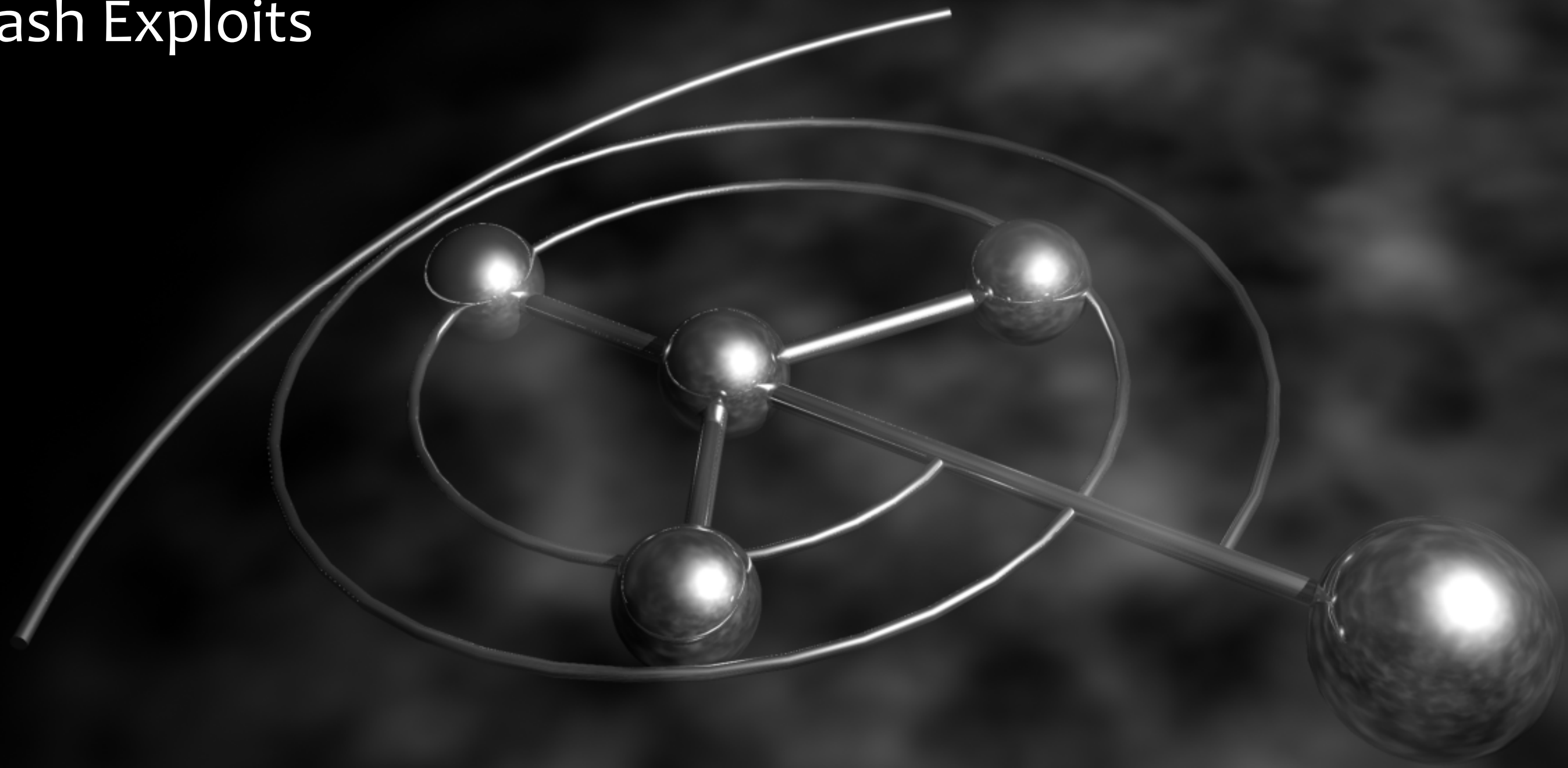
Blitzableiter – The Release (BETA)

Countering Flash Exploits



Felix 'FX' Lindner
BlackHat USA, July 2010

Agenda

- Motivation
- Flash Attack Surface
- Flash Victims
- Flash Security Options
- Introduction of Blitzableiter
- Flash Internals
- Blitzableiter Internals
- Adobe Virtual Machine 1
- AVM1 Code Analysis
- Enforcement of Functionality

Motivation

- Results from a project initiated in late 2008 by the German Federal Office for Information Security (Bundesamt für Sicherheit in der Informationstechnik) showed Adobe Flash to be the weakest Rich Internet Application technology
  - Adobe Flash runtime unfixable (at least for a third party)
  - Traditional detection mechanisms (AV/IDS) #fail
- The constant surfacing of new attacks against Flash requires a defense approach that doesn't depend on attack signatures
  - We didn't want to build yet another AV
  - The goal still is to be done with it at some point in time, once and for all.

Adobe Flash Attack Surface

- Flash files (SWF) is a container format for:
  - Vector graphics data (shapes, morphing, gradients)
  - Pixel graphics formats (various JPEG, lossless bitmaps)
  - Fonts and text
  - Sound data (ADPCM, MP3, Nellymoser, Speex)
  - Video data (H.263, Screen Video, Screen Video V2, On2 Truemotion VP6)
  - Virtual machine byte code for the Adobe Virtual Machines (AVM)
- All data structures from file format version 3 until the current version 10 are still supported
- The parser is completely written in unmanaged languages (C/C++)

Flash Victims I: ~~Pr0n~~ End Users

- End user's Flash Player can be triggered by any web page
  - Commonly exploiting parser vulnerabilities (e.g. CVE-2007-0071*, CVE-2010-2174), yielding direct code execution within the victim's browser process
  - DNS rebinding attacks
  - CSRF-style attacks including additional HTTP headers (e.g. UPNP)
  - Exploit toolkits with Flash frontend: Determining exact OS and browser versions, then downloading the appropriate exploit.
- 97% of all web browsers report Flash installed

* "Application-Specific Attacks: Leveraging the ActionScript Virtual Machine", Mark Dowd

End User Requirements

- The vast majority of exploits use intentionally malformed Flash files to trigger a vulnerability
- End users need a verification or enforcement mechanism to ensure Flash files are well-formed
  - Technically, a property the Flash Player must ensure, but that’s exactly where the problem is
  - Preferably integrated into web browser or proxy server
- End users require said mechanism to perform well, i.e. not taking too long or requiring too many resources

Flash Victims II: Web Site Owners & Ad Networks

- Advertisement Networks are forced to accept pre-compiled Flash content from Ad-Agencies as banner material
  - Submitted content is manually inspected (if at all)
  - No way to verify or enforce contractual requirements
  - Flash byte code sometimes changes behavior after the banner was accepted: It pulls trigger or additional code from remote server.
- Malicious advertisements have hit major news sites
  - NYTimes.com, Handelsblatt.de, Zeit.de, Heise.de, etc.

Web Site Owner & Ad Network Requirements

- Ensuring the Flash file is well-formed and does not carry an exploit is only partially sufficient for web site operators
  - It helps, however, to protect the review people from Flash exploits
- Desired is the ability to define rules mapping contractual requirements
  - E.g.: a banner advertisement can only forward the user's browser to the previously agreed campaign URL
  - E.g.: a social network site widget is not allowed to load additional content from a third party server
- Computational expense is of less concern, thoroughness is
  - Processing happens upon submission of the content, on the server side

Native Security Functionality of Adobe Flash

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Native Security Functionality of Adobe Flash

- Very limited settings within the Flash Player configuration page, using an actual Flash file
  - Camera and microphone access, local storage limits, hardware video acceleration, “older security system”, DRM licenses
- Much more useful settings can only be made in mms.cfg, a local user specific configuration
  - AutoUpdateDisable, AllowUserLocalTrust, LocalFileLegacyAction, LegacyDomainMatching, ThirdPartyStorage, FileDownloadDisable, FileUploadDisable
- There is no proof of origin for Flash files (i.e. no digital signatures)

Flash Malware and the Anti-Virus Industry

- Flash malware is not very well detected by anti-virus software
- AV software epically fails when the malware is uncompressed

Sample	Detection	Detection (uncompressed)
Simple generic downloader	**18/41 (43.91%)**	**16/39 (41.03%)**
Gnida.A	**29/41 (70.73%)**	**8/40 (20.00%)**
SWF_TrojanDownloader.Small.DJ	**21/39 (53.85%)**	**11/41 (26.83%)**

Statistics generated using Virustotal.com on December 24, 2009

Blitzableiter – An Alternative Defense Approach

- Straight command-line filter program
  - “Blitzableiter” is the German term for lightning rod, since it turns dangerous lightning into a harmless flash
  - Implemented in fully managed C#, targeting the .NET 2.0 runtime
  - Binary compatible with the Microsoft CLR as well as Mono 1.2
- Receives a potentially malicious Flash file (SWF) as input
  - Grossly malformed files are rejected
- Produces a (hopefully) non-malicious Flash file as output
  - Well-formed input files produce functionally equivalent output files

NoScript Supports Blitzableiter

- Giorgio Maone introduced support for external filters in his popular NoScript add-on for Mozilla Firefox
  - MIME-Type based filtering using external programs
  - Required some serious design and code changes to allow for processing in background threads
  - Current versions (1.9.9.x and above) already support external filters, development versions (2.0rc2 and above) provide additional information to the filter (origins of page and content)
- We would like to thank Giorgio very much for his support!
  - His extraordinary willingness to cooperate, responsiveness, speed and quality of implementation should be an example for many others.

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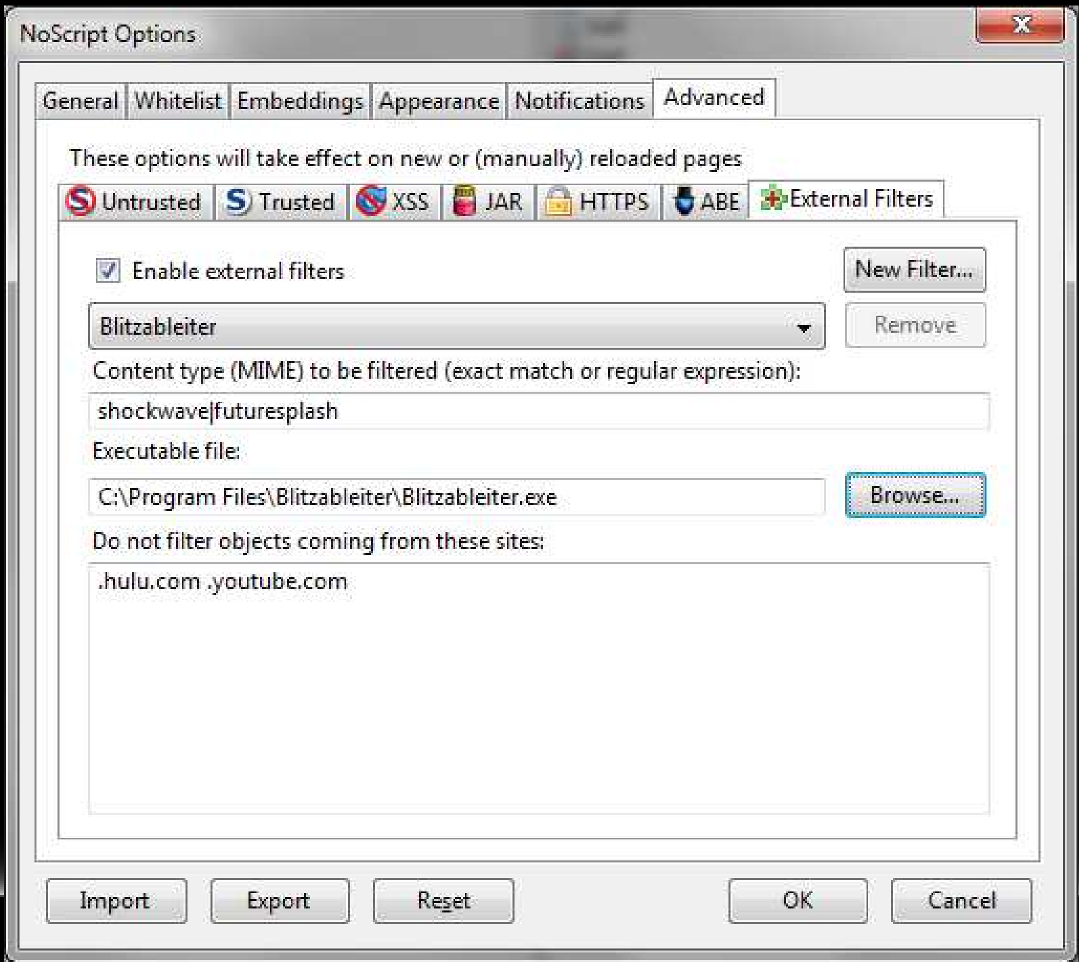
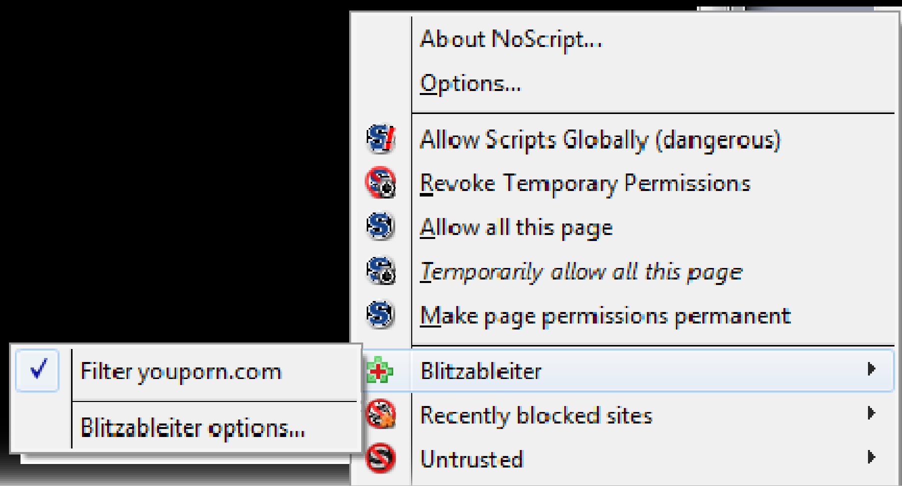
Introducing the Blitzableiter Security Tool

NoScript Supports Blitzableiter





Integrating Blitzableiter into Web Sites

- Web Site integration as post-processing step for upload functionality is trivial
  - Simply start Blitzableiter with the uploaded file as input
  - If OS return value is 0, move the output to the intended destination
  - If OS return value is < 0, present upload user with log output
- A Blitzableiter SOAP API is under consideration / construction

Blitzableiter is Open Source under GPLv3

- This project is open source, so you can apply something like Kerckhoffs' Principle and verify its protection value yourself
  - No yellow box solution that magically protects you
- We would love to see more integration in other software that must deal with Flash files
- Bug reports are also very welcome

http://blitzableiter.recurity.com

Demo Time

… what can possibly go wrong?

Flash Files from the Inside

- Flash files (also called movies) follow the SWF (apparently pronounced "swiff") file format specification
  - Version 3 to Version 10 are specified
- SWF files can be compressed using zlib methods
- Type-Length-Value structure
  - The elements are called "Tags"
  - The element ordering determines (partially) the rendering
  - 63 Tag types are documented for Version 10
- Data structures are heavily version dependent

A few Example Tag Types

- Control Tags manage general aspects of the file
  - SetBackgroundColor, FrameLabel, Protect, End, EnableDebugger, EnableDebugger2, FileAttributes, Metadata, …
- Display List Tags define and show graphic elements
  - PlaceObject, PlaceObject2, PlaceObject3, RemoveObject, RemoveObject2, ShowFrame, …
- Bitmap Tags hold bitmap graphics data
  - DefineBits, DefineBitsJPEG2, DefineBitsJPEG3, DefineBitsLossless, …
- Buttons are special graphic objects that allow interaction (programming)
  - DefineButton, DefineButton2, DefineButtonCxform, DefineButtonSound

A Tag Data Structure Example

- Every Tag type has its own data structures, often deeply nested ones
- Many data structures are composed of lists of sub-structures, great places for integer overflows and signedness issues
- The Tag to the right is what caused CVE-2007-0071 by using a negative SceneCount and a missing allocation return value check in Flash Player

DefineSceneAndFrameLabelData

Field	Type	Comment
Header	RECORDHEADER	Tag type = 86
SceneCount	EncodedU32	Number of scenes
Offset1	EncodedU32	Frame offset for scene 1
Name1	STRING	Name of scene 1
...	...	...
OffsetN	EncodedU32	Frame offset for scene N
NameN	STRING	Name of scene N
FrameLabelCount	EncodedU32	Number of frame labels
FrameNum1	EncodedU32	Frame number of frame label #1 (zero-based, global to symbol)
FrameLabel1	STRING	Frame label string of frame label #1
...	...	...
FrameNumN	EncodedU32	Frame number of frame label #N (zero-based, global to symbol)
FrameLabelN	STRING	Frame label string of frame label #N

Preventing Format Based Exploits: Normalization through Recreation

1. Safely parse the complete SWF file
   - Strictly verify all data structures against their specified properties
2. Discard the original file
3. Verify inter-Tag consistency and AVM byte code
   - Potentially adjust the AVM byte code
4. Create a new, “normalized” SWF file for the final consumer (e.g. the Flash Player)

Implementation Details

- The Blitzableiter parser is completely managed code
  - Out-of-bounds conditions and integer overflows are caught by the runtime and cause an exception to be raised
- All TLV-style data structures are handled in individual memory streams, thus only offering as much data as declared in the TLV header
  - Trailing data is therefore discarded before parsing
  - Parser modules ensure that all content of the TLV container is used
- The parser only accepts well-documented SWF data structures
  - To provide the desired security level, this approach requires to parse every known data structure within the SWF specification
- The parser also verifies version dependencies of data structures

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Blitzableiter Internals

Example: Catching CVE-2007-0071

```
protected override void Parse()
{
    log4net.ILog log = log4net.LogManager.GetLogger(System.Reflection.MethodBase.GetCurrentMethod()
    log.DebugFormat("0x{0:X08}: reading DefineSceneAndFrameLabelData-Tag", this.Tag.OffsetData);

    BinaryReader br = new BinaryReader(_dataStream);
    _sceneCount = SwfEncodedU32.SwfReadEncodedU32(br);
    _sceneOffset = new ulong[_sceneCount];
    _sceneName = new string[_sceneCount];

    for (ulong i = 0; i < _sceneCount; i++
    {
        _sceneOffset[i] = SwfEncodedU32.Sw
        _sceneName[i] = SwfStrings.SwfStri
        log.DebugFormat("0x{0:X08}:\tScene
    }

    _frameNum = SwfEncodedU32.SwfReadEncode
    _frames = new ulong[_frameNum];
    _frameLabel = new string[_frameNum];

    for (ulong i = 0; i < _frameNum; i++)
    {
        _frames[i] = SwfEncodedU32.SwfReadE
        _frameLabel[i] = SwfStrings.SwfStr
        log.DebugFormat("0x{0:X08}:\tFrame
    }
```

OverflowException occurred

Arithmetic operation resulted in an overflow.

Troubleshooting tips:

Make sure you are not dividing by zero.

Get general help for this exception.

Search for more Help Online...

Actions:

View Detail...

Enable editing

Copy exception detail to the clipboard

```
reading rejected: Tag handler failed parsing: System.OverflowException
```

Adobe Virtual Machines

- The Flash Player contains ***two*** virtual machines
- AVM1 is a historically grown, weakly typed stack machine with support for object oriented code
  - AVM1 is programmed in ActionScript 1 or ActionScript 2
  - Something around 80% of the Flash files out there are AVM1 code, including YouTube, YouPorn, etc.
- AVM2 is an ECMA-262 (JavaScript) stack machine with a couple of modifications to increase strangeness
  - AVM2 is programmed in ActionScript 3
  - The Flash developer community struggles to understand OOP

The History of AVM1

- First scripting capability appears in SWF Version 3
  - Something like a very simple click event handler
- SWF Version 4 introduces the AVM
  - Turing complete stack machine with variables, branches and sub-routine calls
  - All values on the stack are strings, conversion happens as needed
- SWF 5 introduces typed variables on the stack
  - Addition of a constant pool to allow fast value access
  - Introduction of objects with methods

The History of AVM1

- SWF 6 fixes SWF 5
  - New Tag type allows initialization code to be executed early
  - Checking of the type of an object instance is added
  - Type strict comparisons are added
- SWF 7 brings more OOP
  - New function definition byte code
  - Object Inheritance, extension and test for extension (implements)
  - Exception generation and handling (Try/Catch/Finally)
  - Explicit type casting

The History of AVM1

- SWF 8 never happened
- SWF 9 already brings the AVM2 into the format
  - They call the byte code “ABC”
- SWF 10 is the currently specified standard

Keep in mind that all this is still supported!

AVM1 Code Locations in a Flash File

- A Flash file can contain AVM1 code in 5 different types of locations
  - DoAction Tag contains straight AVM1 code
  - DoInitAction Tag contains AVM1 code for initialization
  - DefineButton2 Tag contains ButtonRecord2 structure that can carry conditional ButtonCondActions, which are AVM1 code
  - PlaceObject2 and PlaceObject3 Tags can contain ClipActions whose ClipActionRecords may contain AVM1 code
- Many tools, including security tools, only handle DoAction

AVM1 Code Properties

- AVM1 byte code is a variable length instruction set
  - 1-Byte instructions
  - n-Byte instructions with 16 Bit length field
- Branch targets are signed 16 Bit byte offsets into the current code block
- Function declarations are performed using one of two byte codes inline with the other code
  - Function declarations can be nested
  - Functions may be executed inline or when called
- Try/Catch/Finally blocks are defined by byte code similar to functions

Design Weaknesses in AVM1

- The byte offset in branch instructions allows:
  - Jumps into the middle of other instructions
  - Jumps outside of the code block (e.g. into image data)
- The signed 16 Bit branch offset prevents large basic blocks
  - The Adobe Flash Compiler emits illegal code for large IF statements
- Instruction length field allows hiding of additional data
  - Length field is parsed even for instructions with defined argument sizes
- Argument arrays contain their own length fields after the instruction length field

Design Weaknesses in AVM1

- The order of code execution appears to be non-deterministic
  - Depends on the Tag order and type
  - Depends on references to other Flash files
  - Depends on the conditions set to execute
  - Depends on the visibility of the object (z-axis depth)

AVM1 Code Verification performed by Blitzableiter

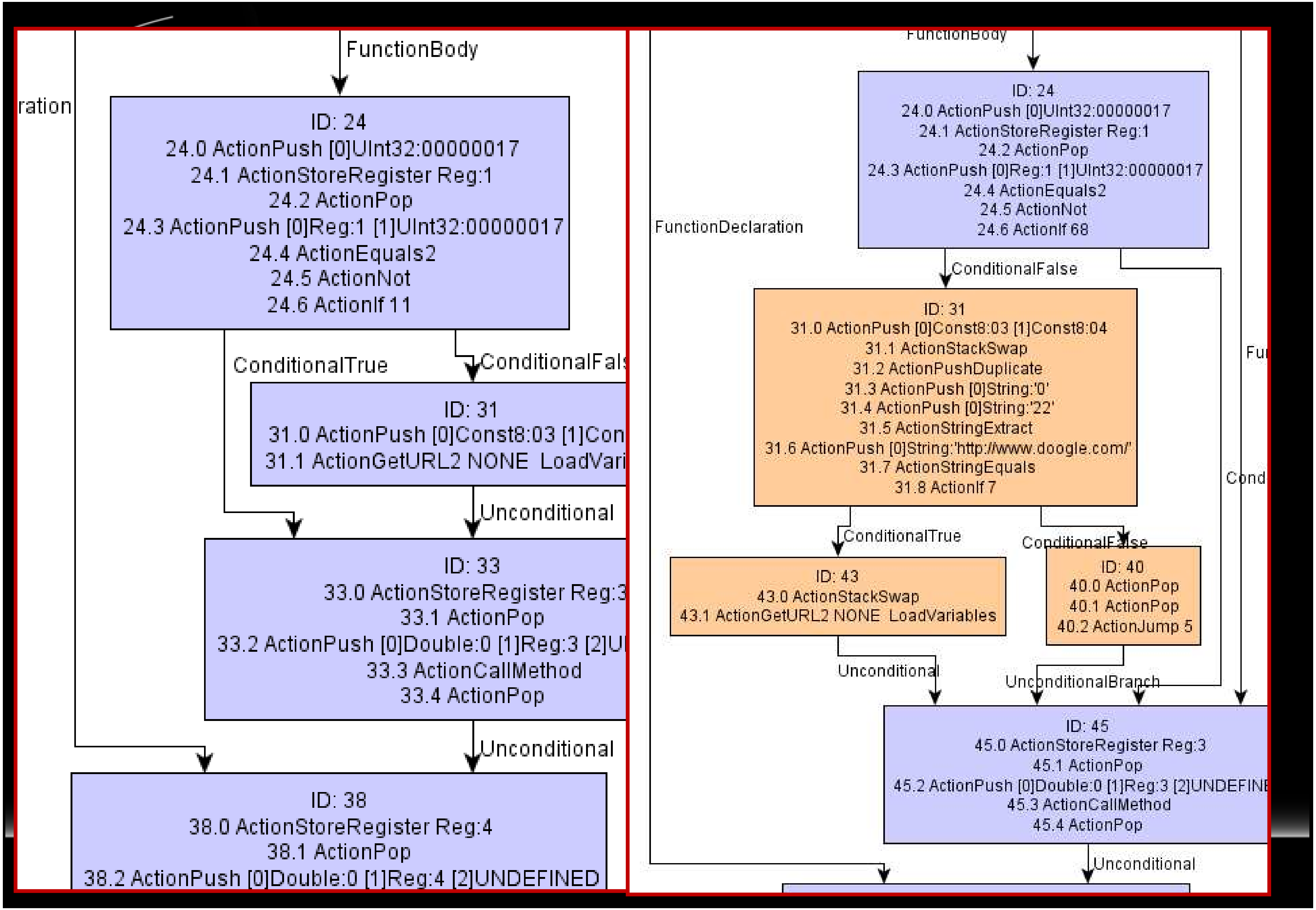
- Is the instruction legal within the declared SWF Version?
- Does the instruction have exactly the number of arguments specified?
- Is the declared instruction length correct and completely used?
- Does the code flow remain within the code block?
- Do all branches, try/catch/finally and all function declaration target addresses point to the beginning of an instruction?
  - This is ensured using linear disassembly instead of code flow disassembly
- Do all instructions belong to one and only one function?

Countering Functional Attacks

- If done correctly and completely, the format normalization so far leaves you with a representation of a nice and tidy SWF file that you completely understand.
- Static analysis will provably not be able to determine what any given code is actually doing.
- Emulation will cause a state discrepancy between your emulation and the Flash player's interpretation of the same code.

Patching the Point of Execution

- In runtime analysis, you verify the arguments to the final API call before the call is made.
- We are not part of the show when execution actually happens.
- But we can introduce AVM1 code before the final API call that inspects and verifies the arguments for us when executed.



FunctionBody
ration
ID: 24
24.0 ActionPush [0]UInt32:00000017
24.1 ActionStoreRegister Reg:1
24.2 ActionPop
24.3 ActionPush [0]Reg:1 [1]UInt32:00000017
24.4 ActionEquals2
24.5 ActionNot
24.6 ActionIf 11
ConditionalTrue
ConditionalFals
ID: 31
31.0 ActionPush [0]Const8:03 [1]Con
31.1 ActionGetURL2 NONE LoadVari
Unconditional
ID: 33
33.0 ActionStoreRegister Reg:3
33.1 ActionPop
33.2 ActionPush [0]Double:0 [1]Reg:3 [2]U
33.3 ActionCallMethod
33.4 ActionPop
Unconditional
ID: 38
38.0 ActionStoreRegister Reg:4
38.1 ActionPop
38.2 ActionPush [0]Double:0 [1]Reg:4 [2]UNDEFINED
FunctionBody
FunctionDeclaration
ID: 24
24.0 ActionPush [0]UInt32:00000017
24.1 ActionStoreRegister Reg:1
24.2 ActionPop
24.3 ActionPush [0]Reg:1 [1]UInt32:00000017
24.4 ActionEquals2
24.5 ActionNot
24.6 ActionIf 68
ConditionalFalse
ID: 31
31.0 ActionPush [0]Const8:03 [1]Const8:04
31.1 ActionStackSwap
31.2 ActionPushDuplicate
31.3 ActionPush [0]String:'0'
31.4 ActionPush [0]String:'22'
31.5 ActionStringExtract
31.6 ActionPush [0]String:'http://www.doogle.com/'
31.7 ActionStringEquals
31.8 ActionIf 7
Fu
Cond
ConditionalTrue
ConditionalFalse
ID: 43
43.0 ActionStackSwap
43.1 ActionGetURL2 NONE LoadVariables
ID: 40
40.0 ActionPop
40.1 ActionPop
40.2 ActionJump 5
Unconditional
UnconditionalBranch
ID: 45
45.0 ActionStoreRegister Reg:3
45.1 ActionPop
45.2 ActionPush [0]Double:0 [1]Reg:3 [2]UNDEFINE
45.3 ActionCallMethod
45.4 ActionPop
Unconditional

Determining What Method Is Called

- Method calls are implemented in AVM1 as a sequence of:

```
ActionConstantPool 0:'receiving_lc' [...] 8:'connect'
ActionPush [0]Const8:07 [1]UInt32:00000001 [2]Const8:00
ActionGetVariable
ActionPush [0]Const8:08
ActionCallMethod
```

- Therefore, we need to check if we are dealing with an instance of the object first and then determine the method:

```
ActionStackSwap
ActionPushDuplicate
ActionPush String:OBJECTTYPE
ActionGetVariable
ActionInstanceOf
ActionNot
ActionIf ExitPatch:
ActionStackSwap
ActionPushDuplicate
ActionPush String:connect
ActionStringEquals
ActionIf CleanUp:
```

Generically Cleaning Up The Stack

```
ActionPop                           # Remove method name
ActionPop                           # Remove object reference
ActionPush String:$RANDOM           # Create a variable with a random name
ActionStackSwap                     # Swap variable name and number of arguments
ActionSetVariable                   # Store number of arguments
RemovalLoop:
ActionPush String:$RANDOM           # Push random variable name
ActionPushDuplicate                 # Duplicate
ActionGetVariable                   # Get number of arguments
ActionPush UInt32:0                 # Push 0
ActionEquals2                       # Compare
ActionIf RemovalLoopDone:           # If number of arguments == 0, we are done
ActionPushDuplicate                 # Duplicate random variable name again
ActionGetVariable                   # Get number of arguments
ActionDecrement                     # Decrement it
ActionSetVariable                   # Store in random variable name
ActionPop                           # Now remove one of the original arguments
ActionJump RemovalLoop:             # Repeat
ActionPop                           # Remove remaining string
ActionPush UNDEFINED                # Return UNDEFINED to the code that called
                                    # the method
```

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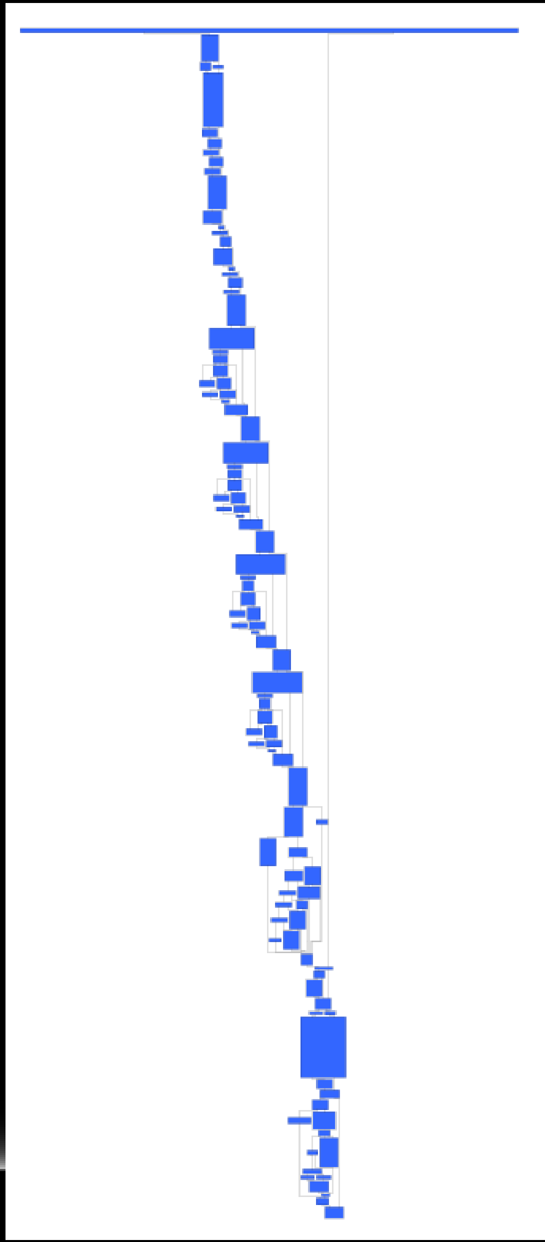
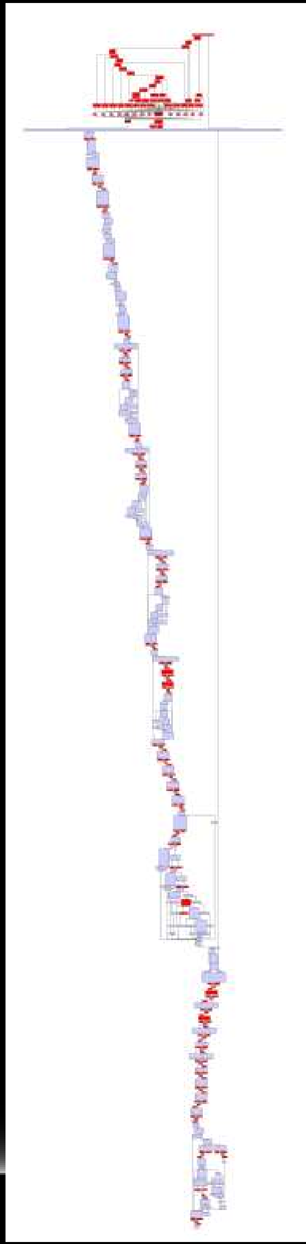
Example: Gnida

- Adding a function to the top of the code sequence in order to perform all the object and method checks in one place
- Patching all ActionCallMethod places to verify the call using our check function
- One can easily see the significant code blow-up (~250% the original size)





Static Analysis

- We can provably not determine all call arguments using static analysis, therefore a code patch is the safer method
  - But we can determine calls and arguments that are loaded directly from the constant pool or static values on the stack
- In order to determine values, we need:
  - Backward tracing of the virtual machine stack using code flow
  - Code Flow Graphs in order to trace along basic blocks and edges
    - E.g.: even the constant pool can be overwritten anywhere in AVM1 code

Higher Level Verification Modelling

- The goal is to model:
  "Does the 2nd argument of any call to ObjectA.MethodB begin with the following string?"
- The current implementation uses a dual stack machine approach
  - An internal stack machine performs individual static analysis operation steps to model conditions we want to verify
  - If the internal stack machine cannot deterministically continue, all basic operations emit AVM1 code to perform the same operation within the file.
- The individual operations are of small granularity
  - Example: ArgN determines the value of the n-th argument on the stack
  - Easier to verify the equivalence of the internal and the AVM1 representation

Covering the AVM2

- The AVM2 implementation is its own can of worms
- AVM2 is currently still incomplete in Blitzableiter ☹

Real World Behavior

- We are “eating our own dog food” and are happy so far
  - YouTube and YouPorn work, and so do many other sites
  - Just in case, you can switch individual Tag type parsers in the configuration file from parsing and normalization to simple byte array copy mode
- Flash files with code obfuscation will in almost all cases be rejected for format violations within the AVM byte code
  - This also affects some larger sites, such as hulu.com
- Many third party SWF generators emit invalid Flash files
  - Use of undocumented Tag types for unknown purposes
  - Use of reserved fields or undocumented AVM byte codes
  - Simply ridiculously broken files, which the Flash Player will accept anyway (the problem!)

Please Report Compatibility Issues

- When a Flash file is rejected by Blitzableiter, you receive an error log dialog (configurable)
  - The dialog allows you to send the log to us, in case you are convinced the Flash file in question was not malformed
    - Please keep in mind that many non-malicious Flash files are nevertheless malformed files and should be filtered
  - We only store the API request and the log file content
    - It’s HTTP, sniff it yourself if you don’t believe us
- We also want to know about Flash files that are visually or audibly different from the not normalized input file. We need your help to fix those cases!

Conclusions

- We think that Blitzableiter shows the viability of signature-free protections against file format based attacks using a managed language parser and format normalization.
- Automated code property verification and enforcement allow distributors of Flash content to enforce contractual regulations and requirements right when they receive it.
  - Not surprisingly, it’s also a fairly tricky area.
- We hope the tool is a useful addition to your browser protection measures and we rely on your feedback!

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Finishing Up

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fx@recurity-labs.com