SEMINAR 4
INTRODUCTION TO REVERSING

A primer on analyzing programs

JOSÉ MANUEL REDONDO LÓPEZ *"S-81 ISAAC PERAL"* PROJECT V4.0




Source: Bing Chat AI

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INTRODUCTION

What is Ghidra?

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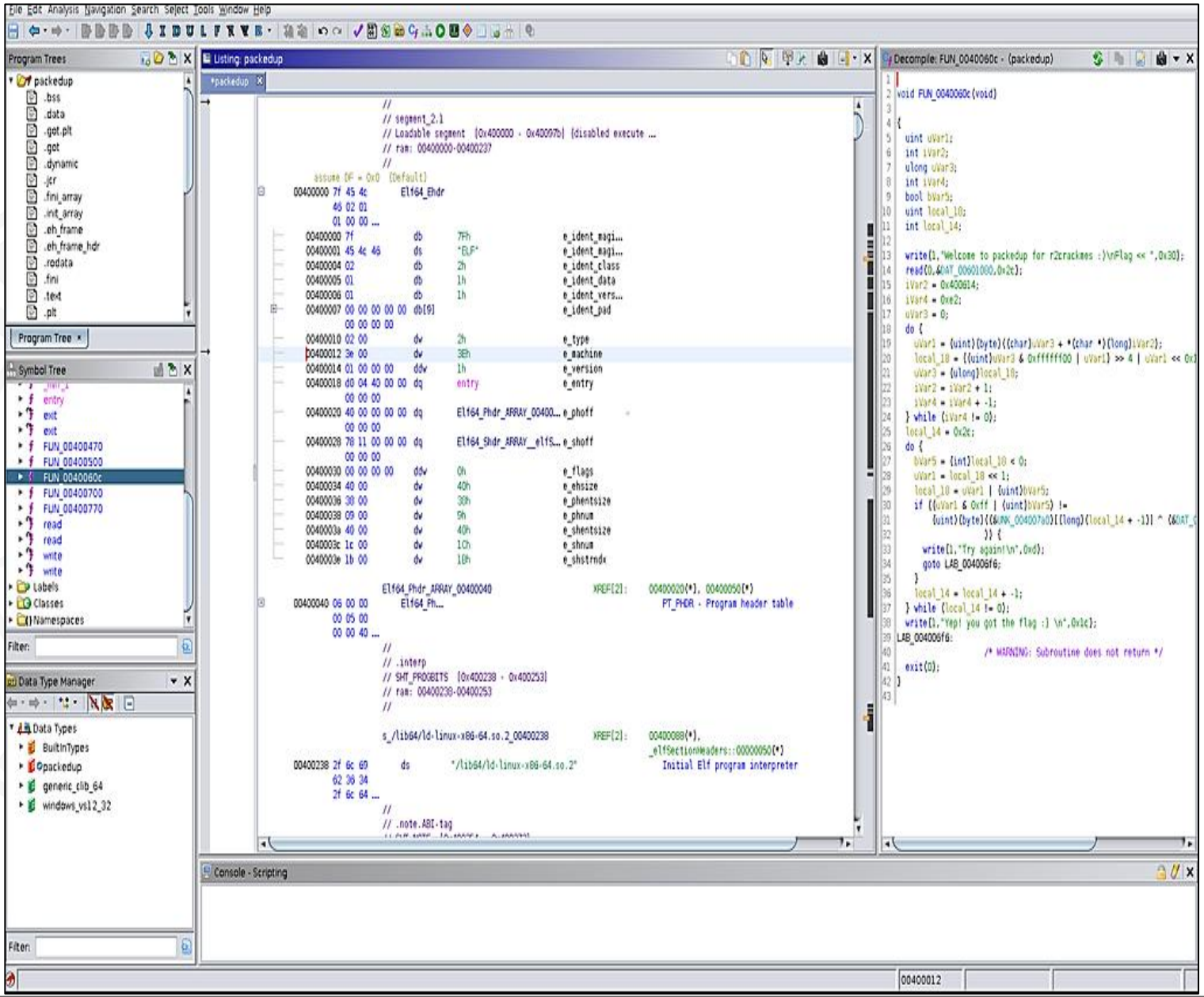
Introduction

- **This seminar describes an approach for using Ghidra to perform malicious code analysis**
  - It is just a brief introduction of common analysis operations
  - This field is much much more complex! ☺
- **Ghidra is a free software reverse engineering (SRE) framework**
  - Developed by the National Security Agency (NSA) of the United States
  - It is powerful reverse engineering tool available to all for free
  - Allows to analyze malware to better understand it
    - This helps to locate vulnerabilities in systems and networks
- **Since its release, Ghidra has attracted a growing community of contributors**

GHIDRA

https://ghidra-sre.org/

- **Free alternative to the popular IDA Pro**
- **Main features**
  - Analysis of compiled code in Windows, Mac OS, and Linux
  - Disassembly, assembly, decompile and display code
  - Do/Undo actions
  - Large set of CPU instructions and executable formats supported
  - Supports third-party plugins or scripts in Java o Python (Jython) using its API



Source: https://en.wikipedia.org/wiki/Ghidra

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Launching Ghidra & loading an executable

Setting up the analysis environment

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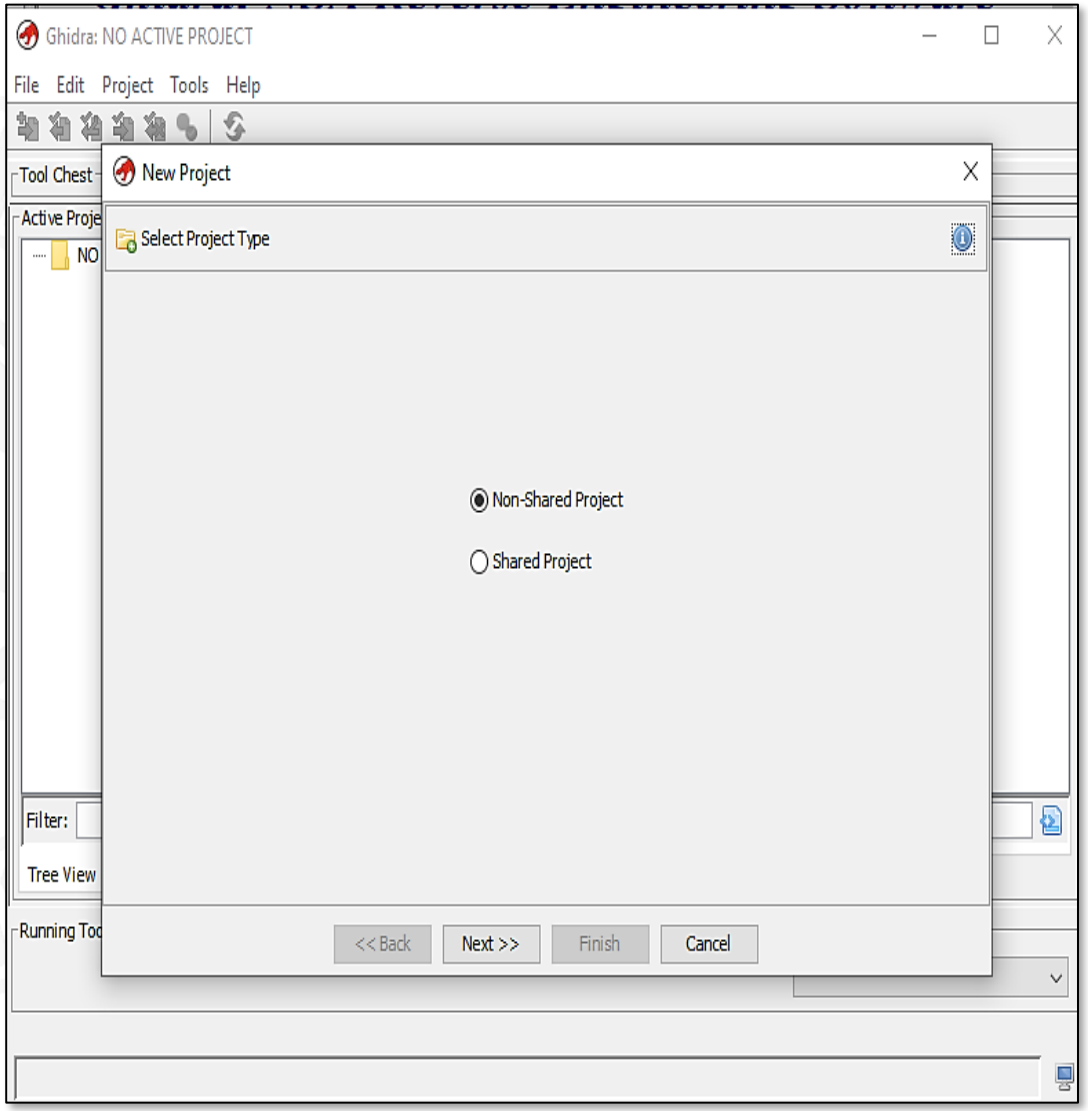
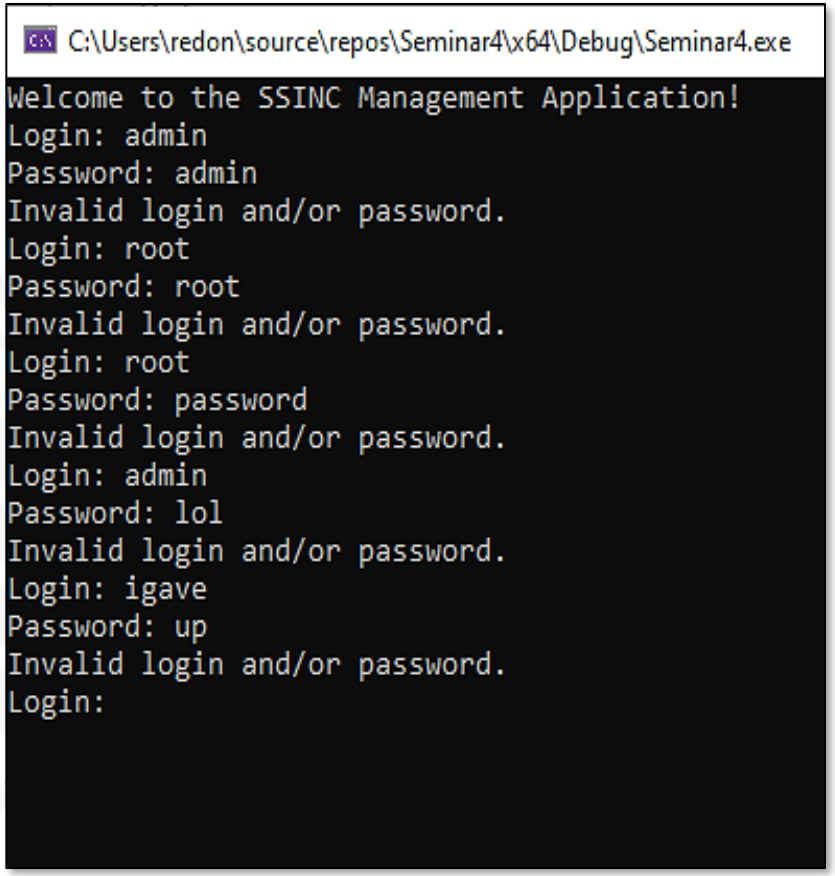
LOADING AN EXECUTABLE

- **Installing Ghidra requires**
  - Downloading and extracting a zip file and launch the batch file
  - Installing **JDK/OpenJDK 17+**
    - https://adoptopenjdk.net/index.html?variant=openjdk11&jvmVariant=hotspot
- **Then, create a project (File - New Project)**
  - Reverse engineering often target multi-component malware, so it uses projects instead of individual files
  - Project options include
    - "Non-Shared" for single-user analysis
    - "Shared" for collaborative work (multiple users can access a project repository on a server)
  - **We will focus on single user projects**
    - But the other type is good for sharing reversing efforts
  - Projects need a name



Our executable

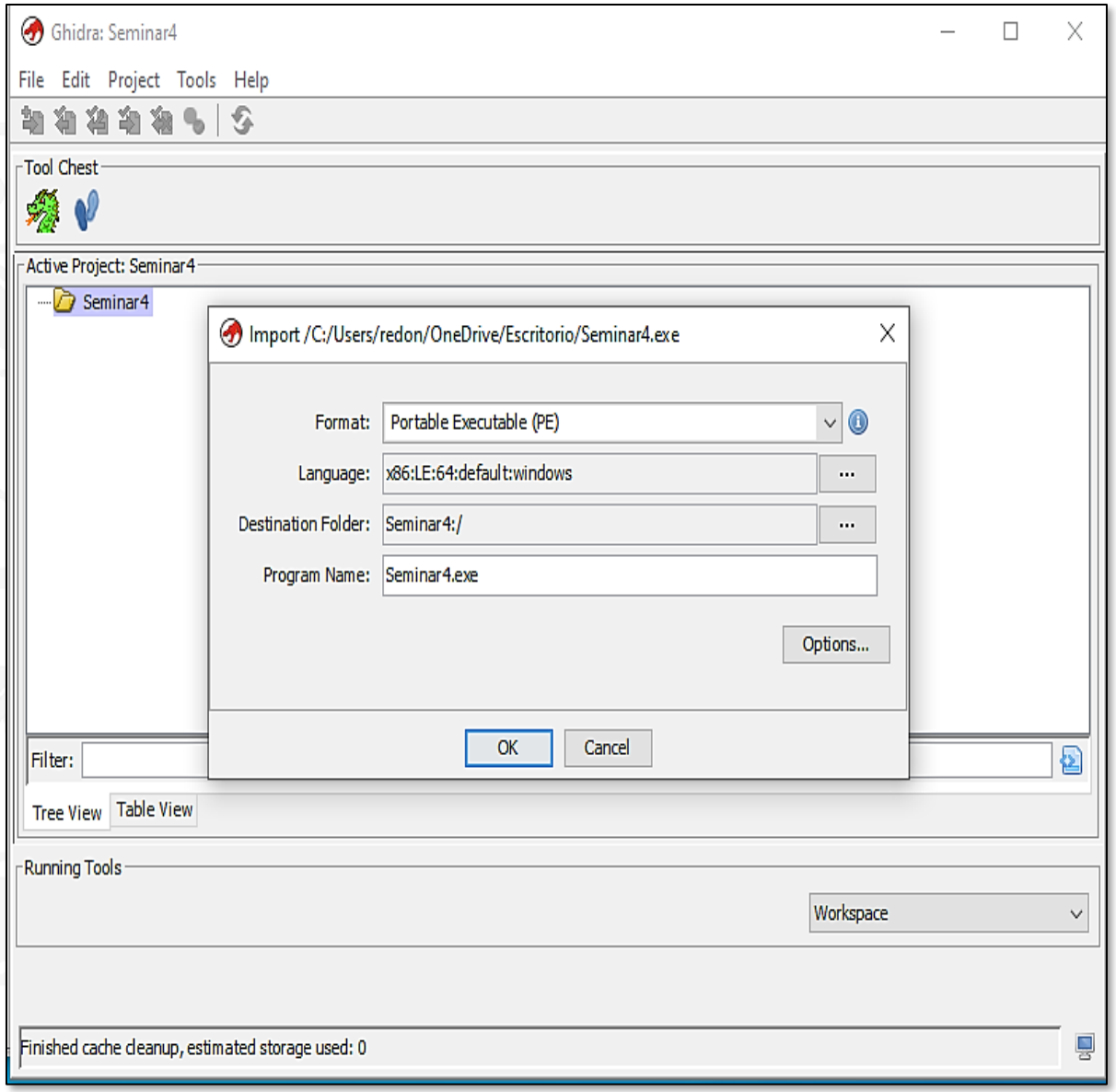
- **We are going to reverse-engineer a custom executable we provide**
  - It is a fake command-line management application, created with Visual Studio C++
    - No GUI to keep code size small
  - Compiled in debug mode
  - It contains a login-password initial step
  - If successfully logged in, it shows a menu
  - All options are “under construction” ☺
  - But, upon successful login, the program steals user clipboard data periodically!
    - Don’t worry, it only displays it ☺
    - But it will be very easy to store it, send it to another system…
  - **Copy the `.exe` and `.pdb` files to the same folder**



The Visual Studio Project source code is available in the virtual campus!

LOADING AN EXECUTABLE

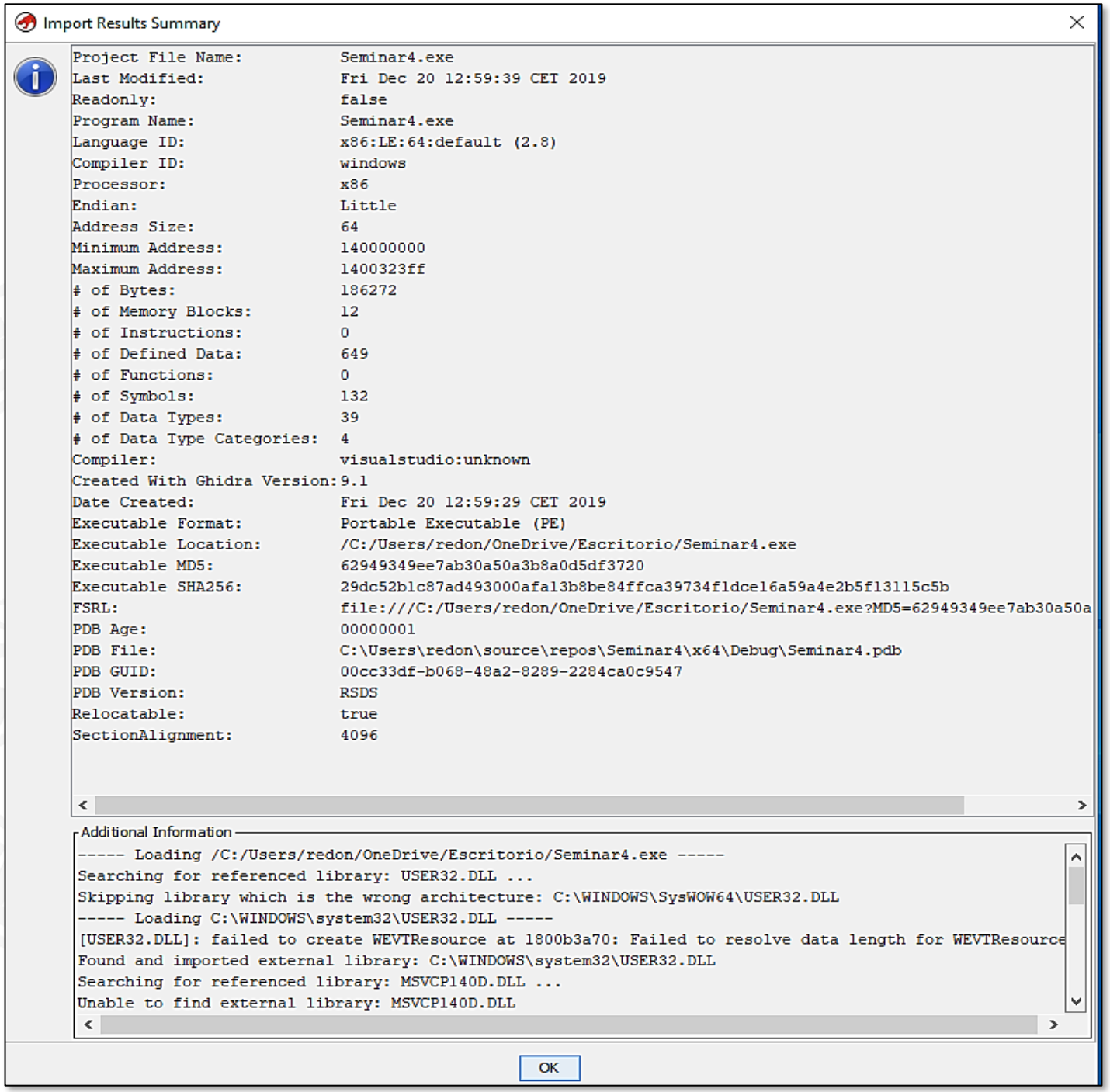
- To analyze an executable file, you need to drag and drop the `.exe` file into the project window
- This will launch a dialog box where you can accept the defaults and click OK
- If in the same folder a `.pdb` file exists, Ghidra will attempt to use it
  - These files contain the debugging symbols
  - They could not work on some configurations (we will see this later)



Loaded executable information

Computer Security

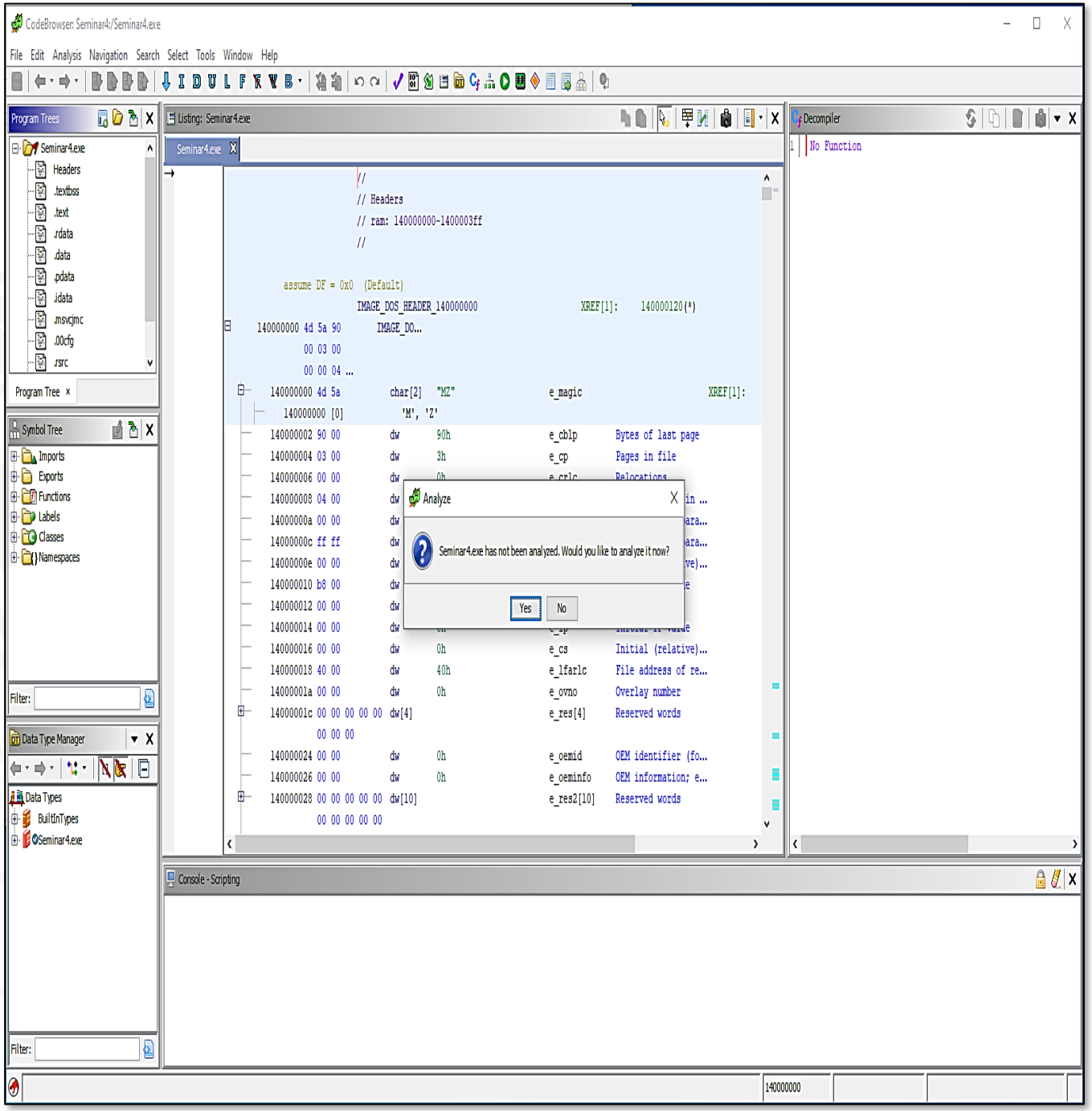
- When a file is added to a Ghidra project for the first time, a special information window appear
- This window contains a lot of useful **information about the file**, such as
  - Various sizes
  - Compiler used to create it
  - Timestamps
  - Exe hashes
  - Architecture



Analyzing an Executable

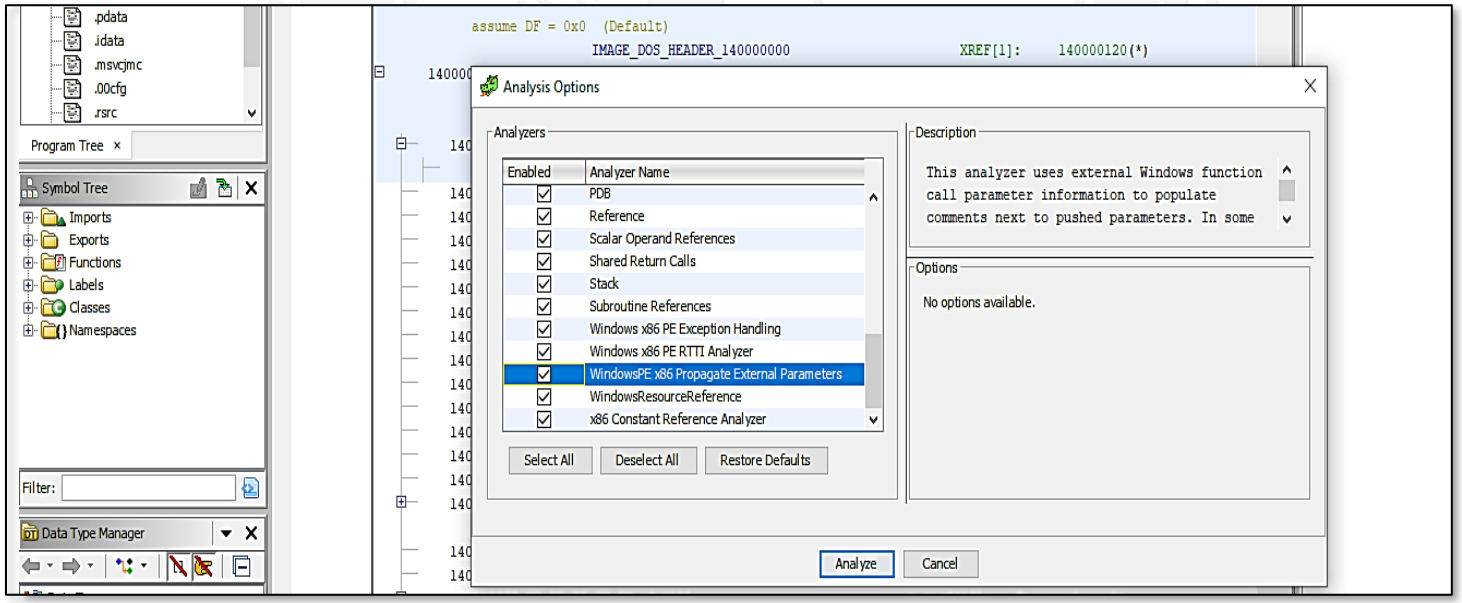
Computer Security

- **Double-clicking the imported file in the project window runs the Code Browser**
  - If not done previously, the tool will ask to analyze the file now
  - **This is required** to continue the reversing process
  - Analysis can be done / redone manually in the "Analysis" menu
- **Enable the option "WindowsPE x86 Propagate External Parameters"**
  - It writes arguments of functions in the comments
  - This is convenient for better understand the analyzed code



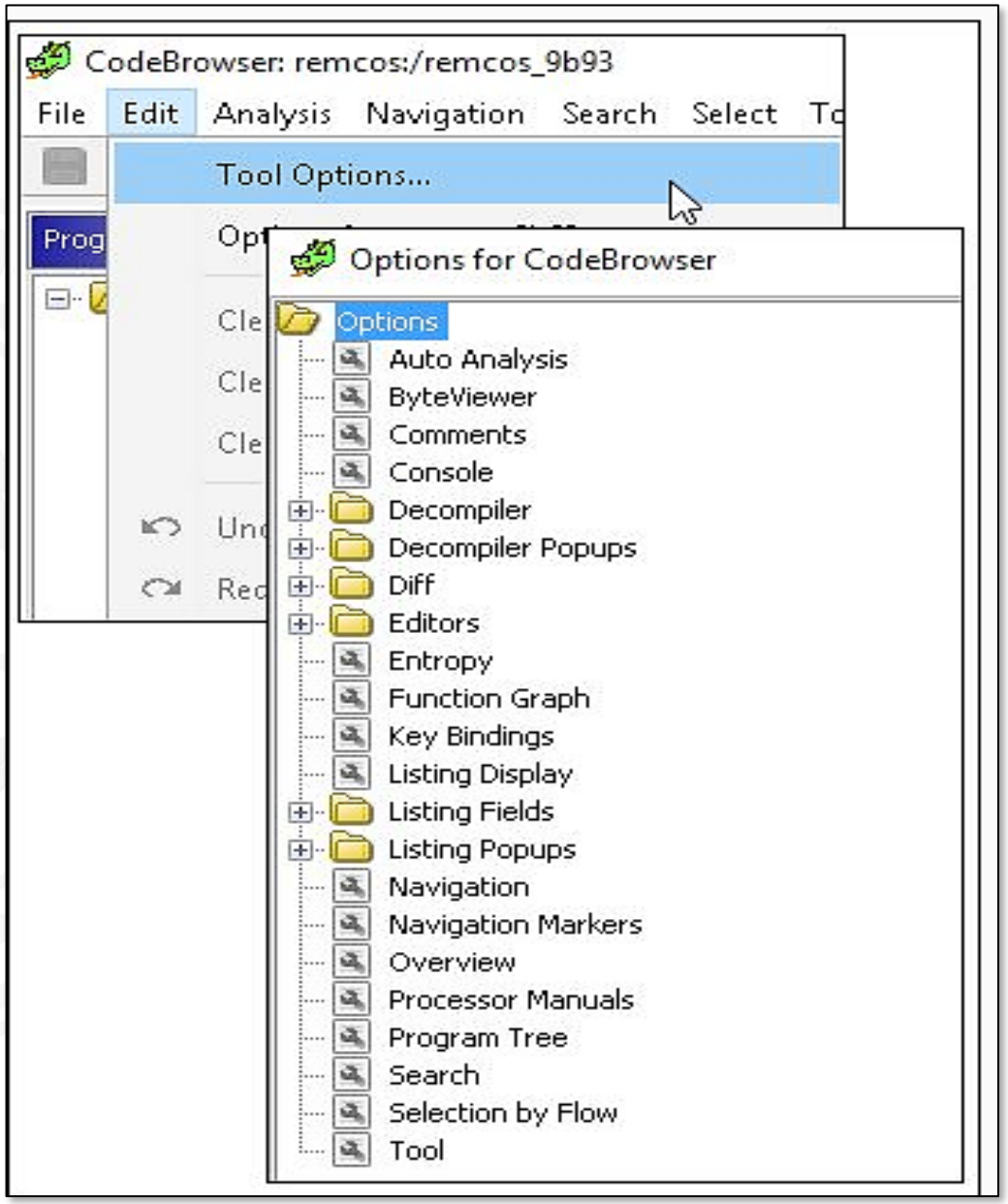
ANALYZING AN EXECUTABLE

- **To start the analysis, let Ghidra collect information about our `.exe`**
  - As we are in Windows and a `.pdb` is provided, Ghidra should load it and complete the exe information
  - However, it could complain about not finding **the DIA SDK** that is used to fully load `.pdb` files
    - This SDK is installed with Visual Studio (even free versions, like Visual Studio Community)
    - In theory, you could search for the file `msdia140.dll` in the hard disk and register it with `regsvr32` from a terminal with `Administrator` privileges
    - **But this does not work in some cases**: we cannot see extended information (like function names)
    - We will proceed anyway, as having a `.pdb` file is not a common case in real deployments



Modify Displayed Elements

- It is useful to make some changes to the Listing window via **Edit - Tool Options** for easier reading
  - **Listing Display**: Increase the font size and enable bold formatting
  - **Listing Fields: Bytes Field**: Change “Maximum Lines to Display” to 1
  - **Listing Fields: Cursor Text Highlight**: Change “Mouse Button to Activate” to LEFT
  - **Listing Fields: EOL Comments Field**: Check “Show Semicolon at Start of Each Line”
  - **Listing Fields: Operands Field**: Check “Add Space After Separator”



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INSPECTING EXECUTABLE DATA

Analyzing strings within the executable

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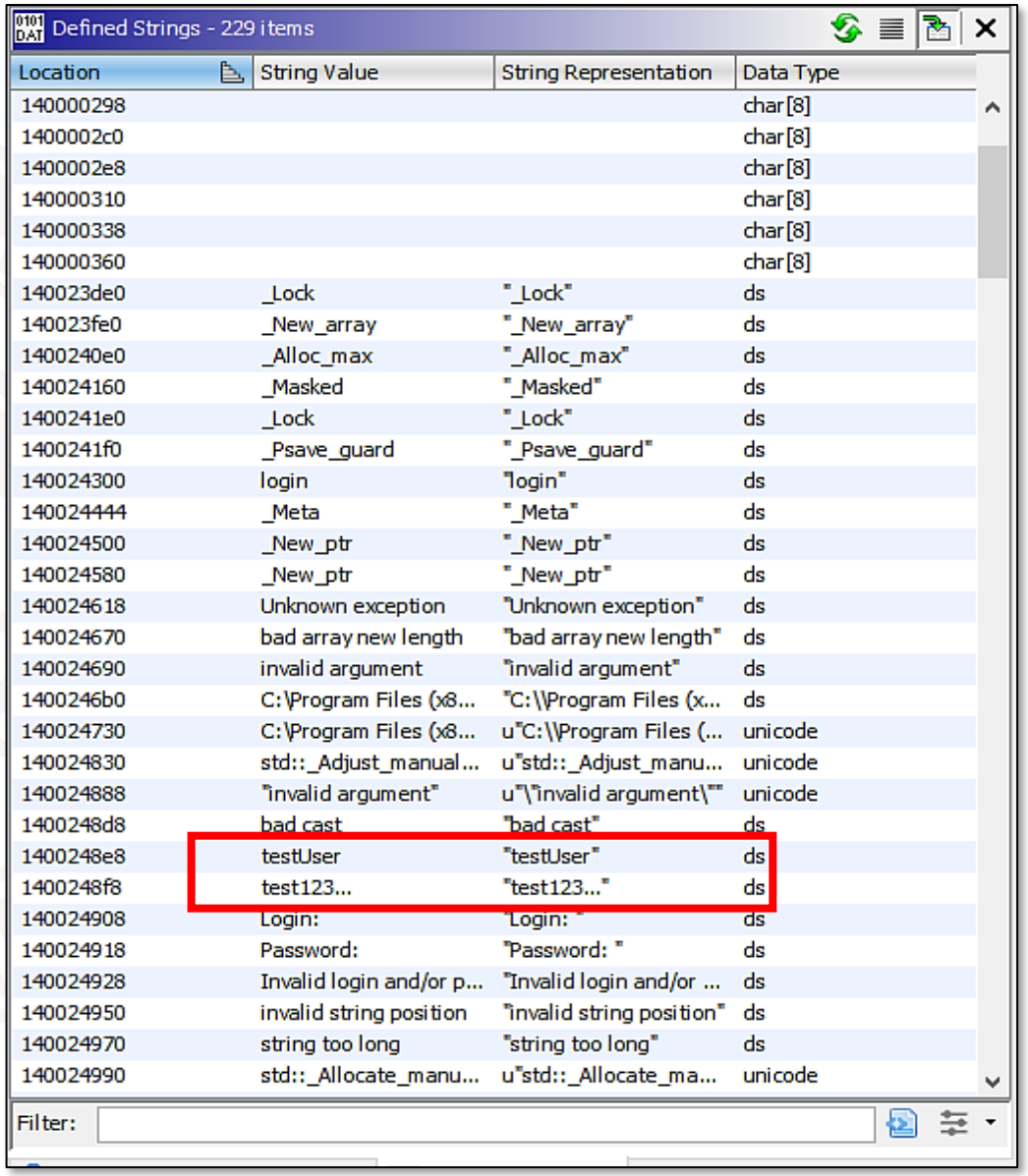
Investigating string references

- One of the things we could not be aware of is **that hardcoded strings in our executable are viewable** with tools like **Ghidra**
- This means that creating constants with passwords, important IDs, usernames, passwords, etc. (aka “hardcoding”) **is always a bad idea**
  - Strings with important data must be encrypted
  - Or, much better, loaded from external encrypted sources
- Data declared within the source code can be located and used against us
  - E.g.: we have no clue about how to bypass an application authentication mechanism
  - What if the application code have some kind of “hidden” authentication information? (backdoor?)
- For just viewing hardcoded strings inside an executable, the command-line tool `strings` is recommended

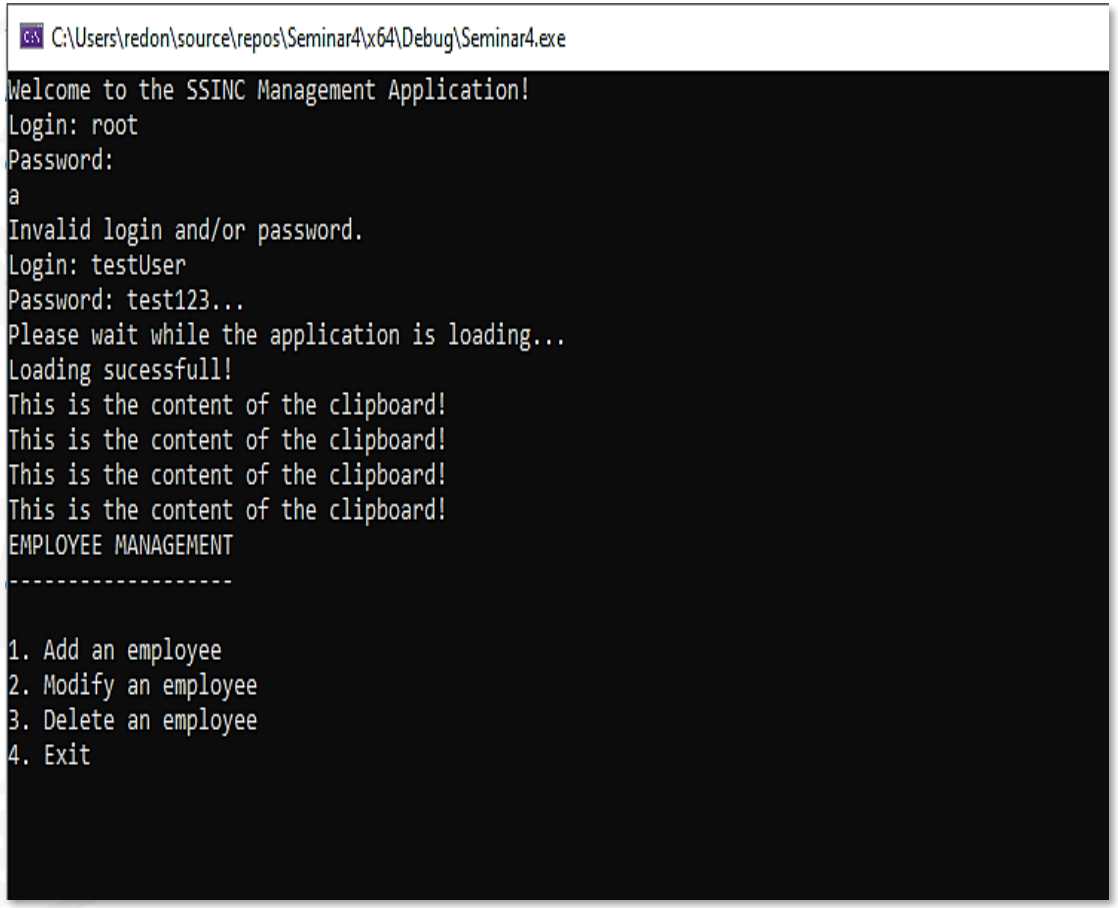
INVESTIGATING STRING REFERENCES

- **To view strings embedded in an executable go to Window - Defined Strings**
  - This window shows a list of all the defined strings
  - Including its address within the code, value and string representation
  - We see that there are a lot of strings belonging to application standard messages
  - But we also located two suspicious ones "`testuser`" and "`test123...`" that seems to be a username / password
- **What happens if we try this combination?**



Hidden? Data within an executable

- **We correctly guessed that these were a combination of valid user / password**
- **Is this situation common?**
  - Certainly, it is not rare to find backdoors / privileged information hardcoded in an executable file
  - Valid usernames
  - Passwords
  - API Keys
  - IDs
  - “Secret” (not linked) URLs / IPs / routes…
  - Undocumented functionality names
  - …
- **Hardcoding important stuff is not safe!**



NOTE: Our sample application crashes if the clipboard contents is not a string

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Decompiling >

Data >

Code >

INSPECTING EXECUTABLE CODE AND BEHAVIOR

See what our program does

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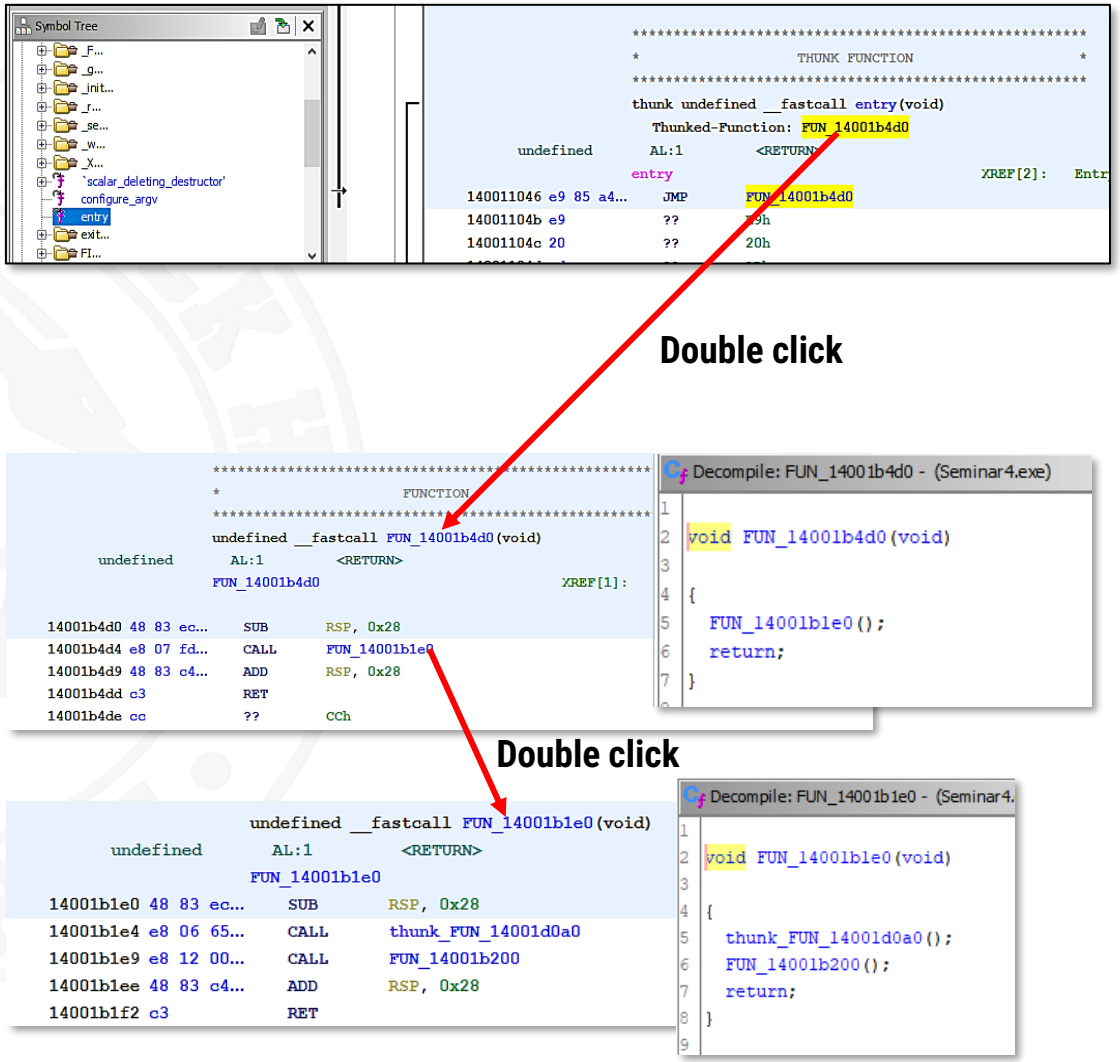
"Following" a program

- **Program behavior can be inspected analyzing its calls from its entry point**
  - Program entry points have a special name in the symbol tree (`entry`)
  - From there we can follow the execution (it is like the typical `main` function of languages like Java or C#)
- **We may find thunked functions**
  - Functions used to **inject additional calculations** into another ones
  - Used to delay a calculation until its result is needed
  - Or to insert operations at function beginning or end
  - Commonly used by compiler's code generation phase
  - Most of the times we can just **follow them ignoring their contents**



REVERSING IS NOT EASY... AND WE WILL FIND OBSTACLES

- **Ghidra can try to make it easier for you to see the value of a variable**
  - By interpreting and displaying it by its type
  - Which sometimes leads to "easter eggs", like this image
- **Companies know that someone is going to decompile their programs**
- **Programs often have obfuscation or counter-reversing techniques**
  - They make your job harder because they don't want you to see how the program does certain things
    - E.g.: Check that it is not a pirated copy ☺
  - Therefore, don't despair if there are very difficult to understand things

```
001b6835 30              ??         30h    0
001b6836 20              ??         20h
001b6837 35              ??         35h    5
001b6838 30              ??         30h    0
001b6839 20              ??         20h
001b683a 31              ??         31h    1
001b683b 36              ??         36h    6
001b683c 20              ??         20h
001b683d 31              ??         31h    1
001b683e 00              ??         00h
                    JPEG_001b683f+23300                    XREF[0,2]:   FUN_000291f8:0002
                    JPEG_001b683f+23861                                 FUN_0002a248:0002
001b683f ff d8 ff        JPG
         e0 00 10
         4a 46 49 ...
001bc742 00              ??         00h
                    GIF_001bc743+385                       XREF[0,1]:   FUN_000291f8:0002
001bc743 47 49 46        GIF
         38 39 61
         97 00 28 ...
001bc973 00              ??         00h
001bc974 b7              ??         B7h                                 ? -> 001bc8
001bc975 c8              ??         C8h
001bc976 1b              ??         1Bh
001bc977 00              ??         00h
001bc978 a1              ??         A1h                                 ? -> 001bc8
001bc979 c8              ??         C8h
001bc97a 1b              ??         1Bh
001bc97b 00              ??         00h
001bc97c 8b              ??         8Bh                                 ? -> 001bc8
```

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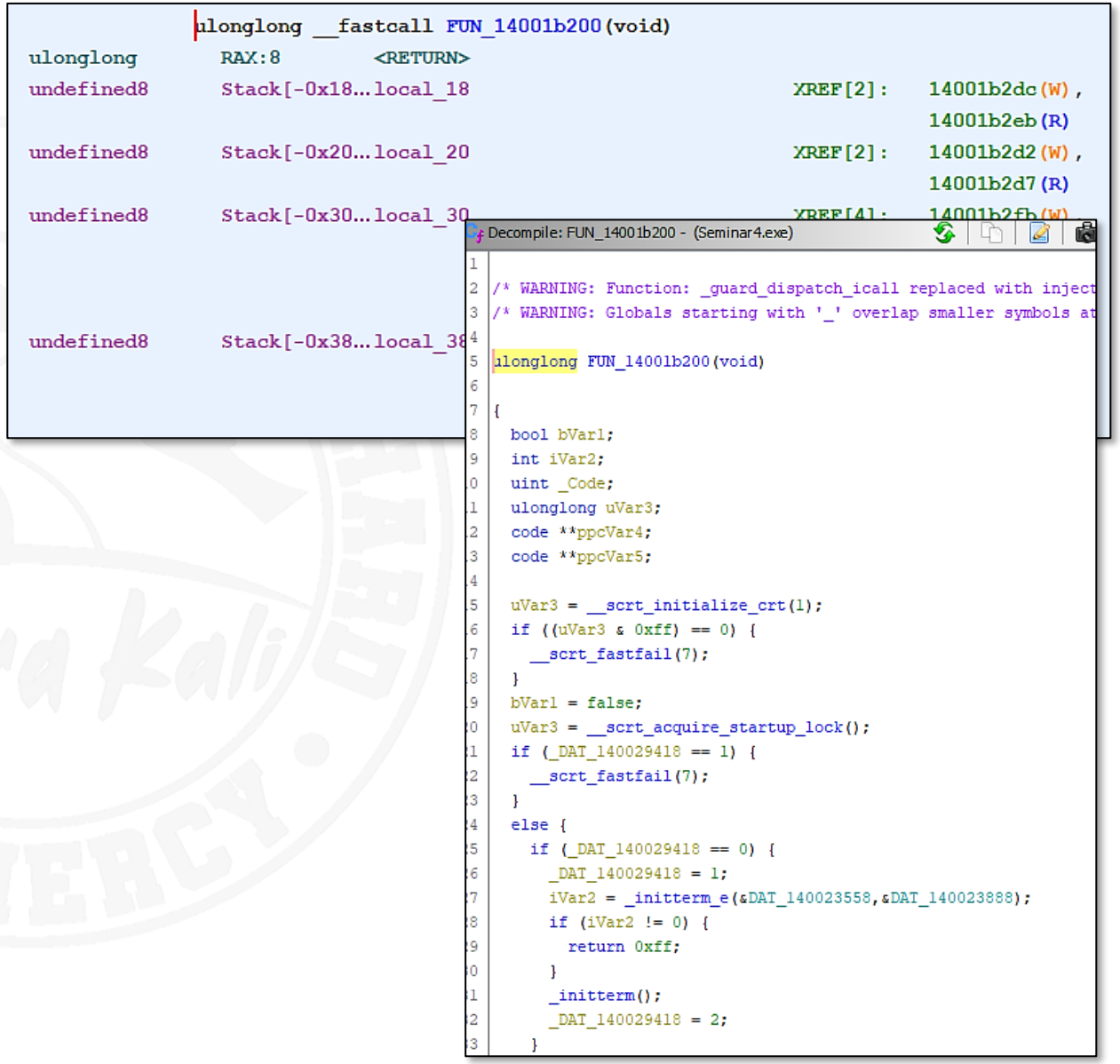
PUBLIC KEY CRYPTOSYSTEM

Decompiling

Obtaining readable source code

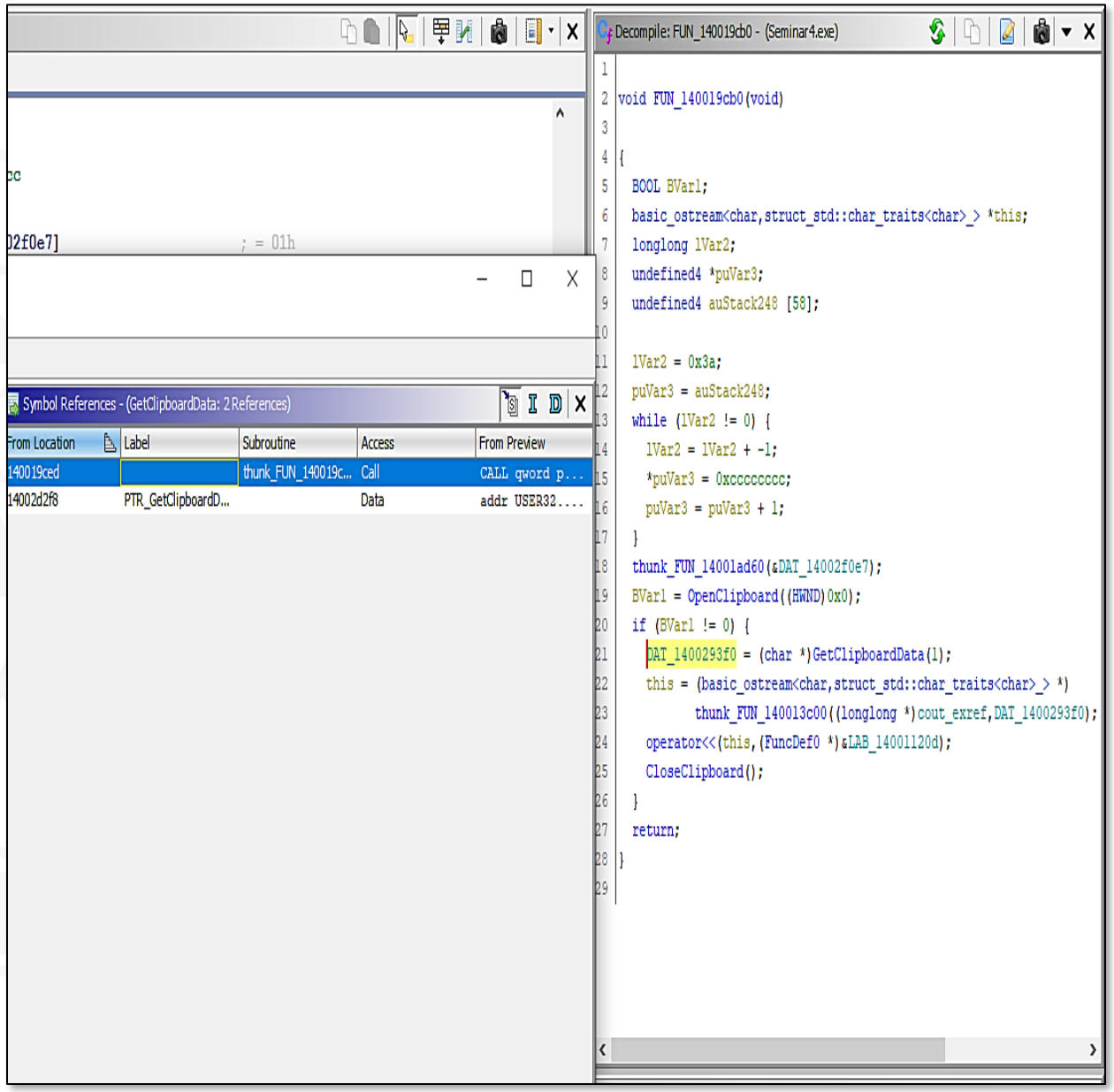
"Following" a program: Decompiling

- Following the call sequence, we will arrive to functions with the actual program code
- We can see the layout of the assembly code and the output of a **decompiler**
- This decompiler will try to express the ASM code **in equivalent C code**
  - This code is more readable, but unfortunately **it is also difficult to follow**
  - Compiling to x86 assembly loses information
    - About variable and function names, among other things
    - Also, some different code constructs can output the same assembly source



VIEW DECOMPILER OUTPUT

- **This means that, while helpful, we cannot obtain the original source code**
  - Even worse if we cannot use debugger (.pdb) files
- **Decompiler output syncs with changes made within the Listing view**
  - Yes, Ghidra allows us **to perform changes in the program executable code**
  - Why don't we do that? because is way beyond the objectives of this course ☺
  - Any changes made to the function, variable, or argument names in either the Listing or Decompile view will update the other window



Investigating an API reference

- It is a common practice to identify interesting code based on **OS API references**
- To do that go to **Window - Symbol References**
- Select an API call you want to investigate and identify where that function is called (**Symbol References** window)
  - For example, the `GetClipboardData` API is worth investigating to understand what this program do
  - To locate a reference to this API simply click on the reference on the right-hand side
  - This populates the **Listing view** with the appropriate disassembly (ASM + C code)

INVESTIGATING AN API REFERENCE

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```
140019cda 33 c9          XOR       ECX, ECX
140019cdc ff 15 1e...    CALL      qword ptr [->USER32.DLL::OpenClipboard]
140019ce2 85 c0          TEST      EAX, EAX
140019ce4 75 02          JNZ       LAB_140019ce8
140019ce6 eb 3b          JMP       LAB_140019d23

                     LAB_140019ce8                          XREF[1]:   140019ce4(j)
140019ce8 b9 01 00...    MOV       ECX, 0x1
140019ced ff 15 05...    CALL      qword ptr [->USER32.DLL::GetClipboardData]
```

```
9   undefined4 auStack248 [58];
10
11  lVar2 = 0x3a;
12  puVar3 = auStack248;
13  while (lVar2 != 0) {
14    lVar2 = lVar2 + -1;
15    *puVar3 = 0xcccccccc;
16    puVar3 = puVar3 + 1;
17  }
18  thunk_FUN_1400lad60(&DAT_14002f0e7);
19  BVar1 = OpenClipboard((HWND)0x0);
```

Symbol References, Symbol Table [CodeBrowser: Seminar4:/Seminar4.exe]

File Edit Tools Help

Symbol Table - (Filter settings matched 780 Symbols)

Name	Location	Symbol T...	Data Type	Namespace	Source	Referenc...	Offcut Re...
FUN_140020600	140020600	Function	undefined	Global	Default	0	0
FUN_140020630	140020630	Function	undefined	Global	Default	0	0
FUN_140020660	140020660	Function	undefined	Global	Default	0	0
FUN_140020690	140020690	Function	undefined	Global	Default	0	0
FUN_1400206c0	1400206c0	Function	undefined	Global	Default	0	0
FUN_1400206f0	1400206f0	Function	undefined	Global	Default	0	0
FUN_140020720	140020720	Function	undefined	Global	Default	0	0
FUN_140020750	140020750	Function	undefined	Global	Default	0	0
FUN_140020780	140020780	Function	undefined	Global	Default	0	0
FUN_1400207b0	1400207b0	Function	undefined	Global	Default	0	0
FUN_1400207e0	1400207e0	Function	undefined	Global	Default	0	0
FUN_140020880	140020880	Function	undefined	Global	Default	0	0
FUN_1400208c0	1400208c0	Function	ulonglong	Global	Default	0	0
FUN_1400219a0	1400219a0	Function	undefined	Global	Default	1	0
GetClipboardData	External[0002ddfe]	External ...	HANDLE	USER32....	Imported	2	0
GetCurrentProcess	External[0002eab4]	External ...	HANDLE	KERNEL3...	Imported	2	0

Symbol References - (GetClipboardData: 2 References)

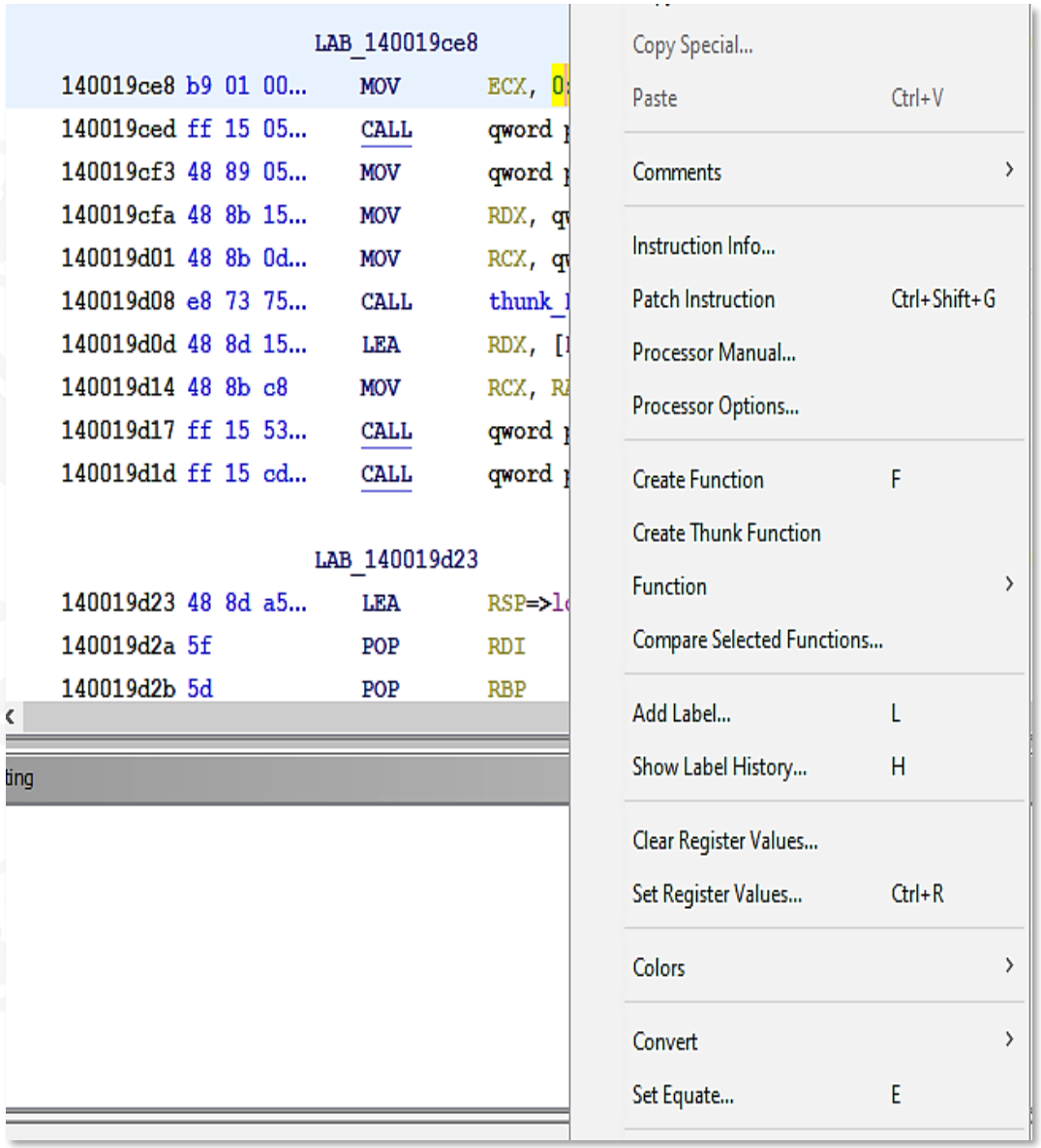
From Location	Label	Subroutine	Access	From Preview
140019ced		thunk_FUN_140019c...	Call	CALL qword p...
14002d2f8	PTR_GetClipboardD...		Data	addr USER32....

Data annotation and location

Giving meaning to data contained inside source code

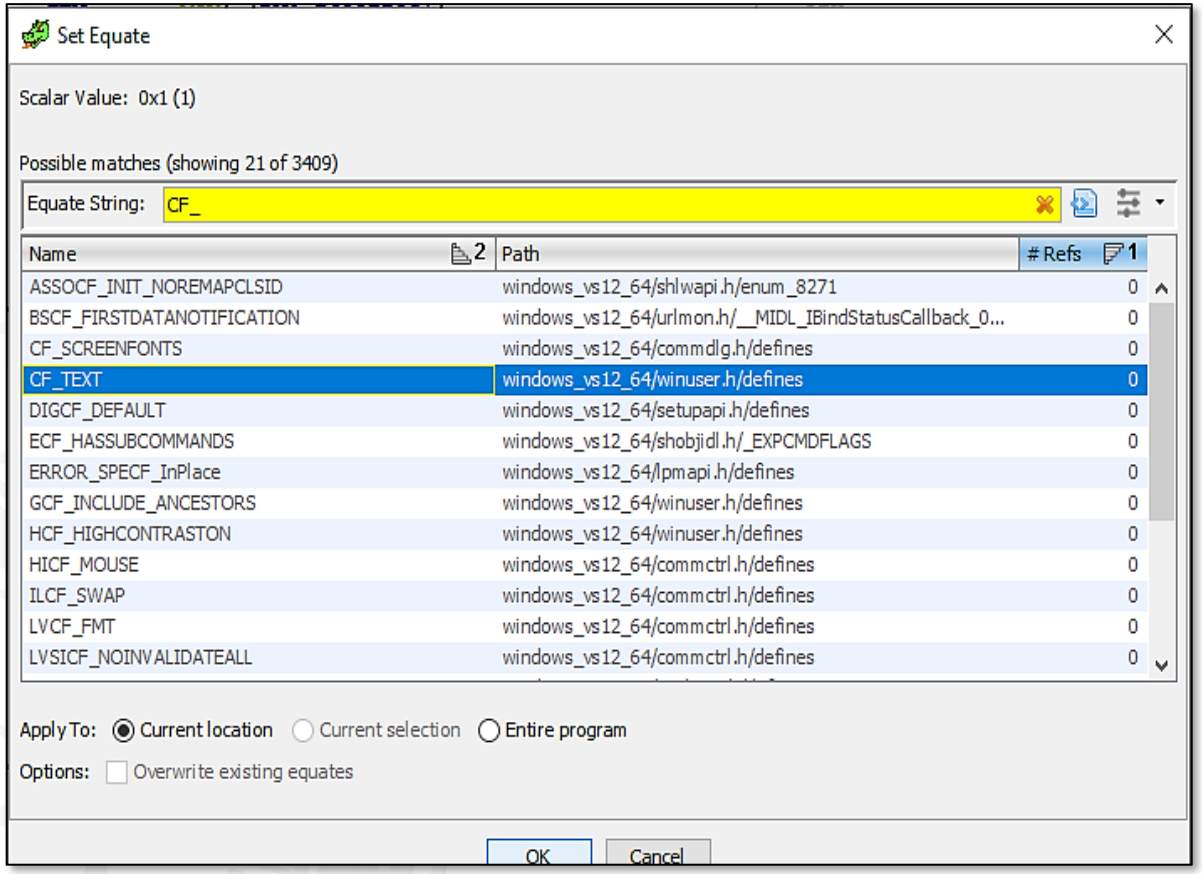
Data annotation

- **In the listing view we see**
  - The initial `CALL` to the API function
  - Potential `PUSH` instructions above the `CALL` refer to the function arguments (if any)
  - On the right, autogenerated comments that identify the function parameters
    - As described on Microsoft's website
- **The only parameter of `GetClipboardData` is the expected clipboard data format**
  - https://docs.microsoft.com/en-us/windows/win32/api/winuser/nf-winuser-getclipboarddata
  - The value `0x1` represents a symbolic constant
  - We can convert this to a **more human-readable representation**
    - By right-clicking the value and selecting "**Set Equate…**"



DATA ANNOTATION

- The resulting window offers options for the chosen hexadecimal value
- To know the correct one, we check the API call documentation
  - https://docs.microsoft.com/es-es/windows/win32/dataxchg/clipboard-formats
  - Most of the clipboard formats begin with CF_
  - Typing this into the "Equate String" field yields only one compatible option: CF_TEXT
    - Means that the clipboard is expected to contain text
    - https://docs.microsoft.com/es-es/windows/win32/dataxchg/clipboard-formats
  - Select this value and press OK
- The assembly now displays the text, not the hexadecimal value
- We know how to annotate flags and values and make it persist!

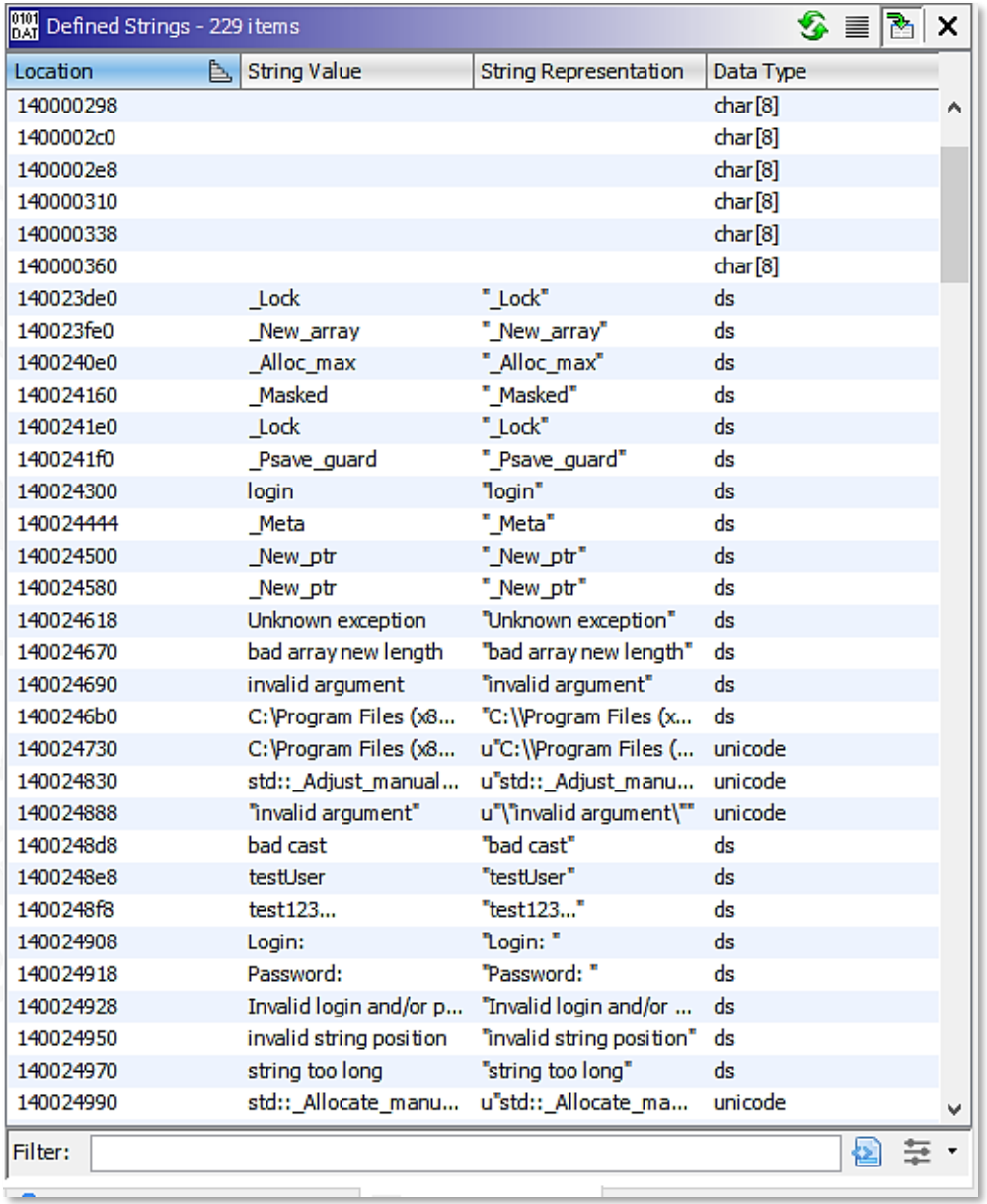



```
B_140019ce8                                    XREF[1]:   140019ce4(j)
  MOV       ECX, CF_TEXT
  CALL      qword ptr [->USER32.DLL::GetClipboardData]
  MOV       qword ptr [DAT_1400293f0], RAX
  MOV       RDX, qword ptr [DAT_1400293f0]
  MOV       RCX, qword ptr [->MSVCP140D.DLL::std::cou...; = 0002e464
  CALL      thunk_FUN_140013c00                        ; undefined thunk_FUN_140
  LEA       RDX, [LAB_14001120d]
  MOV       RCX, RAX
  CALL      qword ptr [->MSVCP140D.DLL::std::basic_os...
  CALL      qword ptr [->USER32.DLL::CloseClipboard]

B_140019d23                                    XREF[1]:   140019ce6(j)
```

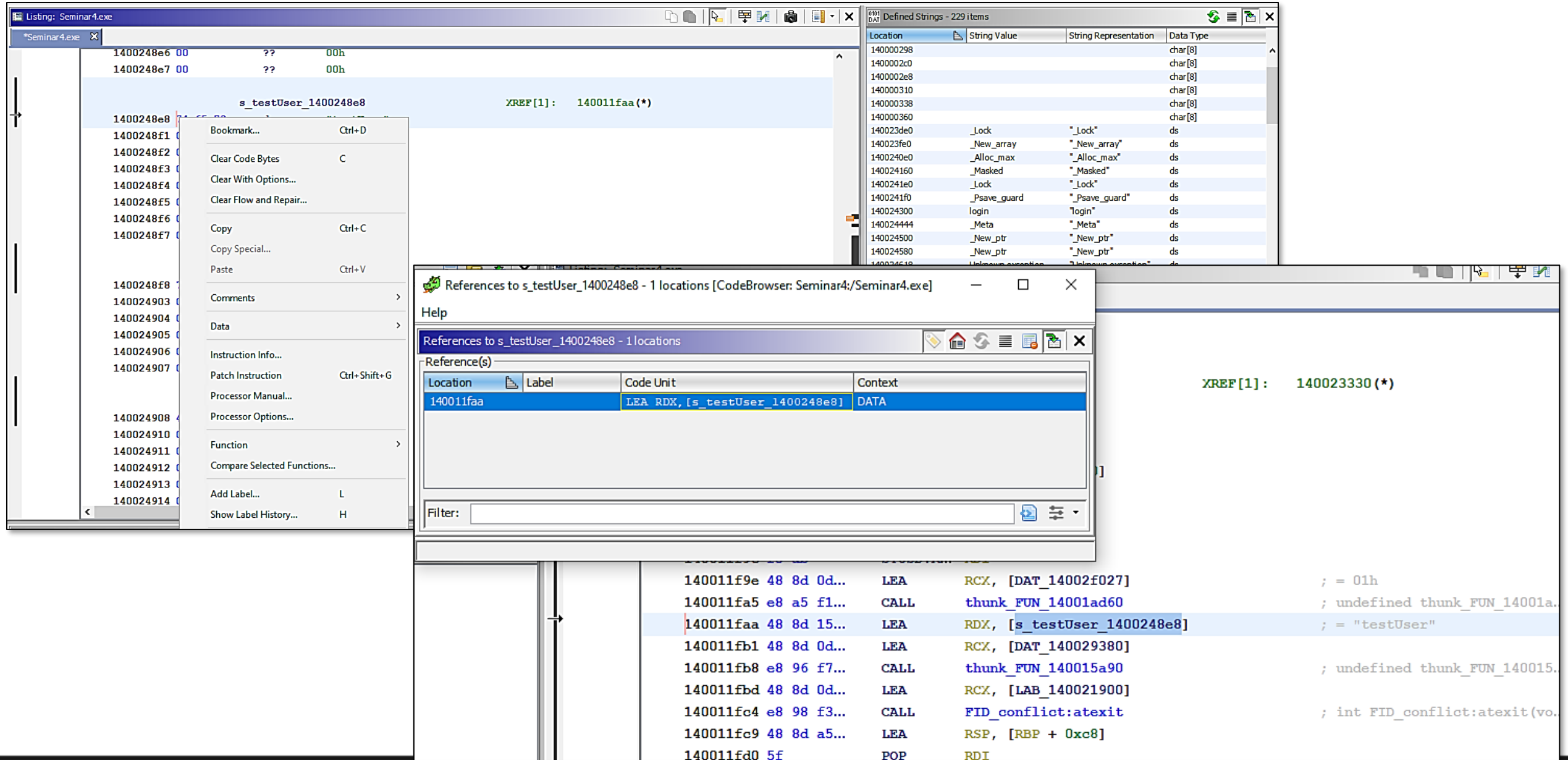
LOCATING CODE FROM STRING REFERENCES

- String analysis not only allows to guess hidden information within the executable
  - But also, **to trace where these strings are used in the source code**
- Clicking on the row associated with a string populates the **Listing** window with the data at its address
- To identify references to this string we can right-click in the **blue area - References - Show References to Address**
- Let's see what happens with the "**testUser**" string we located



LOCATING CODE FROM STRING REFERENCES

Computer Security

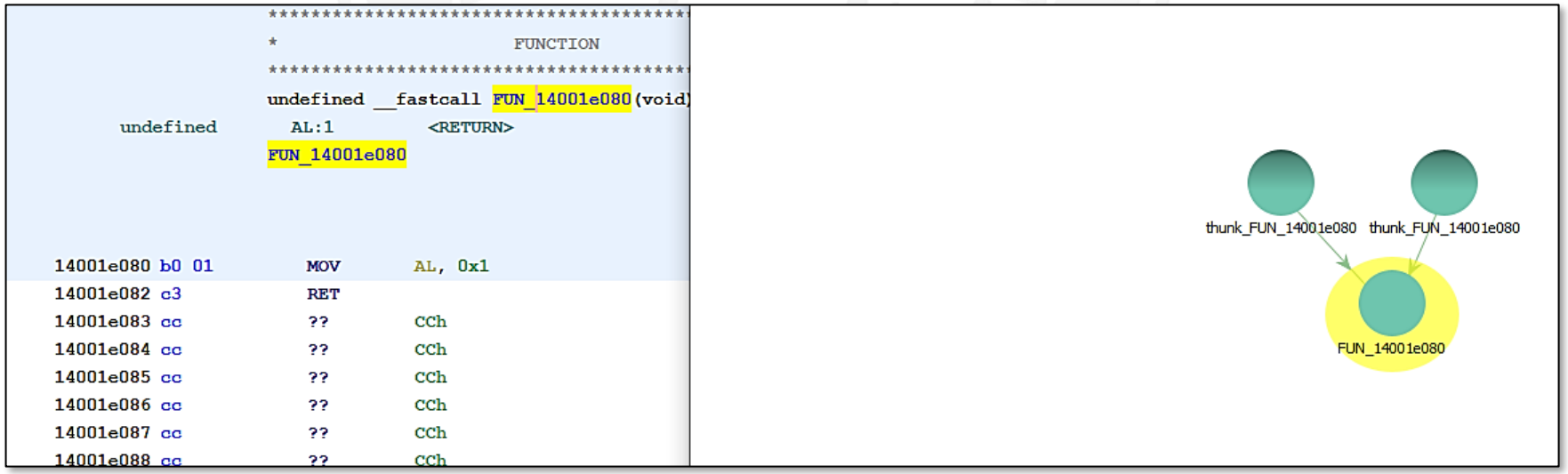


Call graphs

Tools to help us understanding the source code

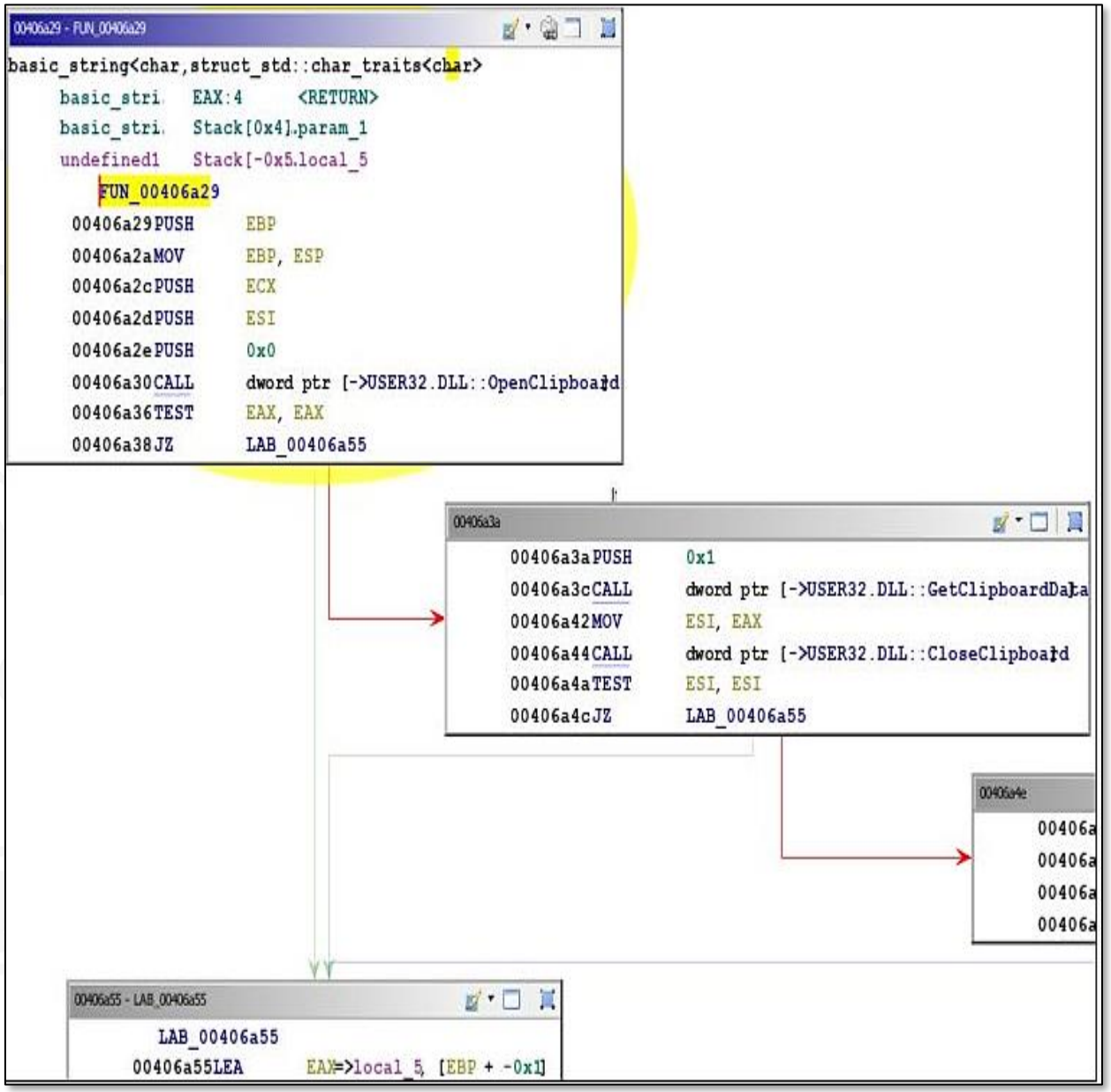
FUNCTION CALL GRAPHS

- Once a reference is identified, we can also analyze the call sequence that ends in the code that uses it
- To do this, we can go to the beginning of the function that uses the string and click on **Window- Function call graph**
  - This displays the relationships between functions and provides **a high-level overview of function calls**
    - Much faster than doing it manually!
  - This may allow us to discover **undocumented or unexpected calls to Windows APIs**
    - Potential malicious activity…
  - Or just to better understand the analyzed program behavior



FUNCTION GRAPHS

- Checking function behavior may be done reviewing the disassembly text in the decompile window
- However, it is often beneficial to **see a visual representation** of decision points within a function
- You can obtain it with the **Window - Function Graph**
- It displays the function's **individual code blocks**
  - The arrows represent **conditional and unconditional jumps**

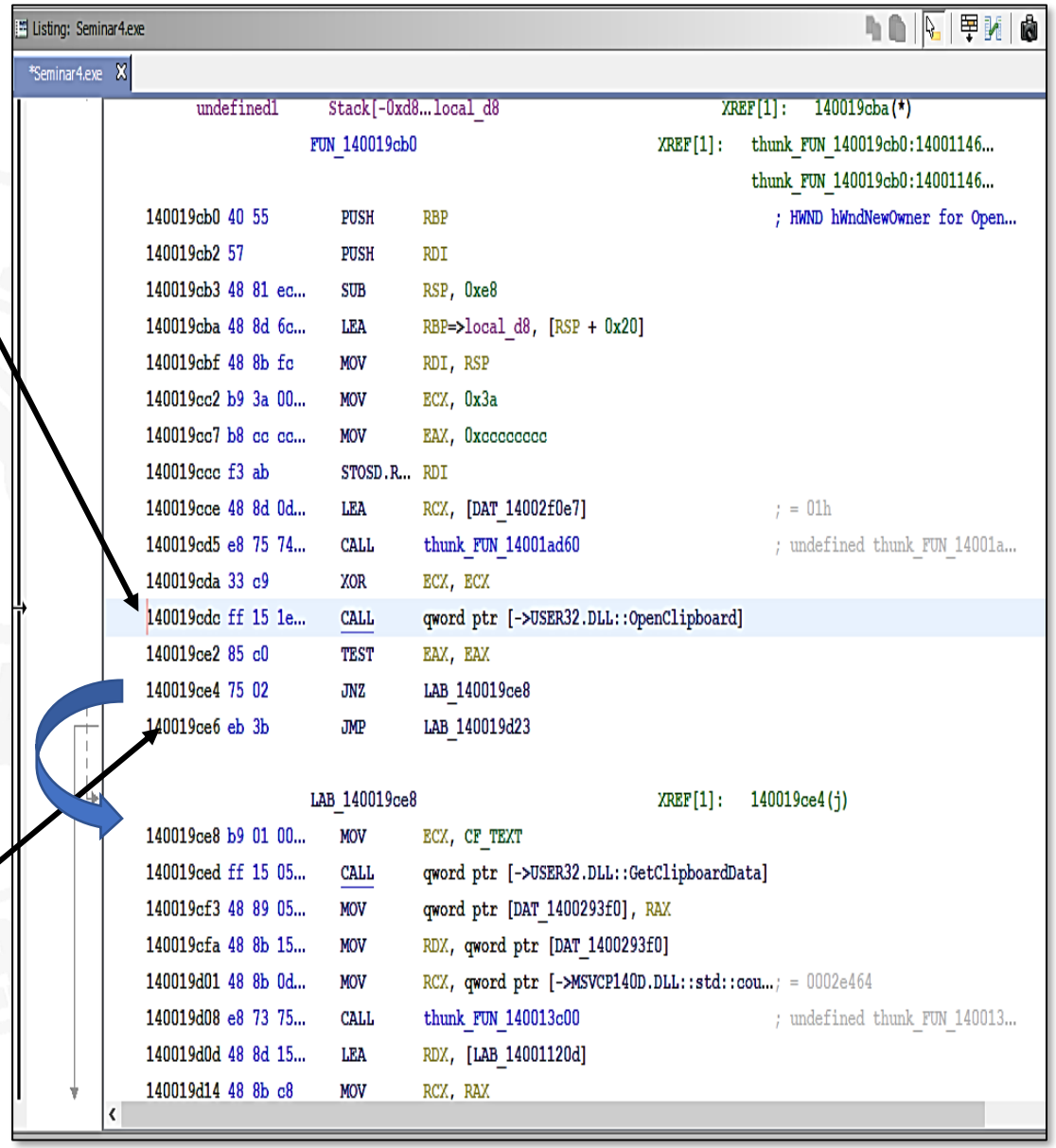


UNDERSTANDING ASSEMBLY

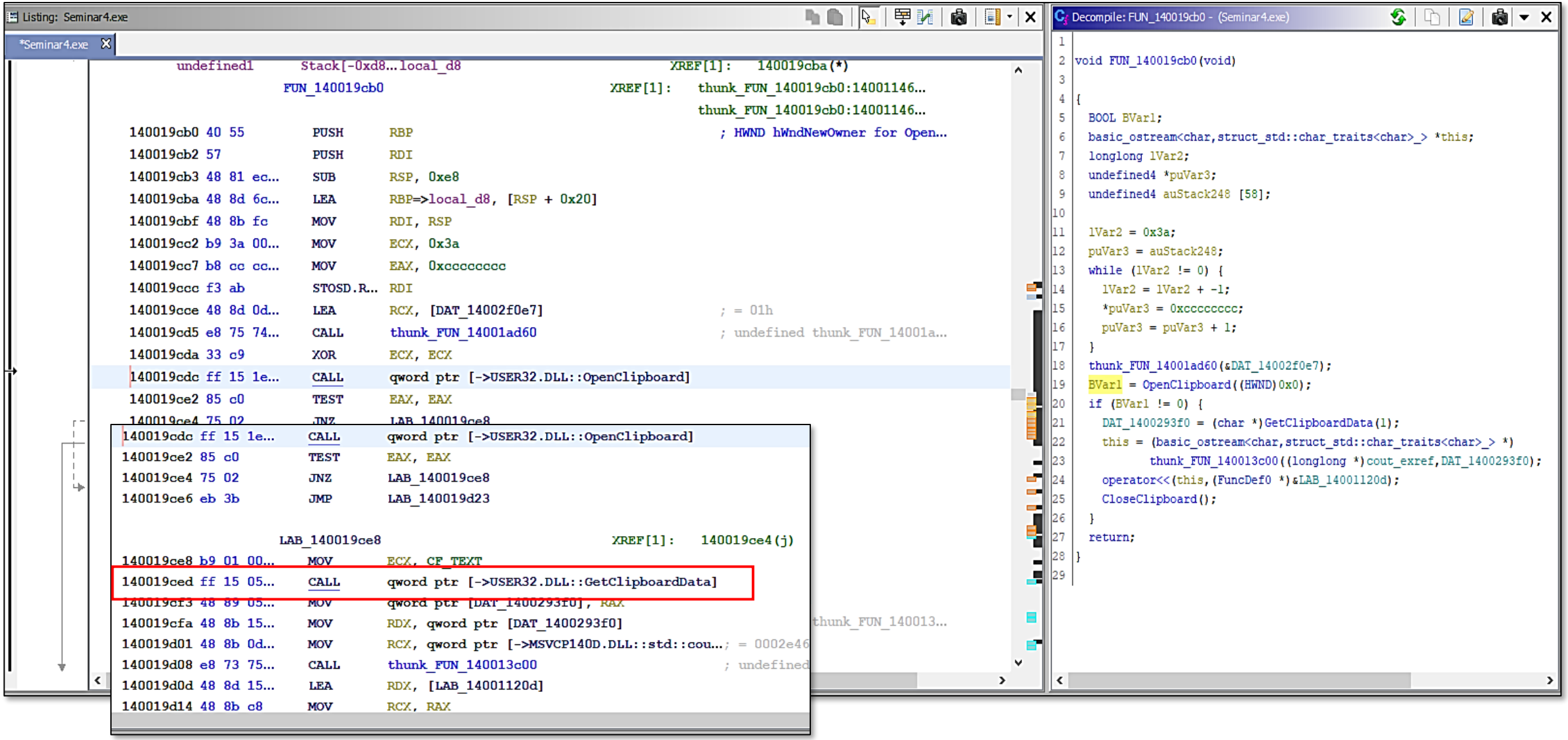
- Finally, once we can view data, functions and call sequences, we need to **understand the program code**
- This requires **a high level of assembly interpretation skills, experience and patience** (you saw some in **FCR**)
  - That is way beyond the objectives of this course
- However, with practice is possible to understand most of the possible instruction patterns we may find
  - Code translators typically use coherent code structures that we may be able to recognize
  - And don't forget that we have the valuable help of the decompiler and the function graph to better understand what the code does
- A good starting reference is: https://www.cs.virginia.edu/~evans/cs216/guides/x86.html
- Let's see an example

UNDERSTANDING ASSEMBLY

- In this code block we call to `OpenClipboard`
  - Followed by `TEST` and `JNZ` (jump if not zero) instructions
  - These evaluate the return value stored in `EAX`
- `JNZ` indicates that execution should jump to `LAB_140019ce8` if `EAX` is not `0`
  - A return value of zero means a failed call to `OpenClipboard`
- If this jump is performed, the code block where other API calls obtain clipboard data will be run
- If not, the execution will `JMP` (unconditional jump) to another address
  - If the clipboard opens, obtain its data
  - Otherwise, do not execute code to gather clipboard information



UNDERSTANDING ASSEMBLY



More information

- **Ghidra** has become one of the most popular reversing tools
- **There are many tutorials** teaching how to use Ghidra and introducing you into the reversing world
  - **(YouTube tutorial channel)** https://www.youtube.com/playlist? list=PLRAe18TJ_NTE9cr18OPphn82WS8gVv-te
  - **An Introduction To Code Analysis with Ghidra**: https://threatvector.cylance.com/en_us/home/an-introduction-to-code-analysis-with-ghidra.html
  - **Using OOAnalyzer to reverse engineering object-oriented code with Ghidra**: https://insights.sei.cmu.edu/sei_blog/2019/07/using-ooanalyzer-to-reverse-engineer-object-oriented-code-with-ghidra.html
  - **Practical case: Crack Me 0x01**: https://maxkersten.nl/binary-analysis-course/assembly-basics/practical-case-crack-me-0x01/
- Outside **Ghidra**, you can also use this resources
  - **Analyzing Modern Malware Techniques**
    - Part 1: https://0x00sec.org/t/analyzing-modern-malware-techniques-part-1/18663
    - Part 2: https://0x00sec.org/t/analyzing-modern-malware-techniques-part-2/18765
  - **University of Cincinnati course CS6038/CS5138: Malware Analysis**: https://class.malware.re/
  - Repository with lot of reversing resources: https://github.com/xiosec/Reverse-engineering

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Source: Bing Chat AI

Reversing programs created in high-level languages

Inspecting .Net or Java programs

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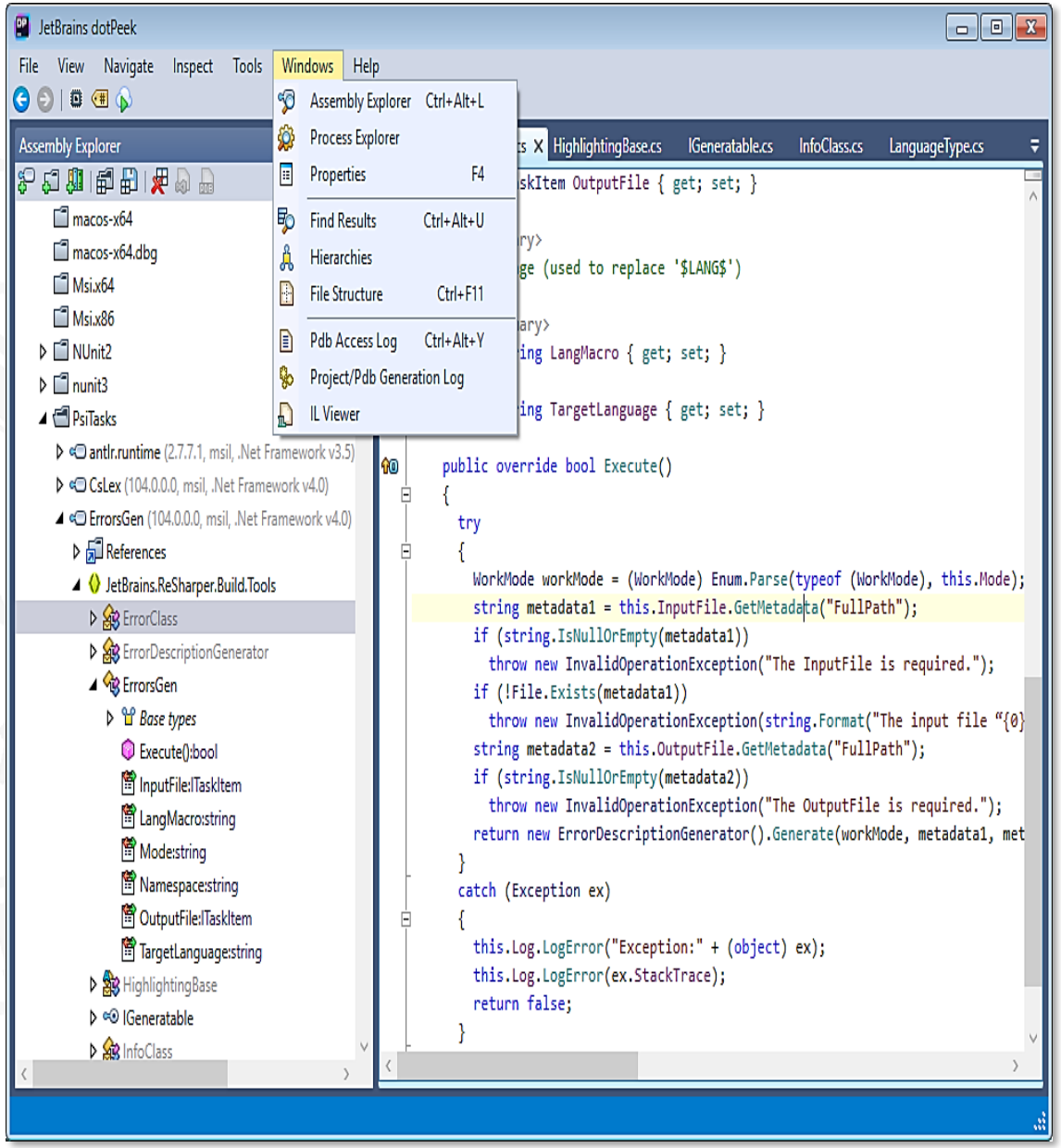
Reversing programs created in high-level languages

- We have seen a tool for decompiling and analyzing programs made in low/medium level languages (C/C++)
- The same is possible with those coded in C#, Java, or other high-level languages
  - So, you can analyze programs created in courses like TPP, EDI, MP, etc. even if you don't have the source code
- In fact, these programs are usually much easier to reverse and analyze
- We just must look for a suitable tool for the language in which the program (or the part we want to study) is created

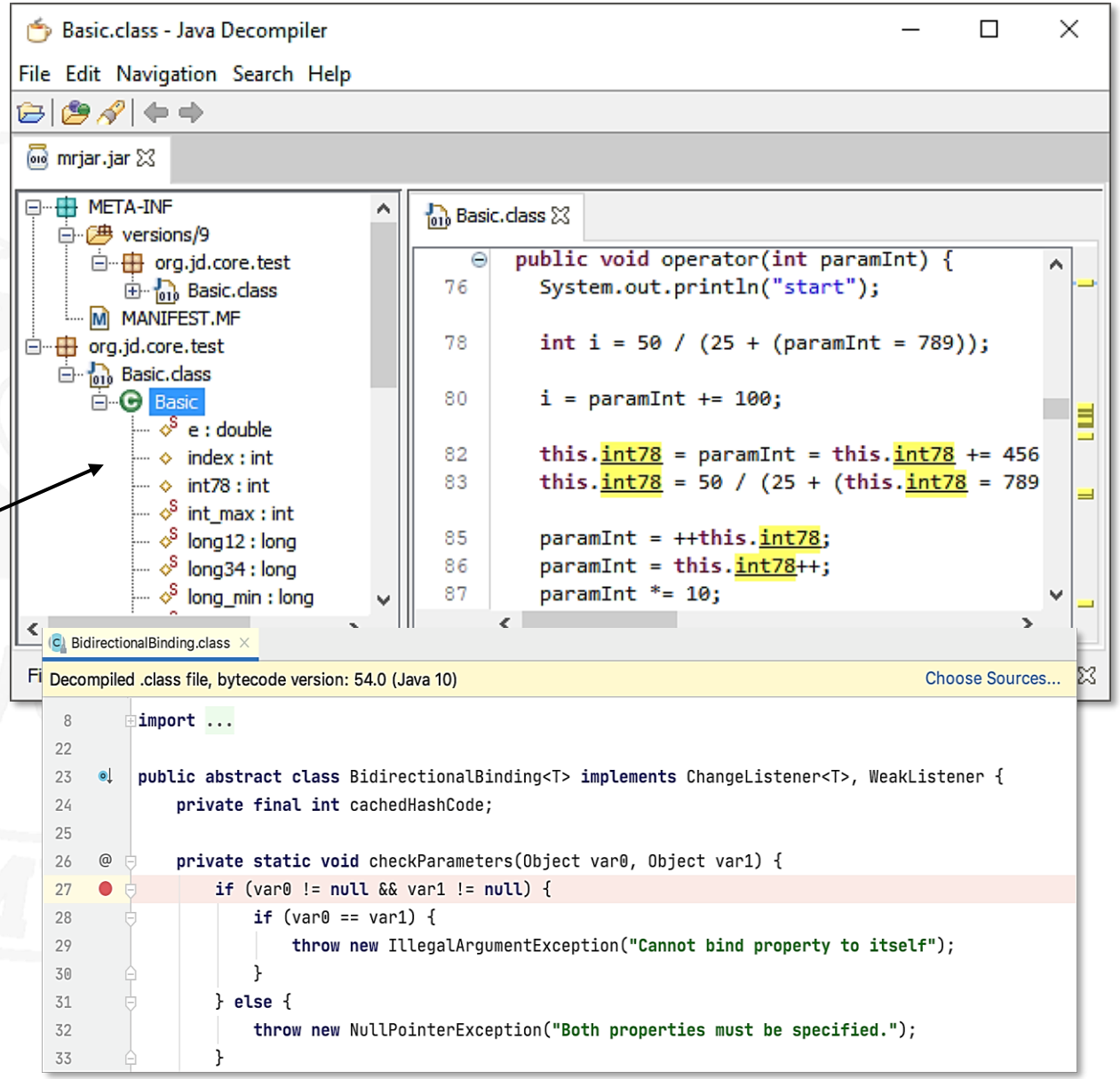
Analyzing .Net programs

- There are several decompilers on the market that can do this
- A very powerful one is **DotPeek**
  - https://www.jetbrains.com/es-es/decompiler/
  - Creating a JetBrains account with a university email account normally gives you free access to all its tools for one year (renewable)
- Loads `.exe` or `.dll` assemblies and displays the code of their classes
  - In an understandable and easily analyzable way
- Therefore, knowing what a program whose sources are not available does gets simpler



Analyzing Java programs

- Java programs can be decompiled with very good results too
- There are several tools for this, but one of the most popular open-source ones is **JD-GUI**
  - https://github.com/java-decompiler/jd-gui
- The **JetBrains** IDE for Java, **IntelliJ**, also has that feature built in if you open a `.class`
  - https://blog.jetbrains.com/idea/2020/03/java-bytecode-decompiler/



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Source: Bing Chat AI

AUTOMATED EXECUTABLE INSPECTION TOOLS

Automated reversing

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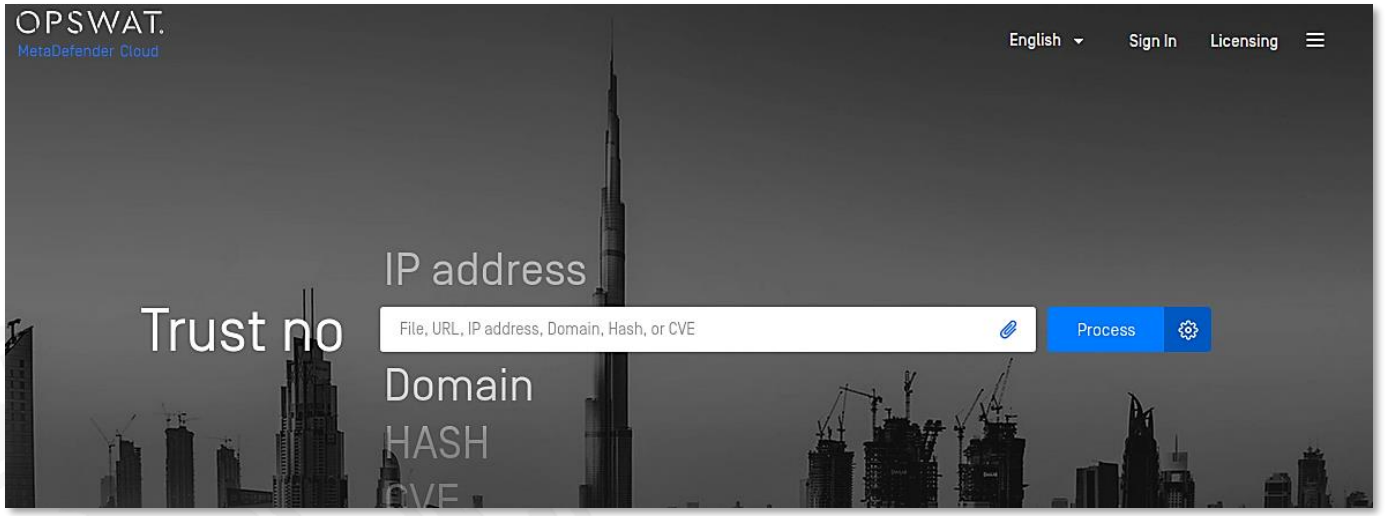
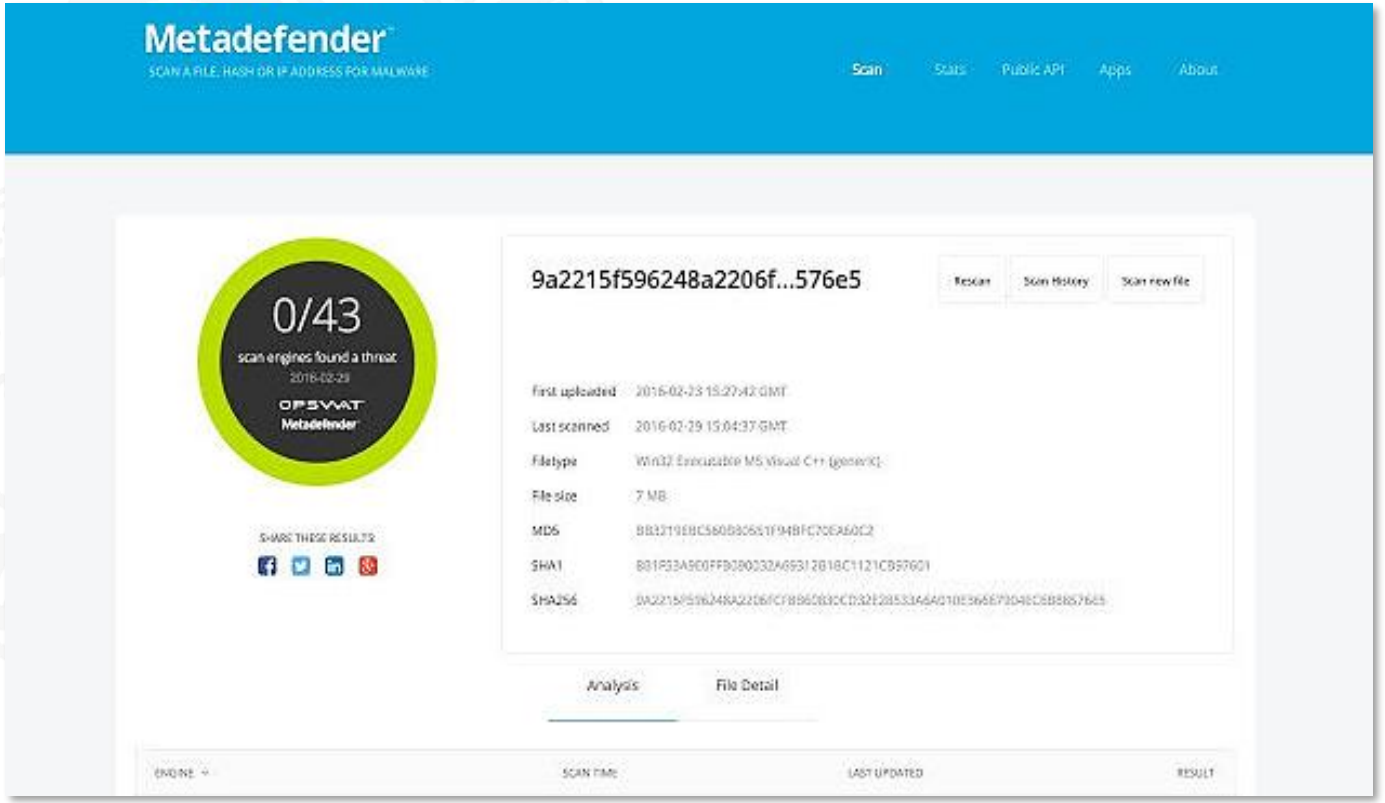
METADEFENDER CLOUD

https://metadefender.opswat.com/

Computer Security

- **Many times, we will only want to know if an executable behaves strangely to avoid malware**
  - In that case, doing a manual analysis may be too much
- **There are tools that allow us to automate this process**
  - We can use one that checks if an executable is detected as malware
- **Metadefender is a tool that analyzes executables to find out precisely that**
  - Another option is Virustotal, seen at the beginning of the course



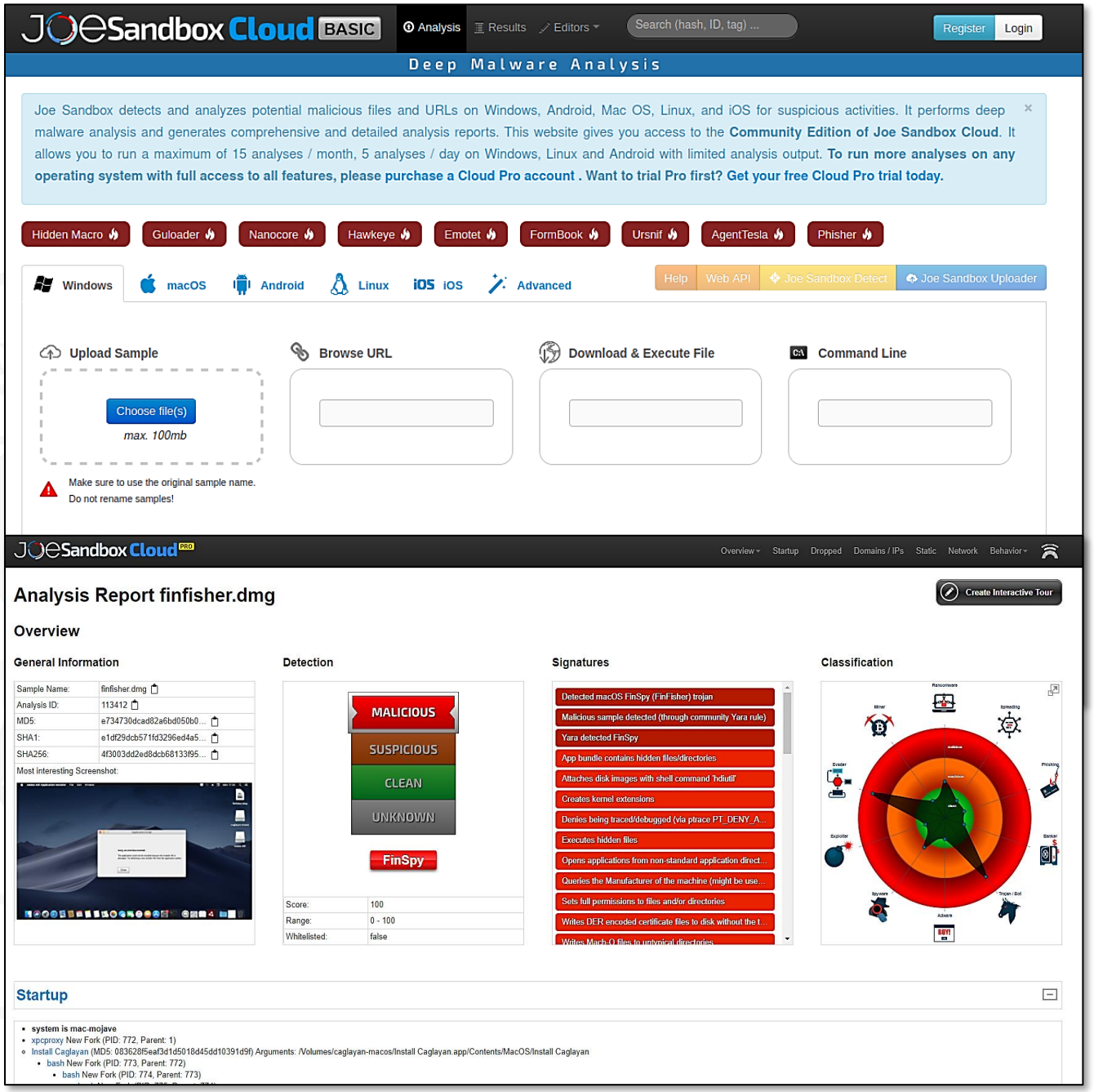


Joe SandBox Cloud

https://www.joesecurity.org/#

Computer Security

- If we want a 2nd opinion, we can use a **sandbox**
- Run a program and analyze its runtime behavior
  - Looking for "suspicious" behavior
    - System calls known as problematic, attempts to access restricted parts, etc.
  - So, we can extract conclusions about whether the program is trusted
  - Returns us a report of its actions and the "dangerousness" they have
- Although it is not free, there is a limited "Community" version
  - https://www.joesandbox.com/#windows

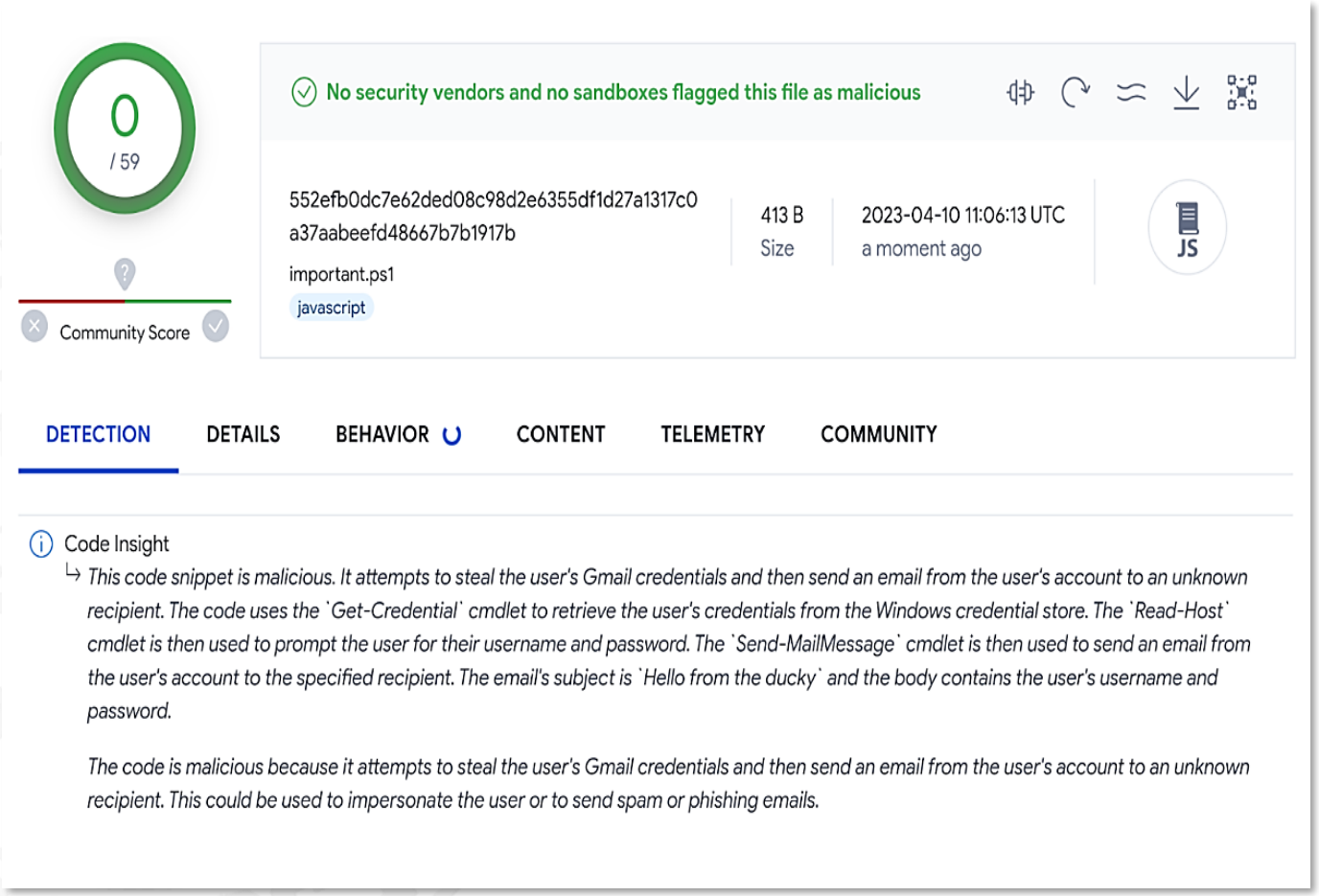


Source: https://www.joesecurity.org/blog/1896065926254527264

Will AI replace reversing?

Computer Security

- **Today, generative AI is being successfully experimented with to analyze executables**
  - They allow us to know what an executable does in "human" language
- **It will not replace 100% reversing**
  - But it will make it **much more accessible** to a lot of people!
- **An example is Code Insight by Virustotal**
  - https://blog.virustotal.com/2023/04/introducing-virustotal-code-insight.html
  - https://assets.virustotal.com/reports/2023-ai



Antivirus products do not detect anything in the executable, but the AI that analyzes it determines that it's a malicious executable by understanding its behavior. Awesome, right? It also explains it in plain words, so that anyone who has no experience in reversing can understand it

Self-evaluation achievement list: Seminar 4

?

- Understand de purpose and utility of the Ghidra decompiler
- Know how to load an executable and analyze its contents
- Locate source code that uses certain string references
- Know how to display function and call graphs
- Know automated program analysis platforms and its usage
- Know how to locate and investigate string references within an executable
- Know how to follow code execution of a program
- Know how to perform decompilation of code and its limitations
- Know how to annotate data
- Apply your ASM knowledge to the output of Ghidra
- Locate and investigate an API call within an executable
- Choose the appropriate tool to decompile programs created with C# or Java

SEMINAR 4
INTRODUCTION TO REVERSING

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