CS 253 Cyber Security
Control Hijacking Attacks

ShanghaiTech University

Admin

- Project 1 to be released

PART ONE

01

Control Hijacking Basics

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.

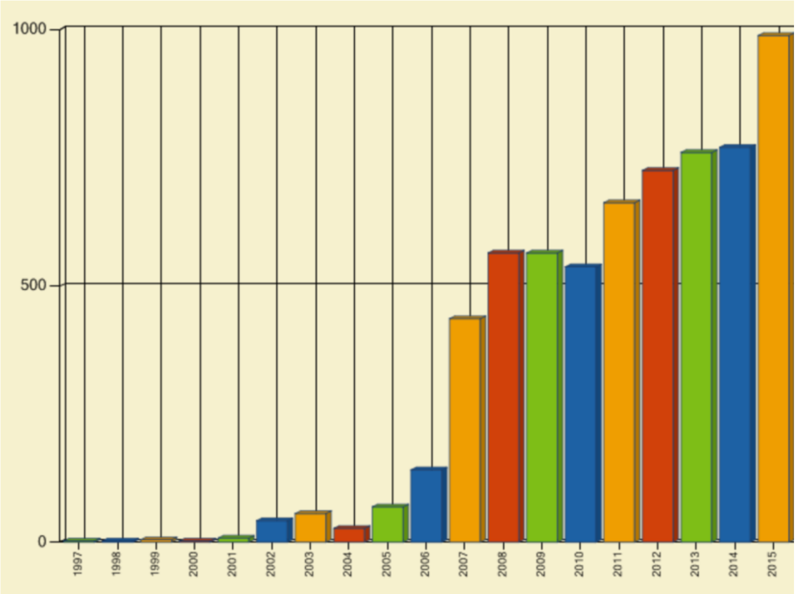
- First major exploit: 1988 Internet Worm. Fingerd.

Whenever possible avoid C/C++

Often cannot avoid C/C++ :

- Need to understand attacks and defenses

Feb. 2024: White House support for memory safety



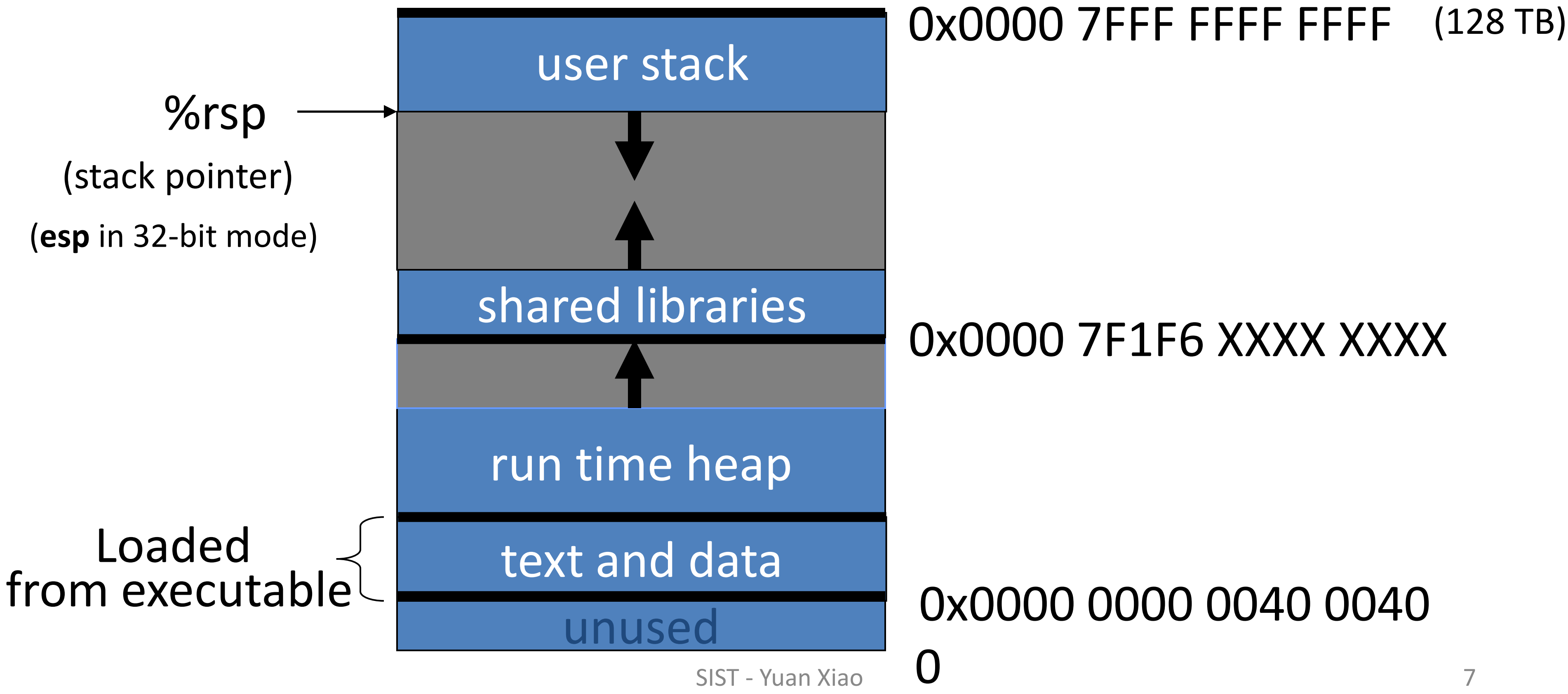
Source: web.nvd.nist.gov

What is needed

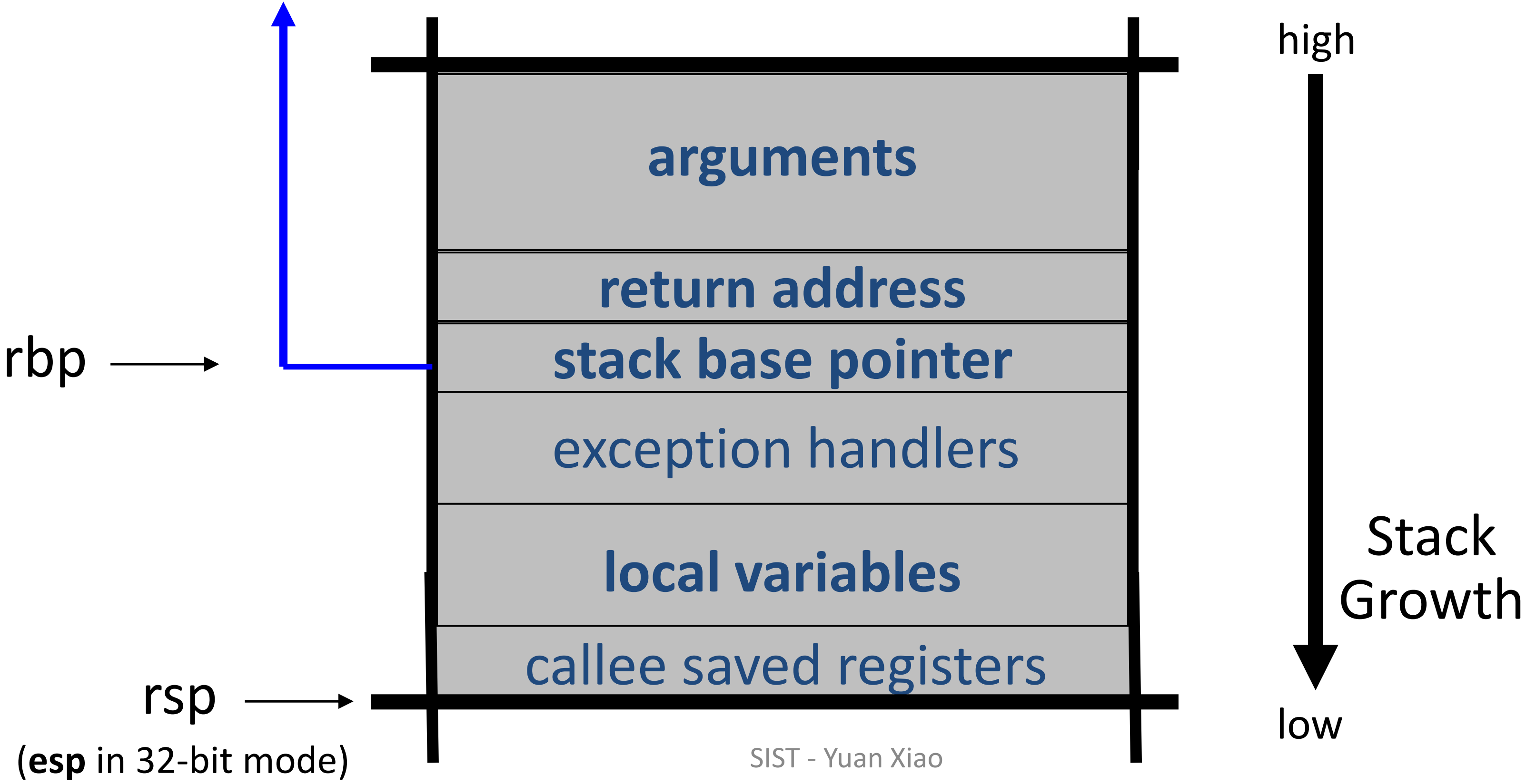
- Understanding C functions, the stack, and the heap.
- Know how system calls are made
- The exec() system call

- Attacker needs to know which CPU and OS used on the target machine:
  - Our examples are for x86-64 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



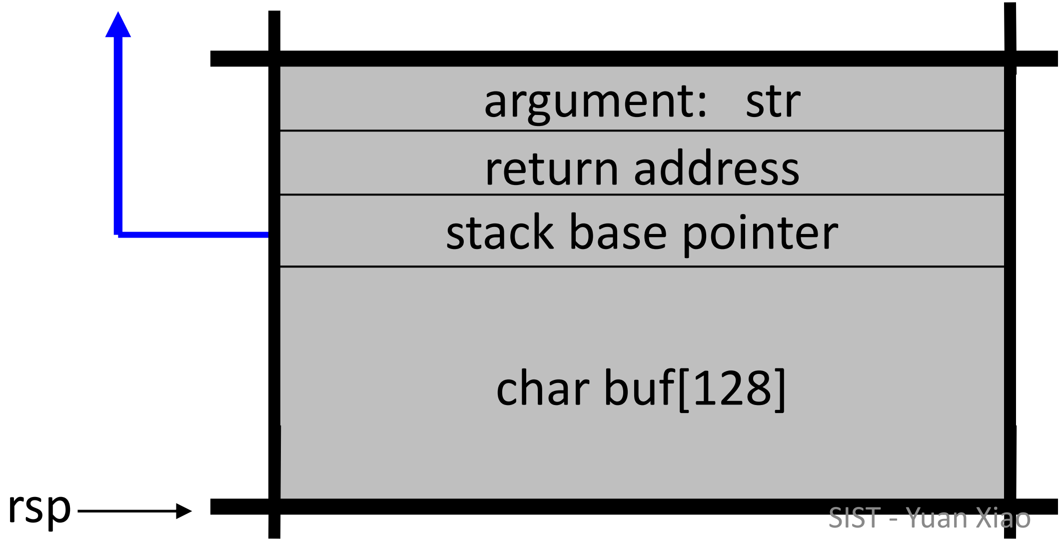
rbp
rsp
(**esp** in 32-bit mode)
arguments
return address
stack base pointer
exception handlers
local variables
callee saved registers
high
Stack Growth
low

What are buffer overflows?

Suppose a web server contains a function:

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

    strcpy(buf, str);
    do-something(buf);
}
```

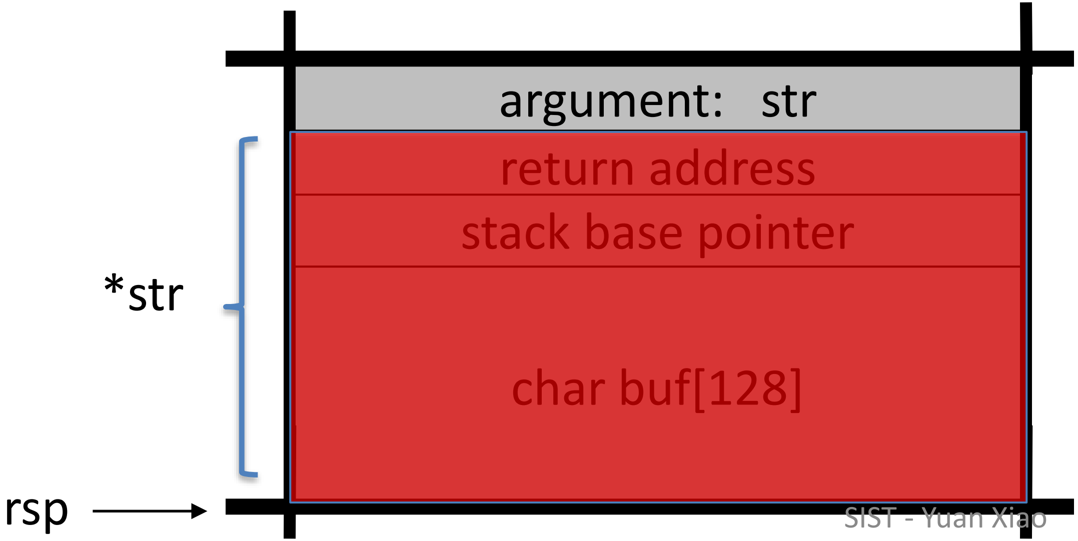
After func() is called stack looks like:



What are buffer overflows?

What if `*url` is 144 bytes long?

After `strcpy`:




```
void func(char *url) {
    char buf[128];

    strcpy(buf, url);
    do-something(buf);
}
```

Poisoned return address!

Problem:

no bounds checking in strcpy()

Basic stack exploit

Suppose *url is such that after strcpy stack looks like:

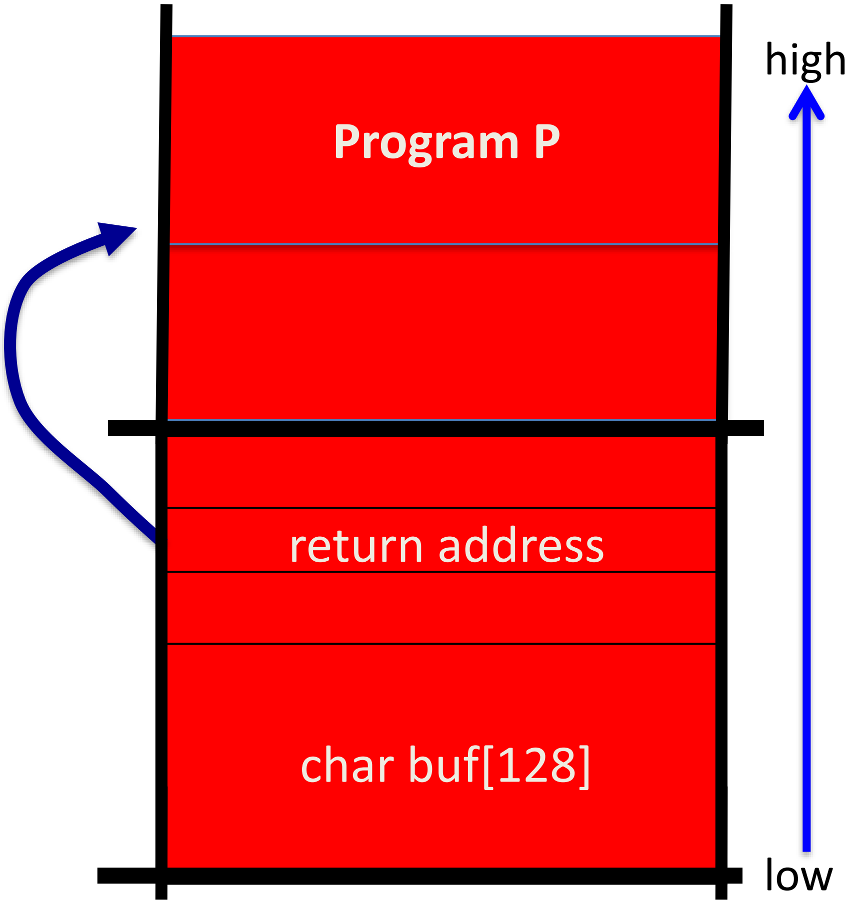
Program P: exec("/bin/sh")

(exact shell code by Aleph One)

When func() exits, the user gets shell !

Note: attack code P runs *in stack*.

Stack



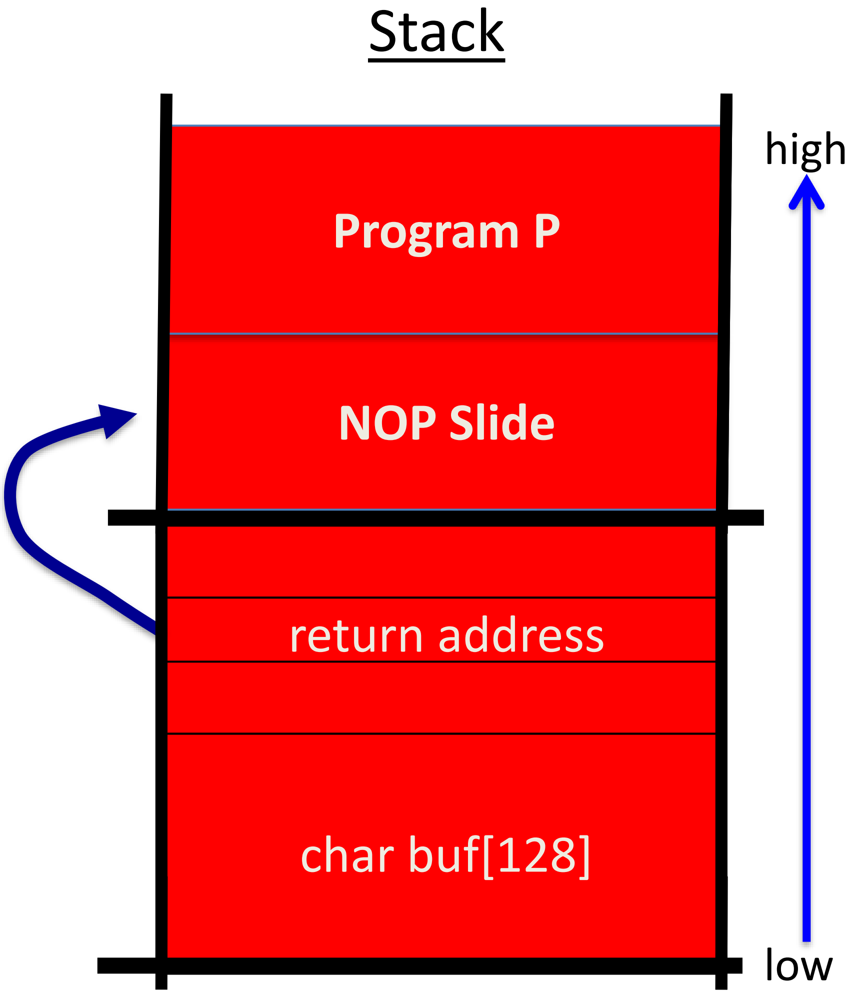
The NOP slide

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 <u>remote</u> 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

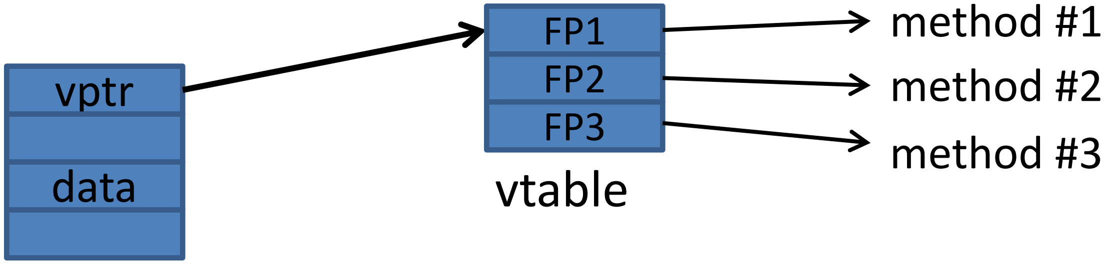
Buffer overflow opportunities

- 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)

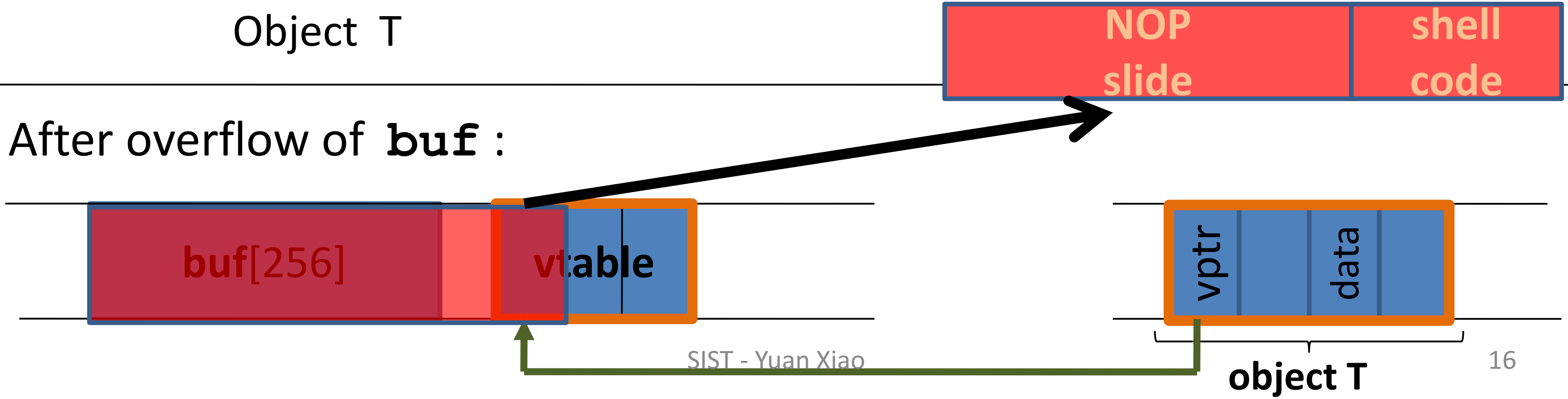
  - Overflowing buf will override function pointer.
- Longjmp buffers: longjmp(pos) (e.g. Perl 5.003)
  - Overflowing buf next to pos overrides value of pos.

Heap exploits: corrupting virtual tables

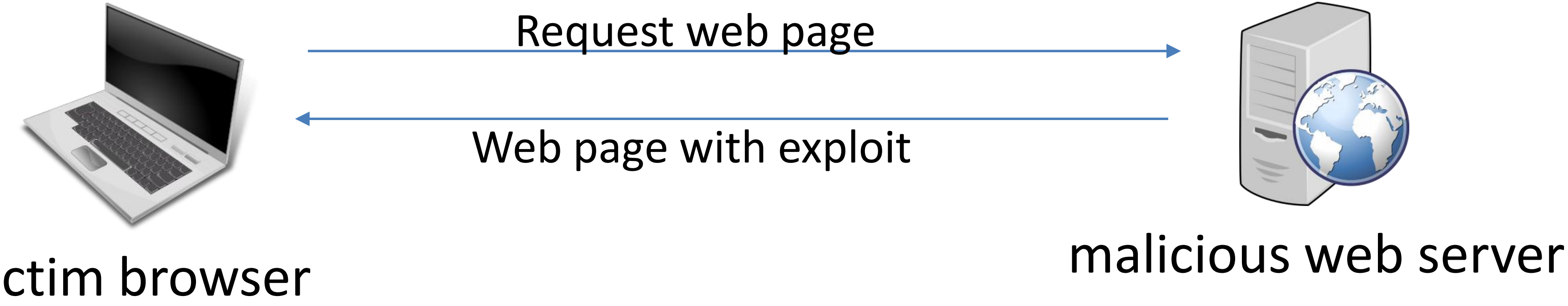
Compiler generated function pointers (e.g. C++ code)



After overflow of **`buf`** :



An example: exploiting the browser heap



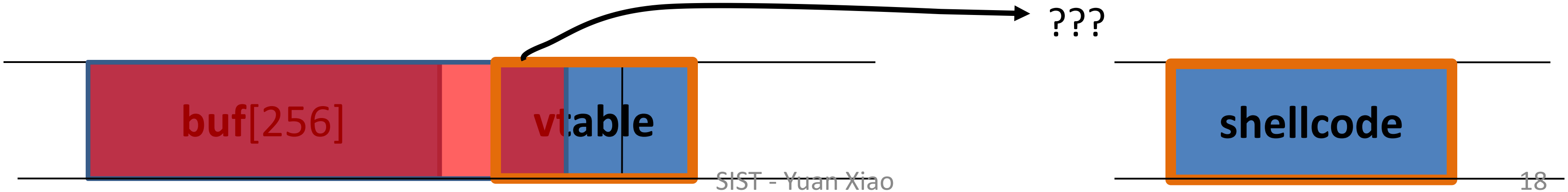
Attacker’s goal is to infect browsers visiting the web site

- 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

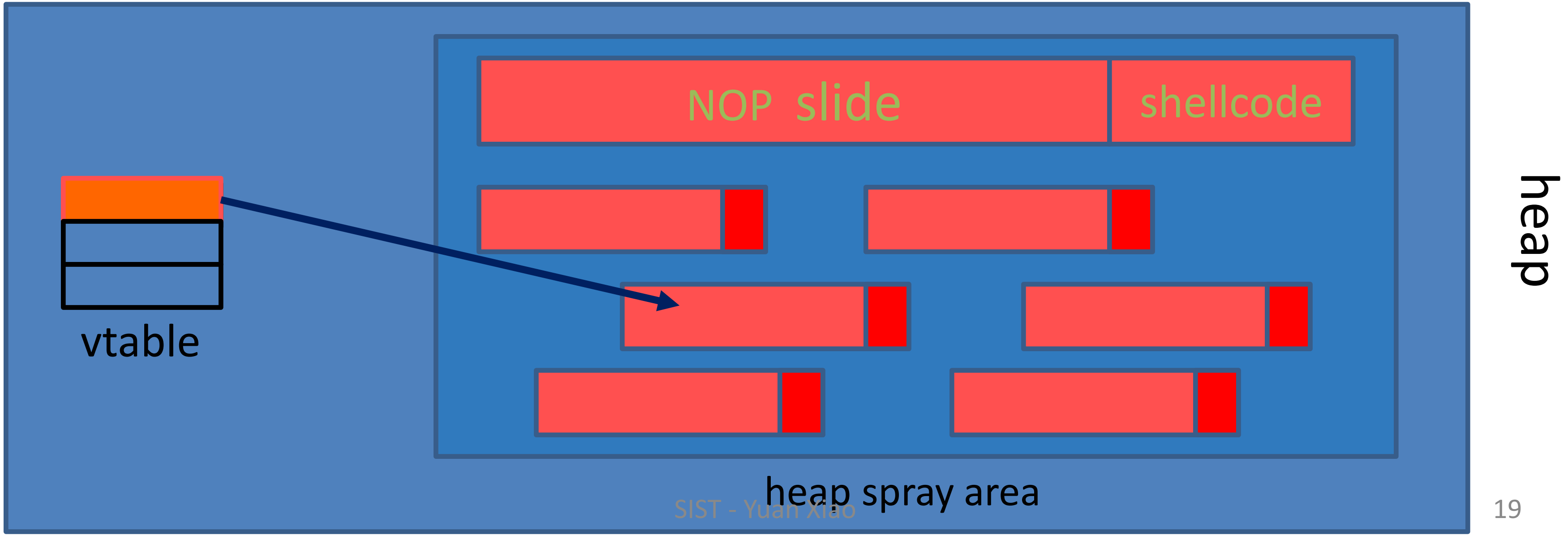


Heap Spraying [SkyLined]

Idea:

1. use Javascript to spray heap
   with shellcode (and NOP slides)

2. then point vtable ptr anywhere in spray area



Javascript heap spraying

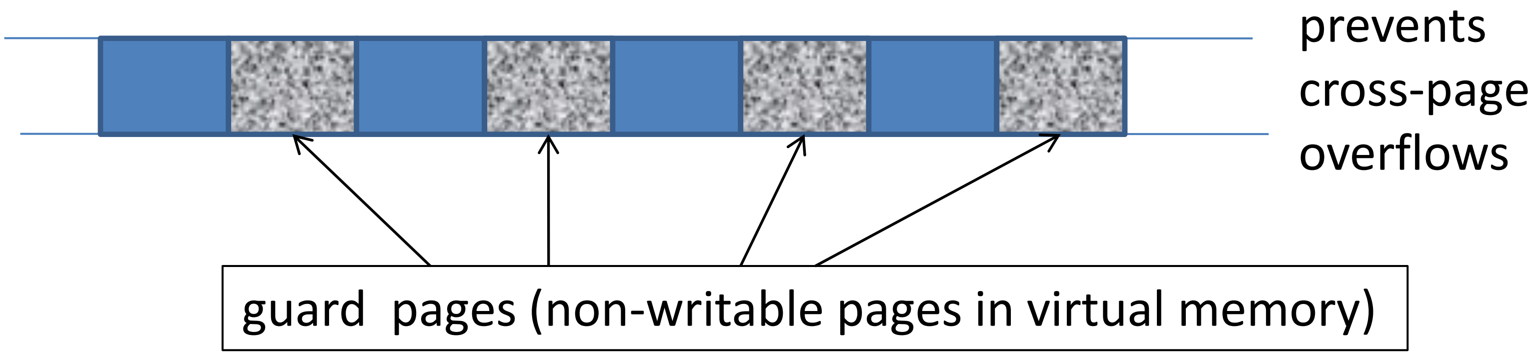
```
var  nop = unescape(“%u9090%u9090”)
while (nop.length < 0x100000)  nop += nop;

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)

$\Longrightarrow$ 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 "$$$$$")
    - Fuzzers: automated tools for this (next week)
  - If web server crashes,
    search core dump for "$$$$$" to find overflow location

- Construct exploit (not easy given latest defenses in next lecture)

PART TWO

02

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	⇒	c = 0
s = 0xff80 + 0x80	⇒	s = 0
m = 0xffffff80 + 0x80	⇒	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
}
```

What if **len1 = 0x80,** **len2 = 0xffffff80** ?

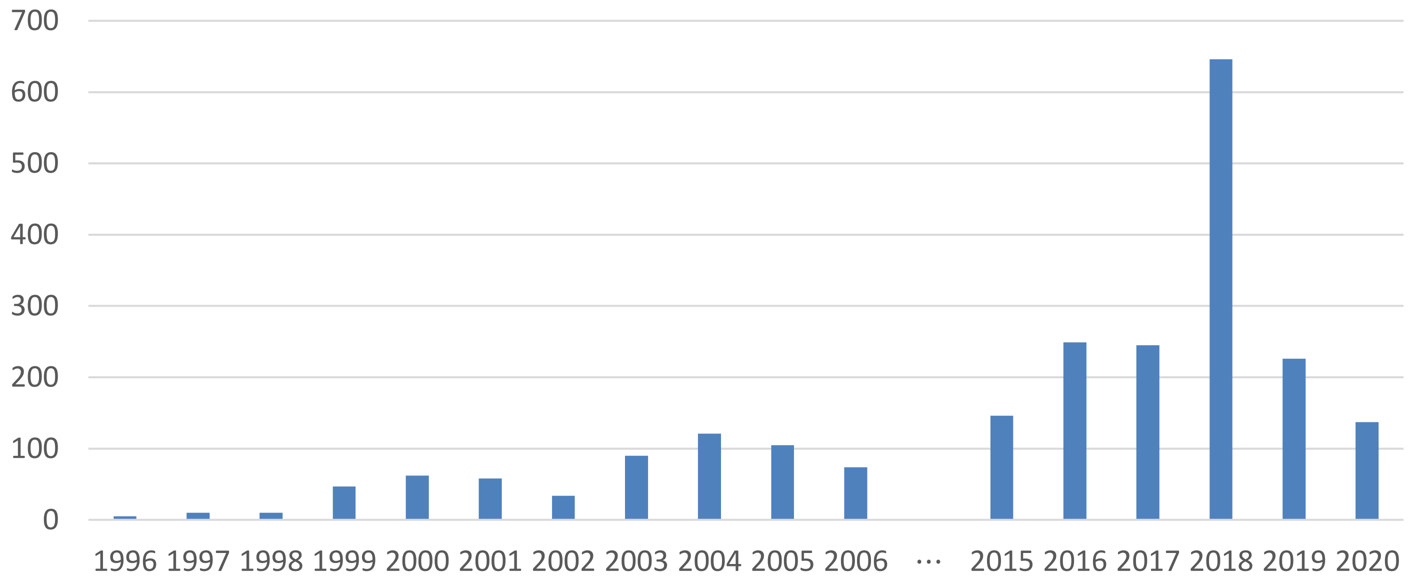
$\Rightarrow$ len1+len2 = 0

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)   ||   (len1+ 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;
```

Source: NVD/CVE

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

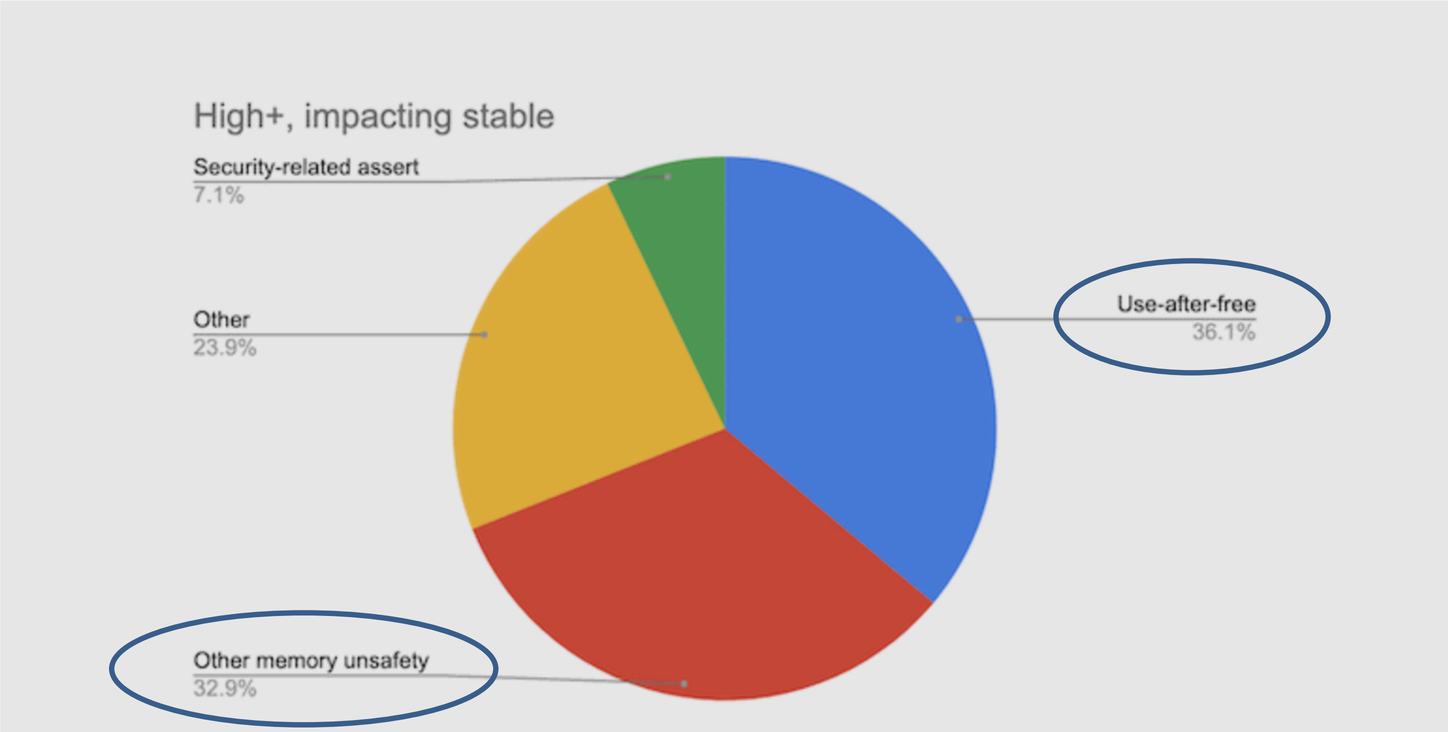
Exploit

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

- Writing to memory:
  - printf(“hello %n”, &temp)   --   writes ‘6’ into temp.
  - printf(“%08x.%08x.%08x.%08x.%n”) -- difficult to exploit

Use after free exploits

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



70% due to memory management bugs

Image: Google

IE11 Example: CVE-2014-0282 (simplified)

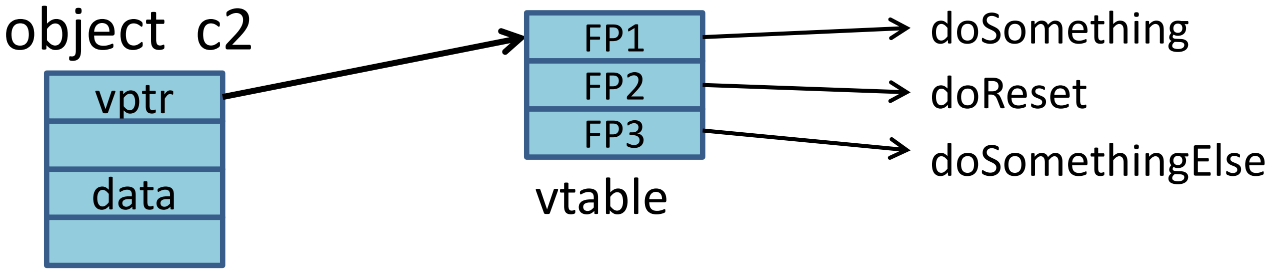
(IE11 written in C++)

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

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

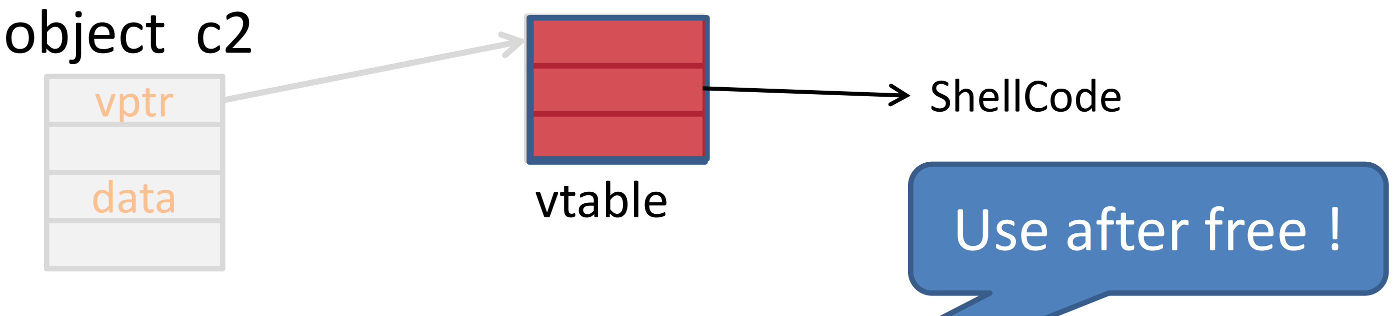
What just happened?

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



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

References on heap spraying

[1] **Heap Feng Shui in Javascript**,
by A. Sotirov, *Blackhat Europe* 2007

[2] **Engineering Heap Overflow Exploits with JavaScript**
M. Daniel, J. Honoroff, and C. Miller, *WooT* 2008

[3] **Interpreter Exploitation: Pointer inference and JiT spraying**,
by Dion Blazakis