SYNACKTIV

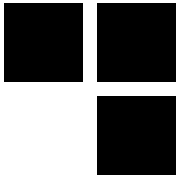
black hat EUROPE

THIS IS FOR THE PLAYERS

PWNERS

QUENTIN MEFFRE & MEHDI TALBI

Outline



Who are we?

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- Security researcher @Synacktiv
- Academia (in a previous life)
- Vulnerability research & exploitation

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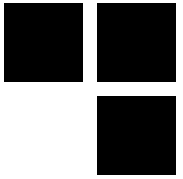
- Security researcher @Synacktiv
- Vulnerability research & exploitation

Synacktiv

- Offensive security company
- Based in France
- ~70 Ninjas
- We are hiring !!!

Introduction



Disclaimer

- This research is done purely out of curiosity and presented for educational purposes.
- This research does not help/support/enable/endorse to break the copyright law.

Introduction

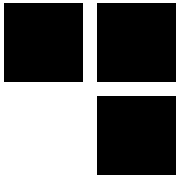
Motivation

- Active console hacking community…
- .. but only few public exploits

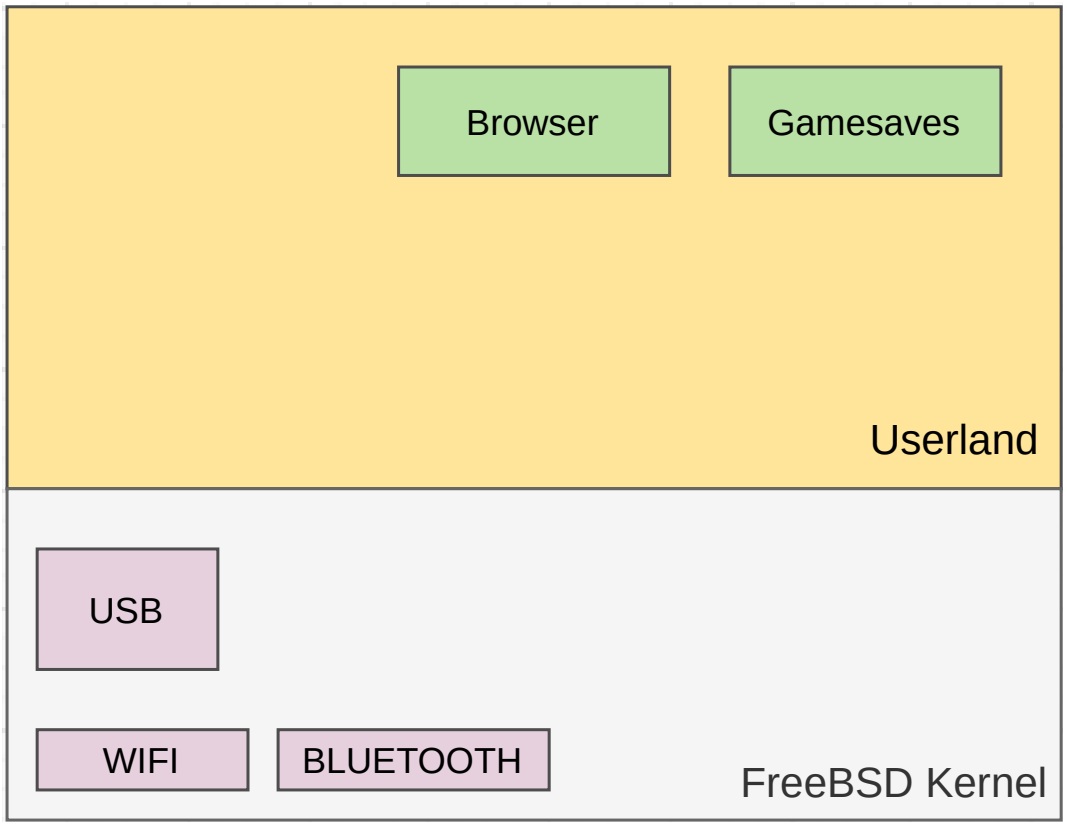
Goal

- A walk through of a 0-Day WebKit Exploit
- How hard is it to exploit a vulnerability on the PS4 ?

Outline



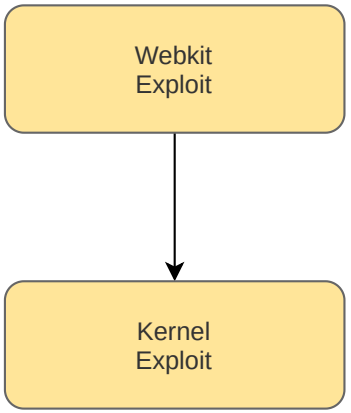
PS4 attack surface



PS4 attack surface

Exploit chain

- Typical exploit chain : Webkit exploit → Kernel exploit



Attacking the browser

- WebKit-based browser
- Sandboxed
- No JIT
- No modern mitigations
  - Gigacage
  - StructureID randomization
- ASLR. Weak ? Partial ?
- … And no debug

WebKit exploits

CVE-2018-4386

- Found by Lokihardt (from P0)
- A.k.a Bad-Hoist exploit by @Fire30_
- Last known public exploit
- Arbitrary Read/Write primitives
- Works on 6.00-6.72 firmwares

CVE-2018-4441

- Found by Lokihardt (from P0)
- Exploit by @SpecterDev
- Arbitrary Read/Write primitives
- Works on 6.00-6.20 firmwares

More exploits ...

- For older firmwares (< 6.xx)
- By @qwertyoruiopz, @SpecterDev, @CTurt, ...

Kernel exploits

CVE-2020-7457

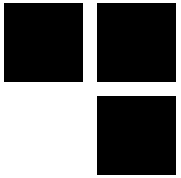
- Reported by @theflow0
- Kernel Read/Write primitives
- Reachable from WebKit Sandbox
- Present in firmware 7.02 and 6.xx
- Used in conjunction with Bad-Hoist exploit

Berkeley Packet Filter vulnerability

- Discovered and exploited by @qwertyoruiopz
- Works on firmwares up to 5.07.
- Excellent write-up by @SpecterDev

Outline

Introducing the bug (1/2)



Presentation

- Vulnerability in WebKit DOM engine
- Triggered by our internal fuzzers
- Impacts all PS4 firmwares (and PS Vita as well) prior to 8.00
- Reported to Sony through their Bug Bounty Program
- Awarded 2500$
- Fixed on Webkit : **11 Sept. 2020**

Introducing the bug (2/2)

The vulnerable code

- Use-After-Free in `WebCore::ValidationMessage::buildBubbleTree` method
- Extra dereference while making a weak pointer
- *ValidationMessage* could be destroyed during a layout update
- *updateLayout* runs user registered JS callbacks

```
void ValidationMessage::buildBubbleTree()
{
    /* ... */

    auto weakElement = makeWeakPtr(*m_element);

    document.updateLayout(); // [1] call user registered JS events

    if (!weakElement || !m_element->renderer())
        return;

    adjustBubblePosition(m_element->renderer()->absoluteBoundingBoxRect(), m_bubble.get());

    /* ... */
}
```

Fixing the code (1/2)

Protect frames during style and layout changes Browse files

https://bugs.webkit.org/show_bug.cgi?id=198047
<rdar://problem/50954082>

Reviewed by Zalan Bujtas.

Be more careful about the scope and lifetime of objects that participate in layout or style updates. If a method decides a layout or style update is needed, it needs to confirm that the elements it was operating on are still valid and needed in the current operation.

The so close fix

```
void ValidationMessage::buildBubbleTree()
{
    /* ... */
+
+   auto weakElement = makeWeakPtr(*m_element);
+
    document.updateLayout();

+   if (!weakElement || !m_element->renderer())
+       return;

    adjustBubblePosition(m_element->renderer()->absoluteBoundingBoxRect(), m_bubble.get());

    /* ... */
}
```

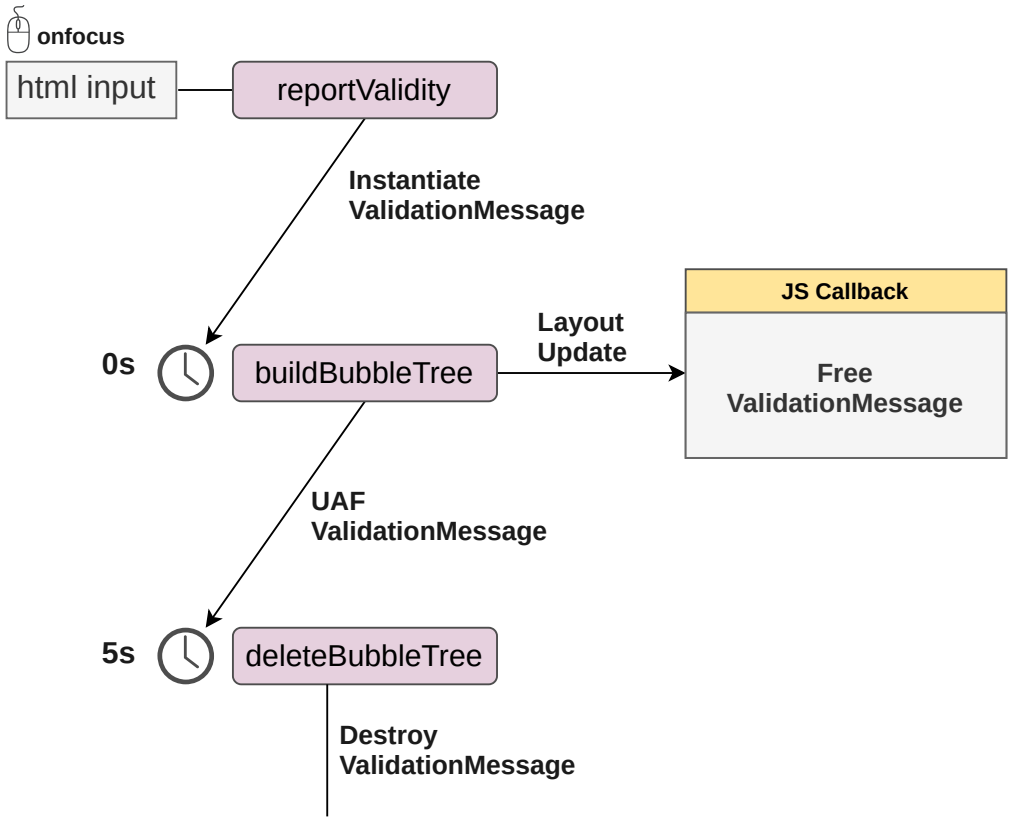
Fixing the code (2/2)

The good fix

- Avoid doing layout update in `ValidationMessage::buildBubbleTree`

```
void ValidationMessage::buildBubbleTree()
{
    /* ... */
-
-   auto weakElement = makeWeakPtr(*m_element);
-
-   document.updateLayout();
-
-   if (!weakElement || !m_element->renderer())
-       return;
-
-   adjustBubblePosition(m_element->renderer()->absoluteBoundingBoxRect(), m_bubble.get());

    /* ... */


+   if (!document.view())
+       return;
+   document.view()->queuePostLayoutCallback([weakThis = makeWeakPtr(*this)] {
+       if (!weakThis)
+           return;
+       weakThis->adjustBubblePosition();
+   });
}
```

The vulnerable path



Triggering the bug (1/2)

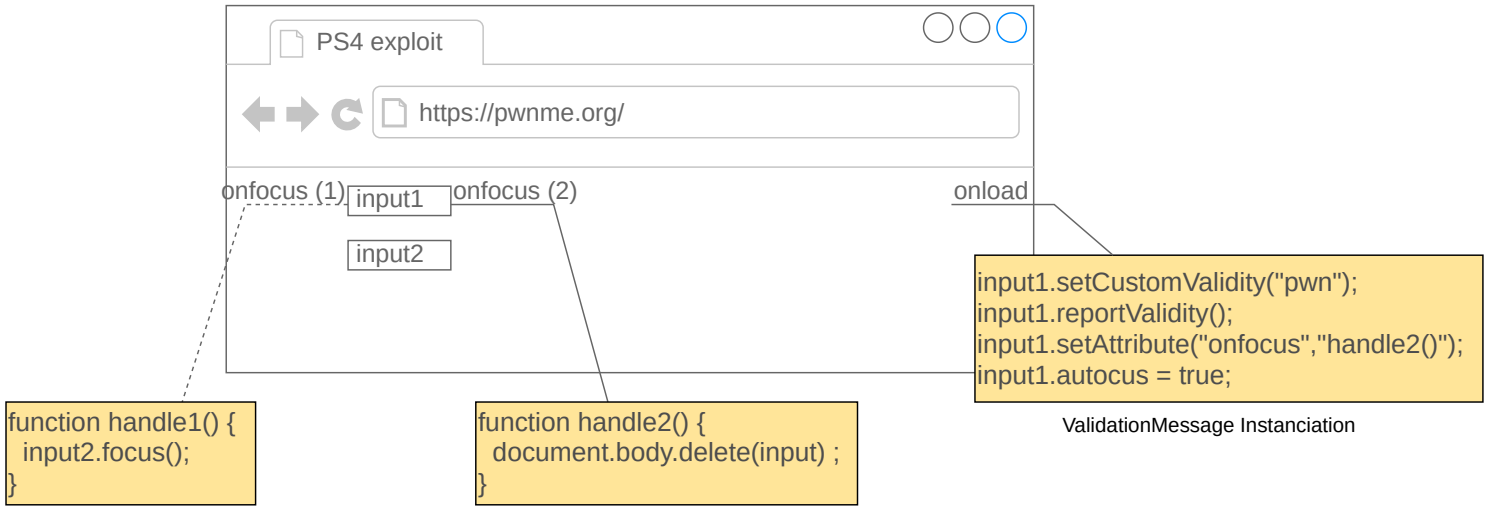
First Attempt

1. Register a JS event (e.g. onfocus) on some input text field.
2. Instanciate a *ValidationMessage* object
   - → Fire-up a timer to call *buildBubbleTree*
   - → Run user registered JS events
3. Destroy *ValidationMessage* instance on JS callback
4. No crashs !!
   - *reportValidity* sets the focus on input
   - user JS callback called too early.

Triggering the bug (2/2)

Solution

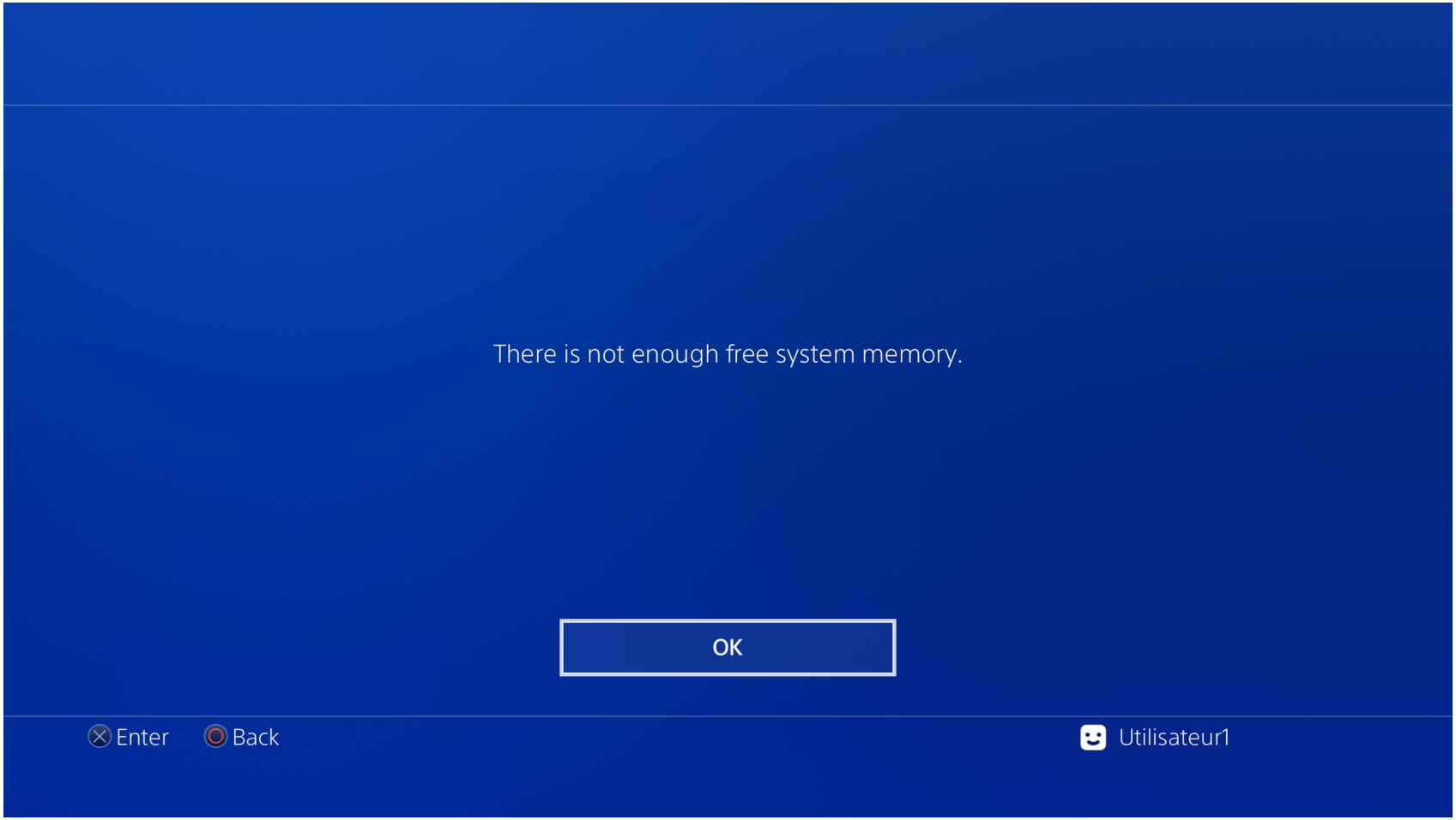
1. Register a JS event handler *handler1* on *input1*
2. Instanciate a *ValidationMessage* (on *input1*)
   - focus is set on input1 → *handler1* is executed
   - *handler1* sets the focus elsewhere (*input2*)
3. Set *handler2* as new handler for focus event on *input1*
4. *handler2* is executed while running JS user callback from *buildBubbleTree*
   - Destroy *ValidationMessage* instance
5. PS4 browser crashs and restarts



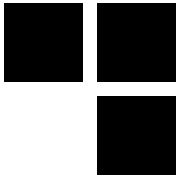
ValidationMessage Instanciation

ValidationMessage Destruction

Crash !


There is not enough free system memory.
OK
Enter
Back
Utilisateur1

Debugging the bug (1/2)



Problem

- No debugging capabilities on PS4
- All we get are crashes :-(

Option 1 : Setup a similar environment

- Install a FreeBSD box
- Compile WebKit sources from doc.dl.playstation.net
- → Helpful **BUT** working exploit on our env does not fully work on PS4
- MORE DEBUG

Debugging the bug (2/2)

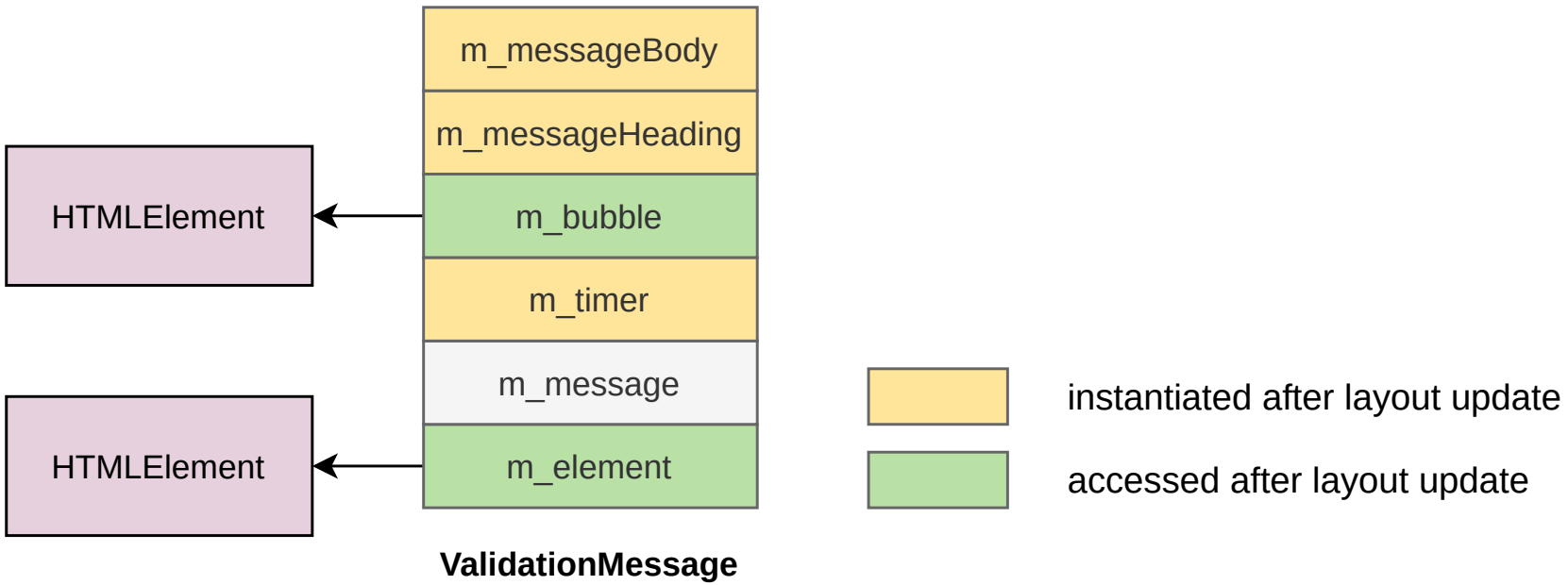
Option 2 : Debugging a 0-day with a 1-day

- Get insights on memory mappings
- Dump the content on allocated pages
- → Use bad-hoist exploit by @Fire30_ :
  - (+) Read/Write primitives
  - (+) Addrof/fakeobj primitives
  - (-) Works on 6.xx firmware only
  - (-) Adds some noise on heap shaping
  - (-) Reliability

Anatomy of a vulnerable object

ValidationMessage object

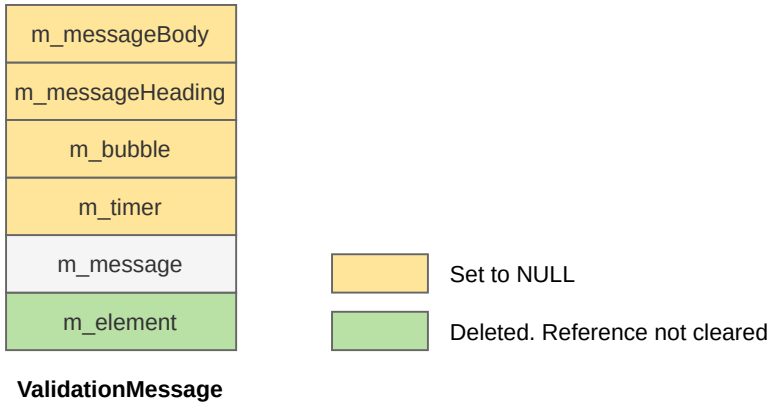
- Instantiated by *reportValidity()* (fastMalloc'ed)
- Accessed by *buildBubbleTree()*
- Destroyed by *deleteBubbleTree()*



Surviving an (inevitable) crash (1/3)

Back from user JS callback

- 2 UAFs : *this* and *m_element* are freed
  - But we still have a reference on *m_element*
- Crash on first virtual call (on *m_bubble*)
- Situation : Not comfortable



Exploitability

1. A memory Leak, Or
2. … An ASLR Bypass

Surviving an (inevitable) crash (2/3)

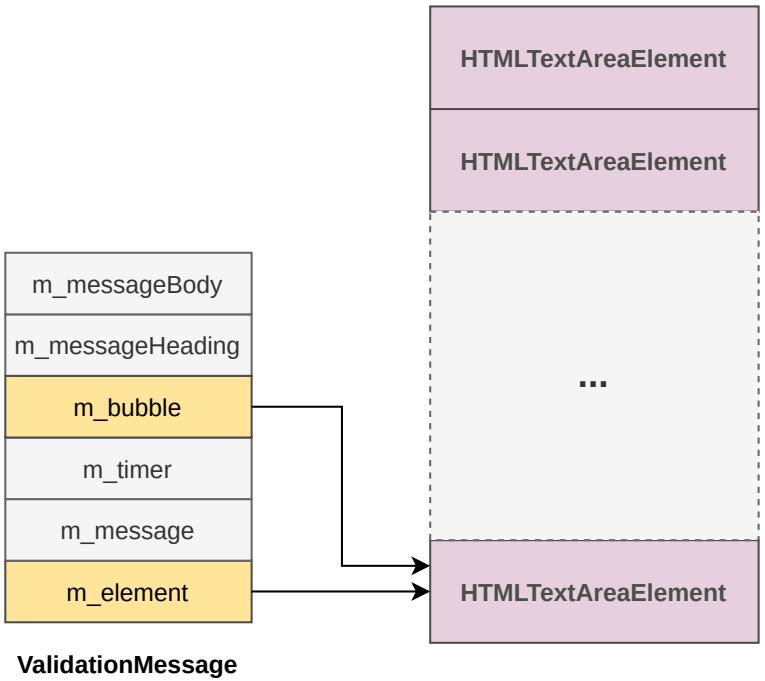
Bypassing ASLR

- Heap spraying → objects end-up allocated at a **predictable location** !!
  - Spraying ~ 2MB is enough to predict a heap address
- Require a prior knowledge on the memory mapping
  - Works on 6.xx firmware
  - May work on 7.xx. More on this later …

Surviving an (inevitable) crash (3/3)

Surviving the crash

- Spray HTMLElement obj. (e.g. HTMLTextAreaElement)
- Shape the heap → Reuse ValidationMessage Obj.



Exploitation primitive

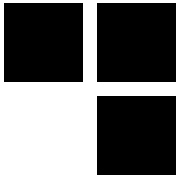
Vulnerable path epilogue

```
void ValidationMessage::deleteBubbleTree()
{
    if (m_bubble) {
        m_messageHeading = nullptr;
        m_messageBody = nullptr;
        m_element->userAgentShadowRoot()->removeChild(*m_bubble);
        m_bubble = nullptr;
    }
    m_message = String();
}
```

Exploitation primitive

- *nullptr* assignement on refcounted classes are overloaded
- → refcount decrement on multiple controlled *ValidationMessage* pointer fields
- UAF → Arbitrary Decrement (refcount decrement)
- **Exploitable**
- Requires multiple heap shaping/spraying stages

Outline



Webkit Allocator

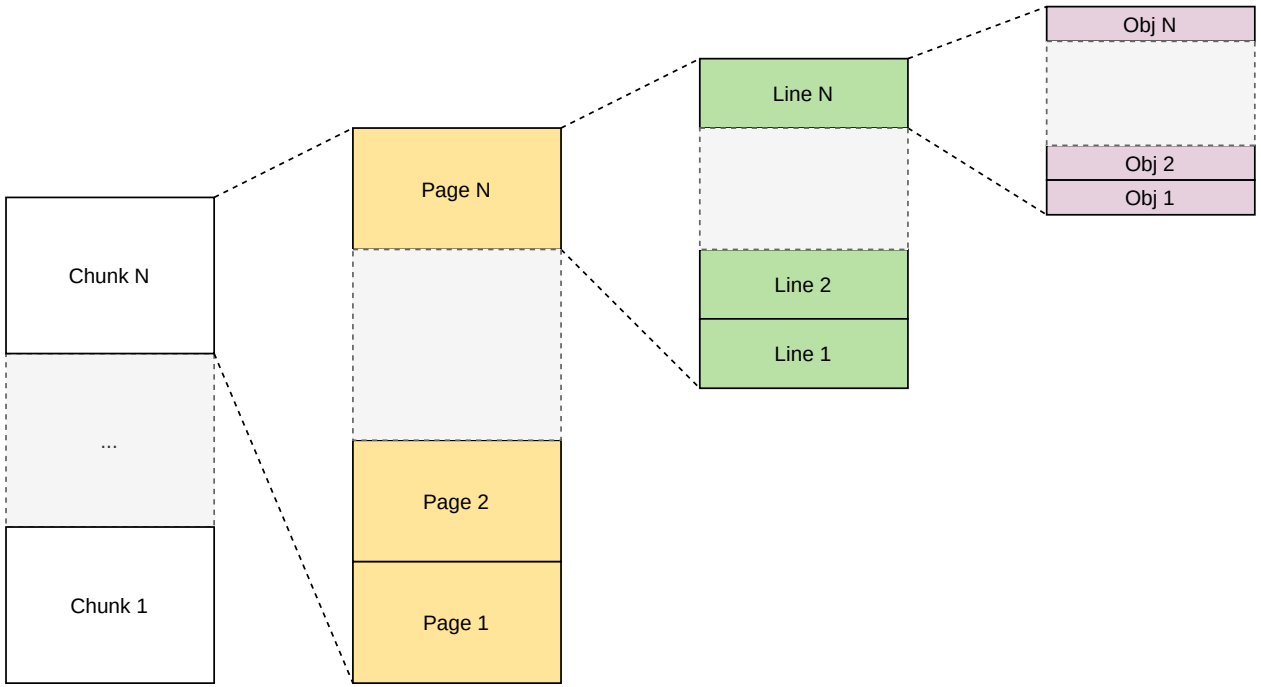
Many allocators

- **FastMalloc** : standard allocator
- **IsoHeap** : sort each allocation using its type to mitigate Use-After-Free
  - Used by the DOM engine
- **Garbage Collector** : used to allocate *JSObject*(s)
- **IsoSubspace** : same as the **IsoHeap** but used in the Javascript engine
- **Gigacage** : provide mitigation to prevent out-of-bound R/W on specific objects
  - Disabled on PS4

The Primary Heap Allocator

Overview

- **Heap** is made of **chunks**
- **Chunk** split into **pages** (4 kB)
- **Page** divided into **lines** (256 Bytes)
- **Line** holds several **objects**
- Each page serves allocations for same-sized obj.



FastMalloc (1/2)

The Fast Path

- Bump Allocator (per size class)

```
--m_remaining;
char* result = m_ptr;
m_ptr += m_size;
return result;
```

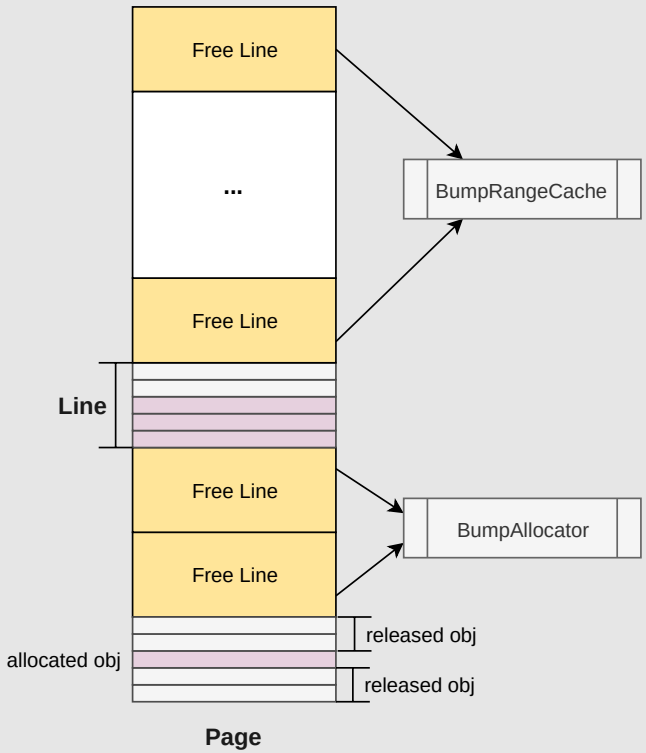
FastMalloc (2/2)

The Slow Path

- No more available free slots → Refill allocator :
  1. From cache *BumpRangeCache* (fast path)
  2. From newly allocated page (slow path)
     - After processing previously released obj.

Refilling the allocator - The slow path

- Allocate a new page
  1. Pick it from cache (another one)
  2. Pick the last released page from the last allocated chunk
- Fill allocator with the first free contigous lines
- Fill the cache with the rest of the freed lines

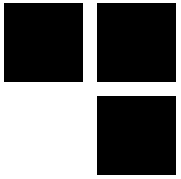


Deallocation

Deallocation

- Released objects are not made immediately available → pushed in a dedicated vector (*m_objectLog*).
- Released objects are processed if *m_objectLog* reaches its maximal capacity (512)
- Chunks/Pages/Lines are refcounted
- Chunks/Pages/Lines are released if *refCount == 0*

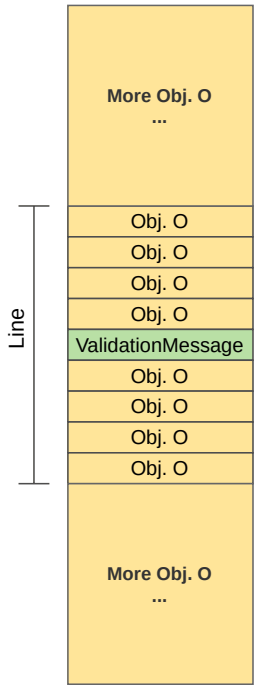
Outline



Exploiting UAF (1/3)

Shaping the heap

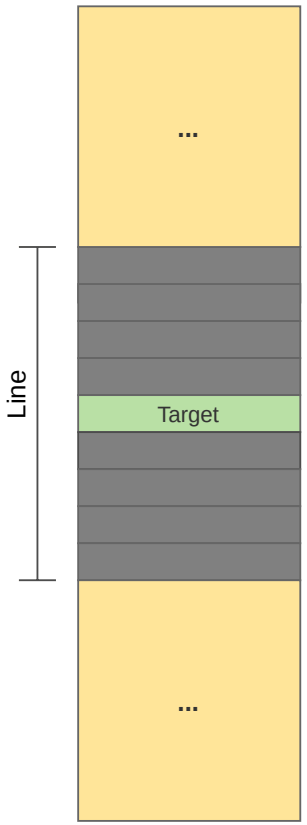
1. Allocate **N/2** of objects *O*
   - sizeof(O) = sizeof(ValidationMessage)
2. Instanciate a ValidationMessage Obj
3. Allocate **N/2** of objects *O*



Exploiting UAF (2/3)

Shaping the heap

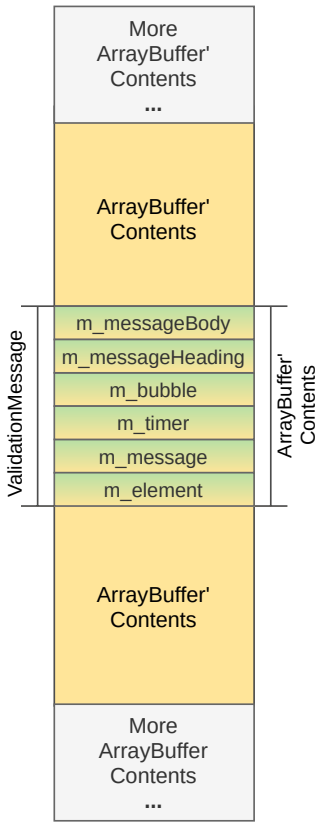
1. Delete few objects *O* around *ValidationMessage*
2. Destroy *ValidationMessage* object
   - Line released → Page cached



Exploiting UAF (3/3)

Shaping the heap

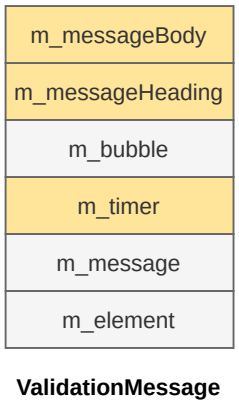
- Spray few objects *T* to get back ValidationMessage :
  - E.g. spray with *ArrayBuffer(ValidationMessageSize)*



Initial memory leak

Memory leak

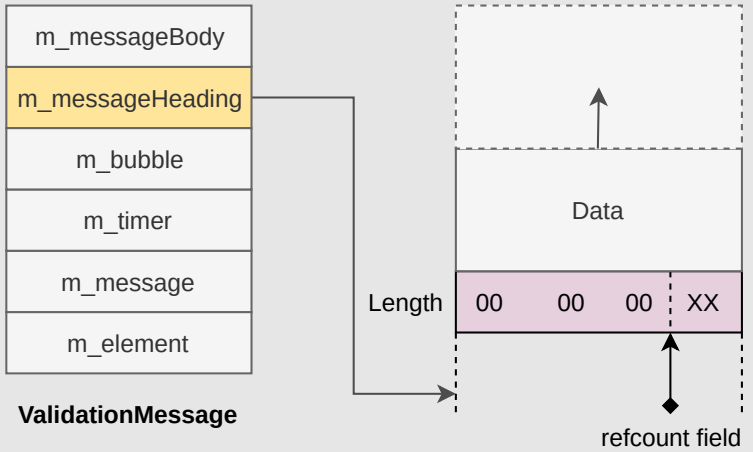
- *m_messageBody*, *m_messageHeading* & *m_timer* instantiated after obj. reuse
- *m_timer* is “fastMalloc’ed”
  - → Guess the address of objects allocated on the same page



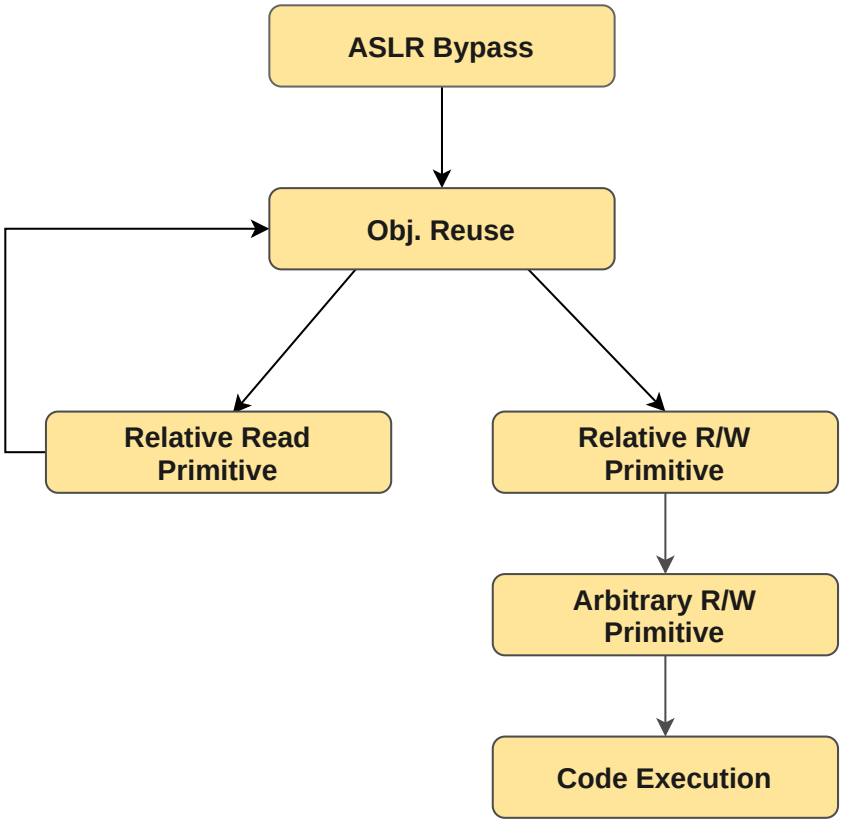
Arbitrary decrement primitive

Exploitation

- Corrupt the *m_messageHeading* pointer
- Target : obj with length and data field
- Confuse some obj length field with *m_messageHeading* refcount
- Misaligned write on length field → Enlarge size of data buffer
- → Relative read/[write] primitive.



Exploitation strategy



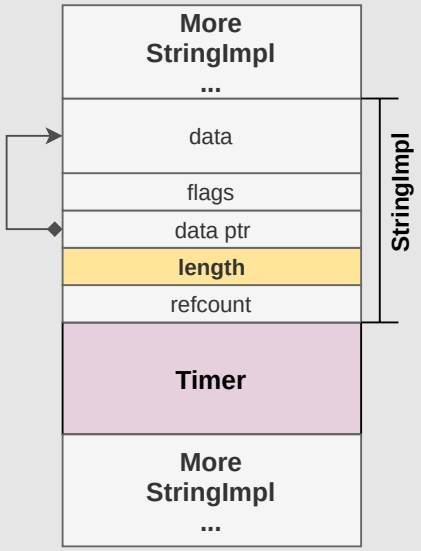
Relative read primitive (1/2)

Goal

- Leak the address of JSC allocated obj. (*JSArrayBufferView*)

How

1. Spray heap with multiple *StringImpl*
   Obj :
   - Before/After *Timer* allocation leak
   - sizeof(Timer) = sizeof(StringImpl)
2. Use arbitrary decrement on *StringImpl* length's field
3. → read beyond *data* frontier in fastMalloc heap



Relative read primitive (2/2)

Leaking JSArrayBufferView pointers (1/2)

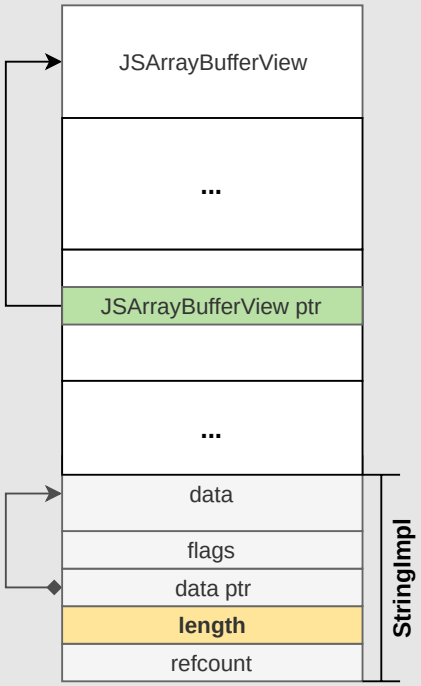
- DOM objects and JS objects use two different allocators
  - We can't access JSObject using our relative read
- The JS builtins **Object.defineProperties** allocate two objects that store JSObject references
  - **Vector** and **MarkedArgumentBuffer** are our target

```
static JSValue defineProperties(ExecState* exec, JSObject* object, JSObject* properties)
{

    Vector<PropertyDescriptor> descriptors;
    MarkedArgumentBuffer markBuffer;

    /* ... */
    JSValue prop = properties->get(exec, propertyNames[i]);
    /* ... */
    PropertyDescriptor descriptor;
    toPropertyDescriptor(exec, prop, descriptor);
    /* ... */
    descriptors.append(descriptor); // [1] store JSValue reference on fastMalloc
    /* ... */
    markBuffer.append(descriptor.value()); // [2] store one more JSValue reference on fastMalloc
}
```

Relative read primitive (2/2)

Leaking JSArrayBufferView pointers (2/2) [1]

1. Allocate multiple *JSArrayBufferView*
2. Get reference on fastMalloc heap using *Object.defineProperties*
   - Both target objects are freed at the end of the builtin
   - Must not re-use these allocations otherwise we loose our references
3. Use relative read to find these references
   - We want a *JSArrayBufferView* that is allocated after our relative read object to read its content

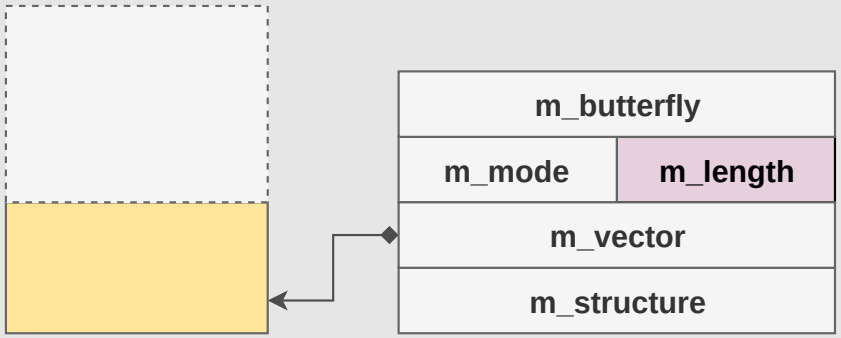


1. Thanks @qwertyoruiopz for the Object.defineProperties technique

Relative read/write primitive

How

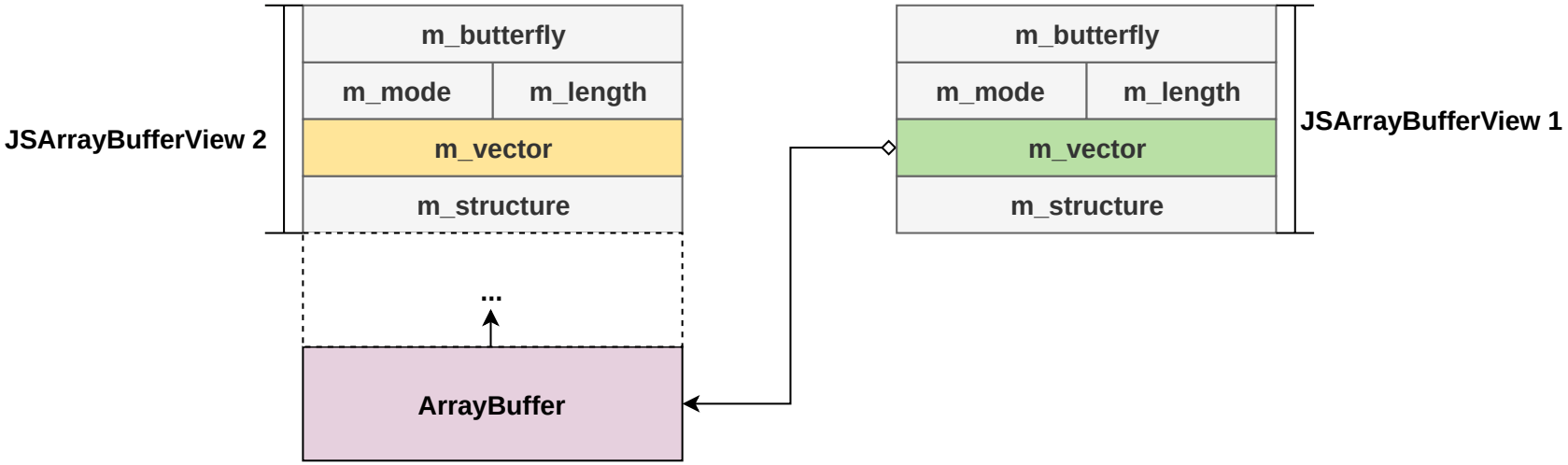
1. Run the exploit again
2. Use arbitrary decrement on **leaked** *JSArrayBufferView* address
3. Enlarge size of backing buffer
4. → read/write primitive



Arbitrary read/write primitive

How

- Relative R/W primitive through *JSArrayBufferView 1*
  - → corrupt *JSArrayBufferView 2*'s vector
- Arbitrary R/W primitive through *JSArrayBufferView 2*



Code execution

How

- We can't allocate *RWX* memory page on PS4
- We can control *RIP*
  - We have a leak of a *HTMLElement* instance
  - Overwrite one vtable ptr of a *HTMLElement*
  - Call the JS method that will trigger the overwritten pointer
- We can do code-reuse to implement the next stage
  - The old previous PS4 jailbreak used this method

Demo

2

2. image credit : TheRegisti

Outline

Conclusion & Future work

Conclusion

- Working WebKit exploit on 6.xx firmwares
- Exploit available on Github https://github.com/Synacktiv

Exploit stability

- Not really stable
- Take ~11 sec to gain arbitrary R/W

Improvements

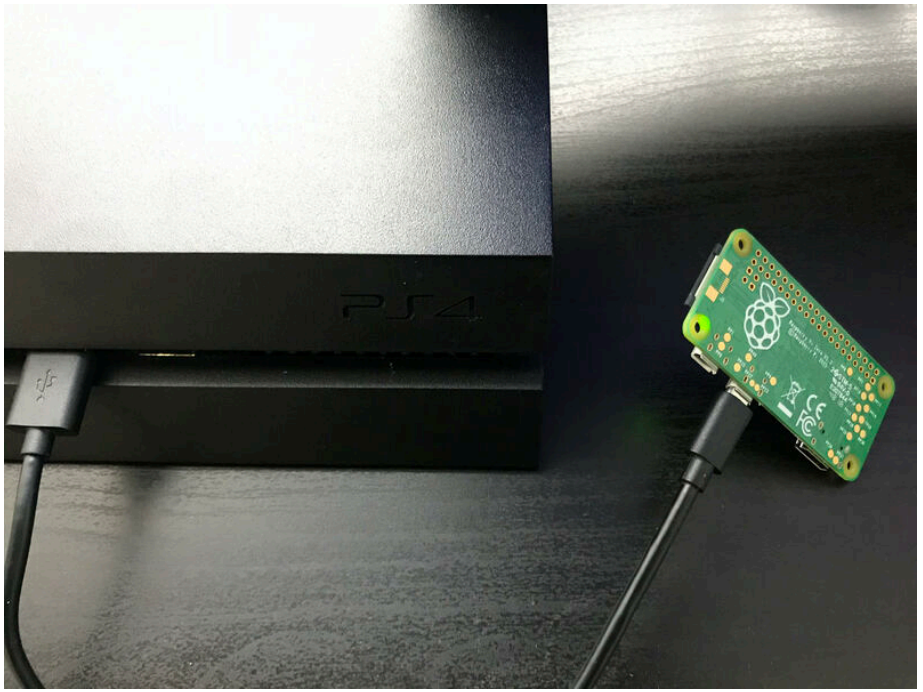
- The exploit reliability could be improved
- The ASLR bruteforce could be more deterministic
  - Our spray mixed fastMalloc and IsoHeap pages
  - It happens that we guess the address of the wrong virtual page
- We could find a better exploitation path that avoid triggering two times the vulnerability

What about 7.xx firmwares (1/2)

Problem

- ASLR bypass not working on 7.xx firmwares
- Cannot survive to crash during obj. reuse :
  - Requires prior knowledge on memory mapping

What about 7.xx firmwares (2/2)



Solution

- Bruteforce ASLR
  - → Guess address of sprayed HTMLElement objs.
- Plug a Raspberry Pi (detected as a keyboard)
- Hit *Enter* keystroke at periodical time (5s)
  - → Automatically reload exploit after a crash
- No results so far :-(

Acknowledgements

Thanks to

- Synacktiv
  - For letting us do the research
- Our colleagues
  - For all the help while developing the exploit
- BlackHat
  - For the great event
- You
  - For your attention !

QUESTIONS ?

THANK YOU FOR YOUR ATTENTION

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