Lecture 08 – Format string vulnerabilities

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Goal

- Take control of the program (as usual)
- How?
  - Write4 (write 4 bytes to an arbitrary location)
  - Inject shellcode (or other exploits) into the process

What should we overwrite?

- Saved instruction pointer/return address (seip) on the stack
- Other pointers to code (we’ll come back to this)

printf operation

- printf takes a format string and arguments
- printf copies the format string to its output, replacing conversion specifiers with values determined by the arguments
- Arguments are (normally) accessed one at a time, in turn
- Internally, printf keeps a pointer to the next argument to be converted by a conversion specifier
- Example: `printf("value = %d %c”, 42, 'm');`
  prints: `value = 42 m`

Common conversion specifiers

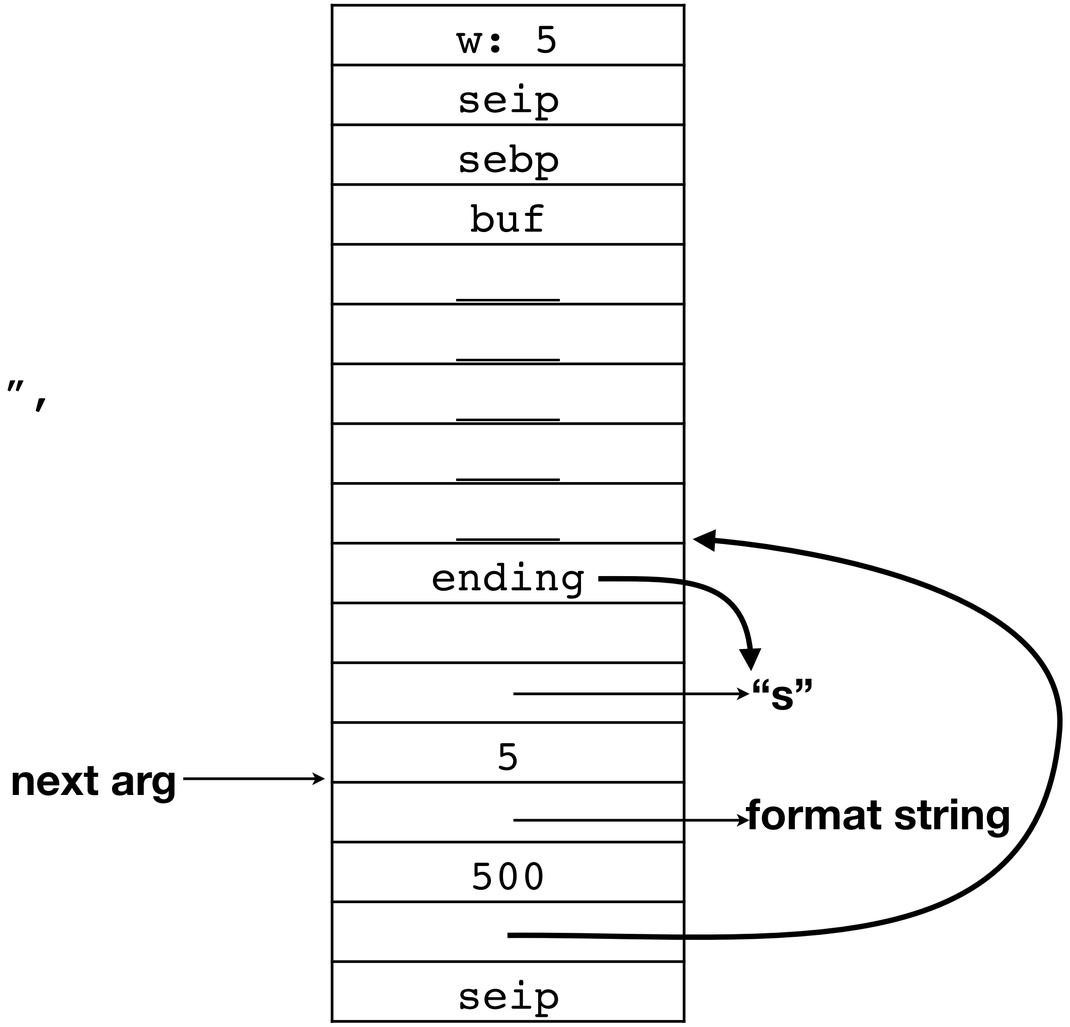
`%c`	Character	`%s`	String
`%d, %i`	Integer	`%p`	Pointer
`%u`	Unsigned integer	`%%`	Literal %
`%x, %X`	Hex	`%n`	Stores number of characters written
`%e, %f,`	Double		

printf family

- printf
- fprintf
- sprintf
- snprintf
- asprintf
- dprintf
- vprintf
- vfprintf
- vsprintf
- vsnprintf
- vasprintf
- vdprintf

The way snprintf() normally works

```
void foo(int w) {
  char buf[500];
  const char *ending = w==1? “”:”s”;
  snprintf(buf, 500, “Hello %d world%s”,
         w, ending);
}
…
foo(5);
```



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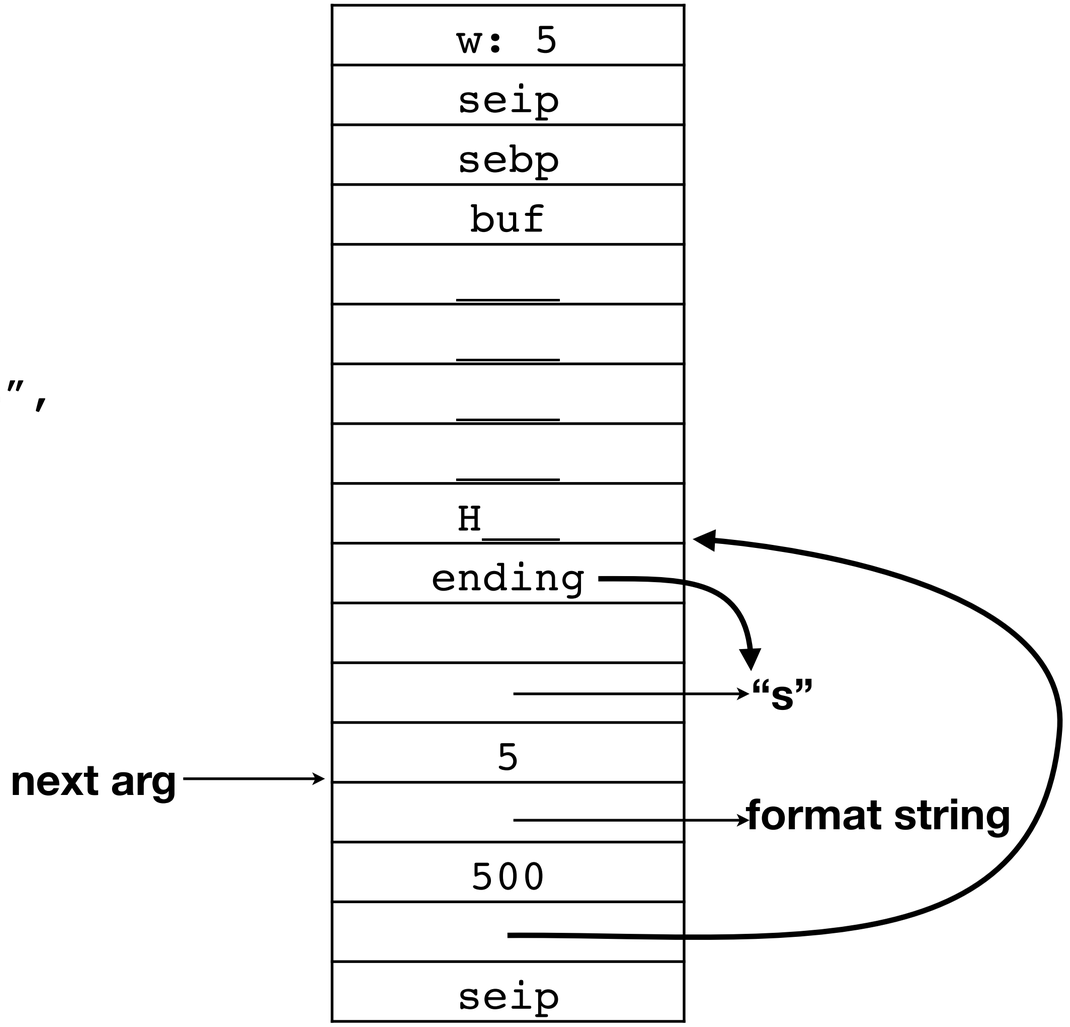

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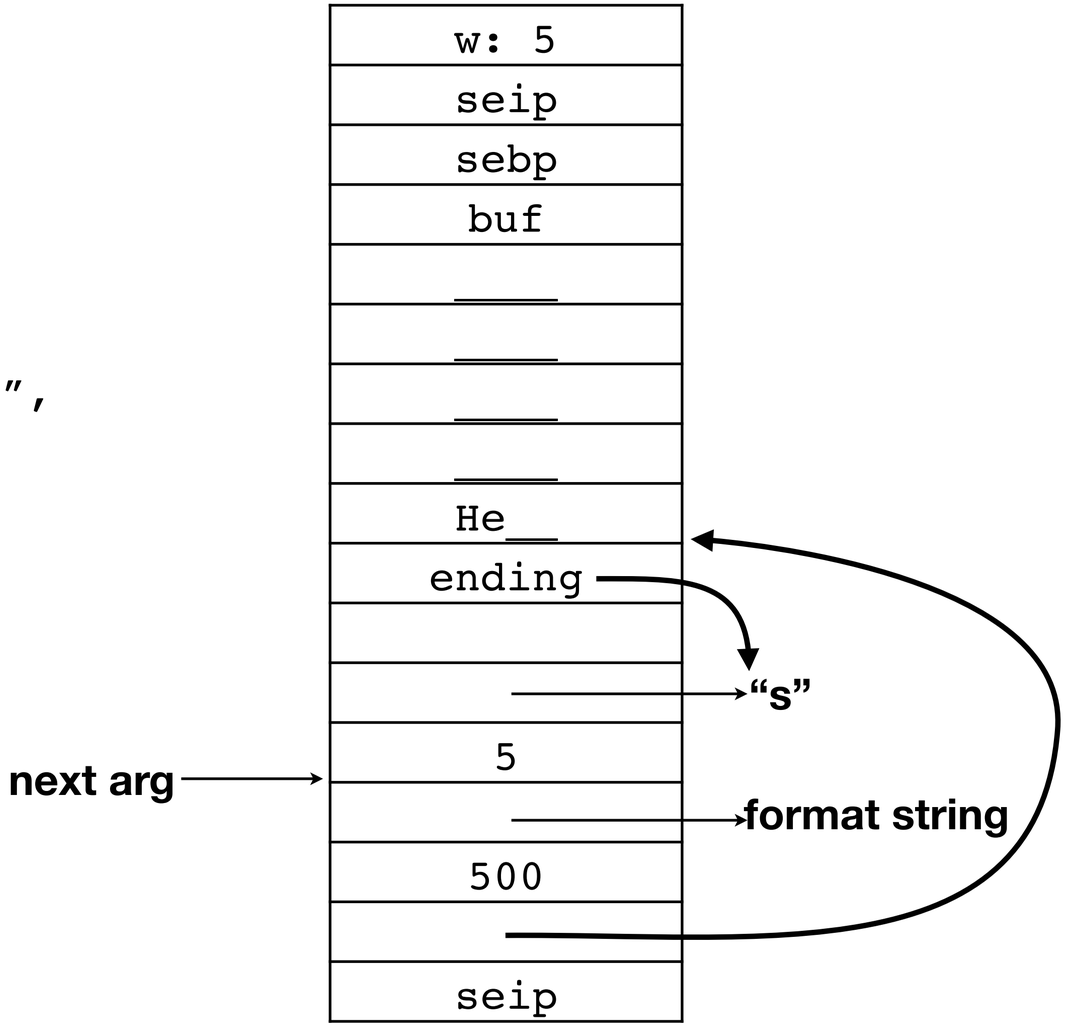

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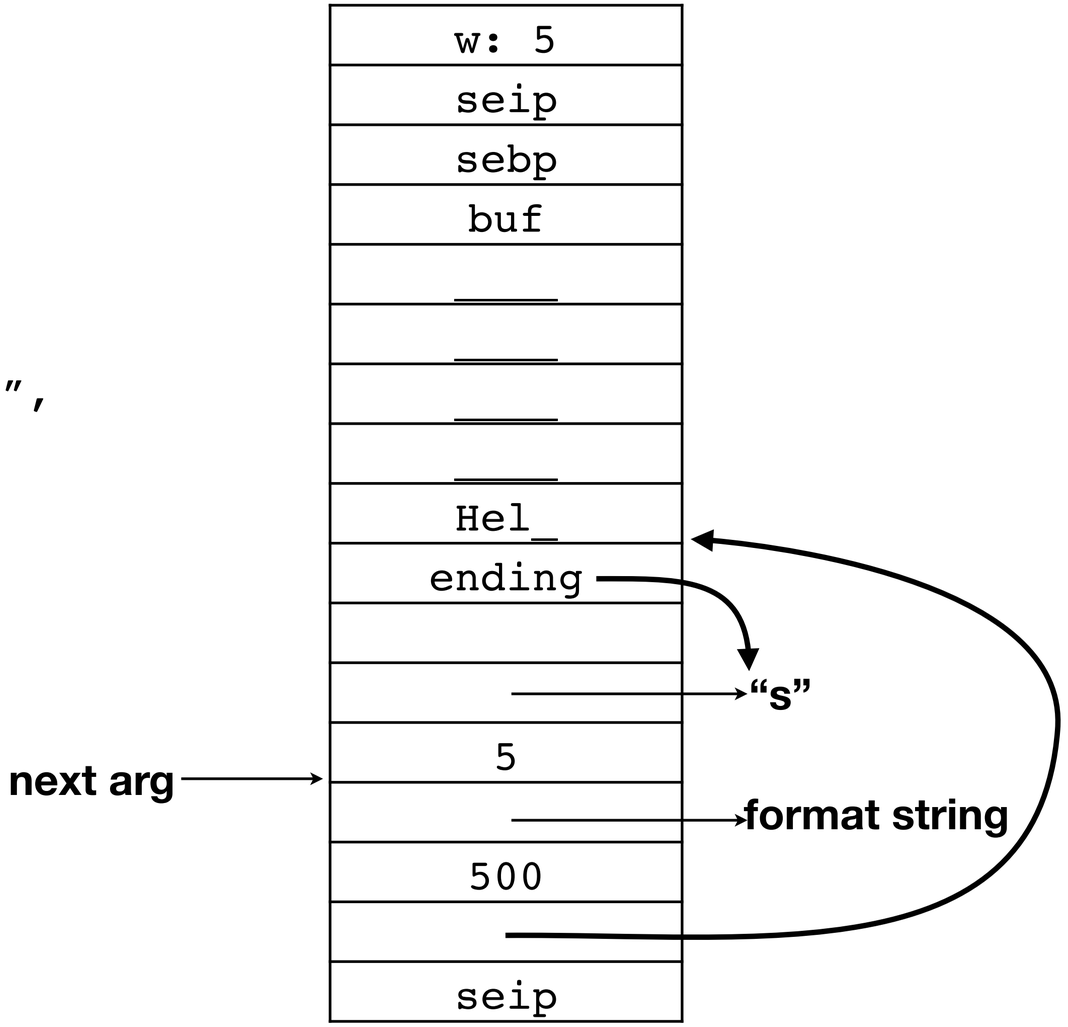

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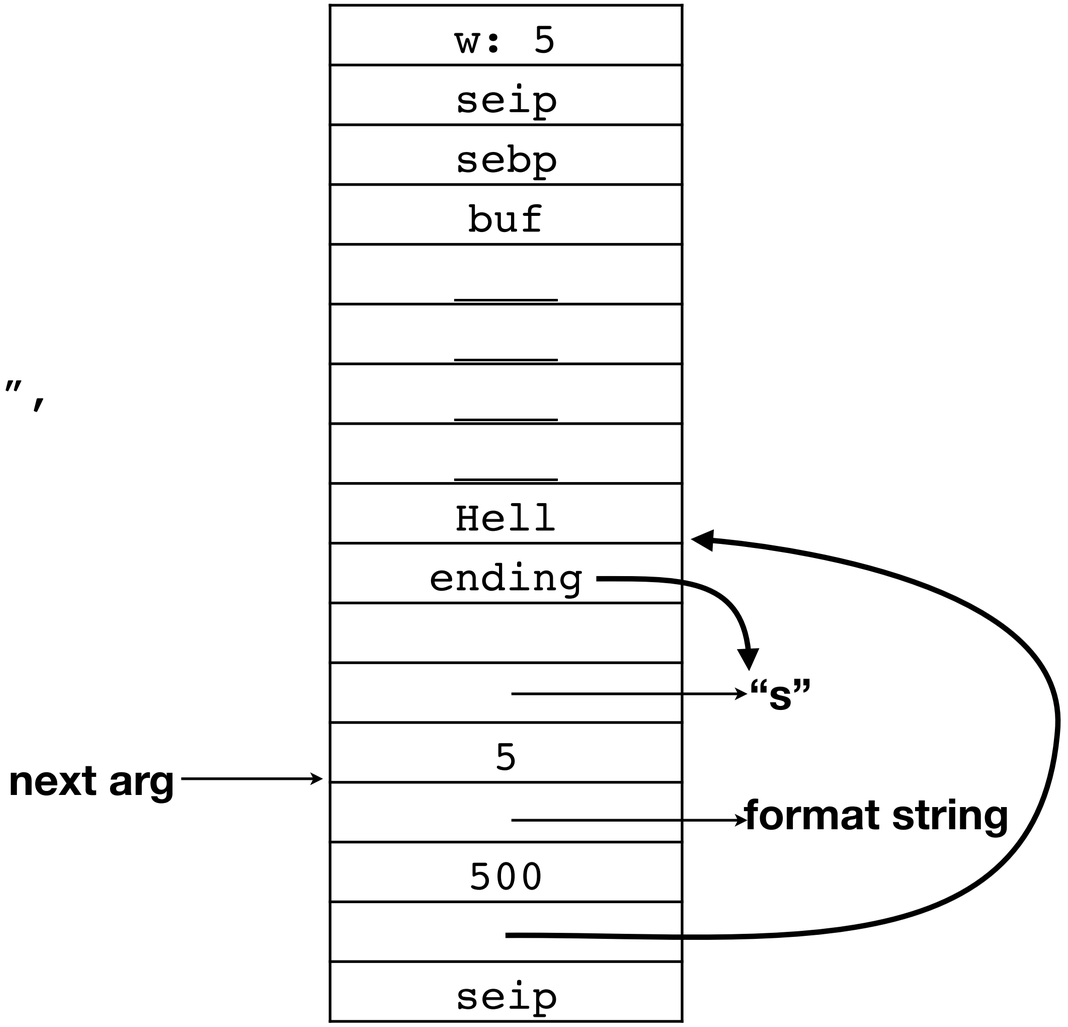

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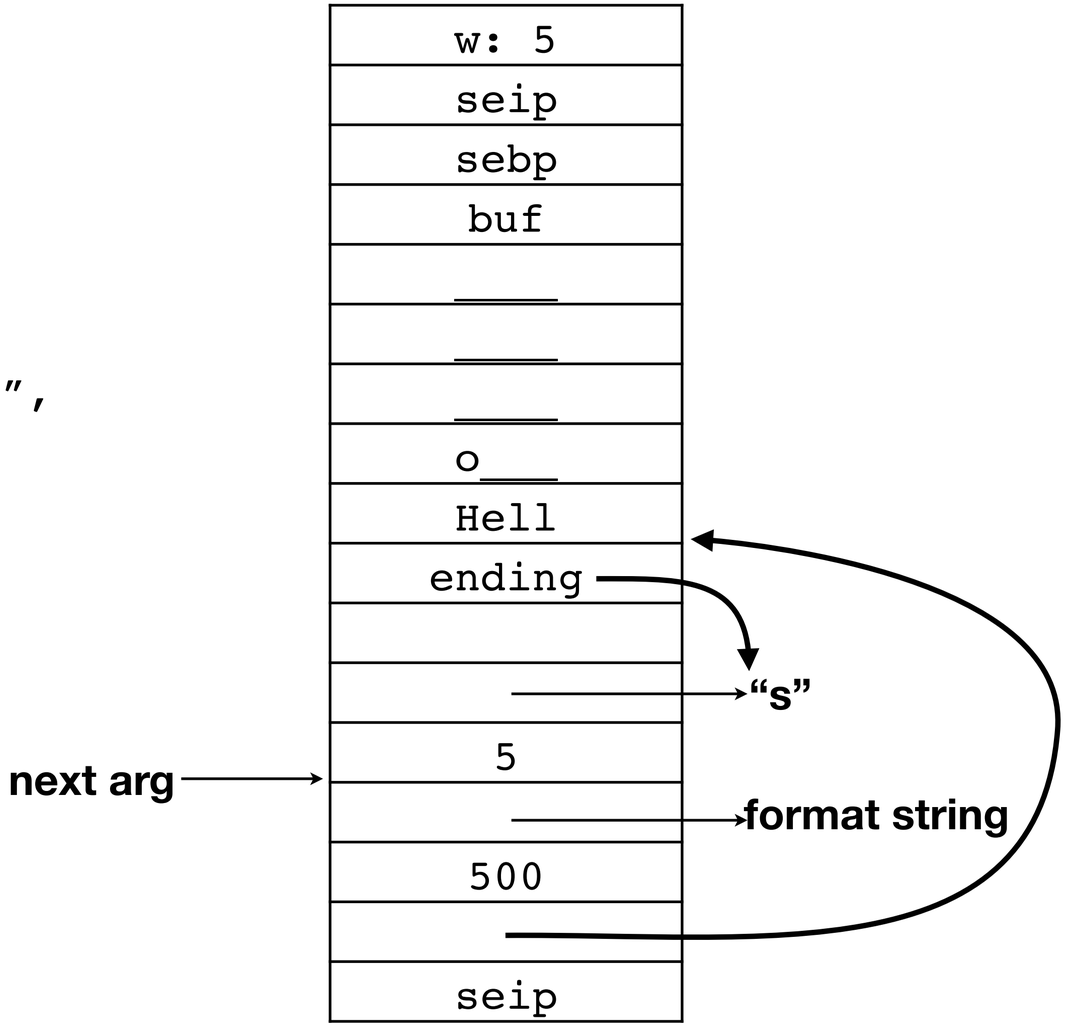

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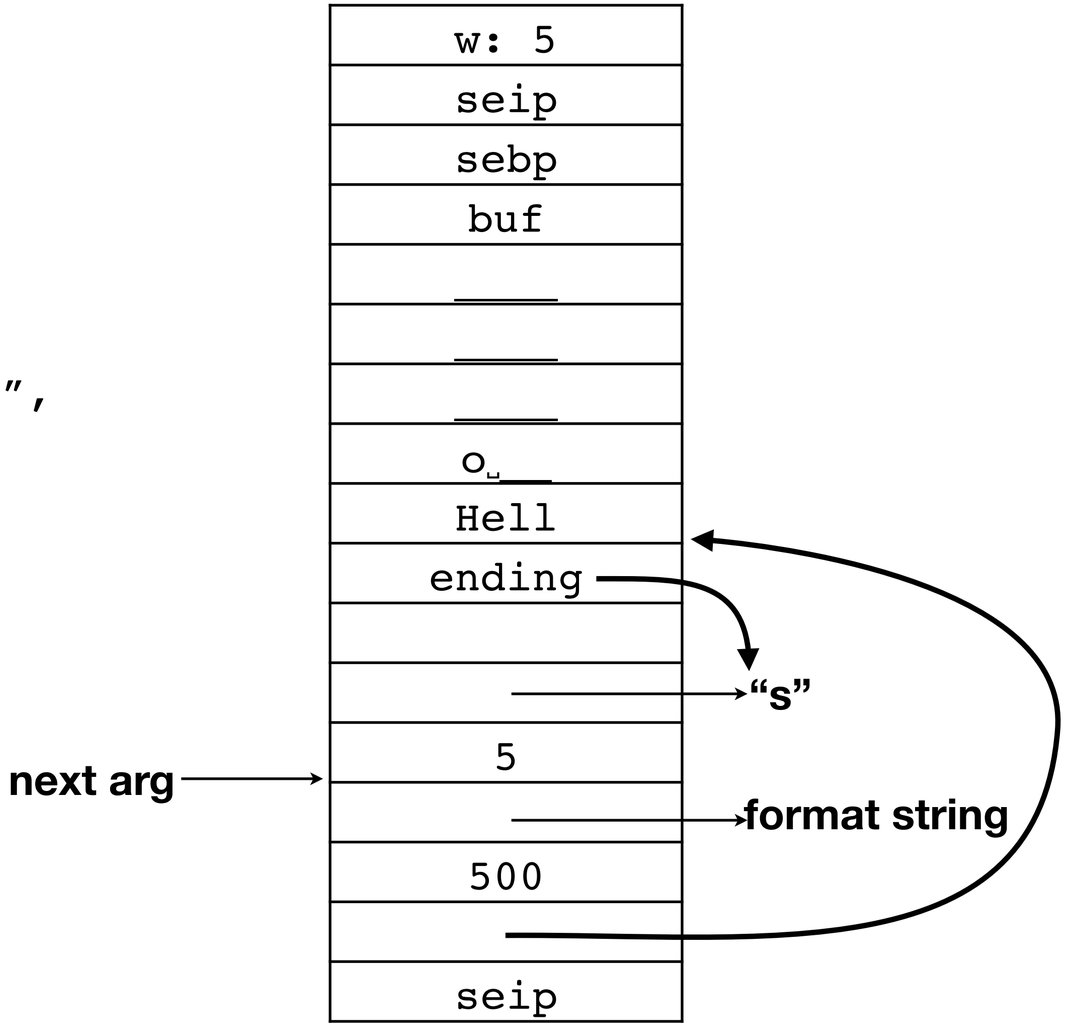

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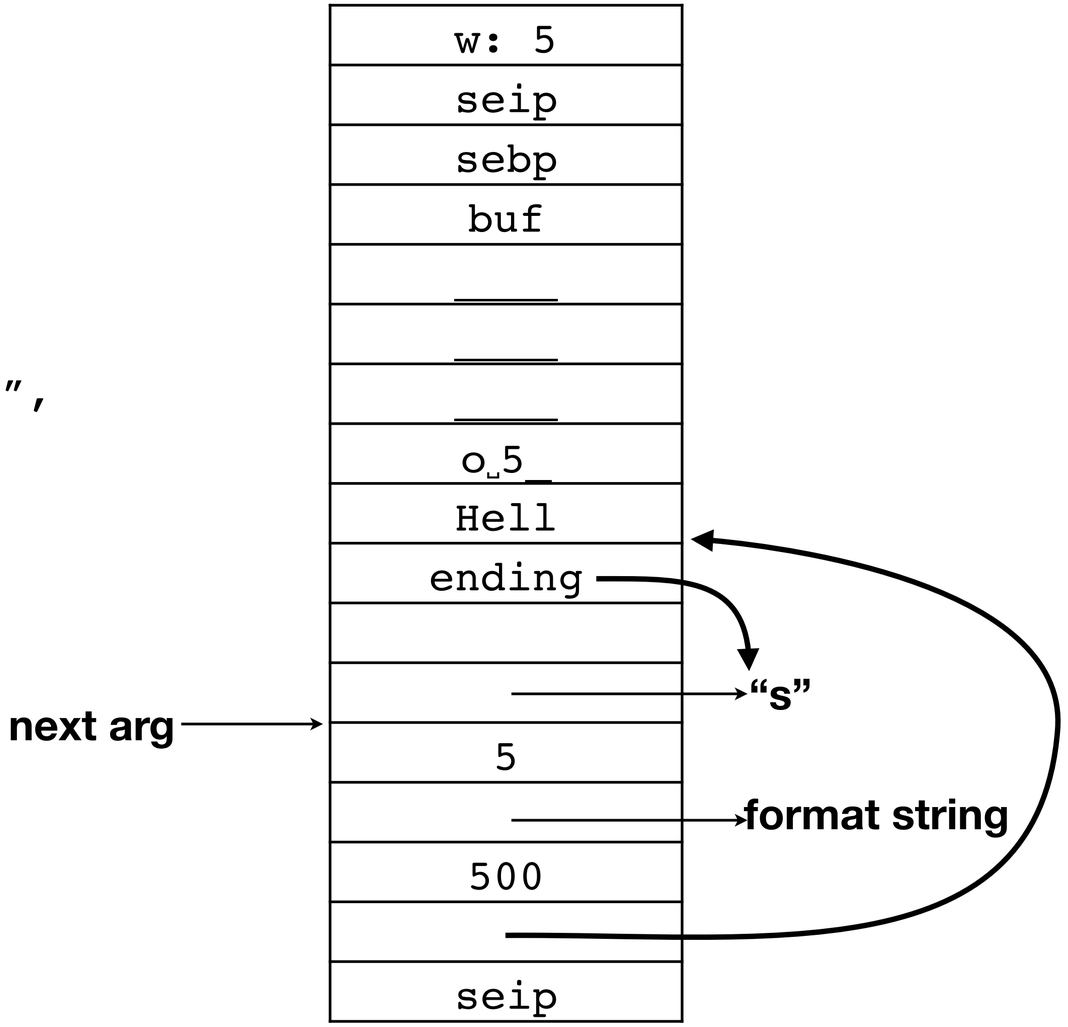

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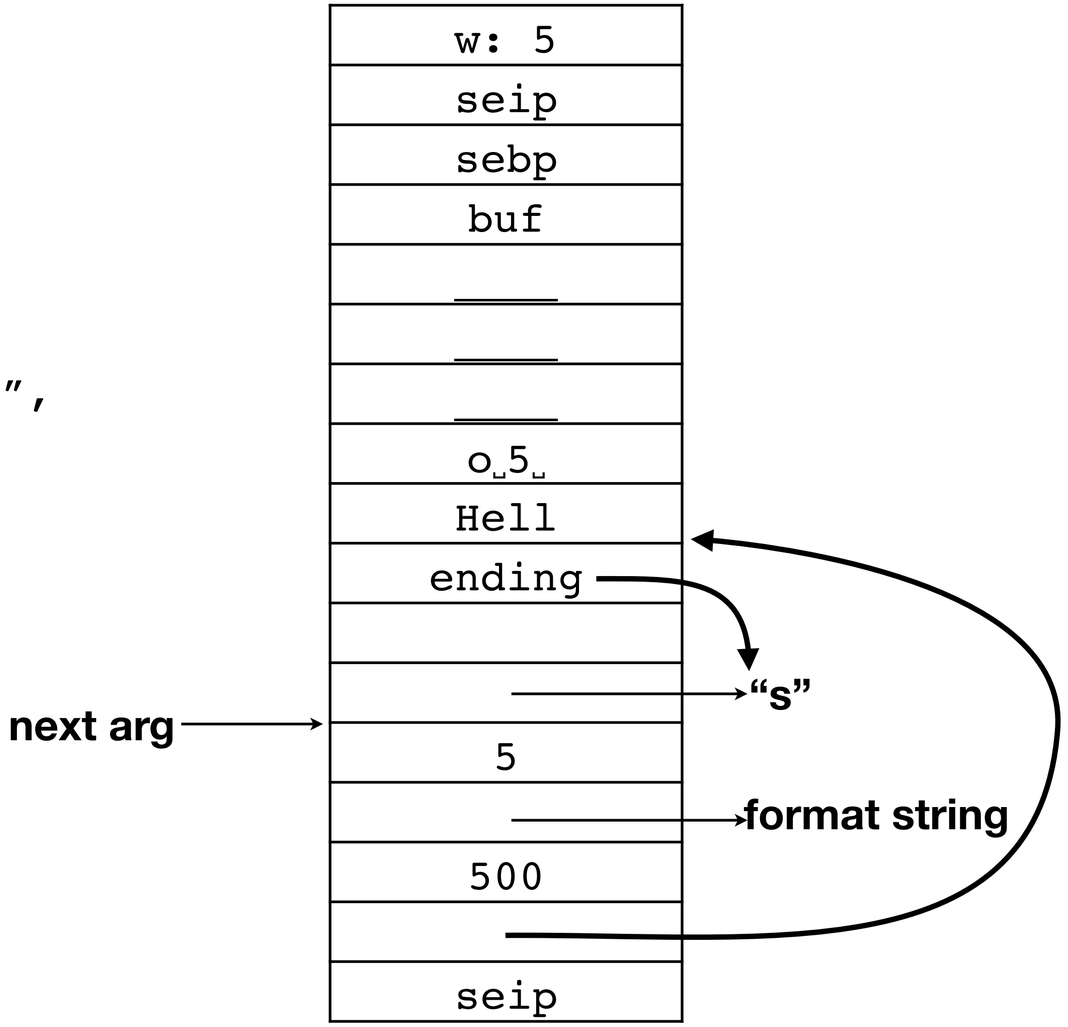

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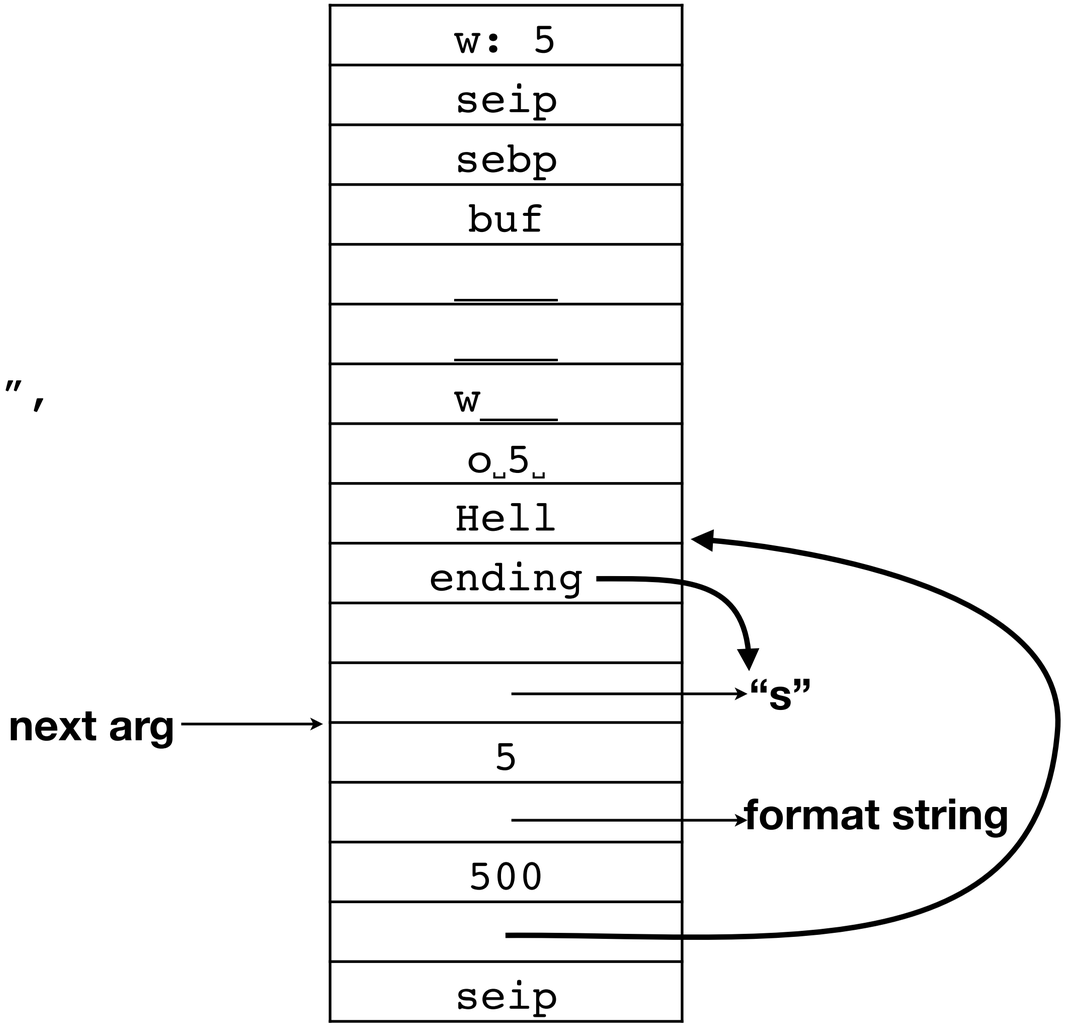

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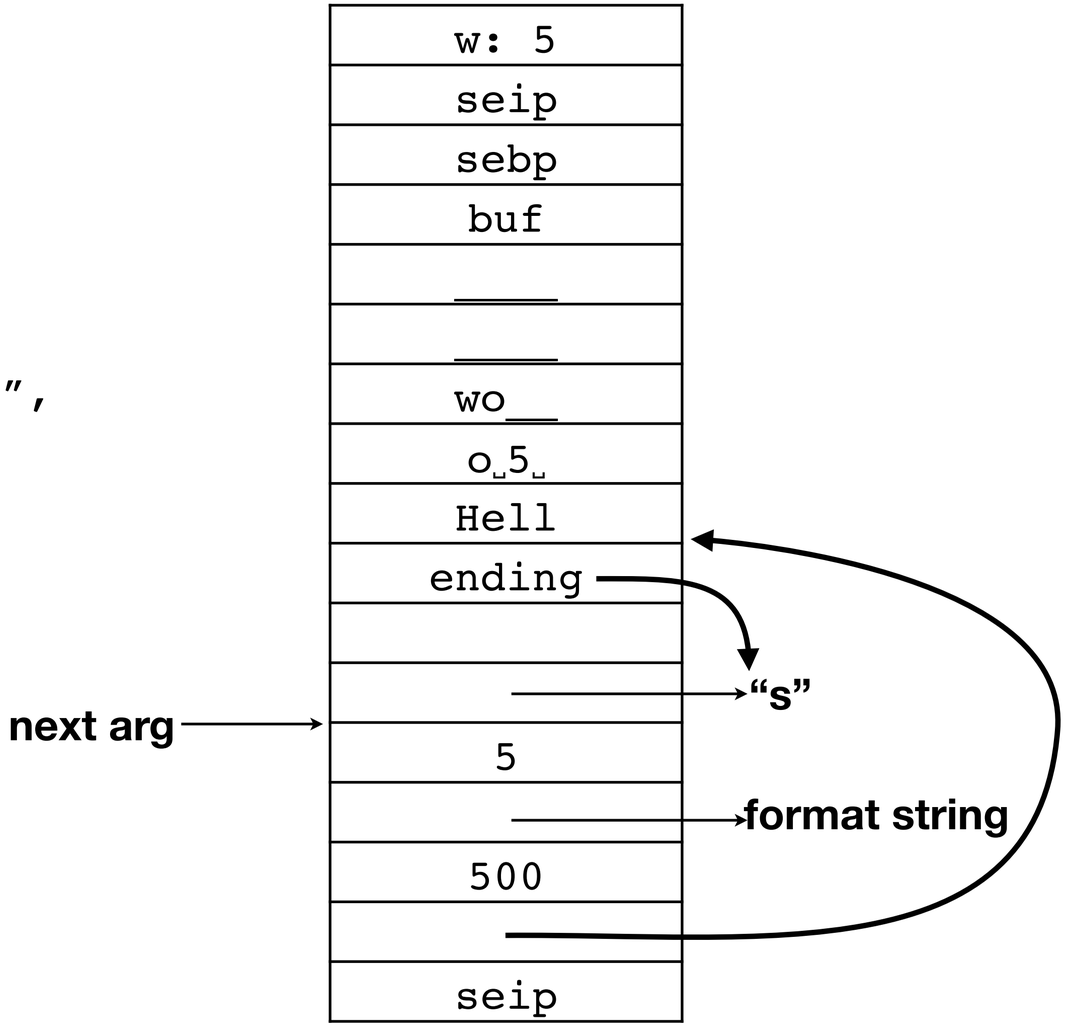

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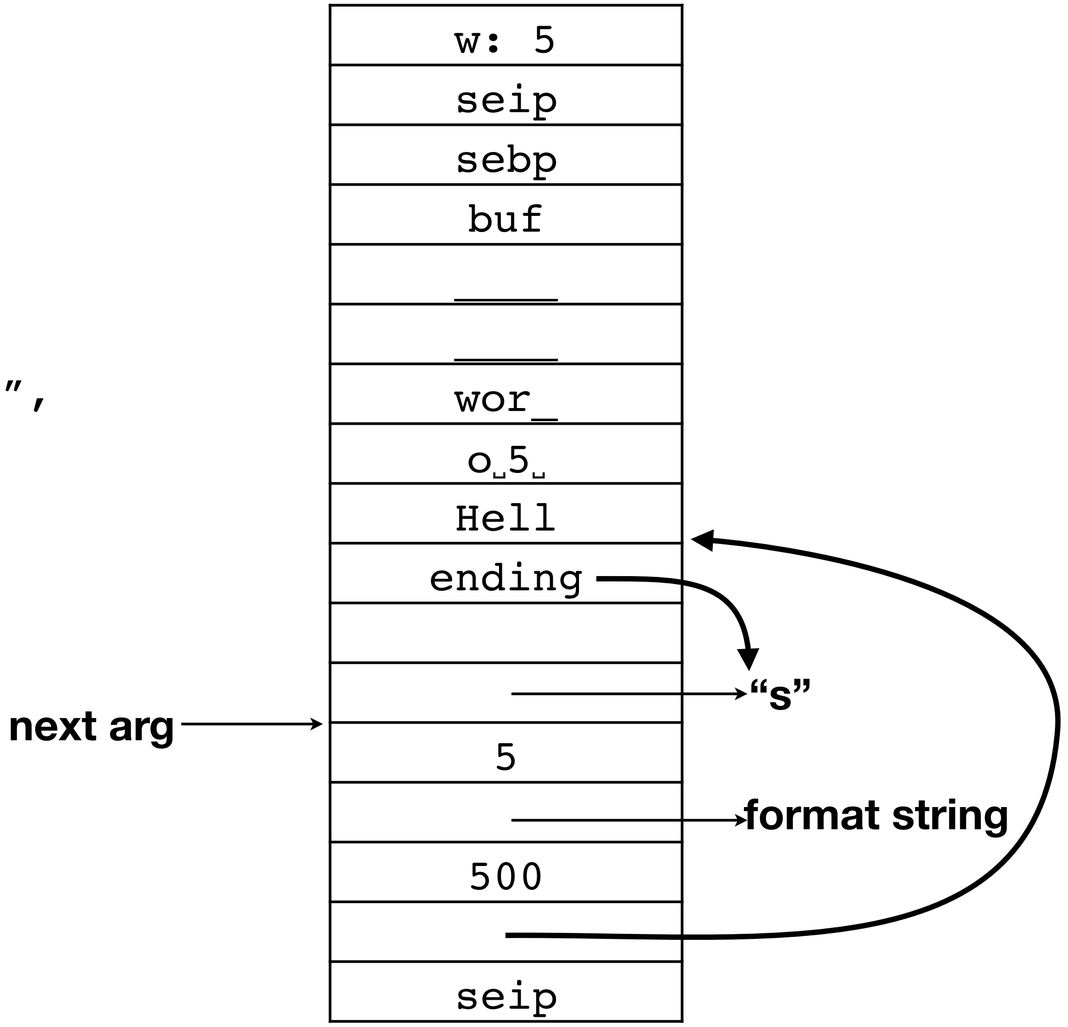

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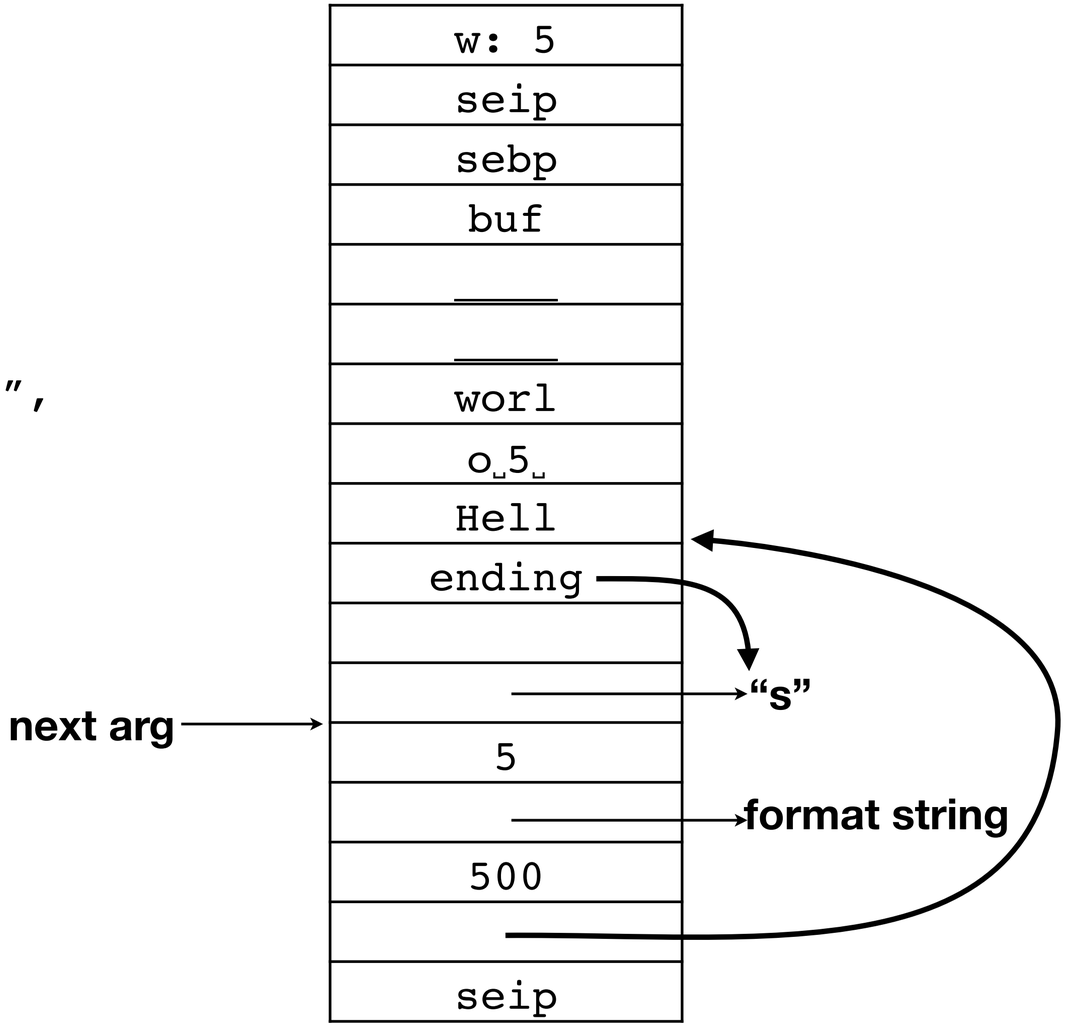

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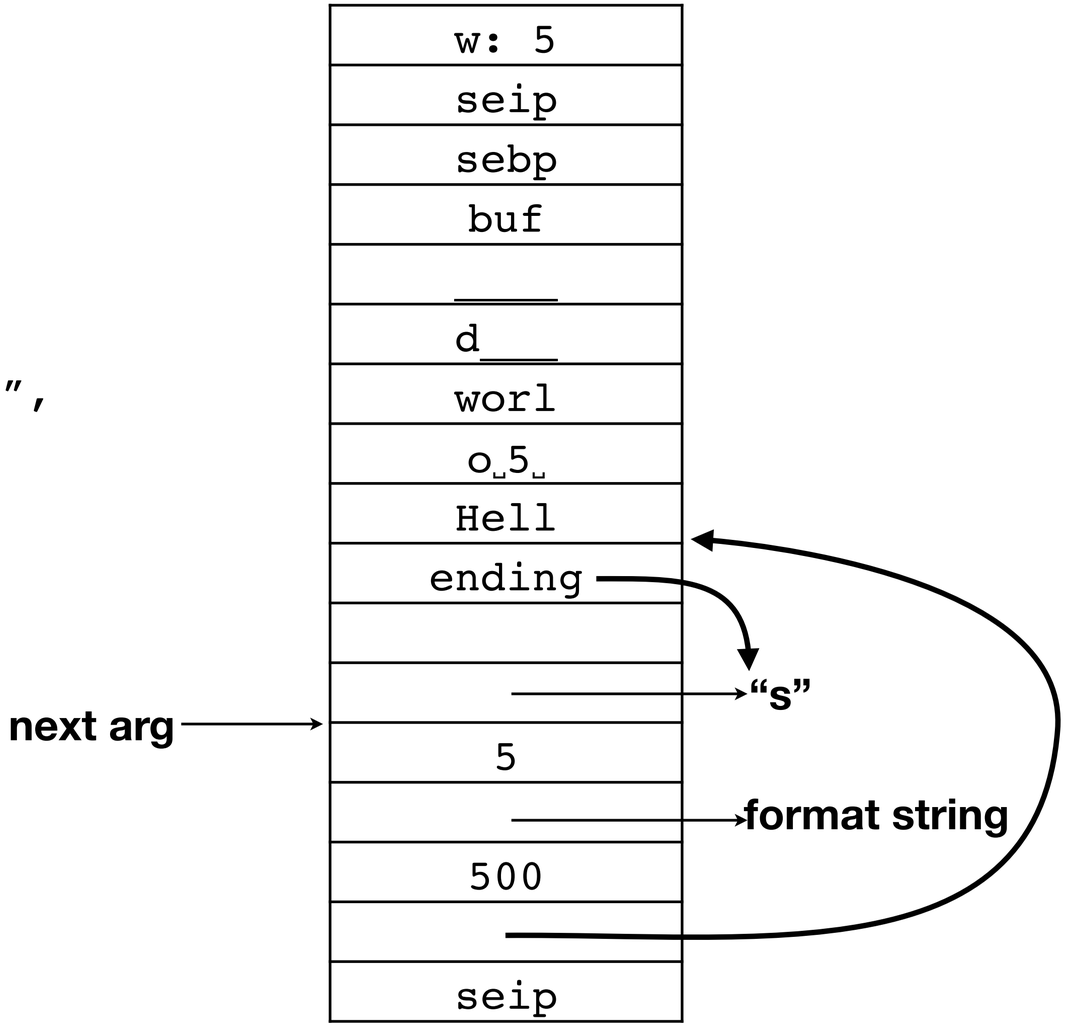

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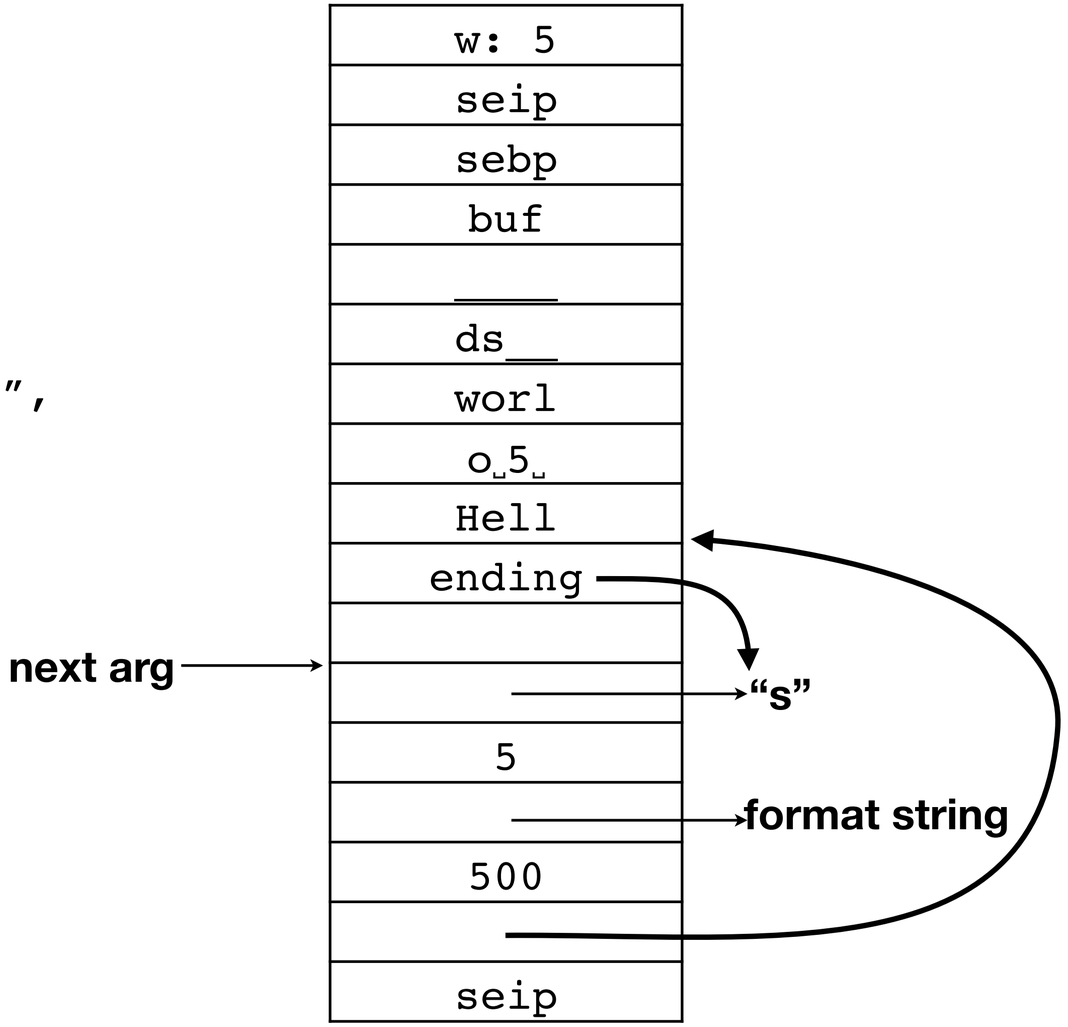

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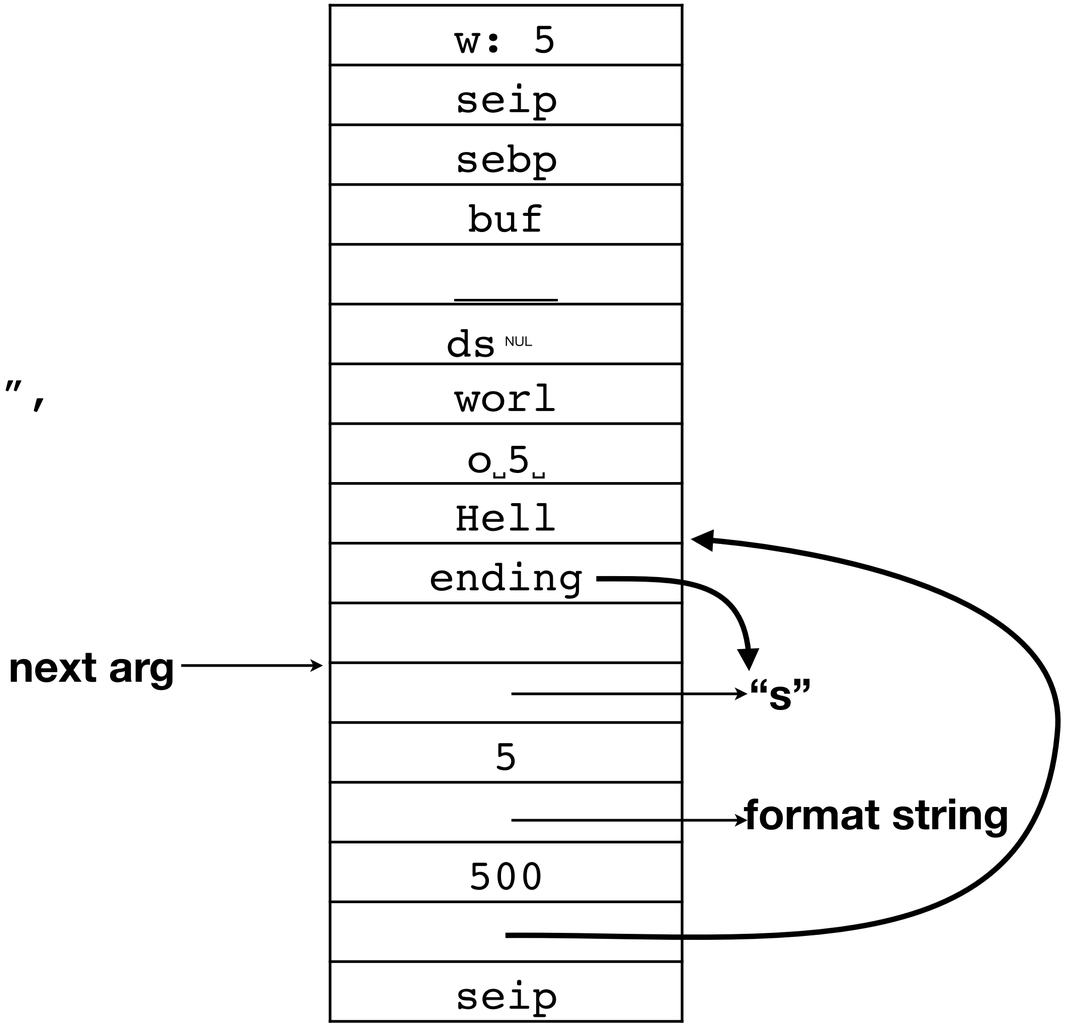

Now with %n

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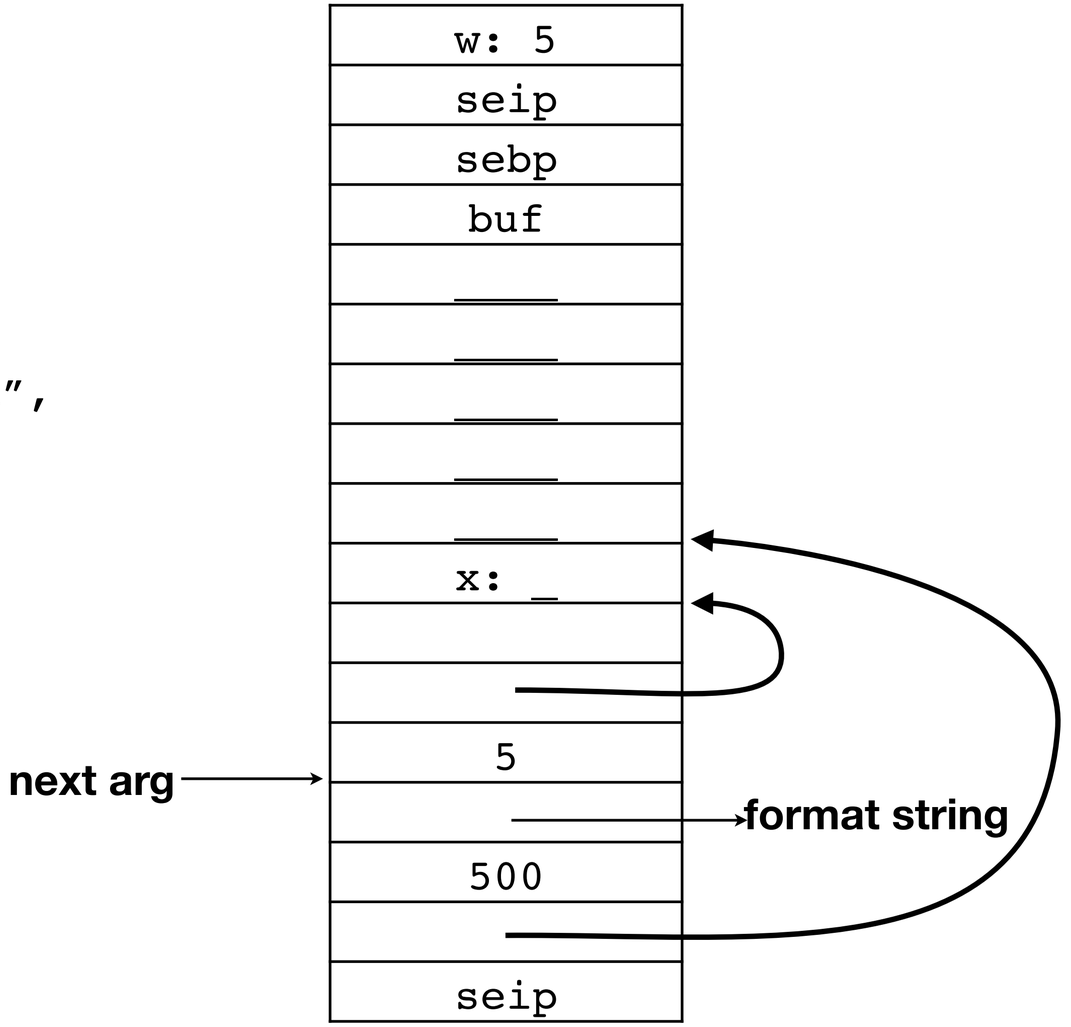

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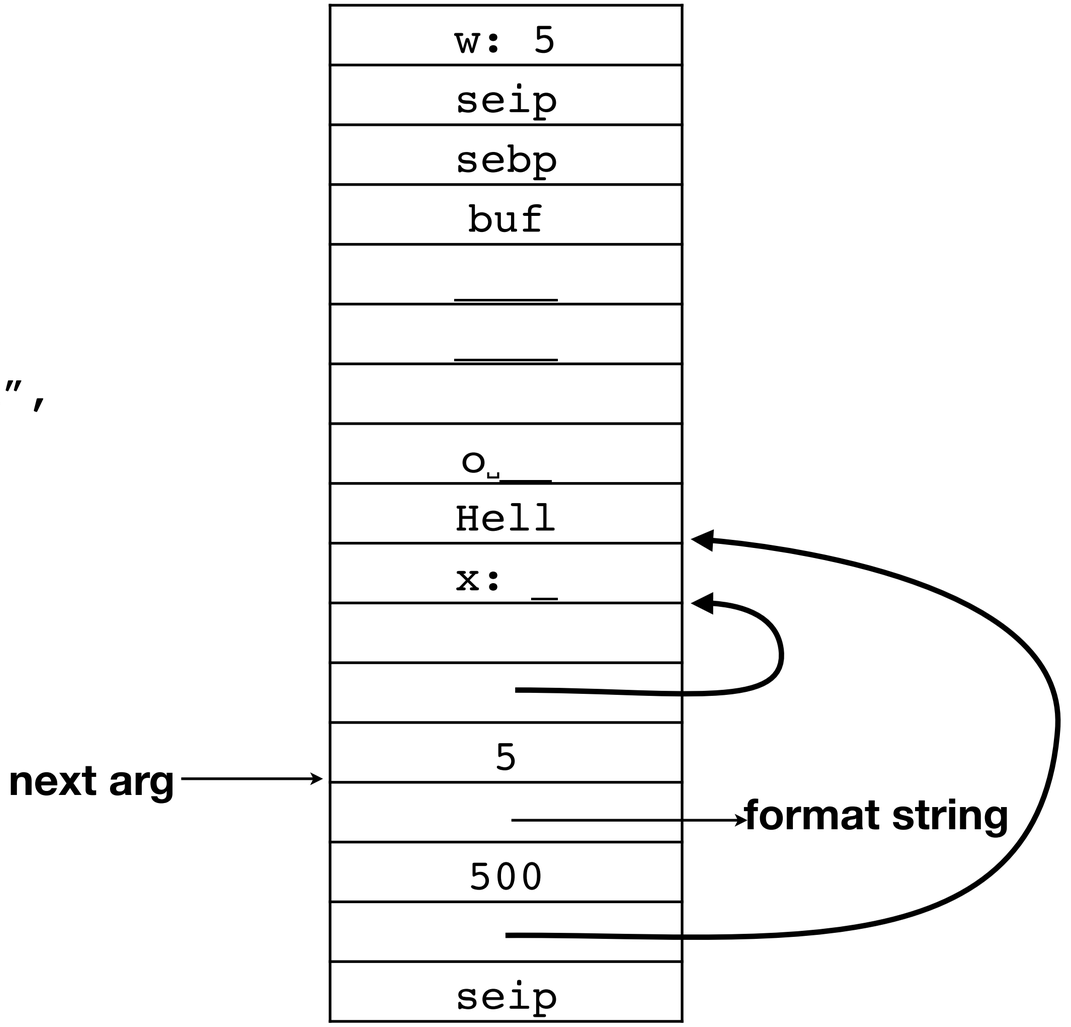

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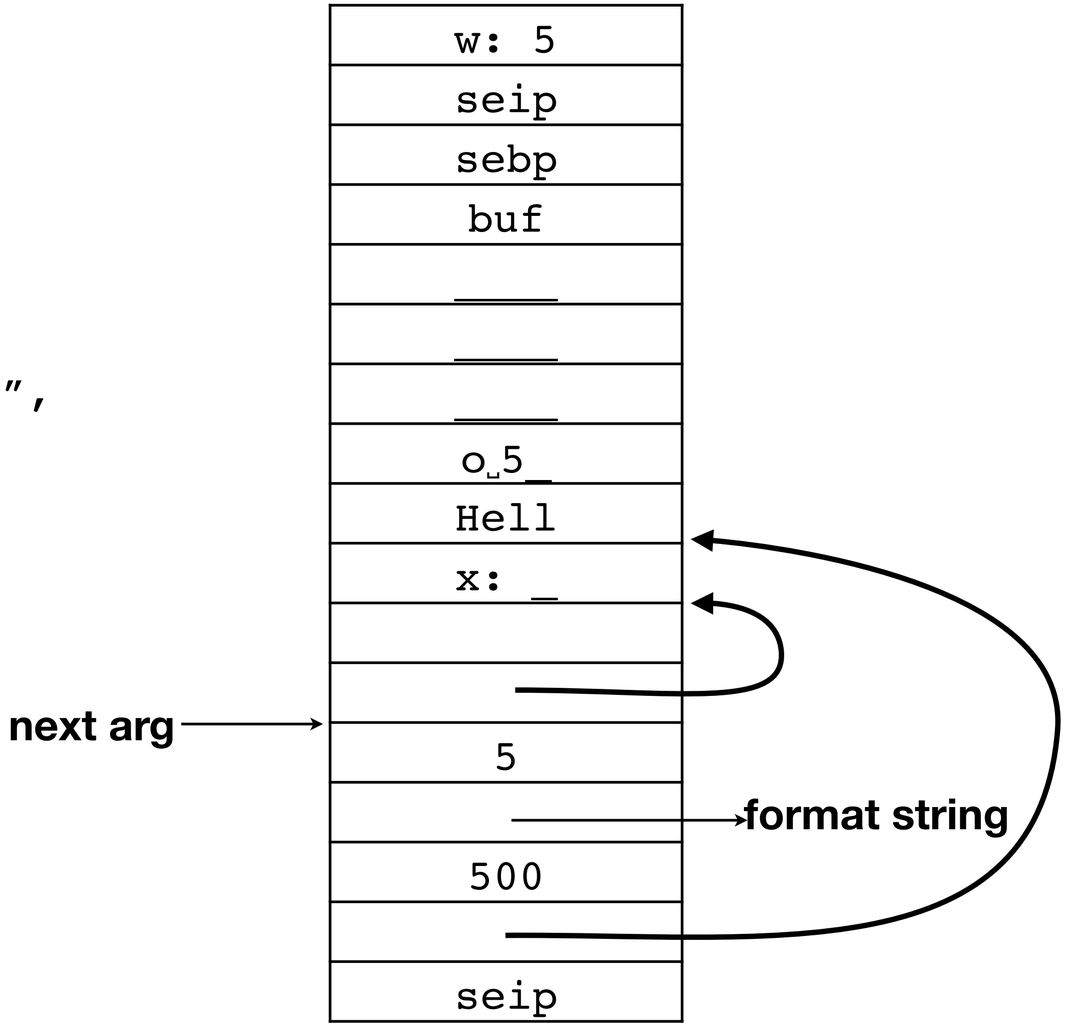

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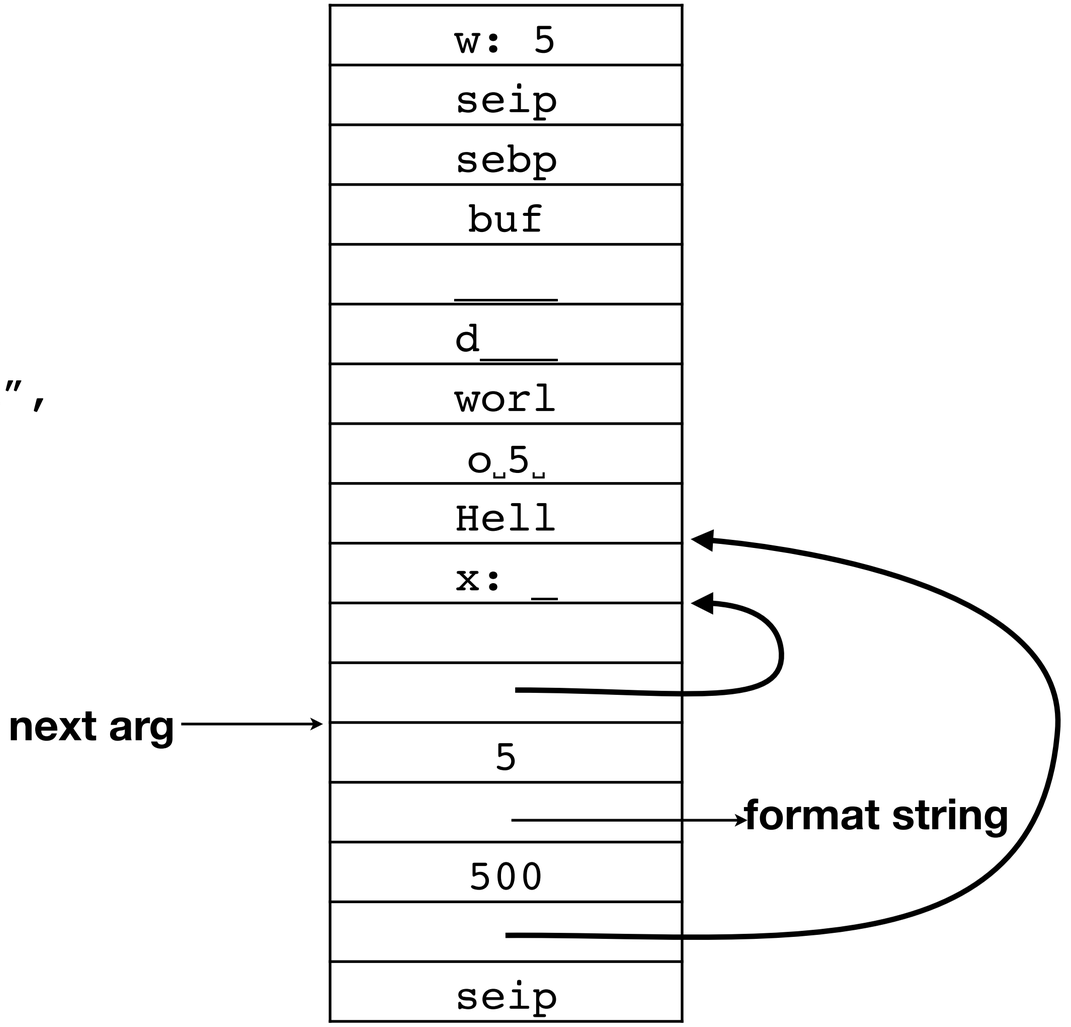

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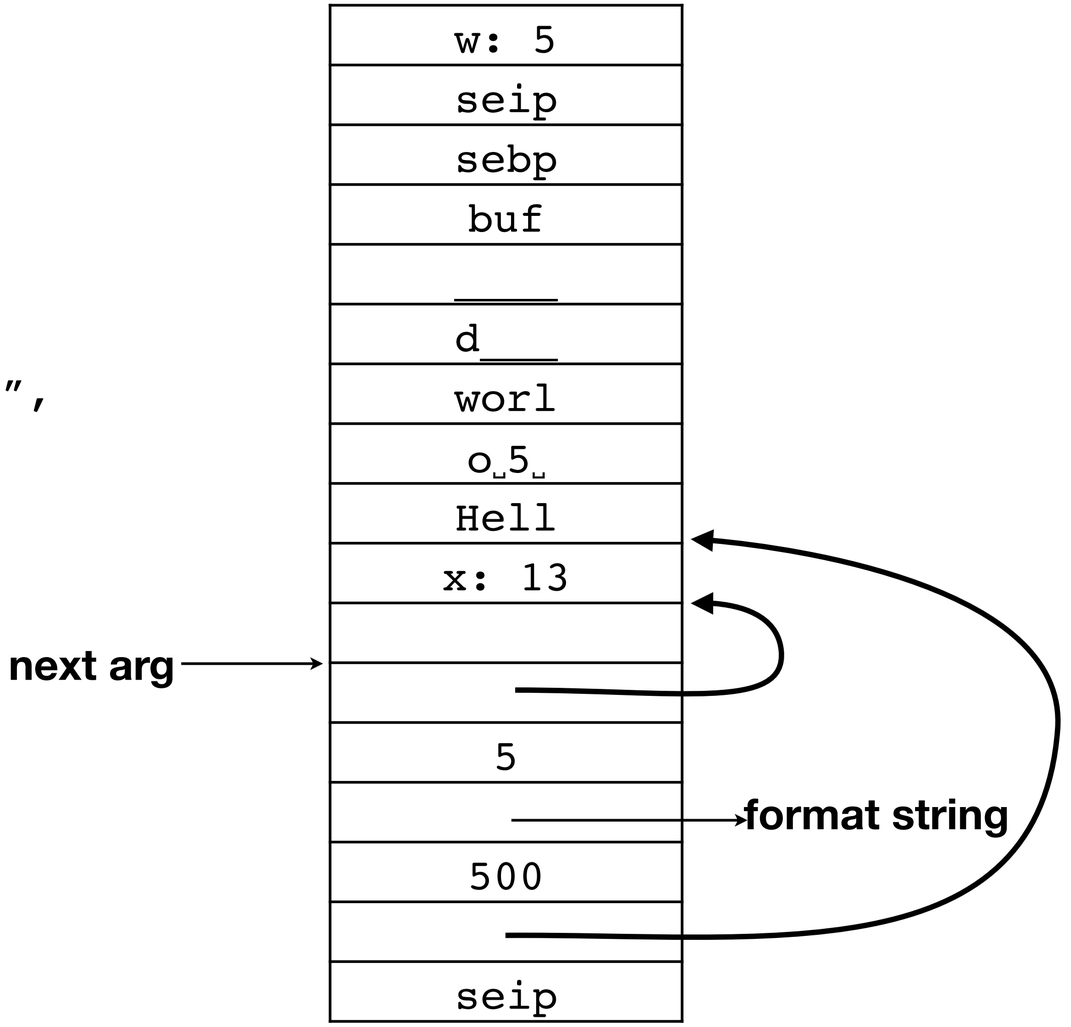

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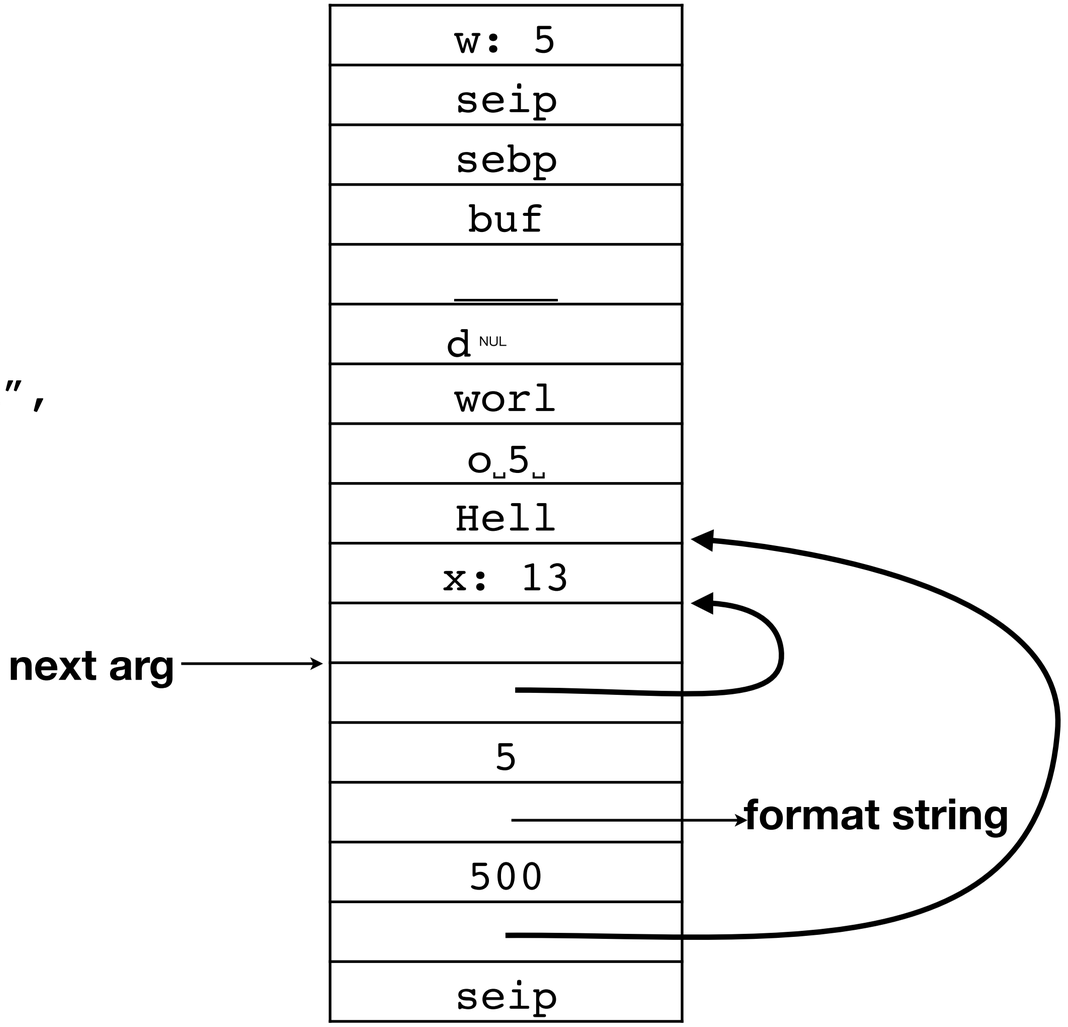
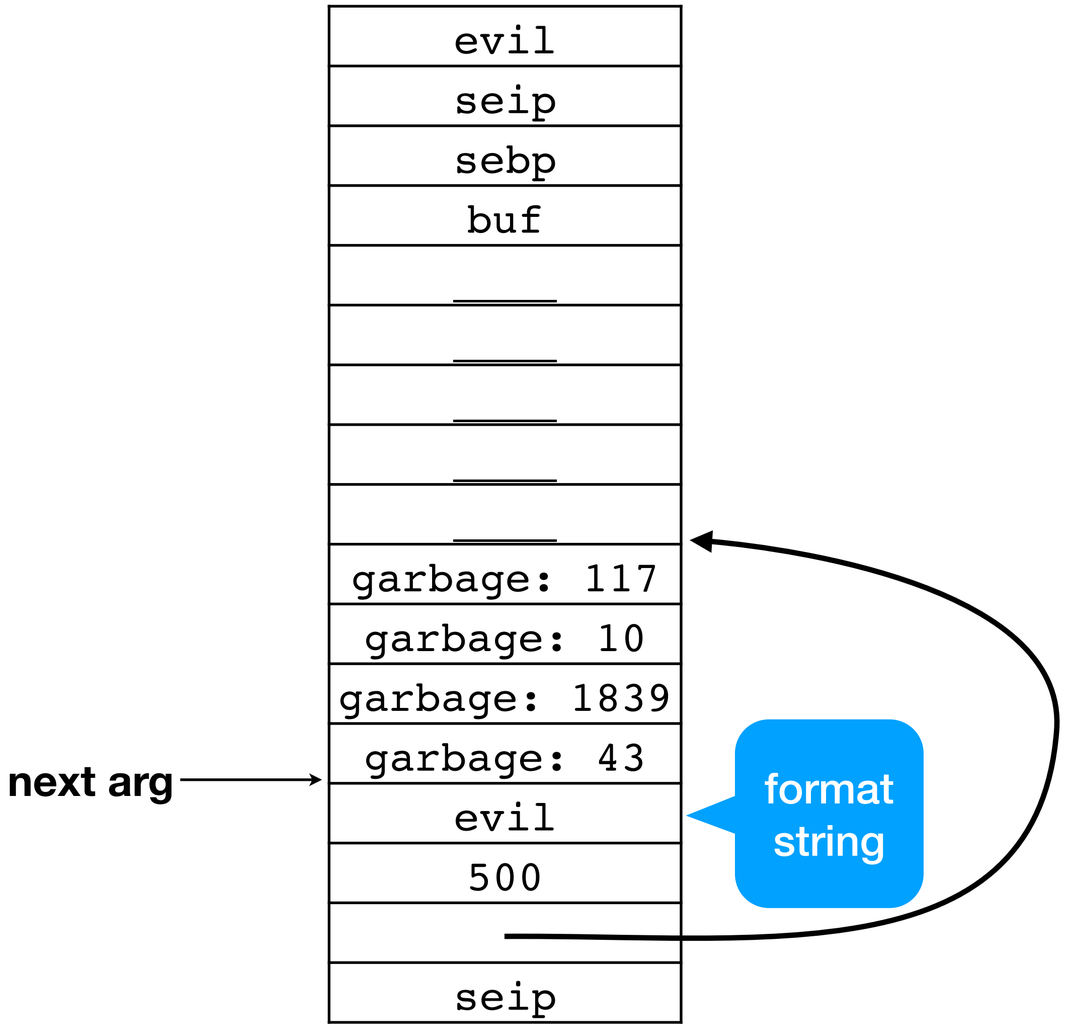


Attacker controlled format string

```
void foo(const char *evil) {
  char buf[500];
  snprintf(buf, 500, evil);
}
…
foo("ZZZZ%x%x%x%x%x");
```



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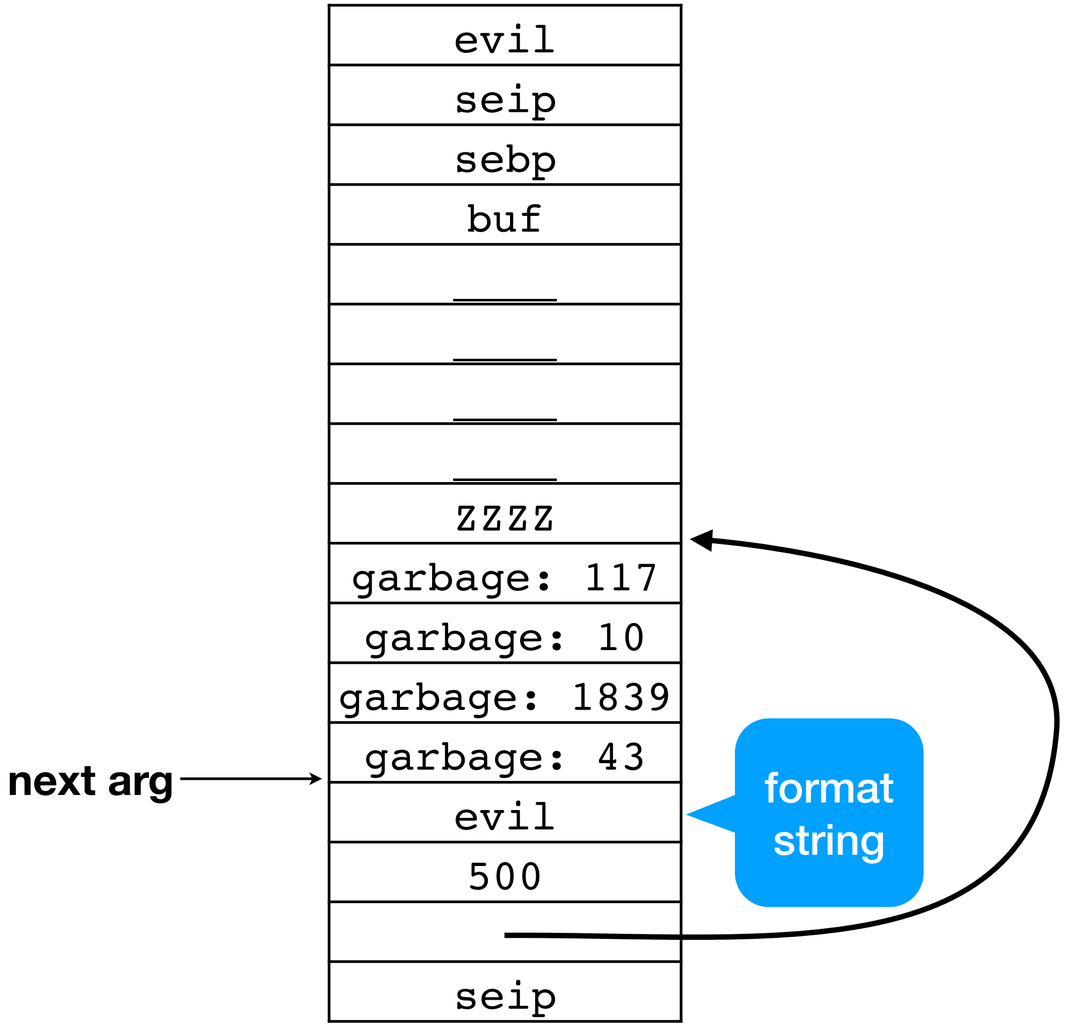

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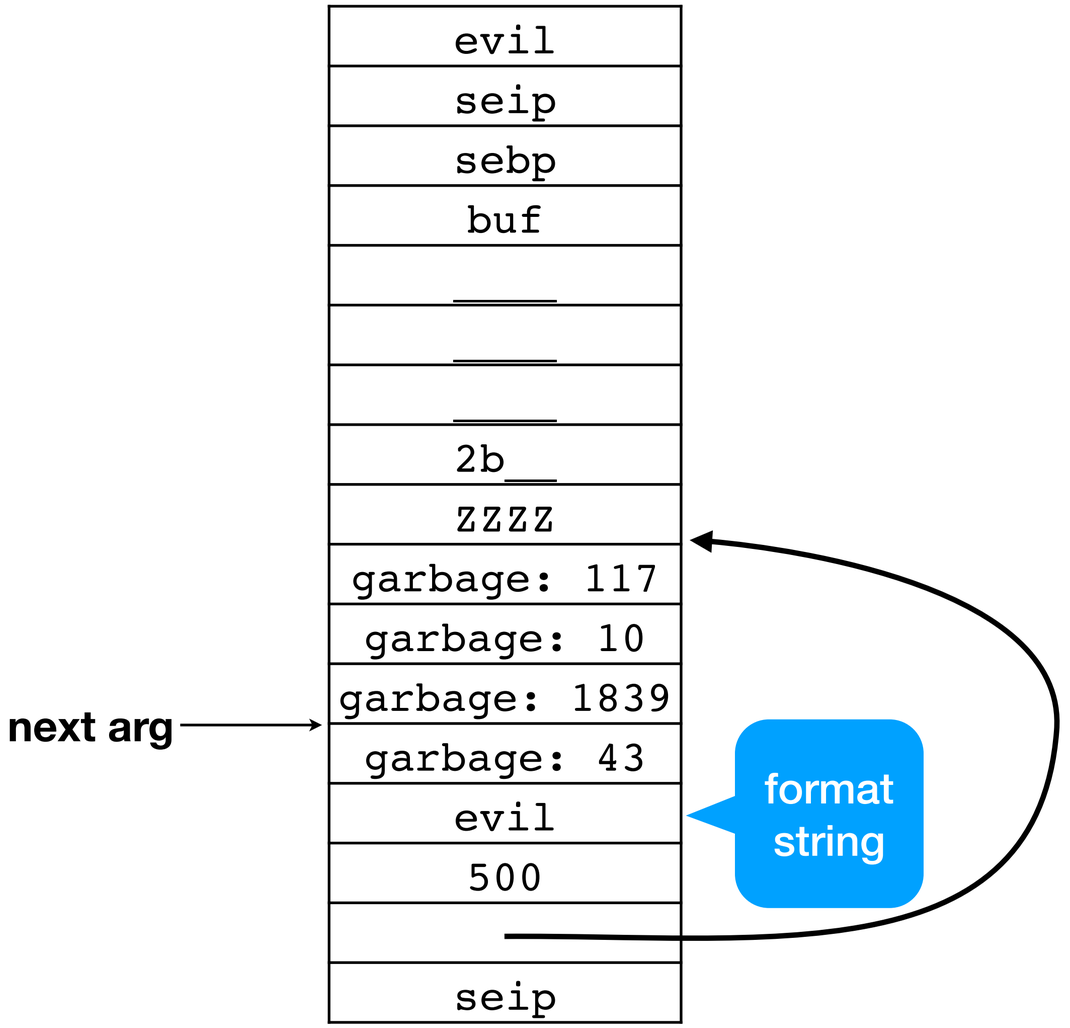

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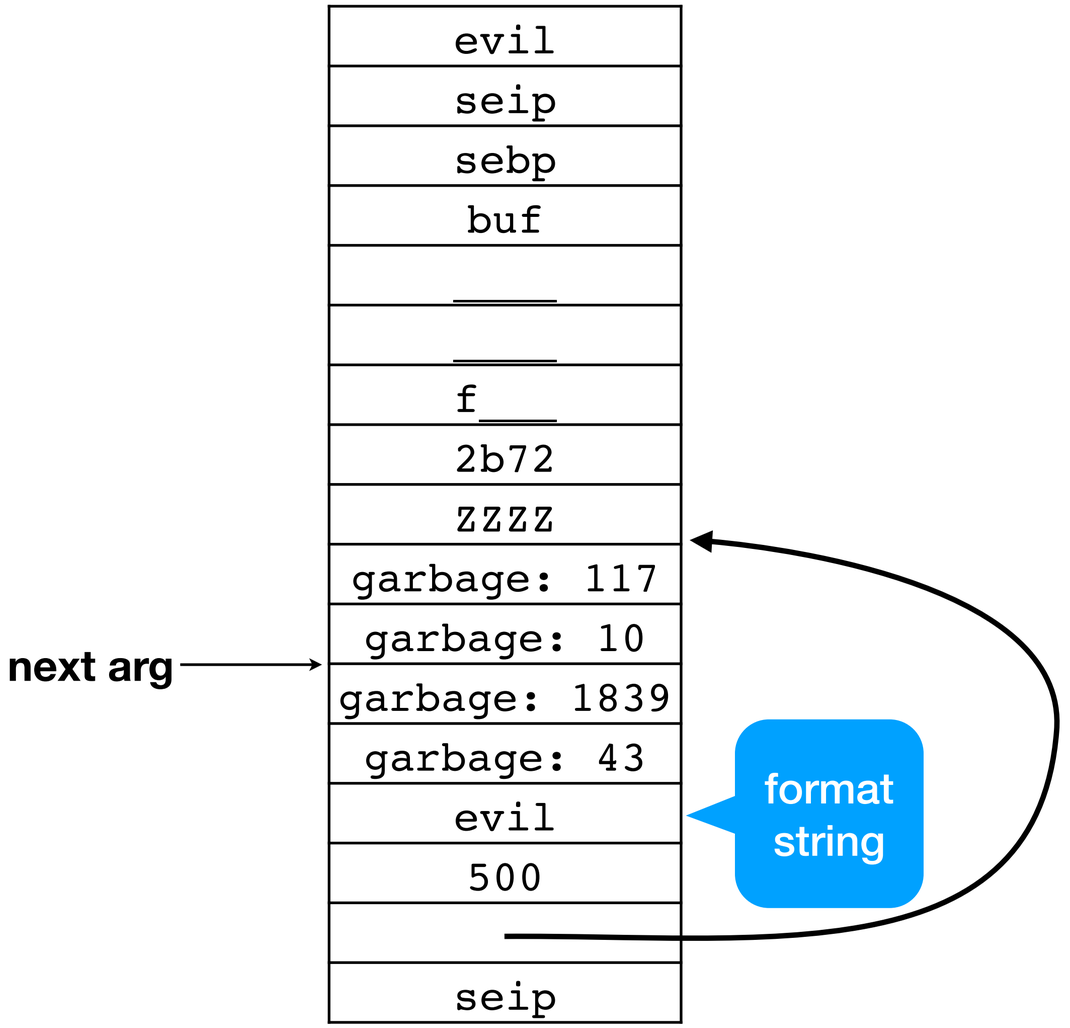

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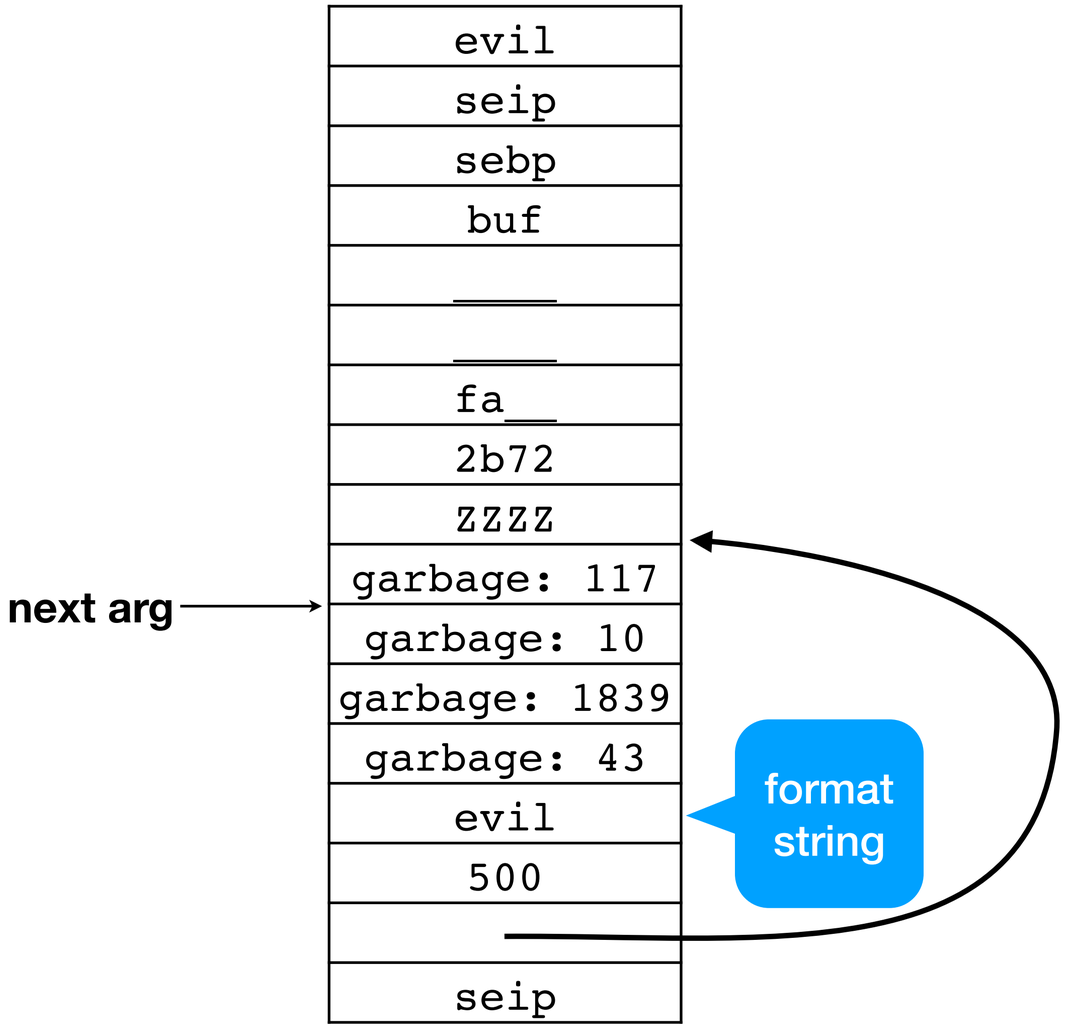

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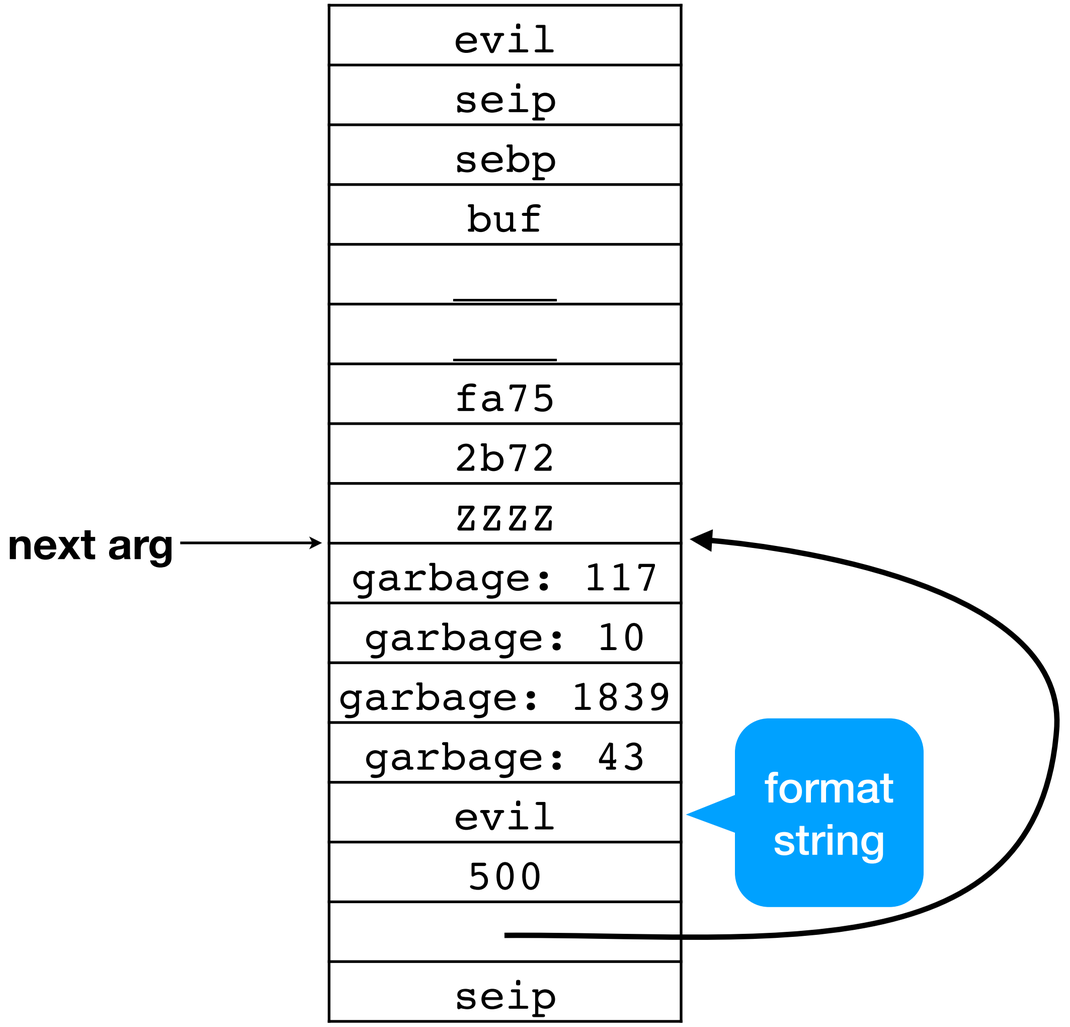

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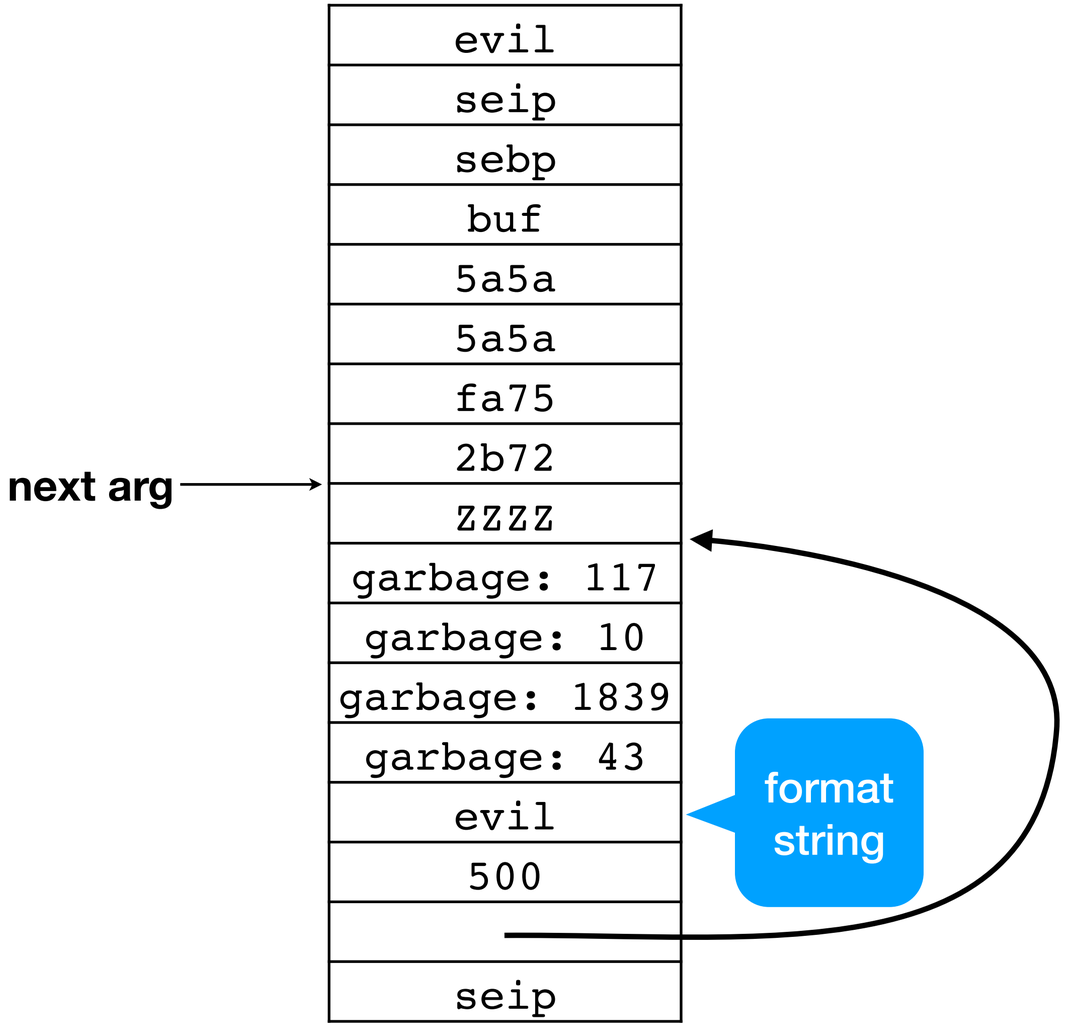

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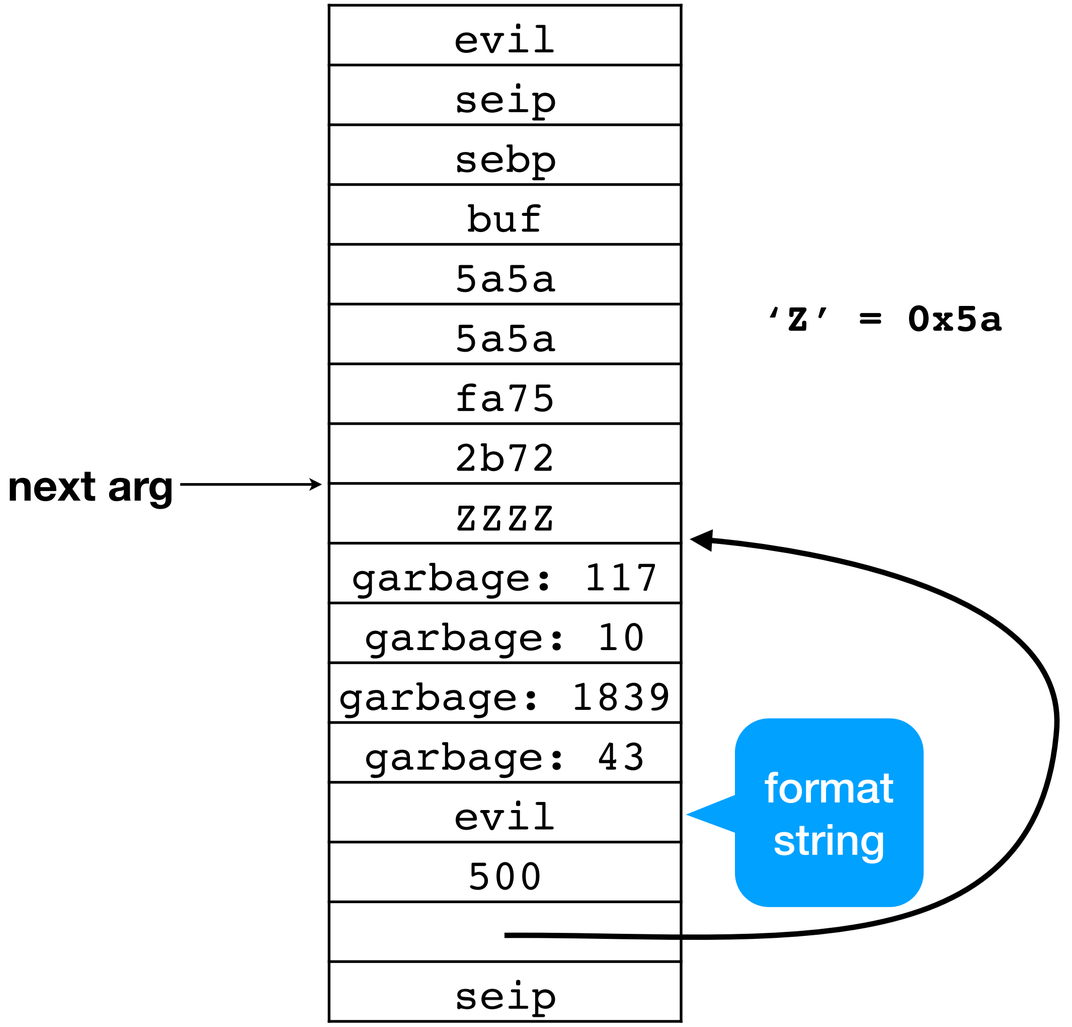

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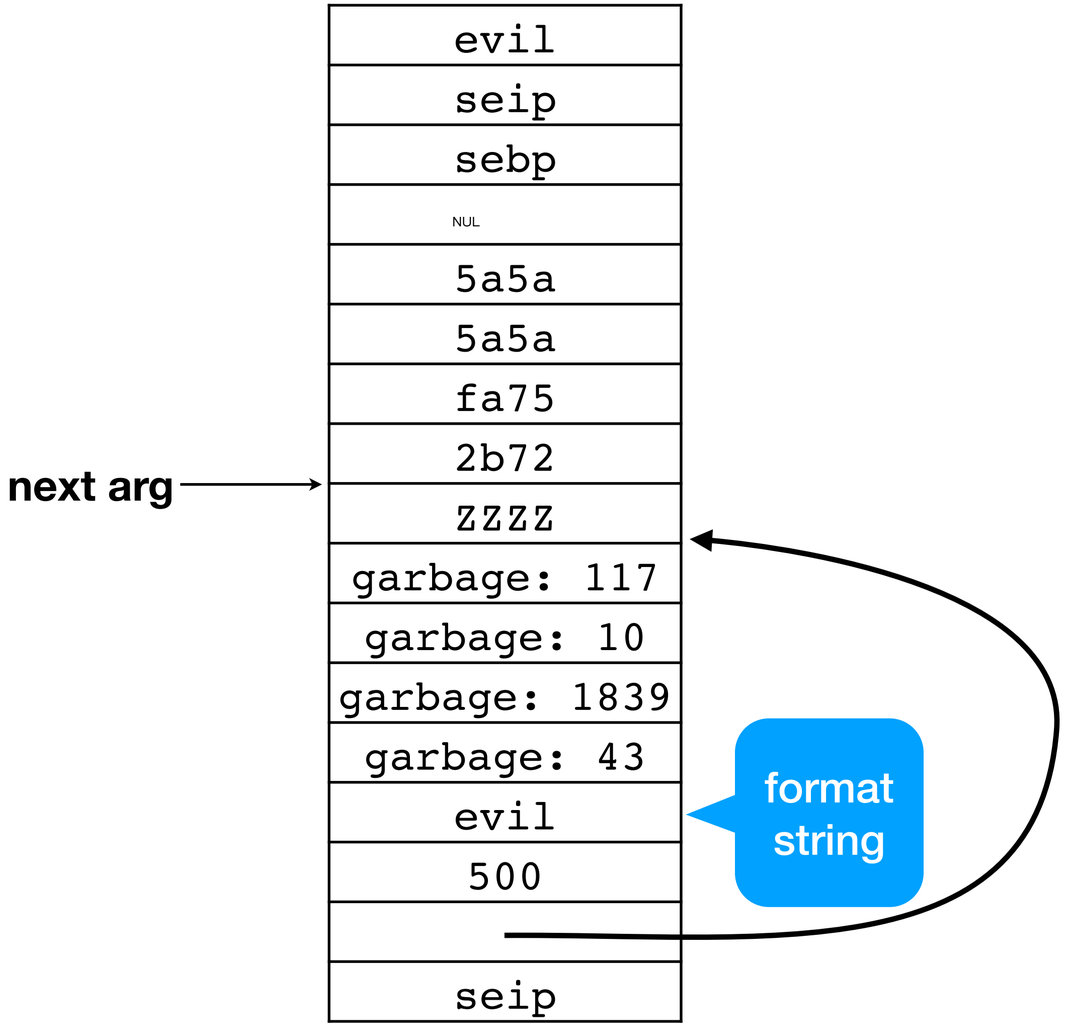

Overwriting seip

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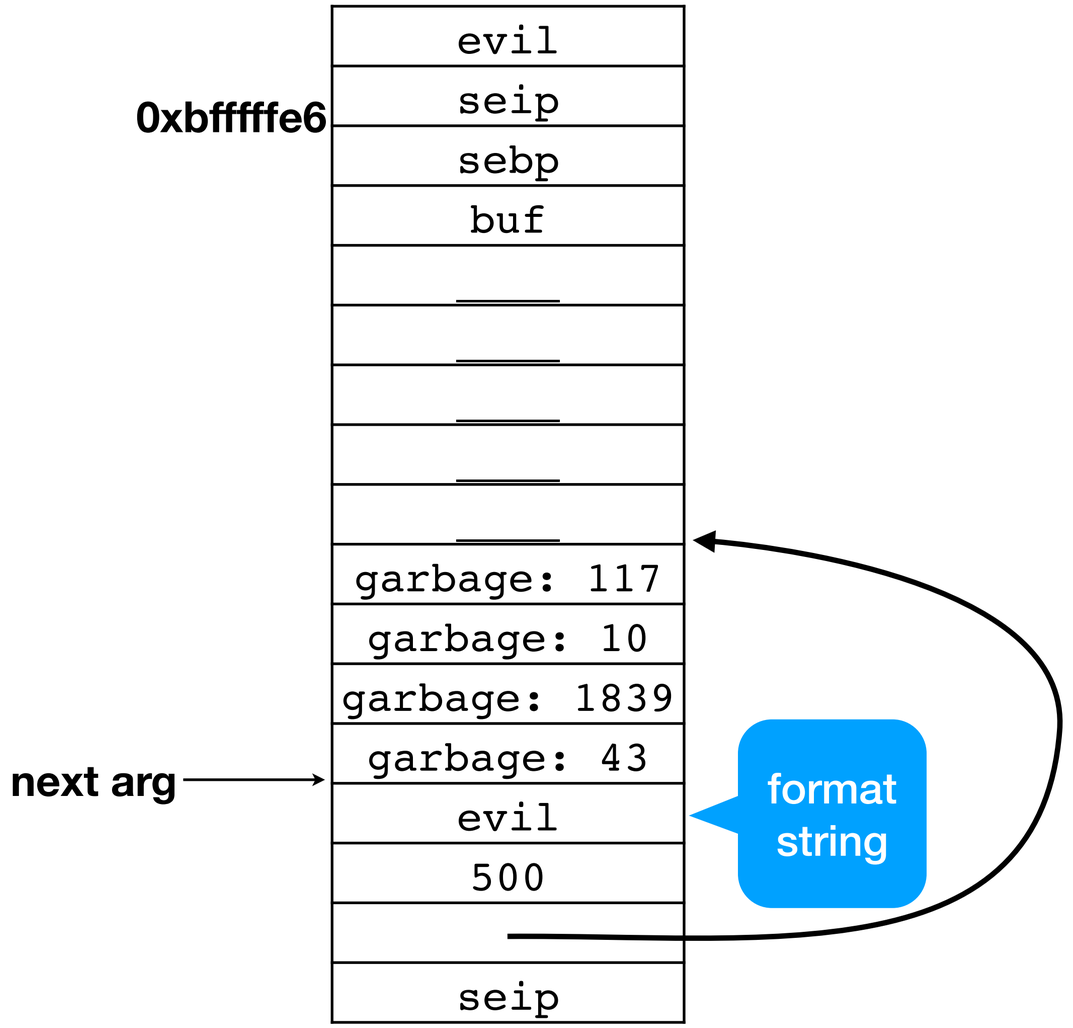

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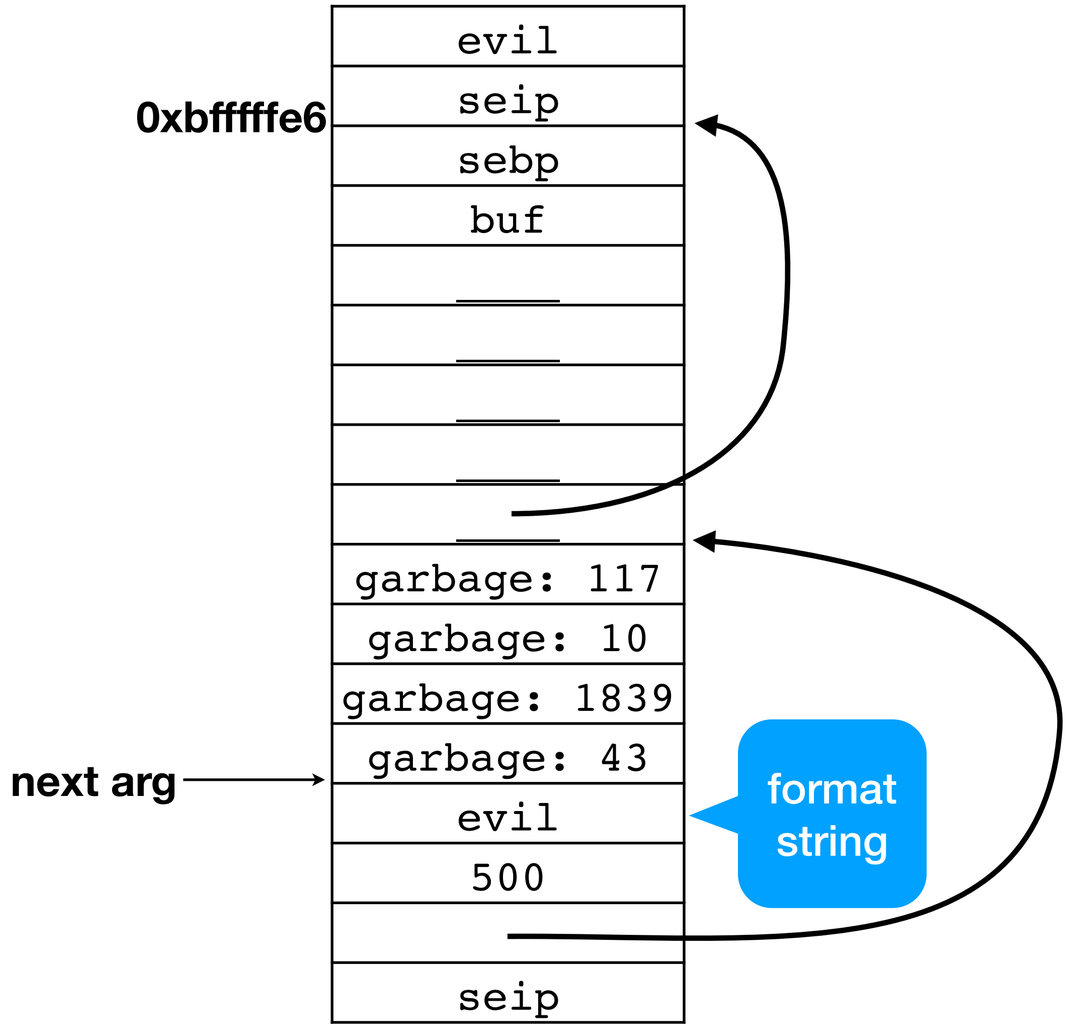

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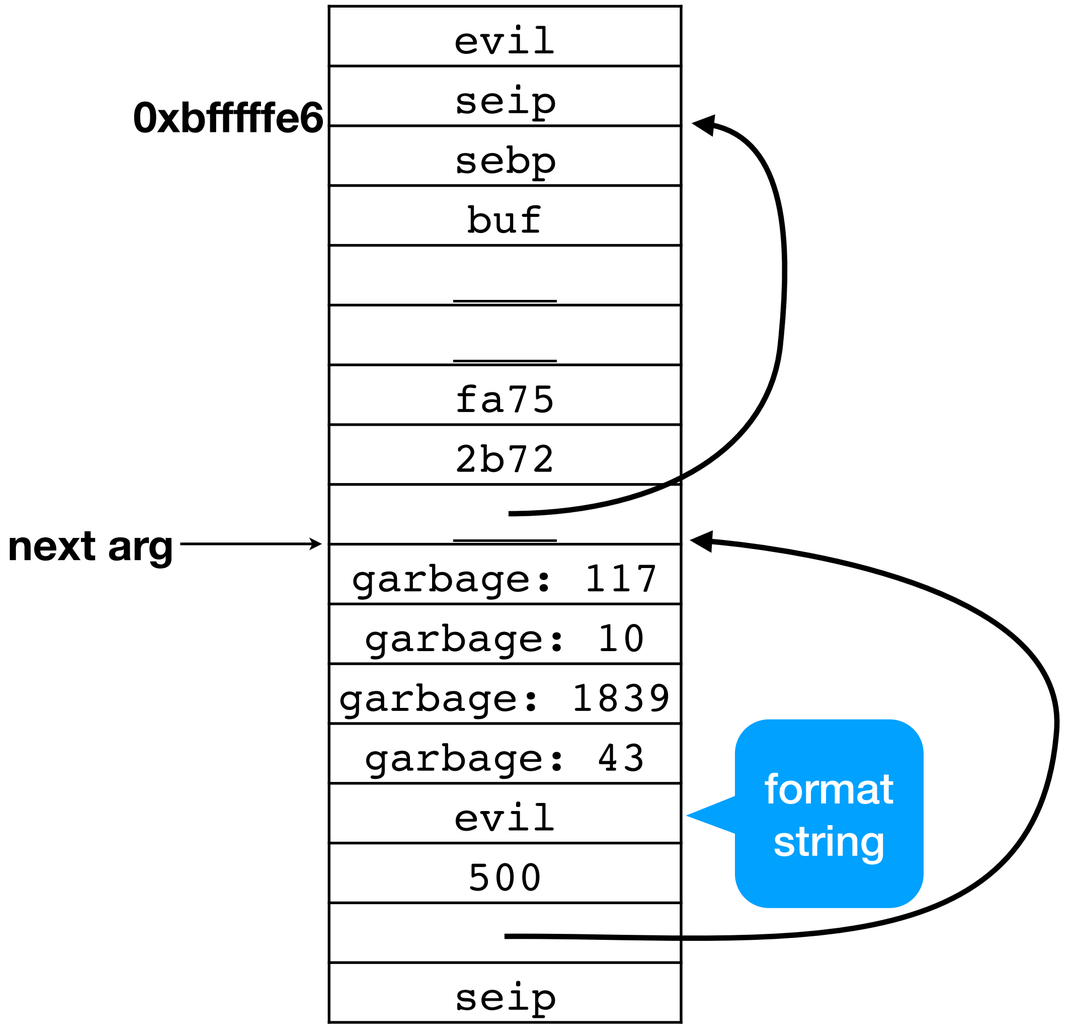

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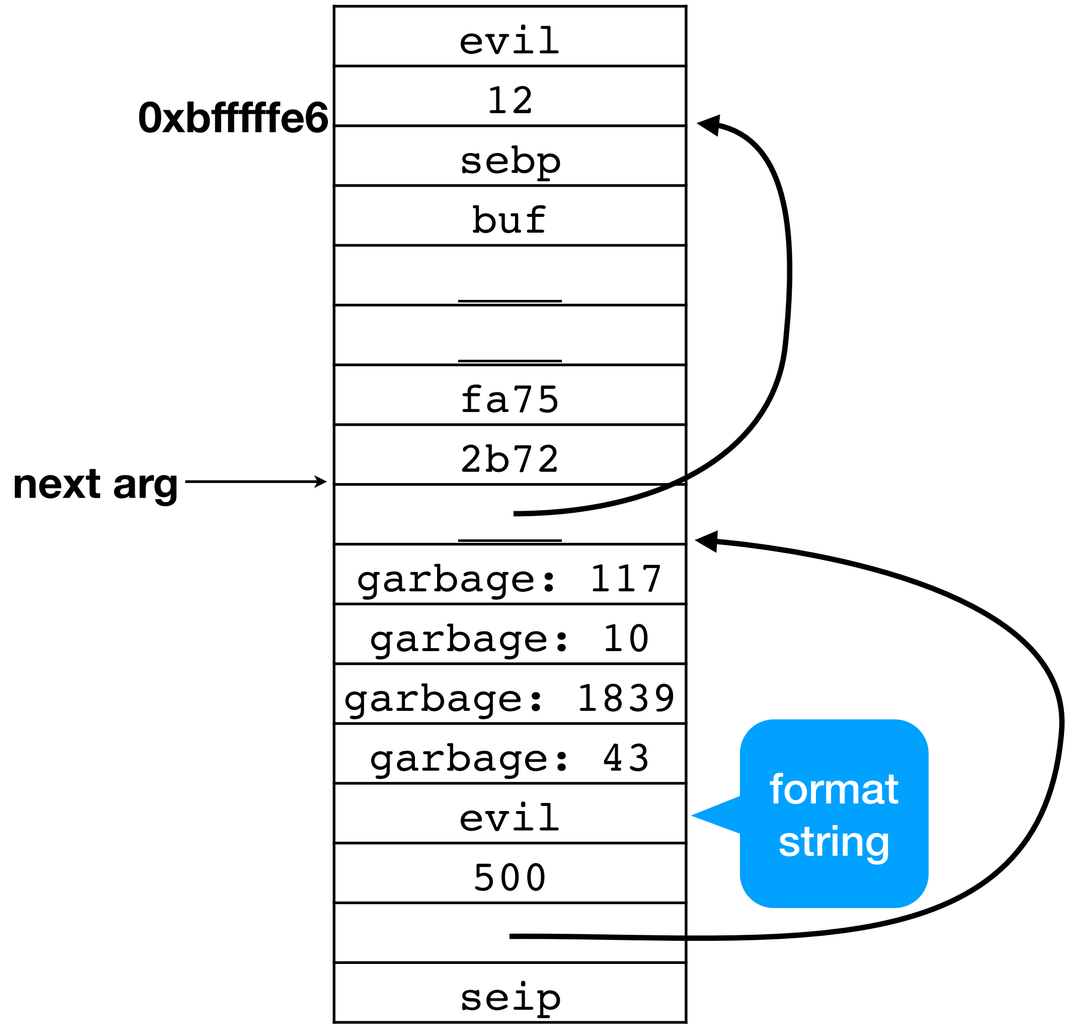

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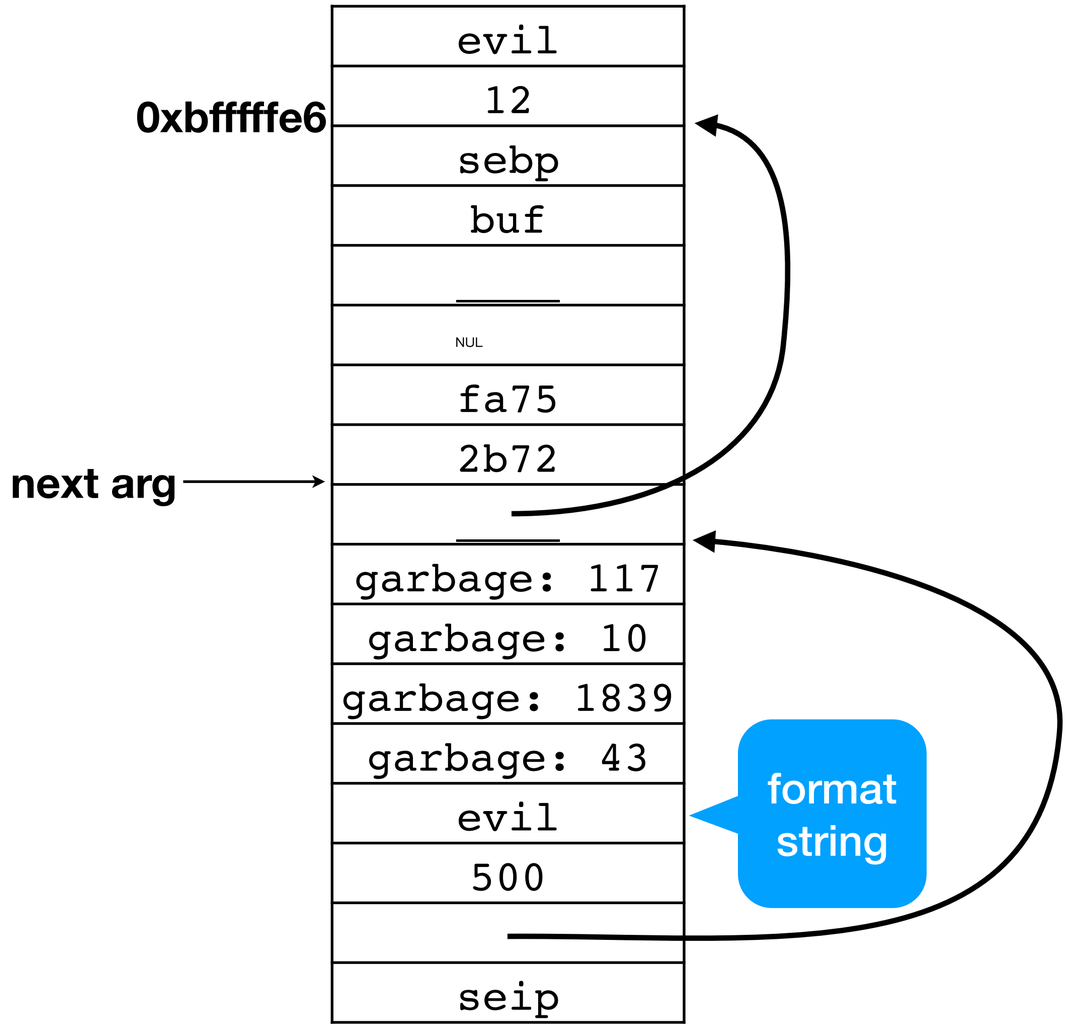


Picking the bytes to write

- Use `%⟨len⟩x` to control the length of the output
- Use `%hhn` to write just the least-significant byte of the length

Almost putting it all together

```
evil = “⟨address⟩ZZZZ”
       “⟨address+1⟩ZZZZ”
       “⟨address+2⟩ZZZZ”
       “⟨address+3⟩”
       “%8x%8x…%8x”
       “%⟨len⟩x%hhn”
       “%⟨len⟩x%hhn”
       “%⟨len⟩x%hhn”
       “%⟨len⟩x%hhn”;
```

Misaligned buf

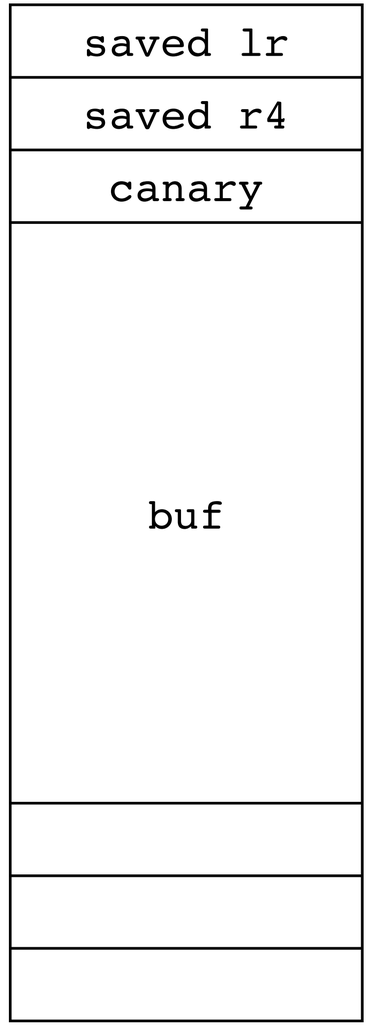
- If `buf` is not 4-byte aligned, prepend 1, 2, or 3 characters to `evil`

Advantages of format string exploits

- No need to smash the stack (targeted write)
- Avoids defenses such as stack canaries!
  - Stack canary is a random word pushed onto the stack that is checked before the function returns

Stack Canaries

```
int bar(char *);
char foo(void) {
   char buf[100];
   bar(buf);
   return buf[0];
}
foo:
        push    {r4, lr}
        sub     sp, sp, #104
        movw    r4, #:lower16:__stack_chk_guard
        movt    r4, #:upper16:__stack_chk_guard
        ldr     r3, [r4]
        str     r3, [sp, #100]
        mov     r0, sp
        bl      bar
        ldrb    r0, [sp]        @ zero_extendqisi2
        ldr     r2, [sp, #100]
        ldr     r3, [r4]
        cmp     r2, r3
        beq     .L2
        bl      __stack_chk_fail
.L2:
        add     sp, sp, #104
        pop     {r4, pc}
```



Disadvantages of format string exploits

- Easy to catch so rarer:

```
$ gcc -Wformat=2 f.c
f.c: In function ‘main’:
f.c:5: warning: format not a string literal and no format arguments
```

- Tricky to exploit compared to buffer overflows

What else can we overwrite?

- Function pointers
- C++ vtables
- Global offset table (GOT)

Function pointers

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

int compare(const void *a,
            const void *b) {
  const int *x = a;
  const int *y = b;
  return *x - *y;
}

int main() {
  int i;
  int arr[6] = {2, 1, 5, 13, 8, 4};
  qsort(arr, 6, 4, compare);
  for (i = 0; i < 6; ++i)
    printf("%d ", arr[i]);
  putchar('\n');
  return 0;
}
```

```
main:
   pushl  %ebp
   movl   %esp, %ebp
   …
   leal   24(%esp), %esi // arr
   …
   movl   $compare, 12(%esp)
   movl   $4, 8(%esp)
   movl   $6, 4(%esp)
   movl   %esi, (%esp)
   call   qsort

 qsort:
   …
   call *0x14(%ebp)
   …
```

C++ Virtual function tables (vtable)

```
struct Foo {
  Foo() { }
  virtual ~Foo() { }
  virtual void fun1() { }
  virtual void fun2() { }
};

void bar(Foo &f) {
  f.fun1();
  f.fun2();
}

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

```
_Z3barR3Foo: // bar(Foo&)
  pushl  %ebp
  movl   %esp, %ebp
  pushl  %ebx
  subl   $20, %esp
  movl   8(%ebp), %ebx     // ebx <- f
  movl   (%ebx), %eax      // eax <- vtable
  movl   %ebx, (%esp)      // (esp) <- this
  call   *8(%eax)          // call virtual function
  movl   (%ebx), %eax      // eax <- vtable
  movl   %ebx, (%esp)      // (esp) <- this
  call   *12(%eax)         // call virtual function
  addl   $20, %esp
  popl   %ebx
  popl   %ebp
  ret
```

vtable for Foo

```
// Real code
_ZN3FooC1Ev:
  pushl  %ebp
  movl   %esp, %ebp
  movl   8(%ebp), %eax
  movl   $_ZTV3Foo+8, (%eax)
  popl   %ebp
  ret

_ZTV3Foo:
  .long  0
  .long  _ZTI3Foo
  .long  _ZN3FooD1Ev
  .long  _ZN3FooD0Ev
  .long  _ZN3Foo4fun1Ev
  .long  _ZN3Foo4fun2Ev
```

```
// Demangled
Foo::Foo():
  pushl  %ebp
  movl   %esp, %ebp
  movl   8(%ebp), %eax
  movl   vtable for Foo+8, (%eax)
  popl   %ebp
  ret

vtable for Foo:
  .long  0
  .long  typeinfo for Foo
  .long  Foo::~Foo()
  .long  Foo::~Foo()
  .long  Foo::fun1()
  .long  Foo::fun2()
```

address of vtable+8 stored in first word of object

Global Offset Table (GOT)

- Contains pointers to code and data in shared libraries
- Library functions aren’t called directly; stub in the Procedure Linkage Table (PLT) called
- E.g., call exit -> call exit@plt
- exit@plt looks up the address of exit in the GOT and jumps to it (not the whole story)
- Overwrite function pointer in GOT