Internet Security [1]

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News from the Lab

- Challenge 5
  - 33 out of 41 solutions working so far
  - mistake in the original challenge description
    - plaintext contains lowercase and uppercase ASCII *as well as hyphen characters*
- Challenge 6
  - issued this week (probably on 9th June)
  - perform stack buffer overflow

Buffer Overflows

Buffer Overflows

- Result from mistakes done while writing code
  - coding flaws because of
    - unfamiliarity with language
    - ignorance about security issues
    - unwillingness to take extra effort

- Often related to particular programming language

- Buffer overflows
  - mostly relevant for C / C++ programs
  - not in languages with automatic memory management
  - these use
    - dynamic bounds checks (e.g., Java)
    - automatic resizing of buffers (e.g., Perl)

Buffer Overflows

- Goal
  - change flow of control (flow of execution), and
  - execute arbitrary code

- Requirements
  1. inject attack code or attack parameters
  2. abuse vulnerability and modify memory such that control flow is redirected

- Change of control flow
  - alter a code pointer (i.e., value that influences program counter)
  - change memory region that should not be accessed

Buffer Overflows

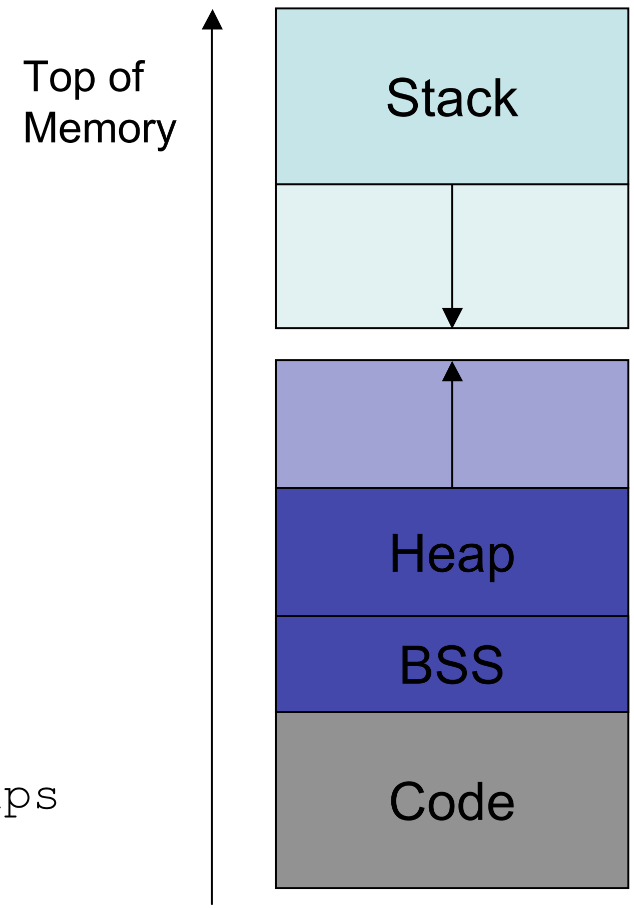
- One of the most used attack techniques

- Advantages
  - very effective
    - attack code runs with privileges of exploited process
  - can be exploited locally and remotely
    - interesting for network services

- Disadvantages
  - architecture dependent
    - directly inject assembler code
  - operating system dependent
    - use call system functions
  - some guess work involved (correct addresses)

Buffer Overflows

- Process memory regions
  - Stack segment
    - local variables
    - procedure calls
  - Data segment
    - global (static) variables (bss)
    - dynamic variables (heap)
  - Code (Text) segment
    - program instructions
    - usually read-only
- Display with `cat /proc/<pid>/maps`



Buffer Overflows

- Overflow memory region on the stack
  - overflow function return address
    - Phrack 49 -- Aleph One: Smashing the Stack for Fun and Profit
    - Phrack 58 -- Nergel: The advanced return-into-lib(c) exploits
  - overflow function frame (base) pointer
    - Phrack 55 -- klog: The Frame Pointer Overflow
  - overflow longjump buffer
- Overflow (dynamically allocated) memory region on the heap
  - Phrack 57 -- MaXX: Vudo malloc tricks
    -- anonymous: Once upon a free() ...
- Overflow function pointers
  - stack, heap, BSS (e.g., PLT)

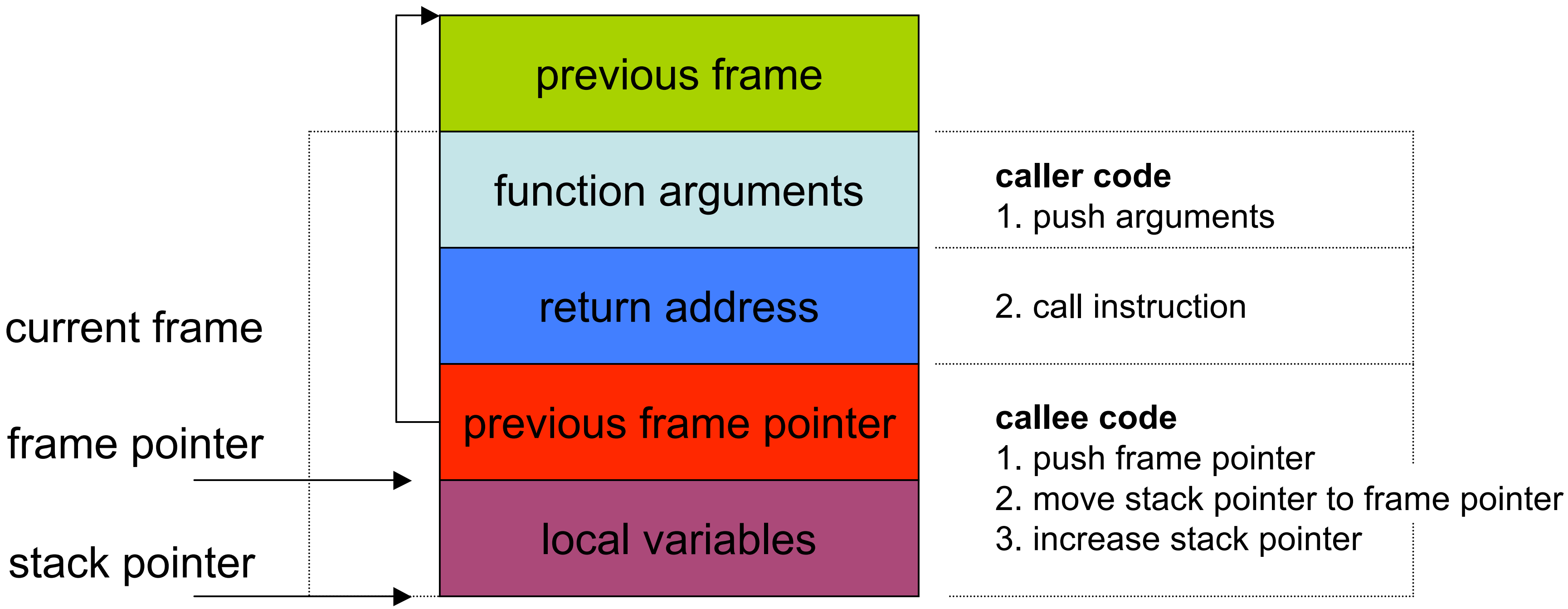
Stack

- Usually grows towards smaller memory addresses
  - Intel, Motorola, SPARC, MIPS

- Processor register points to top of stack
  - `stack pointer – SP`
  - points to <u>last stack element</u> or first free slot

- Composed of frames
  - pushed on top of stack as consequence of function calls
  - address of current frame stored in processor register
    - `frame/base pointer – FP`
  - used to conveniently reference local variables

Stack


previous frame
function arguments
return address
previous frame pointer
local variables
current frame
frame pointer
stack pointer
caller code
1. push arguments
2. call instruction
callee code
1. push frame pointer
2. move stack pointer to frame pointer
3. increase stack pointer

Buffer Overflow

- Code (or parameters) get injected because
  - program accepts more input than there is space allocated

- In particular, an array (or buffer) has not enough space
  - especially easy with C strings (character arrays)
  - plenty of vulnerable library functions

    `strcpy, strcat, gets, fgets, sprintf ..`

- Input spills to adjacent regions and modifies
  - code pointer or application data
    - all the possibilities that we have enumerated before
  - normally, this just crashes the program (e.g., `sigsegv`)

Buffer Overflow

- Simple buffer overflow
  1. create executable content, and
  2. set code pointer to point to this content

- Effect
  - causes a jump to code under our control
  - successfully modifies execution flow
  - have this code executed with privileges of running process

  - difficult to generate correct “payload“
  - different variations for different platforms, and
    - assembly instructions, alignment
  - different operating systems
    - system calls

Buffer Overflow

- Advanced buffer overflow
  1. set up function parameters, and
  2. set code pointer to point to existing code

- Effect
  - causes a jump to existing code with chosen arguments
  - also successfully modifies execution flow, but
  - cannot execute arbitrary code

- Alternative name
  - return-into-libc exploits

Buffer Overflow

- Executable content (called shell code)
  - usually, a shell should be started
    - for remote exploits - input/output redirection via socket
  - use system call (`execve`) to spawn shell

- System calls
  - mechanism to ask operating system for services
  - transition from user mode to kernel mode
  - different implementations

- Linux system calls
  - invoked by
    - passing arguments in registers (or on the stack) and
    - calling `0x80` interrupt

Shell Code

```
void main(int argc, char **argv) {
     char *name[2];
     name[0] = "/bin/sh";
     name[1] = NULL;

   execve(name[0], &name[0], &name[1]);
   exit(0);
}

int execve(char *file, char *argv[], char *env[])
```

- `file` is name of program to be executed
  `"/bin/sh"`
- `argv` is address of null-terminated argument array
  `"/bin/sh", NULL`
- `env` is address of null-terminated environment array
  `NULL`

Shell Code

- `file` parameter
  - we need the null terminated string `/bin/sh` somewhere in memory
- `argv` parameter
  - we need the address of the string `/bin/sh` somewhere in memory,
  - followed by a NULL word
- `env` parameter
  - we need a NULL word somewhere in memory
  - we will reuse the null pointer at the end of argv

Shell Code

- `execve` arguments

located at address `addr`

`/bin/sh0addr0000`

`env` -- pointer to null-word

`arg` -- pointer to address of null-terminated string

`file` -- null-terminated string

Shell Code

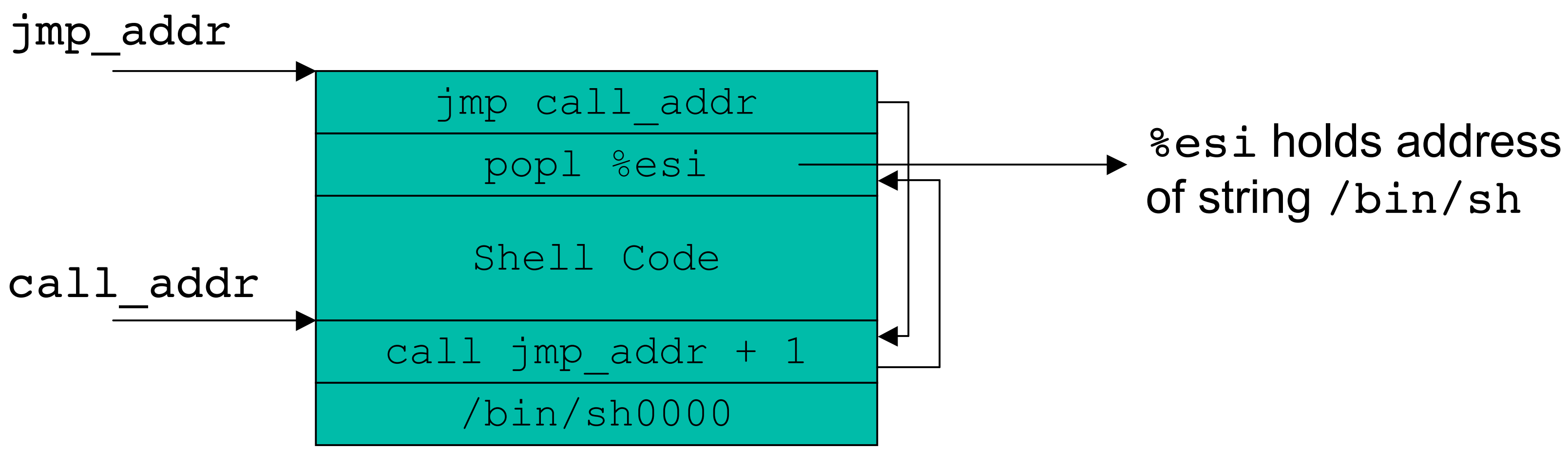
- Spawning the shell in assembly

    1. move system call number (0x0b) into `%eax`
    2. move address of string `/bin/sh` into `%ebx`
    3. move address of the address of `/bin/sh` into `%ecx` (using `lea`)
    4. move address of null word into `%edx`
    5. execute the interrupt 0x80 instruction

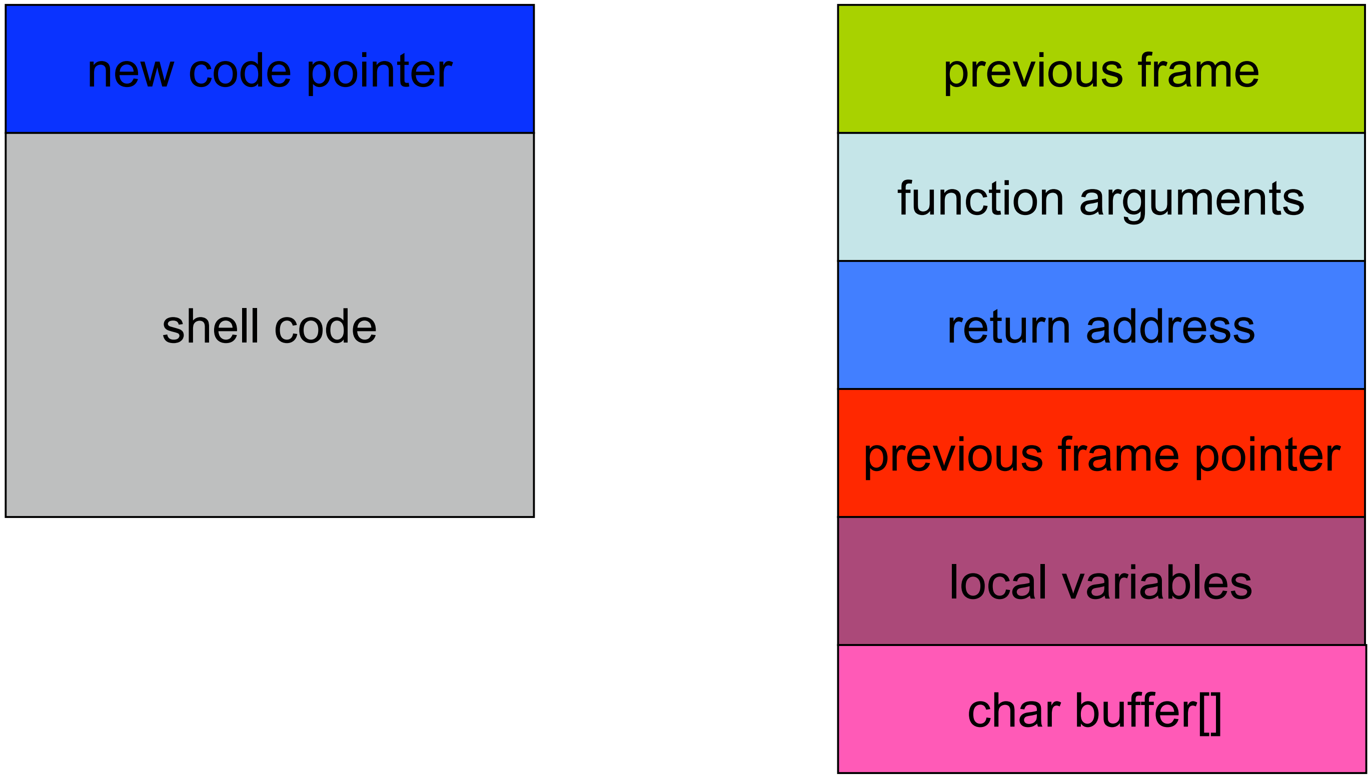
Shell Code

- Problem – position of code in memory is unknown
  - how to determine *address of string*
- We can make use of instructions using relative addressing
- `call` instruction saves IP on the stack and jumps
- Idea
  - `jmp` instruction at beginning of shell code to `call` instruction
  - `call` instruction right before `/bin/sh` string
  - `call` jumps back to first instruction after jump
  - now address of `/bin/sh` is on the stack

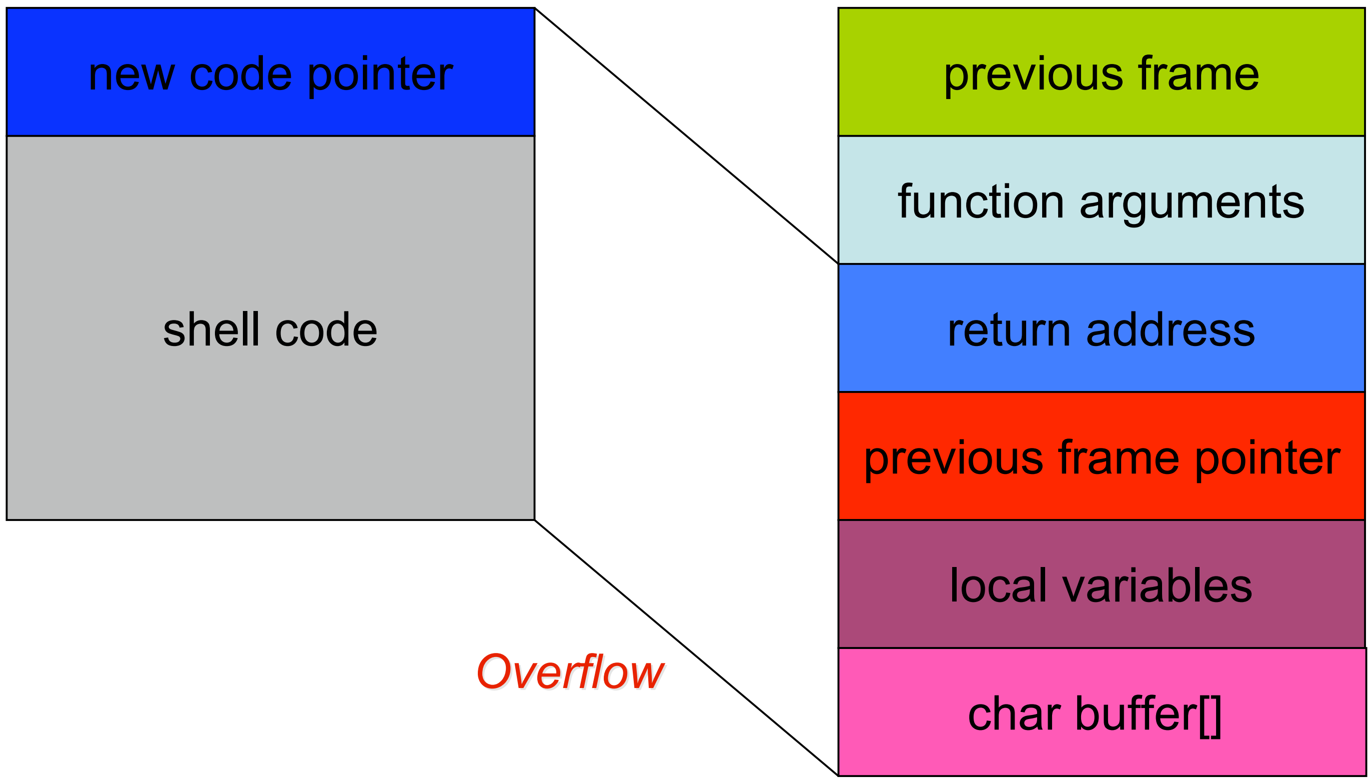
Shell Code


jmp_addr
call_addr
jmp call_addr
popl %esi
Shell Code
call jmp_addr + 1
/bin/sh0000
%esi holds address
of string /bin/sh

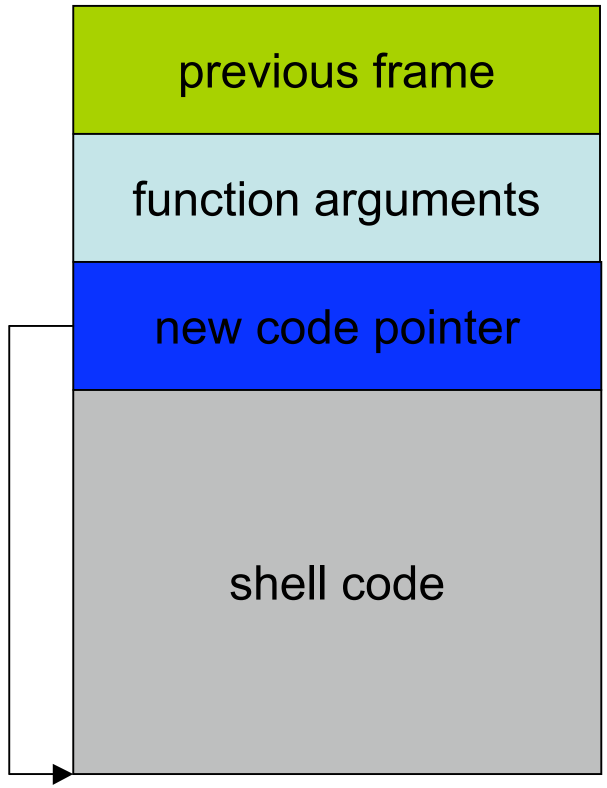
Pulling It All Together



Pulling It All Together



Pulling It All Together



Shell Code

- Shell code is usually copied into a string buffer

- Problem
  - any null byte would stop copying

  → null bytes must be eliminated

➢ **Substitution**

```
mov 0x0, reg     → xor reg, reg
mov 0x1, reg     → xor reg, reg
                   inc reg

e.g. movl 0x0, %eax  → xor %eax, %eax
```

Shell Code

- Concept of user identifiers (uids)
  - real user id
    - ID of process owner
  - effective user id
    - ID used for permission checks
  - saved user id
    - used to temporarily drop and restore privileges
- Problem
  - exploited program could have temporarily dropped privileges

➢ Shellcode has to enable privileges again (using `setuid`)

- *Setuid Demystified*: Hao Chen, David Wagner, and Drew Dean

Code Pointer

- Code pointer
  - e.g., return address in stack frame
  - must be overwritten with correct value
  - start of exploit code (`jmp`)
  - it has to be guessed (must be very precise)

- Hints
  - stack starts at same address for every programm
  - can be obtained by function

```
unsigned long get_sp(void) {
 __asm__("movl %esp, %eax");
}
```

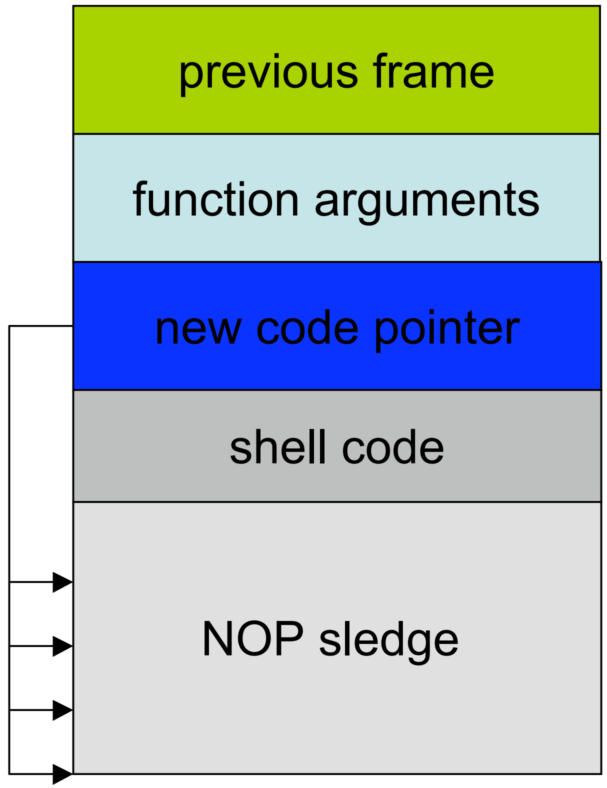
Code Pointer

- NOP (no operation) sledge
  - series of NOP (`0x90`) (no operation) instructions at the beginning of exploit code
  - return address must not be as precise anymore
  - it is enough to hit the NOP sledge

  - can also be obfuscated via instruction substitution to make detection more difficult (e.g., `ADMmutate`)

Code Pointer

any return address into the
NOP sledge succeeds



Small Buffers

- Buffer can be too small to hold exploit code
- Store exploit code in environmental variable
  - environment stored on stack
  - return address has to be redirected to environment variable

- Advantage
  - exploit code can be arbitrary long
- Disadvantage
  - access to environment needed

`setjmp()` and `longjmp()`

- Used in C / C++
- Non-local / inter-procedural ”goto”
- Example usage
  - Error handling
  - User-space threading

setjmp() and longjmp()

```
int main() {
  jmp_buf env;
  int i;

  if (setjmp(env) != 0) {
    printf(”i = %d\n", i);
    exit(0);
  }
  else {
    printf(”i = %d\n", i);
    f1(env);
  }

  return 0;
}
```

```
void f2(jmp_buf e) {
  if (check == error) {
    longjmp(e, ERROR2);
    /* unreachable */
  }
  else
    return;
}

void f1(jmp_buf e) {
  if (check == error) {
    longjmp(e, ERROR1);
    /* unreachable */
  }
  else
    f2(e);
}
```

Buffer Overflow

- Vulnerable buffer can be located
  - on the stack
  - on the heap
  - in static data areas

- Redirect execution flow by modifying
  - stack frames
  - longjump buffers
  - function pointers

➢ what can be done when overflowing a buffer on the heap?

Heap Buffer Overflow

- Overflowing dynamically allocated memory

- Dynamically allocated memory
  - managed by a heap manager

- Heap manager
  - handles memory requested by user programs during run-time
  - sbrk() system call is very simple
  - library between user program and `sbrk()` system call
  - standardized `malloc` interface
  - different implementations for different operating systems

Heap Management

- Implementations

Algorithm	Operating System
Doug Lea's `dlmalloc`	GNU LibC (Linux)
System V (AT&T)	Solaris, IRIX
BSD phk, BSD kingsley	*BSD, AIX
RtlHeap	Microsoft Windows

- `dlmalloc`
  - keeps tags around allocated memory for book-keeping
  - overflow may modify these tags
  - functions `malloc`, `realloc`, `free`, `calloc` might be tricked into executing arbitrary code

Conclusion

- Buffer overflows
  - implementation flaw
  - occur when an application receives more input than there is space allocated for this input
- Exploit steps
  - inject shell code or parameters
    - practical issues
      - locate shell code in memory, NULL bytes, NOP sledge
  - change code pointer
- Code pointer
  - various possibilities to change
    - return address, frame pointer, jump buffer, function pointer