Engineering Heap Overflows with JavaScript

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Overview

- Introduction
- Heap Control
- WebKit JavaScript Details and Exploit Description

Heap Overflows

- Can allow for arbitrary bytes written to specific relative offset from pointer on heap
- What if nothing interesting is after buffer?
  - Unmapped memory
  - Unused memory
  - Unpredictable memory

Heap Overflows

- Safe Unlinking means metadata not viable target
- Often, need function pointer(s) as target
  - malloc'd before overflow
  - Used after overflow
  - Reliably positioned
  - No critical data smashed

Motivation

- 2008 CanSecWest Pwn2Own contest: exploit fully patched, default installation of Mac Leopard, Windows Vista, or Ubuntu laptop
- Found buffer overflow in WebKit's JavaScript PCRE (Perl-Compatible Regular Expression) compilation, accessible through Safari on Leopard

Motivation

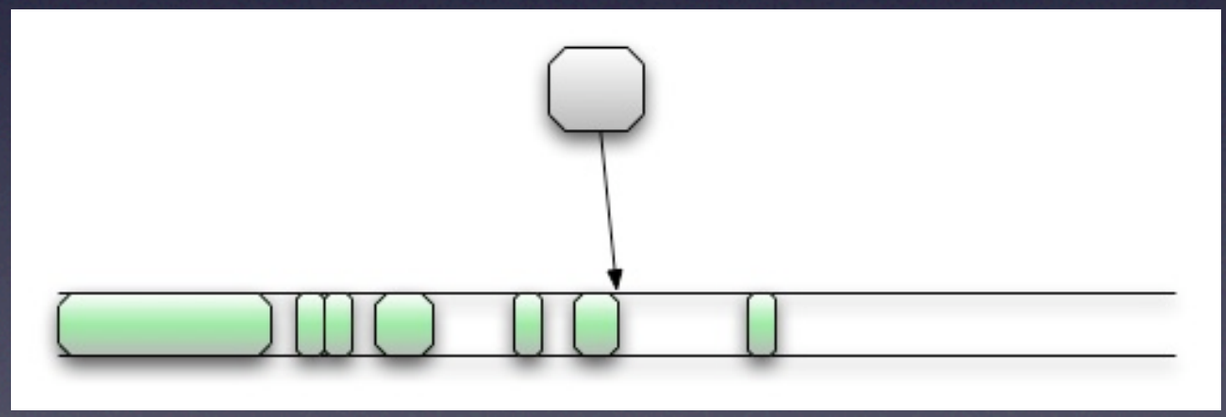
- Overflow itself extremely controllable
  - Size of malloc up to 65535 bytes
  - Exact amount of overflow controllable
  - Bytes in buffer from compiled regular expression: lots of control
- But nothing useful and predictable after buffer...

Heap Control

- Inspired by A. Sotirov's *Heap Feng Shui*
- Assuming non-randomized heap, can control memory after the overflow by:
  - Defragmenting heap
  - Creating holes in heap
  - Landing vulnerable buffer in hole

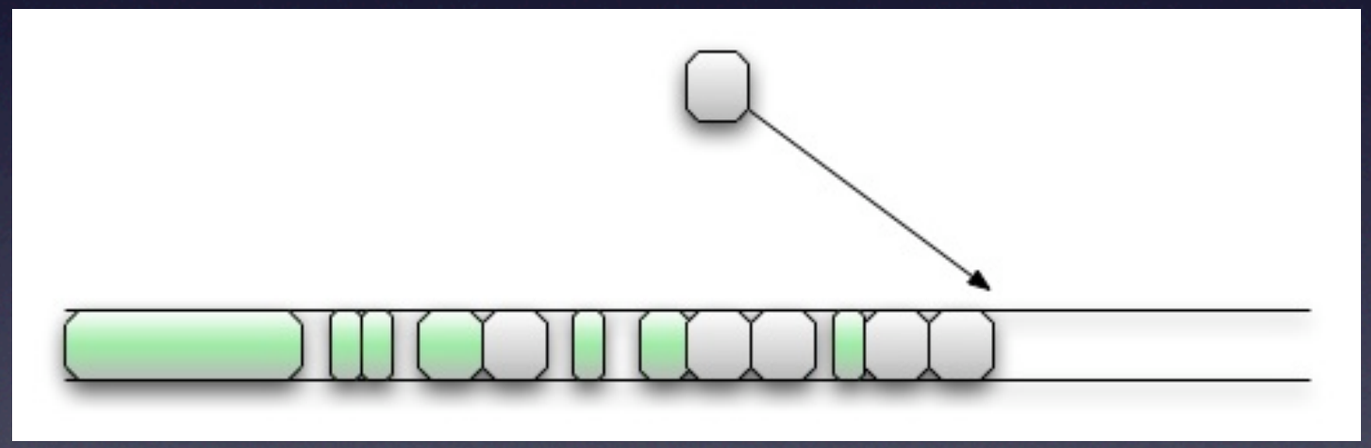
Fragmented Heap

- Non-randomized heaps in unpredictable state with holes from freed buffers. Future allocations land in unpredictable location



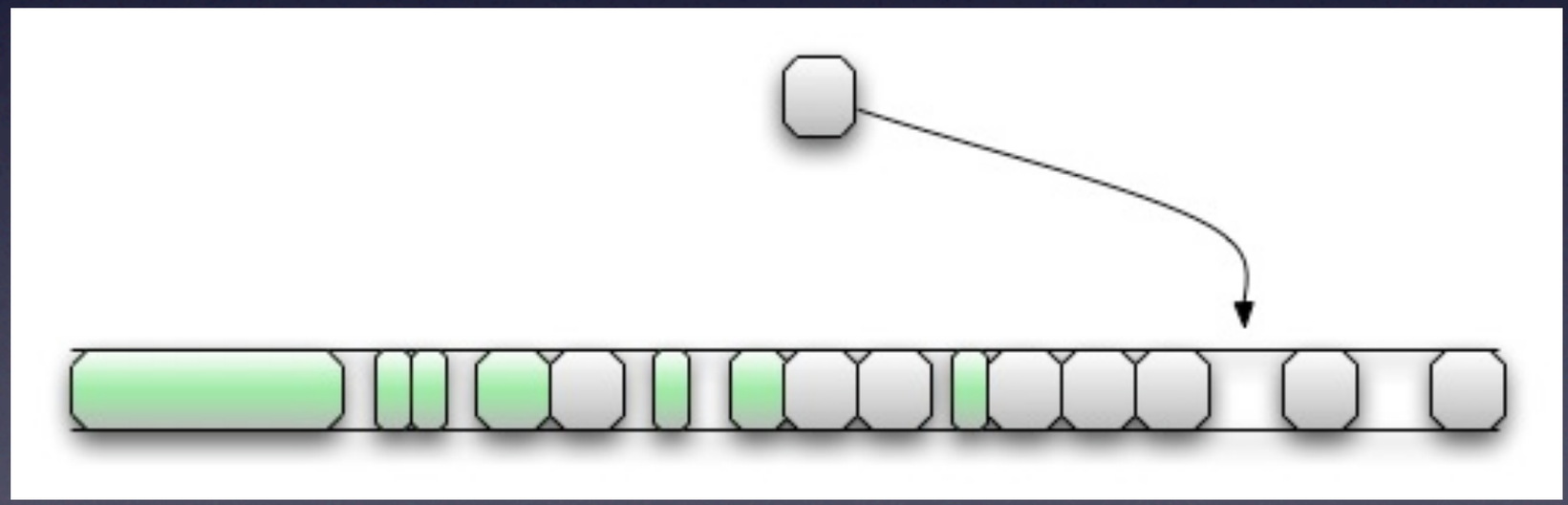
Defragmenting heap

- Can fill these holes with allocations of many same-sized buffers, eventually leading to a long sequence of same-sized buffers



Making Holes

- Free every other buffer, such that subsequent allocations fall in hole with controllable memory after



Defragmenting Heap

- Easy in Javascript:

```
var bigdummy = new Array(1000);
for(i=0; i<1000; i++){
   bigdummy[i] = new Array(size);
}
```

- Each call to `new Array(size)` results in allocation of `4*size+8` bytes on heap from `ArrayStorage` object

Making Holes

- First, delete the JavaScript objects:

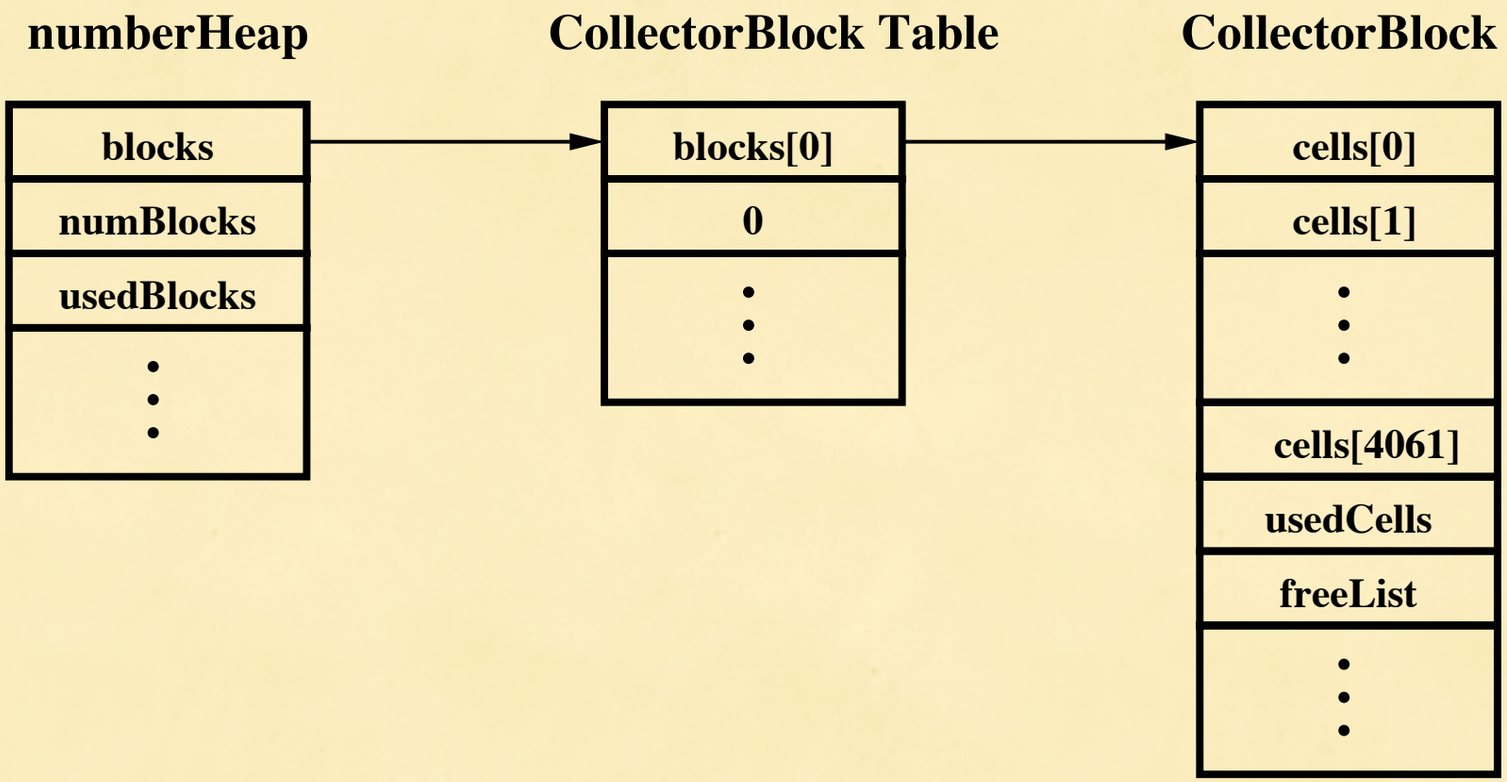
```
for(i=900; i<1000; i+=2){
   delete(bigdummy[i]);
}
```

- But associated storage not freed until Garbage Collection
- In IE, can call `CollectGarbage()`
- In WebKit, need to trigger GC

WebKit GC Overview

- Maintains two structures, `primaryHeap` and `numberHeap`
- Arrays of `CollectorBlock` objects
- Used to store array of `Cells`
- `Cells` contain JavaScript objects

numberHeap Diagram



WebKit GC Overview

- `primaryHeap` used to store objects deriving from `JSObject`, grows with significant browsing
- `numberHeap` used to store `NumberImp` objects, short-lived number objects corresponding to arithmetic computations

Triggering GC

- Expiration of GC timer
- Allocation request when `CollectorBlocks` are full
- Allocation of object(s) with sufficiently large associated storage

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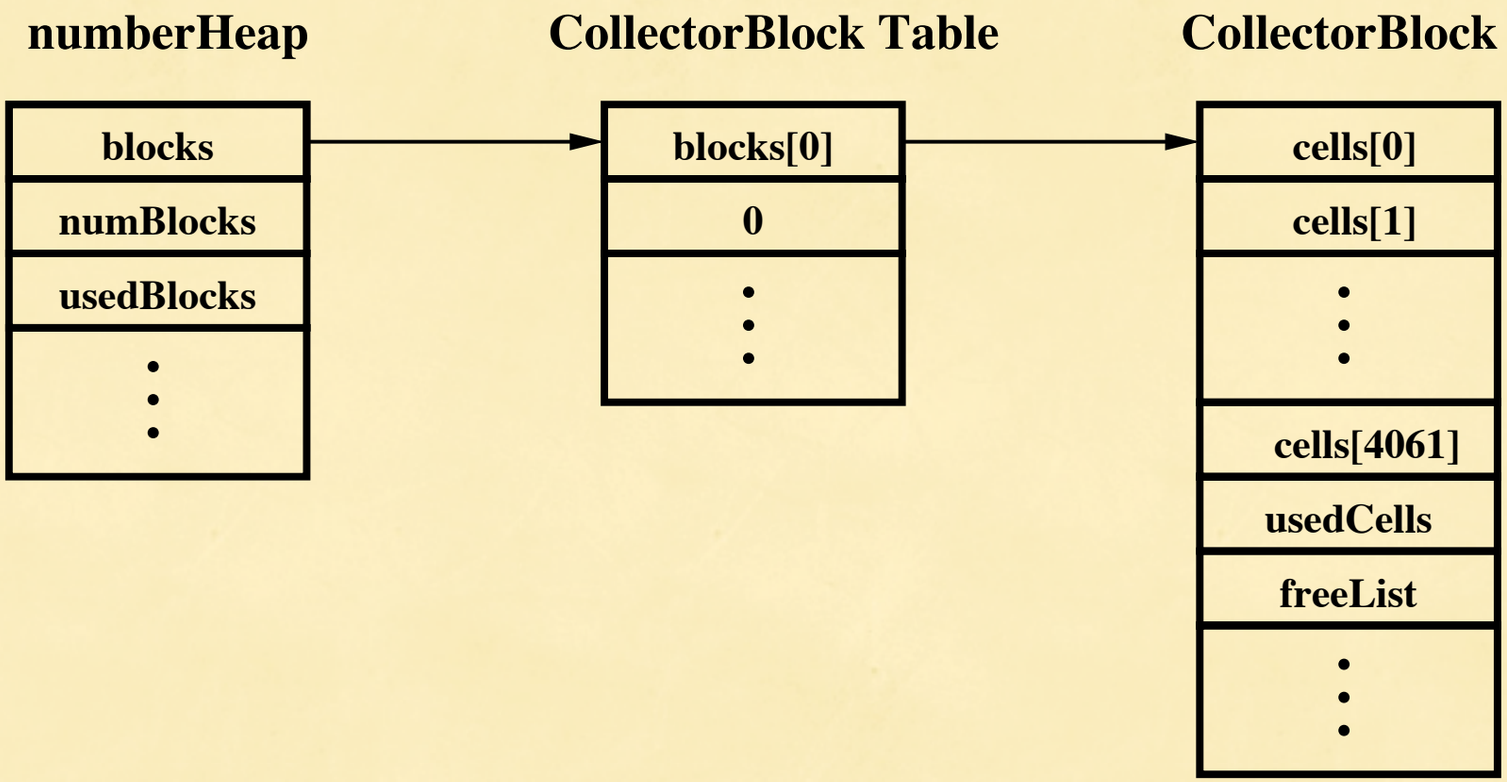
numberHeap Diagram



Triggering GC

- Since `numberHeap` reliably has only one allocated `CollectorBlock`, filling its 4062 `Cells` should trigger GC
- Use manipulation of `doubles` in JavaScript:

```
for(i=0; i<4100; i++){
   a = .5;
}
```

Prepare Blocks

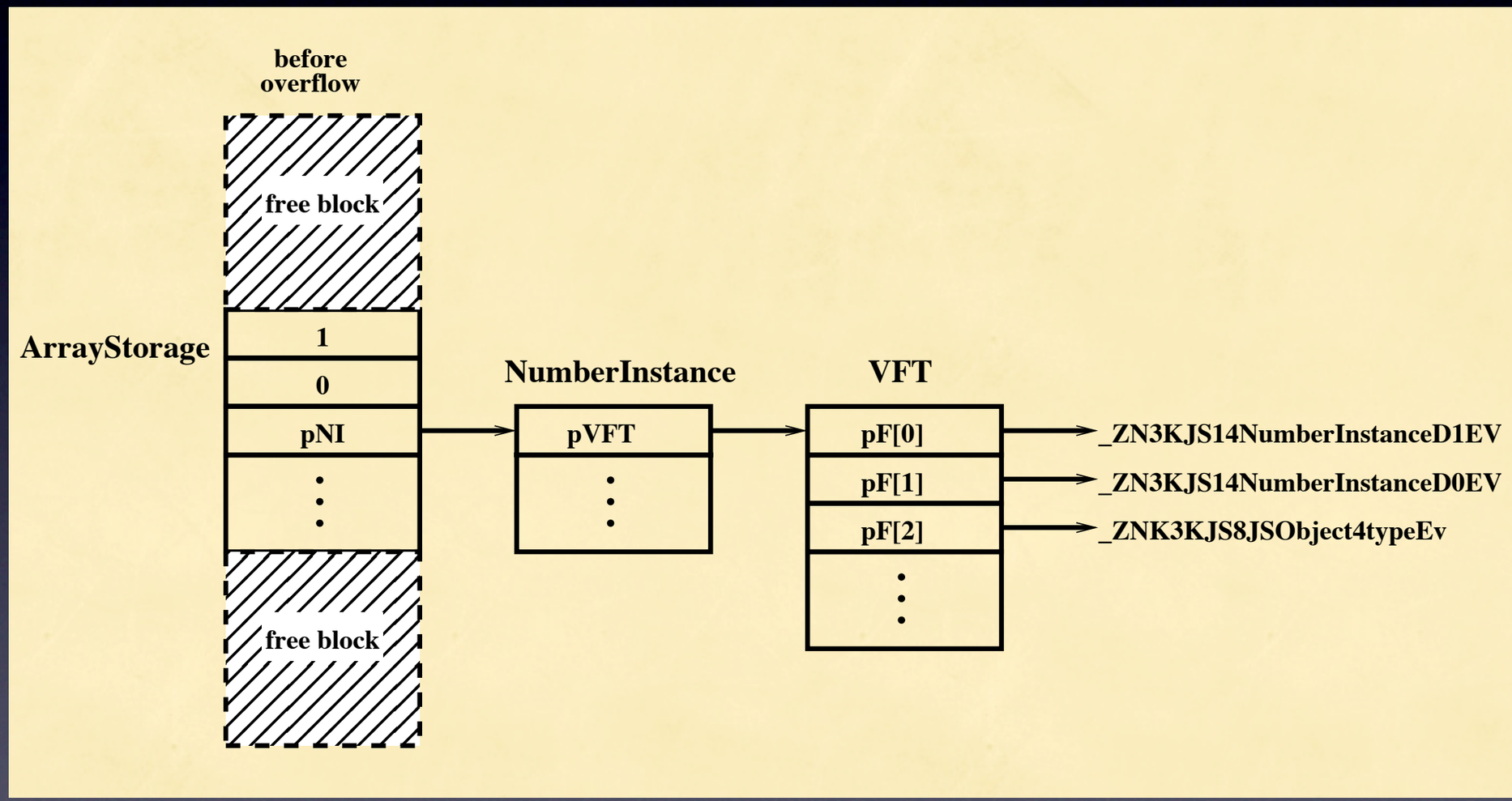
- Recall, the holes were made by freeing alternating `ArrayStorage` objects:

```
for(i=900; i<1000; i+=2){
   delete(bigdummy[i]);
}
```

- Using below code we put a new `NumberInstance` object in the surrounding `ArrayStorage` objects

```
for(i=901; i<1000; i+=2){
   bigdummy[i][0] = new Number(i);
}
```

ArrayStorage Diagram Before Overflow



Trigger Overflow

- Finally, we are ready for the overflow.
- The buffer will land in a hole
- Beginning of overflow preserves the 8-byte `ArrayStorage` metadata
- At third dword we place pointer to self-referential NOP sled followed by shellcode

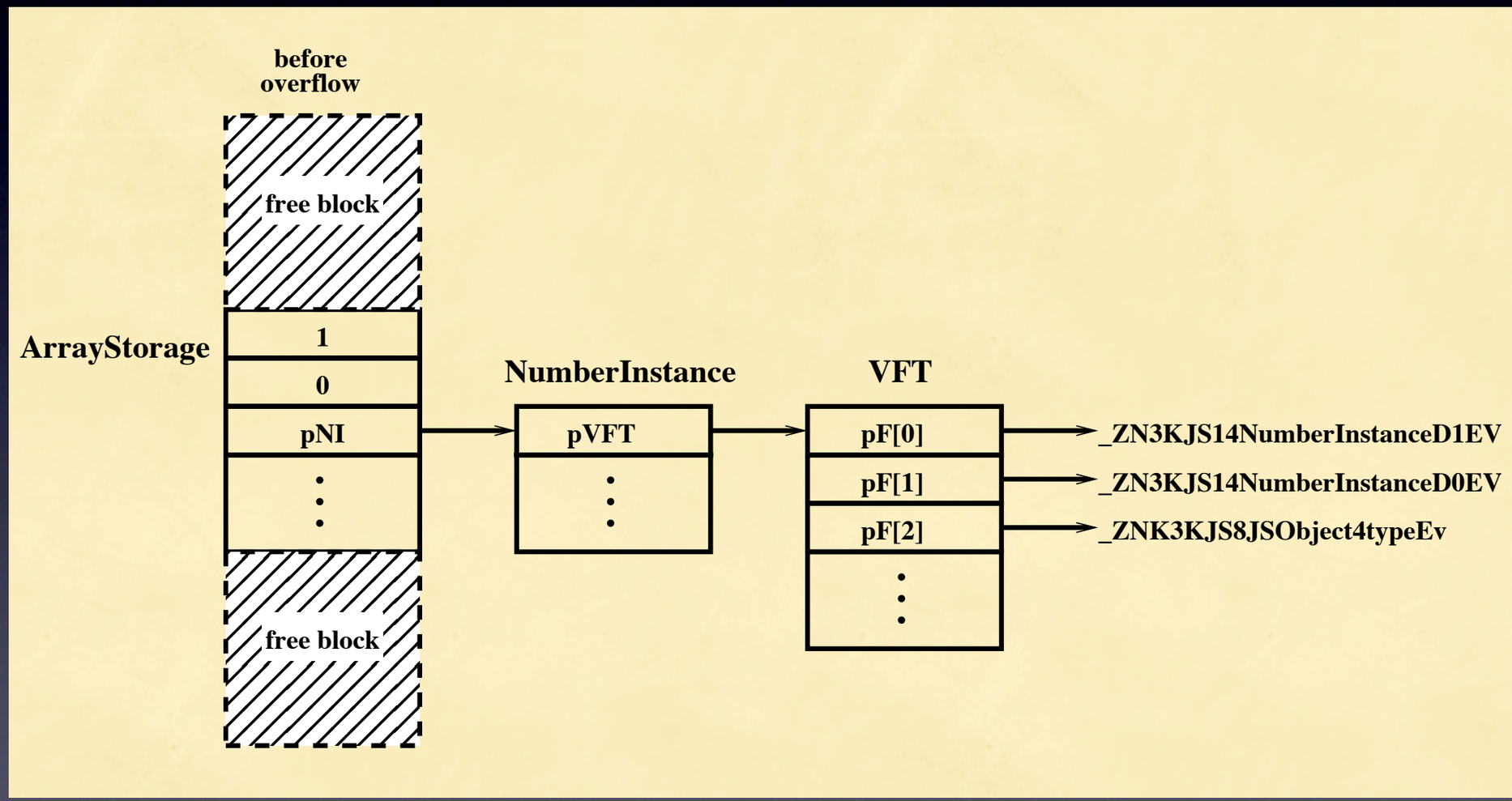
Gaining Control

- Just need to get function pointer called:

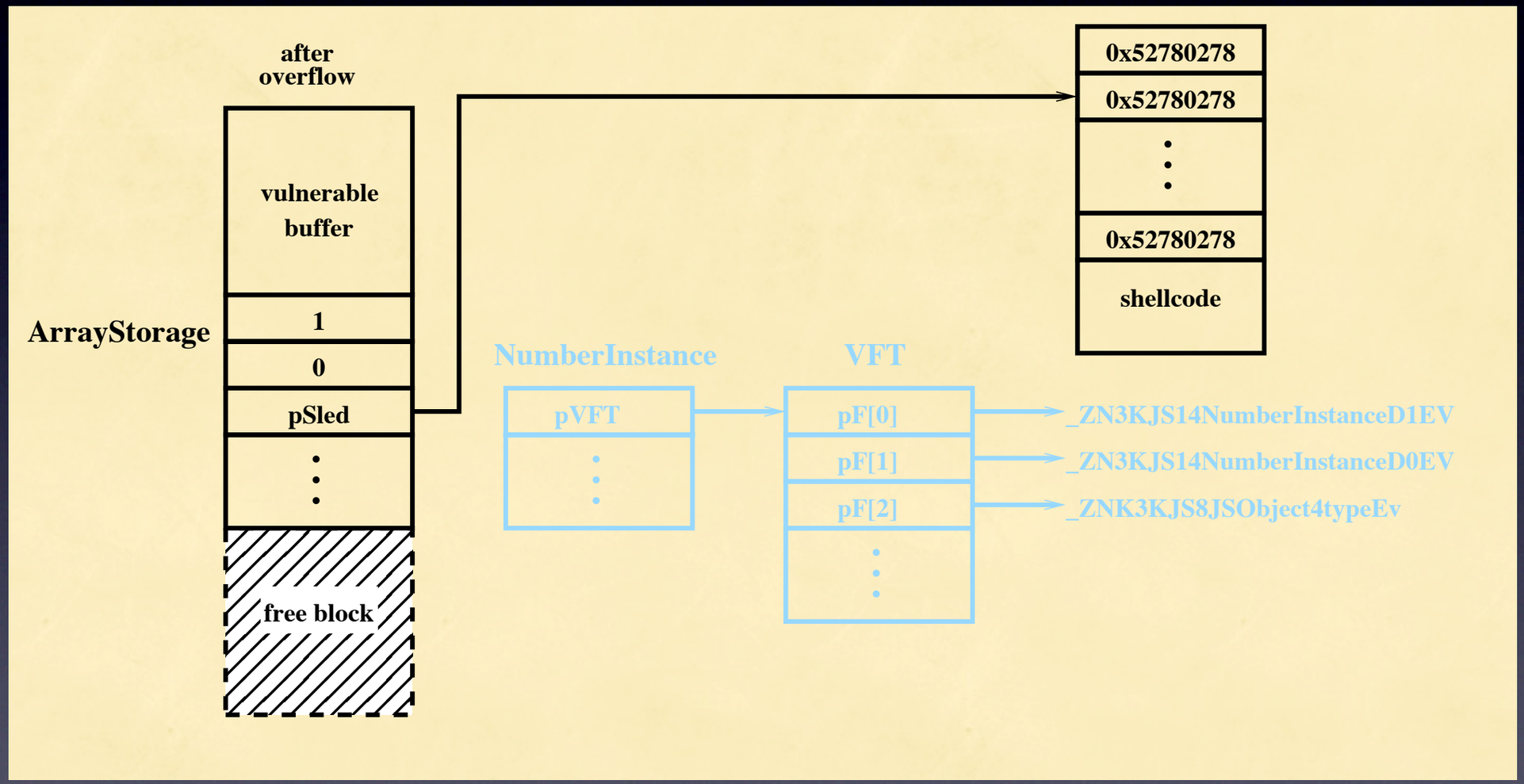
```
for(i=901; i<1000; i+=2){
  document.write(bigdummy[i][0] + "<br />");
}
```

- Conversion to string results in VFT call

ArrayStorage Diagram Before Overflow



After Overflow



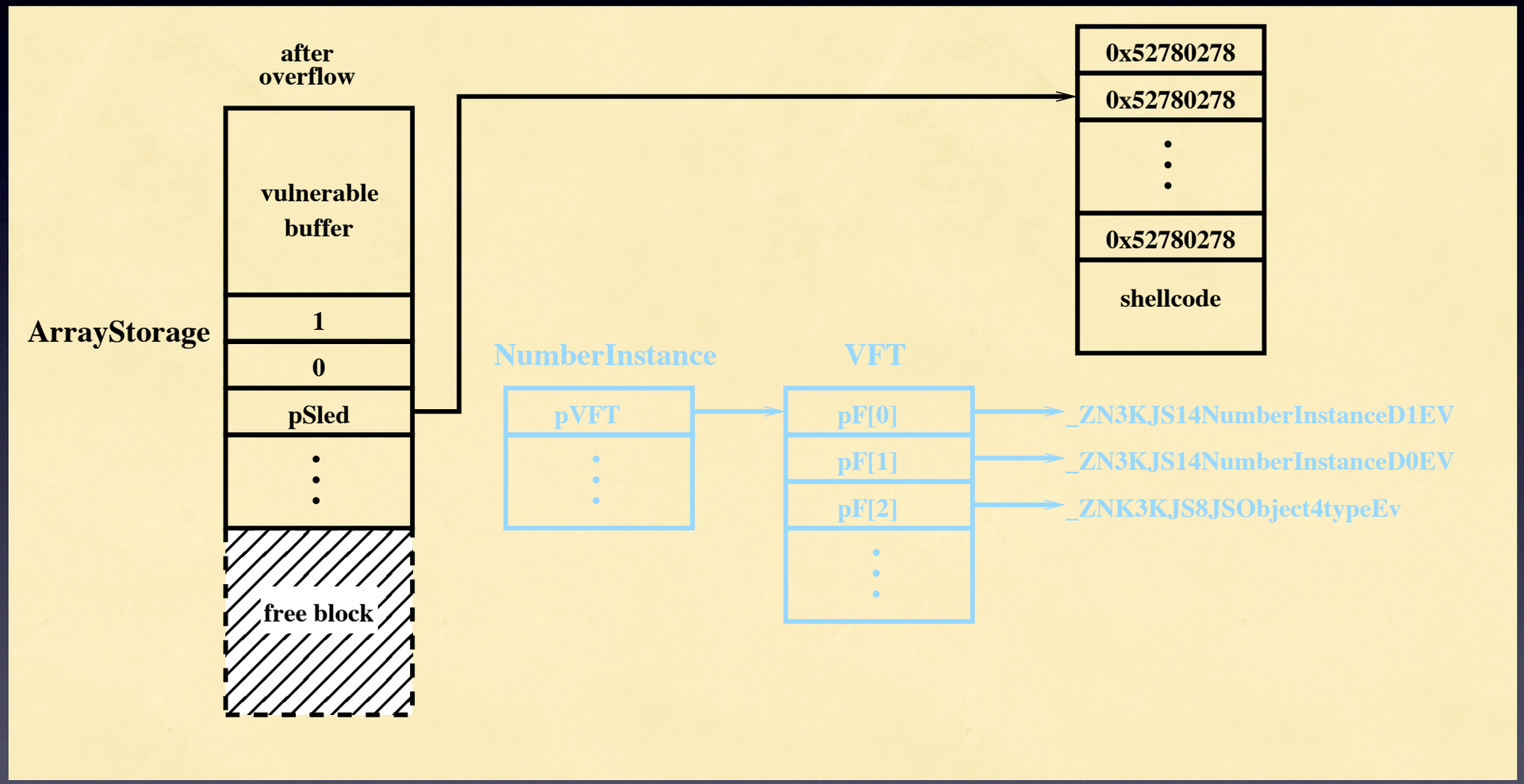
Self-Referential NOP sled

- Using heap spray, we have sled mapped at address 0x52.....
- Use spray of 0x52780278

```
78 02:    js +0x2
78 52:    js +0x52
```

- If 4-byte alignment not necessary, can use 0x....02eb

After Overflow



Conclusions

- Given non-randomized allocator, JavaScript can be used to reliably exploit heap overflows via:
  - Heap defragmentation
  - Creation of holes in heap
  - Positioning of function pointers
  - Getting overwritten VFT called

Questions?