Automating Binary Analysis with Ghidra's P-Code

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Agenda

- Ghidra
- Ghidra Scripts
  - Intro
  - Python vs Java
  - Headless Mode
  - Flat API vs SDK
- P-Code
  - Intro
  - Raw P-Code
  - High P-Code
  - But Why?
  - Examples
- Recap
- Q‘n‘A

https://media.makeameme.org/created/agenda-5b5740.jpg

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What is Ghidra

NSA releases Ghidra, a free software reverse engineering toolkit

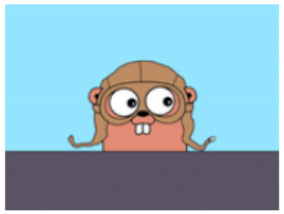
NSA's Ghidra greeted with positive reviews by the infosec community.

Image: NSA

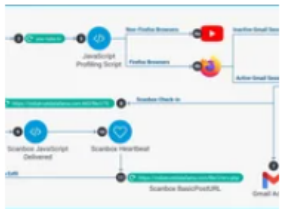
By Catalin Cimpanu for Zero Day | March 6, 2019 -- 02:12 GMT (02:12 GMT) | Topic: Security

MORE FROM CATALIN CIMPANU

Security
Chrome will soon try HTTPS first when you type an incomplete URL



Security
Go malware is now common, having been adopted by both APTs and e-crime groups



Security
Chinese cybersples targeted Tibetans with a malicious Firefox add-on

https://www.zdnet.com/article/nsa-release-ghidra-a-free-software-reverse-engineering-toolkit/

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CodeBrowser(3): flare21:/zyppe_7

File Edit Analysis Navigation Search Select Tools Window Help

Program Trees

- zyppe_7
  - .bss
  - .data
  - .got.plt
  - .got
  - .dynamic
  - .fini_array
  - .init_array
  - .gcc_except_table
  - .eh_frame
  - .eh_frame_hdr
  - .rodata
  - .fini
  - .text
  - .plt
  - .init

Program Tree × DWARF ×

Symbol Tree

- c_str...
- close...
- compare...
- deregister_tm_clones
- encrypt
- find_last_of...
- frame_dummy
- FUN_004013c0
- getenv...
- Init...
- main
  - local_20
  - local_28
  - local_30
  - local_58
  - local_78

Filter:

Data Type Manager

- Data Types
  - BuiltInTypes
  - zyppe_7
  - generic_clib_64
  - jni_all
  - windows_vs12_32

Filter:

Listing: zyppe_7 - (68 addresses selected)

*zyppe_7

```
                    00 00 00
004017b8 8b 45 f4   MOV     EAX,dword ptr [RBP + j]
004017bb 48 98      CDQE
004017bd 8b 94 85   MOV     EDX,dword ptr [RBP + RAX*0x4 + -0x460]
         a0 fb ff ff
004017c4 8b 45 f8   MOV     EAX,dword ptr [RBP + swapper1]
004017c7 8d 34 02   LEA     ESI,[RDX + RAX*0x1]
004017ca 8b 4d f4   MOV     ECX,dword ptr [RBP + j]
004017cd ba 4f ec   MOV     EDX,0x4ec4ec4f
         c4 4e
004017d2 89 c8      MOV     EAX,ECX
004017d4 f7 ea      IMUL    EDX
004017d6 c1 fa 04   SAR     EDX,0x4
004017d9 89 c8      MOV     EAX,ECX
004017db c1 f8 1f   SAR     EAX,0x1f
004017de 29 c2      SUB     EDX,EAX
004017e0 89 d0      MOV     EAX,EDX
004017e2 6b c0 34   IMUL    EAX,EAX,0x34
004017e5 29 c1      SUB     ECX,EAX
004017e7 89 c8      MOV     EAX,ECX
004017e9 48 98      CDQE
004017eb 0f b6 44   MOVZX   EAX,byte ptr [RBP + RAX*0x1 + -0x60]
         05 a0
004017f0 0f be c0   MOVSX   EAX,AL
004017f3 8d 14 06   LEA     EDX,[RSI + RAX*0x1]
004017f6 89 d0      MOV     EAX,EDX
004017f8 c1 f8 1f   SAR     EAX,0x1f
004017fb c1 e8 18   SHR     EAX,0x18
004017fe 01 c2      ADD     EDX,EAX
00401800 0f b6 d2   MOVZX   EDX,DL
00401803 29 c2      SUB     EDX,EAX
00401805 89 d0      MOV     EAX,EDX
00401807 89 45 f8   MOV     dword ptr [RBP + swapper1],EAX
0040180a 8b 45 f4   MOV     EAX,dword ptr [RBP + j]
0040180d 48 98      CDQE
0040180f 8b 84 85   MOV     EAX,dword ptr [RBP + RAX*0x4 + -0x460]
         a0 fb ff ff
00401816 89 45 e4   MOV     dword ptr [RBP + swapper2],EAX
00401819 8b 45 f8   MOV     EAX,dword ptr [RBP + swapper1]
0040181c 48 98      CDQE
0040181e 8b 94 85   MOV     EDX,dword ptr [RBP + RAX*0x4 + -0x460]
         a0 fb ff ff
00401825 8b 45 f4   MOV     EAX,dword ptr [RBP + j]
00401828 48 98      CDQE
0040182a 89 94 85   MOV     dword ptr [RBP + RAX*0x4 + -0x460],EDX
         a0 fb ff ff
00401831 8b 45 f8   MOV     EAX,dword ptr [RBP + swapper1]
00401834 48 98      CDQE
```

Decompile: encrypt - (zyppe_7)

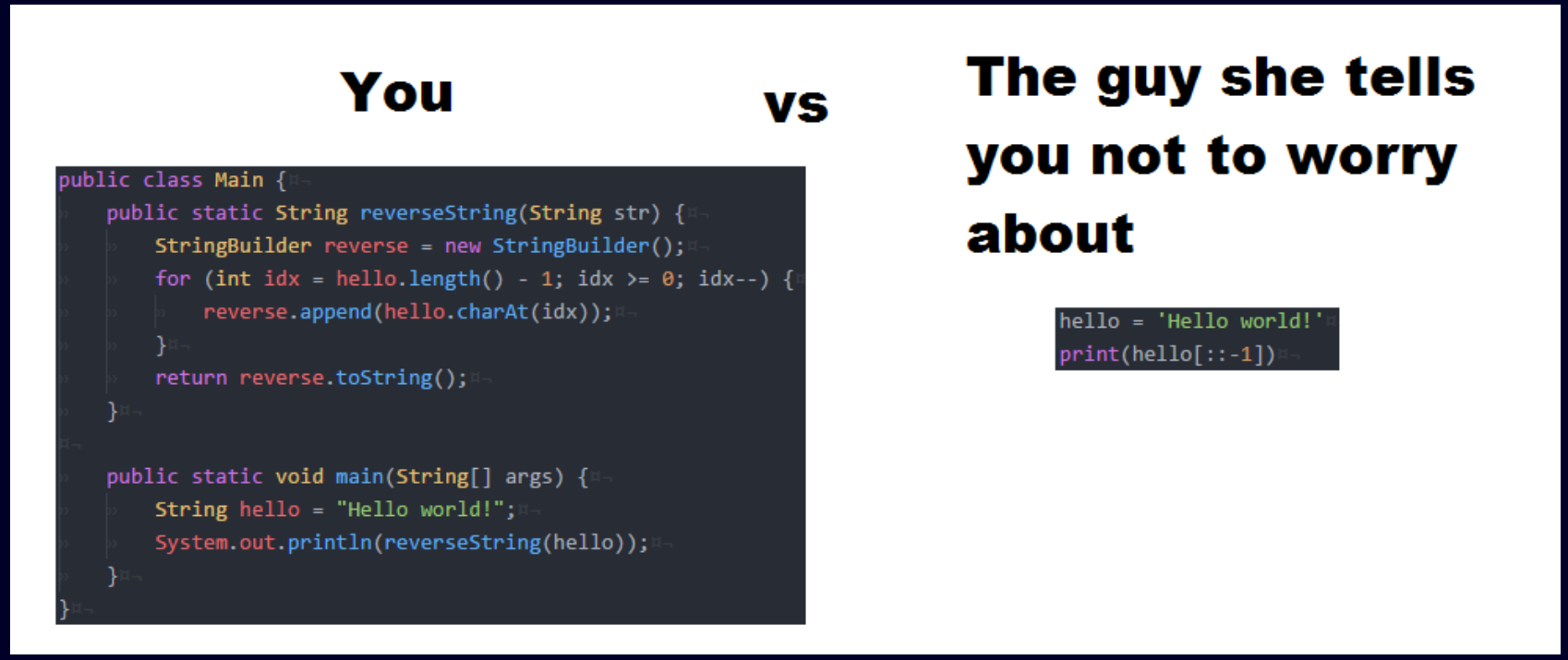
```
23  int key1;
24  int local_18;
25  int j;
26  int swapper1;
27  int i;
28
29  local_68 = 0x7465726365732041;
30  local_60 = 0x6c206f6e20736920;
31  local_58 = 0x2061207265676e6f;
32  local_50 = 0x6f20746572636573;
33  local_48 = 0x656d6f732065636e;
34  local_40 = 0x776f6e6b20656e6f;
35  local_38 = 0x74692073;
36  local_34 = 0;
37  i = 0;
38  while (i < 0x100) {
39    key_base[i] = i;
40    i = i + 1;
41  }
42  swapper1 = 0;
43  j = 0;
44  while (j < 0x100) {
45    iVar2 = key_base[j] + swapper1 + (int)*(char *)((long)&local_68 + (long)(j % 0x34));
46    uVar1 = (uint)(iVar2 >> 0x1f) >> 0x18;
47    swapper1 = (iVar2 + uVar1 & 0xff) - uVar1;
48    swapper2 = key_base[j];
49    key_base[j] = key_base[swapper1];
50    key_base[swapper1] = swapper2;
51    j = j + 1;
52  }
53  local_18 = 0;
54  swapper1 = 0;
55  key1 = 0;
56  plain_text = 0;
57  while (plain_text < 0x400) {
58    uVar1 = (uint)(local_18 + 1 >> 0x1f) >> 0x18;
59    local_18 = (local_18 + 1 + uVar1 & 0xff) - uVar1;
60    uVar1 = (uint)(key_base[local_18] + swapper1 >> 0x1f) >> 0x18;
61    swapper1 = (key_base[local_18] + swapper1 + uVar1 & 0xff) - uVar1;
62    local_28 = key_base[local_18];
63    key_base[local_18] = key_base[swapper1];
64    key_base[swapper1] = local_28;
65    uVar1 = (uint)(key_base[local_18] + key_base[swapper1] >> 0x1f) >> 0x18;
66    key2 = key_base[(int)((key_base[local_18] + key_base[swapper1] + uVar1 & 0xff) - uVar1)];
67    param_1[plain_text] = param_1[plain_text] ^ (byte)key1 ^ (byte)key2;
68    key1 = key2;
69    plain_text = plain_text + 1;
70  }
71  return;
72 }
73
```

Console - Scripting

Address not found in program memory: ffffffffffffb98 004017f3 encrypt LEA EDX,[RSI + RAX*0x1]

Ghidra Scripts

- Like IDAPython
- Extend the functionality
- Full automation is possible
- Java or Python (Jython)
- FlatAPI vs SDK



https://www.reddit.com/r/ProgrammerHumor/comments/66jj7f/java_vs_python/

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Script Manager [CodeBrowser(3): flare21:/zyppe_7]

Help

Script Manager - 240 scripts

- Scripts
  - _NEW_
  - Analysis
  - ARM
  - Assembly
  - Binary
  - Cleanup
  - CodeAnalysis
  - Conversion
  - CustomerSubmissi
  - Data
  - Data Types
  - Examples
  - FunctionID
  - Functions
  - FunctionStartPatte
  - HELP
  - Images
  - Import
  - Instructions
  - iOS
  - Iteration
  - Languages
  - Mac OS X
  - Memory
  - MultiUser
  - PCode
  - Processor
  - Program
  - Project
  - References

In Tool	Status	Name	Description	Key	Category	Modified
☐		AddCommentToProgramScript.java			Examples	02/12/2020
☐		AddCommentToProgramScriptPy.py	Adds a comment to a program. DISCLAIMER...		Examples->Pyt...	02/12/2020
☐		AddReferencesInSwitchTable.java	With cursor on switch's "add pc, .." command...		ARM	02/12/2020
☐		AddSingleReferenceInSwitchTable.java	With a user-inputed base address, this scrip...		ARM	02/12/2020
☐		AppleSingleDoubleScript.java	Given a raw binary Apple Single/Double ima...		Binary	02/12/2020
☐		ArmThumbFunctionTableScript.java	Makes functions out of a run of selected AR...		ARM	02/12/2020
☐		AsciiToBinaryScript.java	Converts an ascii hex file into binary file. W...		Conversion	02/12/2020
☐		AskScript.java	An example of asking for user input. Note th...		Examples	02/12/2020
☐		AskScriptPy.py	An example of asking for user input. Note th...		Examples->Pyt...	02/12/2020
☐		AssembleBlockScript.java	Assemble hard-coded block of instructions.		Assembly	02/12/2020
☐		AssembleCheckDevScript.java	Test assembly of the instruction under the c...	Ctrl-H	Assembly	02/12/2020
☐		AssembleScript.java	Assemble a single instruction, overwriting th...		Assembly	02/12/2020
☐		AssemblyThrasherDevScript.java	Thoroughly test the assembler by attemptin...		Assembly	02/12/2020
☐		AutoRenameLabelsScript.java	Renames default labels in a selected region,...		Symbol	02/12/2020
☐		AutoRenameSimpleLabels.java	A ghidra script that renames simple function...		Symbol	02/12/2020
☐		AutoVersionTrackingScript.java	An example of how to create Version Tracki...		Examples->Ver...	02/12/2020
☐		BadInstructionCleanup.java	This script cleans up the disassembly for kex...		iOS	02/12/2020
☐		BatchRename.java	Recursively finds a folder that matches a str...		Project	02/12/2020
☐		BatchSegregate64bit.java	Separates co-mingled n-bit and 64-bit binari...		Project	02/12/2020
☐		BinaryToAsciiScript.java	Converts a binary file into an ascii hex file.		Conversion	02/12/2020
☐		BTreeAnnotationScript.java	Annotates an HFS+ attributes b-Tree file.		iOS	02/12/2020
☐		BuildFuncDB.java			CodeAnalysis	02/12/2020
☐		BuildGhidraJarScript.java	An example of building a single minimal Ghi...		Examples	02/12/2020
☐		CallAnotherScript.java	Example of a script calling another script.		Examples->De...	02/12/2020
☐		CallAnotherScriptForAllPrograms.java	Shows how to run a script on all of the progr...		Examples	02/12/2020
☐		CallAnotherScriptForAllProgramsPy.py	Shows how to run a script on all of the progr...		Examples->Pyt...	02/12/2020
☐		CallAnotherScriptPy.py	Example of a script calling another script. DI...		Examples->Pyt...	02/12/2020
☐		ChangeDataSettingsScript.java	Changes the dsiplay settings of the current ...		Examples	02/12/2020
☐		ChooseDataTypeScript.java	Example of a script prompting the user for a...		Examples->De...	02/12/2020

Python vs. Java

https://pics.me.me/oh-noone-is-judging-you-sweetie-thats-your-conscience-talking-imgflip-com-no-51807818.png

- Whatever your flavor is, nobody is judging
- Ghidra is written in Java
- Python scripting works pretty well through Jython (python 2)
- Python 3: https://github.com/justfoxing/ghidra_bridge
- Java development environment is great
- Ghidra plugin for Eclipse
- Java dev is supported by NSA
- You might need to let go of your principles

Headless Mode

```
analyzeHeadless /Users/user/ghidra/projects MyProject -import hello.exe -preScript GetInfoScript.java
```

- Way to implement fully automated scripts
- Calling it could be nicer

https://sadanduseless.b-cdn.net/wp-content/uploads/2021/07/headless-gymnasts1.jpg

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Flat API

- Interface to write simple scripts
- Reliability in long term is the main goal
- ~147 methods available
- GhidraScript class is a subclass of FlatProgramAPI
- Stick to it if possible

NOTE:

1. NO METHODS SHOULD EVER BE REMOVED FROM THIS CLASS.
2. NO METHOD SIGNATURES SHOULD EVER BE CHANGED IN THIS CLASS.

This class is used by GhidraScript.

Changing this class will break user scripts.

That is bad. Don't do that.

Program API

https://tenor.com/view/boom-mind-blown-mind-blowing-eyeglasses-gif-15569009

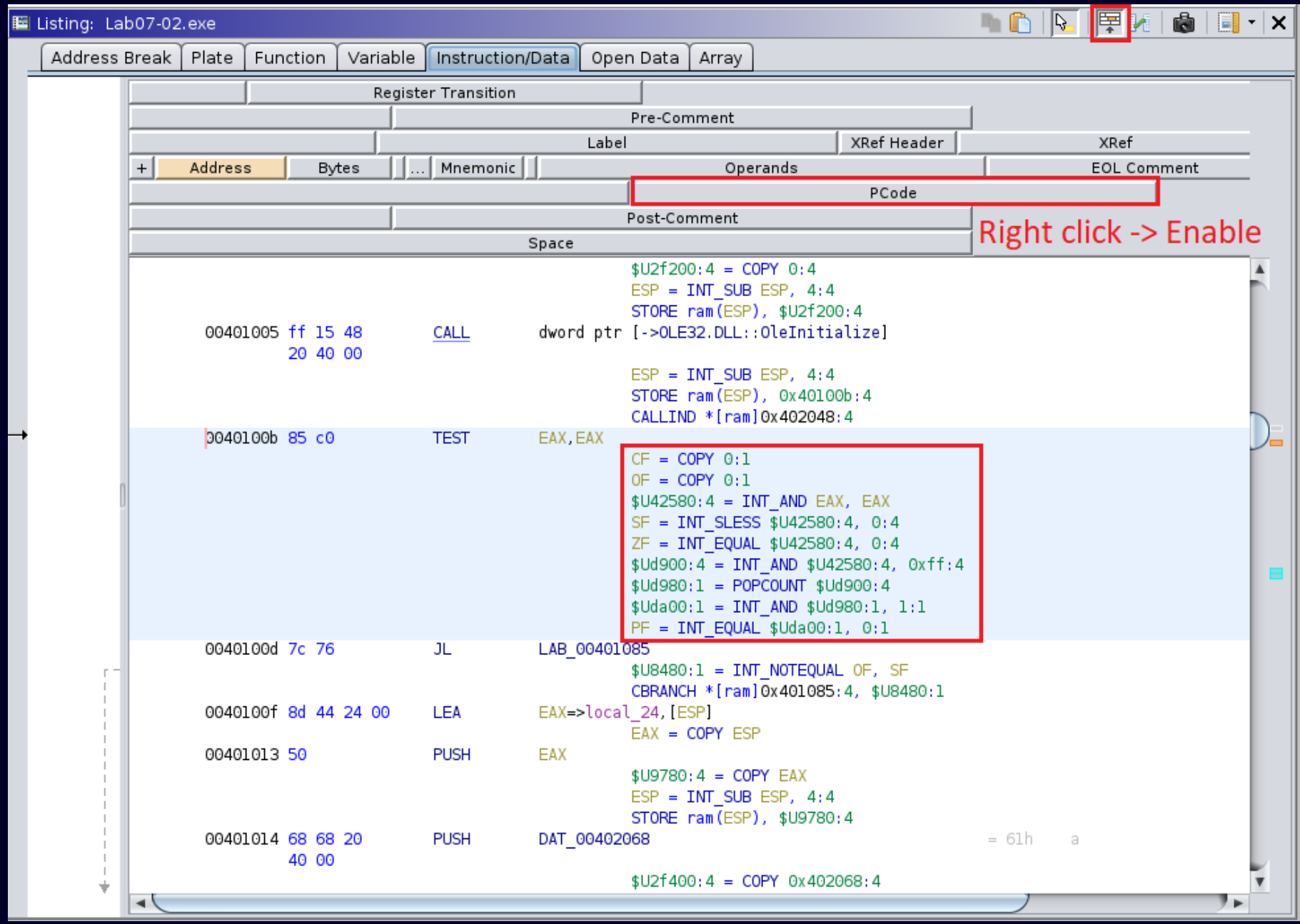
- Practically everything that is Ghidra
- All classes are available
- JavaDoc: https://ghidra.re/ghidra_docs/api/index.html
- Source https://github.com/NationalSecurityAgency/ghidra

Example 1: Listing imported functions

```
1  //This script lists all imported functions used by the binary.
7
8  import ghidra.app.script.GhidraScript;
10
11 public class brucon_01_list_imports extends GhidraScript {
12
13     @Override
14     protected void run() throws Exception {
15         String format = "%-30s %-30s\n";
16         SymbolTable symbolTable = currentProgram.getSymbolTable();
17         SymbolIterator symbolIter = symbolTable.getExternalSymbols();
18         printf("[-] Imported functions of %s\n\n", currentProgram.getExecutablePath());
19         printf(format, "Function Name", "Library");
20         printf("%s\n", "-".repeat(60));
21         for(Symbol symbol: symbolIter) {
22             printf(format, symbol.getName(), symbol.getParentSymbol());
23         }
24
25     }
26 }
```

P-Code

- Intermediate Representation: lies between the assembly code and the decompiled code that the Ghidra UI shows
- Register transfer language, it translates every individual processor instruction to a sequence of P-Code operations
- For each instruction it describes the processor instruction, including all side effects



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Raw P-Code

- This is what you see when you start printing P-Code from a Ghidra Script (we will see later)
- There are no higher-level connections (arguments, variables, etc…)

```
                                        CALLIND (ram, 0x402048, 4)
0040100b 85 c0          TEST        EAX,EAX
                                        (register, 0x200, 1) = COPY (const, 0x0, 1)
                                        (register, 0x20b, 1) = COPY (const, 0x0, 1)
                                        (unique, 0x42580, 4) = INT_AND (register, 0x0, 4), (reg...
                                        (register, 0x207, 1) = INT_SLESS (unique, 0x42580, 4), ...
                                        (register, 0x206, 1) = INT_EQUAL (unique, 0x42580, 4), ...
                                        (unique, 0xd900, 4) = INT_AND (unique, 0x42580, 4), (co...
                                        (unique, 0xd980, 1) = POPCOUNT (unique, 0xd900, 4)
                                        (unique, 0xda00, 1) = INT_AND (unique, 0xd980, 1), (con...
                                        (register, 0x202, 1) = INT_EQUAL (unique, 0xda00, 1), (...
0040100d 7c 76          JL          LAB_00401085
```

High P-Code

- Result of HighFunction()
- “High-level abstraction associated with a low-level function made up of assembly instructions. Based on information the decompiler has produced after working on a function.”
- Closer to the C Pseudo Code
- Higher-level connections, such as function arguments, variables, etc...

https://southpark.fandom.com/wiki/Towelie_(character)

Why use P-Code?

- Because it’s cool
- Most of the binary analysis systems work with some kind of intermediate language.
- Compilers also use IR to separate the processes of parsing source code to a standardized format and translating the code to the machine code of the target architecture.
- Architecture independent
- Provides more information, then assembly (i.e. side effects)

https://pics.awwmemes.com/do-you-ever-think-happen-com-do-you-ever-think-screw-49053453.png

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Demo

You get a Demo!

You get a Demo!

Everybody gets a DEMOOOOOO!

Example 2: Print high P-Code at the COM functions' call site

- Malware often use Component Object Model (COM) as obfuscation
- COM offers standardized interfaces to various functionality
  - Control IE through COM
  - Control the firewall through COM
- Script identifies if binary uses COM objects
- Prints call sites for COM functions

Example 3: Recover CLSID and IID to identify which COM object is used

- CLSID: globally unique identifier of a COM class objects
- CLSIDs and their associated programs are recorded in the registry: HKEY_LOCAL_MACHINE\SOFTWARE\Classes\CLSID\{CLSID}
- To find out what COM object is used we need the CLSID
- IID: the interface that will be used to talk to the object.

```
C++

HRESULT CoCreateInstance(
  REFCLSID  rclsid,
  LPUNKNOWN pUnkOuter,
  DWORD     dwClsContext,
  REFIID    riid,
  LPVOID    *ppv
);
```

Recap

- Ghidra is great
- Ghidra scripts and P-Code have a lot of potential for automation
- Ghidra is relatively well documented
- There are still challenges when one starts to dig deep
- Choose your tool for the task

https://www.avira.com/de/blog/nsa-macht-ghidra-oeffentlich-zugaenglich

References and Thanks

- Alexei Bulazel and Jeremy Blackthorne: https://www.riverloopsecurity.com/blog/2019/05/pcode/
- Rolf Rolles: https://www.msreverseengineering.com/blog/2019/4/17/an-abstract-interpretation-based-deobfuscation-plugin-for-ghidra
- Carlos Garcia Prado (@m0n0sapiens) helped with his infinite wisdom

Q&A

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