



Control Hijacking

Basic Control Hijacking Attacks

Acknowledgments: Lecture slides are from the Computer Security course taught by Dan Boneh and Zakir Durumeric at Stanford University. When slides are obtained from other sources, a reference will be noted on the bottom of that slide. A full list of references is provided on the last slide.

Control hijacking attacks

- Attacker's goal:
 - Take over target machine (e.g. web server)
 - Execute arbitrary code on target by hijacking application control flow
- Examples:
 - Buffer overflow and integer overflow attacks
 - Format string vulnerabilities
 - Use after free

First example: buffer overflows

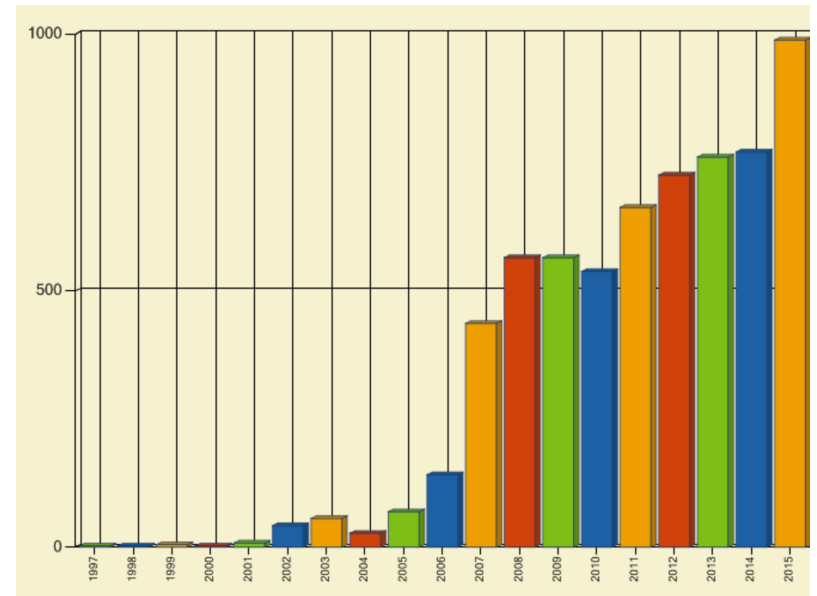
Extremely common bug in C/C++ programs.

- First major exploit: 1988 Internet Worm. Fingerd.

Whenever possible avoid C/C++

Often cannot avoid C/C++ :

- Need to understand attacks and defenses

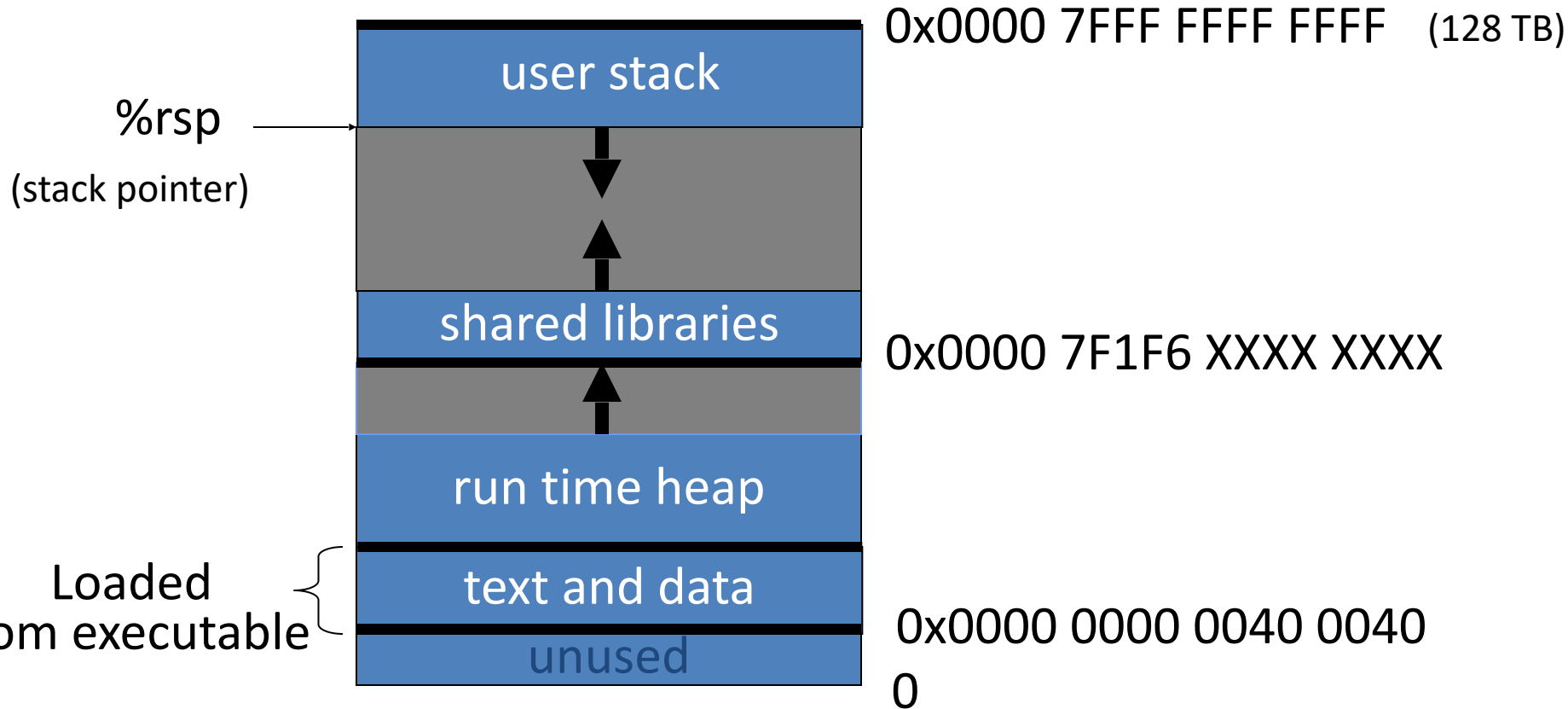


Source: web.nvd.nist.gov

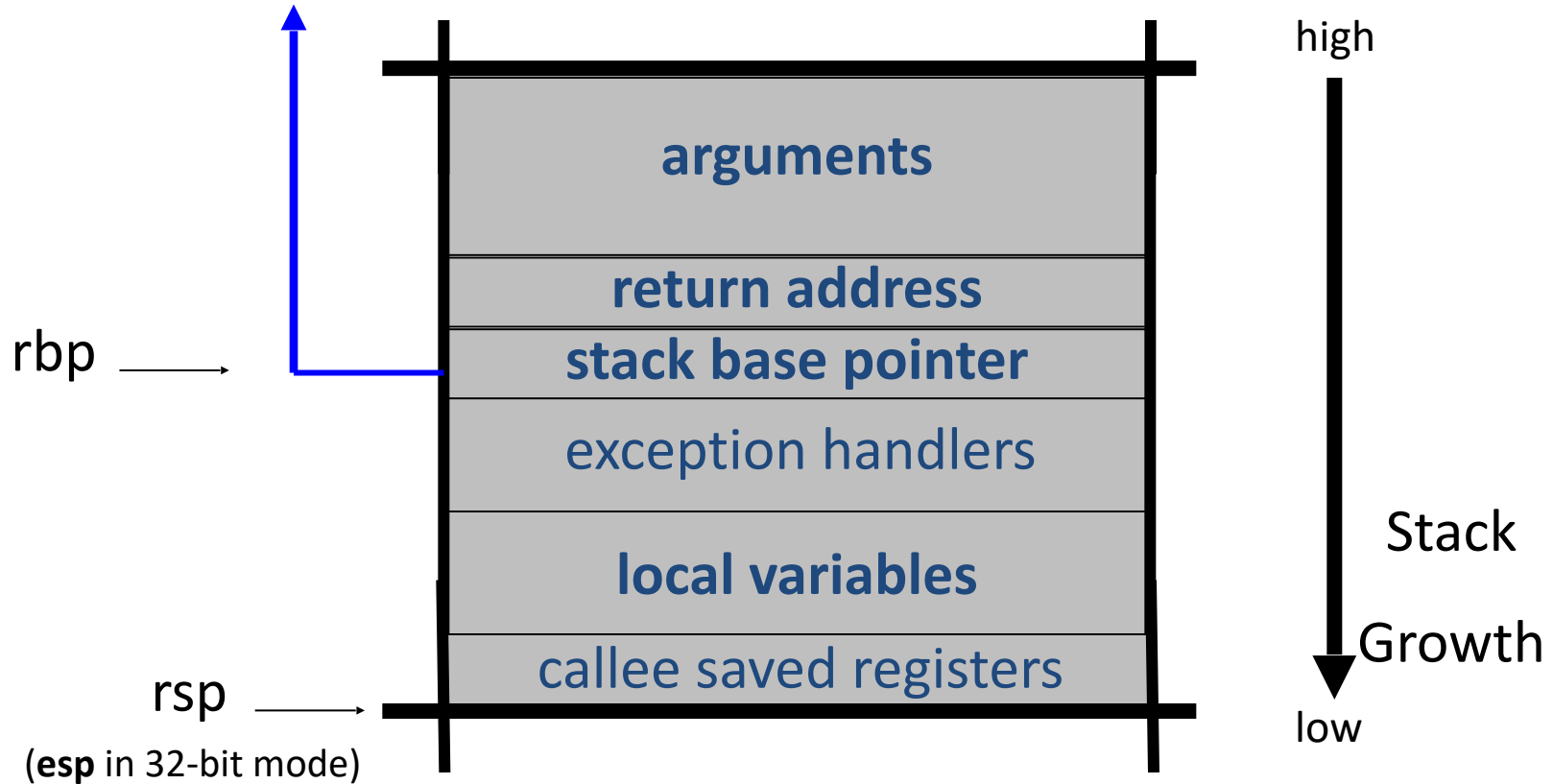
What is needed

- Understanding C functions, the stack, and the heap.
 - Know how system calls are made
 - The `exec()` system call
-
- Attacker needs to know which CPU and OS used on the target machine:
 - Our examples are for x86 running Linux or Windows
 - Details vary slightly between CPUs and OSs:
 - Stack Frame structure (Unix vs. Windows, x86 vs. ARM)
 - Little endian vs. big endian

Linux process memory layout (x86_64)



Stack Frame



What are buffer overflows?

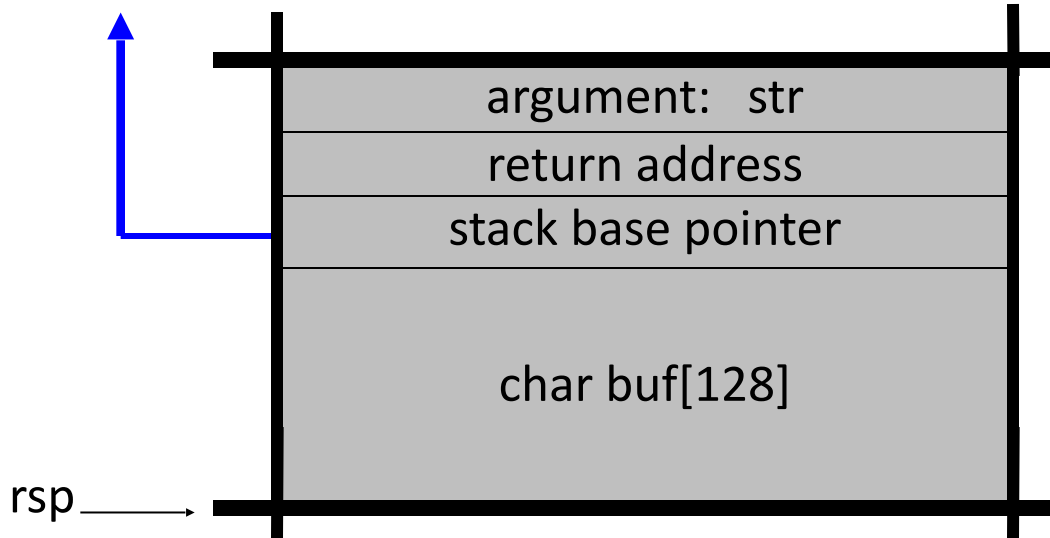
Suppose a web server contains a function:

```
void func(char *str) {  
    char buf[128];  
  
    strcpy(buf, str);  
    do-something(buf);  
}
```

What are buffer overflows?

Suppose a web server contains a function:

After `func()` is called stack looks like:

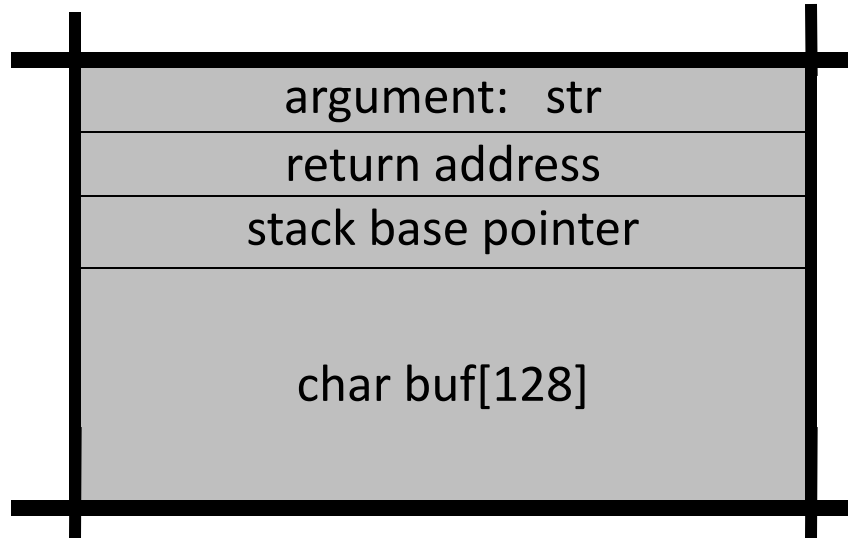


```
void func(char *str) {  
    char buf[128];  
    strcpy(buf, str);  
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}
```


What are buffer overflows?

What if `*str` is 136 bytes long?

After `strcpy`:



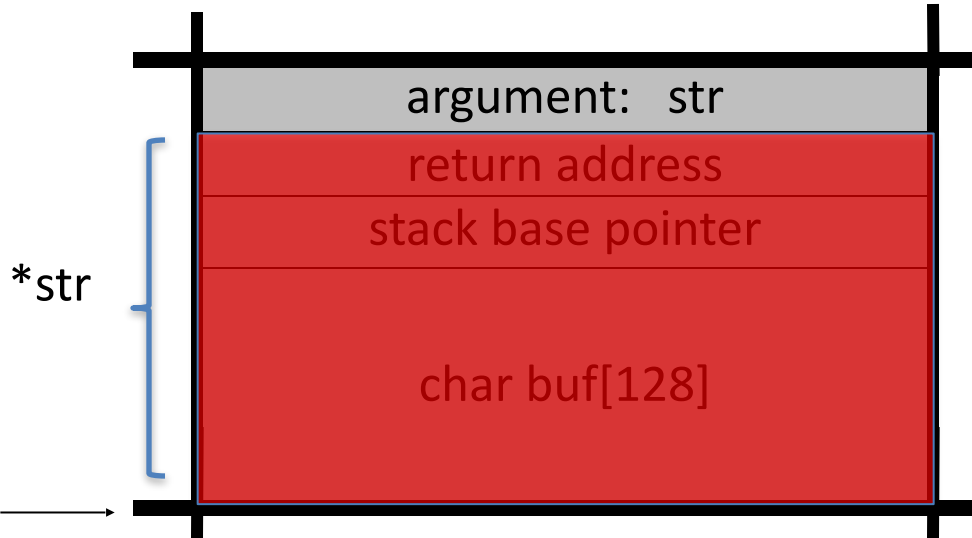
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What are buffer overflows?

What if `*str` is 136 bytes long?

After `strcpy`:

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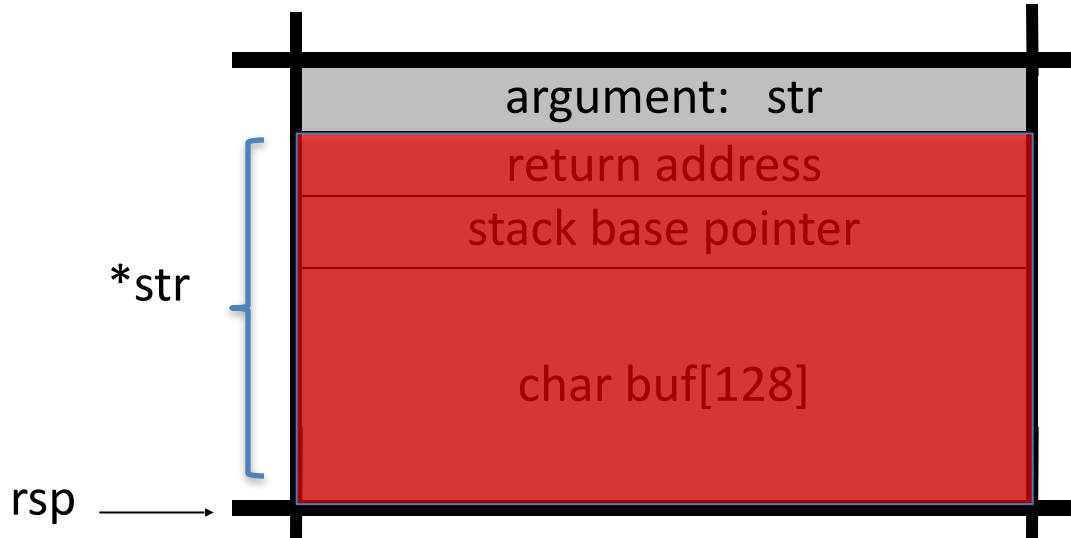


What are buffer overflows?

What if `*str` is 136 bytes long?

After `strcpy`:

```
void func(char *str) {  
    char buf[128];  
    strcpy(buf, str);  
    do-something(buf);  
}
```



Poisoned return address!

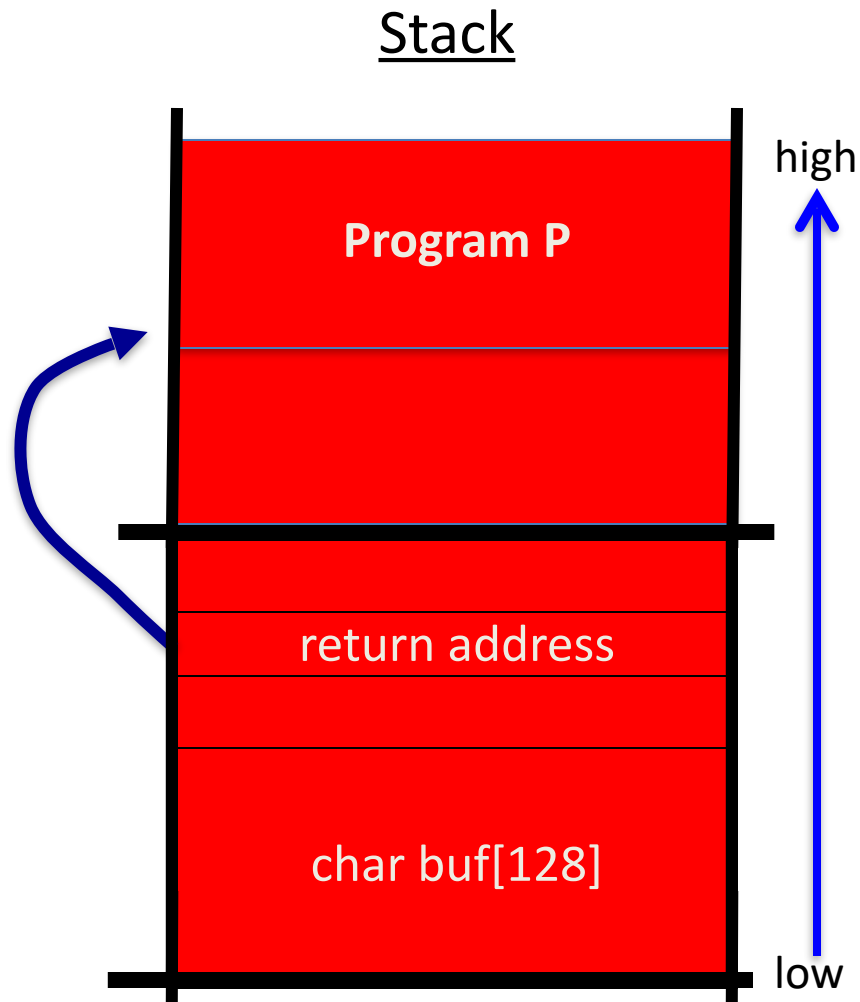
Problem:
no bounds checking in `strcpy()`

Basic stack exploit

Suppose `*str` is such that
after `strcpy` stack looks like:

Program P: `exec("/bin/sh")`

(exact shell code by Aleph One)



Basic stack exploit

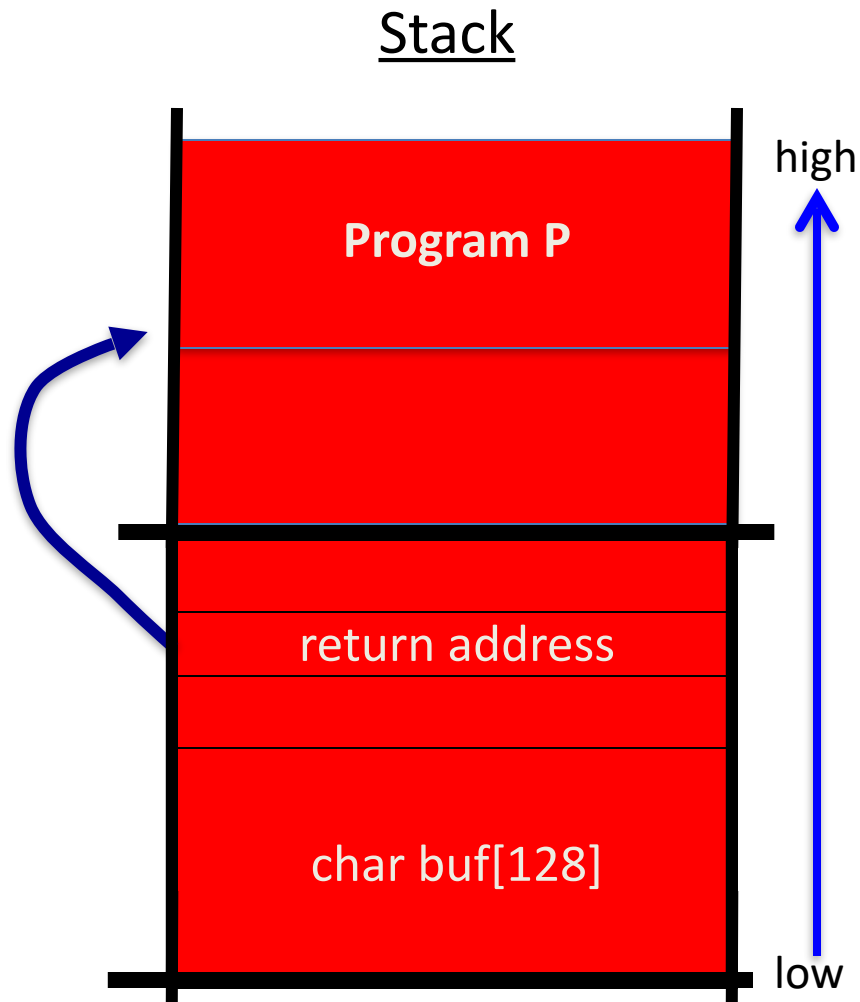
Suppose `*str` is such that
after `strcpy` stack looks like:

Program P: `exec("/bin/sh")`

(exact shell code by Aleph One)

When `func()` exits, the user gets shell !

Note: attack code P runs *in stack*.

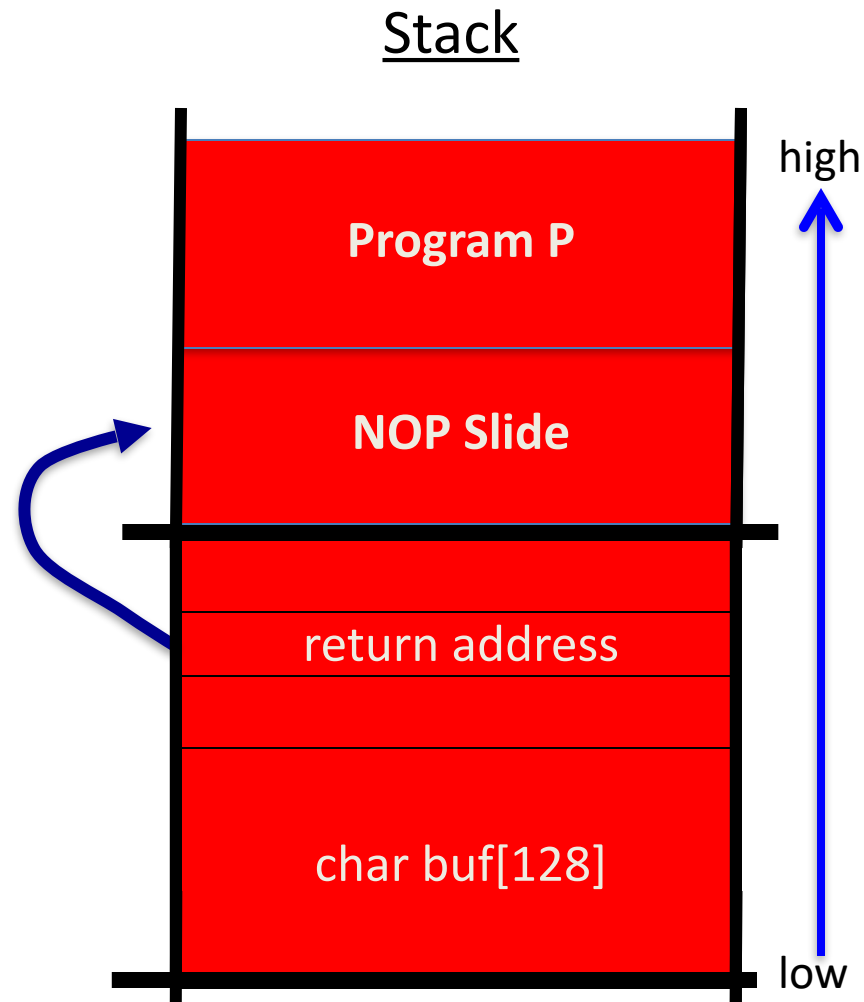


The NOP slide

Problem: how does attacker determine ret-address?

Solution: NOP slide

- Guess approximate stack state when `func()` is called
- Insert many NOPs before program P:
`nop (0x90), xor eax,eax, inc ax`



Details and examples

- Some complications:
 - Program `P` should not contain the `'\0'` character.
 - Overflow should not crash program before `func()` exits.
- (in)Famous remote stack smashing overflows:
 - Overflow in Windows animated cursors (ANI). `LoadAniIcon()`
 - Buffer overflow in Symantec virus detection (May 2016)
`overflow when parsing PE headers ... kernel vuln.`

Many unsafe libc functions

`strcpy` (char *dest, const char *src)

`strcat` (char *dest, const char *src)

`gets` (char *s)

`scanf` (const char *format, ...) and many more.

-
- “Safe” libc versions `strncpy()`, `strncat()` are misleading
 - e.g. `strncpy()` may leave string unterminated.
 - Windows C run time (CRT):
 - `strcpy_s (*dest, DestSize, *src)`: ensures proper termination
-

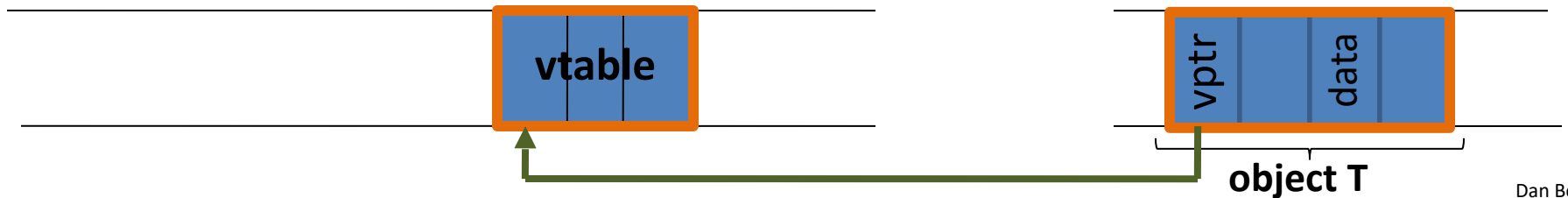
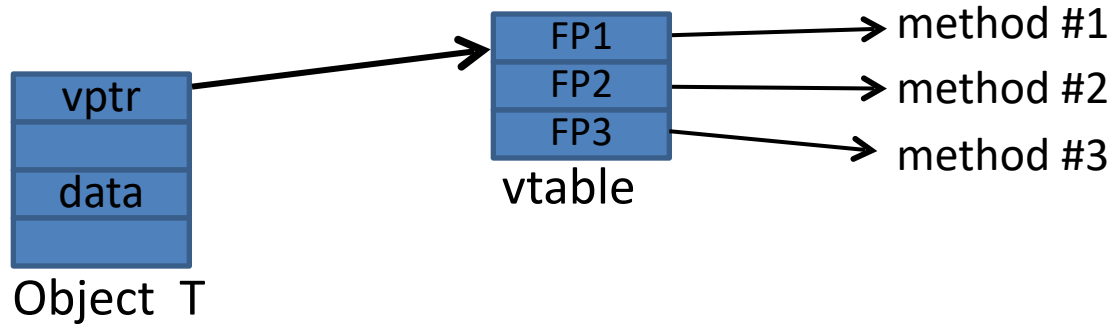
Buffer overflow opportunities

- Exception handlers: (... more on this in a bit)
 - Overwrite the address of an exception handler in stack frame.
- Function pointers: (e.g. PHP 4.0.2, MS MediaPlayer Bitmaps)

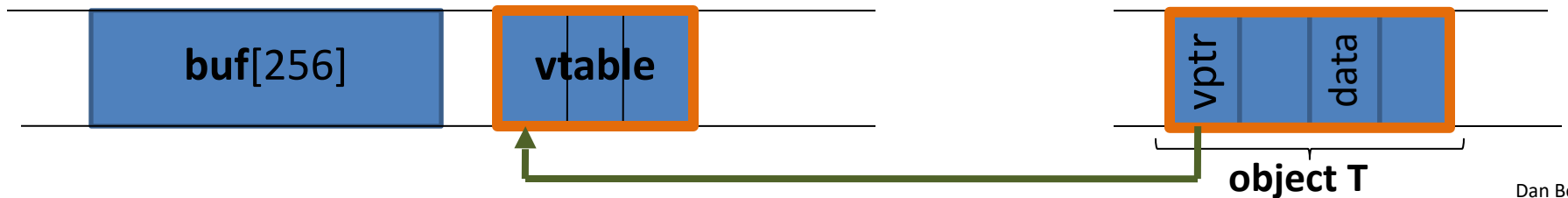
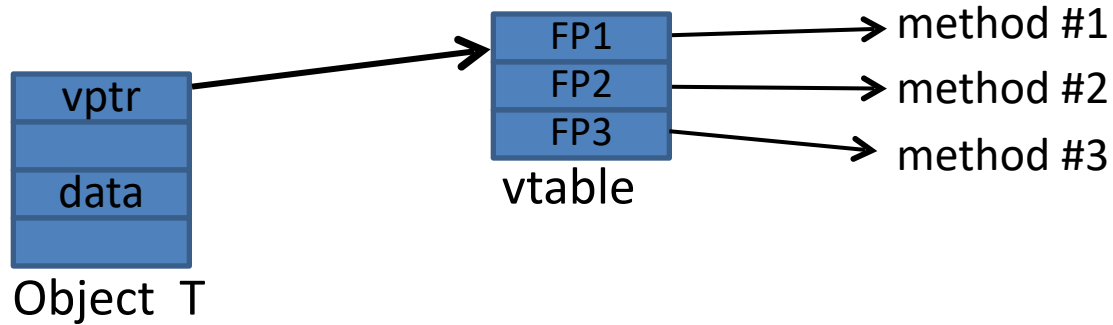


- Overflowing buf will override function pointer.
- Longjmp buffers: longjmp(pos) (e.g. Perl 5.003)
 - Overflowing buf next to pos overrides value of pos.

Heap exploits: corrupting virtual tables

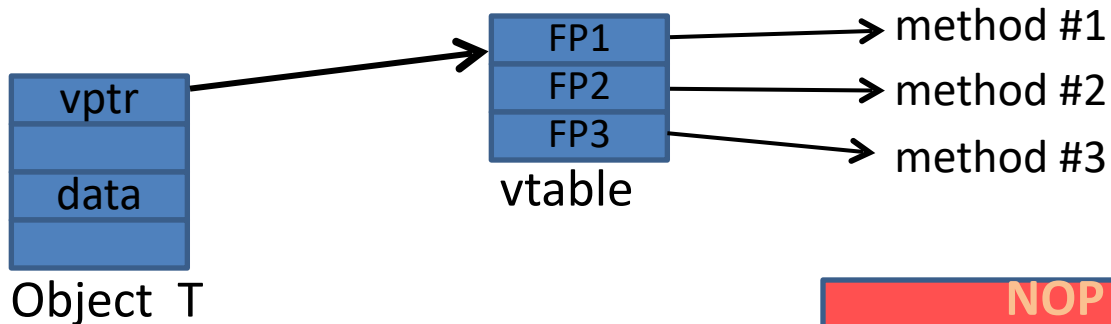


Heap exploits: corrupting virtual tables

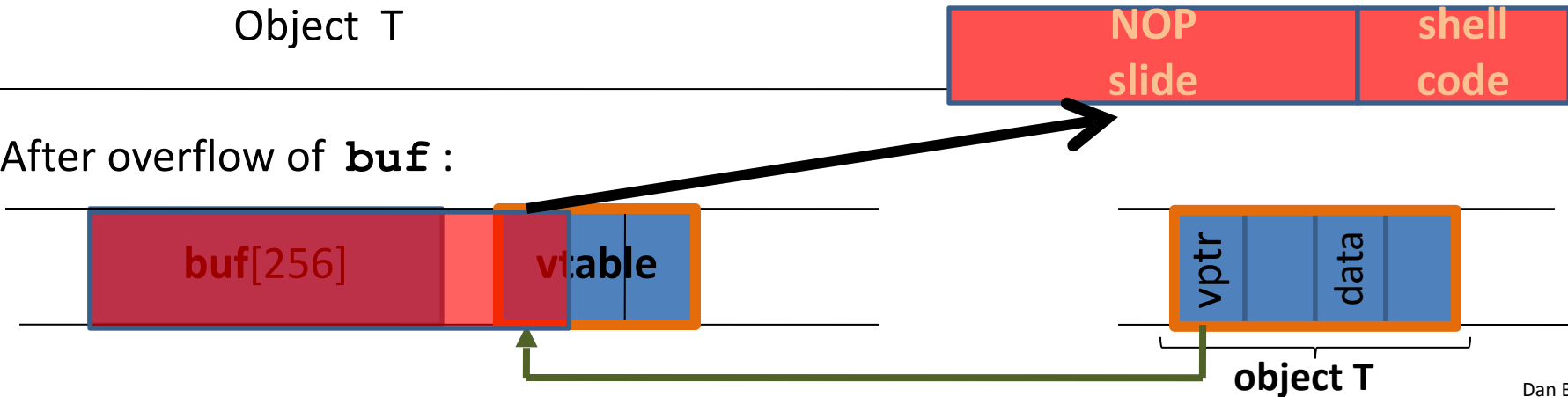


Heap exploits: corrupting virtual tables

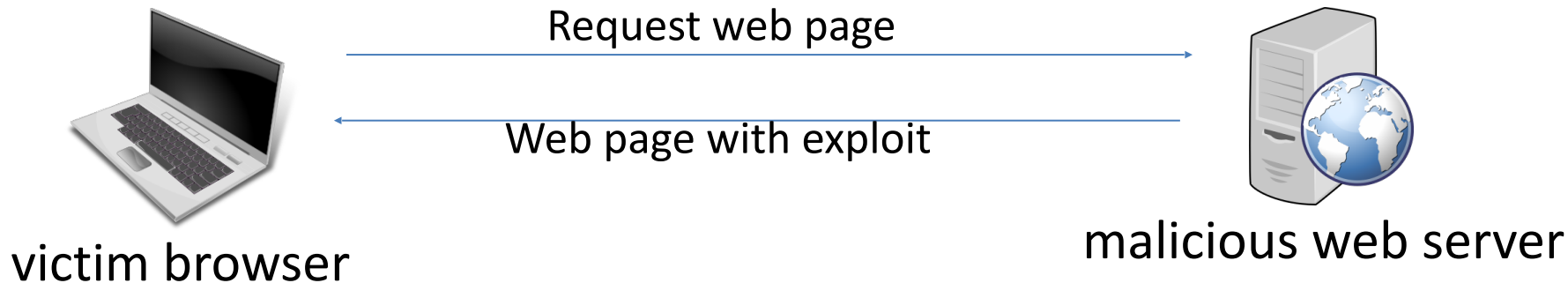
Compiler generated function pointers (e.g. C++ code)



After overflow of `buf` :



An example: exploiting the browser heap



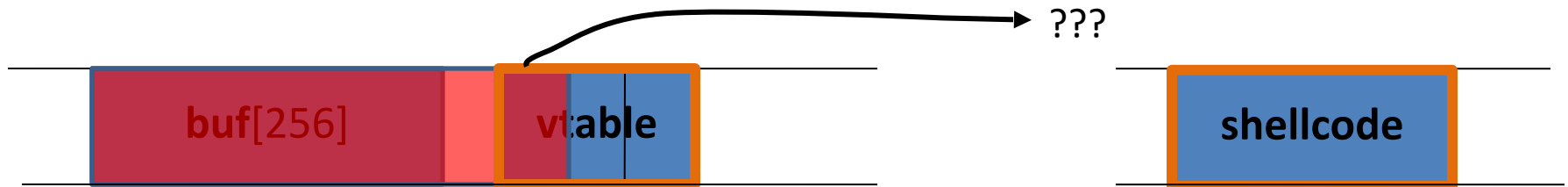
Attacker's goal is to infect browsers visiting the web site

- How: send javascript to browser that exploits a heap overflow

A reliable exploit?

```
<SCRIPT language="text/javascript">  
shellcode = unescape("%u4343%u4343%..."); // allocate in heap  
overflow-string = unescape("%u2332%u4276%...");  
cause-overflow(overflow-string); // overflow buf[ ]  
</SCRIPT>
```

Problem: attacker does not know where browser places **shellcode** on the heap



Heap Spraying

[SkyLined]

Idea:

1. use Javascript to spray heap with shellcode (and NOP slides)
2. then point vtable ptr anywhere in spray area

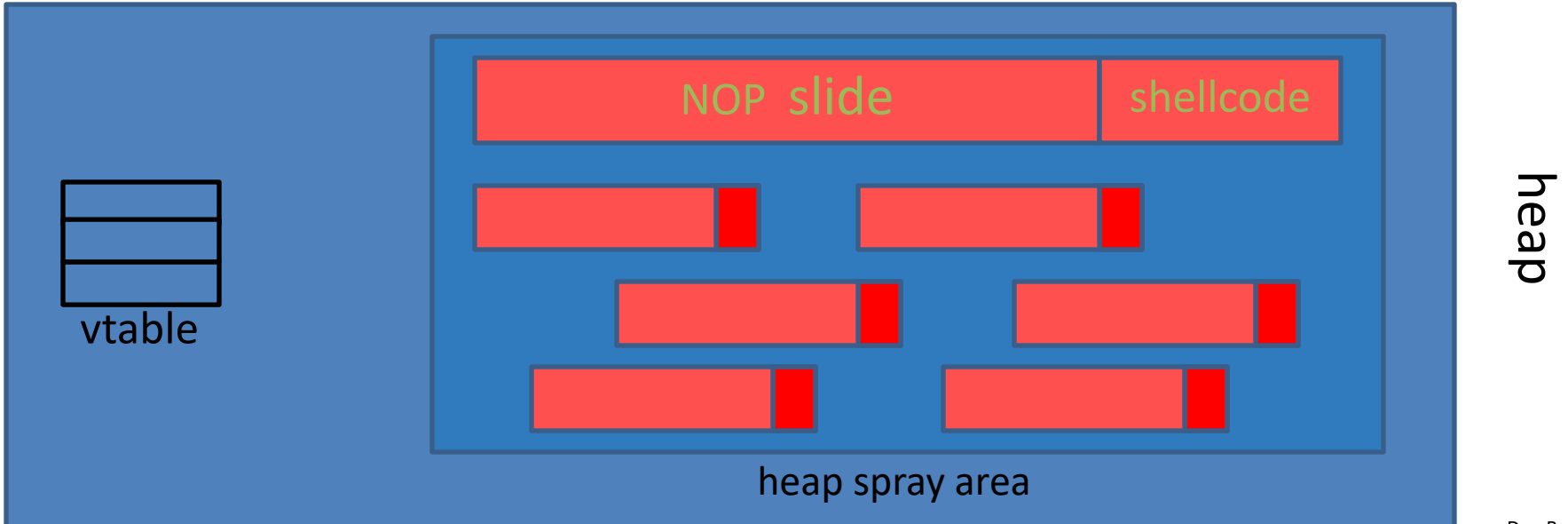


Heap Spraying

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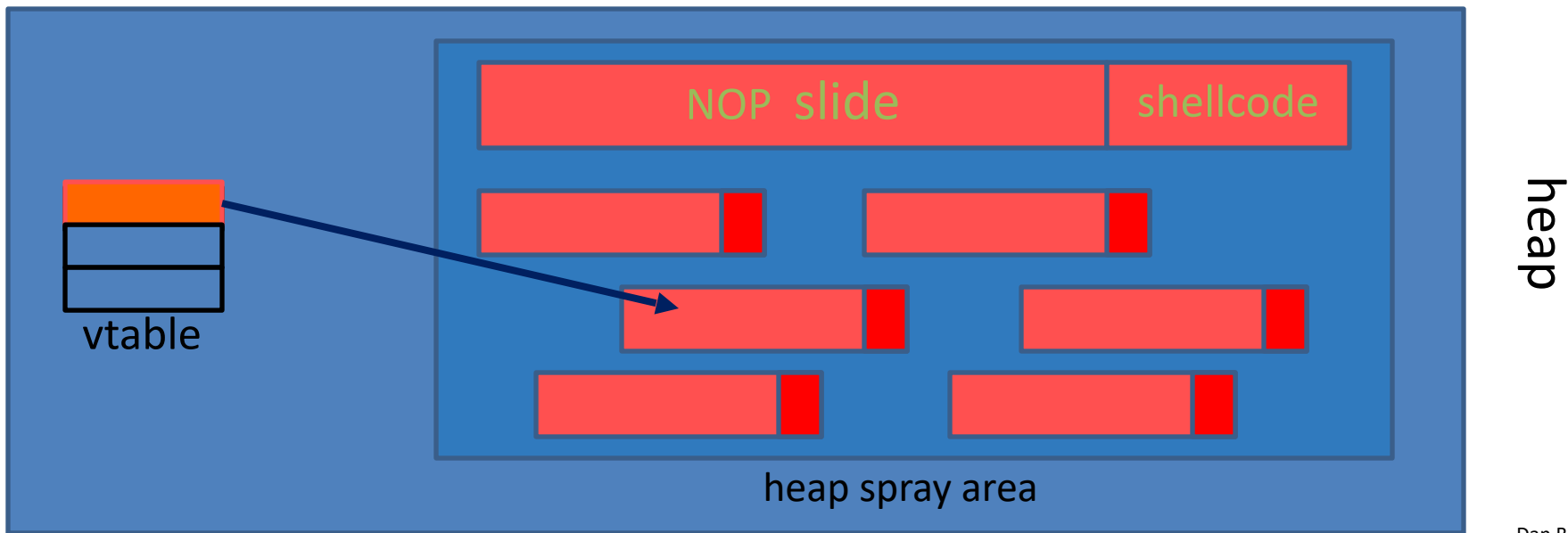


Heap Spraying

[SkyLined]

Idea:

1. use Javascript to spray heap with shellcode (and NOP slides)
2. then point vtable ptr anywhere in spray area



Javascript heap spraying

```
var nop = unescape("%u9090%u9090")
while (nop.length < 0x100000)  nop += nop;

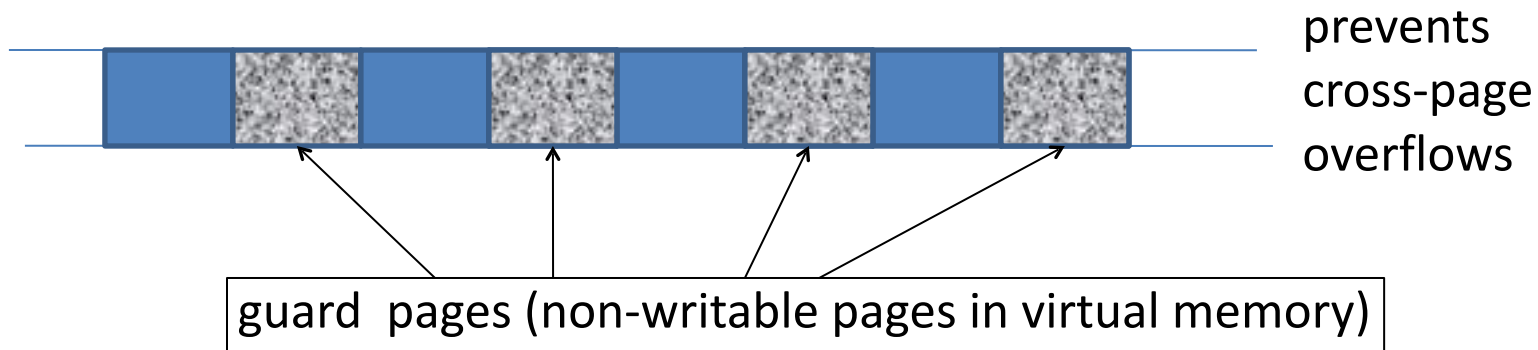
var shellcode = unescape("%u4343%u4343%...");

var x = new Array ()
for (i=0; i<1000; i++) {
    x[i] = nop + shellcode;
}
```

Pointing function-ptr almost anywhere in heap will cause shellcode to execute.

Ad-hoc heap overflow mitigations

- Better browser architecture:
 - Store JavaScript strings in a separate heap from browser heap
- OpenBSD and Windows 8 heap overflow protection:



In theory: allocate every object on a separate page (eFence, Archipelago'08)

⇒ not practical: too wasteful in physical memory

Finding overflows by fuzzing

- To find overflow:
 - Run web server on local machine
 - Use AFL to issue malformed requests (ending with “\$\$\$\$\$”)
 - Fuzzers: automated tools for this (next few weeks)
 - If web server crashes,
search core dump for “\$\$\$\$\$” to find overflow location
- Construct exploit (not easy given latest defenses in next lecture)



Control Hijacking

More Control Hijacking Attacks

More Hijacking Opportunities

- **Integer overflows:** (e.g. MS DirectX MIDI Lib)
- **Double free:** double free space on heap
 - Can cause memory mgr to write data to specific location
 - Examples: CVS server
- **Use after free:** using memory after it is freed
- **Format string vulnerabilities**

Integer Overflows

(see Phrack 60)

Problem: what happens when int exceeds max value?

int m; (32 bits)

short s; (16 bits)

char c; (8 bits)

$$c = 0x80 + 0x80 = 128 + 128$$

$$\Rightarrow c = 0$$

$$s = 0xff80 + 0x80$$

$$\Rightarrow s = 0$$

$$m = 0xffffffff80 + 0x80$$

$$\Rightarrow m = 0$$

Can this be exploited?

An example

```
void func( char *buf1, *buf2,  unsigned int len1, len2) {  
    char temp[256];  
    if (len1 + len2 > 256) {return -1}           // length check  
    memcpy(temp, buf1, len1);                     // cat buffers  
    memcpy(temp+len1, buf2, len2);  
    do-something(temp);                           // do stuff  
}
```


An example

```
void func( char *buf1, *buf2,  unsigned int len1, len2) {  
    char temp[256];  
    if (len1 + len2 > 256) {return -1}           // length check  
    memcpy(temp, buf1, len1);                     // cat buffers  
    memcpy(temp+len1, buf2, len2);  
    do-something(temp);                          // do stuff  
}
```

What if **len1 = 0x80, len2 = 0xffffffff80** ?

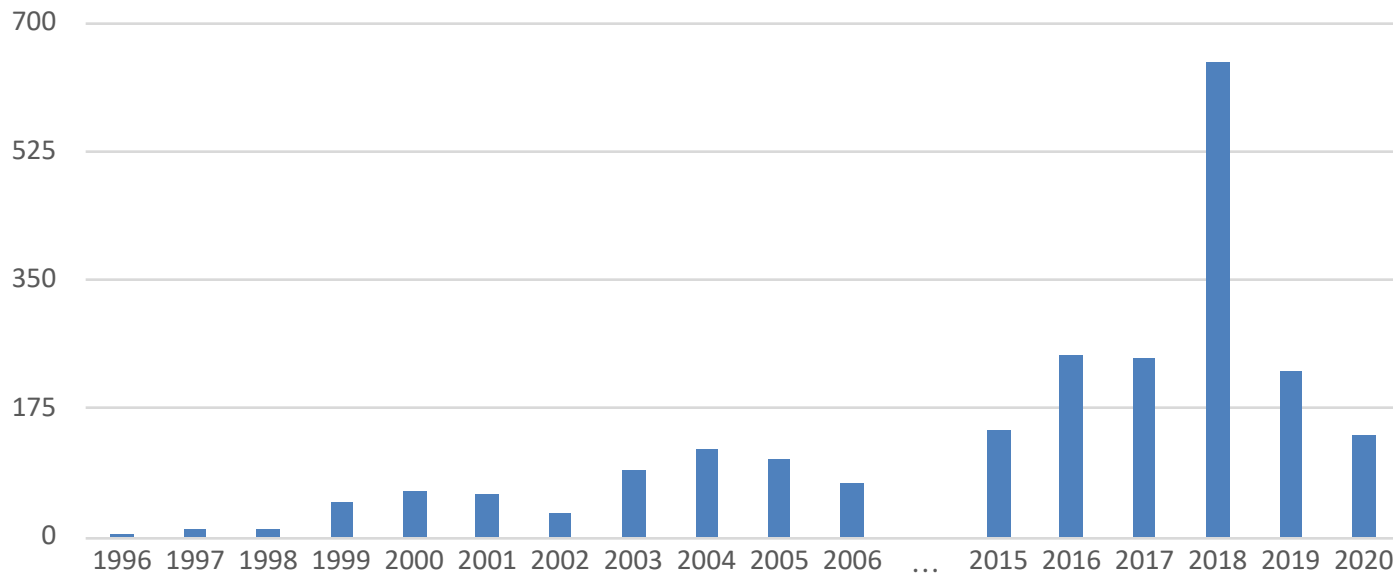
⇒ $len1 + len2 = 0$

Second `memcpy()` will overflow heap !!

An example: a better length check

```
void func( char *buf1, *buf2,  unsigned int len1, len2) {  
    char temp[256];  
    // length check  
    if (len1 > 256) || (len2 > 256) || (len+ len2 > 256)  
        return -1;  
    memcpy(temp, buf1, len1);           // cat buffers  
    memcpy(temp+len1, buf2, len2);  
    do-something(temp);                // do stuff  
}
```

Integer overflow exploit stats



Dec. 2020: integer underflow in F5 Big IP

```
if (8190 - nlen <= vlen) // length check
    return -1;
```

Format string bugs

Format string problem

```
int func(char *user) {  
    fprintf(stderr, user);  
}
```

Problem: what if `*user = "%s%s%s%s%s%s%s" ??`

- Most likely program will crash: DoS.
- If not, program will print memory contents. Privacy?
- Full exploit using `user = "%n"`

Correct form: `fprintf(stdout, "%s", user);`

Vulnerable functions

Any function using a format string.

Printing:

printf, fprintf, sprintf, ...

vprintf, vfprintf, vsprintf, ...

Logging:

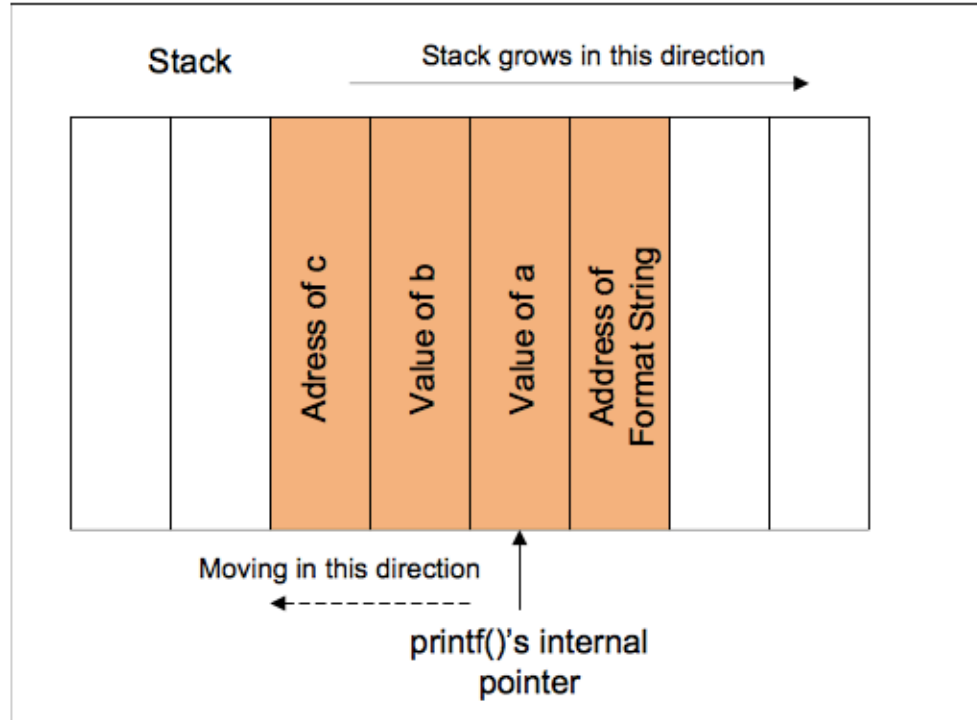
syslog, err, warn

Exploit

- Dumping arbitrary memory:
 - Walk up stack until desired pointer is found.
 - `printf("%08x.%08x.%08x.%08x|%s|")`

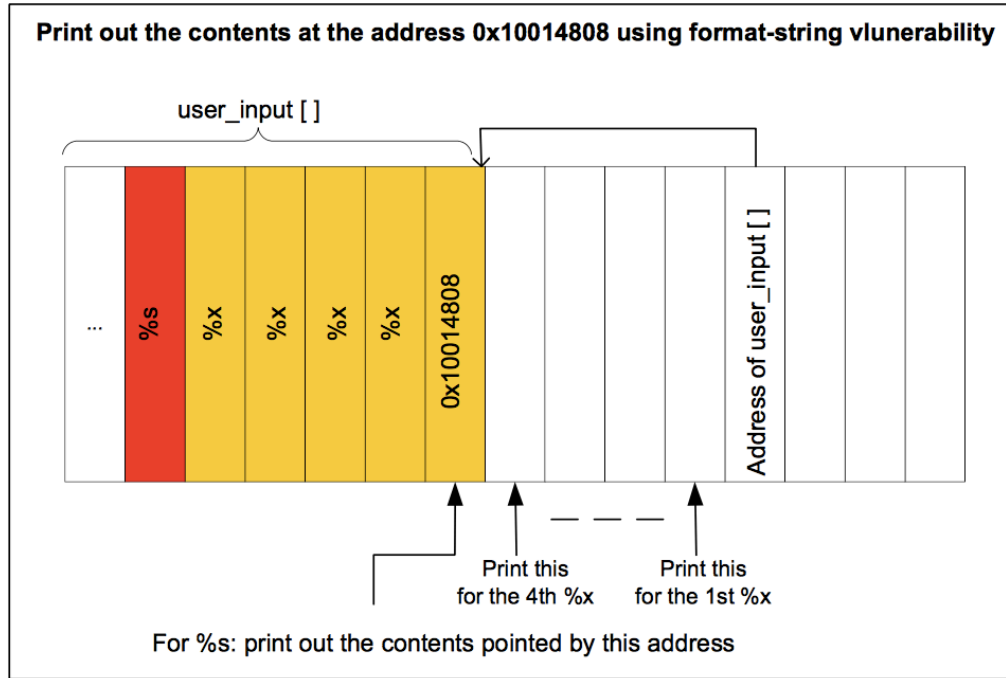
- Writing to arbitrary memory:
 - `printf("hello %n", &temp) --` writes '6' into temp.
 - `printf("%08x.%08x.%08x.%08x.%n")`

Format String



```
printf ("a has value %d, b has value %d, c is at address: %08x\n", a, b, &c);
```

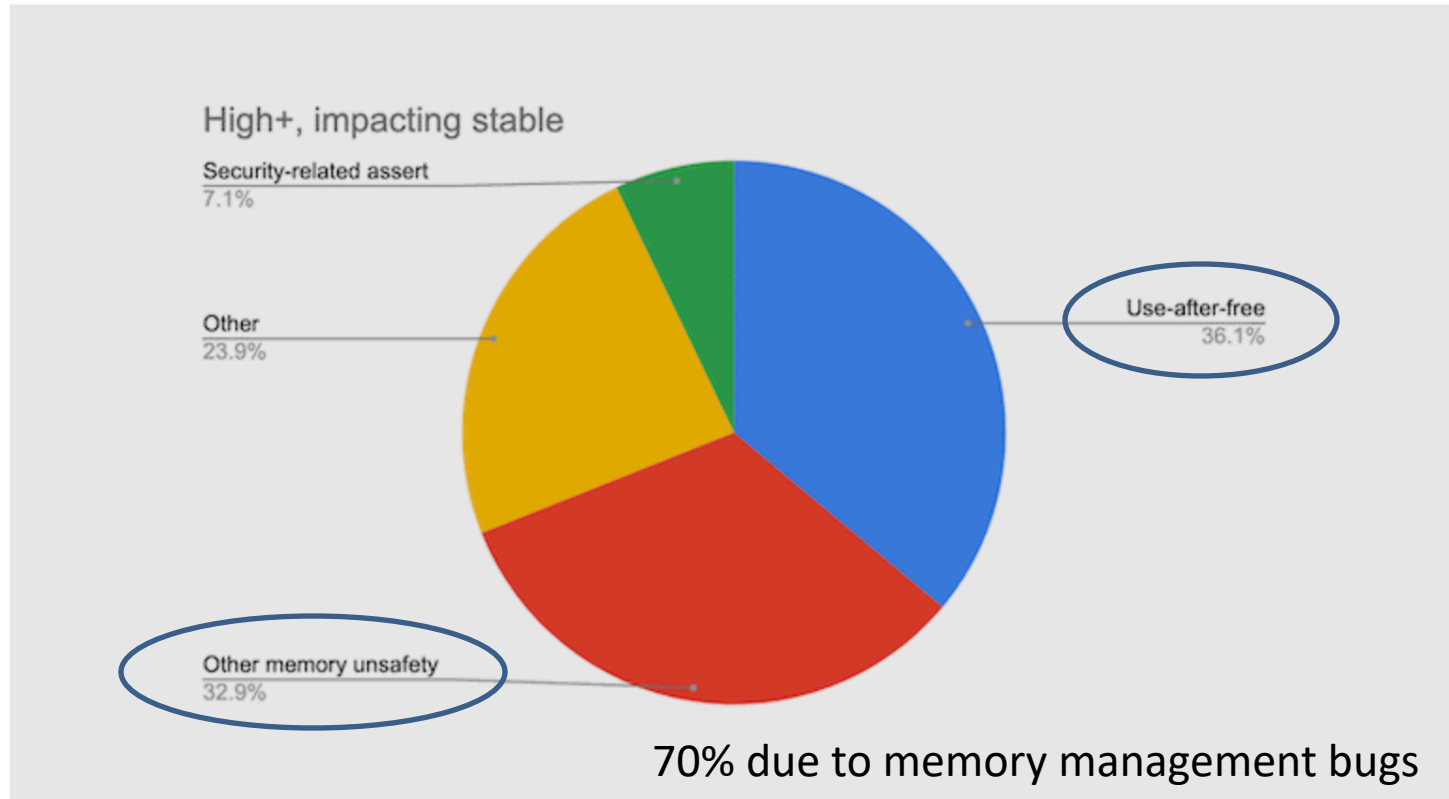

Format String (con't)



```
printf ("\x10\x01\x48\x08 %x %x %x %x %s");
```

Use after free exploits

High impact security vulns. in Chrome 2015 – 2020 (C++)



IE11 Example: CVE-2014-0282 (simplified)

```
<form id="form">                                     (IE11 written in C++)  
  <textarea id="c1" name="a1" ></textarea>  
  <input id="c2" type="text" name="a2" value="val">  
</form>
```

```
<script>  
  function changer() {  
    document.getElementById("form").innerHTML = "";  
    CollectGarbage();    // erase c1 and c2 fields  
  }  
  
  document.getElementById("c1").onpropertychange = changer;  
  document.getElementById("form").reset();  
</script>
```

IE11 Example: CVE-2014-0282 (simplified)

```
<form id="form">
```

(IE11 written in C++)

```
  <textarea id="c1" name="a1" ></textarea>
```

```
  <input id="c2" type="text" name="a2" value="val">
```

```
</form>
```

Loop on form elements:
c1.DoReset()
c2.DoReset()

```
<script>
```

```
  function changer() {
```

```
    document.getElementById("form").innerHTML = "";
```

```
    CollectGarbage();    // erase c1 and c2 fields
```

```
  }
```

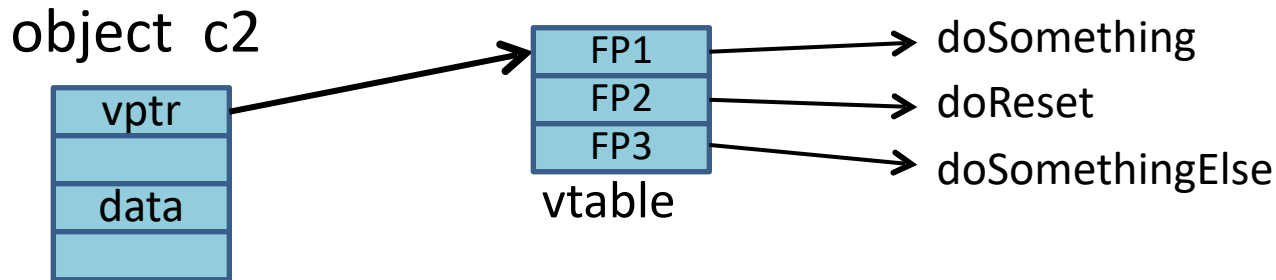
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```

```
  document.getElementById("form").reset();
```

```
</script>
```

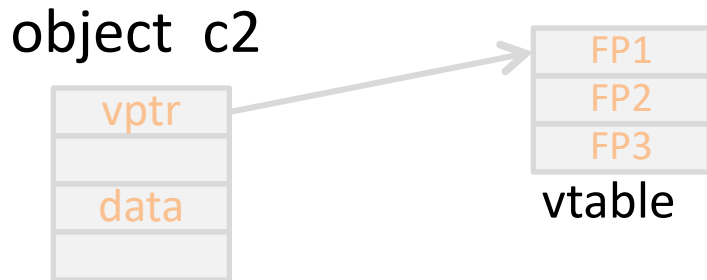
What just happened?

c1.doReset() causes ***changer()*** to be called and free object c2



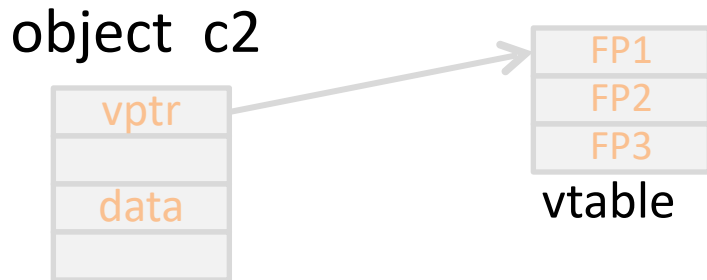
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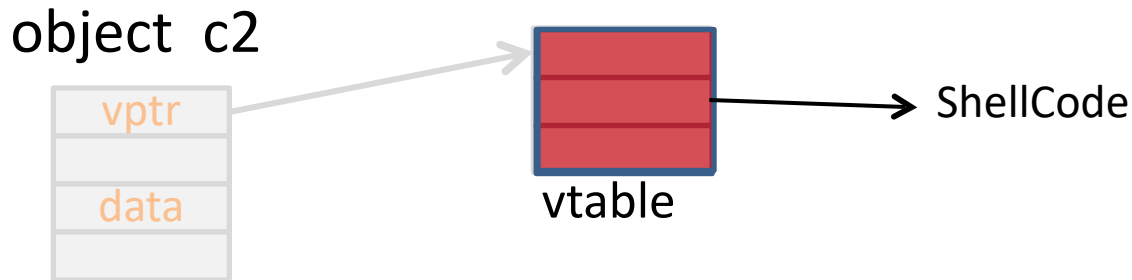
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Suppose attacker allocates a string of same size as vtable

What just happened?

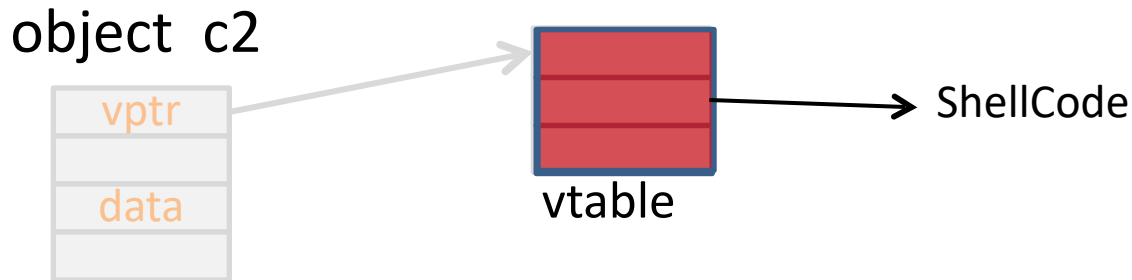
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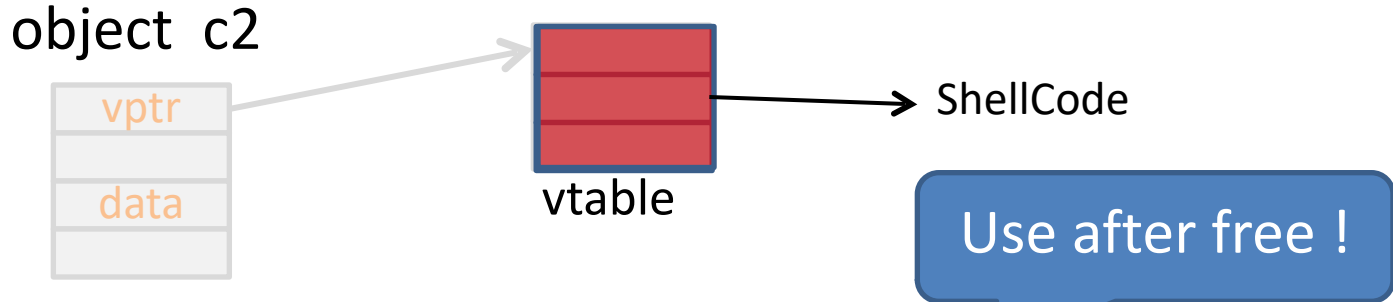


Suppose attacker allocates a string of same size as vtable

When `c2.DoReset()` is called, attacker gets shell

What just happened?

c1.doReset() causes ***changer()*** to be called and free object c2



Suppose attacker allocates a string of same size as vtable

When `c2.DoReset()` is called, attacker gets shell

The exploit

```
<script>  
  function changer() {  
    document.getElementById("form").innerHTML = "";  
    CollectGarbage();  
  
    --- allocate string object to occupy vtable location ---  
  }  
  
  document.getElementById("c1").onpropertychange = changer;  
  document.getElementById("form").reset();  
</script>
```

Lesson: use after free can be a serious security vulnerability !!

Next lecture ...

DEFENSES

THE END