Control Hijacking Attacks

Note: project 1 is out

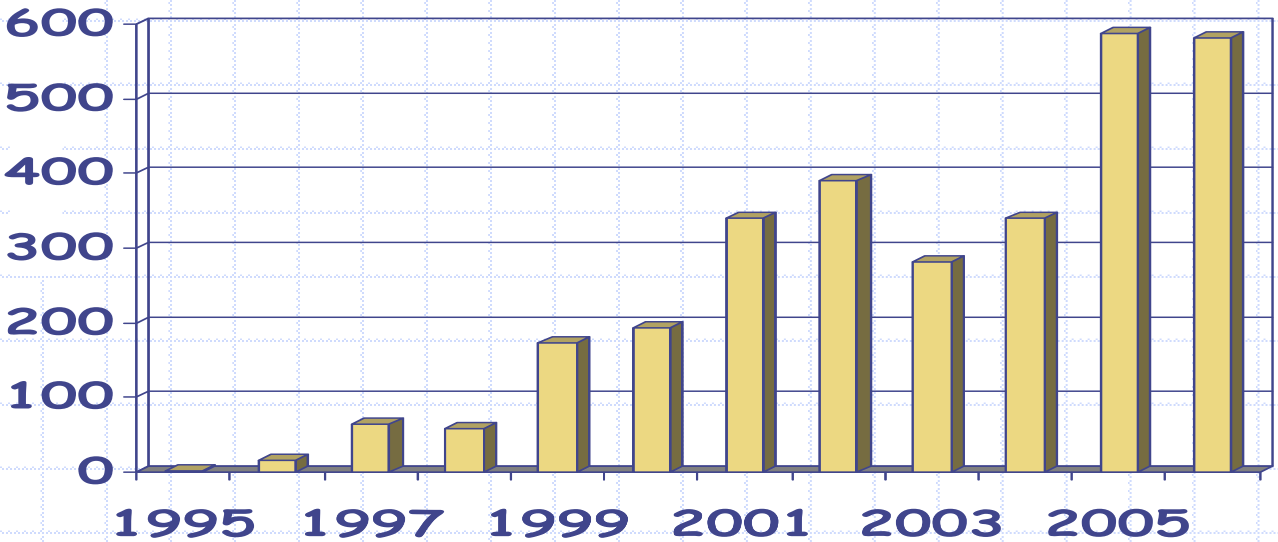
Section this Friday 4:15pm (Gates B03)

Control hijacking attacks

- Attacker's goal:
  - Take over target machine (e.g. web server)
    - Execute arbitrary code on target by hijacking application control flow
- This lecture: three examples.
  - Buffer overflow attacks
  - Integer overflow attacks
  - Format string vulnerabilities
- Project 1: Build exploits

1. Buffer overflows

- Extremely common bug.
  - First major exploit: 1988 Internet Worm. fingerd.



≈20% of all vuln.

2005-2007: ≈ 10%

Source: NVD/CVE

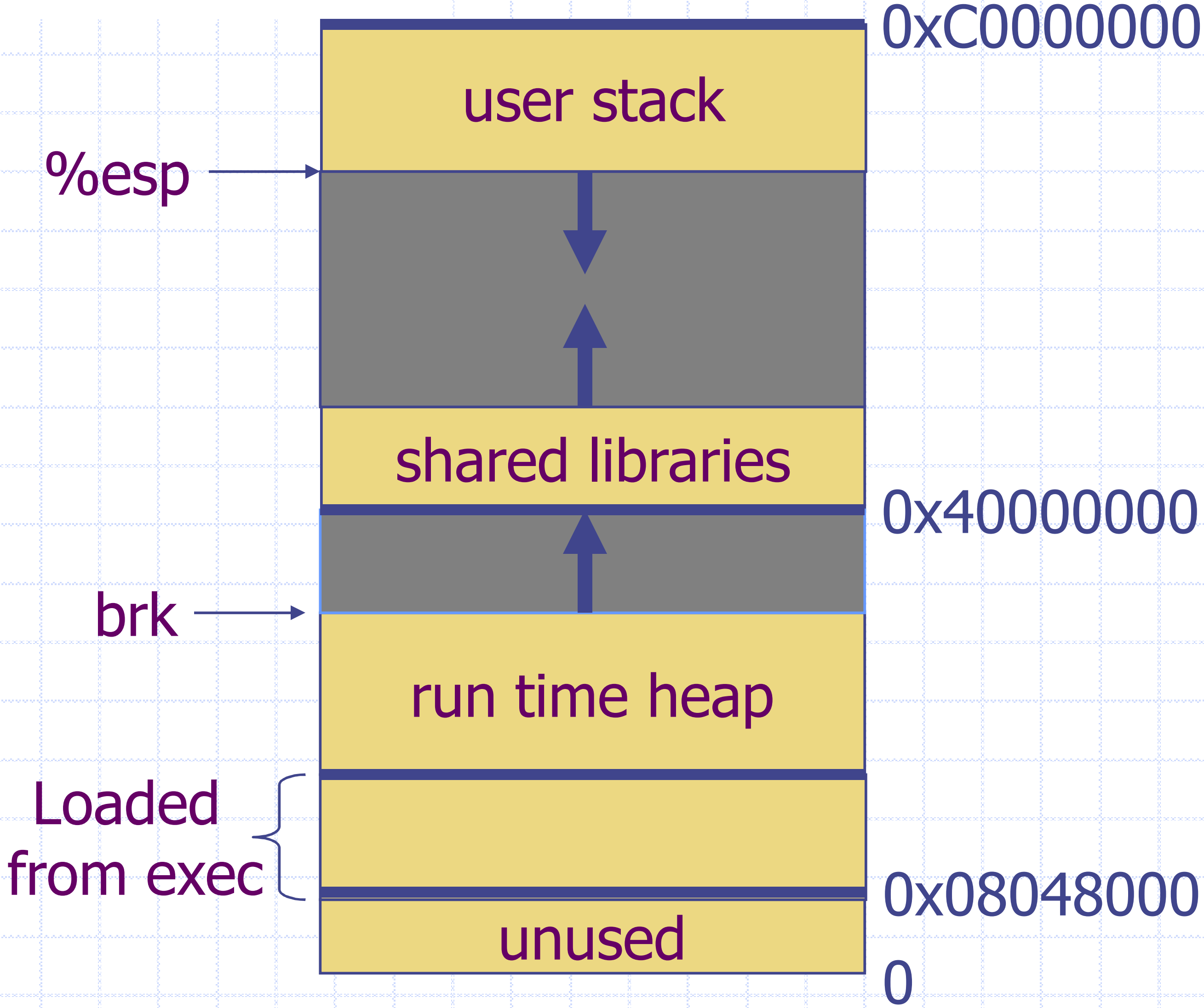
- Developing buffer overflow attacks:
  - Locate buffer overflow within an application.
  - Design an exploit.

What is needed

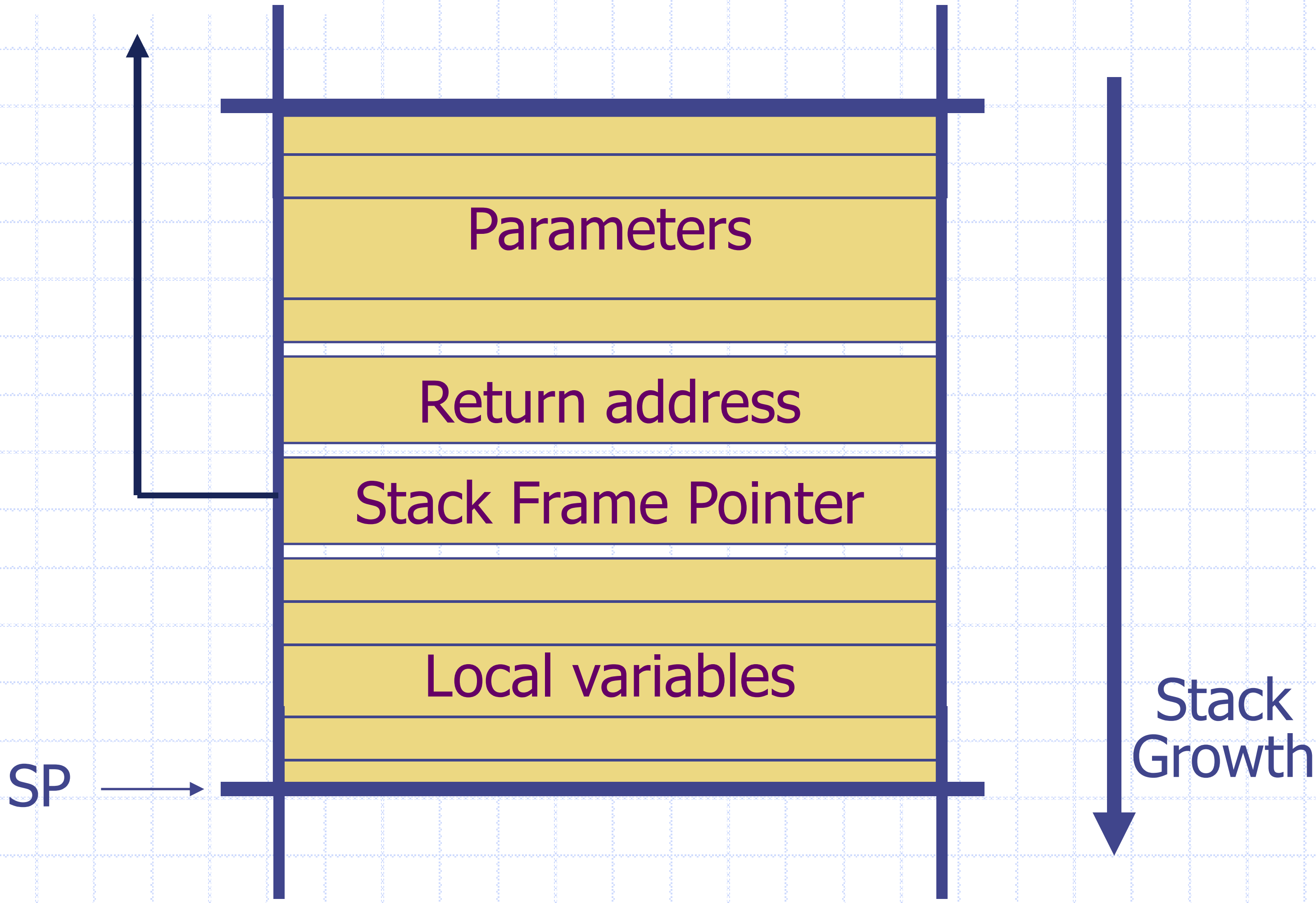
- Understanding C functions and the stack
- Some familiarity with machine code
- Know how systems calls are made
- The exec() system call

- Attacker needs to know which CPU and OS are running on the target machine:
  - Our examples are for x86 running Linux
  - Details vary slightly between CPUs and OSs:
    - Little endian vs. big endian (**x86 vs. Motorola**)
    - Stack Frame structure (Unix vs. Windows)
    - Stack growth direction

Linux process memory layout



Stack Frame


Parameters
Return address
Stack Frame Pointer
Local variables
SP
Stack Growth

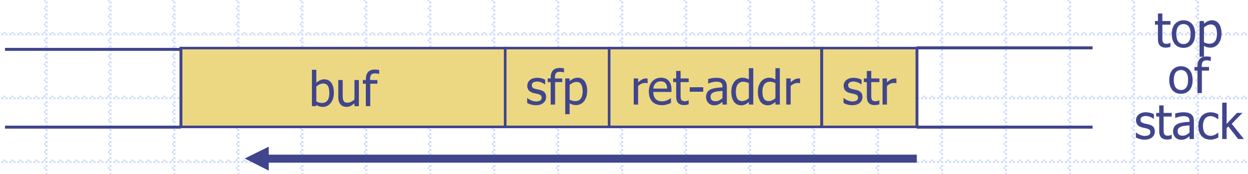
What are buffer overflows?

- Suppose a web server contains a function:

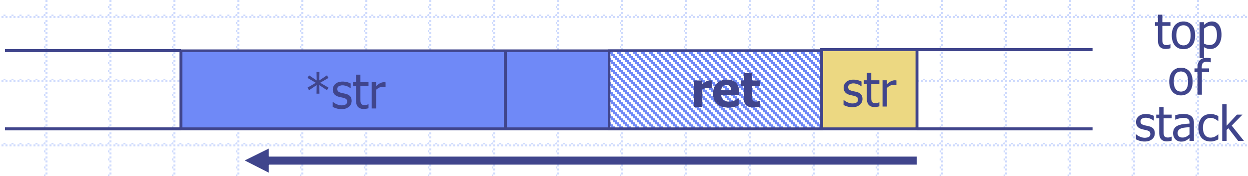
```
void func(char *str) {
   char buf[128];

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

- When the function is invoked the stack looks like:

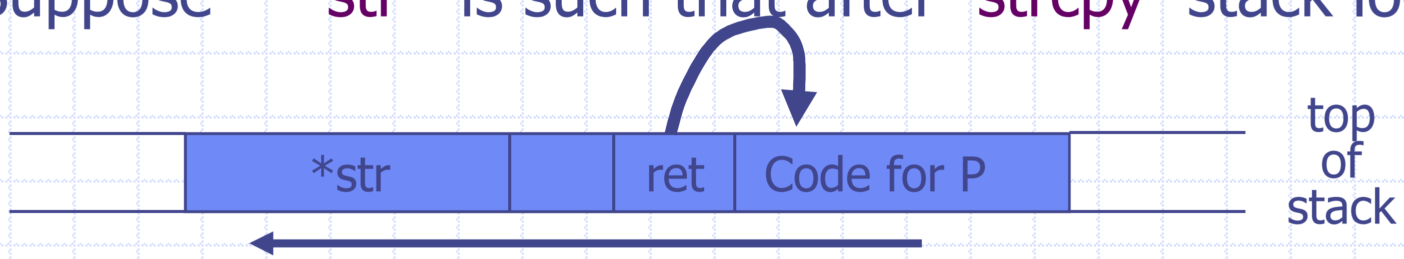


- What if **`*str`** is 136 bytes long? After **`strcpy`**:



Basic stack exploit

- Problem: no range checking in strcpy().
- 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 will be given a shell !
- Note: attack code runs *in stack*.

- To determine ret guess position of stack when func() is called

Many unsafe C lib functions

strcpy (char *dest, const char *src)
strcat (char *dest, const char *src)
gets (char *s)
scanf (const char *format, …)
⋮

- "Safe" versions strncpy(), strncat() are misleading
  - strncpy()   may leave buffer unterminated.
  - strncpy(), strncat()   encourage off by 1 bugs.

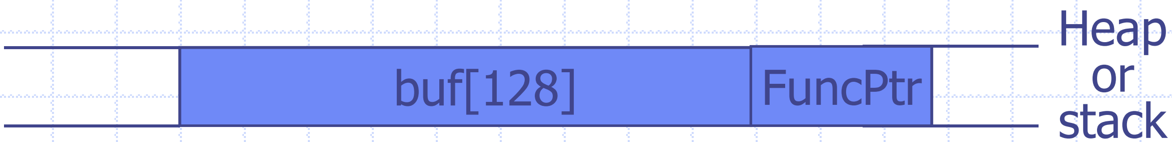
Exploiting buffer overflows

- Suppose web server calls func() with given URL.
  - Attacker sends a 200 byte URL. Gets shell on web server
- Some complications:
  - Program P should not contain the '\0' character.
  - Overflow should not crash program before func() exists.
- Sample remote buffer overflows of this type:
  - (2005) Overflow in MIME type field in MS Outlook.
  - (2005) Overflow in Symantec Virus Detection

```
Set test = CreateObject("Symantec.SymVAFileQuery.1")
test.GetPrivateProfileString "file", [long string]
```

Control hijacking opportunities

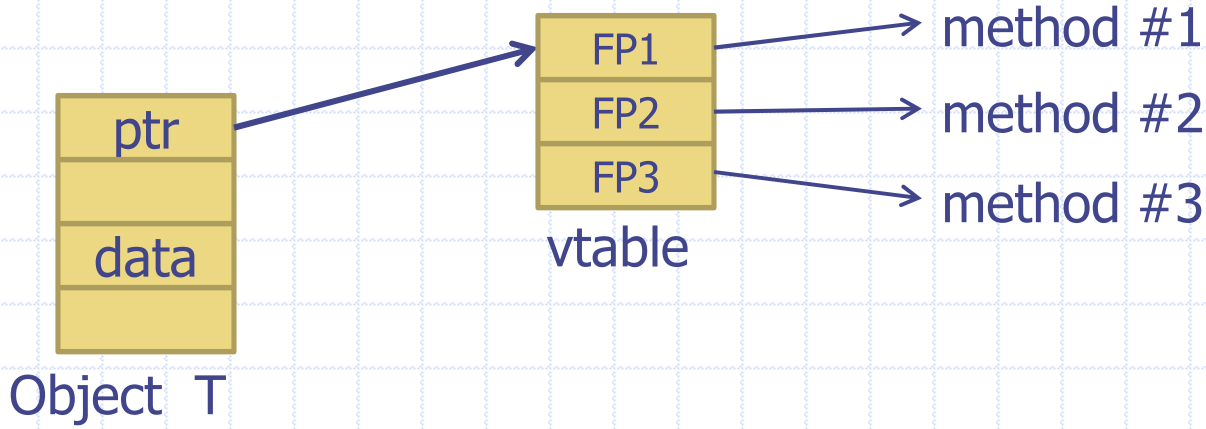
- Stack smashing attack:
  - Override return address in stack activation record by overflowing a local buffer variable.
- Function pointers: (e.g. PHP 4.0.2, MS MediaPlayer Bitmaps)



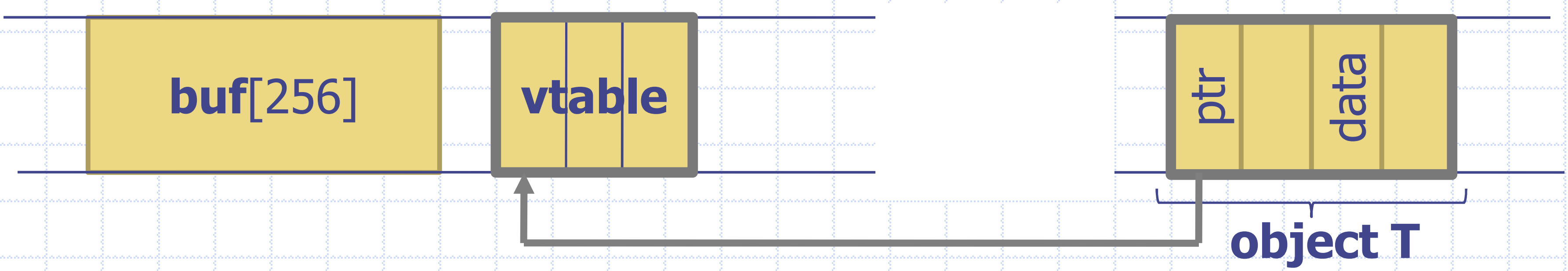
  - Overflowing buf will override function pointer.
- Longjmp buffers: longjmp(pos) (e.g. Perl 5.003)
  - Overflowing buf next to pos overrides value of pos.

Heap-based control hijacking

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



- Suppose vtable is on the heap next to a string object:



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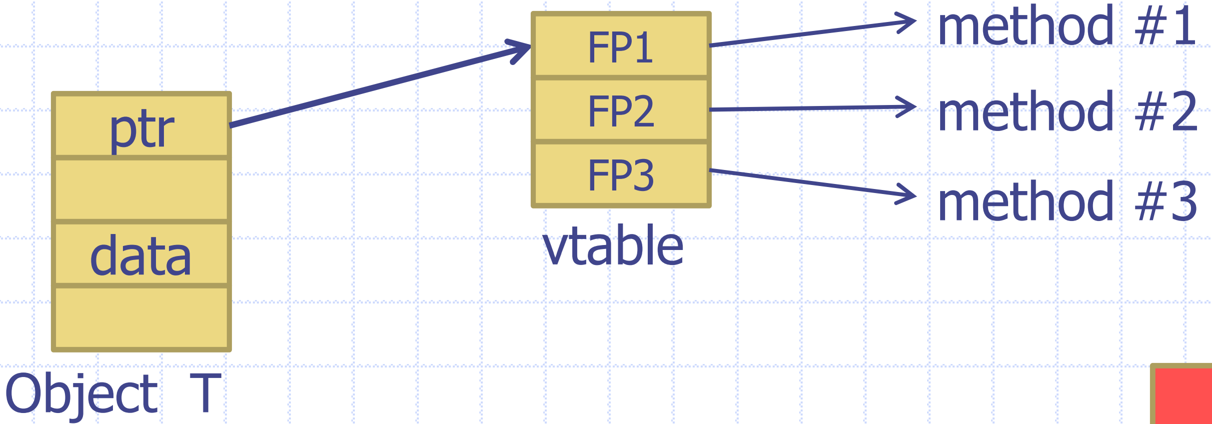
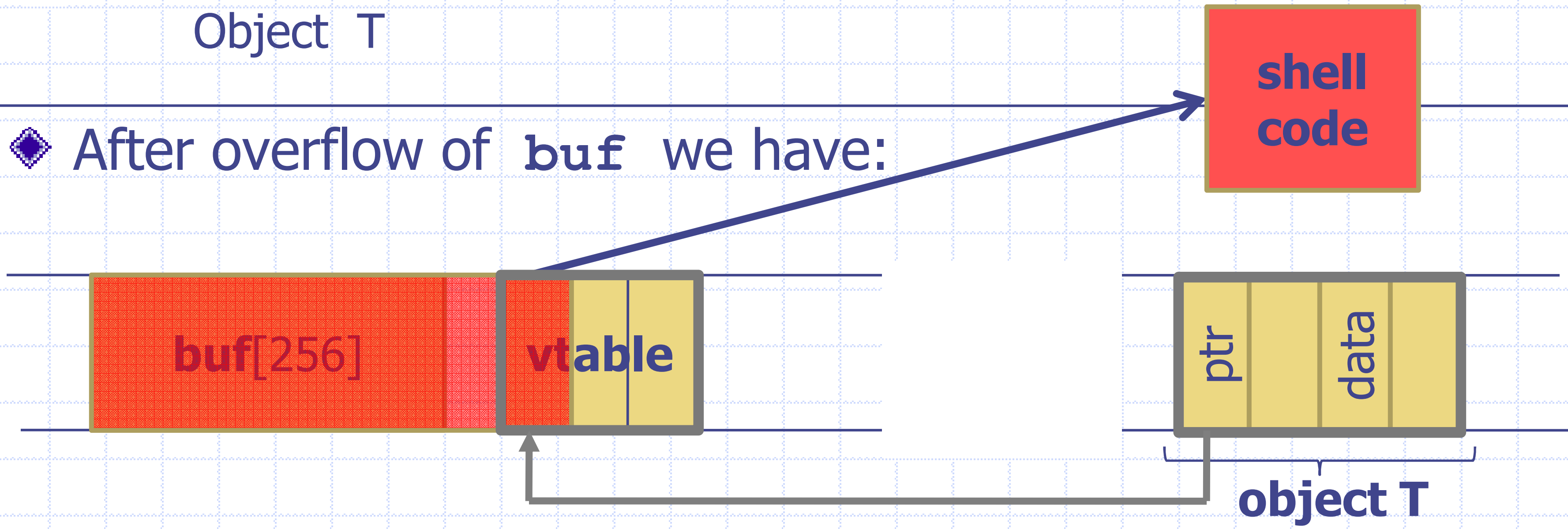


- After overflow of `buf` we have:



Other types of overflow attacks

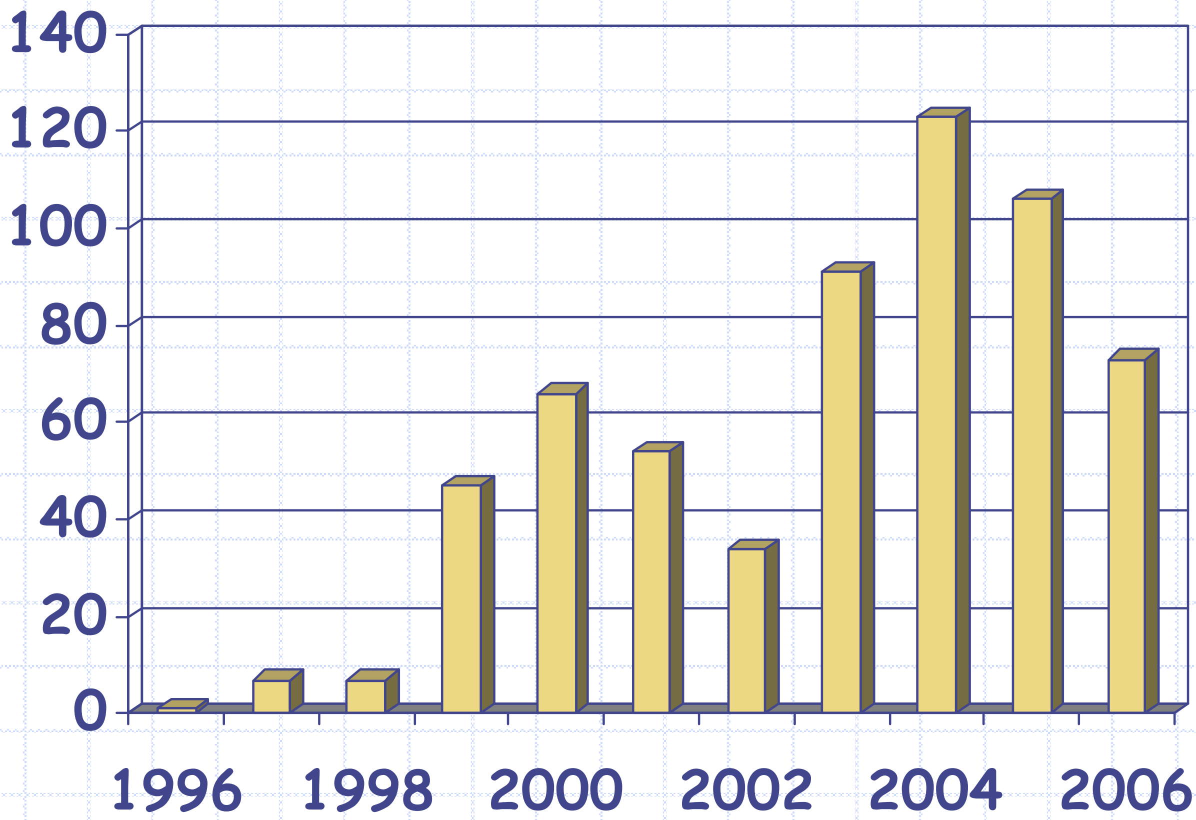
- Integer overflows: (e.g. MS DirectX MIDI Lib) Phrack60

```
void func(int a, char v) {
  char buf[128];
  init(buf);
  buf[a] = v;
}
```

  - Problem: a can point to `ret-addr' on stack.

- Double free: double free space on heap.
  - Can cause mem mgr to write data to specific location
  - Examples: CVS server

Integer overflow stats



Source: NVD/CVE

Finding buffer overflows

- To find overflow:
  - Run web server on local machine
  - Issue requests with long tags
    All long tags end with "$$$$$"
  - If web server crashes,
    search core dump for "$$$$$" to find
    overflow location

- Many automated tools exist (called fuzzers – next lecture)

- Then use disassemblers and debuggers (e.g. IDA-Pro) to construct exploit

Defenses

Preventing hijacking attacks

1. Fix bugs:
   - Audit software
     - Automated tools: Coverity, Prefast/Prefix.
   - Rewrite software in a type safe languange (Java, ML)
     - Difficult for existing (legacy) code …

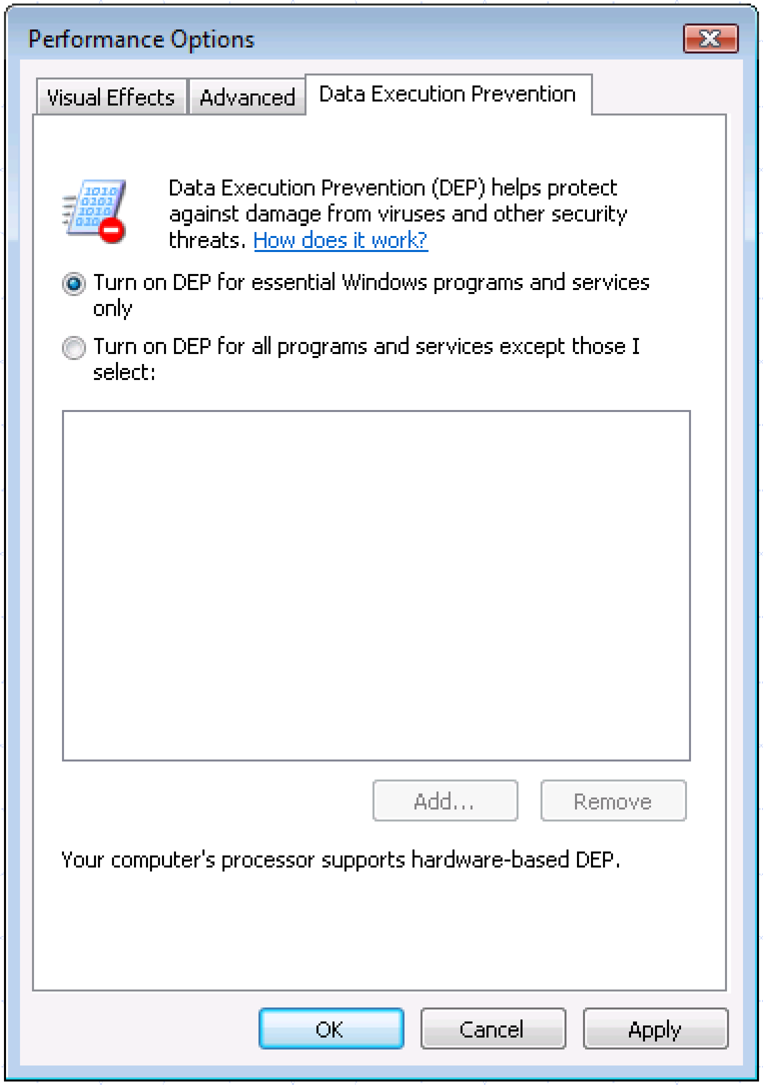
2. Concede overflow, but prevent code execution

3. Add runtime code to detect overflows exploits
   - Halt process when overflow exploit detected
   - StackGuard, LibSafe, …

Marking memory as non-execute (W^X)

- Prevent overflow code execution by marking stack and heap segments as **non-executable**
  - NX-bit on AMD Athlon 64, XD-bit on Intel P4 Prescott
    - NX bit in every Page Table Entry (PTE)
  - Deployment:
    - Linux (via PaX project); OpenBSD
    - Windows since XP SP2 (DEP)
      - Boot.ini : **/noexecute=OptIn** or **AlwaysOn**
- Limitations:
  - Some apps need executable heap (e.g. JITs).
  - Does not defend against \`**return-to-libc**' exploit

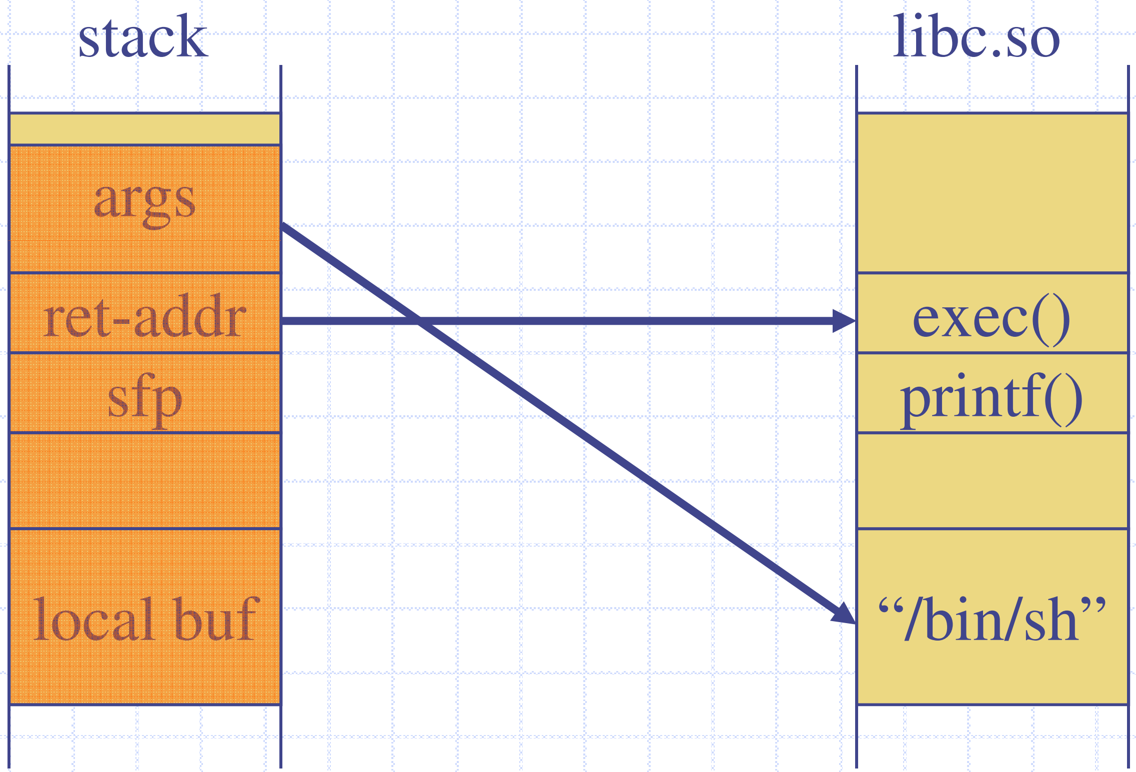
Examples: DEP controls in Vista



DEP terminating a program

Return to libc

- Control hijacking without executing code



Response: randomization

- **ASLR**: (Address Space Layout Randomization)
  - Map shared libraries to rand location in process memory
    ⇒ Attacker cannot jump directly to exec function
  - Deployment:
    - Windows Vista: 8 bits of randomness for DLLs
      - aligned to 64K page in a 16MB region ⇒ 256 choices
    - **Linux** (via PaX): 16 bits of randomness for libraries
  - More effective on 64-bit architectures
- Other randomization methods:
  - Sys-call randomization: randomize sys-call id's
  - Instruction Set Randomization (ISR)

ASLR Example

Booting Vista twice loads libraries into different locations:

ntlanman.dll	0x6D7F0000	Microsoft® Lan Manager
ntmarta.dll	0x75370000	Windows NT MARTA provider
ntshrui.dll	0x6F2C0000	Shell extensions for sharing
ole32.dll	0x76160000	Microsoft OLE for Windows

ntlanman.dll	0x6DA90000	Microsoft® Lan Manager
ntmarta.dll	0x75660000	Windows NT MARTA provider
ntshrui.dll	0x6D9D0000	Shell extensions for sharing
ole32.dll	0x763C0000	Microsoft OLE for Windows

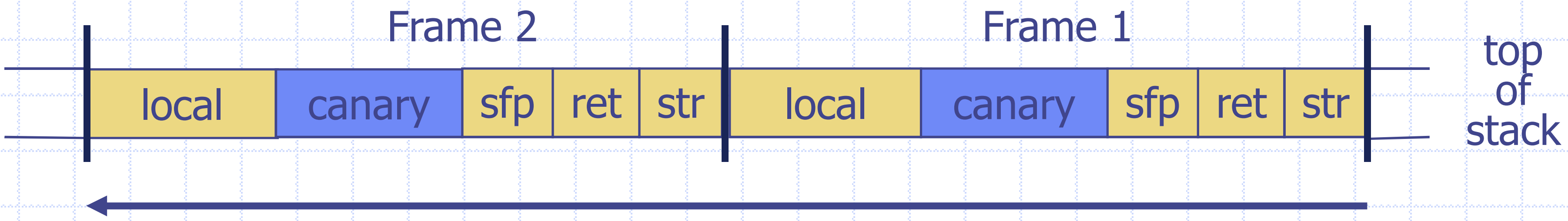
Note: ASLR is only applied to images for which the dynamic-relocation flag is set

Run time checking

Run time checking: StackGuard

- Many many run-time checking techniques …
  - we only discuss methods relevant to overflow protection

- <u>Solution 1</u>: StackGuard
  - Run time tests for stack integrity.
  - Embed "canaries" in stack frames and verify their integrity prior to function return.



Canary Types

- Random canary:
  - Choose random string at program startup.
  - Insert canary string into every stack frame.
  - Verify canary before returning from function.
  - To corrupt random canary, attacker must learn current random string.
- Terminator canary:

  Canary = 0, newline, linefeed, EOF

  - String functions will not copy beyond terminator.
  - Attacker cannot use string functions to corrupt stack.

StackGuard (Cont.)

- StackGuard implemented as a GCC patch.
  - Program must be recompiled.

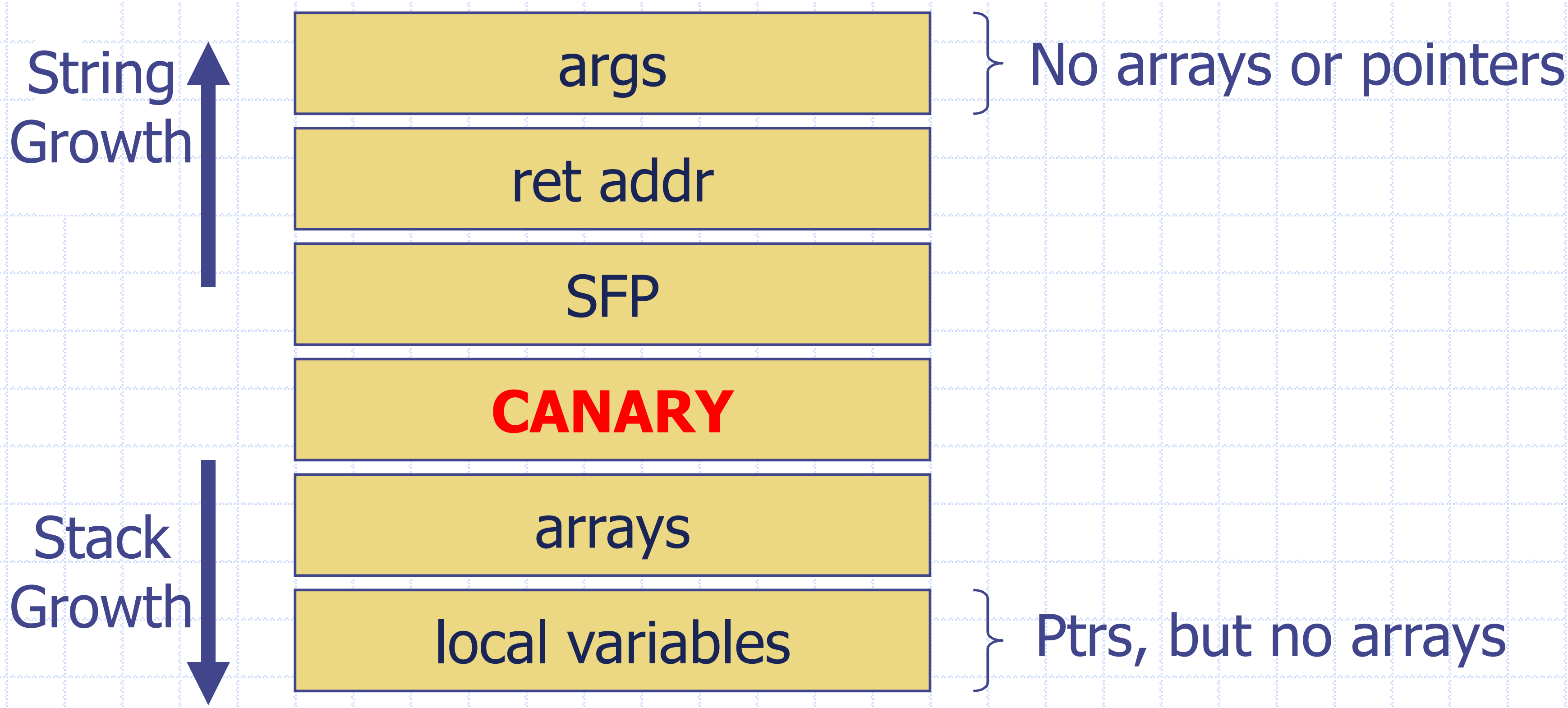
- Minimal performance effects: 8% for Apache.

- Note: Canaries don't offer fullproof protection.
  - Some stack smashing attacks leave canaries unchanged

- Heap protection: PointGuard.
  - Protects function pointers and setjmp buffers by encrypting them: XOR with random cookie
  - More noticeable performance effects

StackGuard variants - ProPolice

- ProPolice (IBM) - gcc 3.4.1. (**-fstack-protector**)
  - Rearrange stack layout to prevent ptr overflow.



MS Visual Studio /GS [2003]

Compiler /GS option:

- Combination of ProPolice and Random canary.
- Triggers UnHandledException in case of Canary mismatch to shutdown process.

```
mov   eax,dword ptr [___security_cookie]
xor   eax,ebp
mov   dword ptr [ebp-8],eax
...
mov   ecx,dword ptr [ebp-8]
xor   ecx,ebp
call  __security_check_cookie@4
```

- Litchfield vulnerability report
  - Overflow overwrites exception handler
  - Redirects exception to attack code

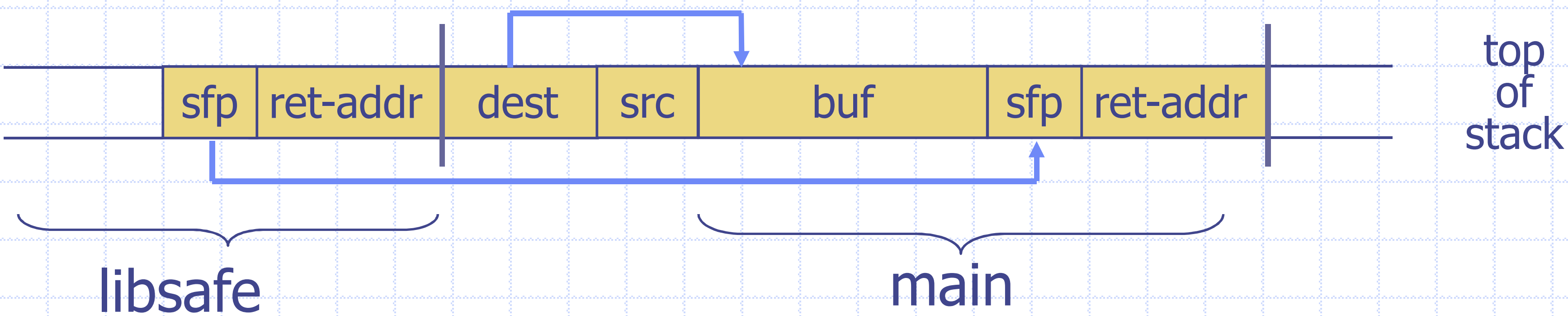
Run time checking: Libsafe

- Solution 2: Libsafe (Avaya Labs)
  - Dynamically loaded library (no need to recompile app.)
  - Intercepts calls to strcpy (dest, src)
    - Validates sufficient space in current stack frame:

      |frame-pointer – dest| > strlen(src)

    - If so, does strcpy,

      otherwise, terminates application



More methods …

- StackShield
  - At function prologue, copy return address RET and SFP to “safe” location (beginning of data segment)
  - Upon return, check that RET and SFP is equal to copy.
  - Implemented as assembler file processor (GCC)

- Control Flow Integrity (CFI)
  - A combination of static and dynamic checking
    - Statically determine program control flow
    - Dynamically enforce control flow integrity

Format string bugs

Format string problem

```
int func(char *user)   {
  fprintf( stdout, 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:

```
int func(char *user)   {
  fprintf( stdout, “%s”, user);
}
```

History

- First exploit discovered in June 2000.
- Examples:
  - wu-ftpd 2.* : remote root
  - Linux rpc.statd: remote root
  - IRIX telnetd: remote root
  - BSD chpass: local root

⋮

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")

Overflow using format string

```
char errmsg[512],  outbuf[512];

sprintf (errmsg, “Illegal command: %400s”, user);
        …
sprintf( outbuf, errmsg );
```

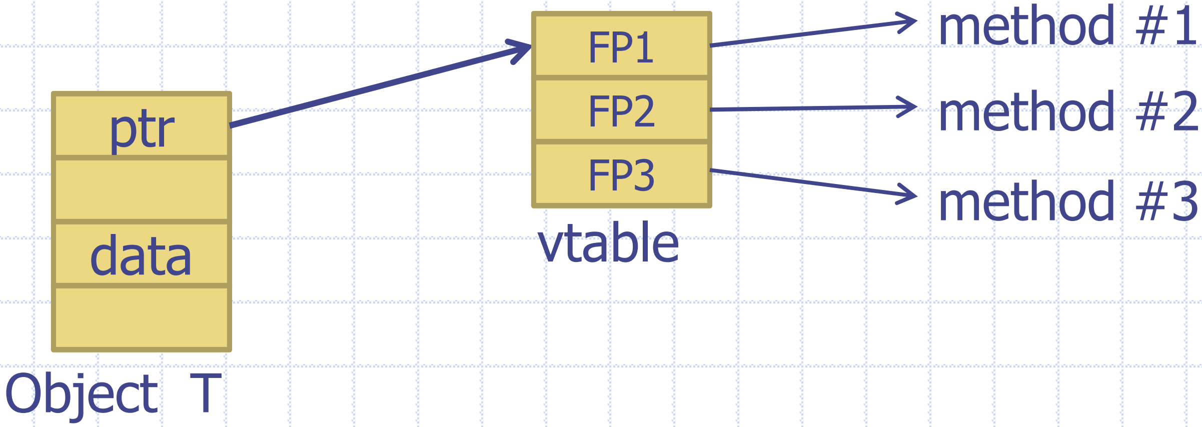
- What if user = “%500d <nops> <shellcode>”
  - Bypass “%400s” limitation.
  - Will ovreflow outbuf.

Heap Spray Attacks

A reliable method for exploiting heap overflows

Heap-based control hijacking

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



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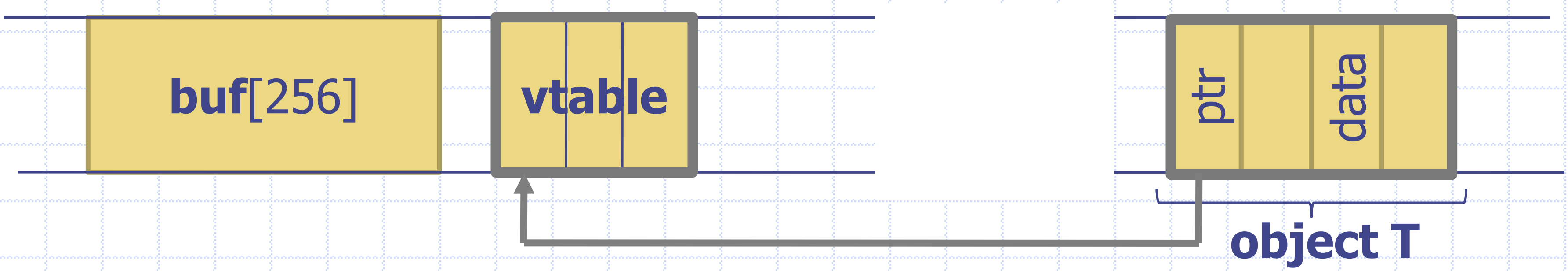

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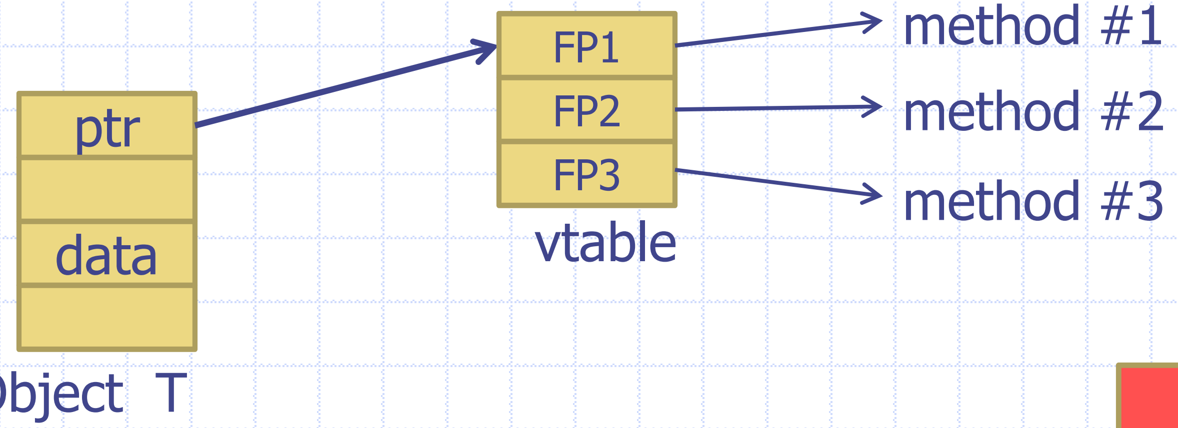
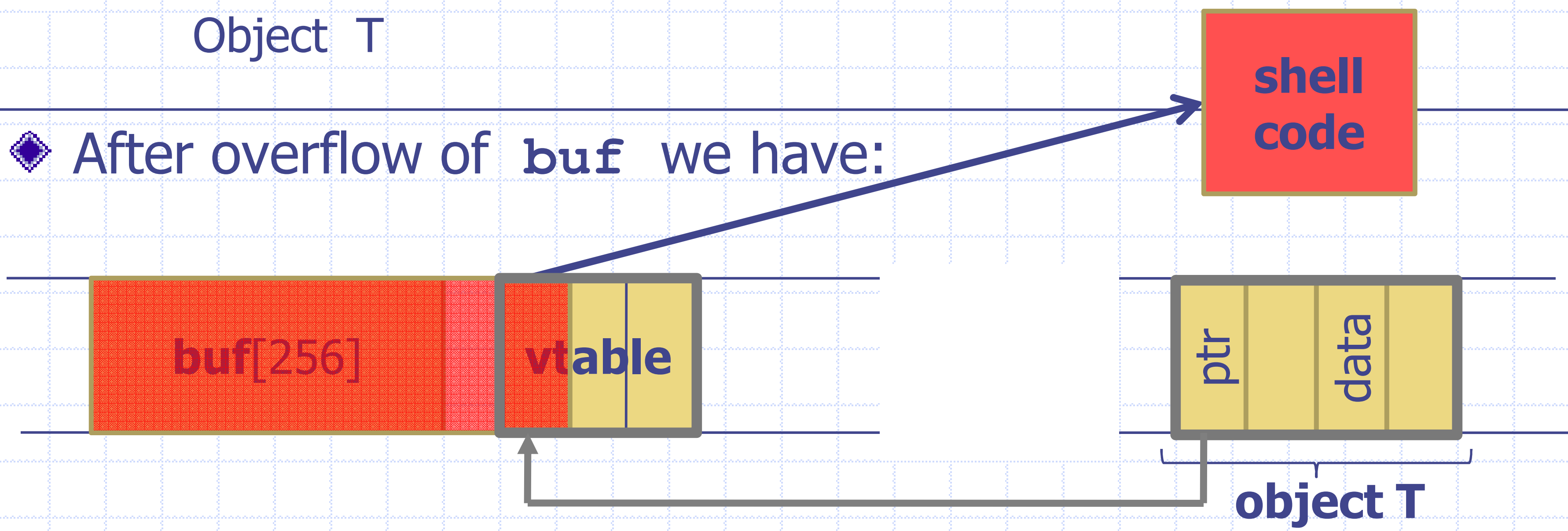


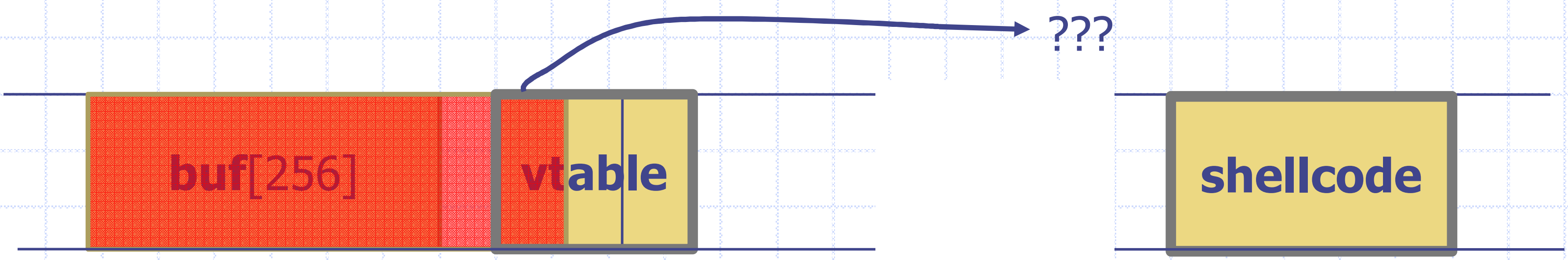
- After overflow of `buf` we have:



A reliable exploit?

```
<SCRIPT language="text/javascript">
 shellcode = unescape("%u4343%u4343%...");
overflow-string = unescape(“%u2332%u4276%...”);

cause-overflow( overflow-string );        // overflow  buf[ ]
</SCRIPT>
```

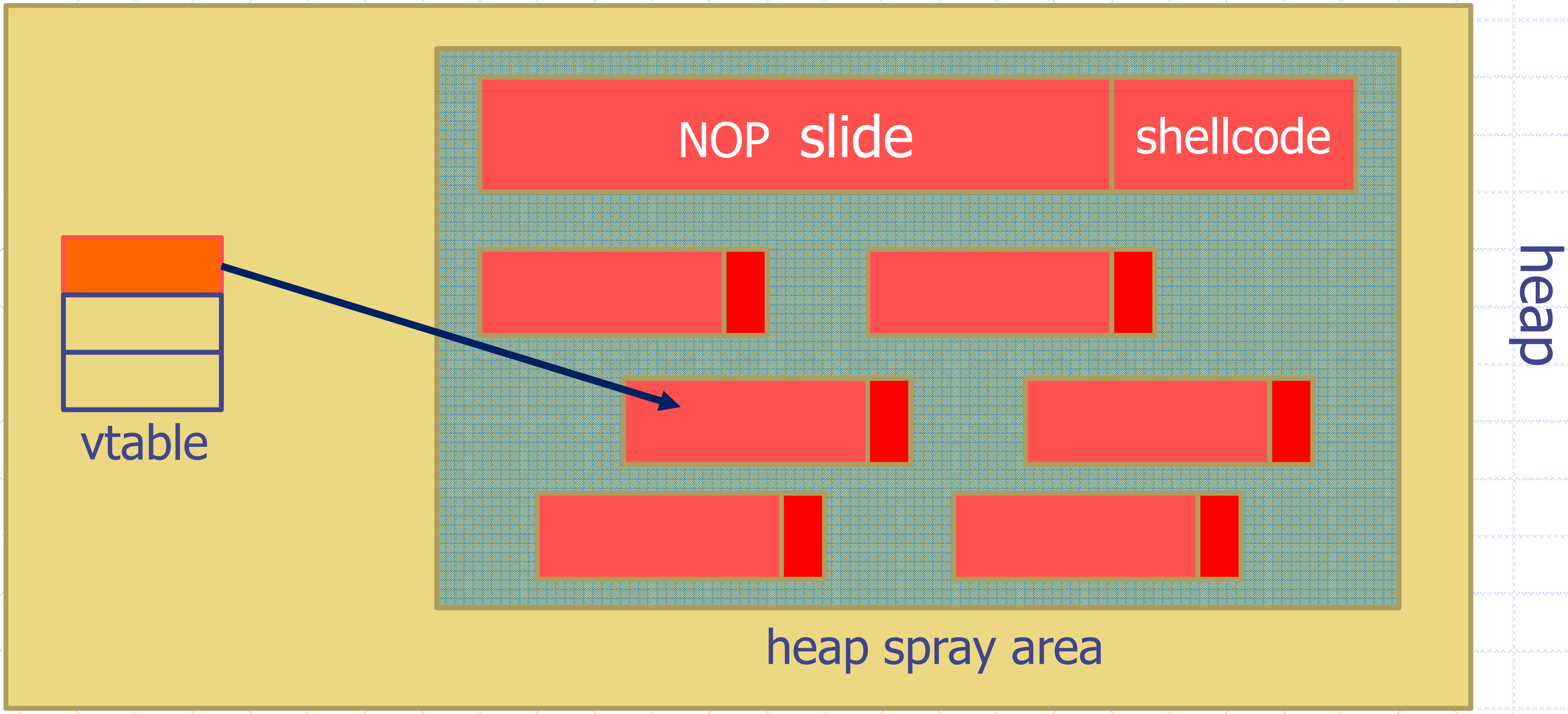
Problem: attacker does not know where browser places **shellcode** on the heap



Heap Spraying [SkyLined 2004]

Idea:

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



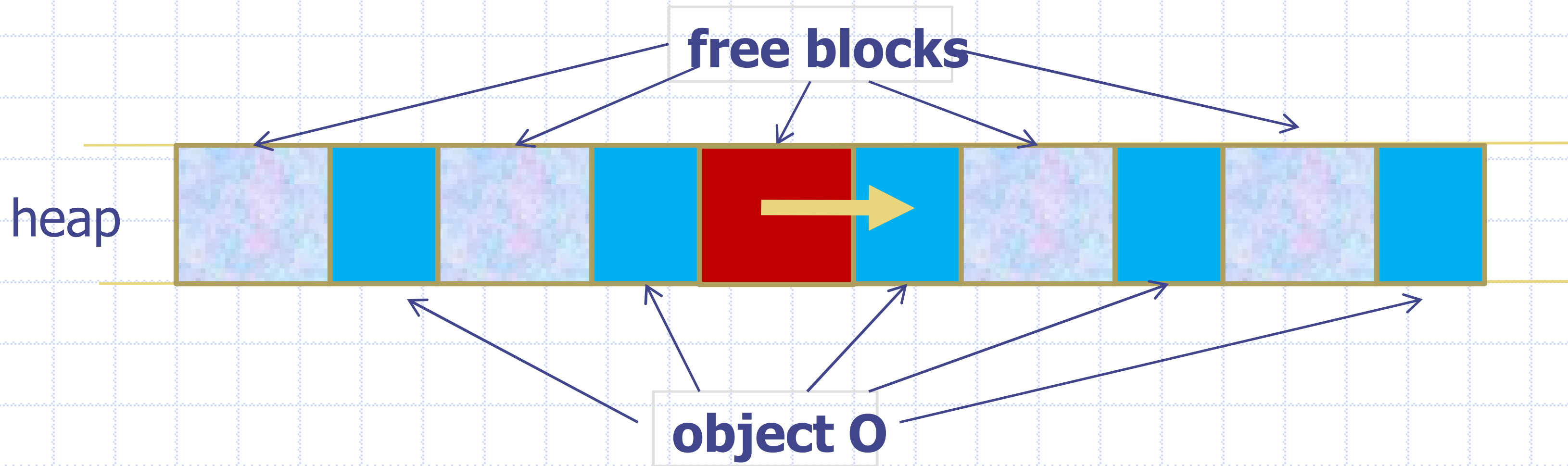
Javascript heap spraying

```
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 func-ptr almost anywhere in heap will cause shellcode to execute.

Vulnerable buffer placement

- Placing vulnerable **`buf[256]`** next to object O:
  - By sequence of Javascript allocations and frees make heap look as follows:



  - Allocate vuln. buffer in Javascript and cause overflow
  - Successfully used against a Safari PCRE overflow [DHM'08]

Many heap spray exploits

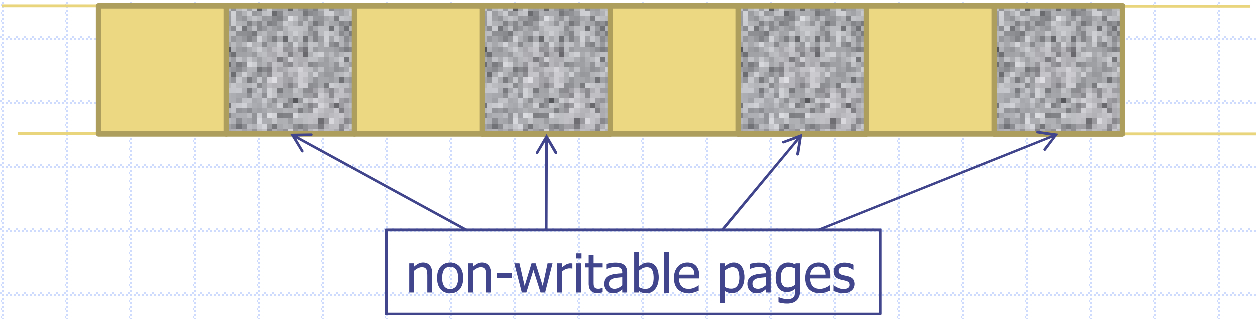
[RLZ'08]

Date	Browser	Description
11/2004	IE	IFRAME Tag BO
04/2005	IE	DHTML Objects Corruption
01/2005	IE	.ANI Remote Stack BO
07/2005	IE	`javaprxy.dll` COM Object
03/2006	IE	`createTextRang` RE
09/2006	IE	VML Remote BO
03/2007	IE	ADODB Double Free
09/2006	IE	WebViewFolderIcon `setSlice`
09/2005	FF	0xAD Remote Heap BO
12/2005	FF	`compareTo()` RE
07/2006	FF	`Navigator` Object RE
07/2008	Safari	Quicktime Content-Type BO

- Improvements: Heap Feng Shui [S'07]
  - Reliable heap exploits **on IE** without spraying
  - Gives attacker full control of IE heap from Javascript

(partial) Defenses

- Protect heap function pointers (e.g. PointGuard)
- Better browser architecture:
  - Store JavaScript strings in a separate heap from browser heap
- OpenBSD heap overflow protection:



prevents cross-page overflows

- Nozzle [RLZ'08] : detect sprays by prevalence of code on heap

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] **Nozzle: A Defense Against Heap-spraying Code Injection Attacks,**
by P. Ratanaworabhan, B. Livshits, and B. Zorn

THE END