



**black hat**<sup>®</sup>  
USA 2019

**AUGUST 3-8, 2019**  
MANDALAY BAY / LAS VEGAS



**GHIDRA**

Software Reverse Engineering (SRE) Framework  
Journey from Classified NSA Tool to Open Source

## BRIAN KNIGHTON

- RESEARCHER
- GHIDRA DEVELOPER
- IoT VULNERABILITY RESEARCH

## CHRIS DELIKAT

- RESEARCHER
- CYBER TEAM LEAD

- ABOUT NSA
- ABOUT GHIDRA
- BACKGROUND
- FEATURES
- FRAMEWORK
- OPEN SOURCE
- NEW FEATURES
- METRICS

- (S)RE - (Software) Reverse Engineering
- VR - Vulnerability Research
- Cyber - Cybersecurity
- CNO - Computer Network Operations
- IC - Intelligence Community
- U, Unclass - Unclassified
- NSA/Mission





GHIDRA is NSA's SRE Framework

In development for ~20 years

Public Release: March 2019 at RSA Conference

Open Source: April 2019

Created as a platform to solve hard cybersecurity problems

What's in your binary?

Needed SRE tool with:

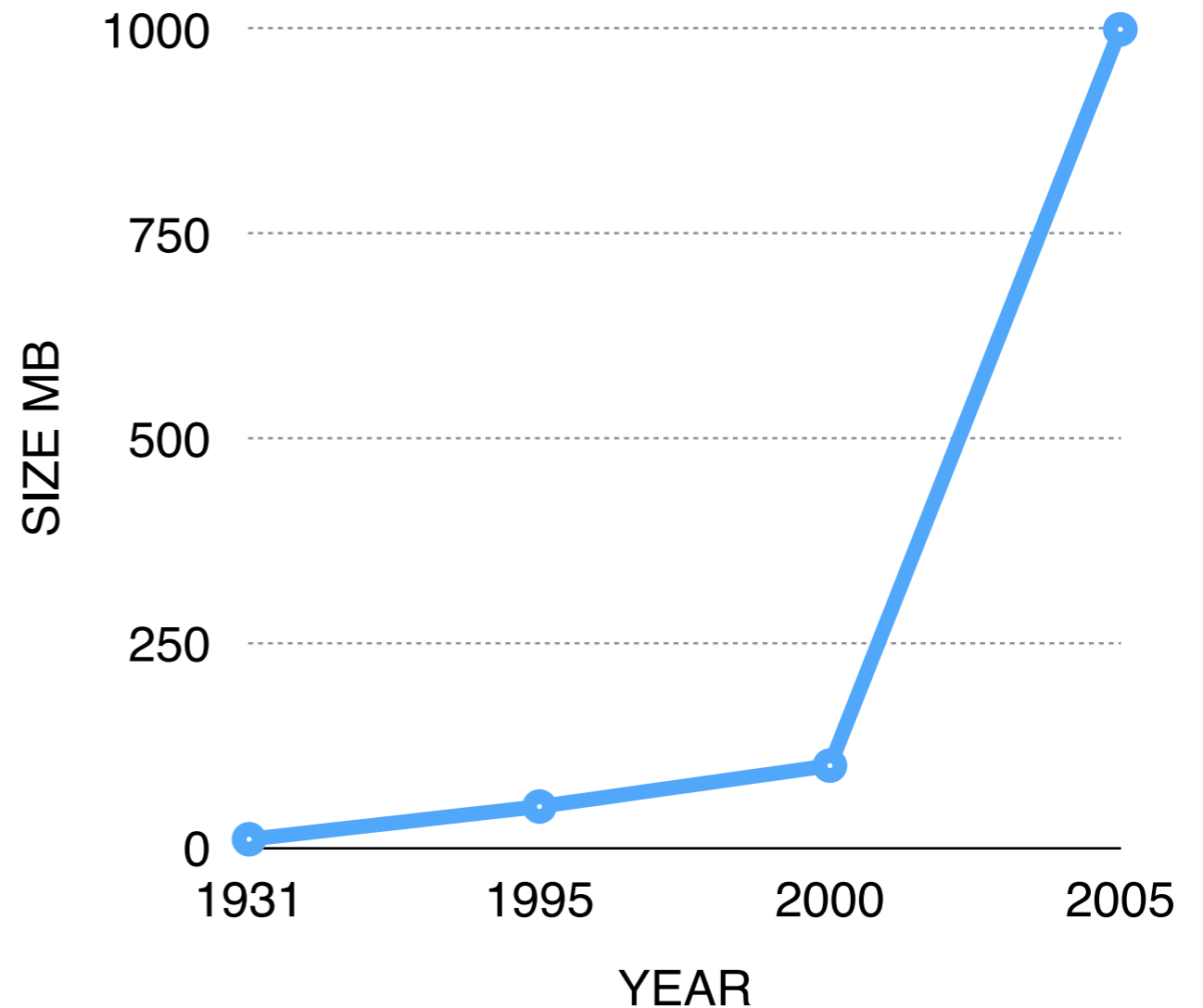
1. Scaling
2. Teaming
3. Extendability
4. Integration
5. Workflow
6. Undo/Redo
7. Headless, automated





## Why?

- Software everywhere
  - Growing in size
- IoT Event Horizon
- Early IoT devices
  - PDA
  - Smart(ish) phones



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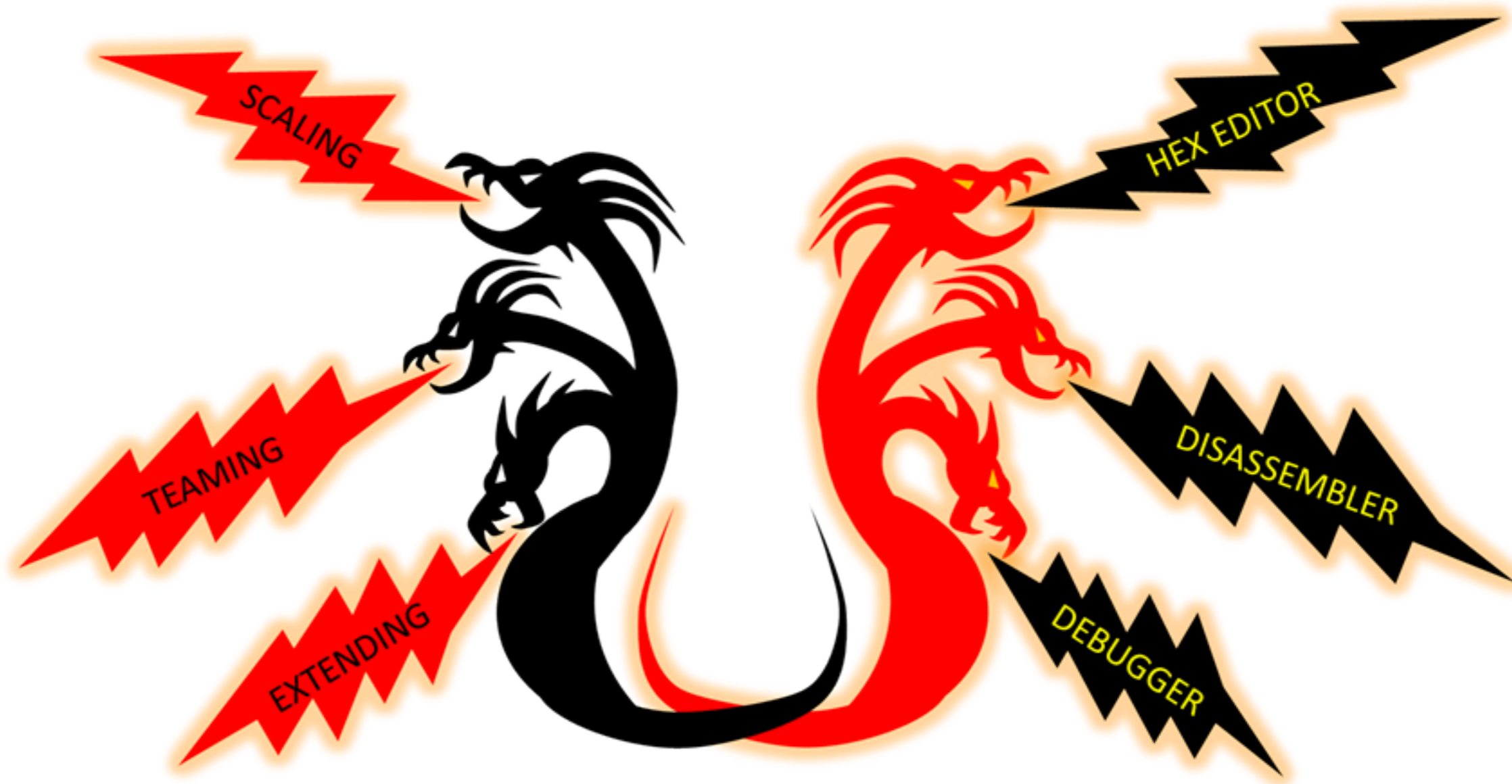


GENERIC  
HEXIDECIMAL  
INTEGRATED  
DECOMPILING  
REVERSE-ENGINEERING  
ARCHITECTURE

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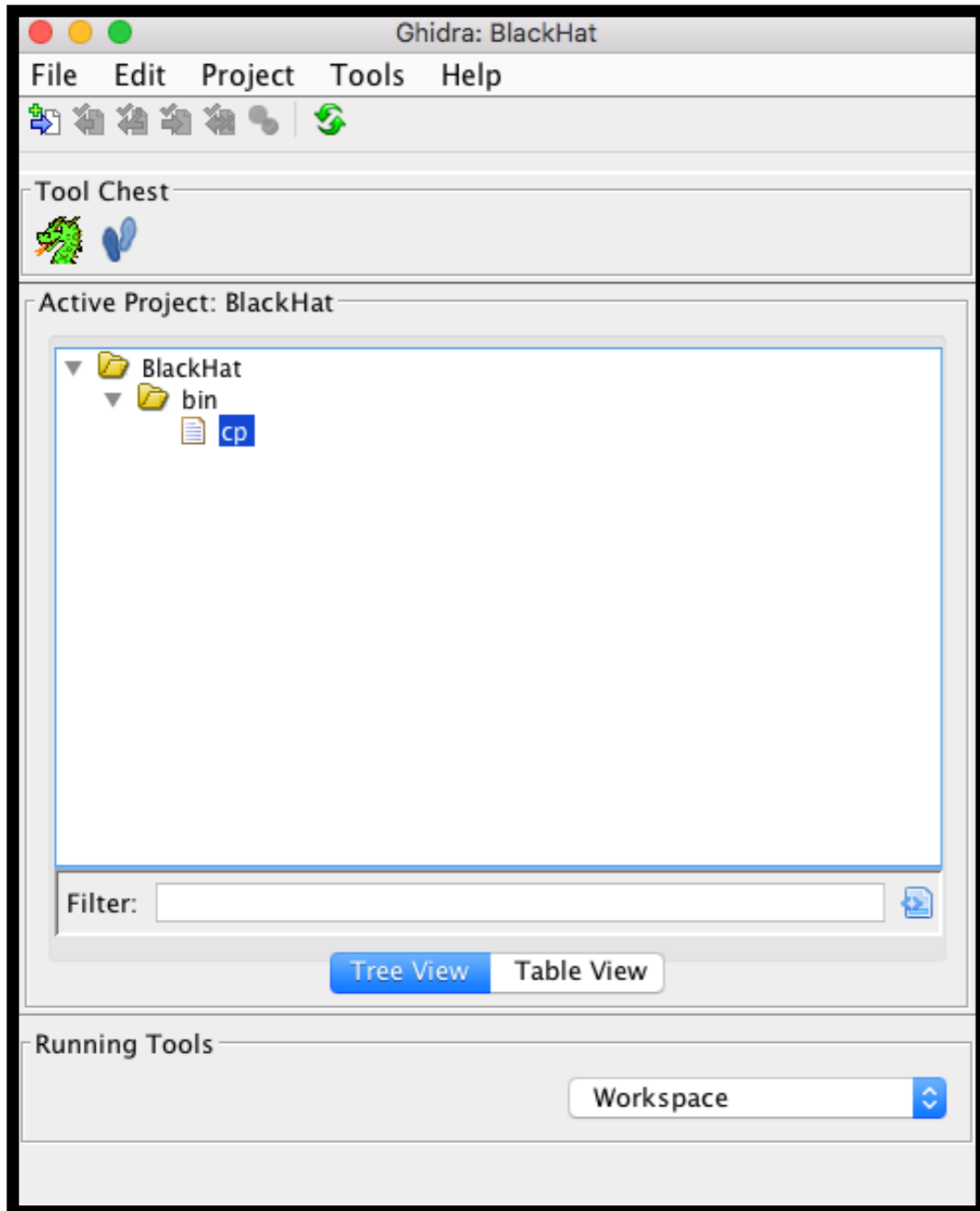
#JIK

# THE GHIDRA NAME

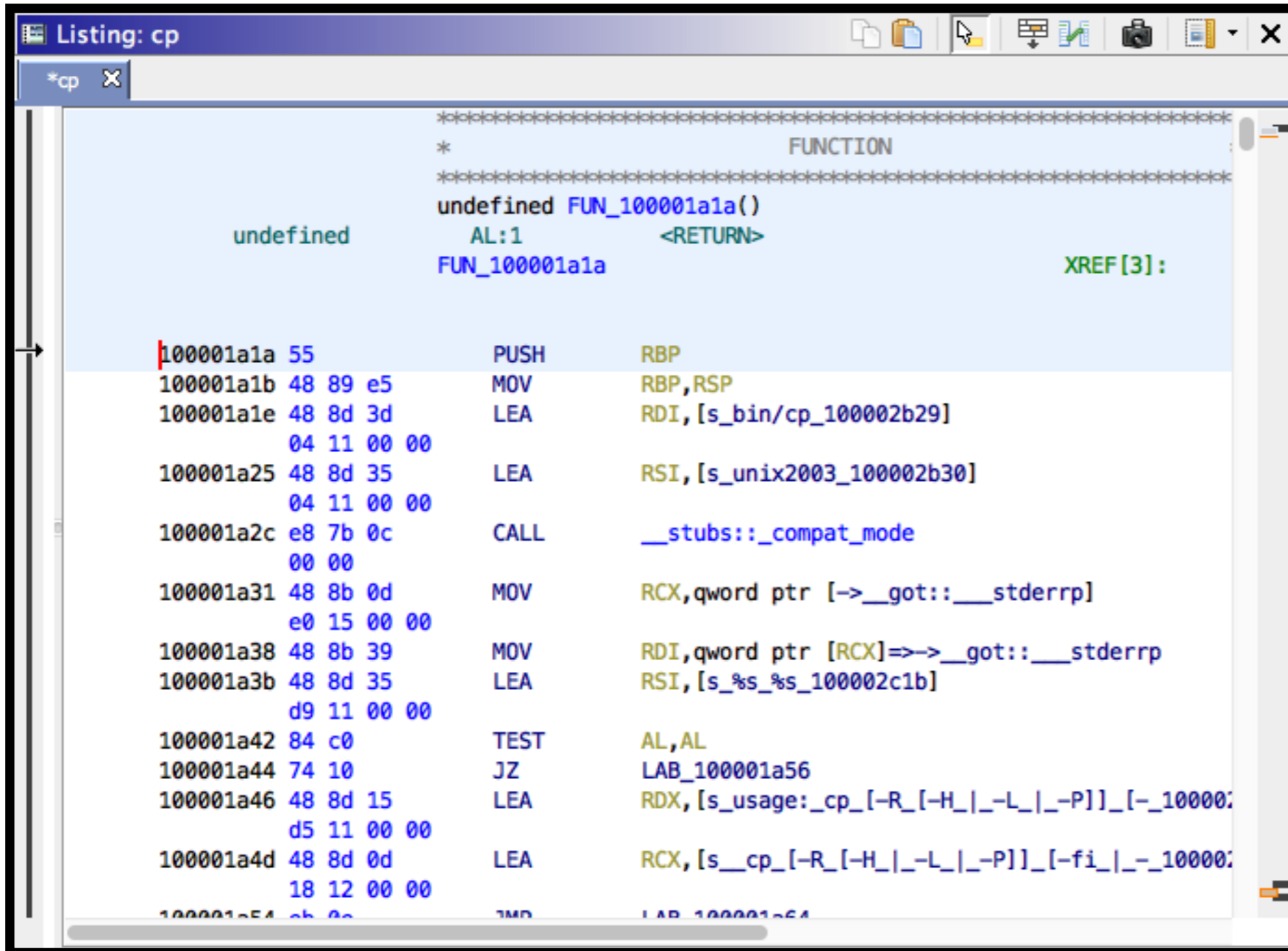


# FEATURES

QUICK OVERVIEW OF MAJOR FEATURES



- Project Window
- aka Front End
- GHIDRA is project based



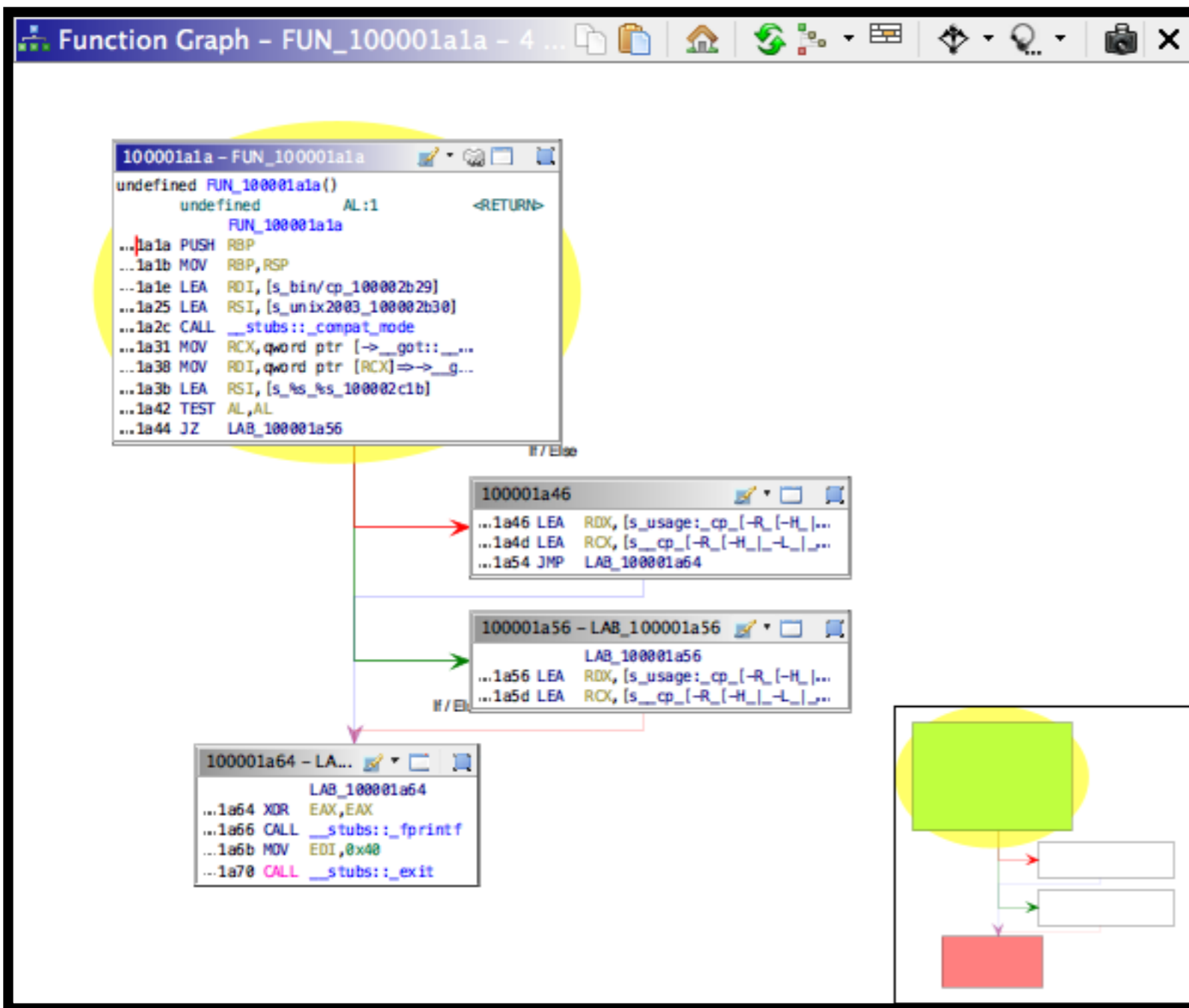
```

Listing: cp
*cp x
*****
*                               FUNCTION
*****
undefined FUN_100001a1a()
undefined AL:1 <RETURN>
FUN_100001a1a XREF [3]:

100001a1a 55          PUSH     RBP
100001a1b 48 89 e5    MOV     RBP,RSP
100001a1e 48 8d 3d    LEA    RDI,[s_bin/cp_100002b29]
          04 11 00 00
100001a25 48 8d 35    LEA    RSI,[s_unix2003_100002b30]
          04 11 00 00
100001a2c e8 7b 0c    CALL   __stubs::_compat_mode
          00 00
100001a31 48 8b 0d    MOV     RCX,qword ptr [->__got:::__stderrp]
          e0 15 00 00
100001a38 48 8b 39    MOV     RDI,qword ptr [RCX]=>>__got:::__stderrp
100001a3b 48 8d 35    LEA    RSI,[s_%s_%s_100002c1b]
          d9 11 00 00
100001a42 84 c0      TEST   AL,AL
100001a44 74 10      JZ     LAB_100001a56
100001a46 48 8d 15    LEA    RDX,[s_usage:_cp_[-R_[-H_|_-L_|_-P]]_[-_10000:
          d5 11 00 00
100001a4d 48 8d 0d    LEA    RCX,[s__cp_[-R_[-H_|_-L_|_-P]]_[-fi_|_-10000:
          18 12 00 00
100001a54 9b 0c      JMB   LAB_100001a54
  
```

- Listing View
- Annotations
- Instructions
- Data
- Comments

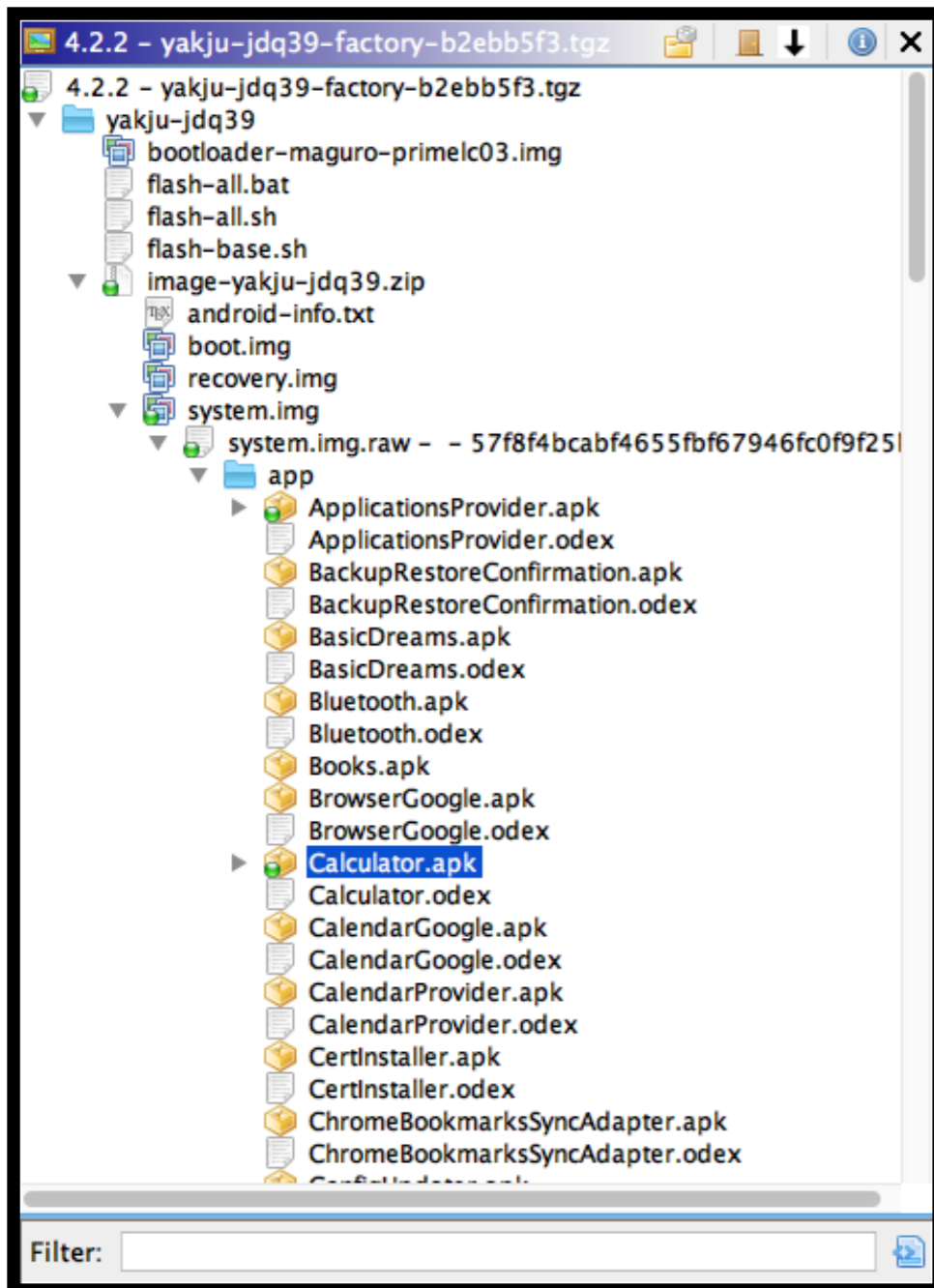




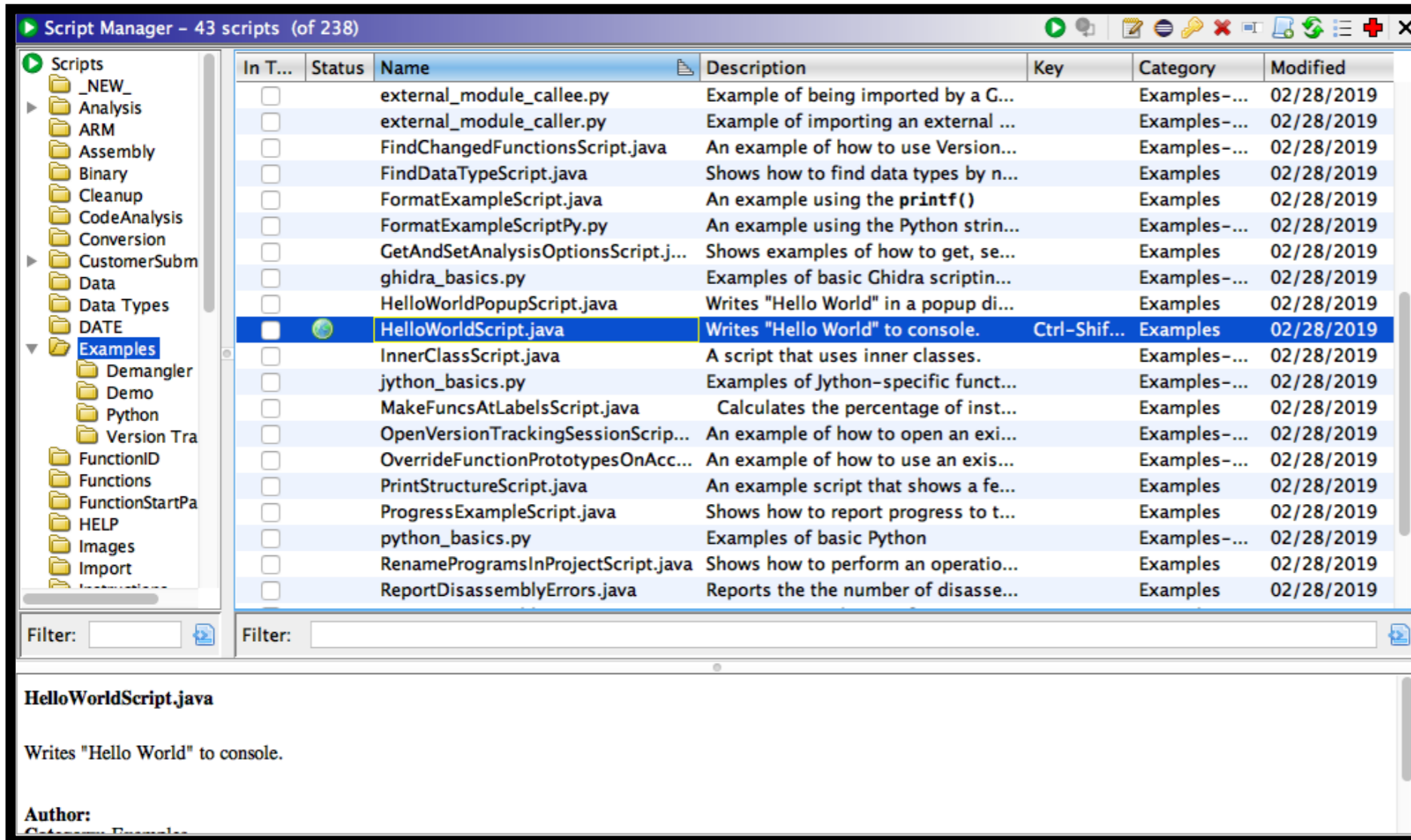
- Function Graph
- Displays functions as code blocks.

```
Decompile: FUN_10001a1a - (cp)
1 |
2 void FUN_10001a1a(void)
3
4 {
5     BOOL BVar1;
6     char *pcVar2;
7     char *pcVar3;
8
9     BVar1 = _compat_mode("bin/cp","unix2003");
10    if ((char)BVar1 == 0) {
11        pcVar3 = "usage: cp [-R [-H | -L | -P]] [-f | -i | -n] [-apvXc]
12        pcVar2 =
13        "      cp [-R [-H | -L | -P]] [-f | -i | -n] [-apvXc] source_f
14    }
15    else {
16        pcVar3 = "usage: cp [-R [-H | -L | -P]] [-fi | -n] [-apvXc] sou
17        pcVar2 = "      cp [-R [-H | -L | -P]] [-fi | -n] [-apvXc] sou
18    }
19    _fprintf(*(FILE **)__stderrp,"%s\n%s\n",pcVar3,pcVar2);
20    /* WARNING: Subroutine does not return */
21    _exit(0x40);
22 }
23
```

- Decompiler
- Sleigh
- Works for all processors with Sleigh spec



- File System Browser
- Allows drilling down into firmware bundles
- Many formats supported
- tar, zip, etc



Script Manager - 43 scripts (of 238)

In T...	Status	Name	Description	Key	Category	Modified
<input type="checkbox"/>		external_module_callee.py	Example of being imported by a G...		Examples-...	02/28/2019
<input type="checkbox"/>		external_module_caller.py	Example of importing an external ...		Examples-...	02/28/2019
<input type="checkbox"/>		FindChangedFunctionsScript.java	An example of how to use Version...		Examples-...	02/28/2019
<input type="checkbox"/>		FindDataTypeScript.java	Shows how to find data types by n...		Examples	02/28/2019
<input type="checkbox"/>		FormatExampleScript.java	An example using the printf()		Examples	02/28/2019
<input type="checkbox"/>		FormatExampleScriptPy.py	An example using the Python strin...		Examples-...	02/28/2019
<input type="checkbox"/>		GetAndSetAnalysisOptionsScript.j...	Shows examples of how to get, se...		Examples	02/28/2019
<input type="checkbox"/>		ghidra_basics.py	Examples of basic Ghidra scriptin...		Examples-...	02/28/2019
<input type="checkbox"/>		HelloWorldPopupScript.java	Writes "Hello World" in a popup di...		Examples	02/28/2019
<input checked="" type="checkbox"/>		<b>HelloWorldScript.java</b>	<b>Writes "Hello World" to console.</b>	<b>Ctrl-Shif...</b>	<b>Examples</b>	<b>02/28/2019</b>
<input type="checkbox"/>		InnerClassScript.java	A script that uses inner classes.		Examples-...	02/28/2019
<input type="checkbox"/>		ython_basics.py	Examples of Jython-specific funct...		Examples-...	02/28/2019
<input type="checkbox"/>		MakeFuncsAtLabelsScript.java	Calculates the percentage of inst...		Examples	02/28/2019
<input type="checkbox"/>		OpenVersionTrackingSessionScrip...	An example of how to open an exi...		Examples-...	02/28/2019
<input type="checkbox"/>		OverrideFunctionPrototypesOnAcc...	An example of how to use an exis...		Examples-...	02/28/2019
<input type="checkbox"/>		PrintStructureScript.java	An example script that shows a fe...		Examples	02/28/2019
<input type="checkbox"/>		ProgressExampleScript.java	Shows how to report progress to t...		Examples	02/28/2019
<input type="checkbox"/>		python_basics.py	Examples of basic Python		Examples-...	02/28/2019
<input type="checkbox"/>		RenameProgramsInProjectScript.java	Shows how to perform an operatio...		Examples	02/28/2019
<input type="checkbox"/>		ReportDisassemblyErrors.java	Reports the the number of disasse...		Examples	02/28/2019

Filter:  Filter:

**HelloWorldScript.java**

Writes "Hello World" to console.

**Author:**  
Custom Example

- Script Manager
- Supports:
- Java
- Python

The screenshot displays the Ghidra software interface with three main panes:

- Disassembly Pane (Left):** Shows assembly instructions for the function `cp`. The instruction at address `100001a44` is highlighted in green: `JZ 74 10 LAB_100001a56`.
- Decompile Pane (Middle):** Shows the decompiled C code for `FUN_100001a1a`. The corresponding C code is highlighted in green: `if ((char)BVar1 == 0) { pcVar3 = "usage: cp [-R [-H | -L | -P]] [-f | -i | -n] [-apv]"; pcVar2 = " cp [-R [-H | -L | -P]] [-f | -i | -n] [-apv]"; }`
- Function Graph Pane (Right):** Shows a control flow graph for the function. A yellow oval highlights the jump instruction at address `100001a54` leading to `LAB_100001a64`.

At the bottom of the interface, a breadcrumb trail shows the current selection: `100001a54 > FUN_100001a1a > JMP 0x100001a64`.

- All windows track selection and location changes

- Assembler
- Bookmarks
- Byte Viewer (Hex Editor)
- Data Type Manager
- Entropy
- Navigation
- Searching (bytes, strings, comments)
- Version Tracking
- Version Control (Multi-user)
- And more!

# CODE BASE

QUICK OVERVIEW OF CODE BASE AND FRAMEWORK

## Main Components

1. FRAMEWORK
  - Generic GUI and Storage
2. FEATURES
  - SRE Focused Plugins and Scripts
3. PROCESSORS
  - Definitions of architectures and platforms
  - Disassembler and Decompiler

Implementation of Design Requirements



## Main Components

### 1. FRAMEWORK

- Generic GUI and Storage

### 2. FEATURES

- SRE Focused Plugins and Scripts

### 3. PROCESSORS

- Definitions of architectures and platforms
- Disassembler and Decompiler

**Let's dig into the Framework**

Implementation of Design Requirements

## Main Components:

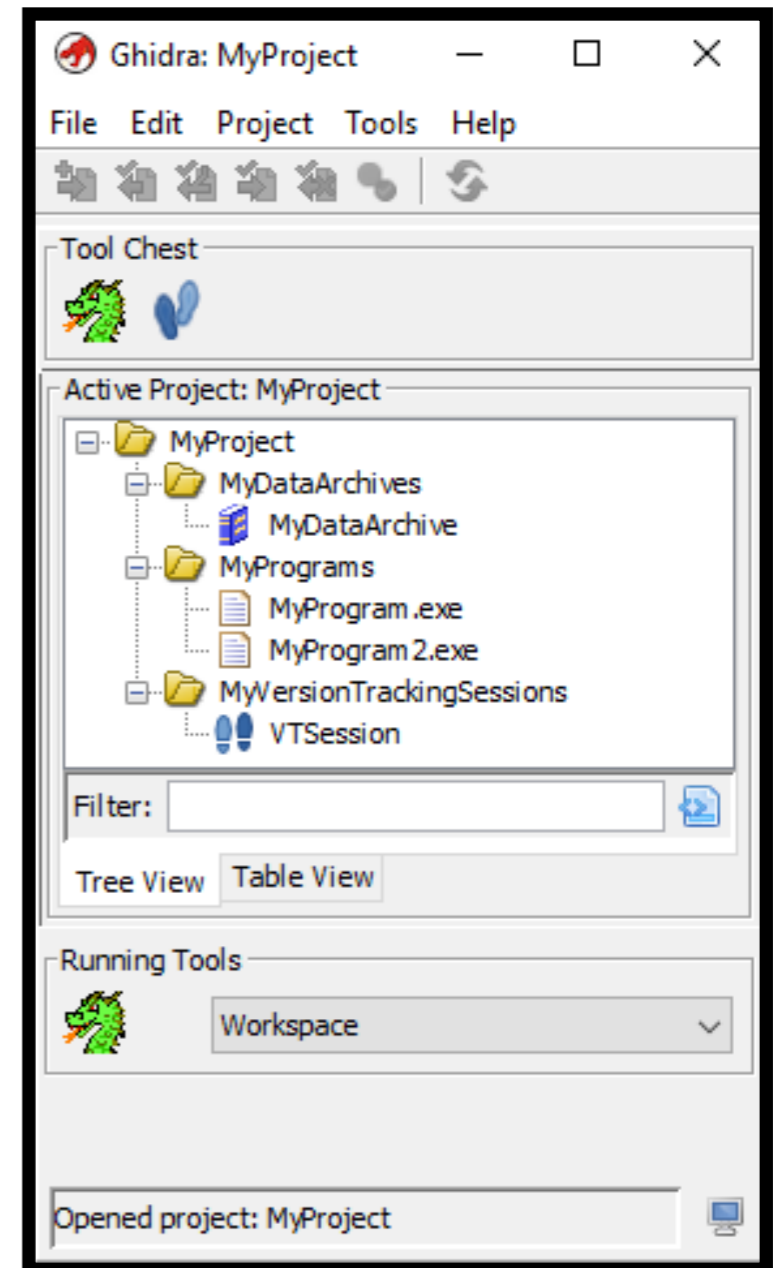
1. DB
2. Model
3. Software Modeling
4. Plugins
5. Docking Windows

## 1. DB

- Custom database to hold Domain Object data
- Tables, Rows, Cols
- Defined in package
  - db.\*
- Created to support
  - Undo/Redo
  - Version Control (Multi-User)

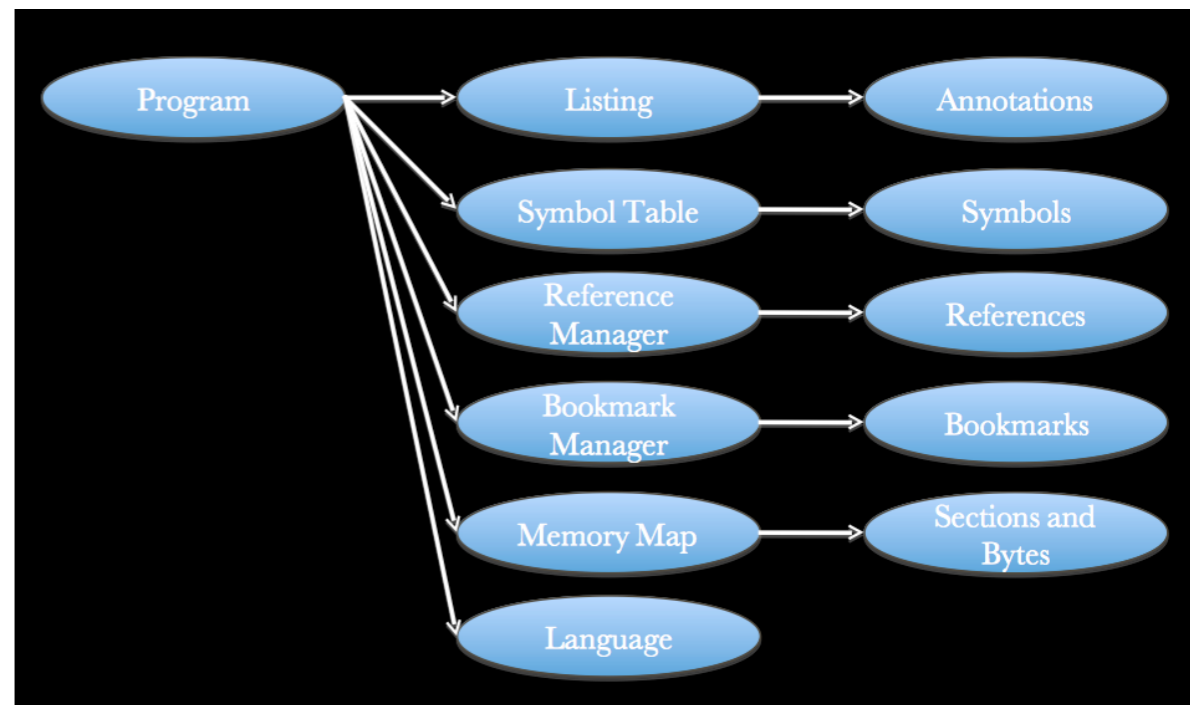
## 2. MODEL

- Data stored within the project
- Project
  - Domain Folder
    - Domain File
      - Domain Object
- Implementations supported:
  - Program
  - Data Type Archive
  - Version Tracking Session



## 3. SOFTWARE MODELING

- Classes to represent a Program
- Program
  - Memory
    - Memory Blocks, Bytes
  - Symbol Table
    - Symbols
  - Listing
    - Instructions, Data
  - Bookmark Manager
    - Bookmarks



## 4. PLUGINS

- Extends “Plugin” base class
- Produces and Consumes
  - Events (PluginEvent)
    - Selections, Locations
  - Services
    - Goto, Program Manager
- Creates
  - Menu and button actions
  - GUI components

## 5. DOCKING WINDOWS

- Customized Java GUI components
  - GTree, GTable
- Improved TableModel and TreeModel
  - Generic Threaded Loading, Sorting, Filtering
- Uniform Look-and-Feel
- Overcome Java Swing limitations, issues, and general wonkiness

Script Manager - 43 scripts (of 238)

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Filter:  Filter:

**HelloWorldScript.java**

Writes "Hello World" to console.

**Author:**  
G... Example



## Column Sorting

The screenshot shows the Ghidra Script Manager window with 43 scripts. A table lists various scripts with columns for In T., Status, Name, Description, Key, Category, and Modified. The 'HelloWorldScript.java' script is selected. Annotations include:

- Column Sorting:** A red box highlights the 'Name' column header, with an arrow pointing to it.
- Table Filtering:** A red box highlights the 'Filter:' input field at the bottom of the table.
- Filter Settings:** A red box highlights the filter settings icon (a small document with a magnifying glass) at the bottom right of the table.

In T.	Status	Name	Description	Key	Category	Modified
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Filter:  Filter:

HelloWorldScript.java  
Writes "Hello World" to console.  
Author:   
Category: Examples

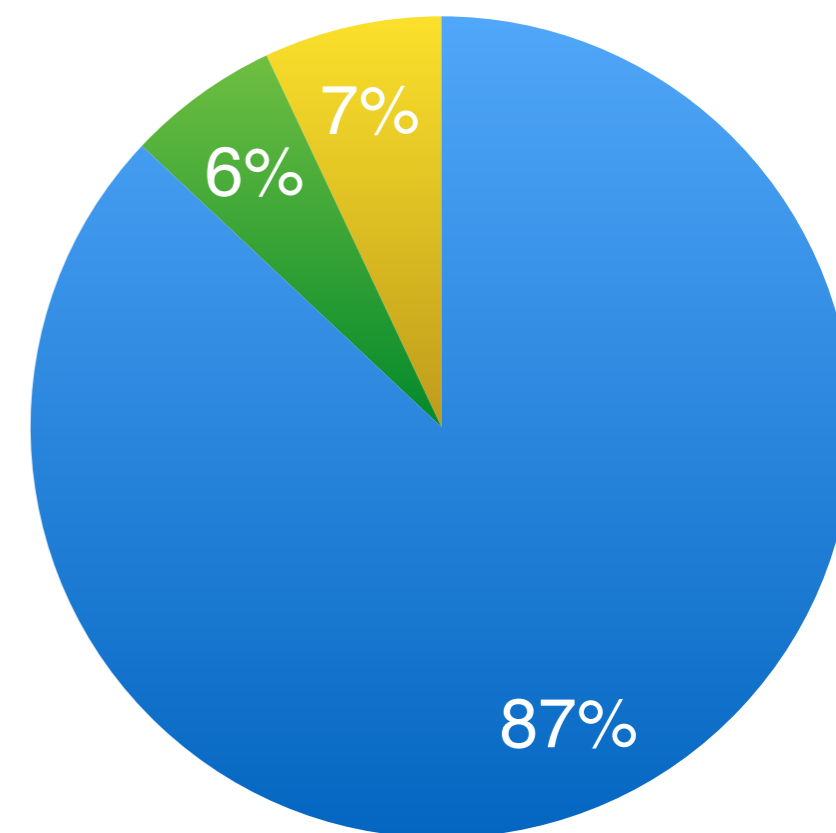
## Table Filtering

## Filter Settings

- Early 2000's ... Java was hot
  - Tried C++
- Platform independent
- Dynamically load classes
  - Plugins, scripts, and other Extension points
  - Restart not required
- Memory management (minimal)

● Java ● C++ ● Other

File Types



# OPEN SOURCE

## THE PROCESS

VERSION	YEAR	MAJOR FEATURES
1.x	2003	Classified version, Proof-of-concept, Framework
2.x	2004	DB, Docking Windows
3.x	2006	Sleigh, Decompiler, Version Control
4.x	2007	Scripting, Version Tracking
5.x	2010	File System Browser
6.x	2014	Unclassified version
7.x, 8.x	2015, 2016	Features, Improvements, Bug Fixes
9.x	2019	PUBLIC version (March 5 at RSA conference)

## **Executive Order 13691 Promoting Private Sector Cybersecurity Sharing**

Organizations engaged in the sharing of information related to cybersecurity risks and incidents play an invaluable role in the collective cybersecurity of the United States. The purpose of this order is to:

- Encourage the voluntary formation of such organizations
- Establish mechanisms to improve their capabilities and functions
- Enable voluntary partnering with the Federal Government

## **Federal Open Source Policy** **[sourcecode.cio.gov](https://sourcecode.cio.gov)** **[code.gov](https://code.gov)**

States that: “...challenges may result in duplicative acquisitions for substantially similar code and an inefficient use of taxpayer dollars. This policy seeks to address these challenges by ensuring that new custom-developed Federal source code be made broadly available for reuse across the Federal Government”.

- Prepublication review of each line of text
  - 2 people per line
  - Code, HTML, Build Scripts, etc.
  - Took awhile
- Redesign build process
  - Make more open source centric
- Stand up infrastructure
- Huge Team Effort
  - Ghidra Team, PAO, OGC, Security

GHIDRA source code pushed to GitHub on April 5, 2019

## BENEFITS

1. Cybersecurity is global issue
2. Collaboration
3. GHIDRA in college, school
4. NSA Recruitment!



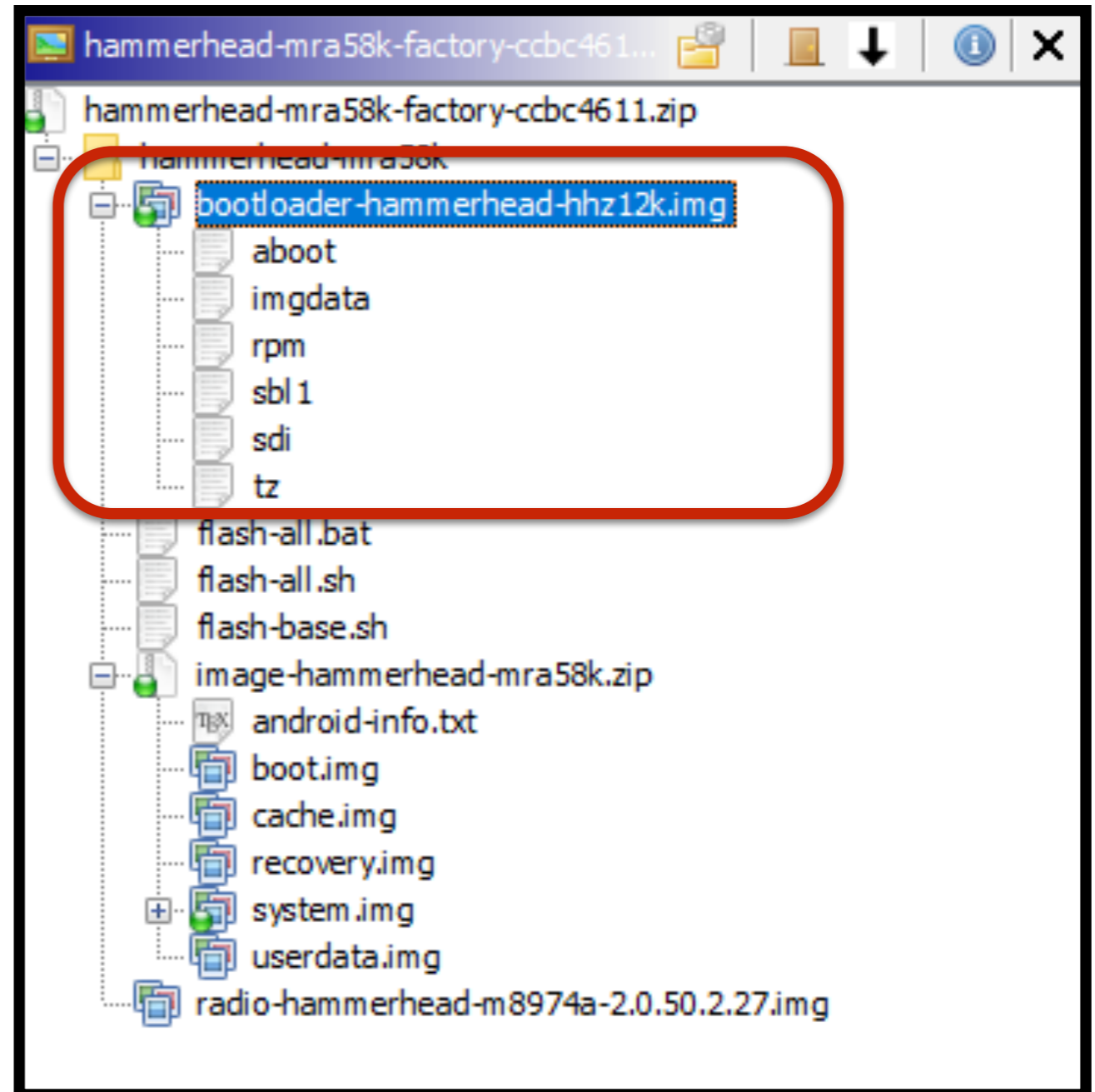


- 9.1
  - Additional Processor Modules
  - Data Type Bit Fields
  - SysCalls
  - Sleigh Editor
- Future
  - Android OAT/ART Support
  - Debugger (Alpha)
- External Engagements
- Bug Fixes

- 9.1
    - Additional Processor Modules
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  - Future
    - Android OAT/ART Support
    - Debugger (Alpha)
  - External Engagements
  - Bug Fixes
- Let's talk more about this**

- Current Format Support:
  - dex - Dalvik VM EXecutable
  - odex - Optimized Dalvik VM EXecutable
- New Format Support:
  - bootldr - Boot Loader binaries
  - odex - Natively Compiled (ELF)
  - oat - Ahead-Of-Time Compiled DEX
  - art - Android Run-Time
  - vdex, cdex
- OS Versions Supported: Lollipop (5.x) - Pie (9.x)

- GFileSystem to open Android Boot Loader format
- Displays contents within the “File System Browser”



```
Listing: LiveWallpapersPicker.odex
LiveWallpapersPicker.odex
oatdata
XREF[2]: Entry Point (*),
_elfSectionHeaders::00.
.rodata:00011000 6f ?? 6Fh o
.rodata:00011001 61 ?? 61h a
.rodata:00011002 74 ?? 74h t
.rodata:00011003 0a ?? 0Ah
.rodata:00011004 30 ?? 30h 0
.rodata:00011005 36 ?? 36h 6
.rodata:00011006 34 ?? 34h 4
.rodata:00011007 00 ?? 00h
.rodata:00011008 78 ?? 78h x
.rodata:00011009 ca ?? CAh
.rodata:0001100a 87 ?? 87h
.rodata:0001100b bf ?? BFh
.rodata:0001100c 03 ?? 03h
.rodata:0001100d 00 ?? 00h
.rodata:0001100e 00 ?? 00h
.rodata:0001100f 00 ?? 00h
.rodata:00011010 07 ?? 07h
.rodata:00011011 00 ?? 00h
.rodata:00011012 00 ?? 00h ? ->
.rodata:00011013 00 ?? 00h
.rodata:00011014 01 ?? 01h
.rodata:00011015 00 ?? 00h
.rodata:00011016 00 ?? 00h
.rodata:00011017 00 ?? 00h
.rodata:00011018 00 ?? 00h
.rodata:00011019 80 ?? 80h
.rodata:0001101a 00 ?? 00h
.rodata:0001101b 00 ?? 00h
```

```

Listing: LiveWallpapersPicker.odex
LiveWallpapersPicker.odex x
oatdata XREF[2]: Entry Point (*),
_elfSectionHeaders::00.
.rodata:00011000 6f 61 OatHeader_Mar...
74 0a
30 36 ...
...00011000 6f 61 74 0ads "oat\n" magic_
...00011004 30 36 34 00ds "064" version_
...00011008 78 ca 87 bfddw BF87CA78h Adler32_checksum_
...0001100c 03 00 00 00ddw 3h instruction_set_
...00011010 07 00 00 00ddw 7h instruction_set_features_bitmap_
...00011014 01 00 00 00ddw 1h dex_file_count_
...00011018 00 80 00 00ddw oatexec executable_offset_ =
...0001101c 00 00 00 00ddw 0h interpreter_to_interpreter_bri...
...00011020 00 00 00 00ddw 0h interpreter_to_compiled_code_b...
...00011024 00 00 00 00ddw 0h jni_dlsym_lookup_offset_
...00011028 00 00 00 00ddw 0h quick_generic_jni_trampoline_o...
...0001102c 00 00 00 00ddw 0h quick_imt_conflict_trampoline_...
...00011030 00 00 00 00ddw 0h quick_resolution_trampoline_of...
...00011034 00 00 00 00ddw 0h quick_to_interpreter_bridge_of...
...00011038 00 00 00 00ddw 0h image_patch_delta_
...0001103c 1d ea 91 4fddw 4F91EA1Dh image_file_location_oat_checks...
...00011040 00 a0 9d 70ddw 709DA000h image_file_location_oat_data_b...
...00011044 3f 03 00 00ddw 33Fh key_value_store_size_
...00011048 63 6c 61 ds "classpath" key_value_store_[0].key
73 73 70
61 74 68 00
...00011052 00 ds "" key_value_store_[0].value
...00011053 64 65 62 ds "debuggable"key_value_store_[1].key
75 67 67
61 62 6c ...

```

```

Listing: LiveWallpapersPicker.odex
LiveWallpapersPicker.odex
oatexec XREF[3]: Entry Point(*),
0001007c(*),
_elfSectionHeaders::00.
.text:00019000 00 ?? 00h
.text:00019001 00 ?? 00h
.text:00019002 00 ?? 00h
.text:00019003 00 ?? 00h
.text:00019004 36 ?? 36h 6
.text:00019005 1d ?? 1Dh
.text:00019006 00 ?? 00h
.text:00019007 00 ?? 00h
.text:00019008 00 ?? 00h
.text:00019009 00 ?? 00h
.text:0001900a 00 ?? 00h
.text:0001900b 00 ?? 00h
.text:0001900c 20 ?? 20h
.text:0001900d 00 ?? 00h
.text:0001900e 00 ?? 00h
.text:0001900f 00 ?? 00h
.text:00019010 20 ?? 20h
.text:00019011 80 ?? 80h
.text:00019012 00 ?? 00h
.text:00019013 00 ?? 00h
.text:00019014 00 ?? 00h
.text:00019015 00 ?? 00h
.text:00019016 00 ?? 00h
.text:00019017 00 ?? 00h
.text:00019018 3a ?? 3Ah :
.text:00019019 00 ?? 00h
.text:0001901a 00 ?? 00h
  
```

```

Listing: LiveWallpapersPicker.odex
LiveWallpapersPicker.odex x

executable_offset_      XREF[4]: Entry Point (*),
oatexec                0001007c (*),
                       00011018 (*),
                       _elfSectionHeaders::00.

.text:00019000 00 00      OatQuickMetho...
                00 00
                36 1d ...
...00019000 00 00 00 00ddw  0h      mapping_table_offset_
...00019004 36 1d 00 00ddw  1D36h   vmap_table_offset_
...00019008 00 00 00 00ddw  0h      gc_map_offset_
...0001900c 20 00 00 Quick...  frame_info_
                00 20 80
                00 00 00 ...
...00019018 3a 00 00 00ddw  3Ah     code_size_

*****
*                FUNCTION                *
*****

undefined <init>()
    assume LRset = 0x0
    assume TMode = 0x1
undefined    r0:1    <RETURN>
undefined4   Stack[-0x...local_18      XREF[2]: 00019048 (W),
                                                00019050 (R)
undefined4   Stack[-0x...local_20      XREF[2]: 00019028 (W),
                                                00019038 (R)
undefined4   Stack[-0x...local_2000    XREF[1]: 00019020 (*)
                                                com::android::wallpaper::livepic... XREF[2]: Entry Point (*),
                                                00016ac8 (*)

.text:0001901c ad f5      sub.w      r12.sp,#0x2000
  
```



## Downloads:

- 9.0.0 : 302k
- 9.0.1 : 36k
- 9.0.2 : 102k
- 9.0.4 : 66k
  
- Video Views: 761k

## Git Hub:

- Stars : 16,518
- Forks : 2,076
- Watchers : 712
- Issues: 690
  - 290 open
- Pull Requests: 139
  - 29 open

As of ~22 July

- Bugs
  - Please report.
  - Provide
    - Source code
    - Relevant bytes from the binary
    - Stack trace(s)
  - Please don't send copyrighted binaries.
- Improvements
- New Features
- **Thanks to all those who contributed!**

- GHIDRA Team is only on GitHub
  - Not on Twitter, etc
- @NSAGov on Twitter announces new releases
- NSA Public Affairs Office (PAO)
  - [mediarelations@nsa.gov](mailto:mediarelations@nsa.gov)

- Software
  - [ghidra-sre.org](http://ghidra-sre.org)
- Source Code
  - [github.com/NationalSecurityAgency/ghidra](https://github.com/NationalSecurityAgency/ghidra)
- All other sites are not official.

**Thank you!**