(Early) Memory Corruption Attacks (cont'd)

CS-576 Systems Security

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Recap

Stack overflows corrupt memory on the stack allowing to overwrite/control

- Return addresses (control-flow hijacking)
- Other data saved in the stack

Global and heap buffer overflows corrupt neighboring memory allowing to overwrite/control

- Other data saved in the stack

Controlling the return address can lead to code injection and arbitrary code execution

Controlling program data can lead to unexpected/undesired behavior

More Attacks

Heap overflows as arbitrary writes

Format string exploits

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Heap overflows as arbitrary writes

Format string exploits

Understanding the Heap

The layout of buffers in memory depends on the implementation off the allocator (i.e., malloc)

```
char *userinput = malloc(20);
char *outputfile = malloc(20);
```

malloc() Implementations

dlmalloc – General purpose allocator

ptmalloc2 – glibc

jemalloc – FreeBSD and Firefox

tcmalloc – Google

libumem – Solaris

…

glibc malloc()

https://sploitfun.wordpress.com/2015/02/10/understanding-glibc-malloc/

Heap memory is obtained from the kernel using the brk() or mmap() system calls

- Provides plenty of “raw” space

The allocator splits memory into **arenas**

- Each thread gets its own arena
- Each arena has its own metadata

Memory within the arena is split into **chunks** and given to program through various allocation functions (e.g., malloc())

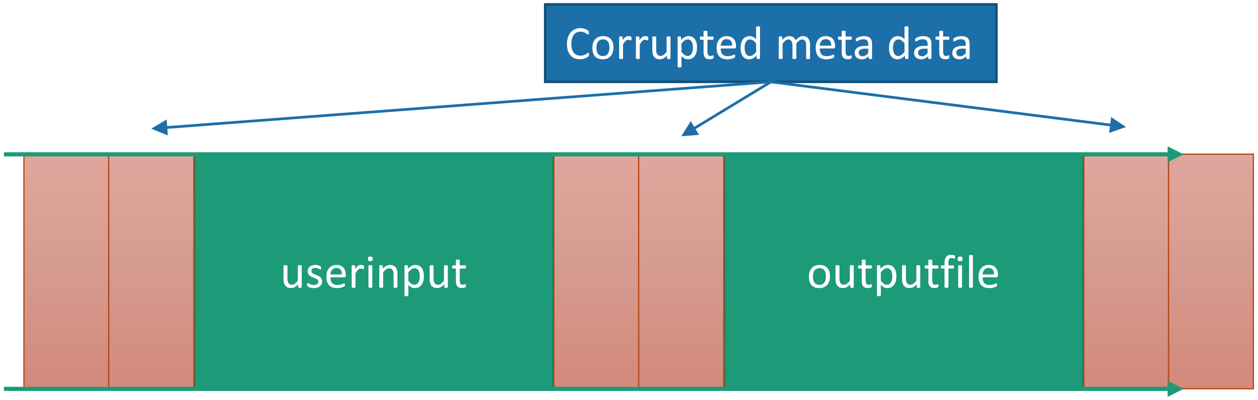
- Chunks are organized in bins, usually through double linked-lists

Buffer/Metadata Interleaving

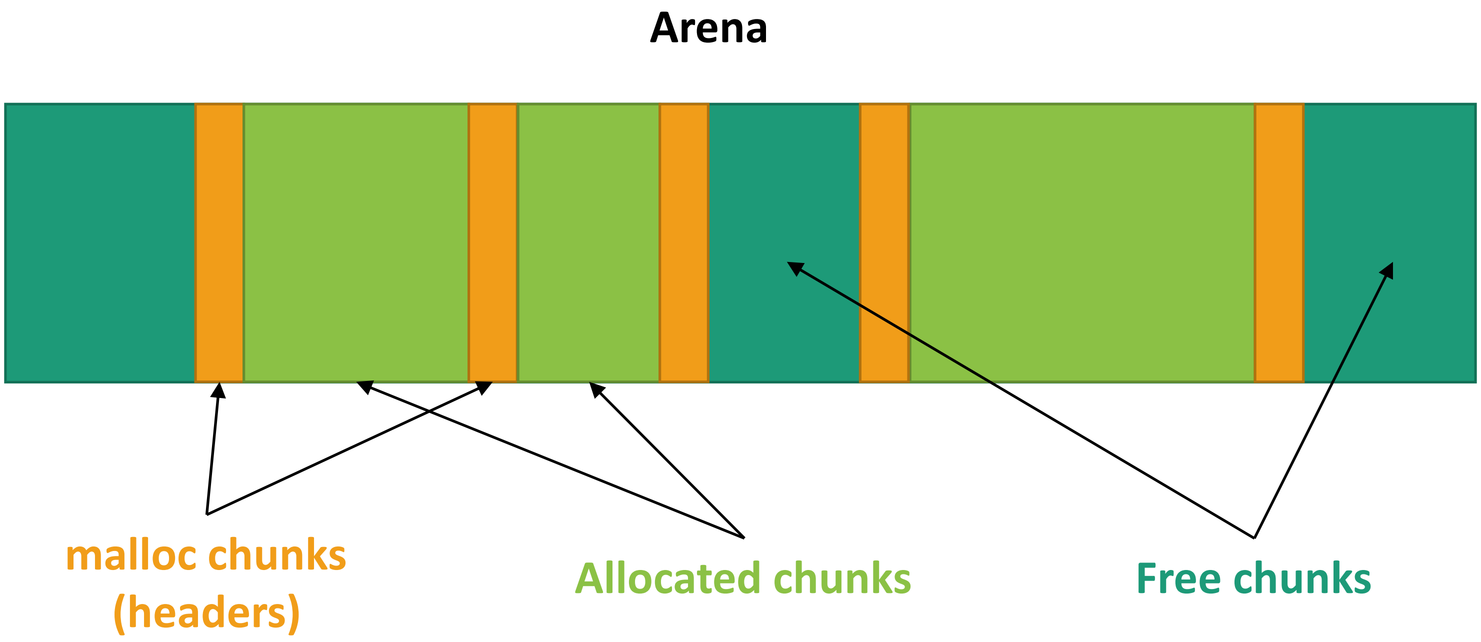
Memory management metadata

Corrupted Metadata

Use of the corrupted meta data and may lead to an arbitrary write, corrupting a code pointer or security critical data

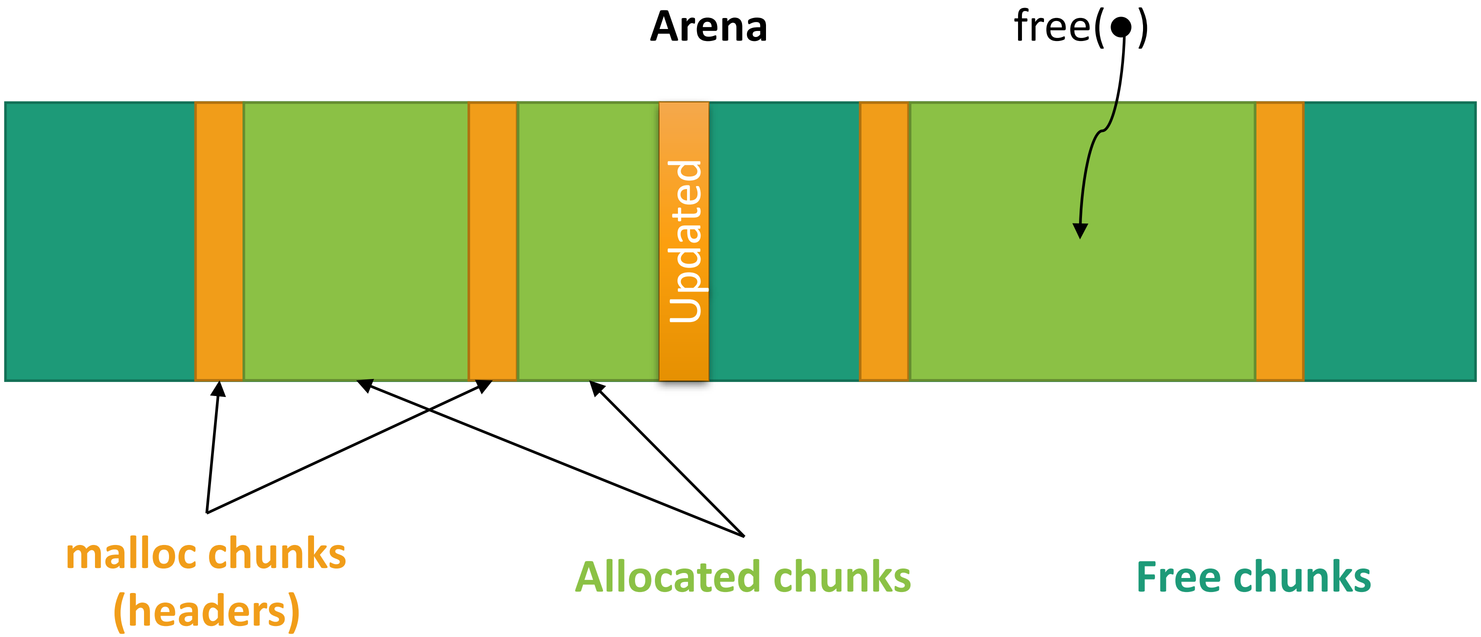


Heap Arena Structure



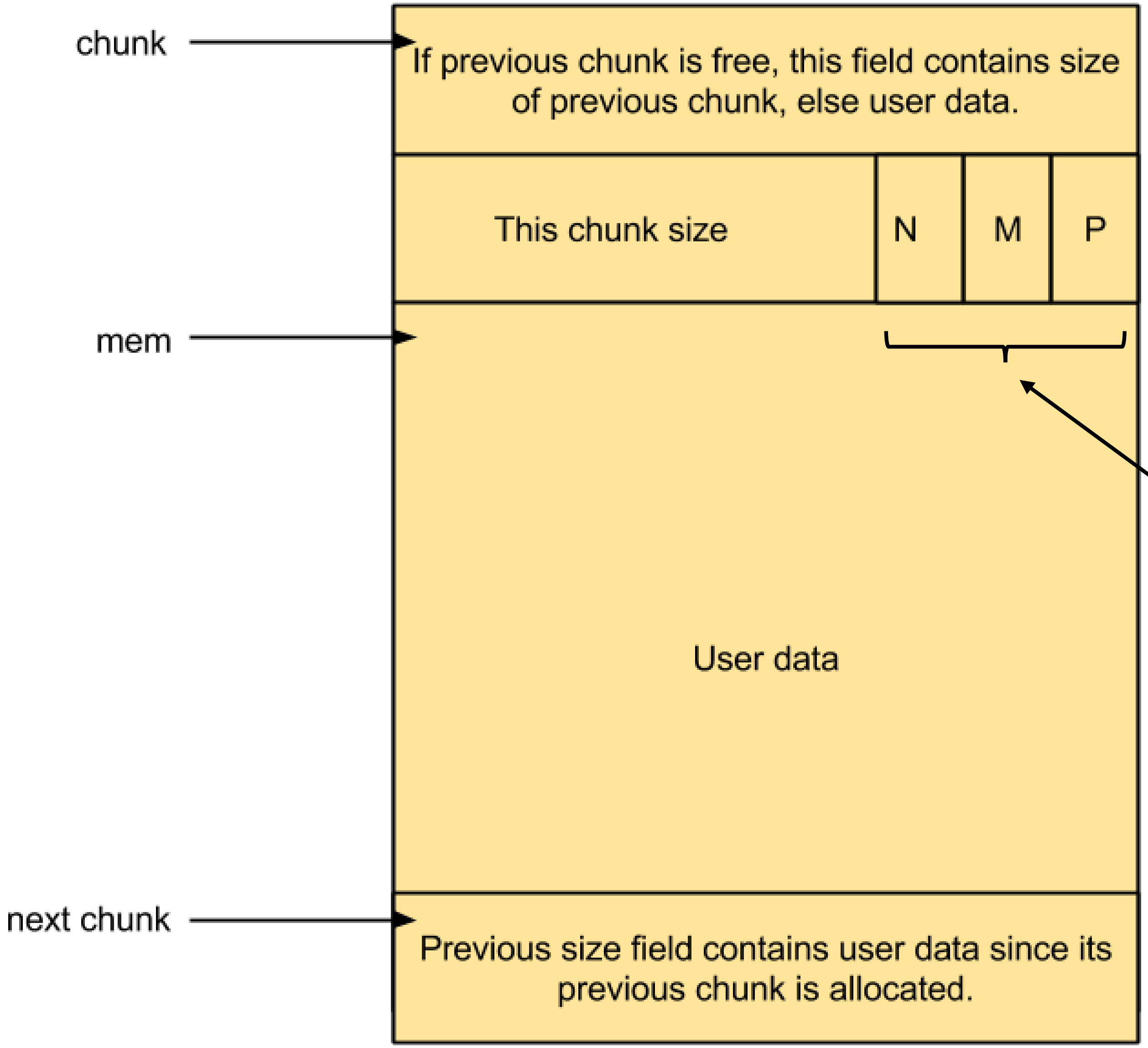
No two free chunks can be adjacent.

Heap Arena Structure



No two free chunks can be adjacent.

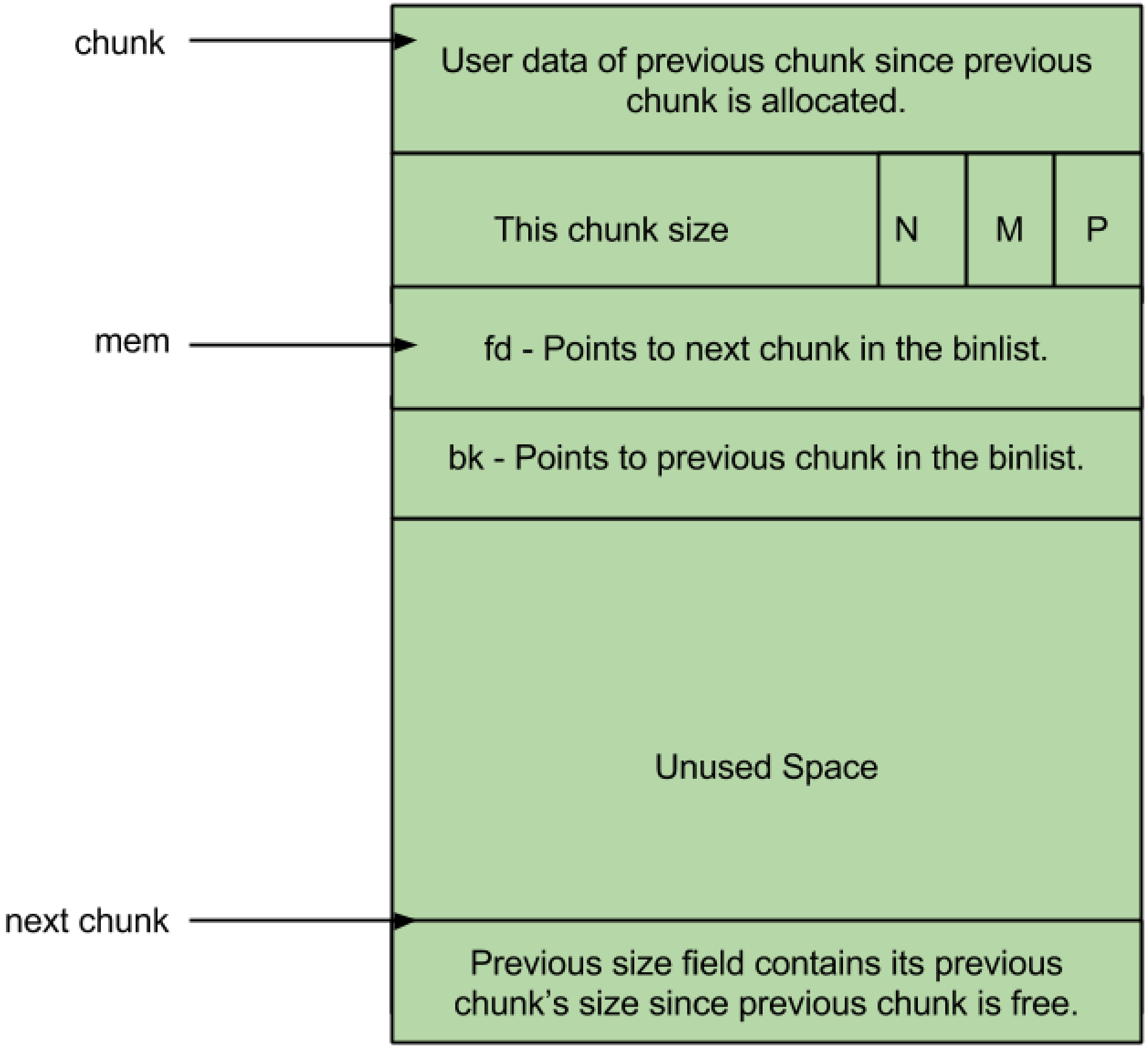
Adjacent free chunks are merged together



Allocated Chunk

Bitmap

- P - This bit is set when previous chunk is allocated
- M - This bit is set when chunk is mmap’d
- N - This bit is set when this chunk belongs to a thread arena.



chunk

User data of previous chunk since previous chunk is allocated.

This chunk size | N | M | P

mem

fd - Points to next chunk in the binlist.

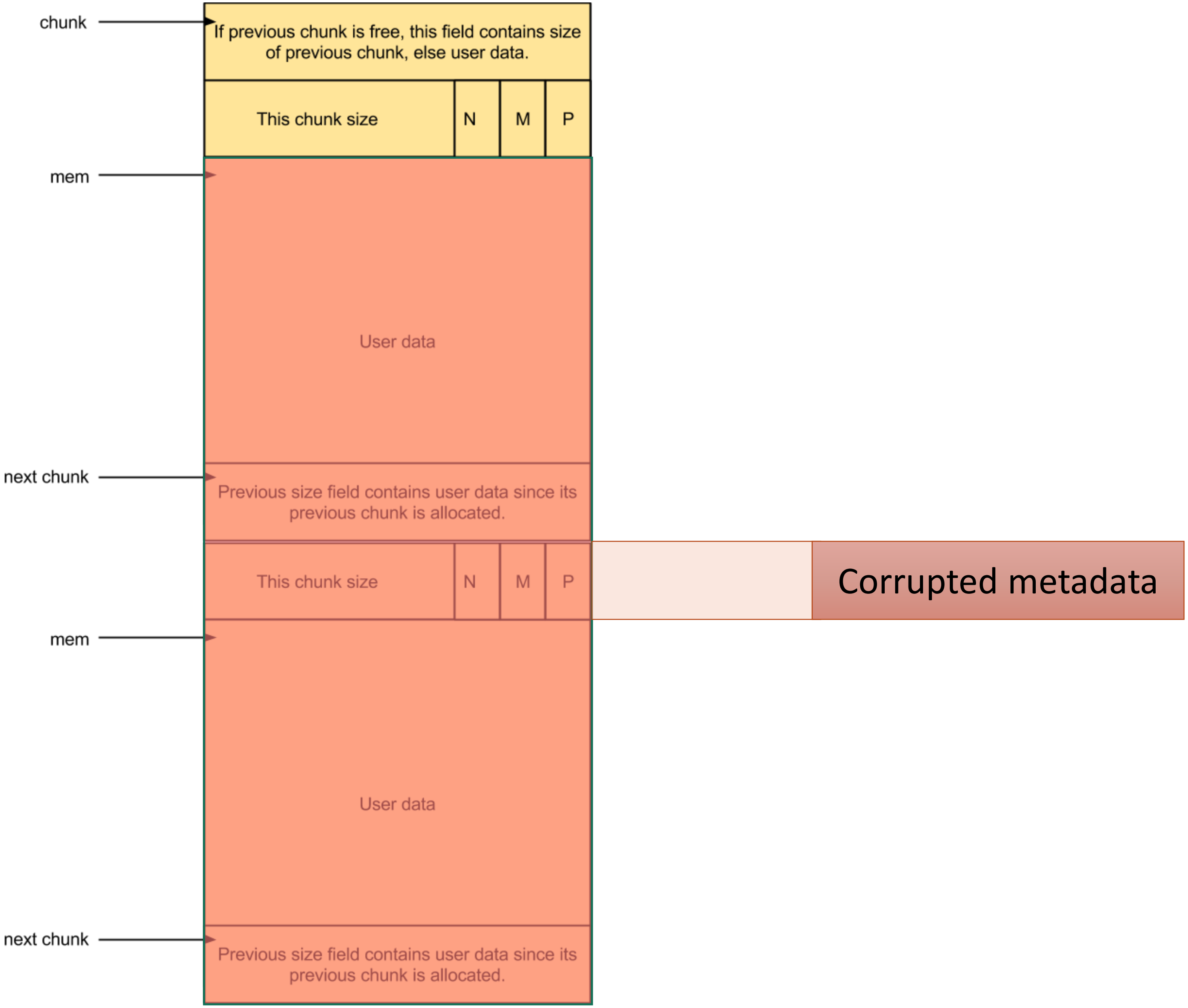
bk - Points to previous chunk in the binlist.

Unused Space

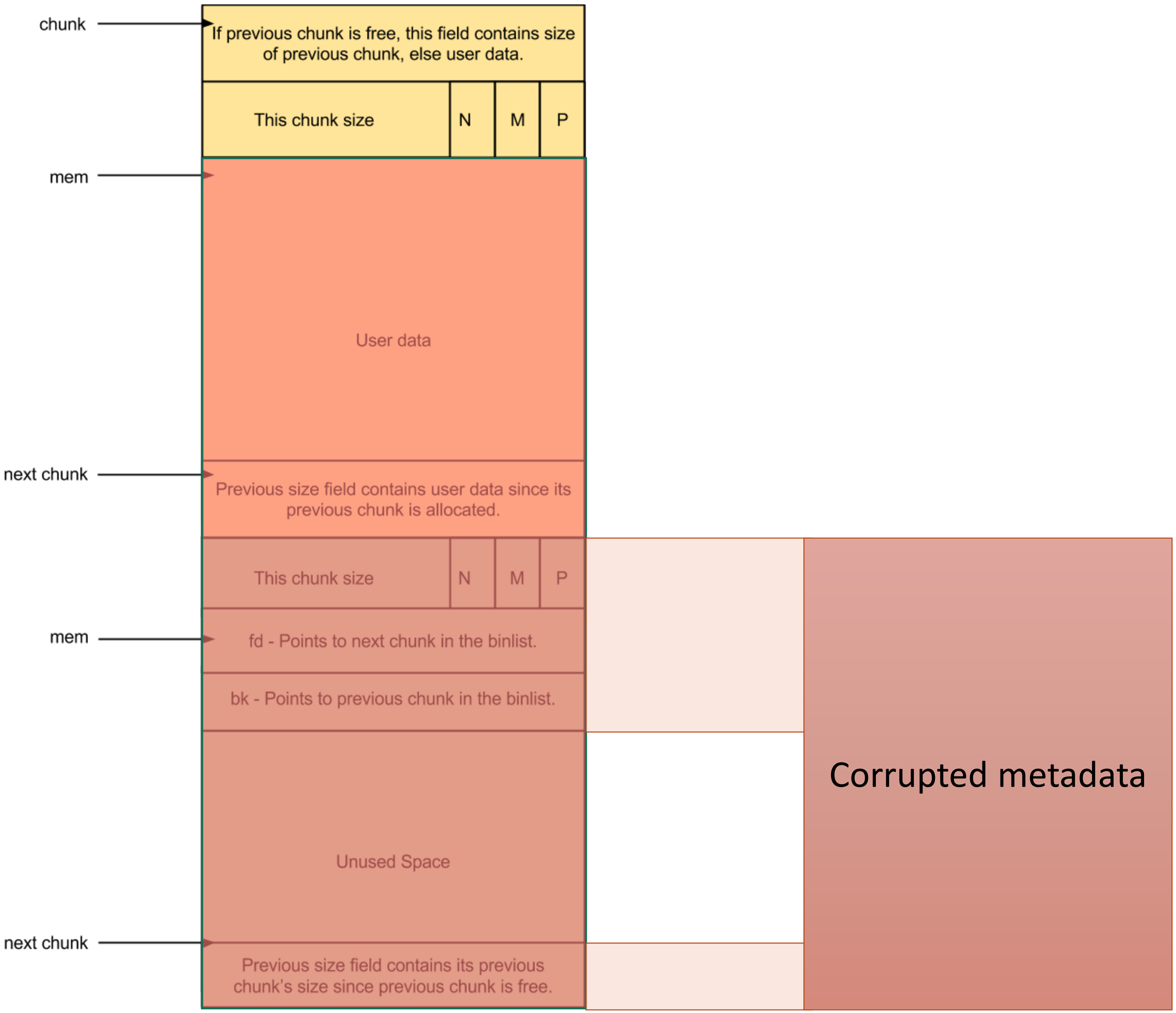
next chunk

Previous size field contains its previous chunk's size since previous chunk is free.

Free Chunk



Corrupted metadata

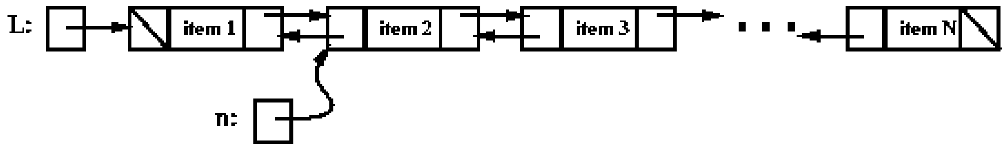


Corrupted metadata

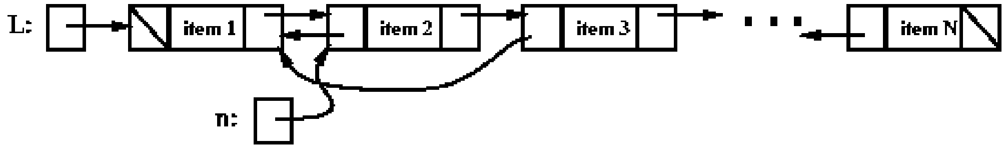
Linked-list Manipulation to Arbitrary Write

Corrupted pointers attacker controlled next and prev pointers due to the overwritten n

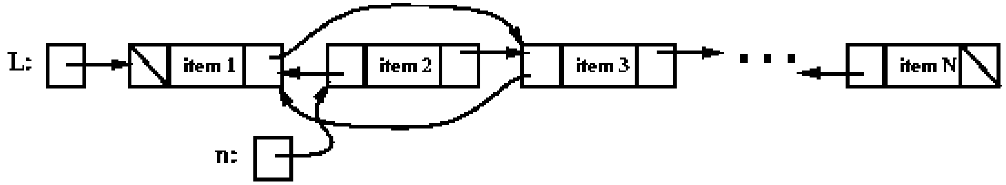
Original list, with a pointer to a node to be removed:



Step 1: Change the prev field of the node to the right of node n:



Step 2: Change the next field of the node to the left of node n (n is now removed from the list):

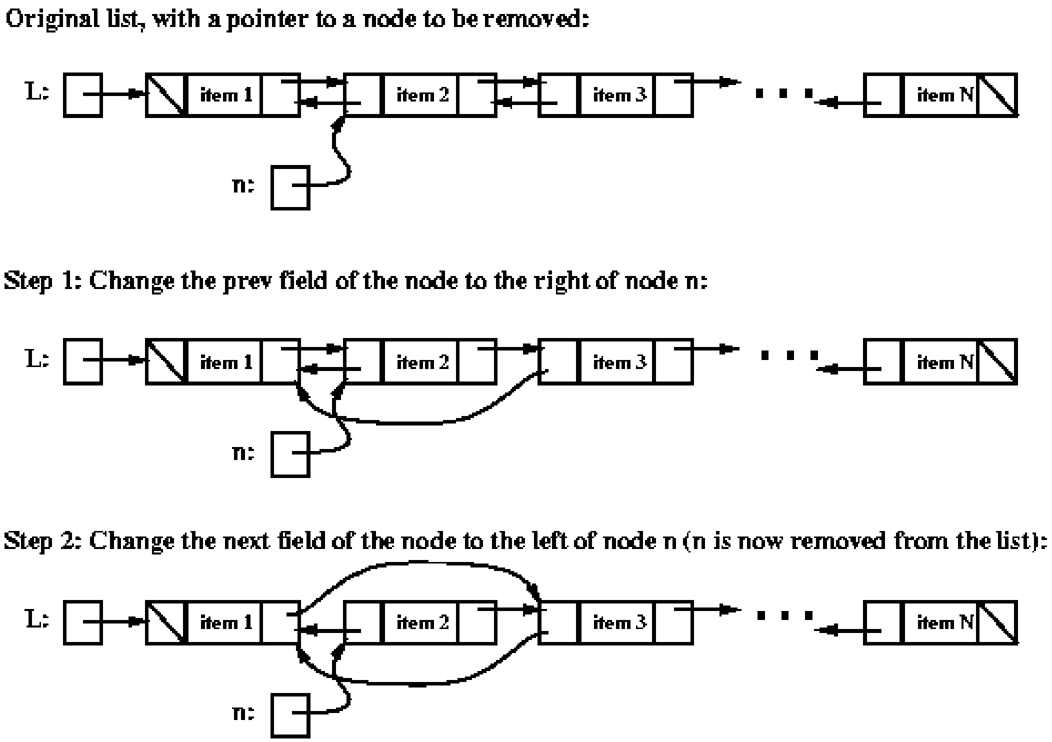


Remove *n*

```
n->next->prev = n->prev;

n->prev->next = n->next;
```

Linked-list Manipulation to Arbitrary Write



Original list, with a pointer to a node to be removed:

Step 1: Change the prev field of the node to the right of node n:

Step 2: Change the next field of the node to the left of node n (n is now removed from the list):

Remove *n*

`*(n->next + prev_offset) = n->next`

`n->next->prev = n->prev;`

`*(n->prev + next_offset) = n->next`

`n->prev->next = n->next;`

Example 1

```
int main(int argc, char **argv)
{
	int i;
	char *buf1;

	buf1 = malloc(64);
	for (i = 0; i < 200; i++)
		buf1[i] = 'A';
	return 0;
}
```

```
int main(int argc, char **argv)
{
	int i;
	char *buf1;

	buf1 = malloc(64);
	for (i = 0; i < 200; i++)
		buf1[i] = 'A';
	free(buf1);
	return 0;
}
```

Example 2

```
int main(int argc, char **argv)
{
	int i;
	char *buf1, *buf2;

	buf1 = malloc(64);
	buf2 = malloc(64);
	for (i = 0; i < 200; i++)
		buf2[i] = buf1[i] = 'A';
	free(buf2);
	free(buf1);
	return 0;
}
```

Example 2

```
int main(int argc, char *
{
	int i;
	char *buf1, *buf2;

	buf1 = malloc(64);
	buf2 = malloc(64);
	for (i = 0; i < 200; i++)
		buf2[i] = buf1[i] = 'A';
	free(buf2);
	free(buf1);
	return 0;
}
```

```
   0x00007ffff7aaa155 <+293>:   pop    %r13
   0x00007ffff7aaa157 <+295>:   pop    %r14
   0x00007ffff7aaa159 <+297>:   pop    %r15
   …
   0x00007ffff7aaa185 <+341>:   cmp    %rax,%rbx
   0x00007ffff7aaa188 <+344>:   je     0x7ffff7aaa9bf <_int_free+2447>
   0x00007ffff7aaa18e <+350>:   testb  $0x2,0x4(%r12)
   0x00007ffff7aaa194 <+356>:   je     0x7ffff7aaaa4e <_int_free+2590>
=> 0x00007ffff7aaa19a <+362>:   mov    0x8(%r13),%rax
```

```
(gdb) x $r13
0x4141414141a15190
```

```
Program received signal SIGSEGV,
Segmentation fault.
_int_free (av=0x7ffff7dd6620 <main_arena>,
p=0x601050, have_lock=0)
    at malloc.c:3966
```

Examples 3

```
int main(int argc, char **argv)
{
        int i;
        char *buf1, *buf2, *buf15;

        buf1 = malloc(64);
        buf15 = malloc(200);
        buf2 = malloc(64);
        for (i = 0; i < 200; i++)
                buf15[i] = buf2[i] = buf1[i] = 'A';
        free(buf2);
        free(buf1);
        return 0;
}
```

Double-Free Bugs

```
int main(int argc, char **argv)
{
	int i;
	char *buf1, *buf2;

	buf1 = malloc(200);
	buf2 = malloc(200);
	for (i = 0; i < 200; i++)
		buf2[i] = buf1[i] = 'A';
	free(buf2);
	free(buf2);
	return 0;
}
```

Freeing the same buffer twice can also lead to metadata corruption

- May be harder to exploit

Heap Overflows In Practice

Exploiting the allocator depends on

- The allocator's implementation
- The sequence of allocator calls in the program

The attacker may need to "guide" the program to perform a long sequence of allocations and deallocations to **align** the objects in the heap

More Attacks

Heap overflows as arbitrary writes

Format string exploits

Format String Bugs

Occurs when untrusted input is used as format string

Exploits how variadic functions and the printf-family of functions specifically work

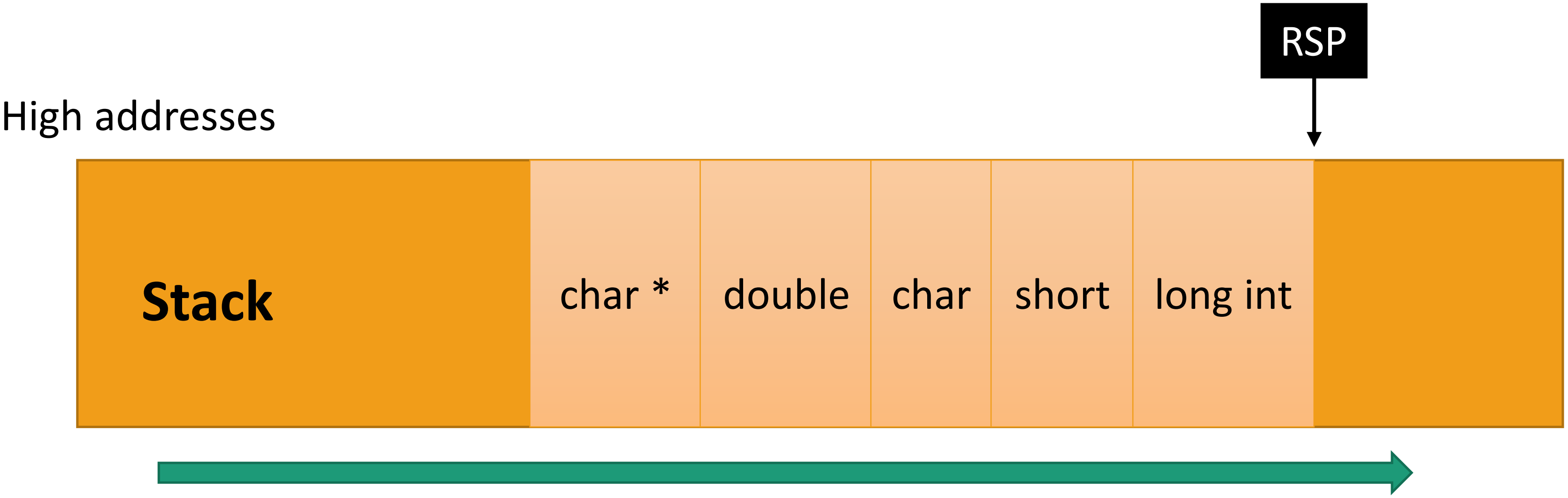
int **printf**(const char * restrict format, ...);

Argument Types and Number Based on Format String

printf("%ld %h %c %g %s", long_integer, short, character, double, string);

Arguments are pushed to the stack!

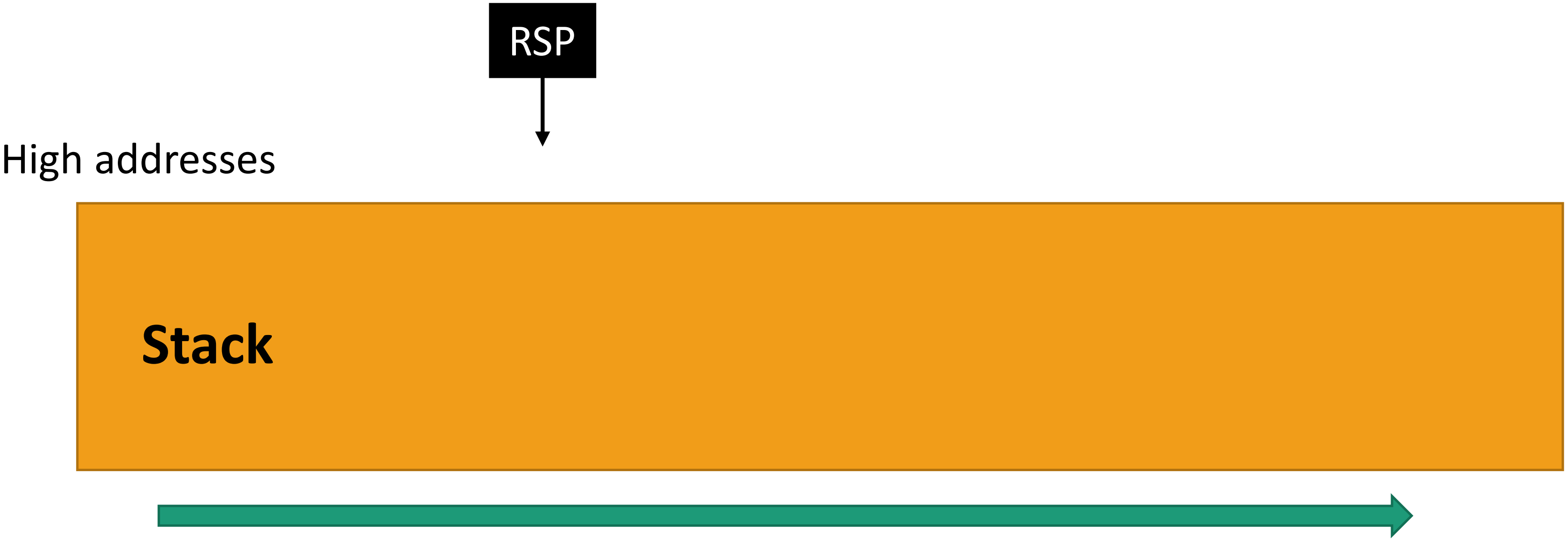
printf reads stack arguments based on the format string



Not Enough Arguments

printf(“%ld %h %c %g %s”);

What happens when there is a mismatch between format string and actual arguments?



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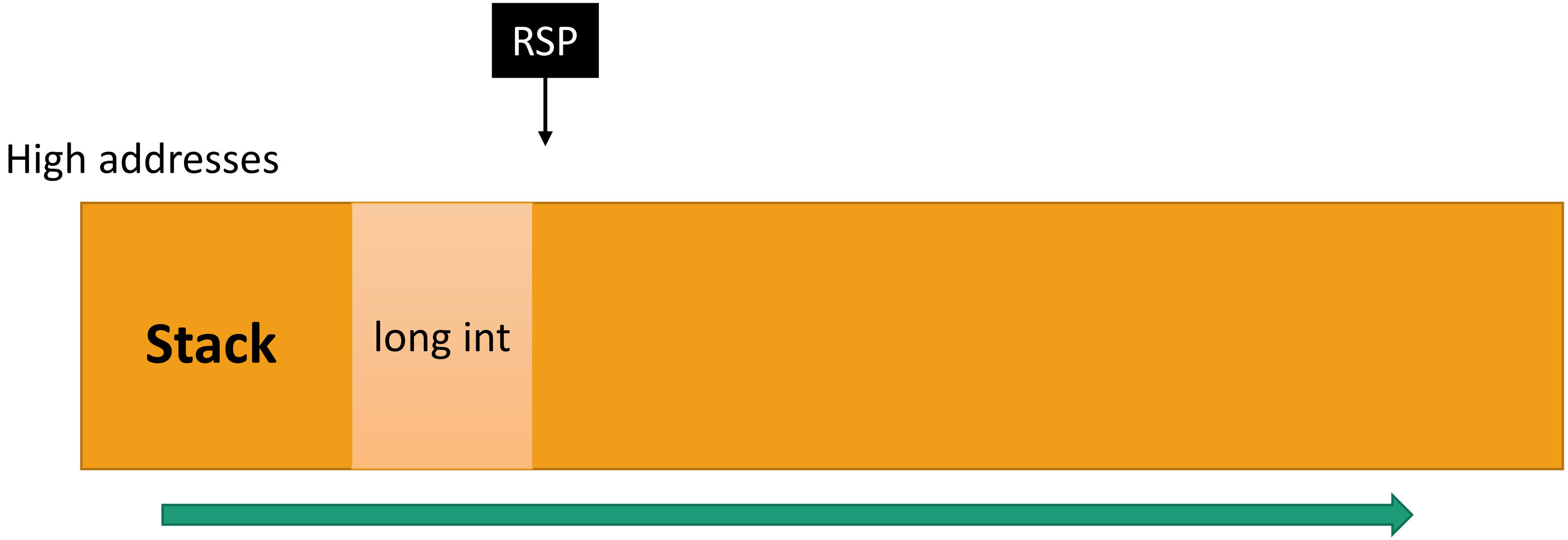
What happens when there is a mismatch between format string and actual arguments?

Memory (stack) data are leaked



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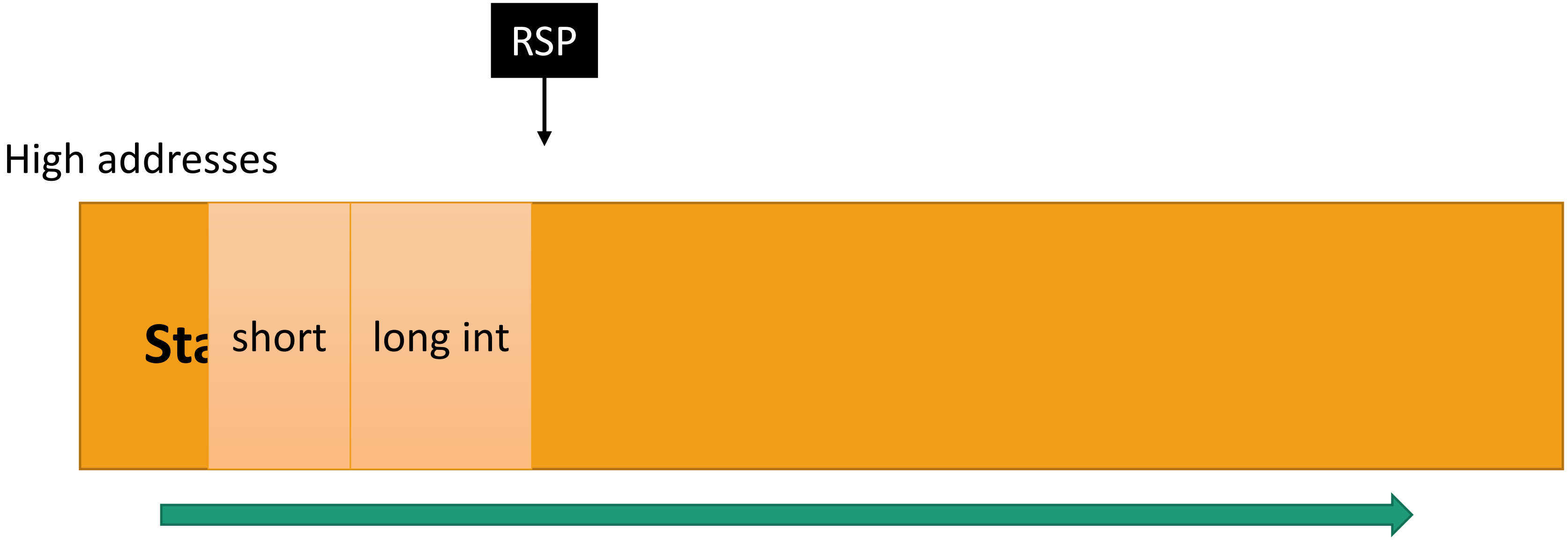

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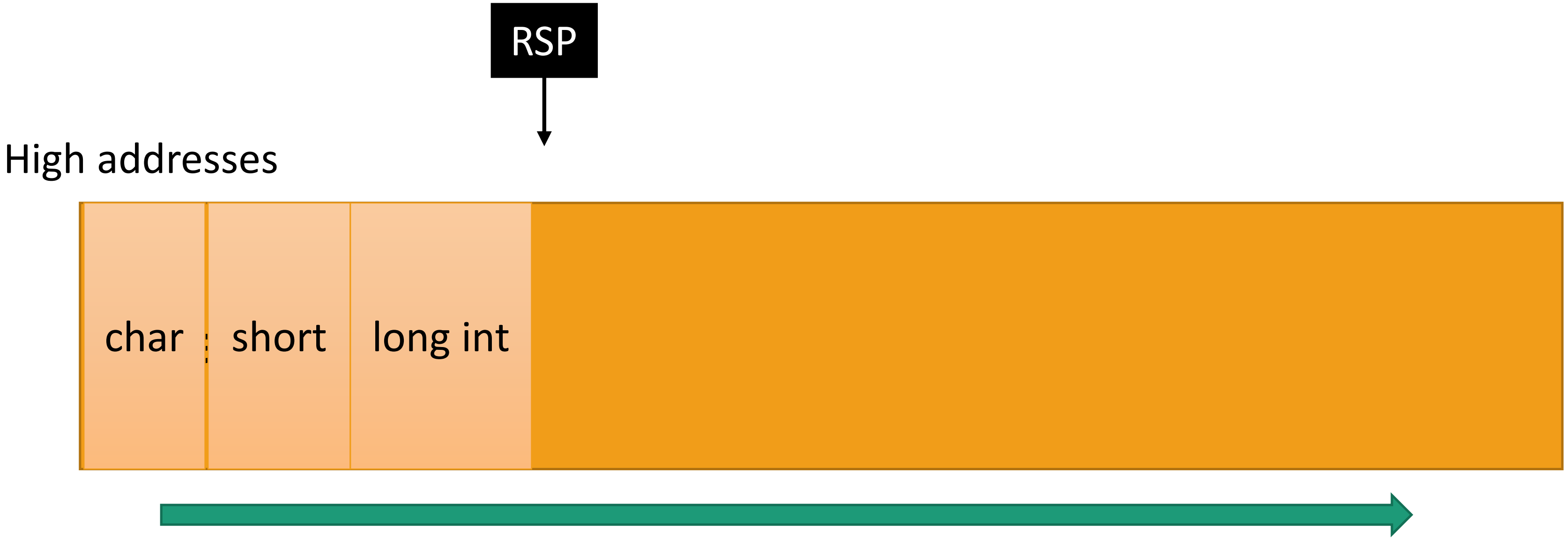
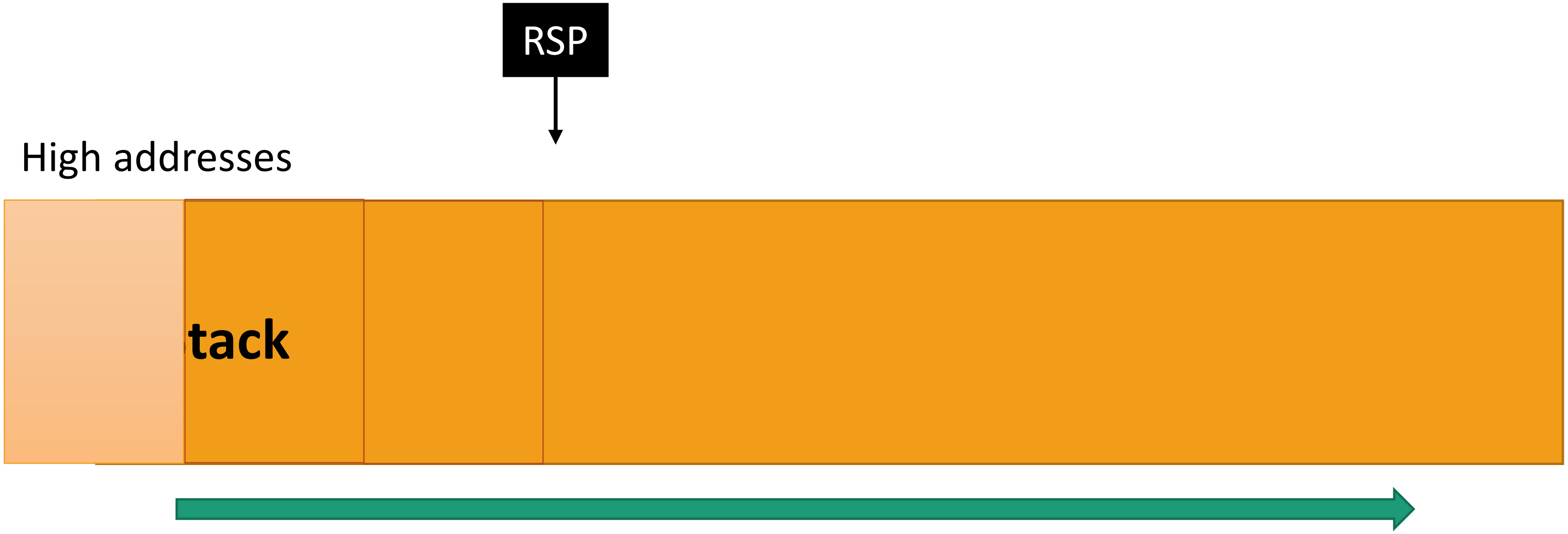


Direct Parameter Access

"%3$x" → Access the 3rd argument



Corrupting Memory Using printf

%n can be used to store the number of written characters into an integer pointer

```
int n;
long li = 100;
printf(“%ld\n%n”, li, &n);
```

Corrupting Memory Using printf

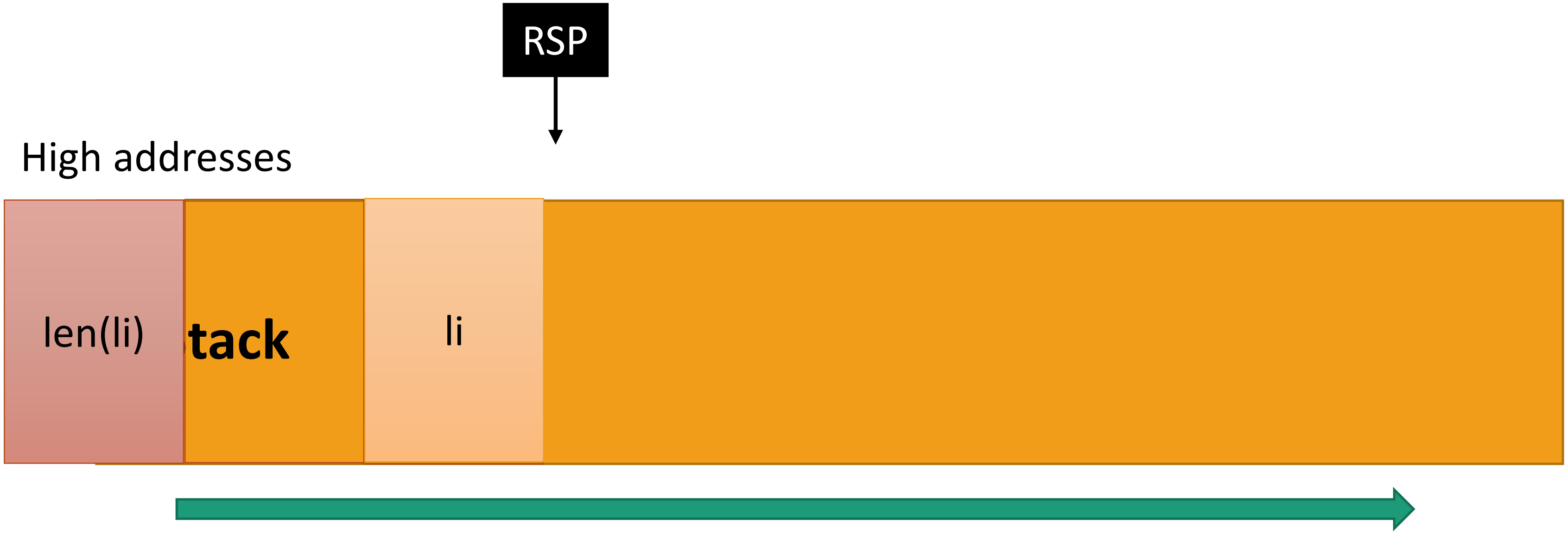
%n can be used to store the number of written characters into an integer pointer

```
int n;
long li = 100;
printf(“%ld\n%n”, li, &n);
```

n = 4

Corrupting Memory Using printf

printf(“%ld%$3n”, li);



More printf()

Length modifier (+ zero padding)

```
long li  = 23;
printf(“%0128ld\n”, li);
```

```
000000000000000000000000000000000000000000000000000000000
000000000000000000000000000000000000000000000000000000000
00000000000023
```

It is easy to write a large number of characters!

printf As An Arbitrary Write

printf(“%0128ld%$3n”, li);