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Heap Feng Shui in JavaScript

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Introduction

- What is Heap Feng Shui?
  - the ancient art of arranging heap blocks in order to redirect the program control flow to the shellcode
- Heap Feng Shui in JavaScript
  - precise application data overwrites
  - reliable browser exploitation

Overview

- State of the art in browser exploitation
- Internet Explorer heap internals
- HeapLib JavaScript library
- Heap manipulation
- Mitigation

Part I

State of the art in browser exploitation

Stack overflows

Very hard to exploit in most cases:

Target	Protection
return address	stack cookies (/GS flag)
SEH frame	SafeSEH exception handler table
local variables	local variable reordering in the Visual C++ compiler

Heap overflows

Generic heap exploitation is also difficult:

Target	Protection
doubly-linked list of free chunks	safe unlinking
heap chunk header	8-bit header cookie in XP, XOR of the header data in Vista
lookaside linked list	removed in Vista

What's left?

- Non-array stack overflows
  - very rare
- Use of uninitialized variables
  - stack variables
  - use after free
- Application data on the heap
  - application specific memory allocators
  - function pointers
  - C++ object pointers

WebView setSlice exploit

- Uses heap spraying to fill the browser heap with shellcode
- Overwrites application data in the previous heap chunk
- Multiple attempts until it either hits an object pointer, or crashes

Heap spraying

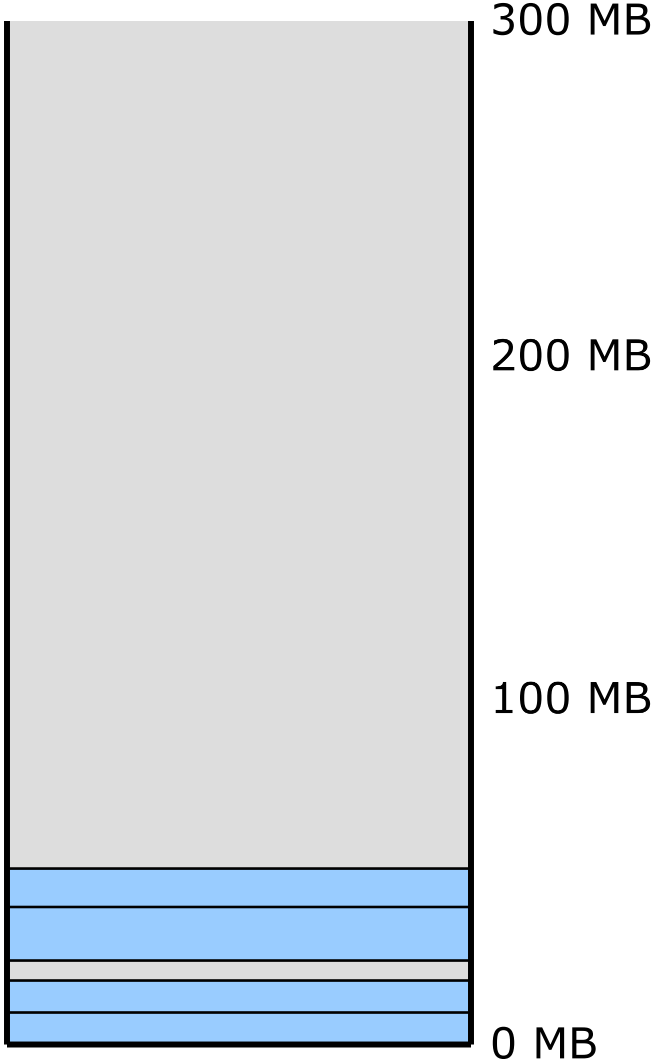
Developed by Blazde and SkyLined, used by most browser exploits since 2004.

```
var x = new Array();

// Fill 200MB of memory with copies of the
// NOP slide and shellcode

for (var i = 0; i < 200; i++) {
    x[i] = nop + shellcode;
}
```

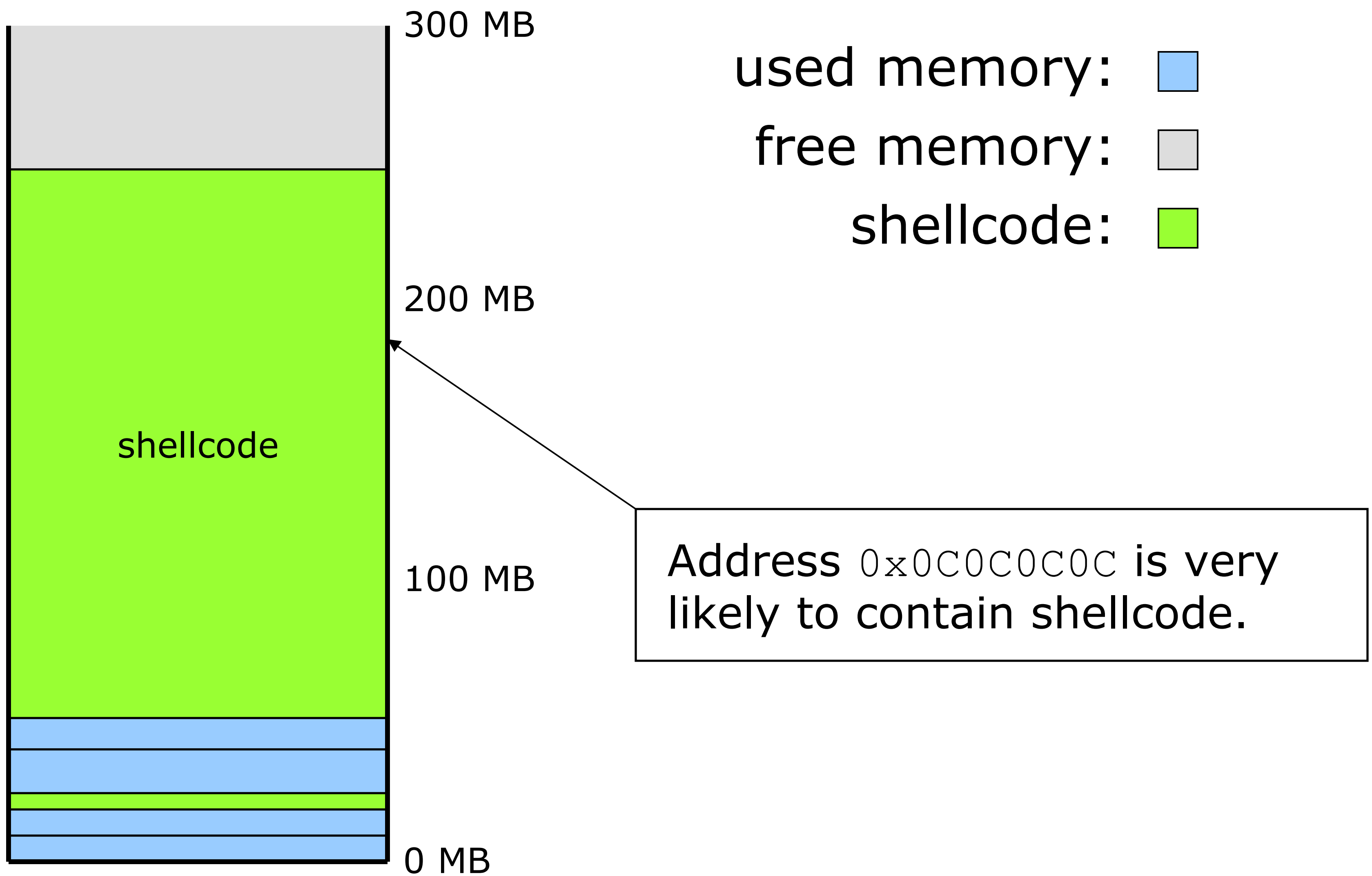
Normal heap layout



used memory:

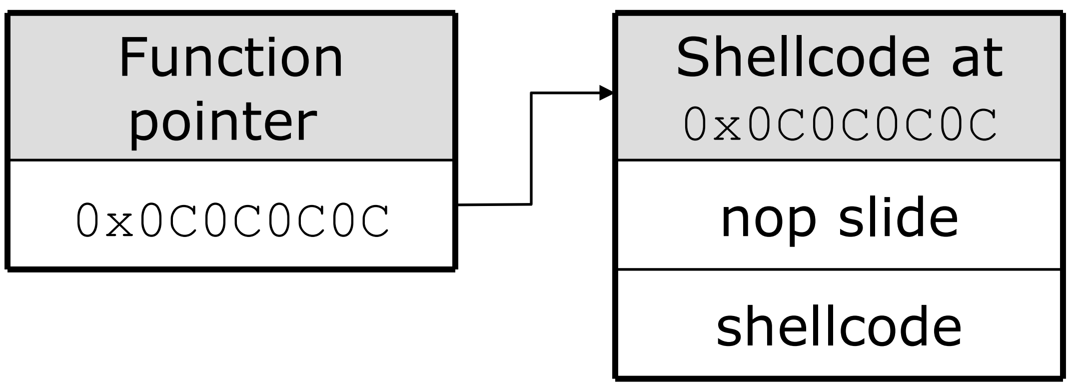
free memory:

After heap spraying



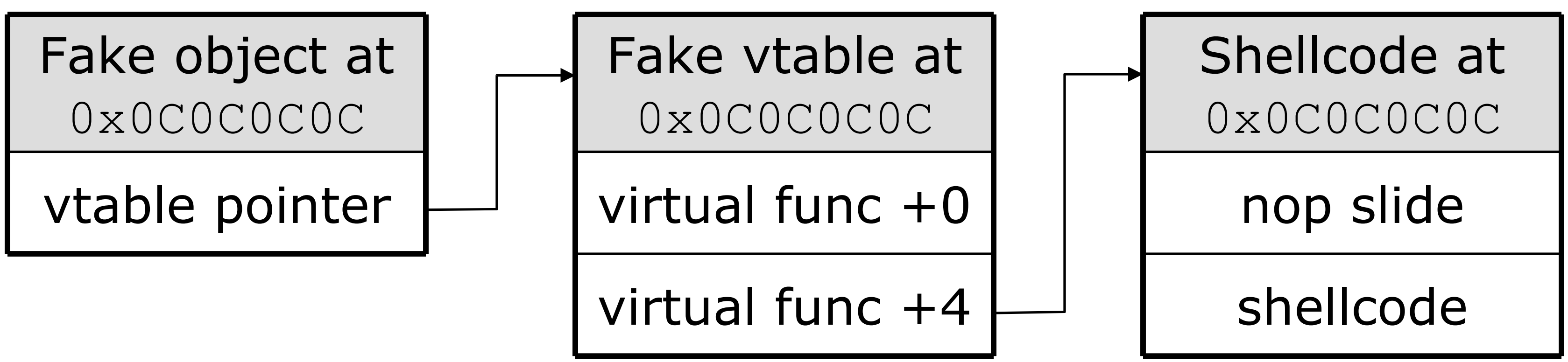
Function pointer overwrite

1. Spray the heap with 200MB of shellcode
2. Overwrite a function pointer with `0x0C0C0C0C`
3. Call the function pointer



Object pointer overwrite

1. Spray the heap with 200MB of shellcode, using byte 0xC as a nop slide
2. Overwrite an object pointer with `0x0C0C0C0C`
3. Call a virtual function of the object



Unreliable exploitation

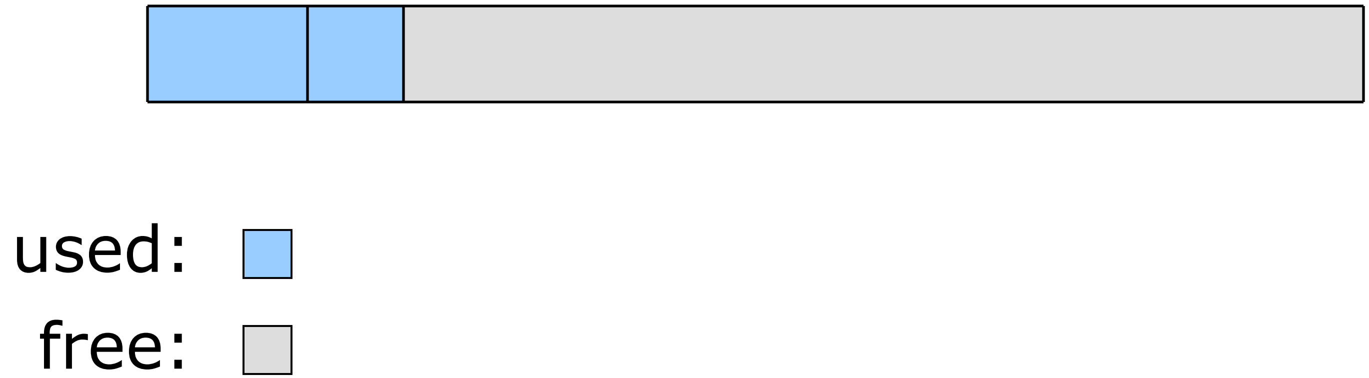
- Heap spraying is a great technique, but the setSlice exploit is still not reliable
- Overwriting application data requires a specific layout of heap chunks
- We need to control the heap state

Part II

Heap Feng Shui

Heap Feng Shui

- The heap allocator is deterministic
- Specific sequences of allocations and frees can be used to control the layout



Heap Feng Shui

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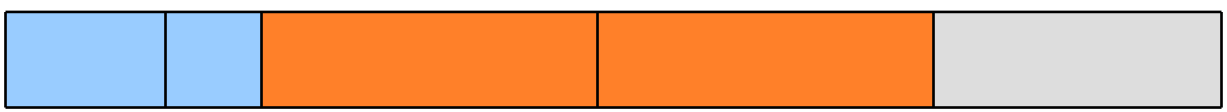

used:

free:

our data:

We allocate two 4KB blocks

Heap Feng Shui

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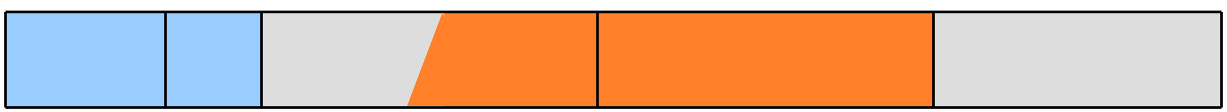

used: free: our data:

We free the first 4KB block

Heap Feng Shui

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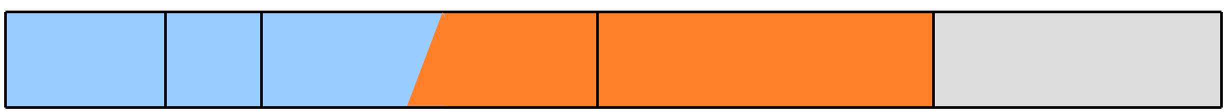

used:

free:

our data:

The application allocates a 4KB block and reuses our data

Heap Feng Shui

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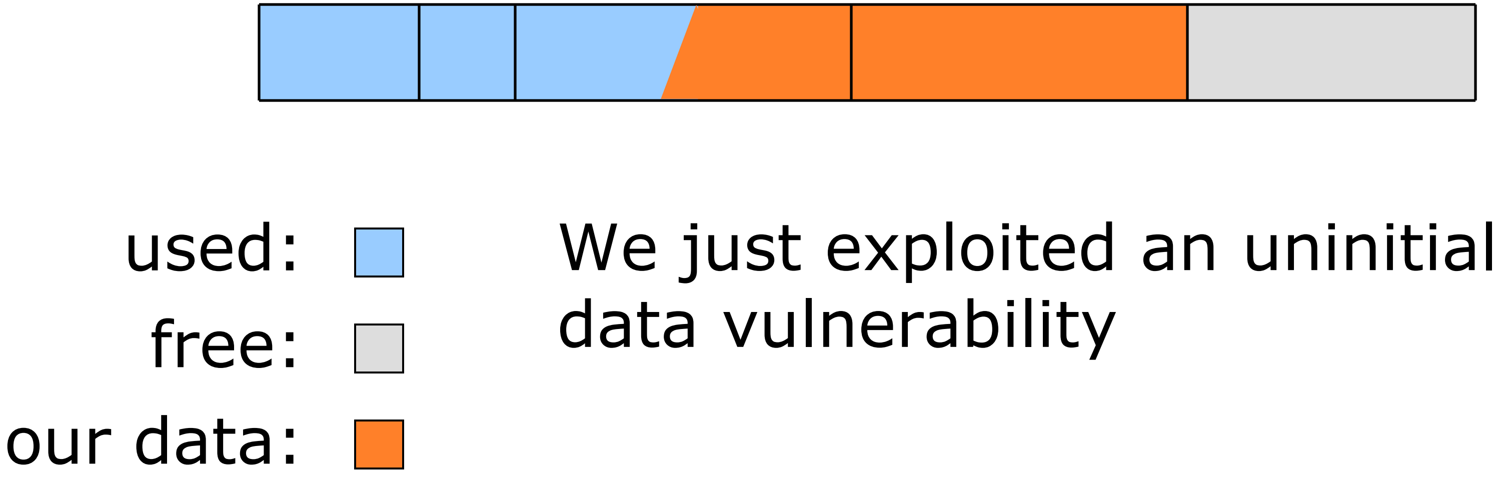


We just exploited an uninitialized data vulnerability

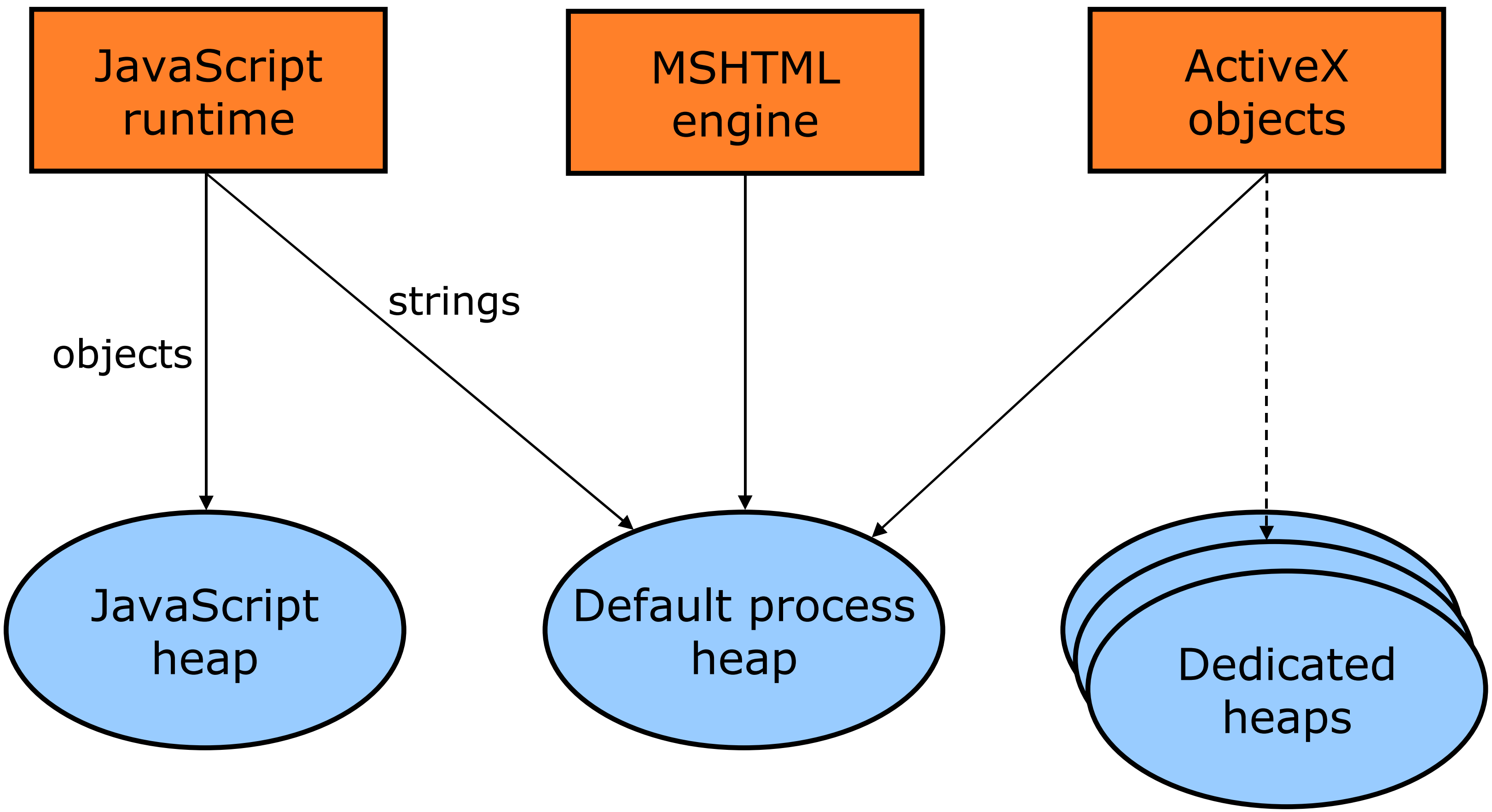
Heap Feng Shui in JavaScript

- We want to set the heap state before triggering a vulnerability
- Heap spraying proves that JavaScript can access the system heap
- We need a way to allocate and free blocks of an arbitrary size

Part III

Internet Explorer heap internals

Internet Explorer heap usage



JavaScript strings

The string "AAAA" is stored as:

string size	string data	null terminator
4 bytes	length / 2 bytes	2 bytes
`08 00 00 00`	`41 00 41 00 41 00 41 00`	`00 00`

We can calculate its size in bytes with:

```
bytes = len * 2 + 6
len = (bytes - 6) / 2
```

String allocation

```
var str1 = "AAAAAAAAAA";  // no allocation

// allocates a 10 character string
var str2 = str1.substr(0, 10);

// allocates a 20 character string
var str3 = str1 + str2;
```

String garbage collection

- Mark-and-sweep algorithm, frees all unreferenced objects
- Triggered by a number of heuristics
- Explicitly by the `CollectGarbage()` call in Internet Explorer

JavaScript alloc and free

```
var padding = "AAAAAAAAAAAAAAAAAAAAAAAAAAAAA…"
var str;

function alloc(bytes) {
      str = padding.substr(0, (bytes-6)/2);
}

function free() {
      str = null;
      CollectGarbage();
}

alloc(0x10000);    // allocate 64KB memory block
free();            // free memory block
```

OLEAUT32 allocator

Not all string allocations and frees reach the system memory allocator

- custom memory allocator in OLEAUT32
- caching of free memory blocks
- 4 bins for blocks of different sizes
- up to 6 free blocks stored in each bin

OLEAUT32 alloc function

```
bin = the right bin for the requested size

if (bin not empty)
     find a block in the bin > requested size
     if (found)
          return block
     else
          return sysalloc(size)
else
     return sysalloc(size)
```

OLEAUT32 free function

```
bin = the right bin for the block size

if (bin not full)
     add block to bin
else
     find the smallest block in the bin
     if (smallest block < new block)
          sysfree(smallest block)
          add new block to bin
     else
          sysfree(new block)
```

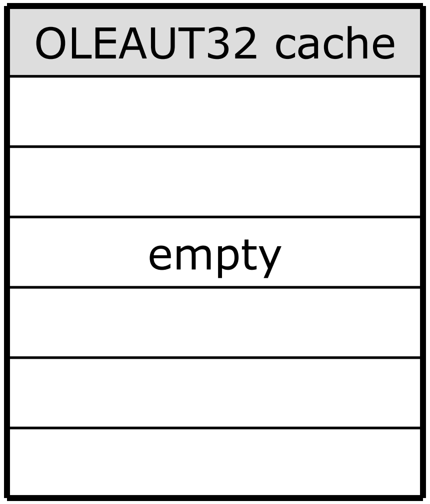
Bypassing the cache

- Our freed blocks will go into the cache
- Freeing 6 maximum sized blocks for each bin will push all smaller blocks out
- Allocating the 6 blocks again will leave the cache empty
- When the cache is empty, allocations will come from the system heap

Plunger Technique

1. Allocate 6 maximum size blocks
2. Allocate our blocks
3. Free our blocks
4. Free 6 maximum size blocks
5. Allocate 6 maximum size blocks

maximum size blocks



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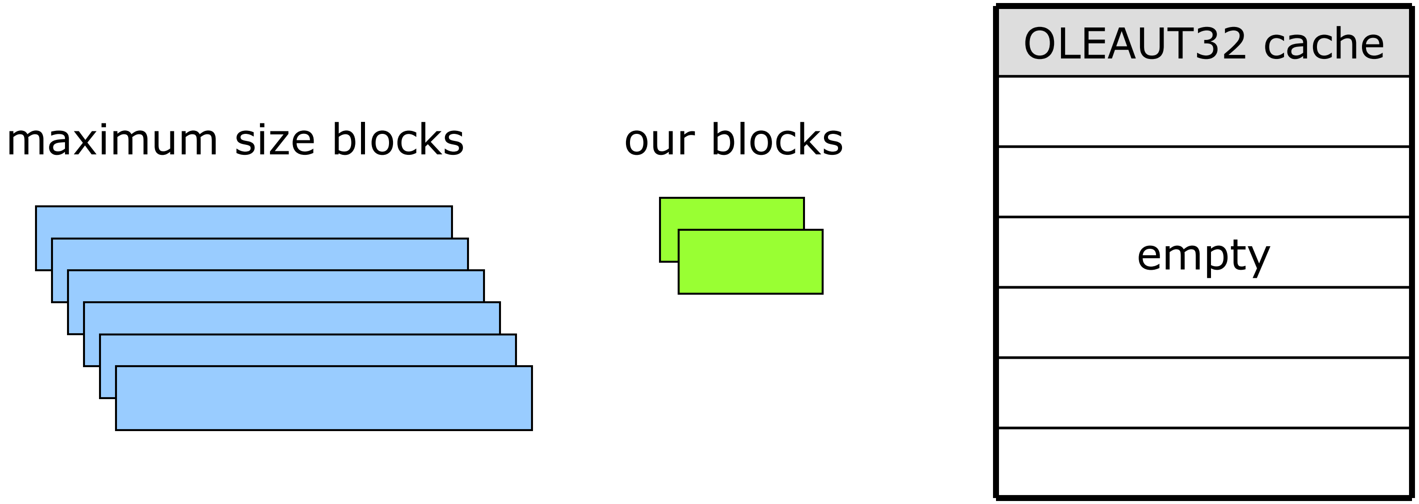

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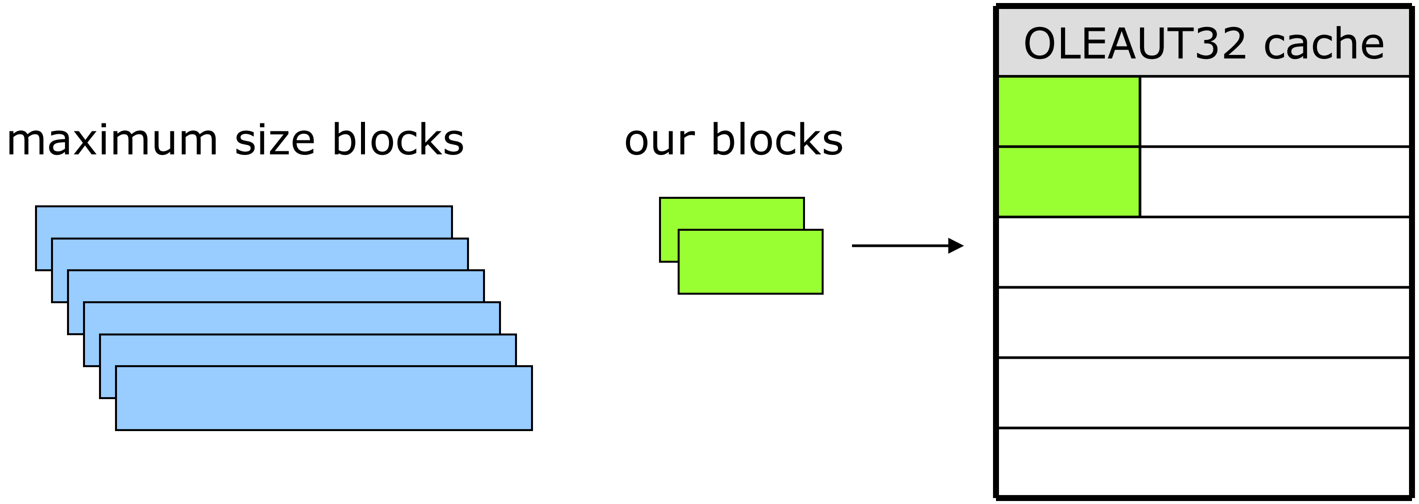

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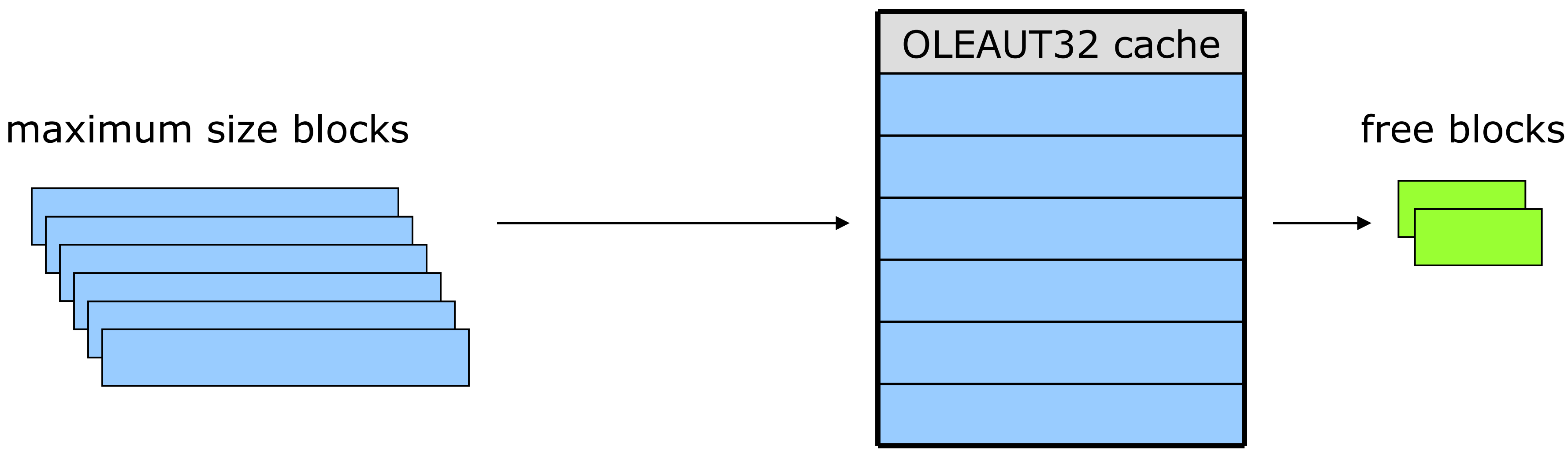

Plunger Technique

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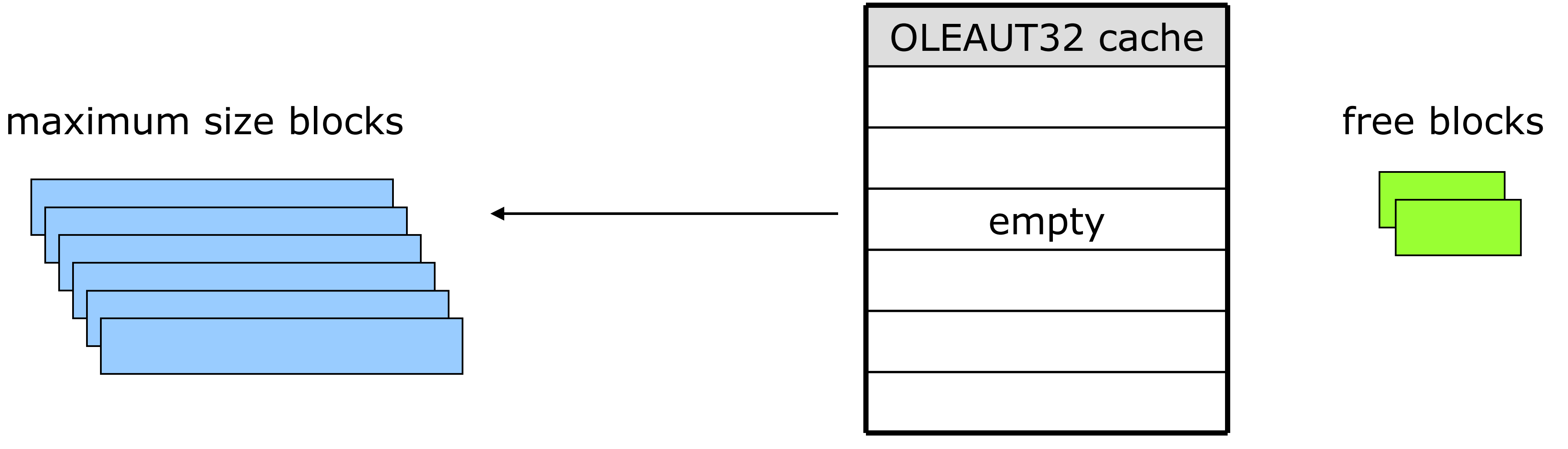

Part IV

HeapLib - JavaScript heap manipulation library

Introducing HeapLib

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- Supports Internet Explorer 5-7
- Object oriented API
- Functions for:
  - heap logging and debugging
  - allocation and freeing of blocks with arbitrary size and contents
  - high-level heap manipulation function (not yet supported on Vista)

Hello world!

determina

```
<script src="heapLib.js"></script>

<script>
   var heap = new heapLib.ie();
   heap.gc();

   heap.debugHeap(true);

   heap.alloc(512);
   heap.alloc("BBBBB", "foo");

   heap.free("foo");

   heap.debugHeap(false);
</script>
```

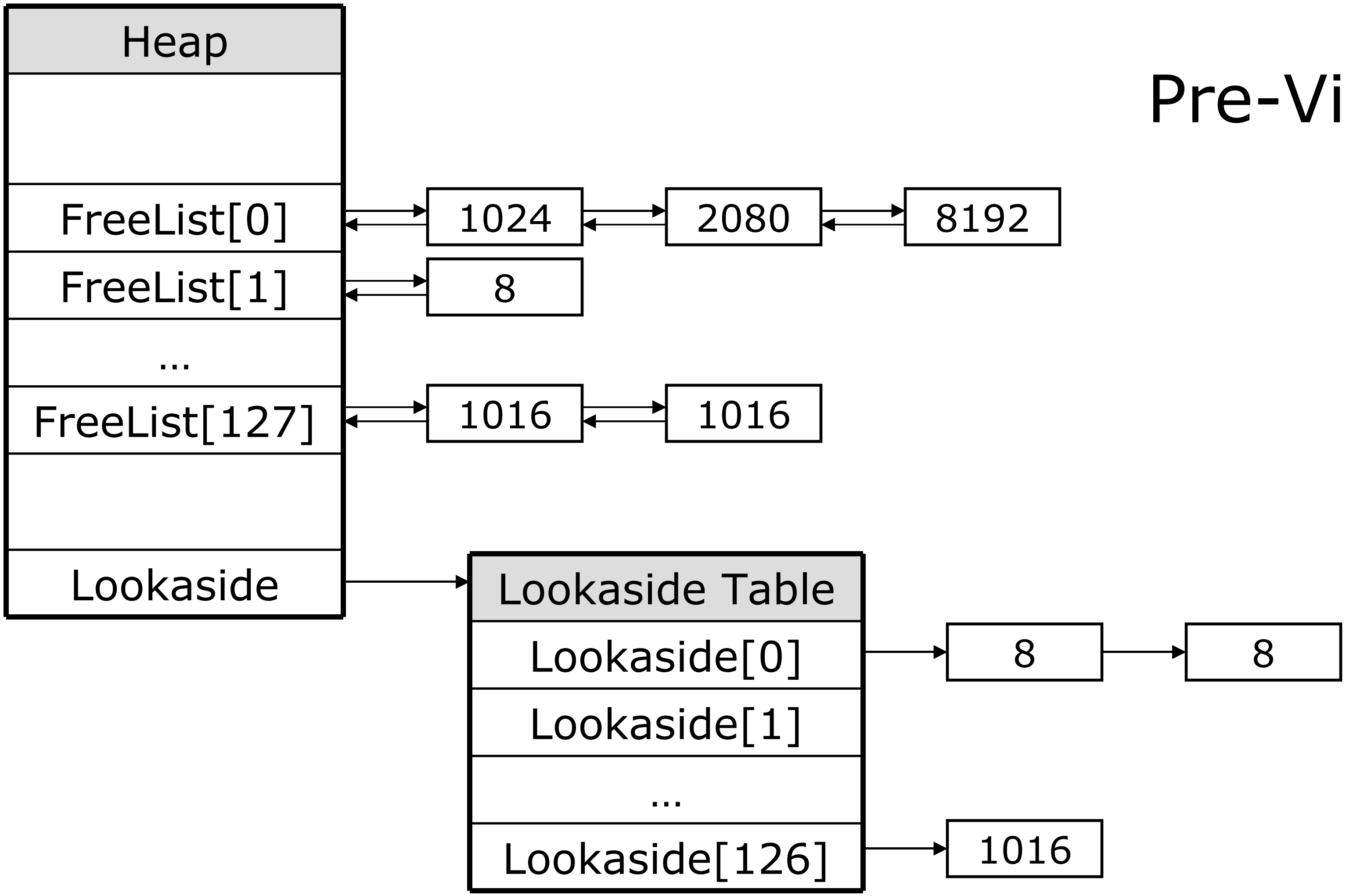
HeapLib Demo

Part V

Windows Heap Manipulation

Windows Heap Overview

Pre-Vista



Free Algorithm

```
if size >= 512KB
      free with VirtualFree
      return

if size < 1KB and lookaside not full
      add to lookaside list
      return

coalesce block with free blocks around it

if size < 1KB
      add to FreeList[size/8]
else
      add to FreeList[0]
```

Allocate Algorithm

```
if size >= 512KB
      alloc with VirtualAlloc
      return

if size < 1KB
      if lookaside not empty
            return a block from the lookaside
      if FreeList[size/8] not empty
            return a block from FreeList[size/8]

if FreeList[0] not empty
      return a block from FreeList[0]

allocate more memory with VirtualAlloc
```

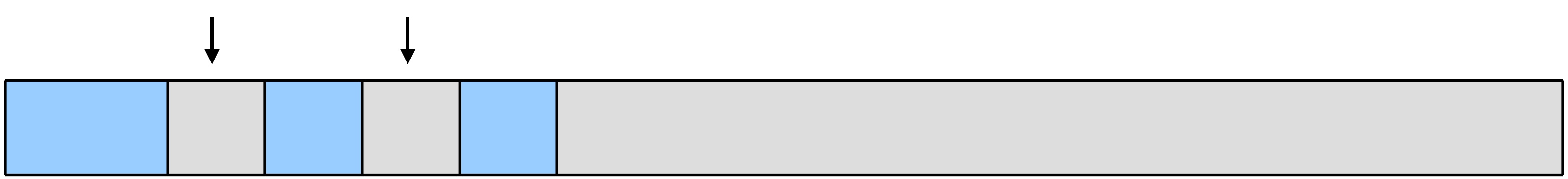
Defragmenting the heap

To allocate two consecutive blocks, we need to defragment the heap.

```
for (var i = 0; i < 1000; i++)
    heap.alloc(0x2010);
```

used:

free:



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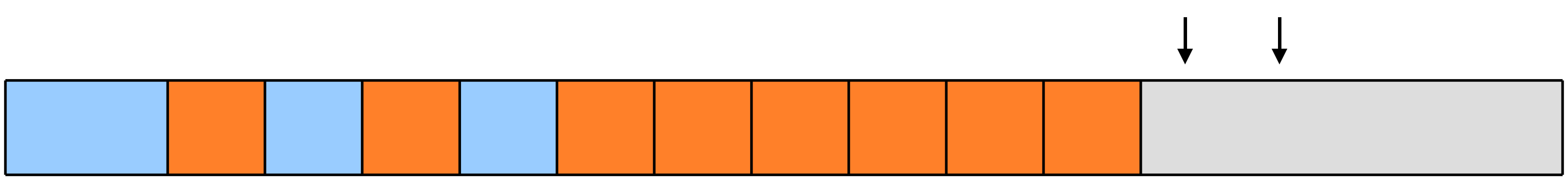


Putting a block on the FreeList

To put a block on the free list, we need to ensure that it is not coalesced.

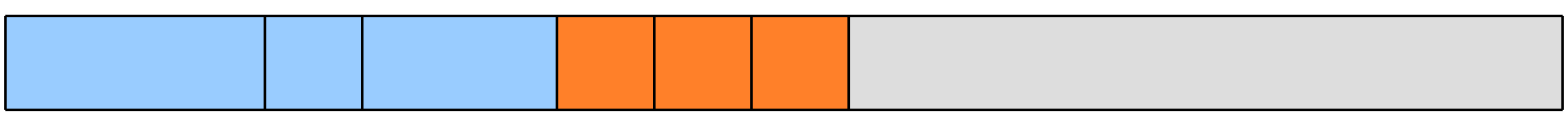
```
heap.alloc(0x2010, "foo");
heap.alloc(0x2010);
heap.alloc(0x2010, "foo");

heap.free("foo");
```

used:

free:

our blocks:



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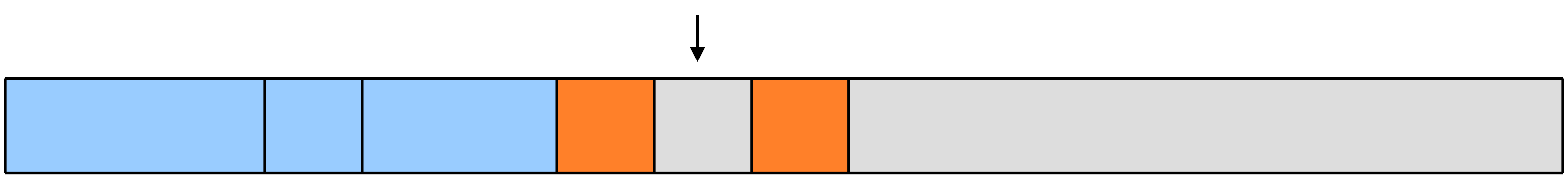


Emptying the lookaside

To empty the lookaside, allocate enough blocks of the same size.

```
for (var i = 0; i < 100; i++)
   heap.alloc(512);
```

Freeing to the lookaside

To put a block on the lookaside, empty it and free the block.

```
for (var i = 0; i < 100; i++)
   heap.alloc(512);

heap.alloc(512, "foo");
heap.free("foo");
```

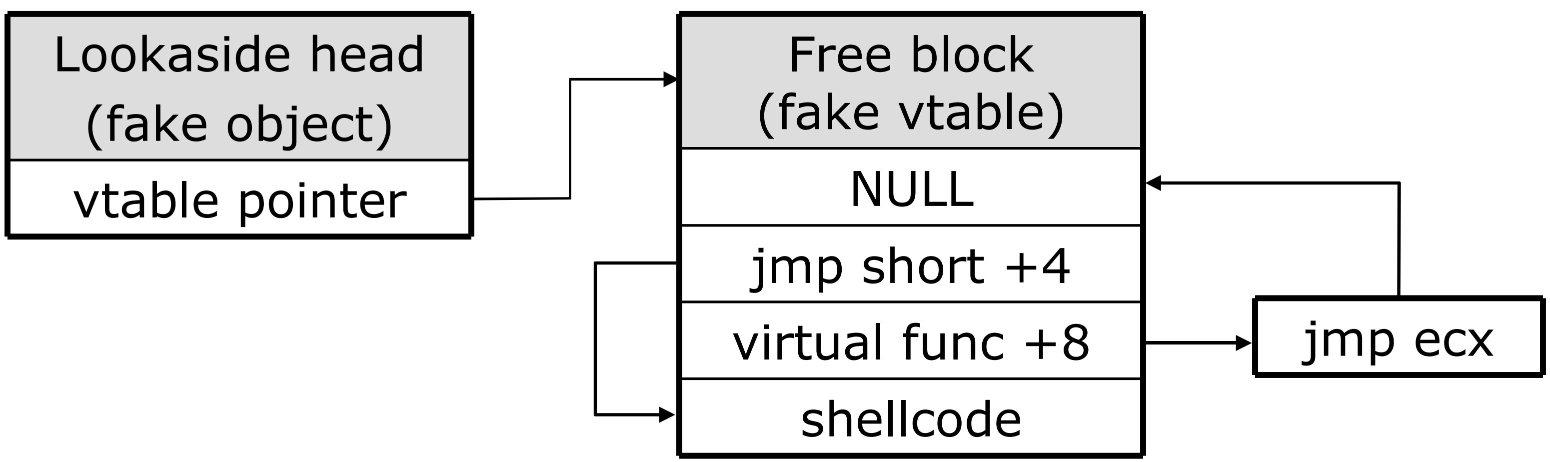
Object pointer overwrite

The lookaside linked list can be used to exploit object pointer overwrites without heap spraying.

1. Empty the lookaside
2. Build a fake vtable block
3. Free the fake vtable to the lookaside
4. Overwrite an object pointer with the address of the lookaside head
5. Call a virtual function of the object

Object pointer overwrite

```
mov ecx, dword ptr [eax]   ; get the vtable address
push eax                   ; push the 'this' pointer
call dword ptr [ecx+08h]   ; call virtual func
```



NULL disassembles as two `sub [eax], al` instructions

Exploit Demo

Mitigation

- Heap isolation
- Non-determinism in the heap allocator

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Questions?

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