_thesis.pdf

Mitigations: Are we safe?

So, with

- Stack canaries
- ALSR
- NX
- Fortify source

we should be safe?!

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Counter example take from `http://www.antoniobarresi.com/security/exploitdev/2014/05/03/64bitexploitation/`

Leaving out fortify source to allow simple creation of buffer overflow

Mitigations: Circumventing them

```c
#include <stdio.h>
#include <string.h>
#include <unistd.h>

void memLeak( void ) {
  char buf[512];
  scanf("%s", buf);
  printf(buf);
}

void vulnFunc( void ) {
  char buf[1024];
  read(0, buf, 2048);
}

int main(int argc, char* argv[]) {
  setbuf(stdout, NULL);
  printf("echo> ");
  memLeak();
  printf("\n");
  printf("read> ");
  vulnFunc();

  printf("\ndone.\n");

  return EXIT_SUCCESS;
}
```

Mitigations: Circumventing them

To be able to use our own shellcode we need to make the stack executable again

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int mprotect(void *addr, size_t len, int prot);
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But NX blocks us → ROP

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But NX blocks us → ROP

Finding gadgets:

```
ROPgadget.py --binary /lib64/libc.so.6 | grep 'pop rdi'
```

Mitigations: Circumventing them

Demo time

What we didn't cover

A lot. For example:

- -fstack-clash-protection
- relro

Outlook

ROP is used in a lot of modern exploits:

- Shadow stacks
- (Hardware) control flow integrity (CFI)
- Data flow intgerity (DFI)

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- Shadow stacks
- (Hardware) control flow integrity (CFI)
- Data flow intgerity (DFI)

These mitigations are rather costly, hard to convince users to take the hit

And they also can be circumvented

Thank you for your attention!

Questions?