BLUEHAT

IL 2022

A Brief History of iMessage Exploitation

Samuel Groß (@5aelo), Ian Beer (@i41nbeer)

iMessage Exploitation ~ 2019

https://googleprojectzero.blogspot.com/2020/01/remote-iphone-exploitation-part-1.html

iMessage Exploit Flow ~ 2019

Attack Surface?

Attack Surface: Deserialization

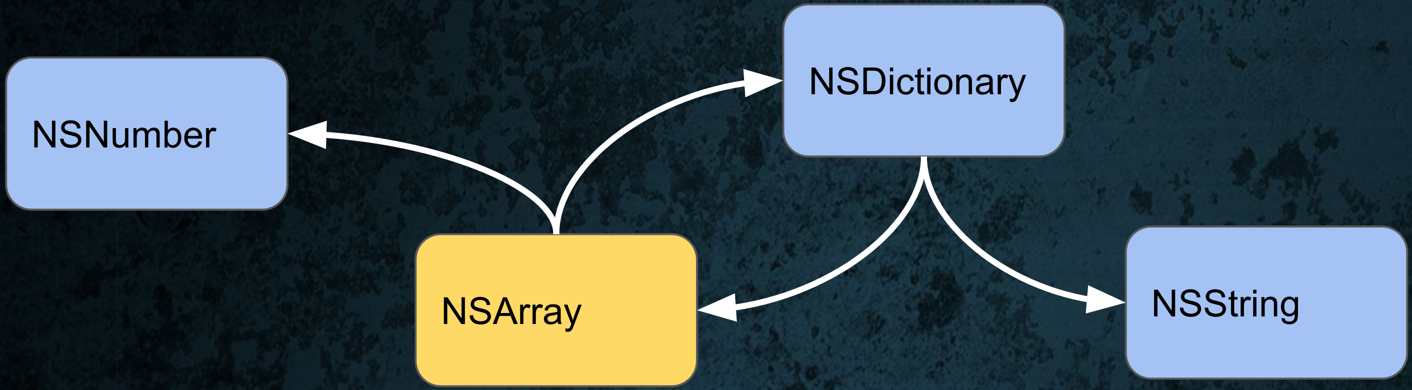
```
{
    ati = [ NSKeyedArchiver Archive ];
    gid = "27EDB72A-DFC1-43DD-B8AE-8DBD2CE70068";
    gv = 8;
    p =     (
        "mailto:sender@foo.bar",
        "mailto:receiver@foo.bar"
    );
    pv = 0;
    r = "E417E766-0B85-4427-AF49-9246AA76C803";
    t = "Hello BlueHat!";
    v = 1;
    x = "<html><body>Hello BlueHat!</body></html>";
}
```

Attack Surface: Deserialization

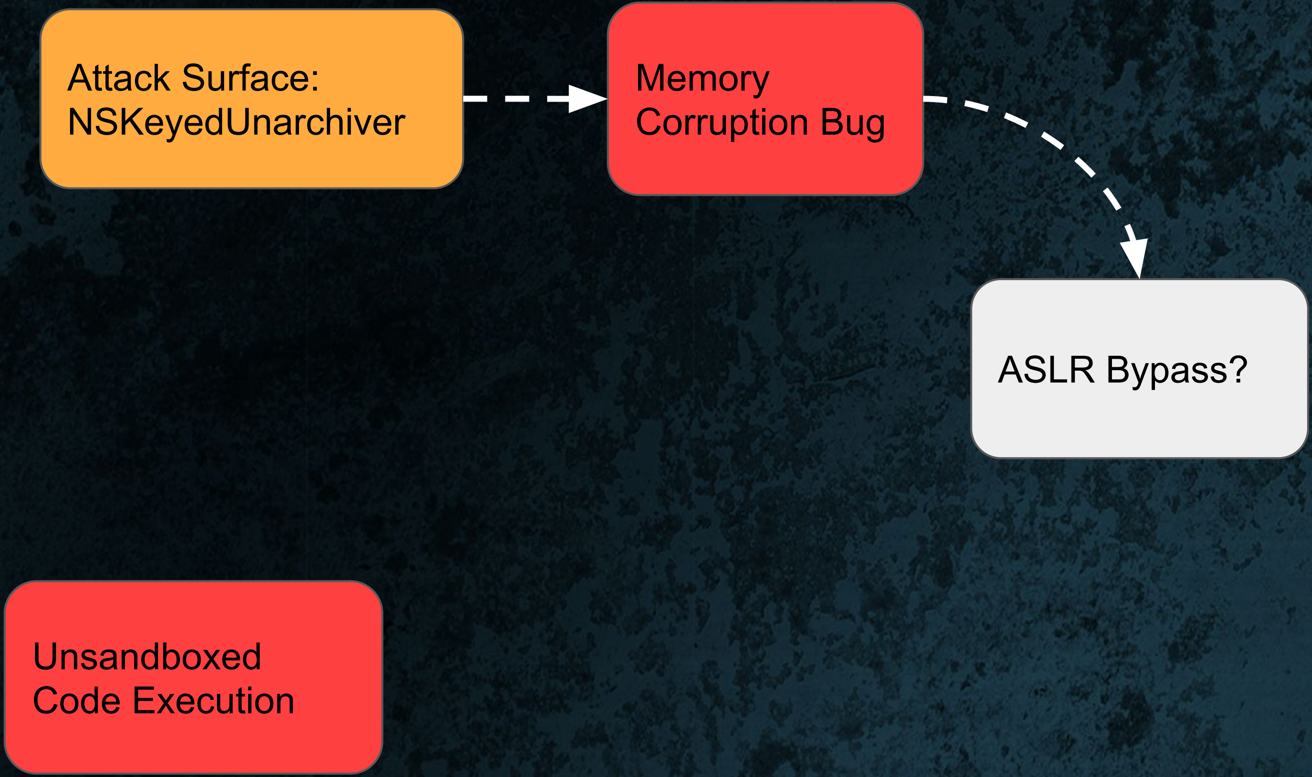
```
{
    ati = [ NSKeyedArchiver Archive ];
    gid = "27EDB72A-DFC1-43DD-B8AE-8DBD2CE70068";
    gv = 8;
    p =     (
        "mailto:sender@foo.bar",
        "mailto:receiver@foo.bar"
    );
    pv = 0;
    r = "E417E766-0B85-4427-AF49-9246AA76C803";
    t = "Hello BlueHat!";
    v = 1;
    x = "<html><body>Hello BlueHat!</body></html>";
}
```

Attack Surface: Deserialization

- "NSKeyedArchiver [...] provides a way to encode objects (and scalar values) into an architecture-independent format suitable for storage in a file."
- Can (de)serialize pretty complex object hierarchies (even circles!)
- This is our attack surface!
- One key is deserialized in Springboard process, which is *unsandboxed*



iMessage Exploit Flow ~ 2019



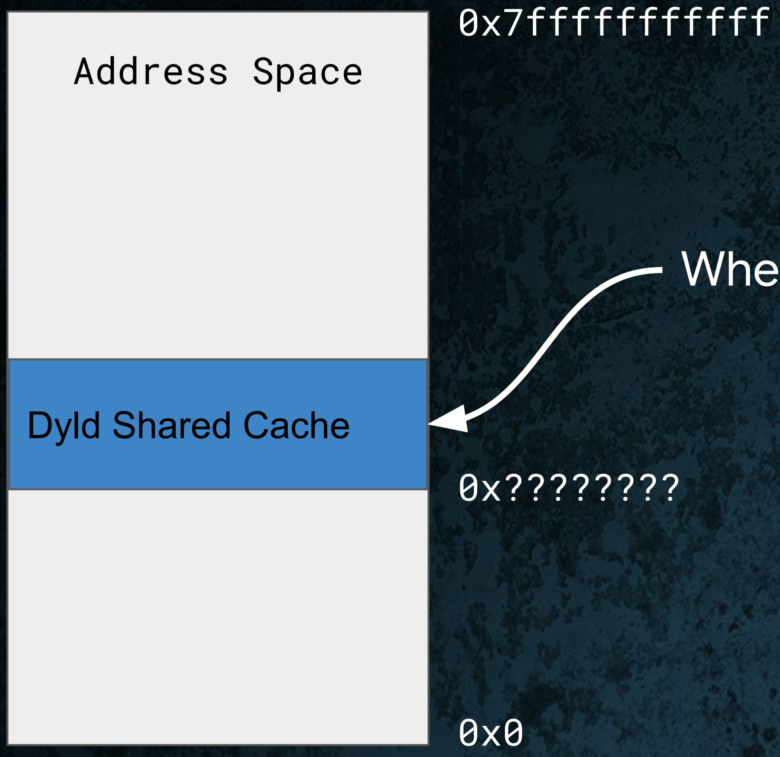
Attack Surface:
NSKeyedUnarchiver

Memory
Corruption Bug

ASLR Bypass?

Unsandboxed
Code Execution

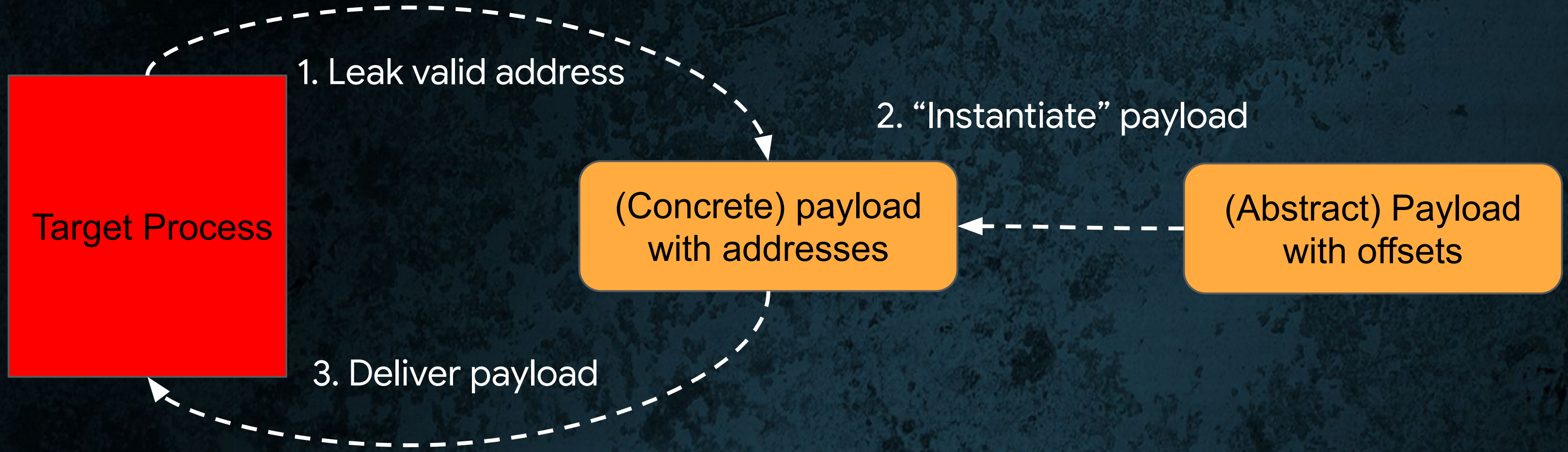
Exploitation (~ 2019): Defeating ASLR



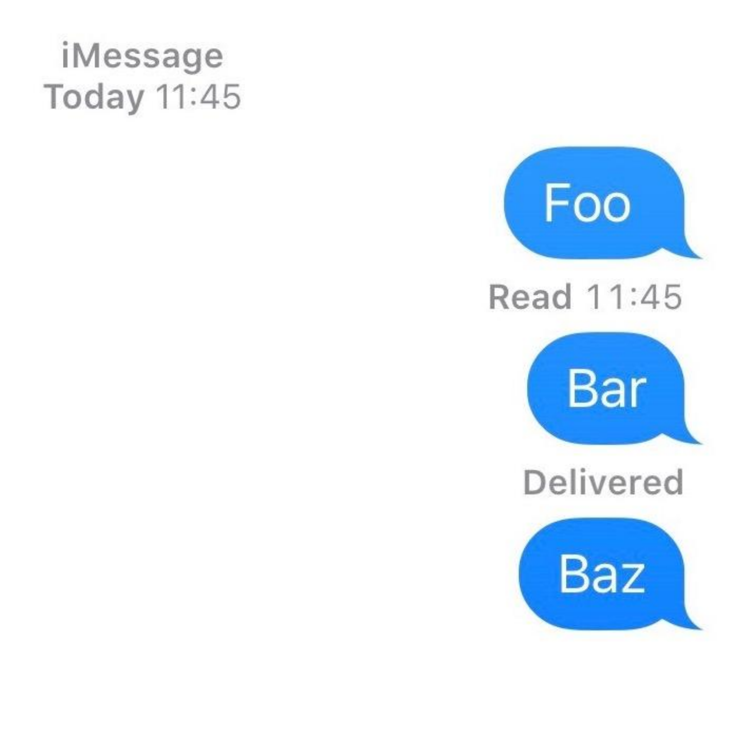
Where is this mapping???

Why is ASLR a Problem?

- **Need communication channel between target process and exploit logic**
- Usually no (big) problem for e.g. browser exploits: exploit logic implemented in JavaScript => Runs inside the targeted process
- It is a problem for something like iMessage though...



Delivery Receipts as Communication Channel



iMessage
Today 11:45

Foo

Read 11:45

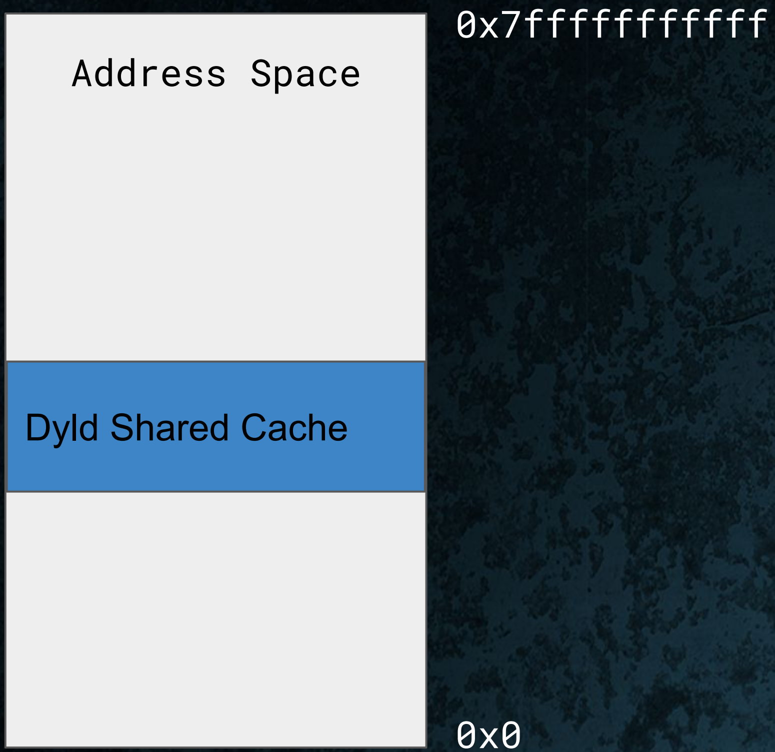
Bar

Delivered

Baz

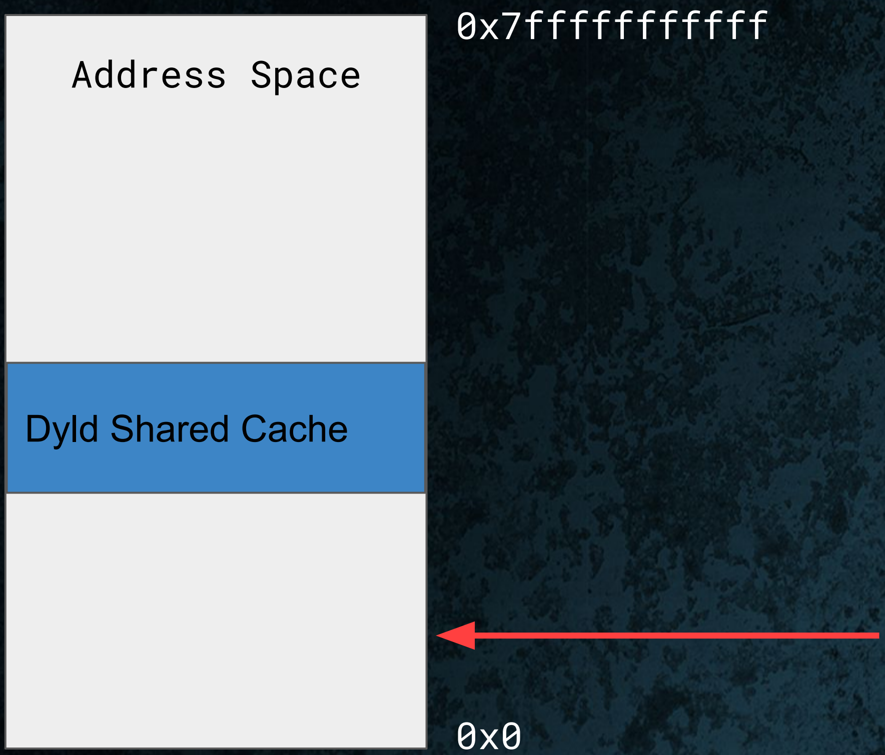
- When iMessage process receives a message, it sends a *delivery receipt* to the sender
- If process crashes before sending the receipt, the delivery receipt message is never sent
- => **1-bit communication channel**: crashed or didn't crash

Crash Oracle + Binary Search = ASLR defeat



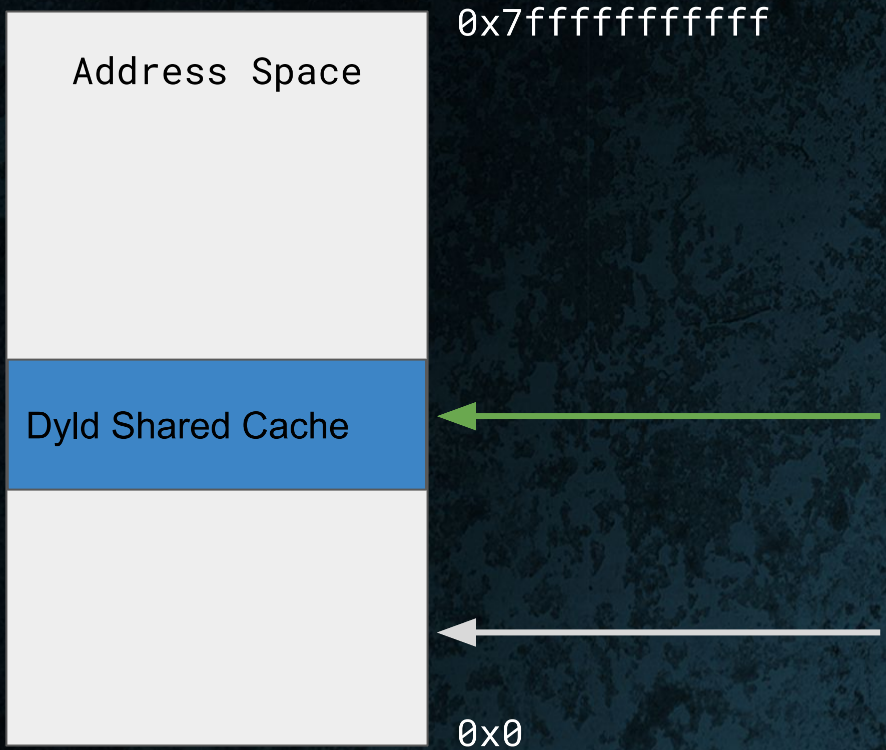
- Construct payload to dereference a given address
- Send payload over iMessage
- Got a delivery receipt? If yes: address is valid, otherwise not
- Do this as binary search to find base address with 20-30 messages

Crash Oracle + Binary Search = ASLR defeat



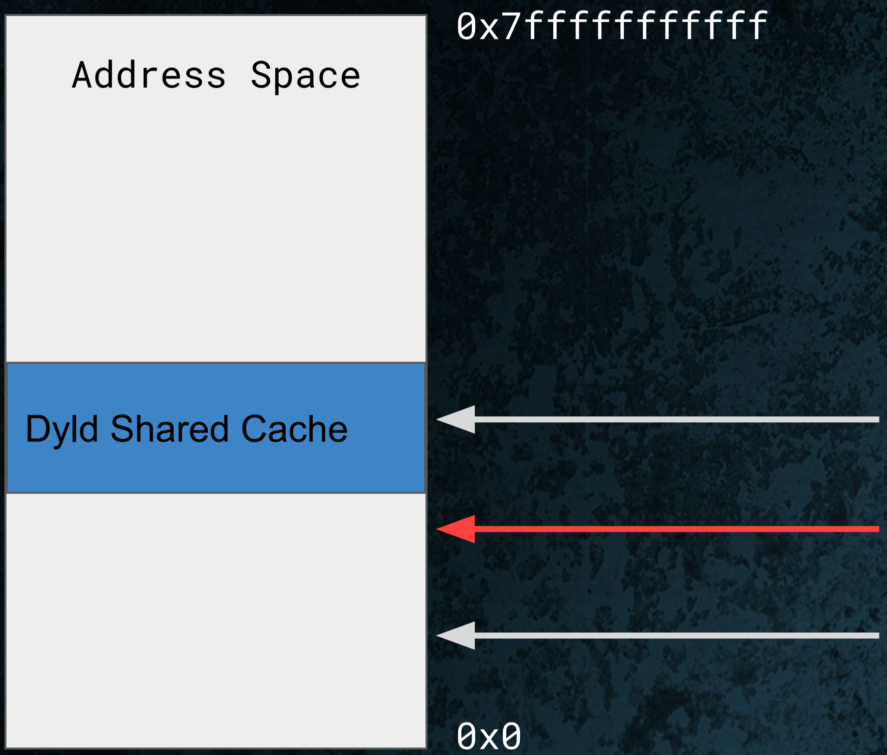
- Construct payload to dereference a given address
- Send payload over iMessage
- Got a delivery receipt? If yes: address is valid, otherwise not
- Do this as binary search to find base address with 20-30 messages

Crash Oracle + Binary Search = ASLR defeat



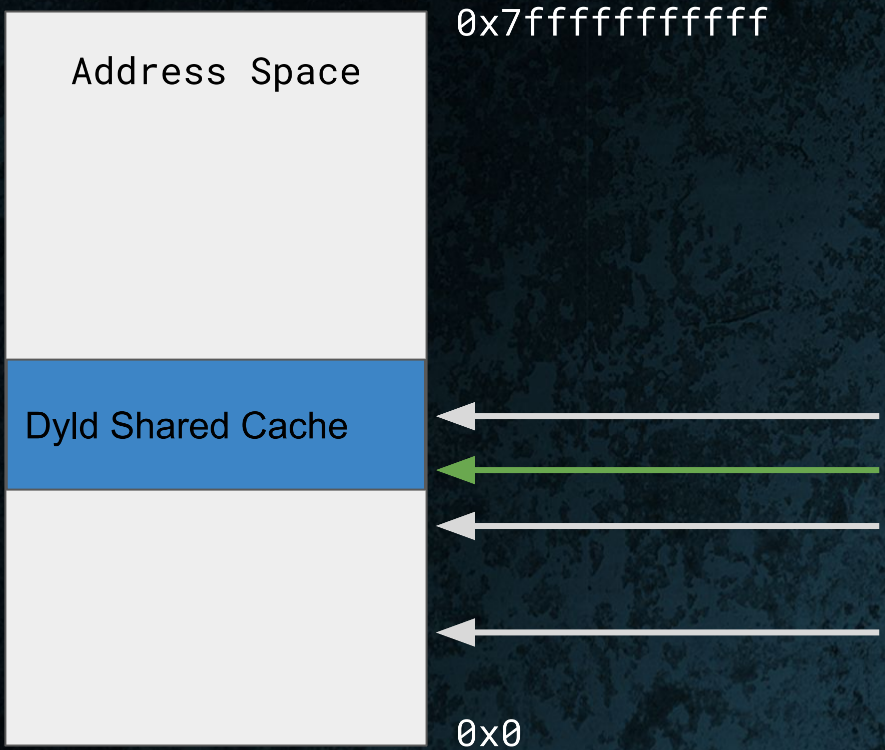
- Construct payload to dereference a given address
- Send payload over iMessage
- Got a delivery receipt? If yes: address is valid, otherwise not
- Do this as binary search to find base address with 20-30 messages

Crash Oracle + Binary Search = ASLR defeat



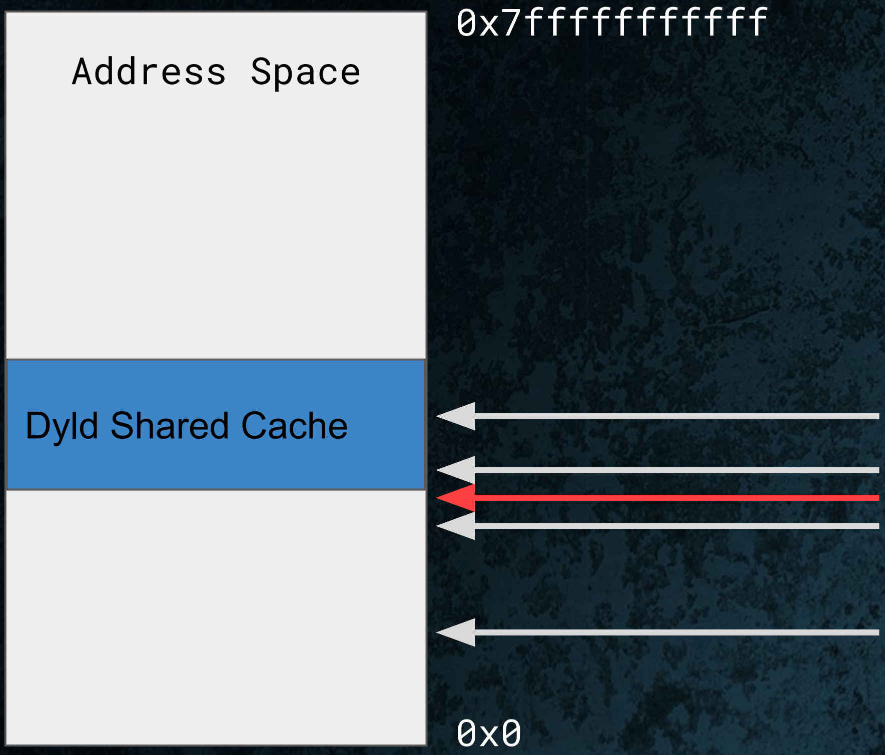
- Construct payload to dereference a given address
- Send payload over iMessage
- Got a delivery receipt? If yes: address is valid, otherwise not
- Do this as binary search to find base address with 20-30 messages

Crash Oracle + Binary Search = ASLR defeat



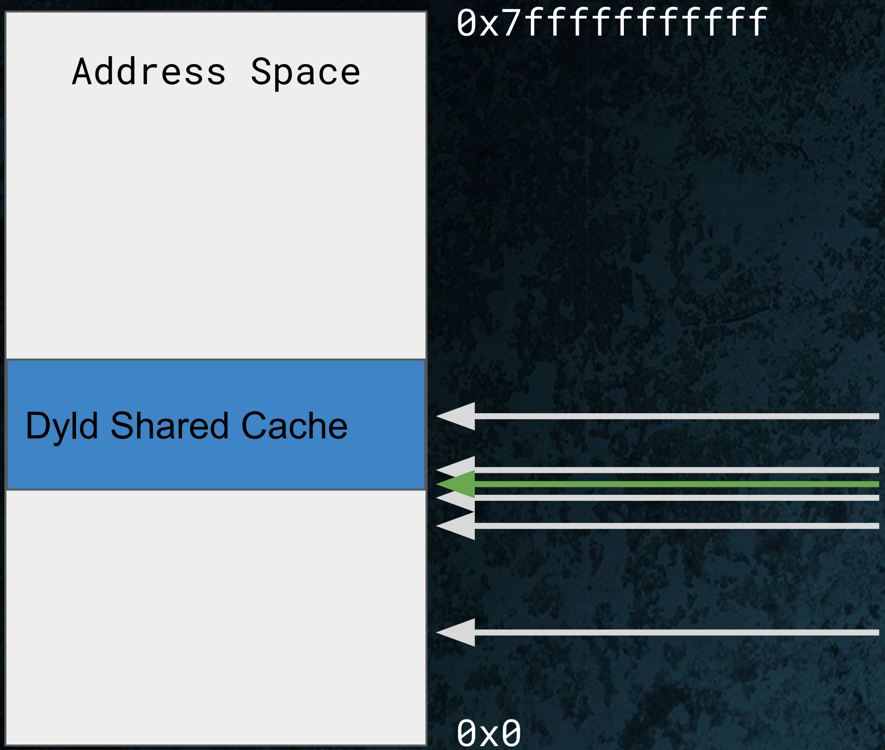
- Construct payload to dereference a given address
- Send payload over iMessage
- Got a delivery receipt? If yes: address is valid, otherwise not
- Do this as binary search to find base address with 20-30 messages

Crash Oracle + Binary Search = ASLR defeat



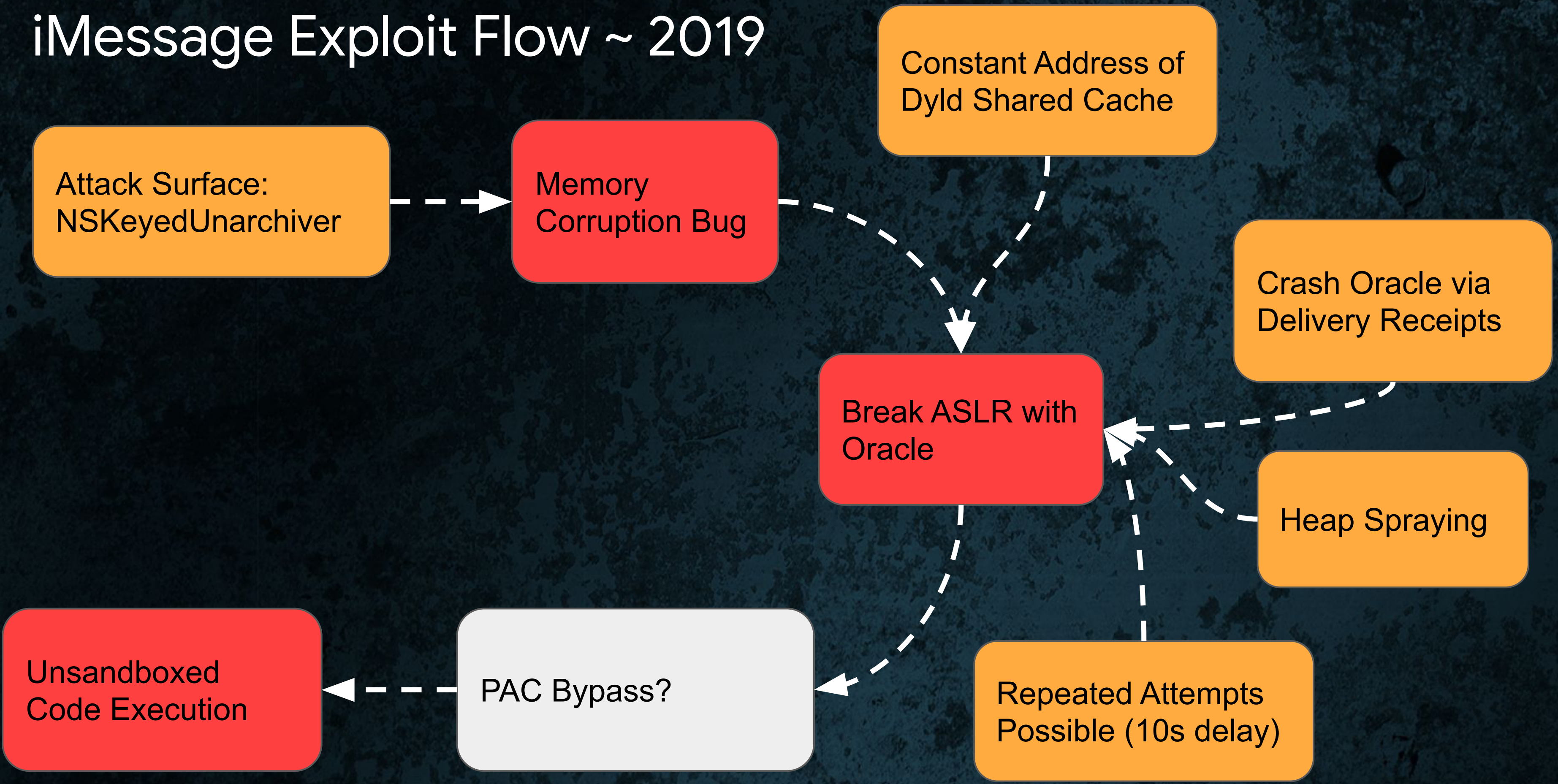
- Construct payload to dereference a given address
- Send payload over iMessage
- Got a delivery receipt? If yes: address is valid, otherwise not
- Do this as binary search to find base address with 20-30 messages

Crash Oracle + Binary Search = ASLR defeat



- Construct payload to dereference a given address
- Send payload over iMessage
- Got a delivery receipt? If yes: address is valid, otherwise not
- Do this as binary search to find base address with 20-30 messages

iMessage Exploit Flow ~ 2019



Attack Surface: NSKeyedUnarchiver

Memory Corruption Bug

Constant Address of Dyld Shared Cache

Crash Oracle via Delivery Receipts

Break ASLR with Oracle

Heap Spraying

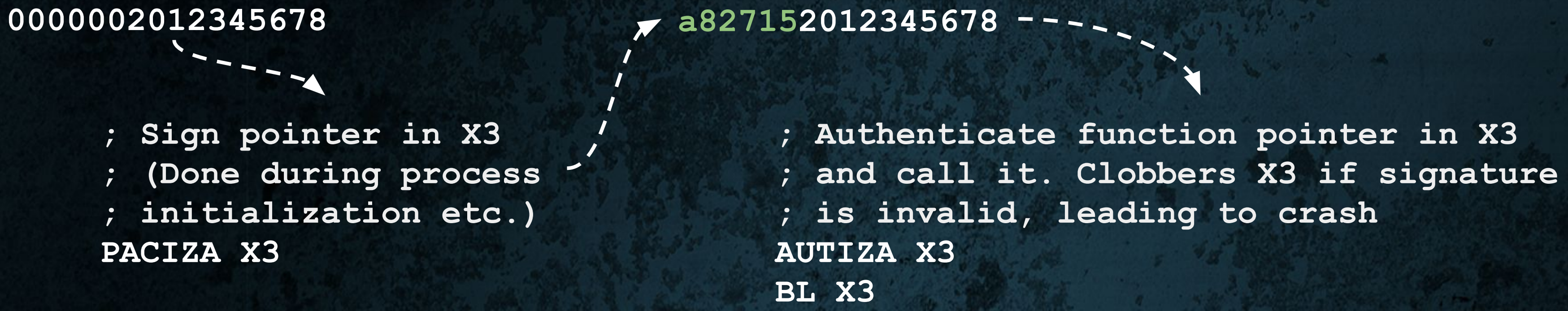
Repeated Attempts Possible (10s delay)

PAC Bypass?

Unsandboxed Code Execution

Defeating PAC (Pointer Authentication)

- PAC: cryptographic signature in unused bits of pointer
- Can no longer forge code pointers => breaks ROP, JOP, ...



```
0000002012345678
```

```
; Sign pointer in X3
; (Done during process
; initialization etc.)
PACIZA X3
```

```
a827152012345678
```

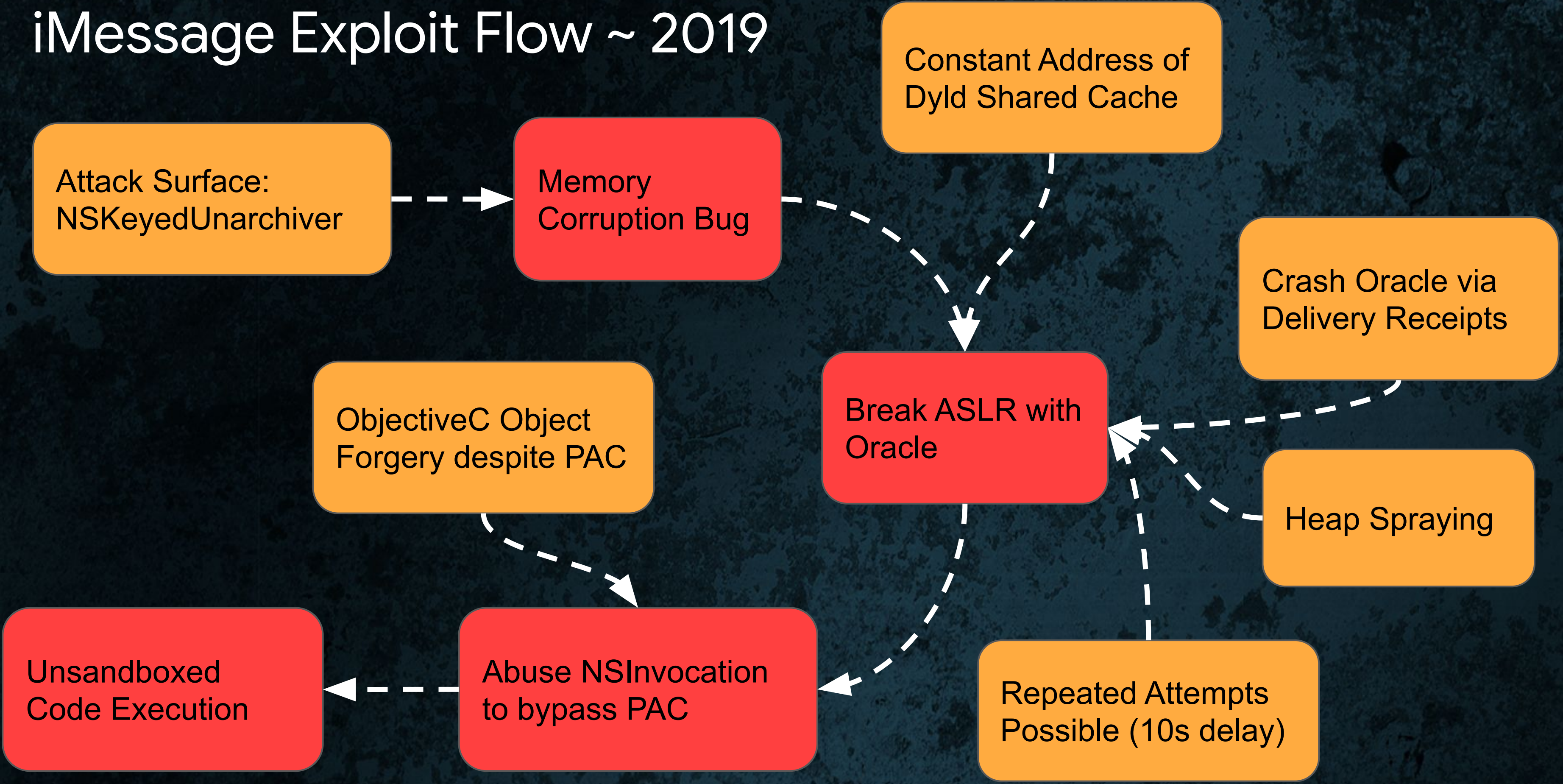
```
; Authenticate function pointer in X3
; and call it. Clobbers X3 if signature
; is invalid, leading to crash
AUTIZA X3
BL X3
```

Defeating PAC (Pointer Authentication)

- PAC: cryptographic signature in unused bits of pointer
- Can no longer forge code pointers => breaks ROP, JOP, ...
- **But really, *arbitrary* code execution isn't necessary**
- (Mostly) enough to call existing functions and method

```
NSInvocation* invocation = [NSInvocation invocationWithMethodSignature:sig];
[invocation setTarget:foo];
[invocation setSelector:@selector(bar)];
[invocation invoke];
// [Foo bar] called
```

iMessage Exploit Flow ~ 2019



Attack Surface: NSKeyedUnarchiver

Memory Corruption Bug

Constant Address of Dyld Shared Cache

Crash Oracle via Delivery Receipts

Break ASLR with Oracle

Heap Spraying

Repeated Attempts Possible (10s delay)

ObjectiveC Object Forgery despite PAC

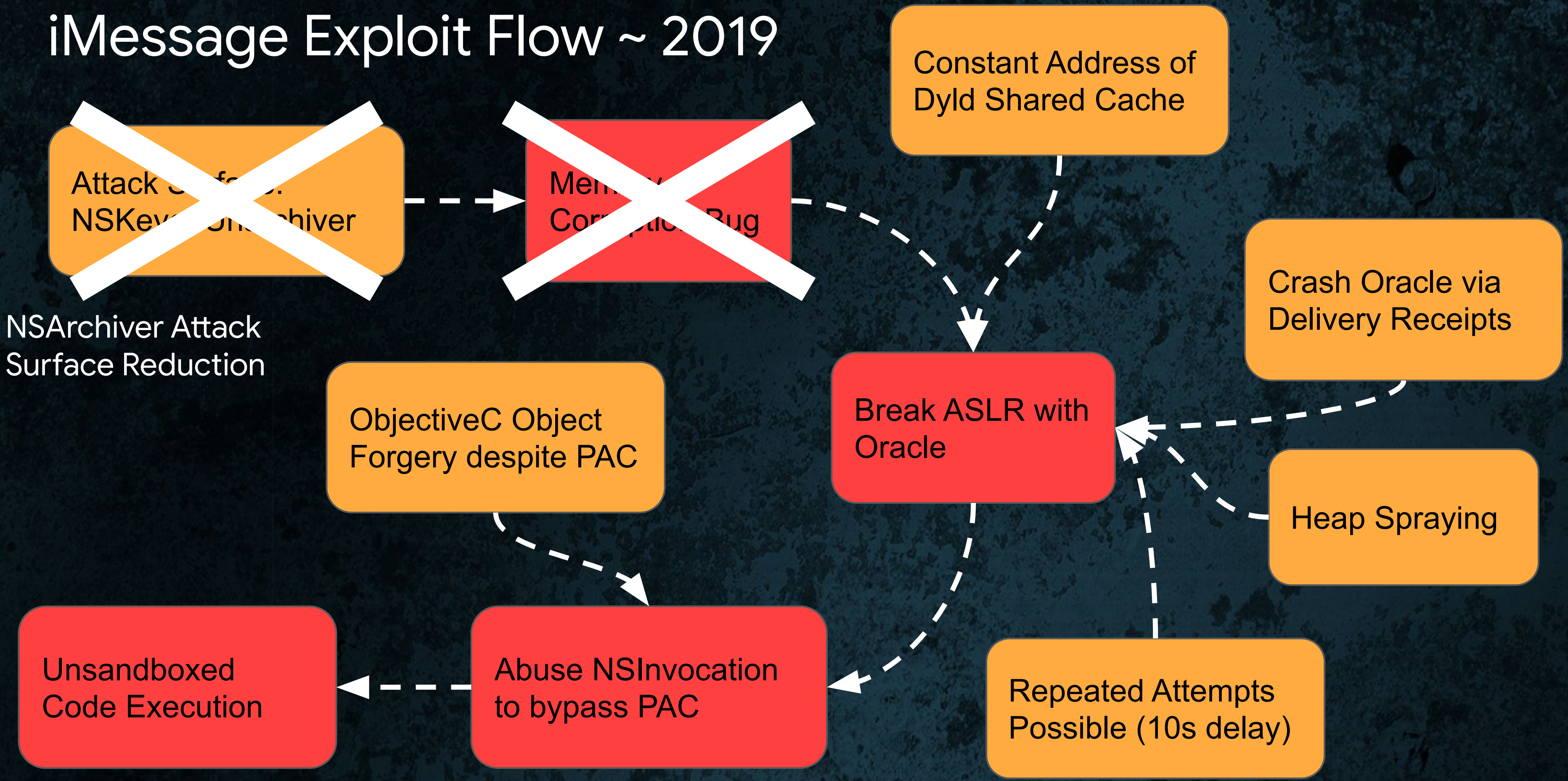
Abuse NSInvocation to bypass PAC

Unsandboxed Code Execution

iMessage Hardening ~ 2019-2020

https://googleprojectzero.blogspot.com/2021/01/a-look-at-imessage-in-ios-14.html

iMessage Exploit Flow ~ 2019



~~Attack Surface: NSKeyedUnarchiver~~

~~Memory Corruption Bug~~

NSArchiver Attack Surface Reduction

Constant Address of Dyld Shared Cache

Crash Oracle via Delivery Receipts

Break ASLR with Oracle

Heap Spraying

Repeated Attempts Possible (10s delay)

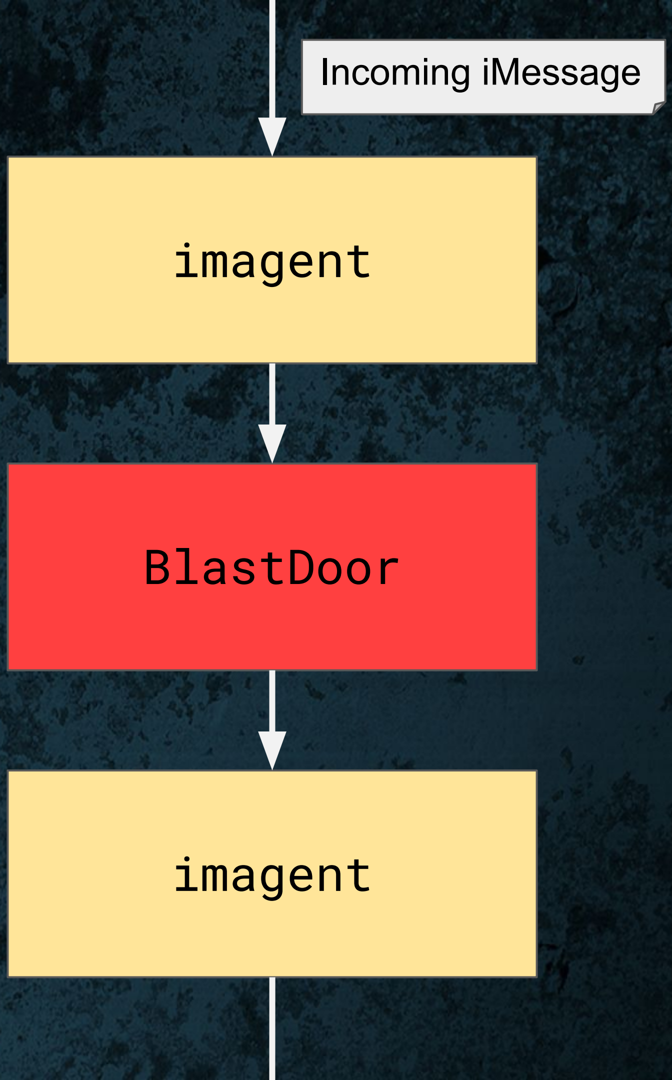
ObjectiveC Object Forgery despite PAC

Abuse NSInvocation to bypass PAC

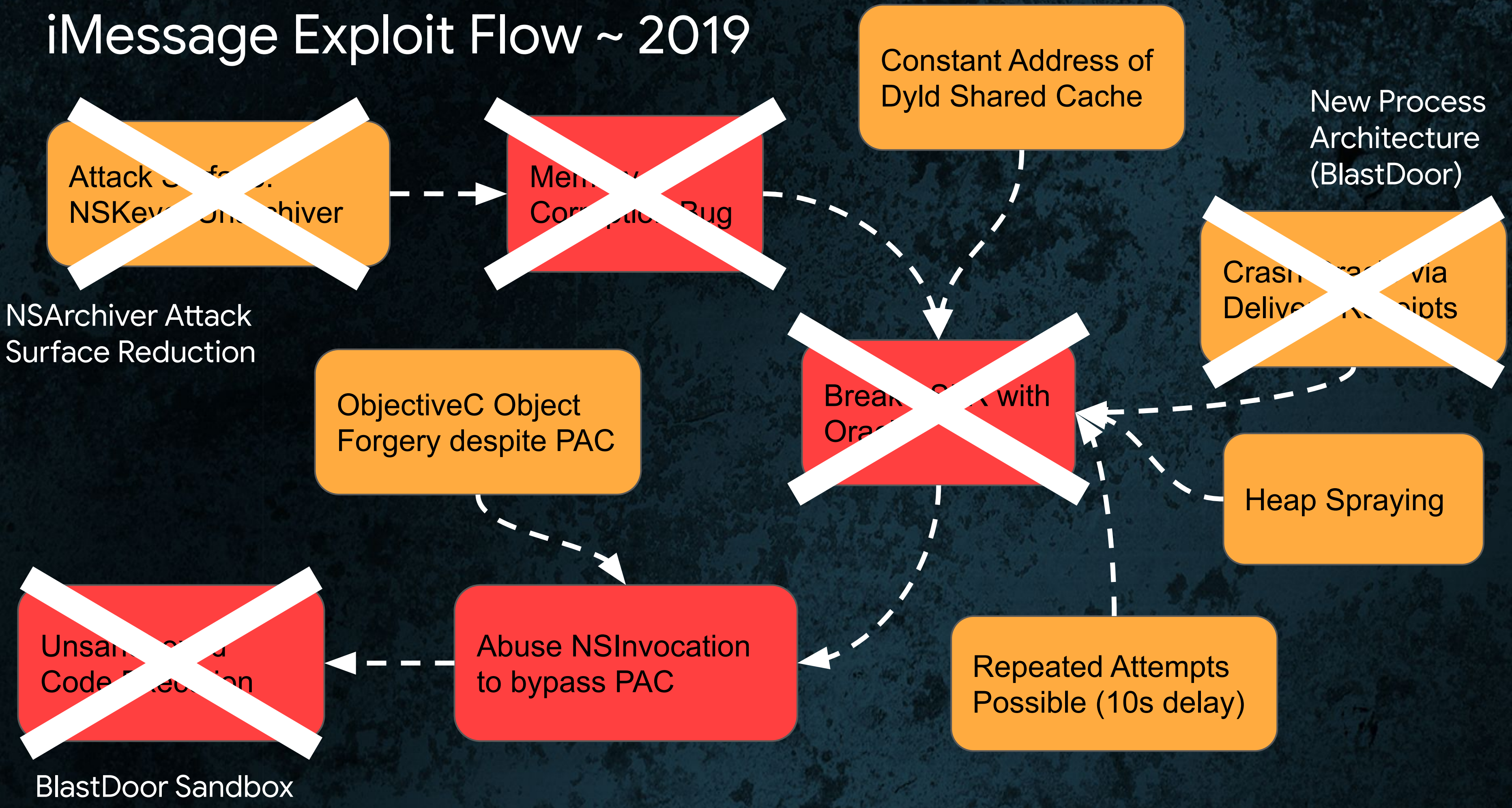
Unsandboxed Code Execution

Blastdoor (iOS 14, ~ mid 2020)

- Re-architectured iMessage processing
- Idea: complex parsing now happens in a tightly sandboxed process: MessagesBlastDoorService
- High-level logic implemented in Swift
- Also breaks crash oracle: crashing process (BlastDoor) is not the process sending the delivery receipt (imagent)



iMessage Exploit Flow ~ 2019



~~Attack Surface: NSKeyedUnarchiver~~

NSArchiver Attack Surface Reduction

~~Memory Corruption Bug~~

Constant Address of Dyld Shared Cache

New Process Architecture (BlastDoor)

~~Crash Oracle via Delivery Receipts~~

~~Break ASLR with Oracle~~

ObjectiveC Object Forgery despite PAC

Heap Spraying

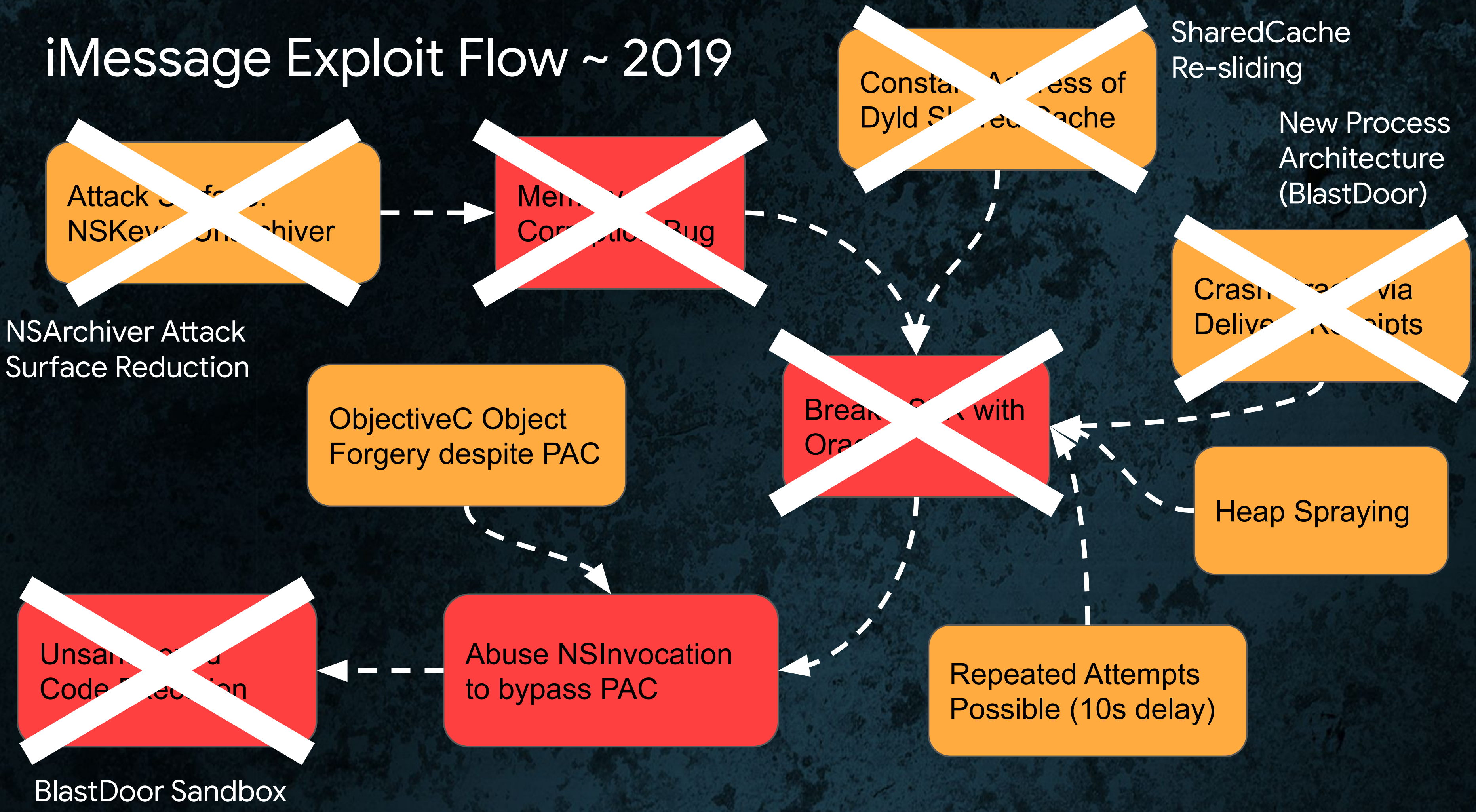
~~Unsandboxed Code Execution~~

BlastDoor Sandbox

Abuse NSInvocation to bypass PAC

Repeated Attempts Possible (10s delay)

iMessage Exploit Flow ~ 2019



~~Attack Surface: NSKeyedUnarchiver~~

NSArchiver Attack Surface Reduction

~~Memory Corruption Bug~~

~~Constant Address of Dyld Shared Cache~~

SharedCache Re-sliding

New Process Architecture (BlastDoor)

~~Crash Oracle via Delivery Receipts~~

~~Break ASLR with Oracle~~

ObjectiveC Object Forgery despite PAC

Heap Spraying

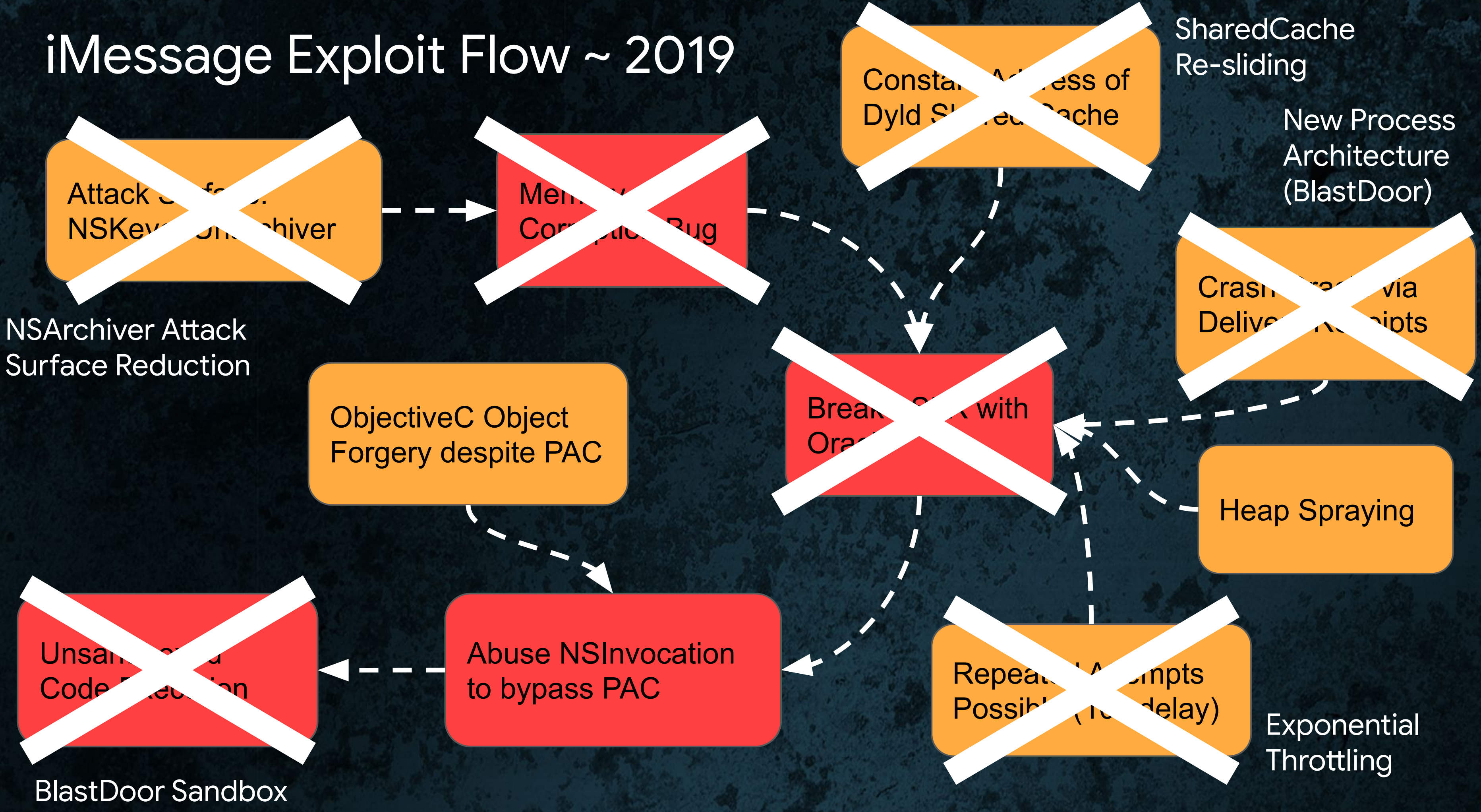
Abuse NSInvocation to bypass PAC

Repeated Attempts Possible (10s delay)

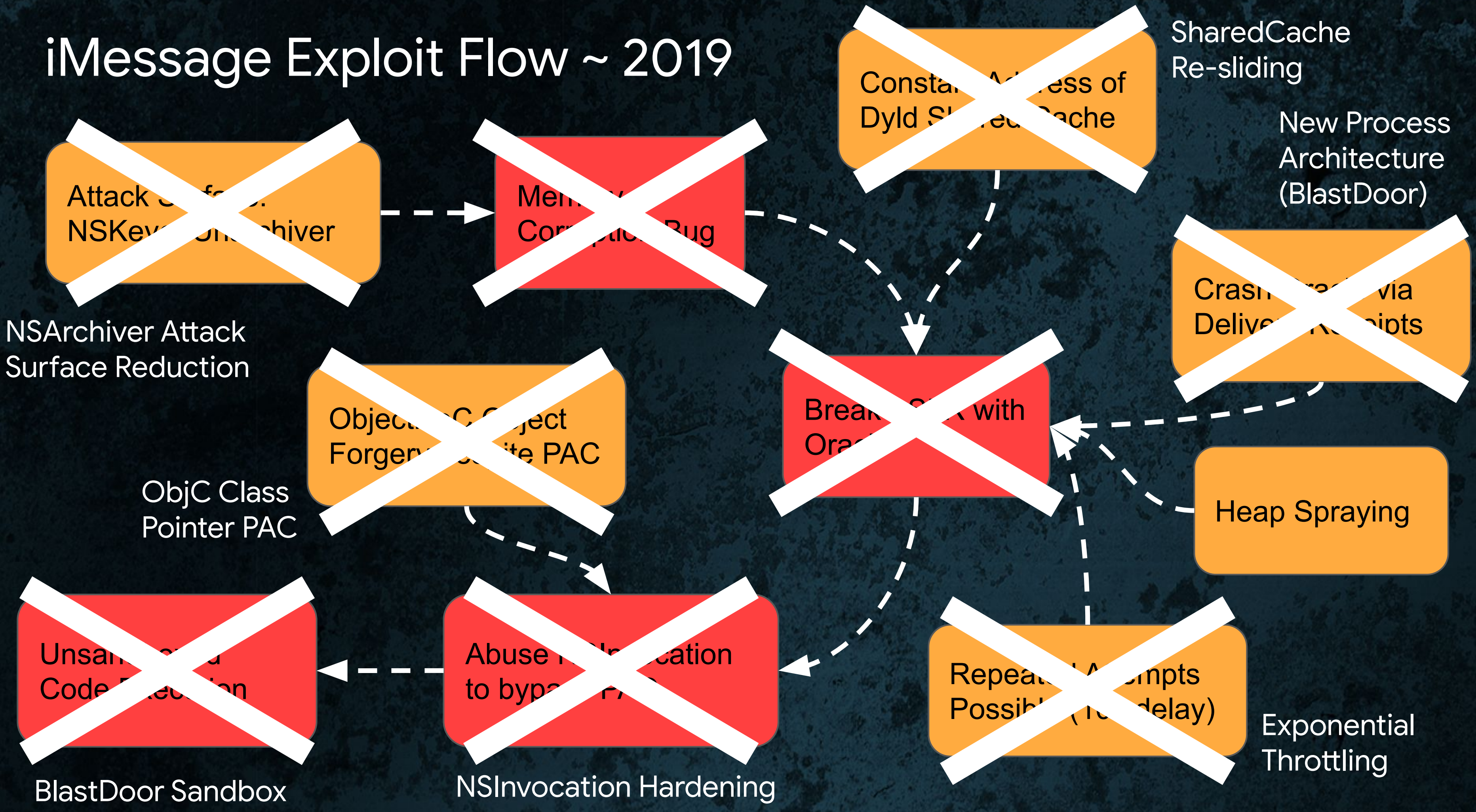
~~Unsandboxed Code Execution~~

BlastDoor Sandbox

iMessage Exploit Flow ~ 2019


~~Attack Surface: NSKeyedUnarchiver~~
NSArchiver Attack Surface Reduction
~~Memory Corruption Bug~~
~~Constant Address of Dyld SharedCache~~
SharedCache Re-sliding
New Process Architecture (BlastDoor)
~~Crash Tracking via Delivery Receipts~~
ObjectiveC Object Forgery despite PAC
~~Break ASLR with Oracle~~
Heap Spraying
~~Unsandboxed Code Execution~~
BlastDoor Sandbox
Abuse NSInvocation to bypass PAC
~~Repeated Attempts Possible (10s delay)~~
Exponential Throttling

iMessage Exploit Flow ~ 2019


Attack S... fo... NSKey... Un... chiver
Mem... Corr... ptio... Bug
Consta... A... ess of Dyld Sh... red... ache
Crash ... via Deliv... R... ipts
Break ... with Ora...
Object... C ... ject Forgery ... ite PAC
Heap Spraying
Unsan... ... d Code ... ion
Abuse ... Invocation to bypa... P...
Repeat... A... mpts Possib... (1... delay)

SharedCache Re-sliding

New Process Architecture (BlastDoor)

NSArchiver Attack Surface Reduction

ObjC Class Pointer PAC

BlastDoor Sandbox

NSInvocation Hardening

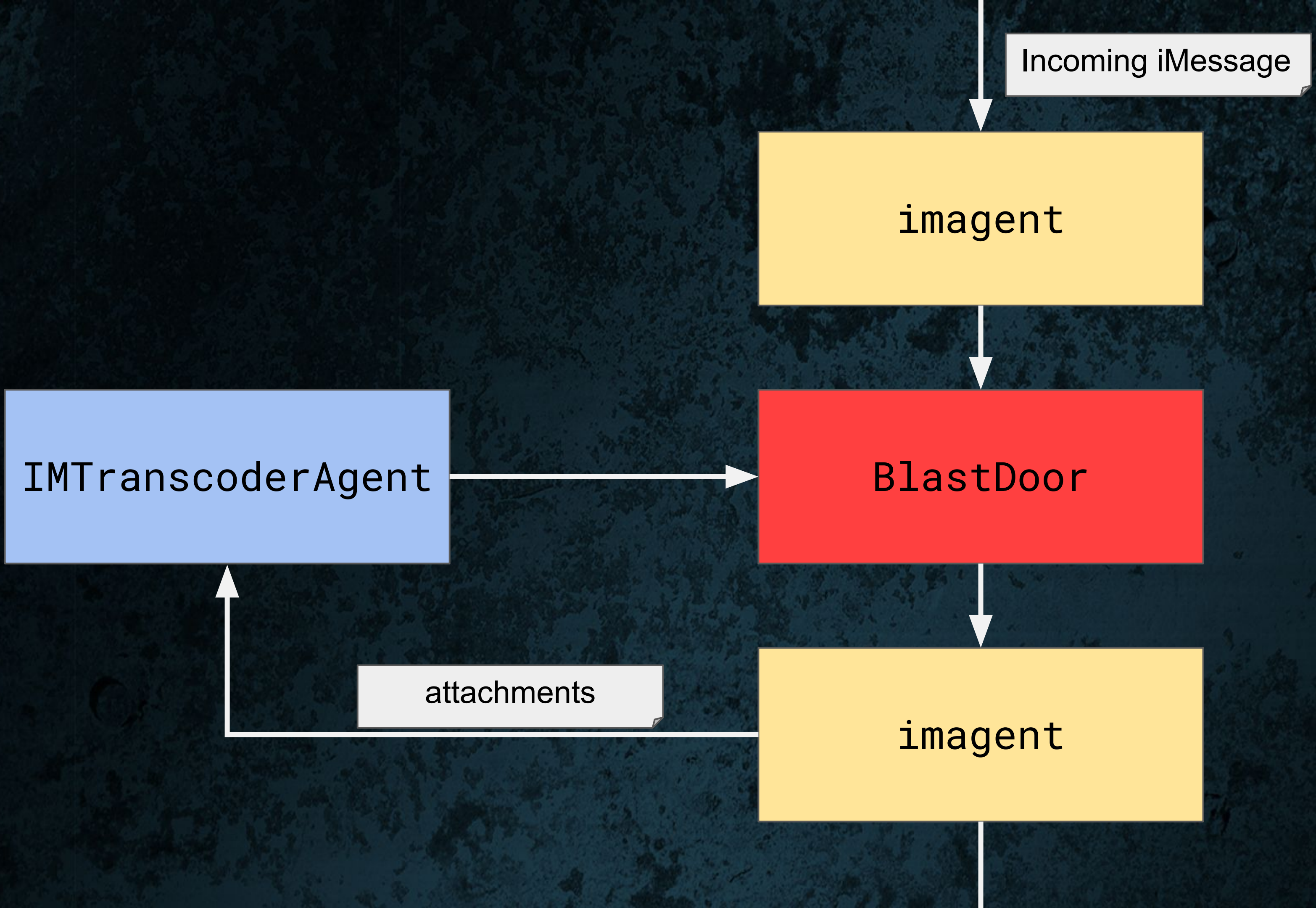
Exponential Throttling

ForcedEntry ~ 2021

https://googleprojectzero.blogspot.com/2021/12/a-deep-dive-into-nso-zero-click.html

iMessage Exploit Flow ~ 2021

Attack Surface?


Incoming iMessage
imagent
IMTranscoderAgent
BlastDoor
attachments
imagent

one_loop.gif

```
...
00000300  08 10 00 00 10 00 08 18  |........|
00000308  00 08 00 00 00 21 ff 0b  |.....!..|
00000310  4e 45 54 53 43 41 50 45  |NETSCAPE|
00000318  32 2e 30 03 01 01 00 00  |2.0.....|
...
```

infinite_loop.gif

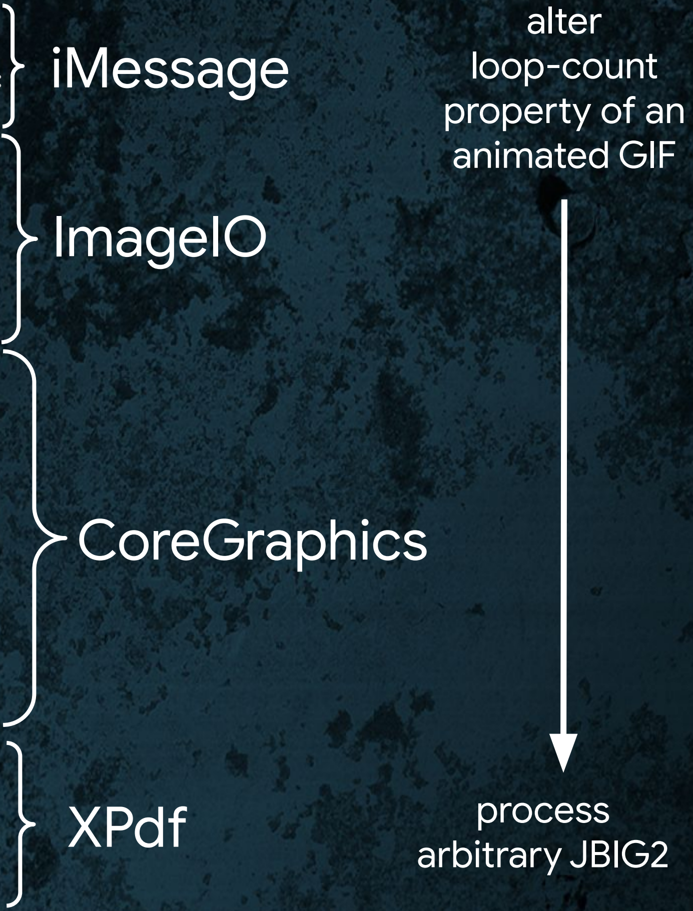
```
...
00000300  08 10 00 00 10 00 08 18  |........|
00000308  00 08 00 00 00 21 ff 0b  |.....!..|
00000310  4e 45 54 53 43 41 50 45  |NETSCAPE|
00000318  32 2e 30 03 01 00 00 00  |2.0.....|
...
```

Implementation of infinite loop GIF edit in iMessage:

```
[IMGIFUtils copyGifFromPath:toDestinationPath:error]

objc_msgSend(a1,
            sel_readFileProperties_fromImageSource_withUpdatedLoopCount_error_,
            &v36,
            v16,
            0LL,    // New loop counter to use
            &v35);
```

```
20: IMSharedUtilities  copyGifFromPath:toDestinationPath:error:
19: IMSharedUtilities  readFileProperties:fromImageSource:withUpdatedLoopCount:error:
18: IMSharedUtilities  readFileProperties:fromImageSource:error:
17: ImageIO            _CGImageSourceCopyProperties
16: ImageIO            IIOImageSource::copyProperties
15: ImageIO            IIOImageSource::getProperties
14: ImageIO            IIO_Reader_PDF::updateSourceProperties
13: ImageIO            CreateSessionPDFRef
12: CoreGraphics       _CGPDFDocumentCreateWithProvider
11: CoreGraphics       _pdf_xref_create
10: CoreGraphics       _CGPDFXRefStreamCreate
 9: CoreGraphics       _xref_stream_create
 8: CoreGraphics       _xref_stream_read_section
 7: CoreGraphics       _CGPDFSourceGetc
 6: CoreGraphics       _CGPDFSourceRefill
 5: CoreGraphics       _jbig2_filter_refill
 4: CoreGraphics       read_bytes
 3: CoreGraphics       JBIG2Stream::reset
 2: CoreGraphics       JBIG2Stream::readSegments
 1: CoreGraphics       JBIG2Stream::readTextRegionSeg
 0: CoreGraphics       JBIG2Stream::readTextRegionSeg
```



iMessage

ImageIO

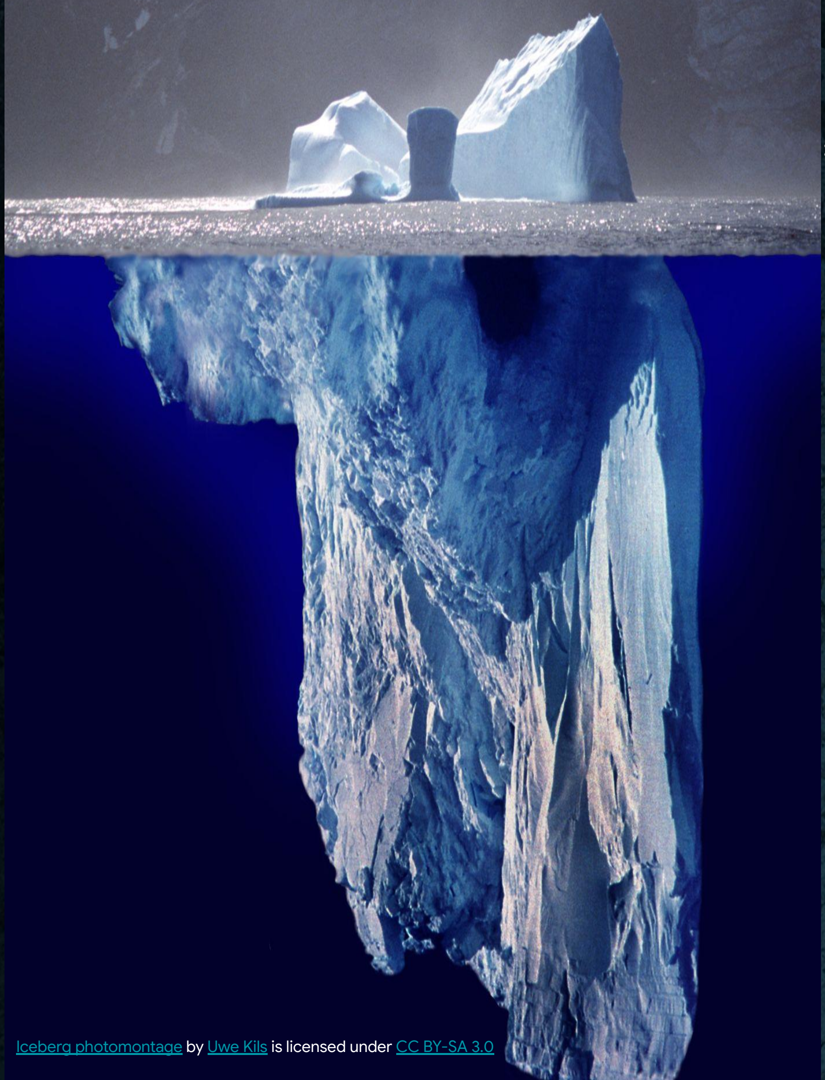
CoreGraphics

XPdf

alter loop-count property of an animated GIF

process arbitrary JBIG2

```
20: IMSharedUtilities
19: IMSharedUtilities
18: IMSharedUtilities
17: ImageIO
16: ImageIO
15: ImageIO
14: ImageIO
13: ImageIO
12: CoreGraphics
11: CoreGraphics
10: CoreGraphics
 9: CoreGraphics
 8: CoreGraphics
 7: CoreGraphics
 6: CoreGraphics
 5: CoreGraphics
 4: CoreGraphics
 3: CoreGraphics
 2: CoreGraphics
 1: CoreGraphics
 0: CoreGraphics
```



Iceberg photomontage by Uwe Kils is licensed under CC BY-SA 3.0

iMessage

ImageIO

CoreGraphics

XPdf

alter loop-count property of an animated GIF

↓

process arbitrary JBIG2

.psd

.bc

.exr

.ai

.cur

.pvr

.bmp

.mpo

.astc

.tiff

.gif

.pbm

.raw

.heif

.ktx

.icns

.rad

.atx

.png

.ico

.jpeg

.jp2

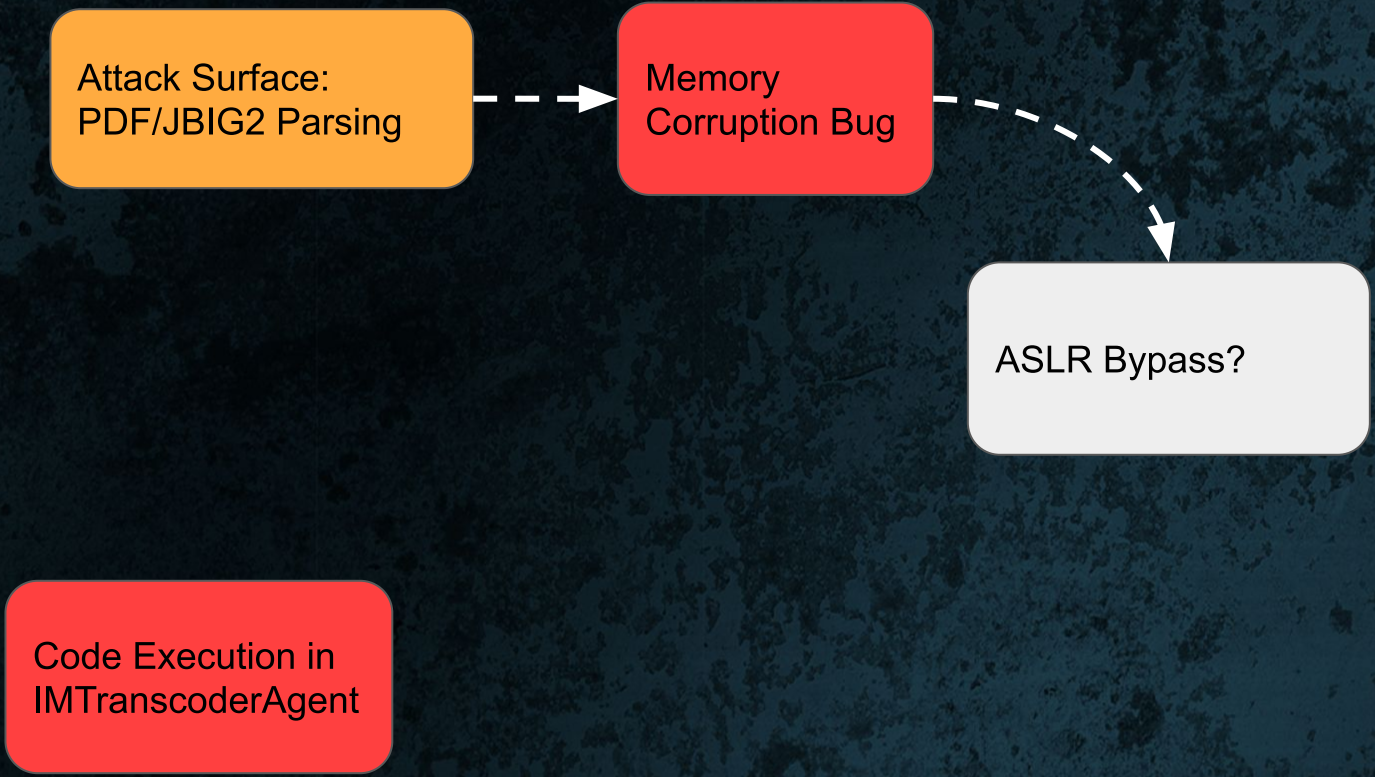
.tga

.pdf

A JBIG2 heap overflow

```
Guint numSyms;
numSyms = 0;
for (i = 0; i < nRefSegs; ++i) {
 if ((seg = findSegment(refSegs[i]))) {
   if (seg->getType() == jbig2SegSymbolDict) {
     numSyms += ((JBIG2SymbolDict *)seg)->getSize();
   }
   // ...
}
// ...
syms = (JBIG2Bitmap **)gmallocn(numSyms, sizeof(JBIG2Bitmap *));
```

iMessage Exploit Flow ~ 2021



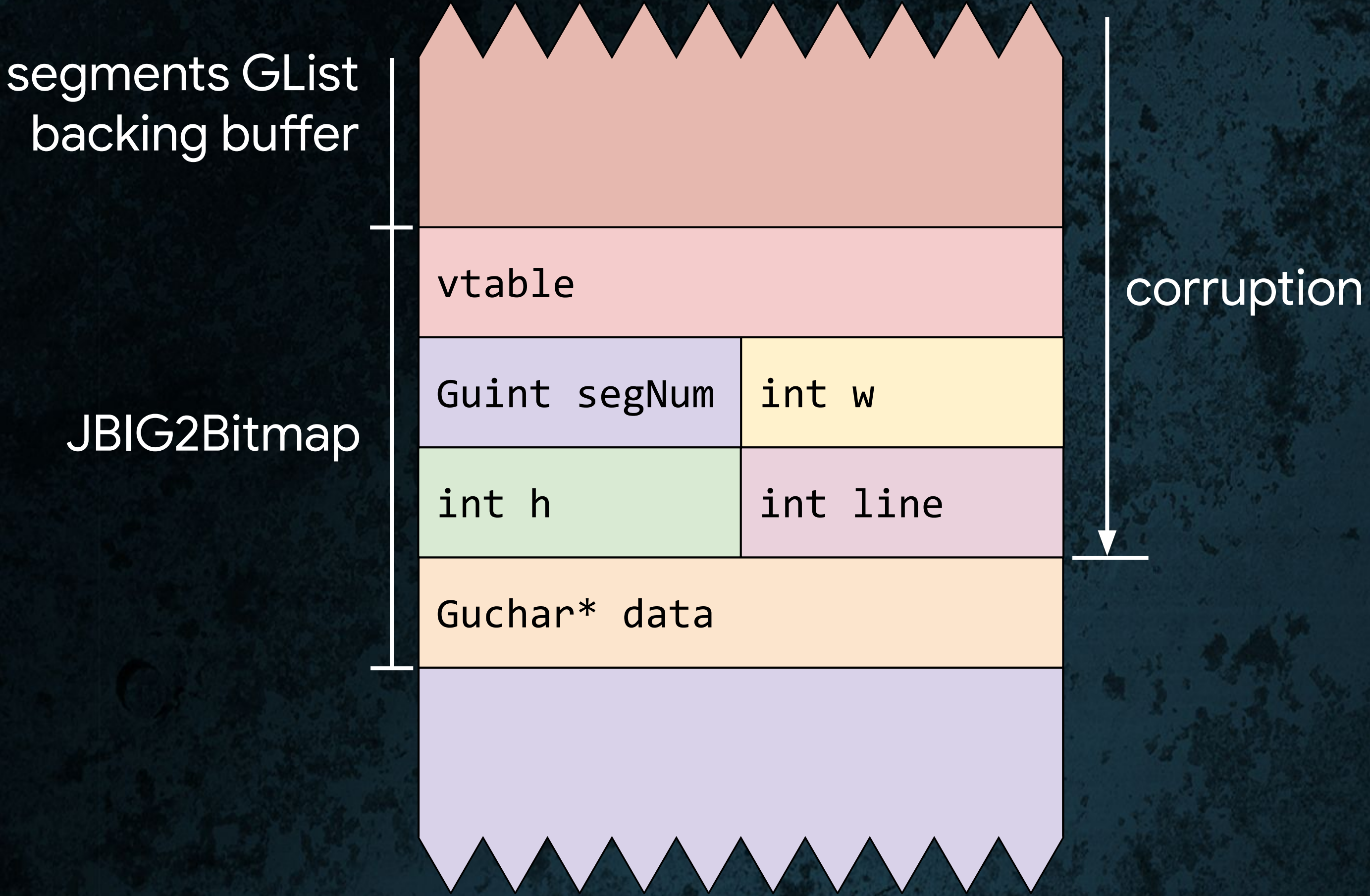
Attack Surface: PDF/JBIG2 Parsing

Memory Corruption Bug

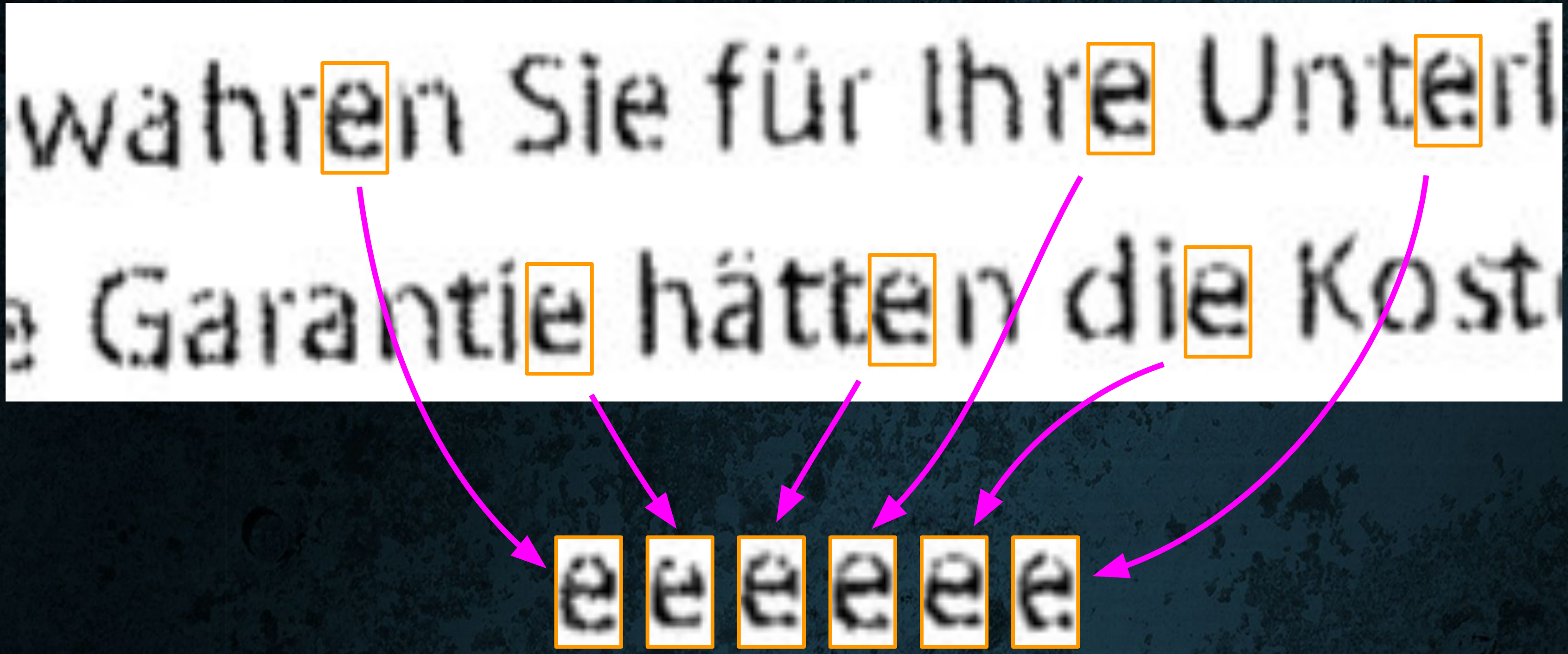
ASLR Bypass?

Code Execution in IMTranscoderAgent

Unbounding JBIG2 canvas with a heap overflow



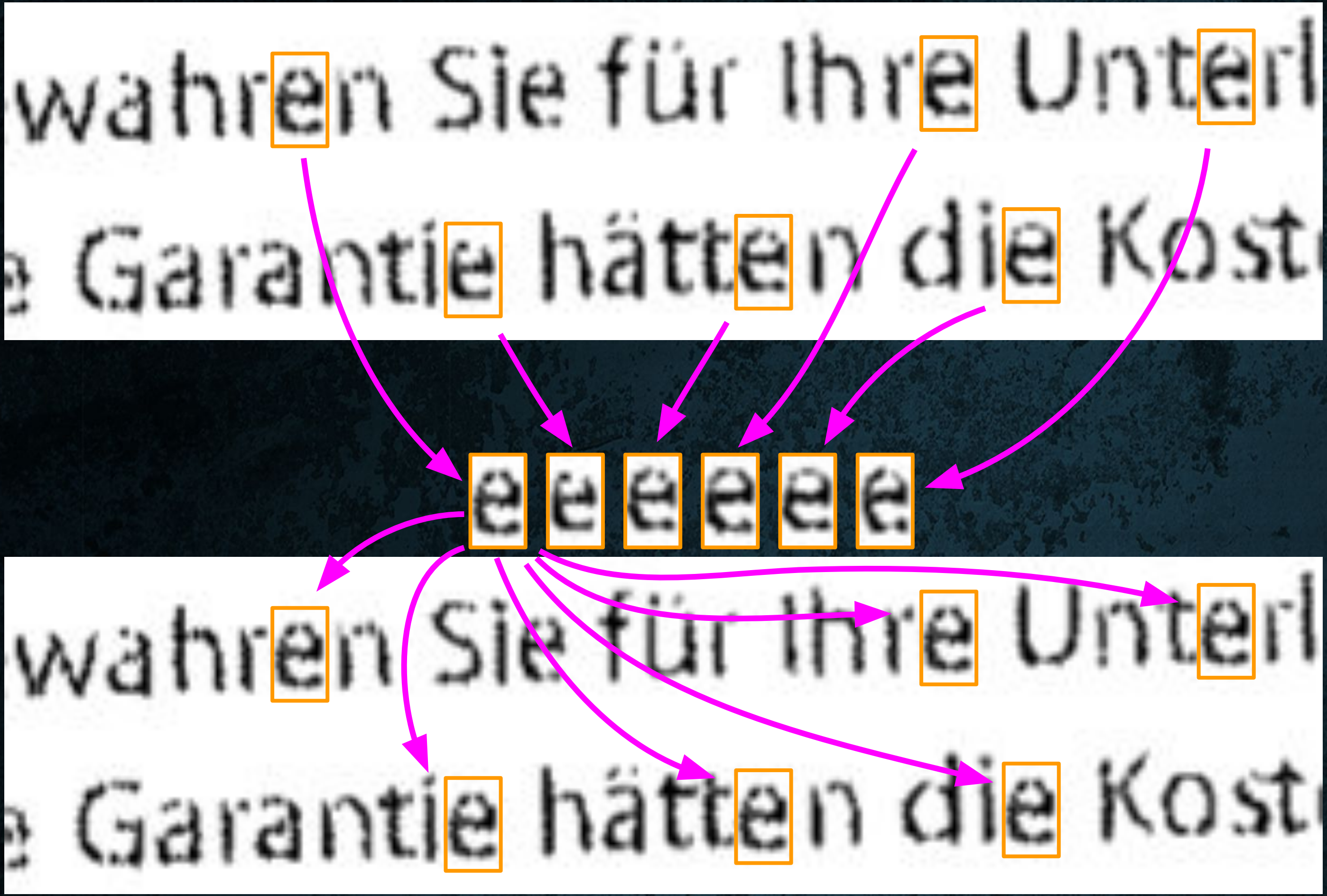
JBIG2 compression



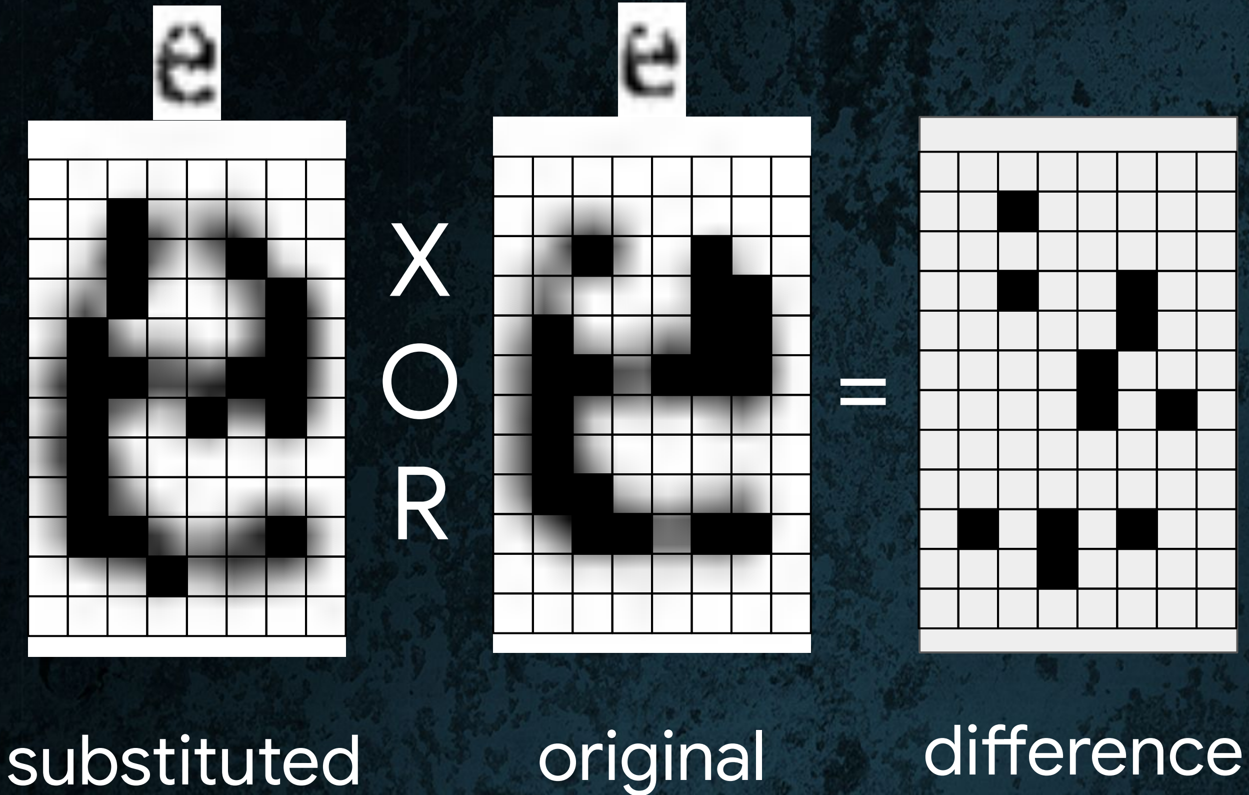
wahren Sie für Ihre Unterl

Garantie hätten die Kost

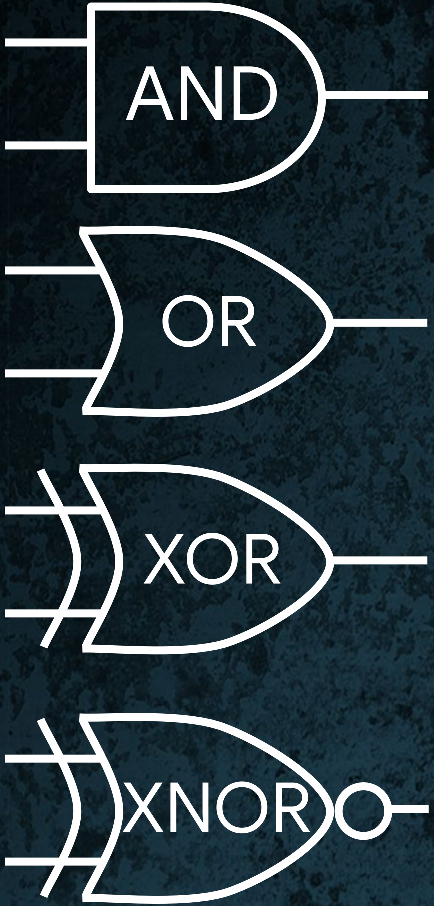
JBIG2 compression


wahren Sie für Ihre Unterl
e Garantie hätten die Kost
e e e e e e
wahren Sie für Ihre Unterl
e Garantie hätten die Kost

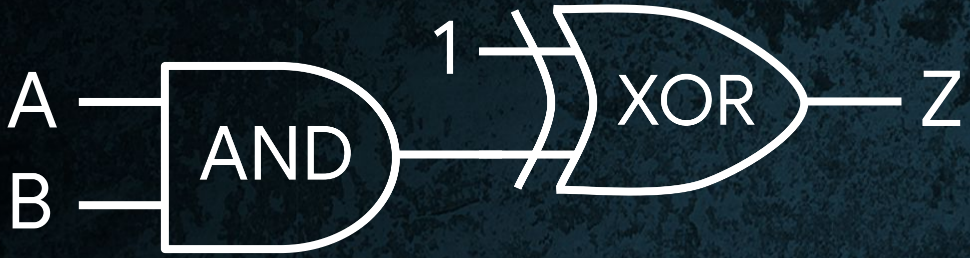
JBIG2 refinement operations



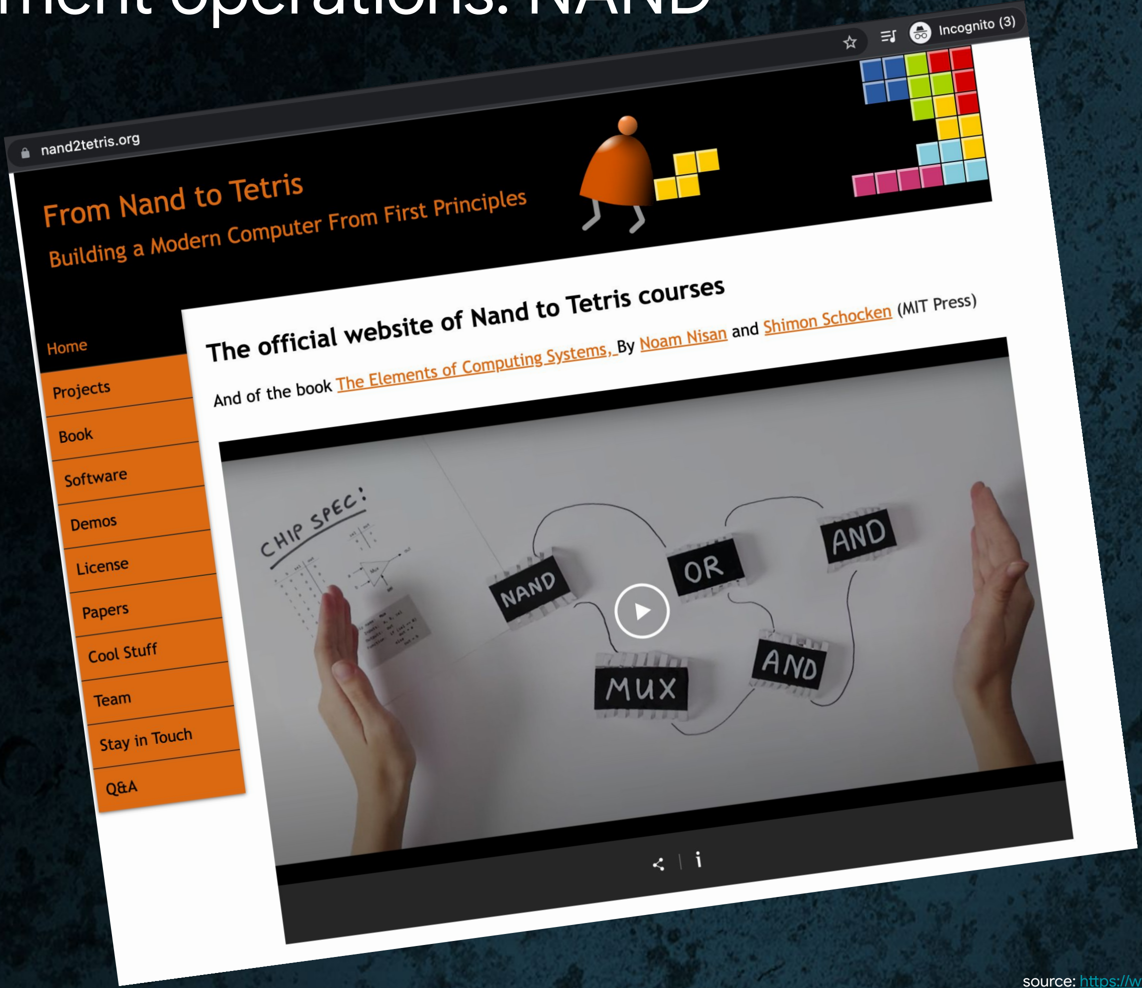
JBIG2 refinement operations: logic gates



JBIG2 refinement operations: NAND



JBIG2 refinement operations: NAND



From Nand to Tetris

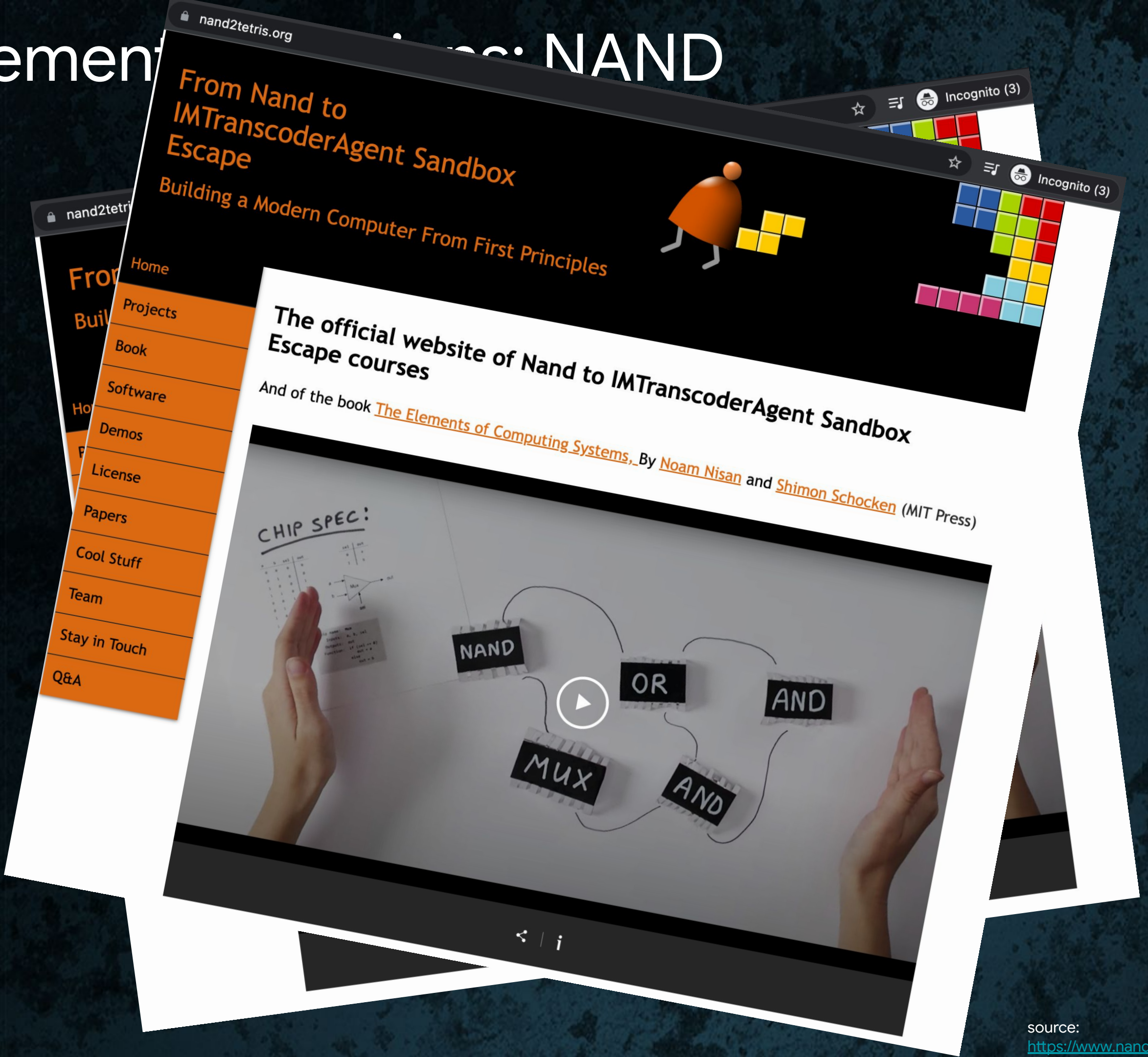
Building a Modern Computer From First Principles

The official website of Nand to Tetris courses

And of the book The Elements of Computing Systems, By Noam Nisan and Shimon Schocken (MIT Press)

source: https://www.nand2tetris.org/

JBIG2 refinement ns: NAND



nand2tetris.org

Incognito (3)

From Nand to IMTranscoderAgent Sandbox Escape

Building a Modern Computer From First Principles

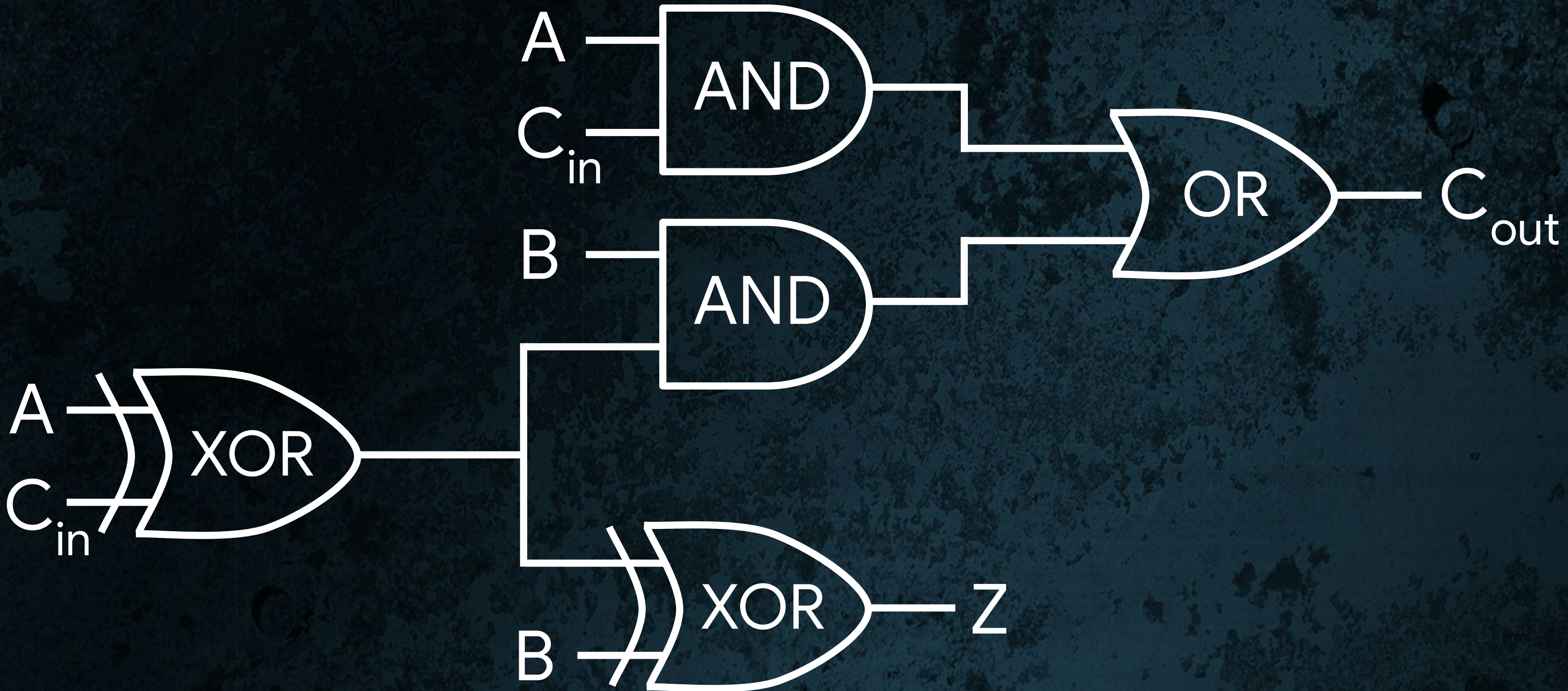
- Home
- Projects
- Book
- Software
- Demos
- License
- Papers
- Cool Stuff
- Team
- Stay in Touch
- Q&A

The official website of Nand to IMTranscoderAgent Sandbox Escape courses

And of the book The Elements of Computing Systems, By Noam Nisan and Shimon Schocken (MIT Press)

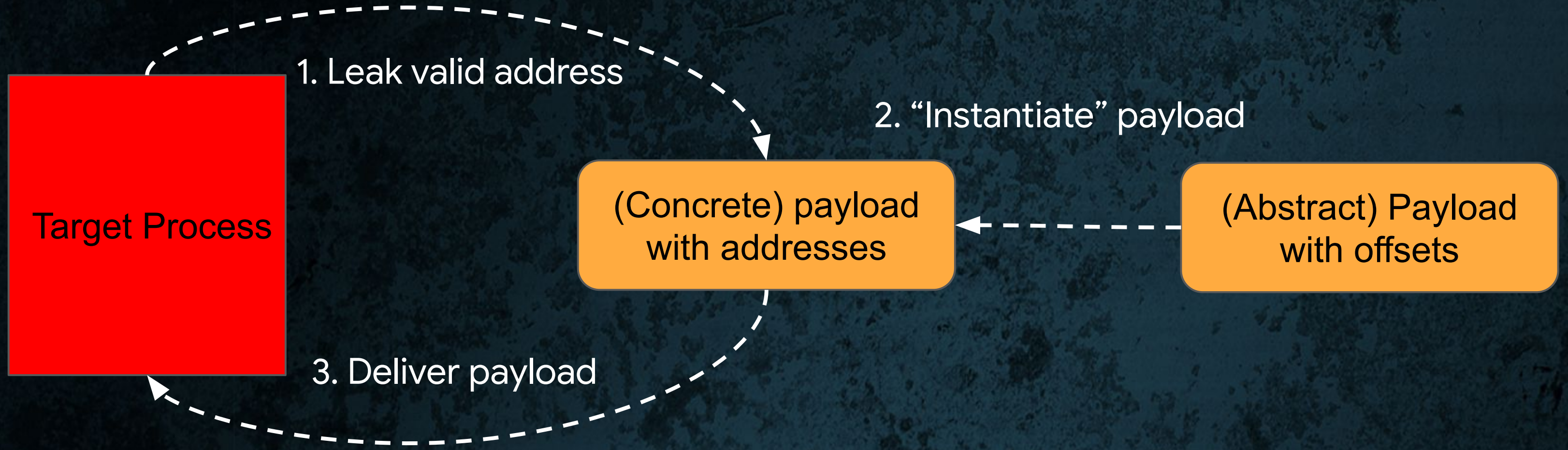
source:
https://www.nand2IMTranscoderAgentSandboxEscape.org/

JBIG2 refinement operations: ripple carry adder

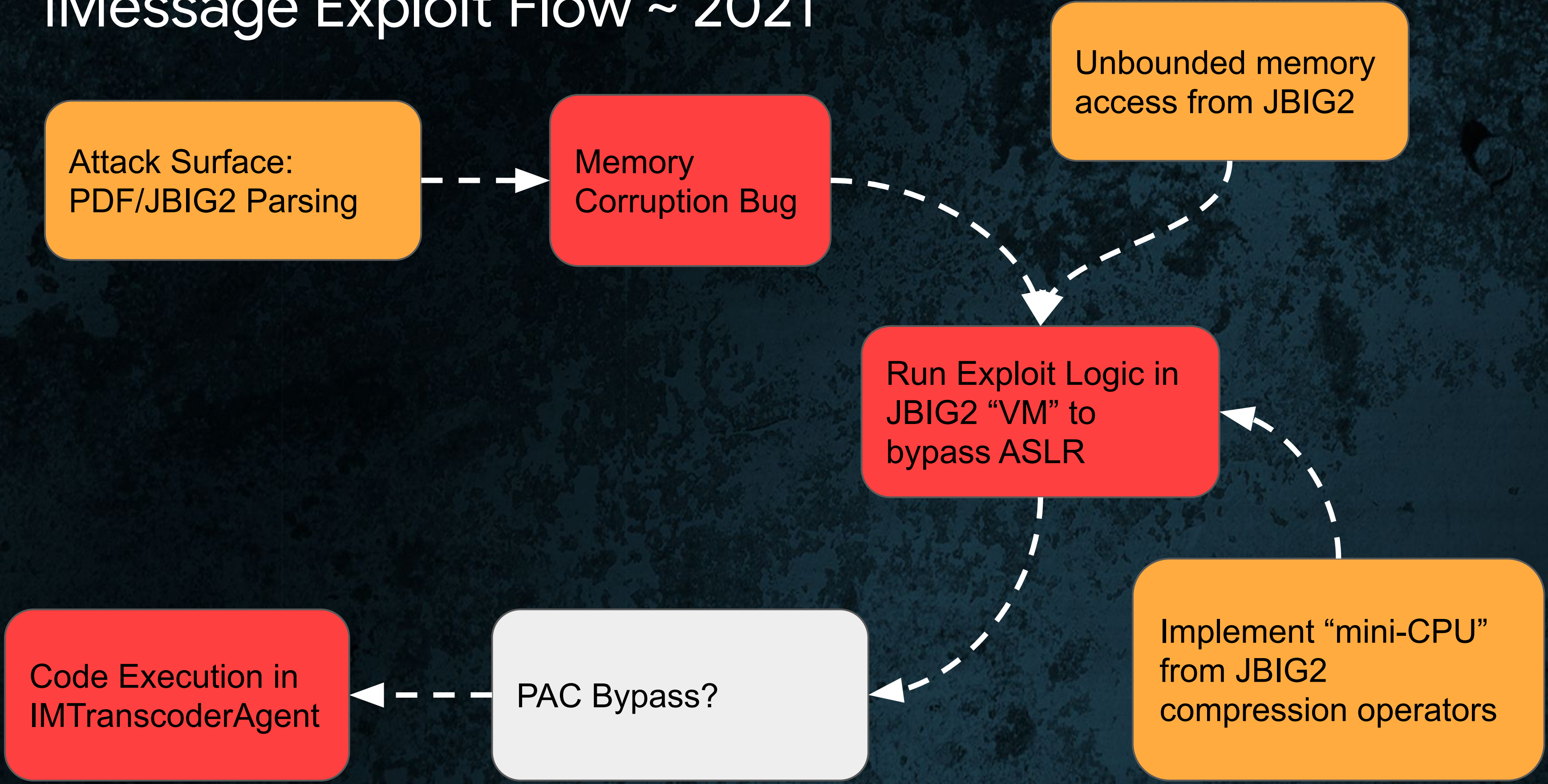


Why is ASLR a Problem?

- Need communication channel between target process and exploit logic
- **Now: Exploit logic implemented in JBIG2 VM => runs inside target process**
- Explicit communication channel with attacker machine not necessary



iMessage Exploit Flow ~ 2021



Attack Surface: PDF/JBIG2 Parsing

Memory Corruption Bug

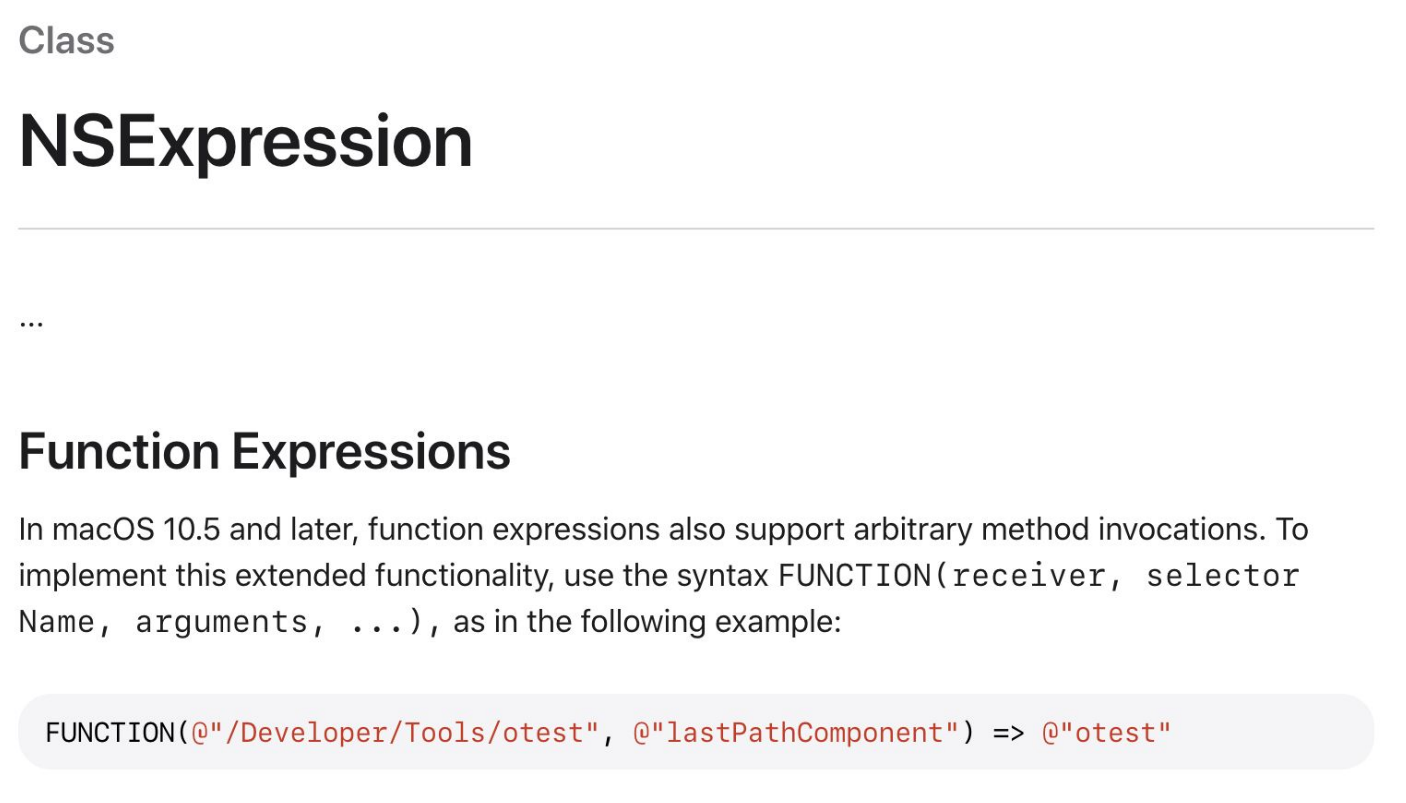
Unbounded memory access from JBIG2

Run Exploit Logic in JBIG2 “VM” to bypass ASLR

Implement “mini-CPU” from JBIG2 compression operators

PAC Bypass?

Code Execution in IMTranscoderAgent



Class

NSExpression

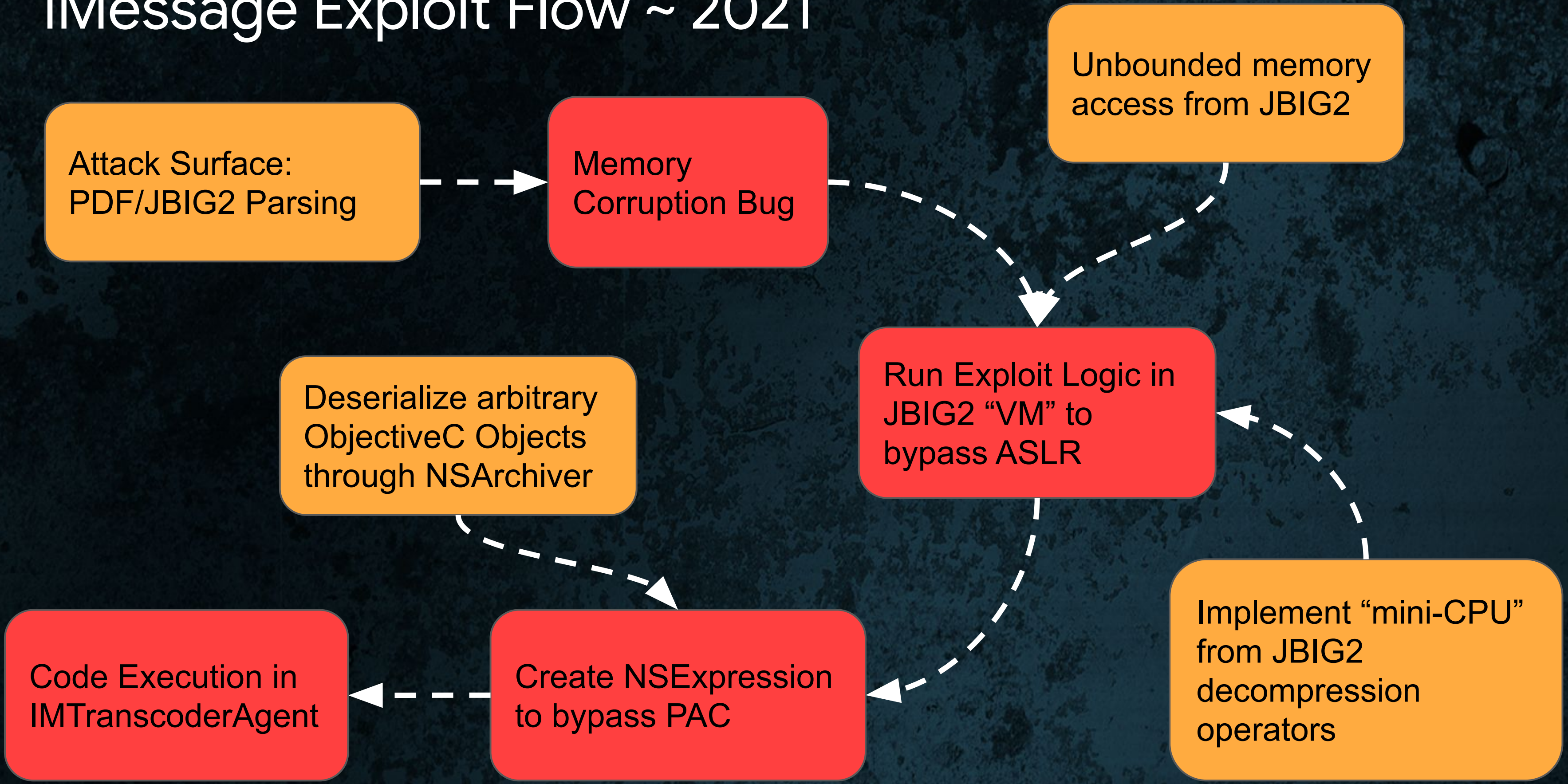
...

Function Expressions

In macOS 10.5 and later, function expressions also support arbitrary method invocations. To implement this extended functionality, use the syntax `FUNCTION(receiver, selectorName, arguments, ...)`, as in the following example:

```
FUNCTION(@"/Developer/Tools/otest", @"lastPathComponent") => @"otest"
```

iMessage Exploit Flow ~ 2021



Attack Surface: PDF/JBIG2 Parsing

Memory Corruption Bug

Unbounded memory access from JBIG2

Run Exploit Logic in JBIG2 “VM” to bypass ASLR

Implement “mini-CPU” from JBIG2 decompression operators

Deserialize arbitrary ObjectiveC Objects through NSArchiver

Create NSExpression to bypass PAC

Code Execution in IMTranscoderAgent

Conclusion

- The right mitigations/hardenings can make a big difference
- Still: should assume memory corruption bugs to be exploitable unless proven otherwise (this is hard...)
- Sometimes not trivial to reason about where code executes
- Look out for hidden attack surface