# 風水

# 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,<br>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

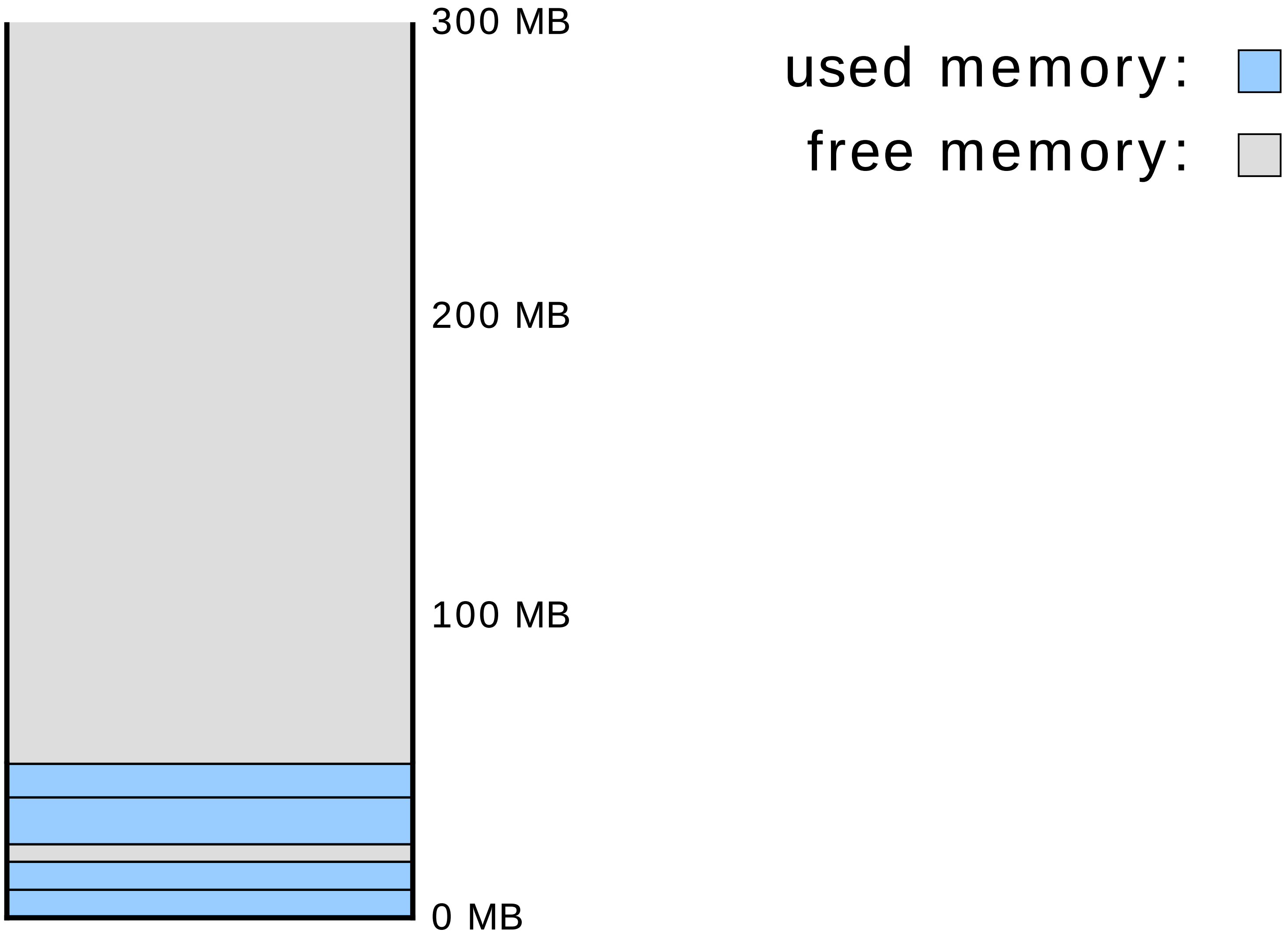
Developed by Blazde and SkyLined, used by most browser exploits since 2004.

```
var x = new Array();

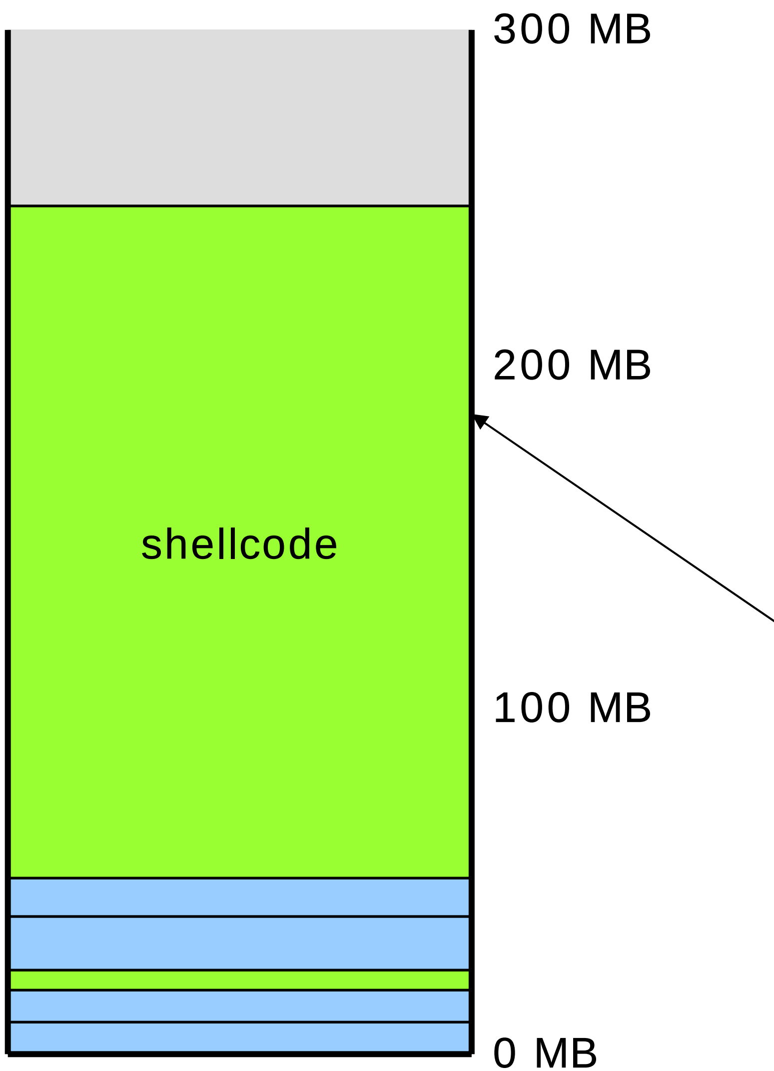
// Fill 200MB of memory with copies of the
// NOP slide and shellcode

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

# Normal heap layout



# After heap spraying




used memory:

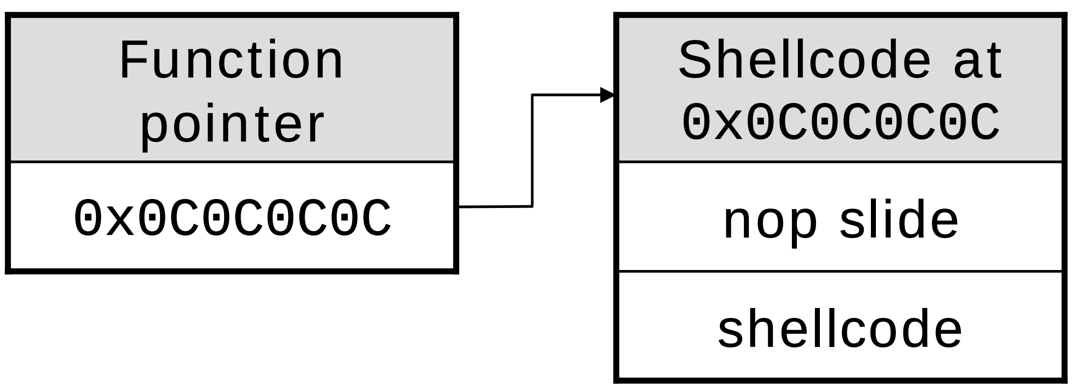
free memory:

shellcode:

Address `0x0C0C0C0C` is very likely to contain shellcode.

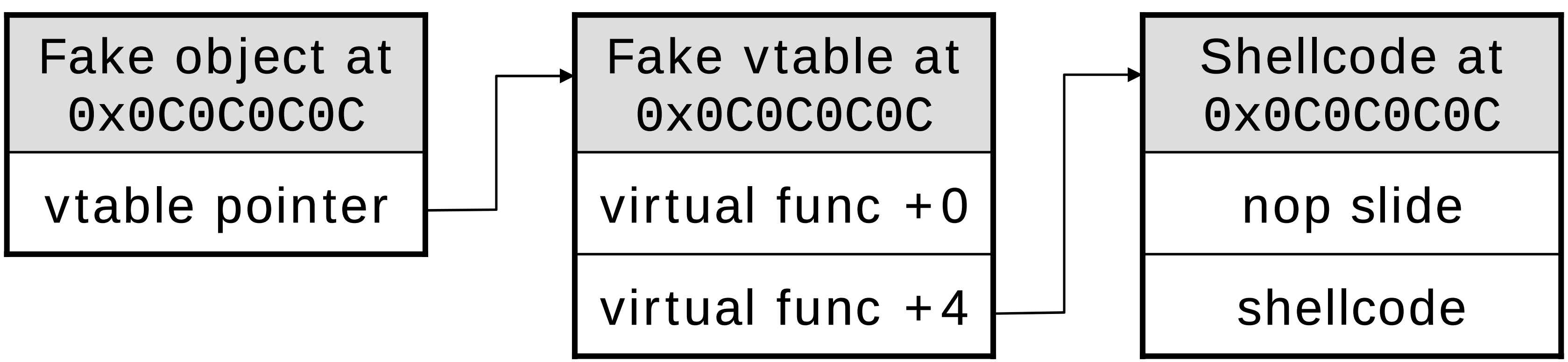
# Function pointer overwrite

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

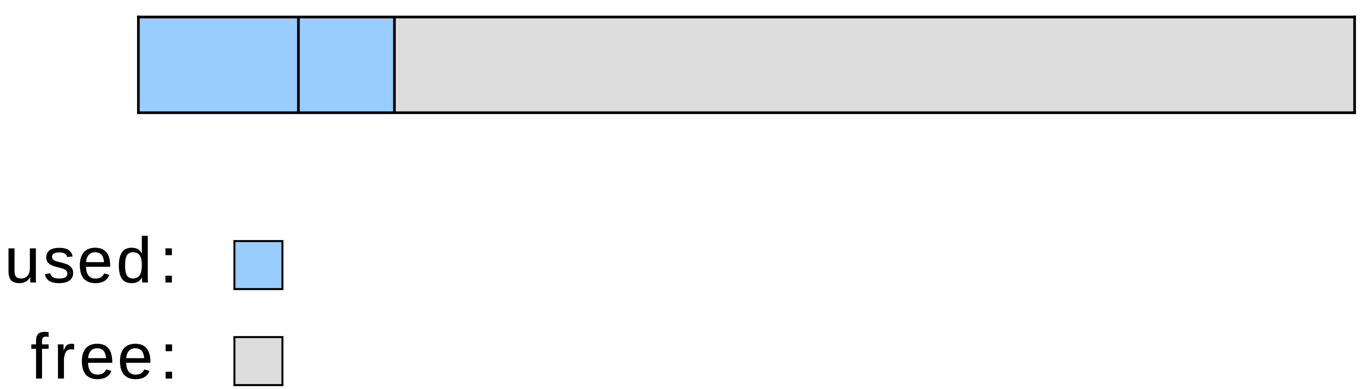
- Heap spraying is a great technique, but the setSlice exploit is still not reliable
- Overwriting application data requires a specific layout of heap chunks
- We need to control the heap state

# 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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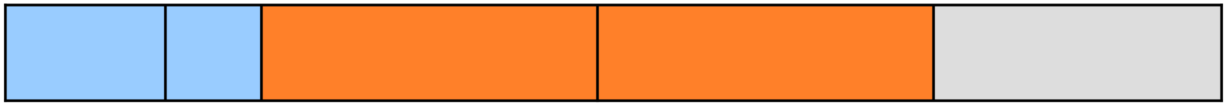

used:

free:

our data:

We allocate two 4KB blocks

# Heap Feng Shui

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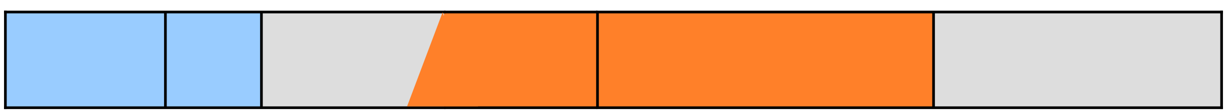

used:
free:
our data:

We free the first 4KB block

# Heap Feng Shui

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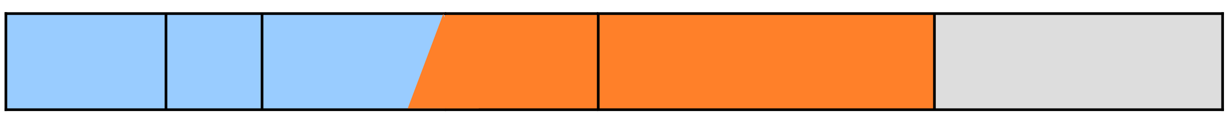

used:

free:

our data:

The application allocates a 4KB block and reuses our data

# Heap Feng Shui

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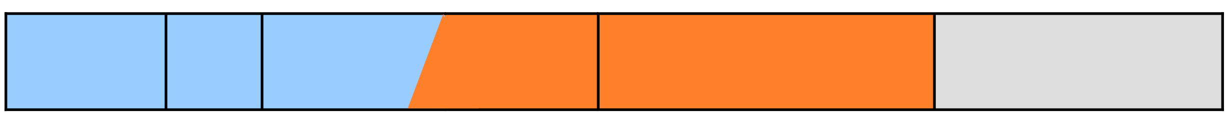


used:

free:

our data:

We just exploited an uninitialized data vulnerability

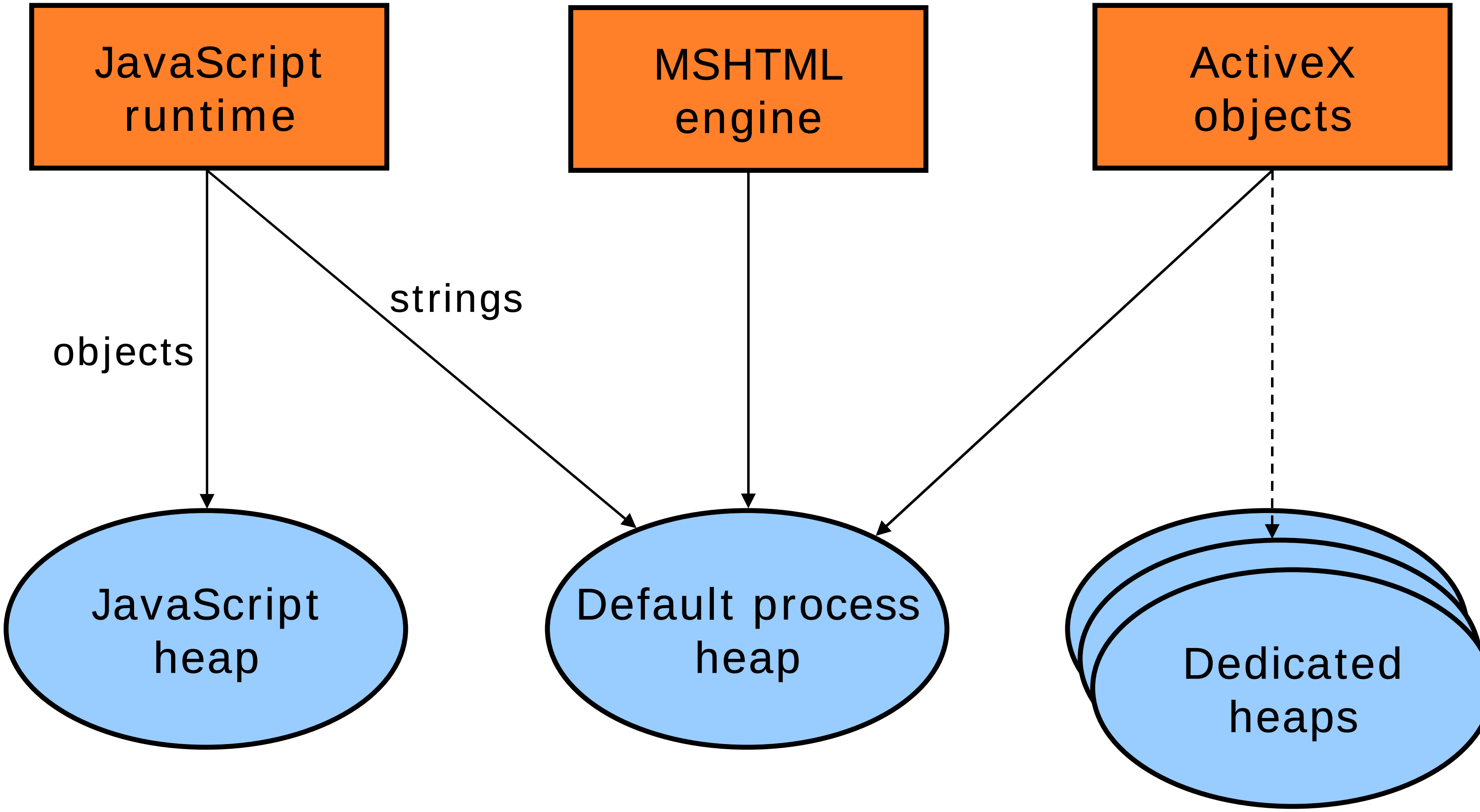
# Heap Feng Shui in JavaScript

- 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)
```

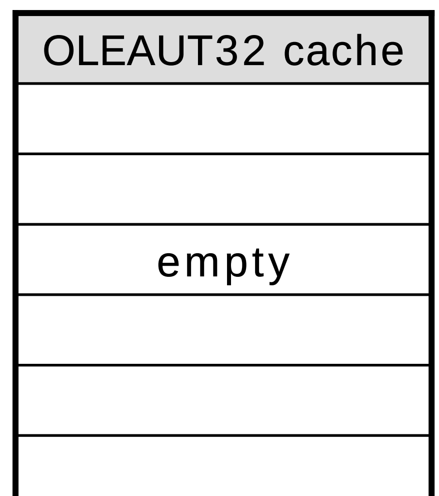
# Bypassing the cache

- 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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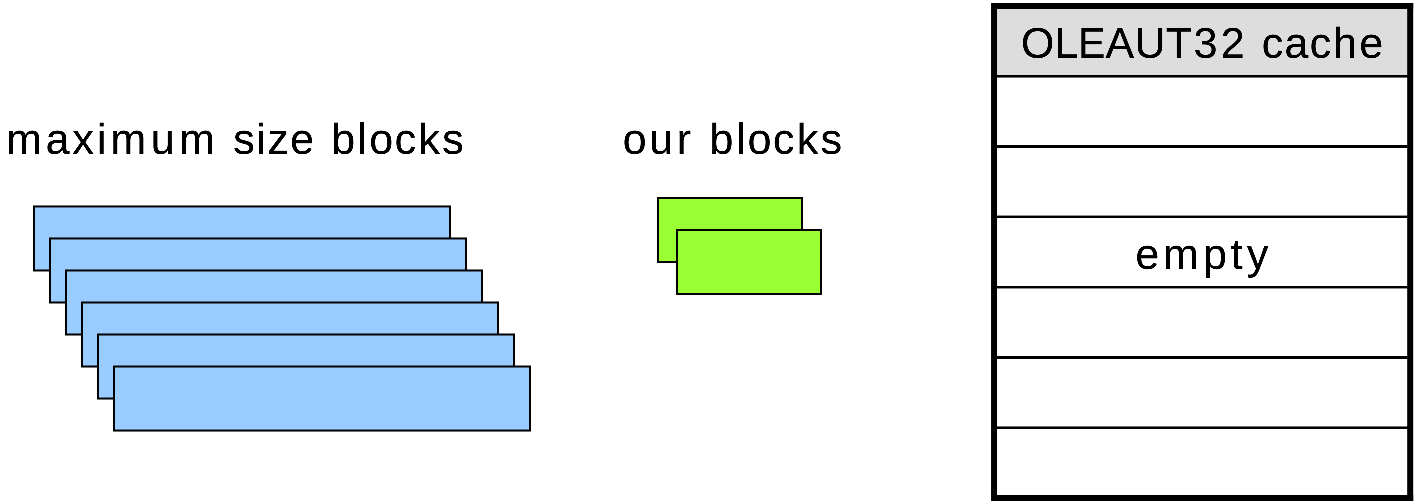

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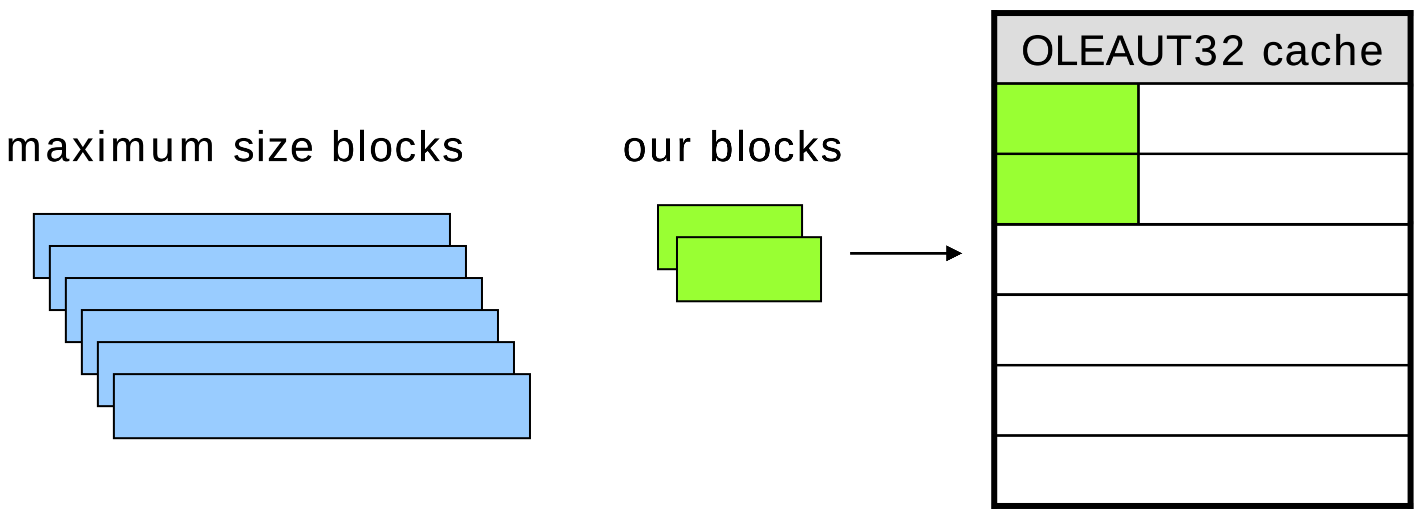

# Plunger Technique

1. Allocate 6 maximum size blocks
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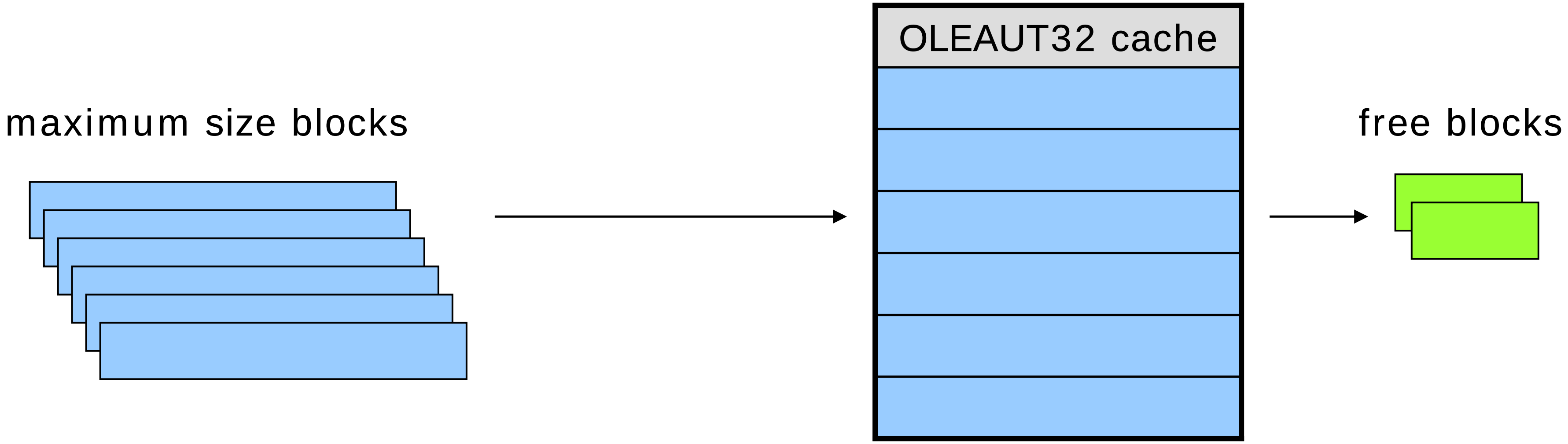

# Plunger Technique

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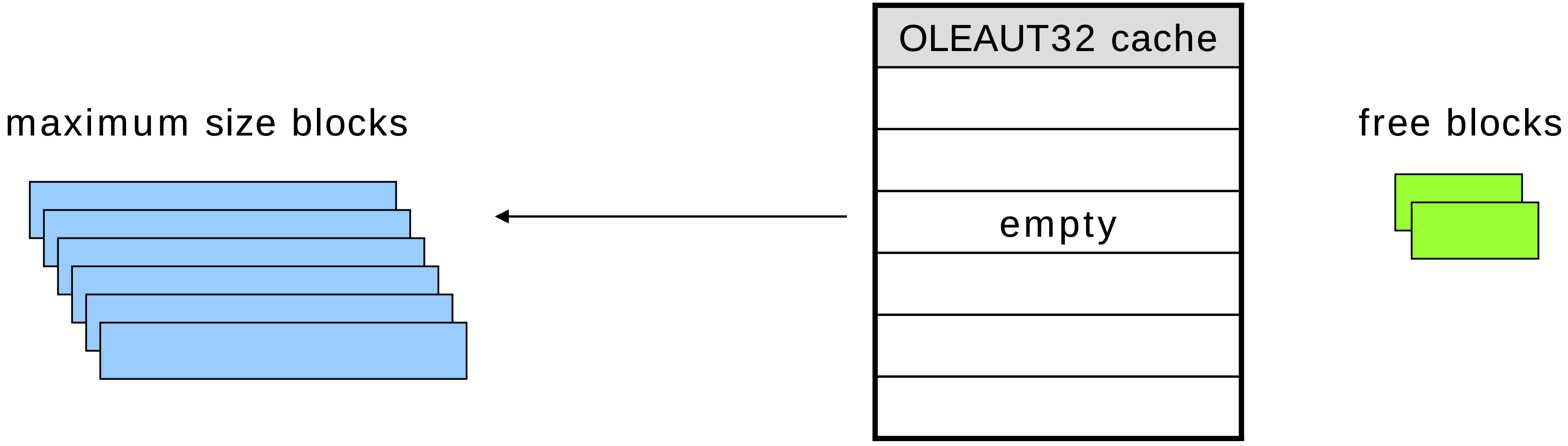


# Part IV

# HeapLib - JavaScript heap manipulation library

# Introducing HeapLib

- 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!

```
<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");

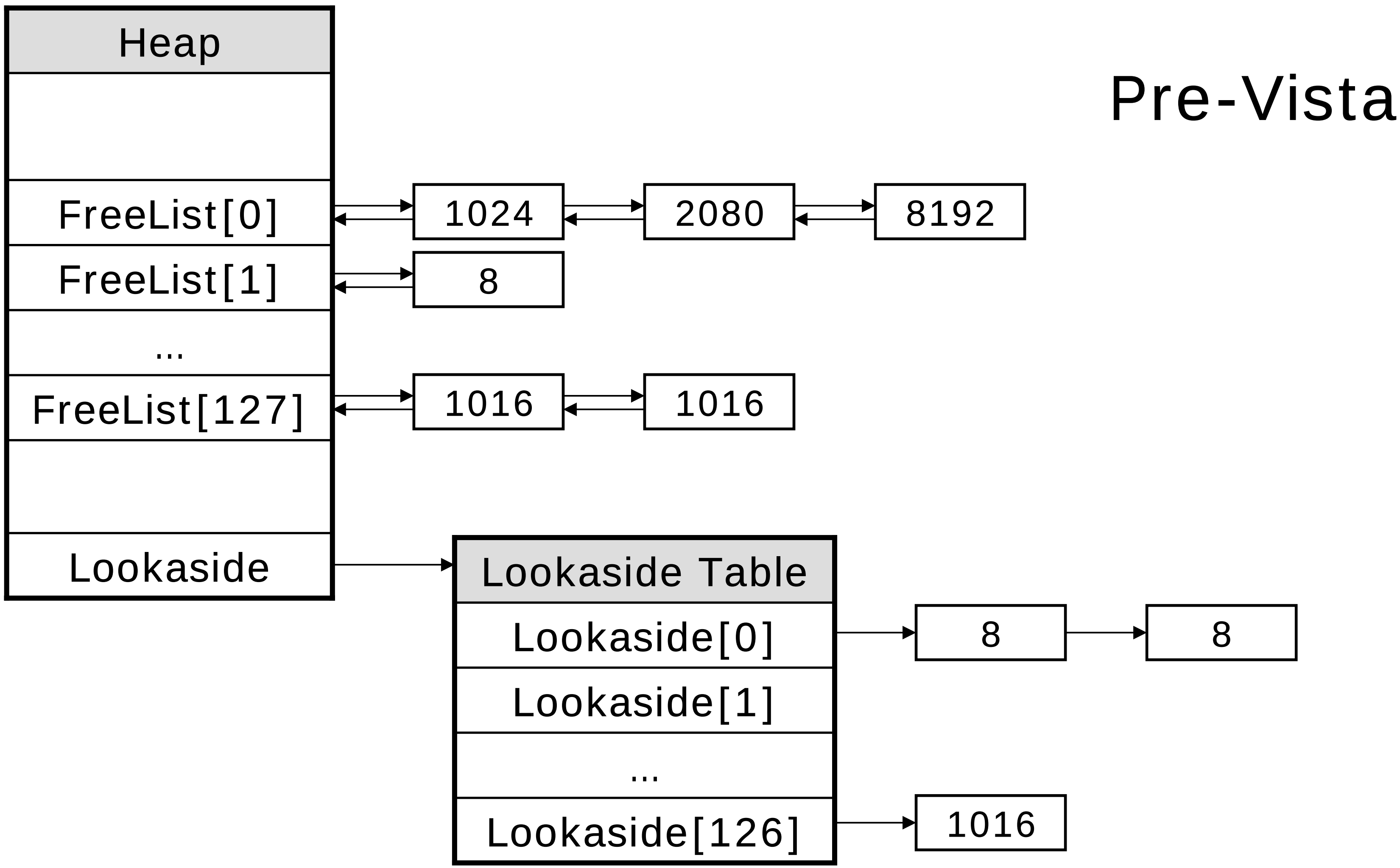
   heap.debugHeap(false);
</script>
```

# HeapLib Demo

# Part V

# Windows Heap Manipulation

# Windows Heap Overview



# 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
```

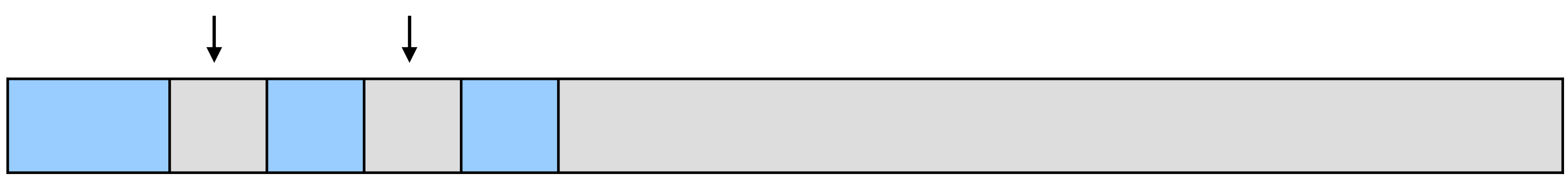
# Defragmenting the heap

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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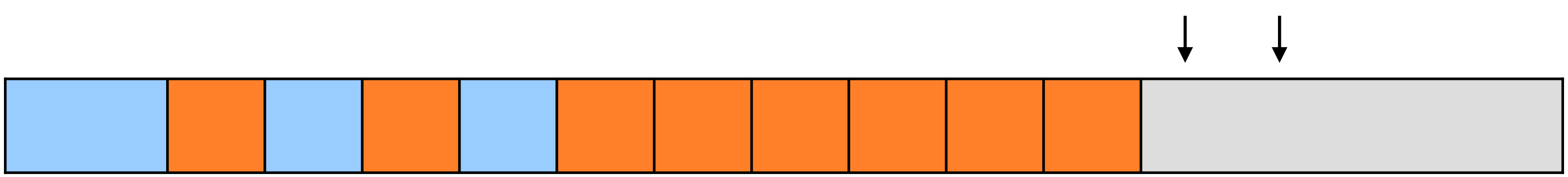


# Putting a block on the FreeList

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

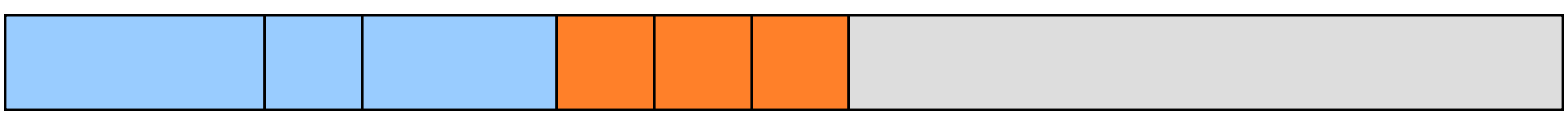
```
heap.alloc(0x2010, "foo");
heap.alloc(0x2010);
heap.alloc(0x2010, "foo");

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

used:

free:

our blocks:



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

used:

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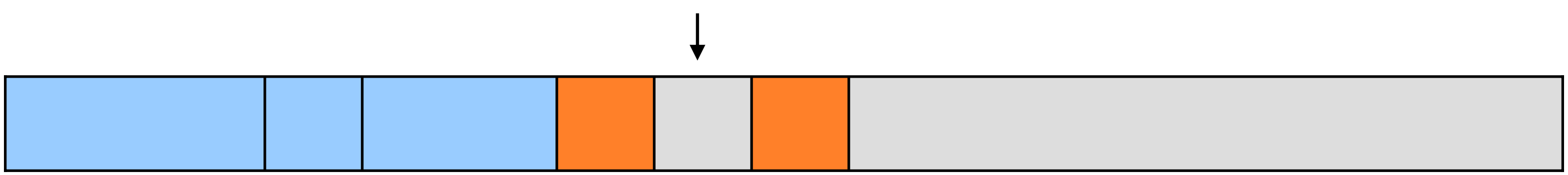
our blocks:



# 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");
```

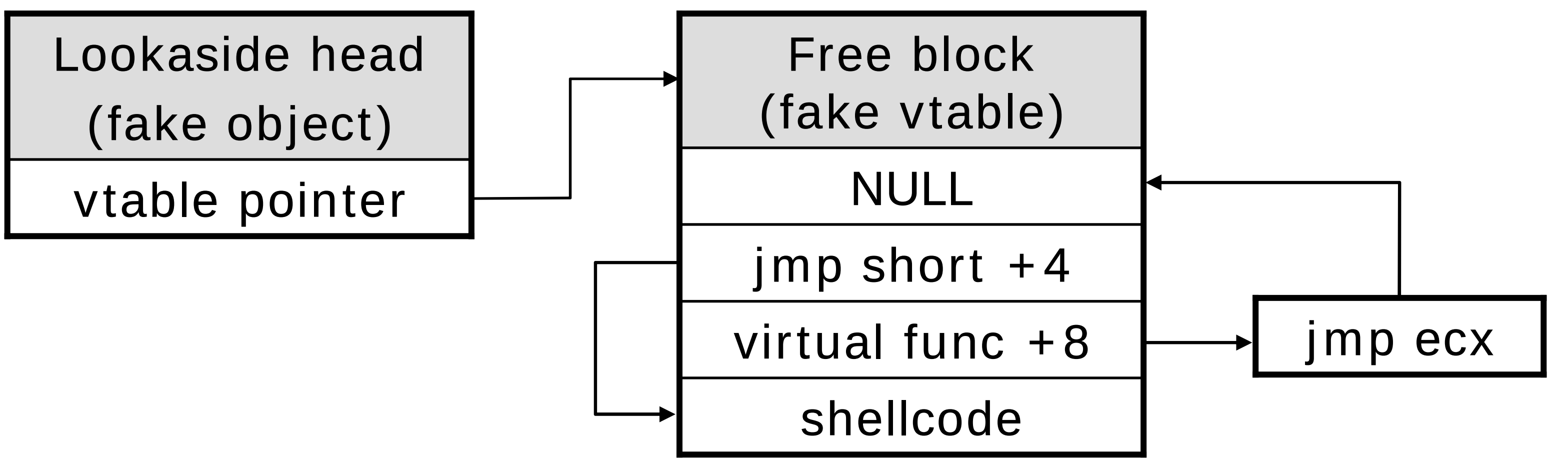
# Object pointer overwrite

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

# Questions?

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