TEL AVIV UNIVERSITY

Information Security – Theory vs. Reality

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Lecture 8: Control hijacking attacks

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Slides credit: Dan Boneh, Stanford course CS155

Control hijacking attacks

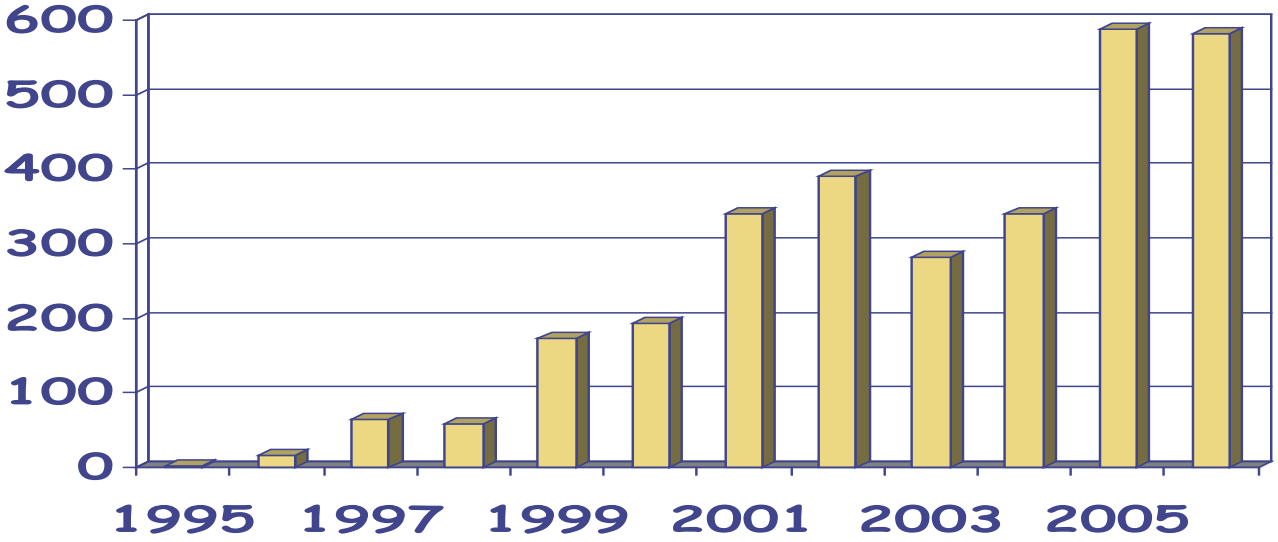
- Attacker's goal:
  - Take over target machine (e.g. web server)
  - Execute arbitrary code on target by hijacking application control flow

- Examples in this lecture:
  - Buffer overflow attacks
  - Integer overflow attacks
  - Format string vulnerabilities

- Various countrmeasures

1. Buffer overflows

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



≈20% of all vuln.

2005-2007: ≈ 10%

Source: NVD/CVE

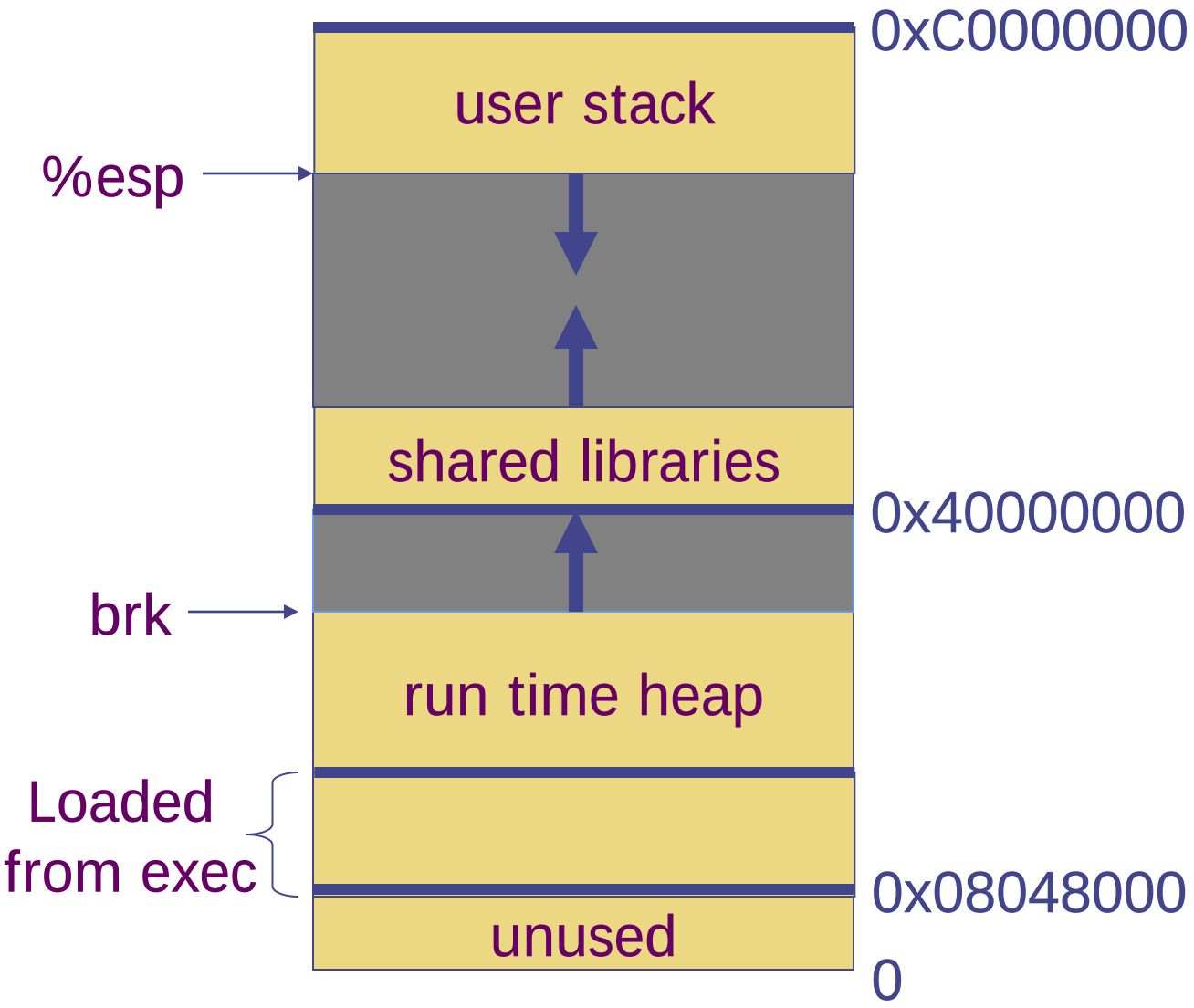
- Developing buffer overflow attacks:
  - Locate buffer overflow within an application.
  - Design an exploit.

What is needed

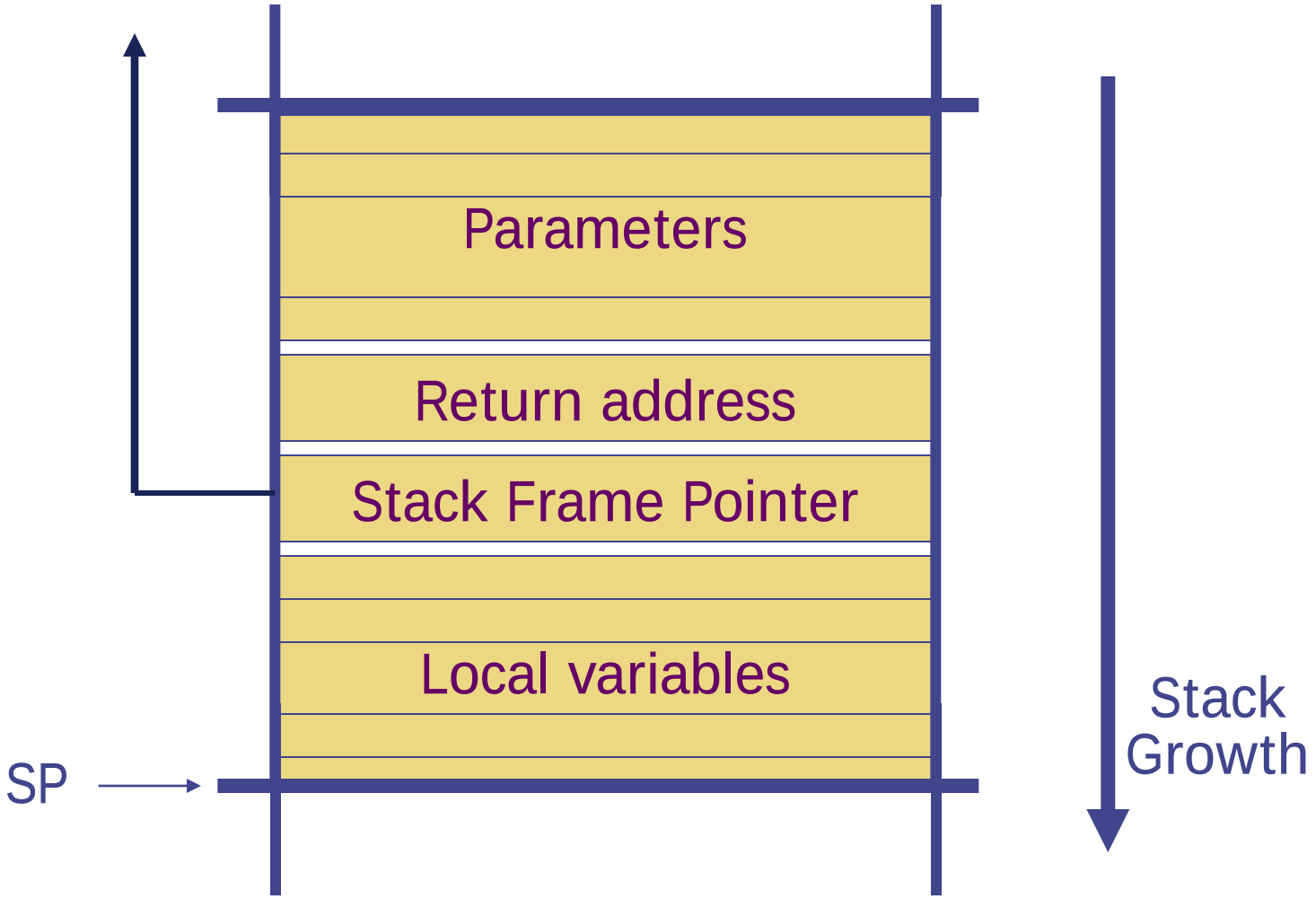
- Understanding C functions and the stack
- Some familiarity with machine code
- Know how systems calls are made
- The exec() system call

- 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

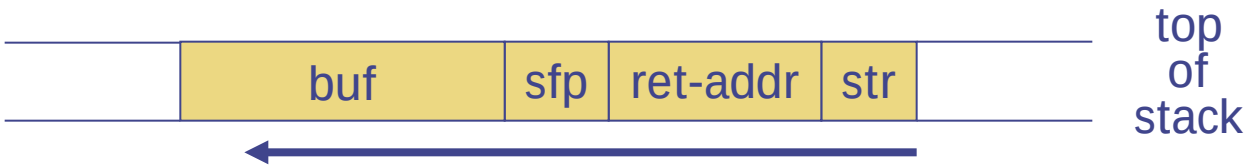
What are buffer overflows?

- Suppose a web server contains a function:

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

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

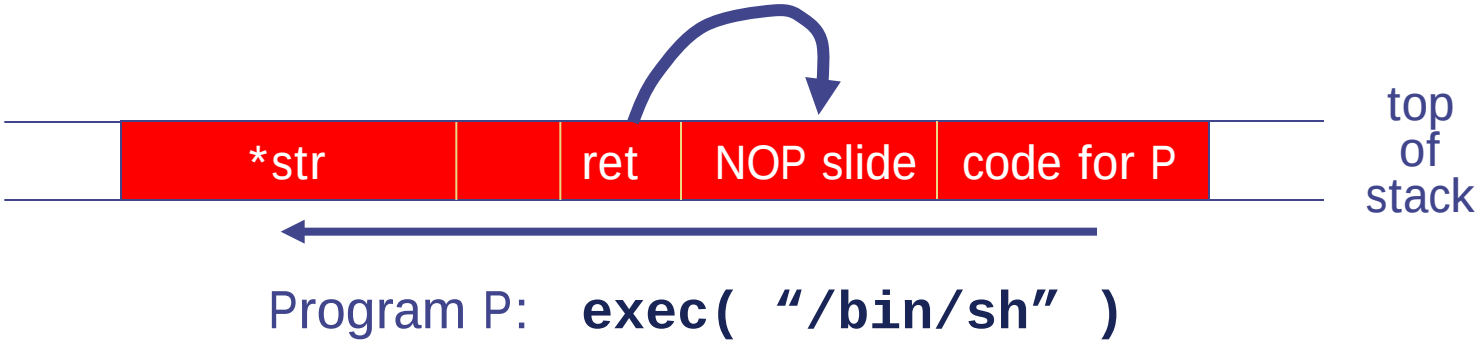
- When the function is invoked the stack looks like:



- 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:



- 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

Terminology

- Bug
  might be a
- Vulnerability
  for which someone will write an
- Exploit
  that hijacks control and runs
- Shellcode
  that typically installs a
- Rootkit
  that “0wn” the computer and hides the traces.

Many unsafe C lib functions

```
strcpy (char *dest,  const char *src)
strcat (char *dest, const char *src)
gets (char *s)
scanf ( const char *format, ... )
```

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- "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.

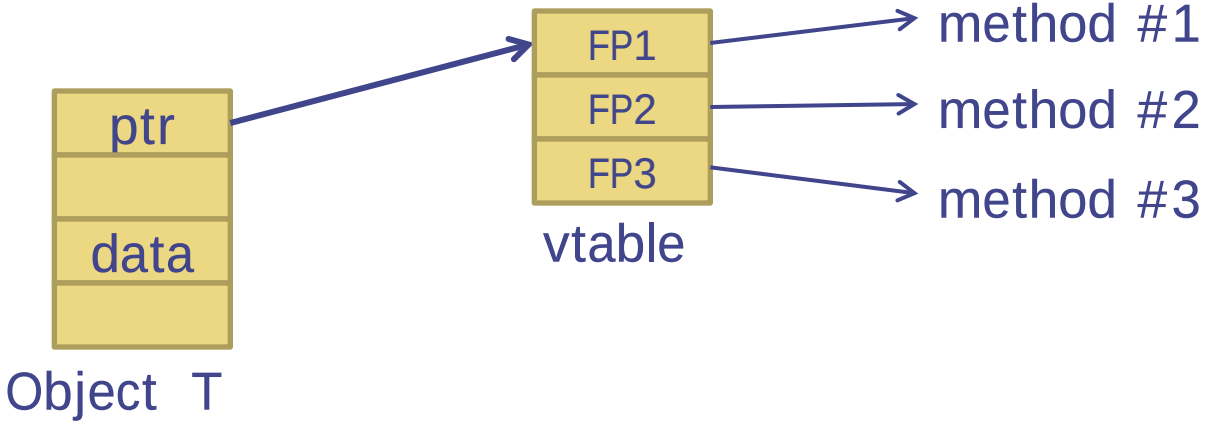
- Function pointers: (e.g. PHP 4.0.2, MS MediaPlayer Bitmaps)

  - Overflowing buf will override function pointer.

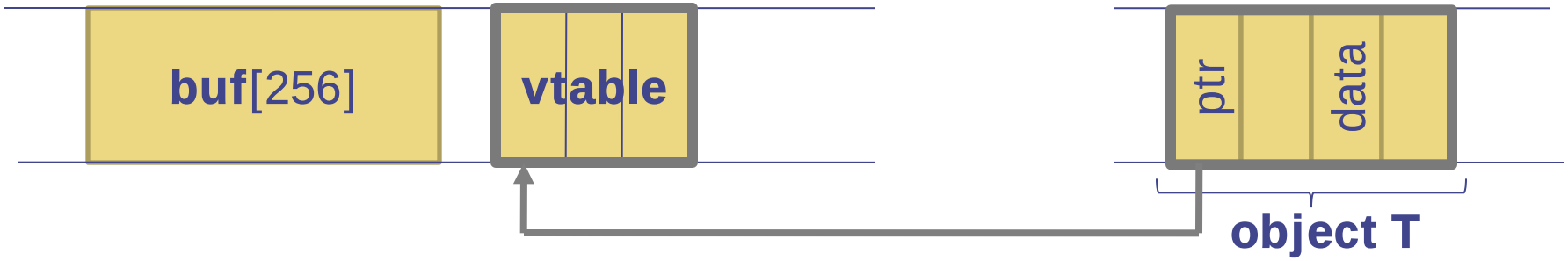
- Longjmp buffers: longjmp(pos) (e.g. Perl 5.003)
  - Overflowing buf next to pos overrides value of pos.

Heap-based control hijacking

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



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



Heap-based control hijacking

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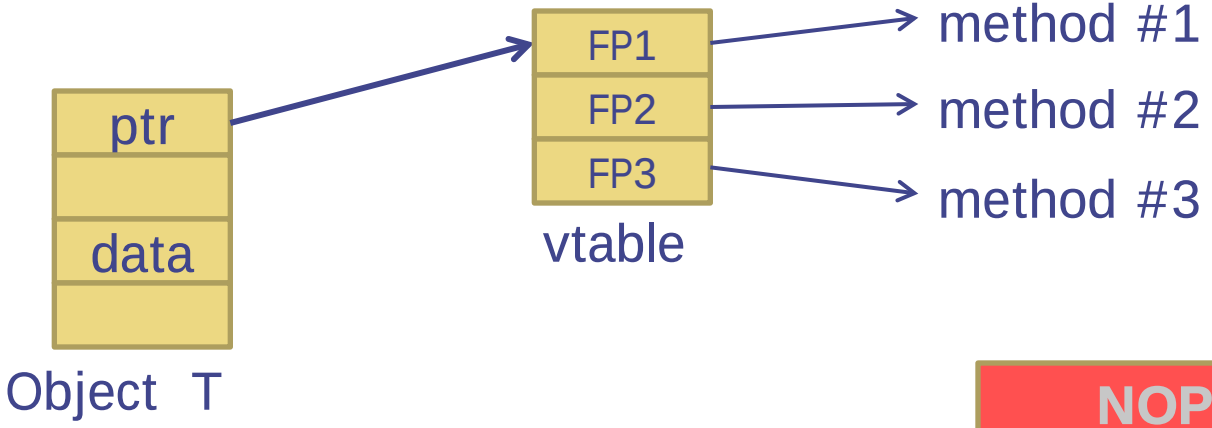
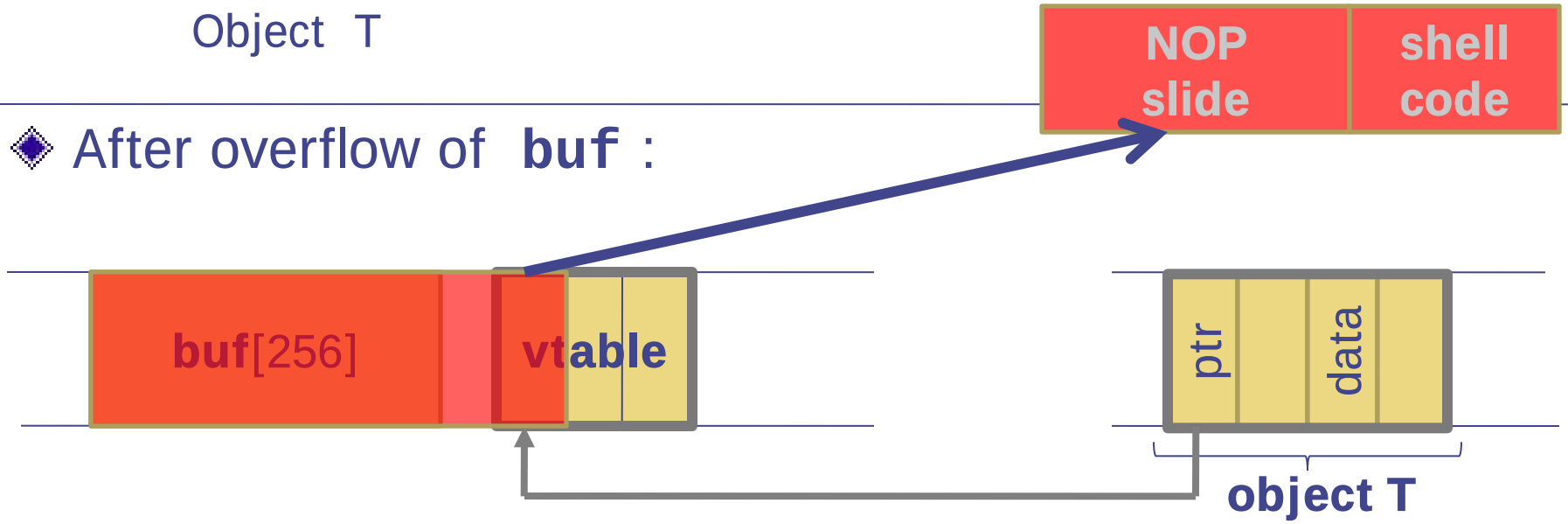


- After overflow of **`buf`** :



Other types of overflow attacks

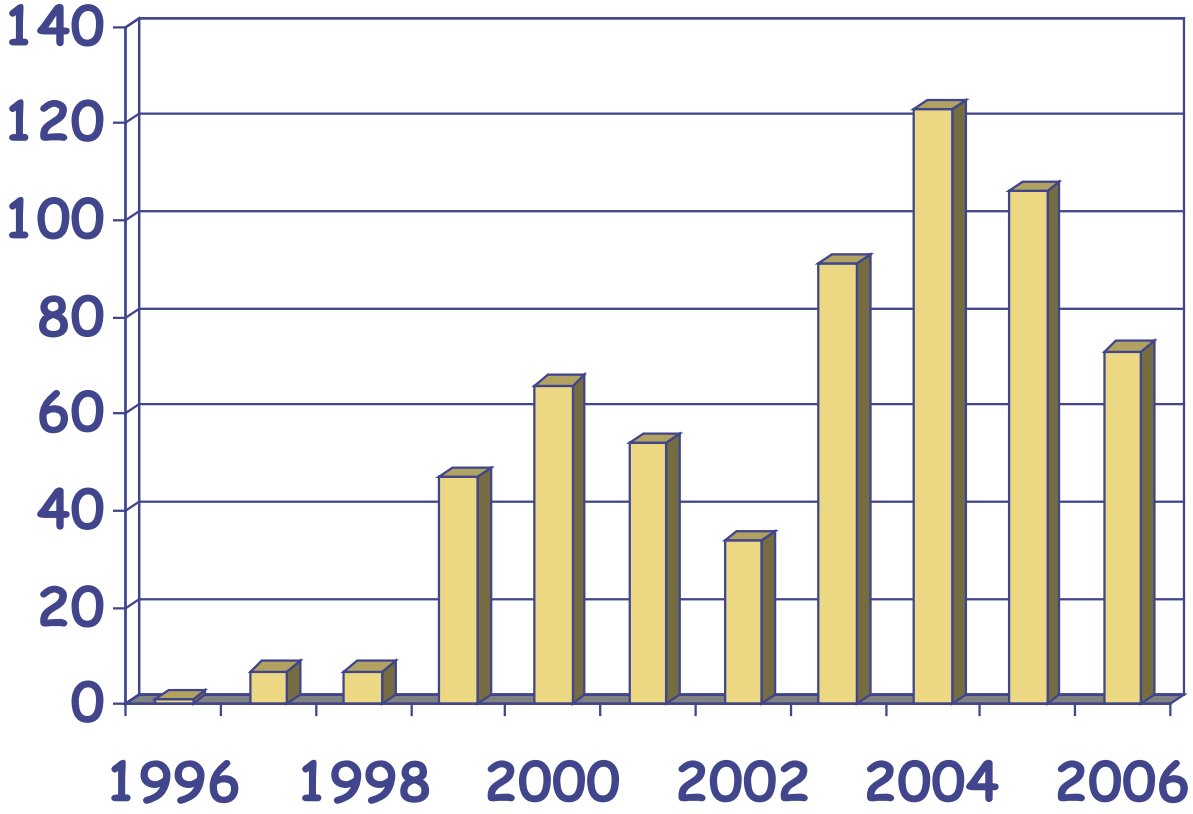
- Integer overflows: (e.g. MS DirectX MIDI Lib) Phrack60

```
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

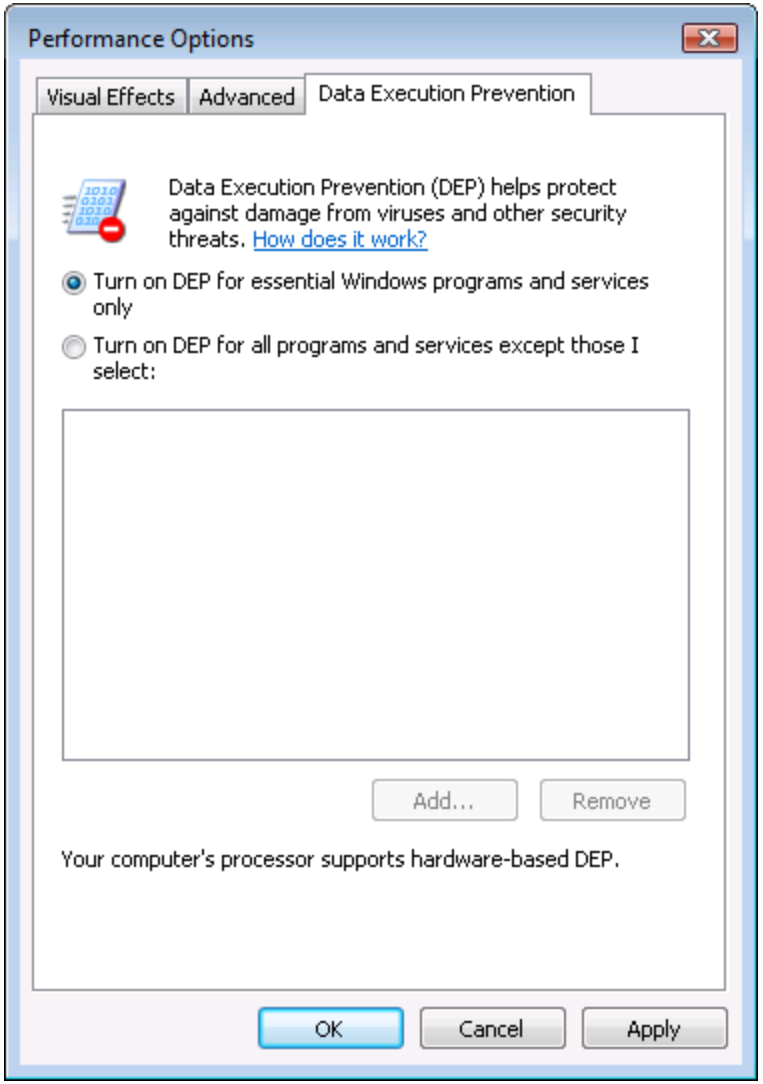
3. Add runtime code to detect overflows exploits
   - Halt process when overflow exploit detected
   - StackGuard, LibSafe, ...

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**
      - Visual Studio: **/NXCompat[:NO]**

- Limitations:
  - Some apps need executable heap (e.g. JITs).
  - Does not defend against `**return-to-libc**' exploit

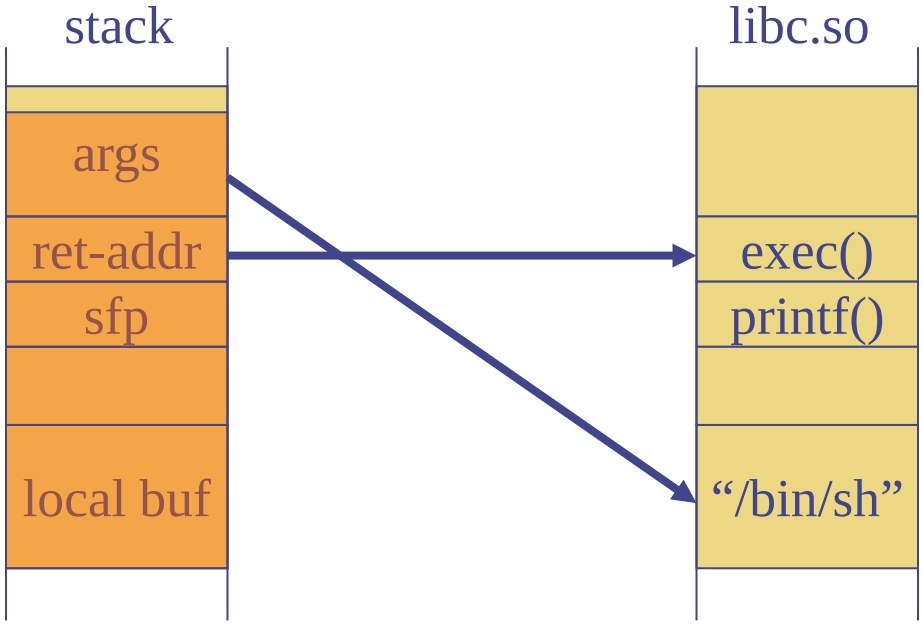
Examples: DEP controls in Windows



DEP terminating a program

Attack: return to libc

- Control hijacking without executing code



For shellcode like exce("/bin/sh"), don't worry about the stack frame pointer (`sfp`).
The x86 function exit sequence is:

```
mov %ebp,%esp
pop %ebp
ret
```

When the attacked functions returns, it will load a corrupted `sfp` value into `%ebp`, but `%esp` will be correctly restored to point to `ret-addr`, so the jump to libc will work. The libc functions read their arguments relative to this (uncorrupted) `%esp`. The corrupted `sfp` matters only if/when libc returns.

- Generalization: can generate arbitrary programs using "return oriented programming".

Response: randomization

- **ASLR**: (Address Space Layout Randomization)
  - Map shared libraries to rand location in process memory
    $\Rightarrow$ Attacker cannot jump directly to exec function
  - Deployment: (/DynamicBase)
    - Windows Vista: 8 bits of randomness for DLLs
      - aligned to 64K page in a 16MB region $\Rightarrow$ 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)
  - Reversed stack direction

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

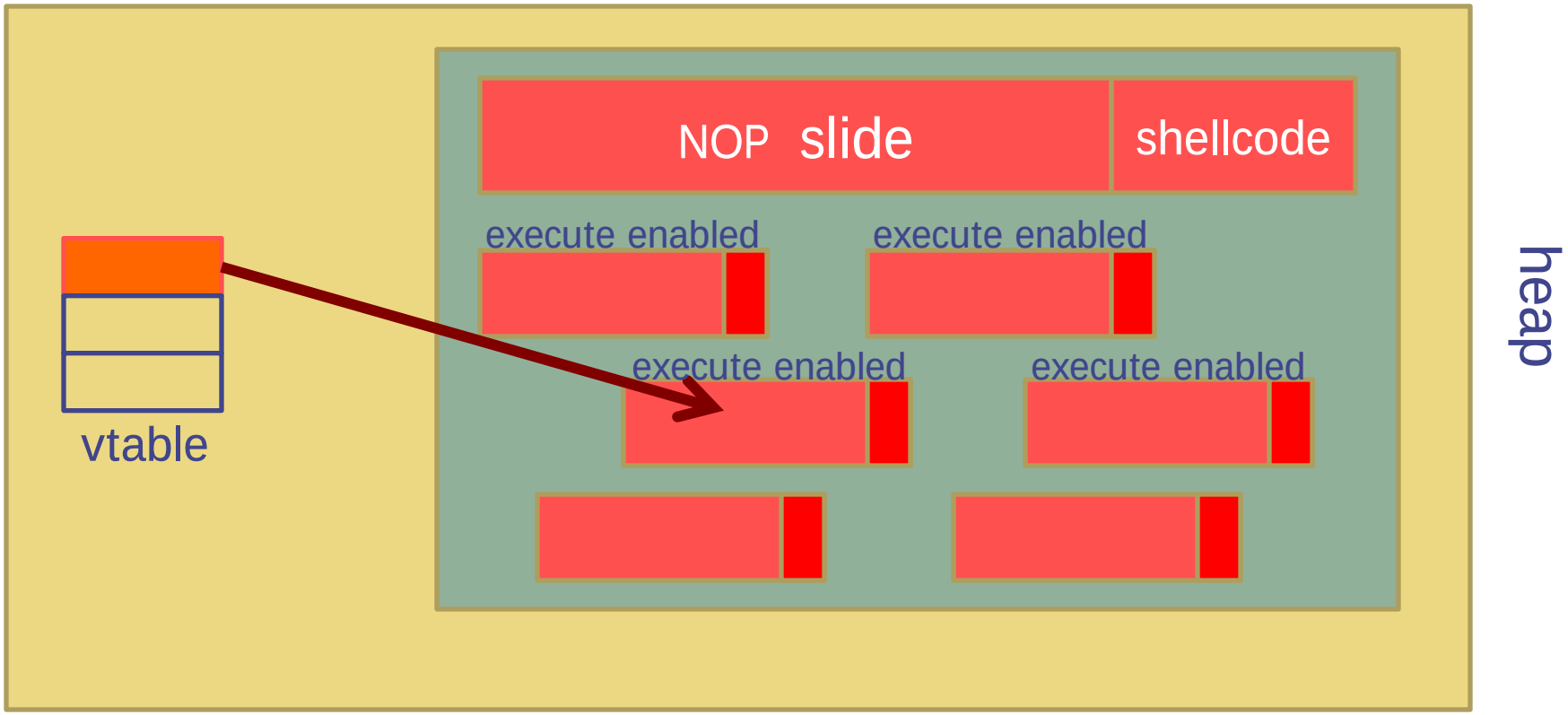
ntlanman.dll	0x6DA90000	Microsoft® Lan Manager
ntmarta.dll	0x75660000	Windows NT MARTA provider
ntshrui.dll	0x6D9D0000	Shell extensions for sharing
ole32.dll	0x763C0000	Microsoft OLE for Windows

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

Attack: JiT spraying

Idea: 1. Force Javascript JiT to fill heap with executable shellcode

2. then point SFP anywhere in spray area

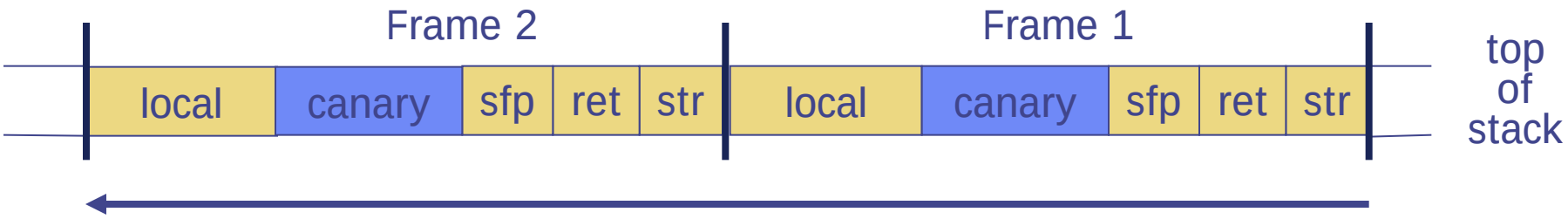


Run time checking

Run time checking: StackGuard

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

- Solution 1: 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

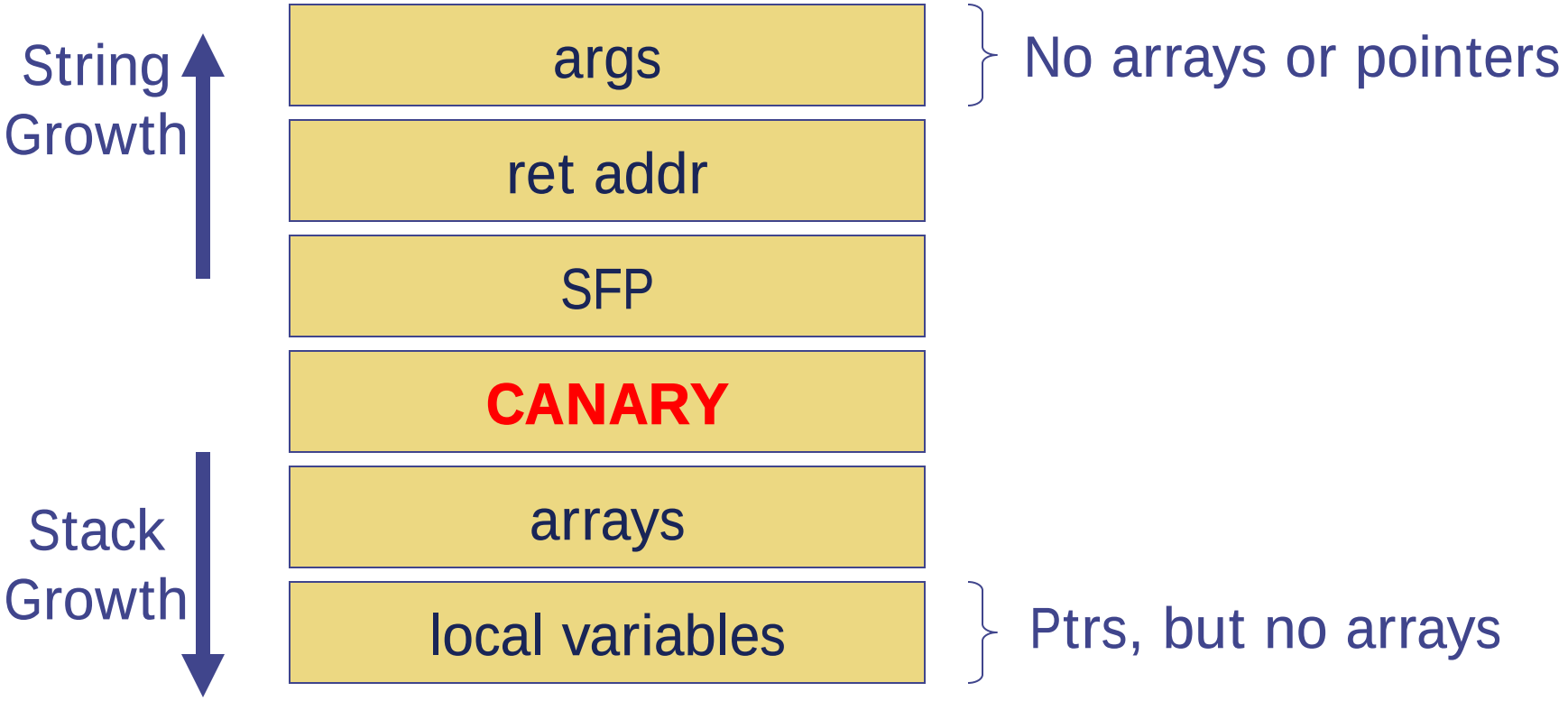
  - String functions will not copy beyond terminator.
  - Attacker cannot use string functions to corrupt stack.

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
  - Less effective, 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
  - /SafeSEH: only call pre-designated exception handler

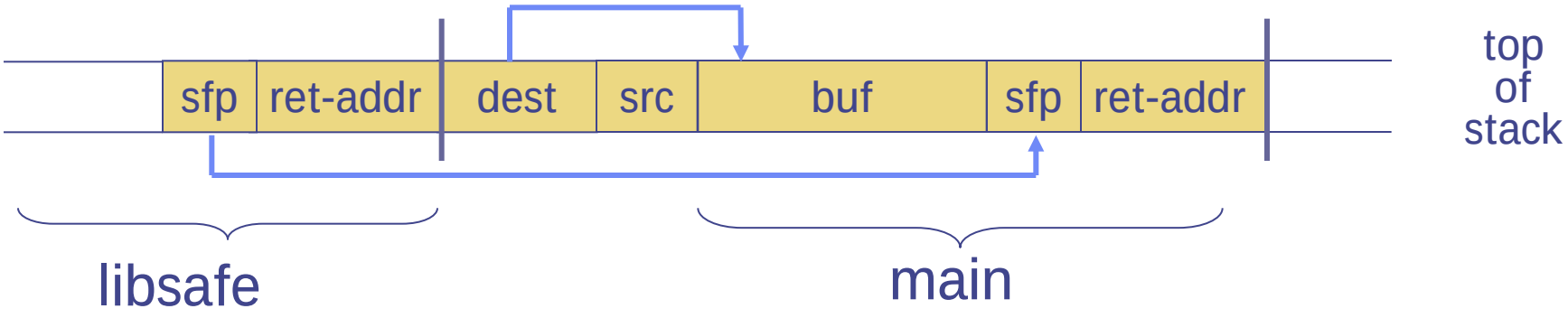
Run time checking: Libsafe

- 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( 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:

```
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

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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.