



Penetration Testing Professional

ASSEMBLERS, DEBUGGERS AND TOOLS ARSENAL

Section 1: System Security - Module 2

v5.0

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2.0 Assemblers, Debuggers and Tools Arsenal



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2.1. Introduction

2.2. Assembler

2.3. Compiler

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2.1 Introduction



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MAP

INTRODUCTION



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2.1 Introduction



The previous module showed you that Assembly is a very low-level programming language consisting of a mnemonic code, also known as an **opcode** (operation code).

Although it is a low-level language, it still needs to be converted into machine code in order for the machine to execute.

2.2 Assembler



ASSEMBLER



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2.2 Assembler



An assembler is a program that translates the Assembly language to the machine code. There are several different assemblers that depend on the target system's **ISA**:

- Microsoft Macro Assembler (**MASM**), x86 assembler that uses the Intel syntax for MS-DOS and Microsoft Windows
- GNU Assembler (**GAS**), used by the GNU Project, default back-end of GCC.
- Netwide Assembler (**NASM**), x86 architecture used to write 16-bit, 32-bit (IA-32) and 64-bit (x86-64) programs, one of the most popular assemblers for Linux
- Flat Assembler (**FASM**), x86, supports Intel-style assembly on the IA-32 and x86-64

<https://msdn.microsoft.com/en-us/library/afzk3475.aspx>
<https://www.gnu.org/software/binutils/>

<https://www.nasm.us/>
<http://flat assembler.net/>

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2.2 Assembler



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Those are only a few, and in this course, we will use **NASM**.

When a source code file is assembled, the resulting file is called an **object file**. It is a binary representation of the program.

While the assembly instructions and the machine code have a one-to-one correspondence, and the translation process may be simple, the assembler does some further operations such as assigning memory location to variables and instructions and resolving symbolic names.

2.2 Assembler



Although exploring the details of the assembling process is not our purpose, it is important to know the process.

Once the assembler has created the object file, a **linker** is needed in order to create the actual executable file. What a linker does is take one or more object files and combine them to create the executable file.

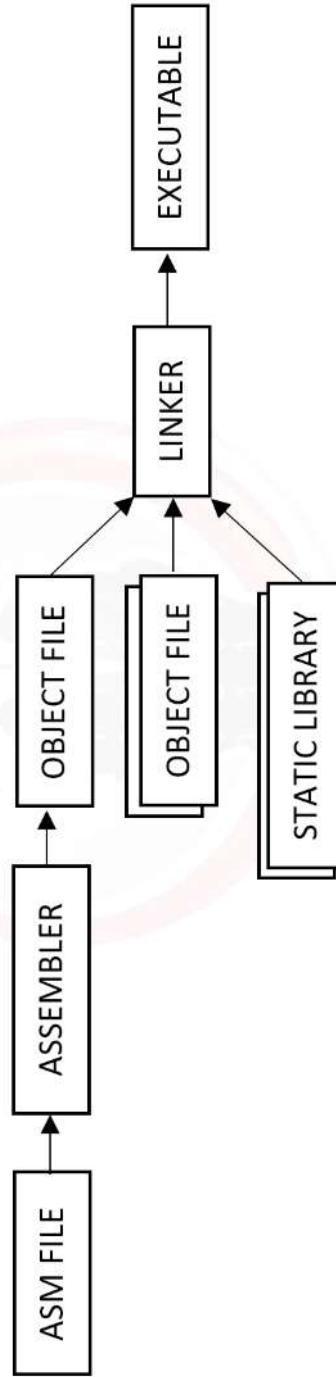
An example of these object files are the *kernel32.dll* and *user32.dll* which are required to create a windows executable that accesses certain libraries.

2.2 Assembler



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The process from the Assembly code to the executable file can be represented here:



In the next few slides, you will learn how to perform this process manually and where to acquire the necessary tools.

2.3 Compiler



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COMPILER



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2.3 Compiler



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The compiler is similar to the assembler. It converts high-level source code (such as C) into low-level code or directly into an object file. Therefore, once the output file is created, the previous process will be executed on the file. The end result is an executable file.

This is important background knowledge, and although we will not cover the entire process it is important to know the differences.

2.4 NASM



REF
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NASM

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2.4 NASM



The assembler we are going to use is **NASM**, and to make things easier, we will use the [NASM-X](#) project. It is a collection of macros, includes, and examples to help **NASM** programmers develop applications.

You are free to configure your machine the way you want, but the Hera Lab configuration will match the following installation instructions.

<https://forum.nasm.us/index.php?topic=1853.0>

2.4.1 Installation Instructions



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Step 1

Download the .zip file from [here](#).

Step 2

Extract the files and save it to a folder on your computer. We will extract it in C :\nasmx. Make sure that your configuration does not have any spaces in the path.

<https://sourceforge.net/projects/nasmx/>

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2.4.1 Installation Instructions



Step 3

Set Windows environment variables. Add in the **Path** variable the path to the **NASM-X** binaries.

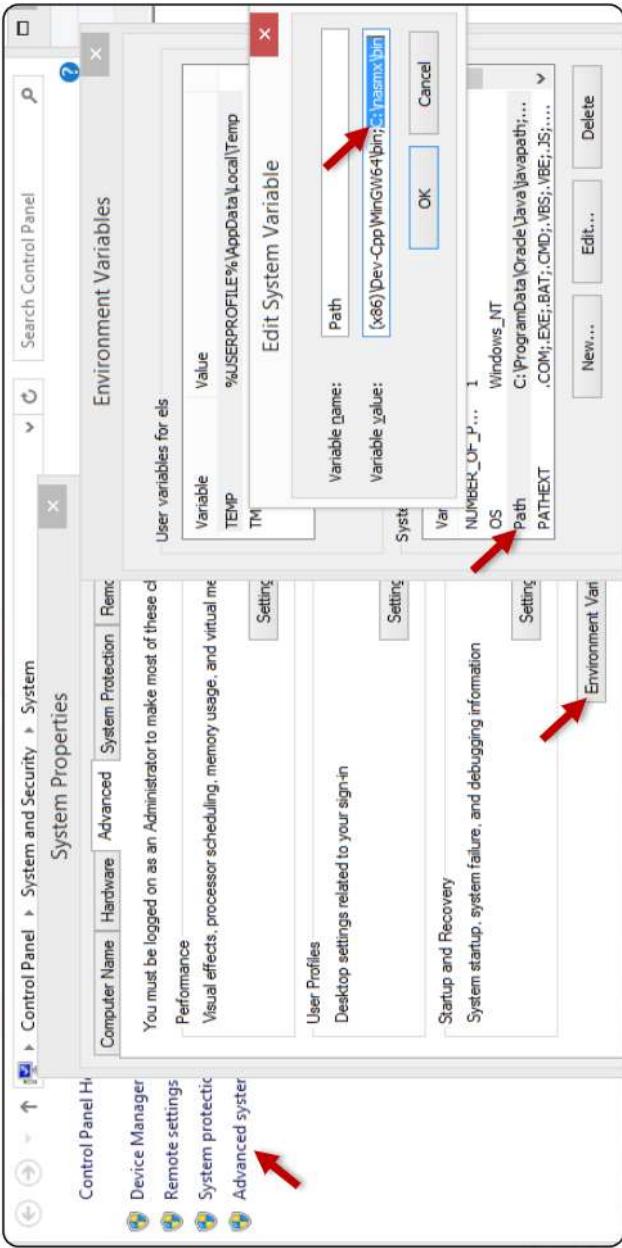
This is done by opening the **Environment Variables** window, selecting the **Path** entry within the **System variable** section, at the bottom of the window, and adding the path C:\nasmx\bin.

2.4.1 Installation Instructions



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This will allow us to use nasm.exe and all the other binaries from any path in our command line prompt.



2.4.1 Installation Instructions



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Next, open the command prompt and navigate the nasmx folder. Once there, let us run setup.bat.

You will see something like this:

```
C:\nasmx>setPaths.bat
"NASMX Development Toolkit"
C:\nasmx>
```

2.4.1 Installation Instructions



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In order to work with the nasmx demos, we need to change one last thing. Navigate to the C:\nasmx\demos folder and edit the file named windemos.inc.

Comment the following line:

```
%include 'nasmx.inc'
```

And add this right after:

```
%include 'C:\nasmx\inc\nasmx.inc'
```

2.4.1 Installation Instructions



Finally, to verify that everything is configured properly, open a new terminal and navigate to the folder C:\nasmx\demos\win32\DEMO1.

Once in the folder, you should see three files:

- demo1.asm is the file containing the assembly code
- demo1.bat is a script that will automatically assemble and link the demo1.asm file to obtain the executable file
- makefile contains all the data and commands needed to transform the source code files to an executable program, but for now, we don't need it

2.4.1 Installation Instructions



To assemble the demo1.asm file we have to run the following command:

```
nasm -f win32 demo1.asm -o demo1.obj
```

With the -f option we are telling **NASM** what the output file format we want is. In this case, it is Microsoft object file format for 32-bit OS. If everything works correctly, it will create a new file in the folder called demo1.obj.

2.4.1 Installation Instructions



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The final step to obtain the executable file is to use the linker, which is stored in the same folder of nasm.exe, and it is called GoLink.exe.

```
GoLink.exe /entry _main demo1.obj kernel32.dll user32.dll
```

With this command, we are instructing the linker to link demo1.obj with the two dll files, kernel32, and user32.

2.4.1 Installation Instructions



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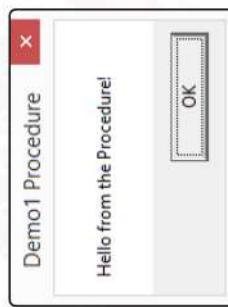
These libraries are required for the program to work correctly because the program calls functions like `MessageBox`, which are defined in these libraries. Moreover, we are telling the linker that the entry point for our program is `_main`.

We will introduce this shortly.

2.4.1 Installation Instructions



If the command succeeds, you should see a new file named `demo1.exe`; this is an executable that we can run. Now we can execute the file and see the program running on our machine. If everything went well, you should see the following window:



If not, don't worry, just go back and verify that the setup configuration matches what is here.

2.4.2 ASM Basics



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Now that we have assembled our first assembly file, let's first introduce **ASM** and x86 basics.

Our purpose is not to teach you how to write assembly programs, but it is essential that we introduce a few instructions and concepts that will help you better understand the few next modules.

2.4.2 ASM Basics



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High-level functions such as `strcpy()` are made of multiple **ASM** instructions put together to perform the given operation (copy two strings).

The simplest assembly instruction is **MOV** that moves data from one location to another in memory.

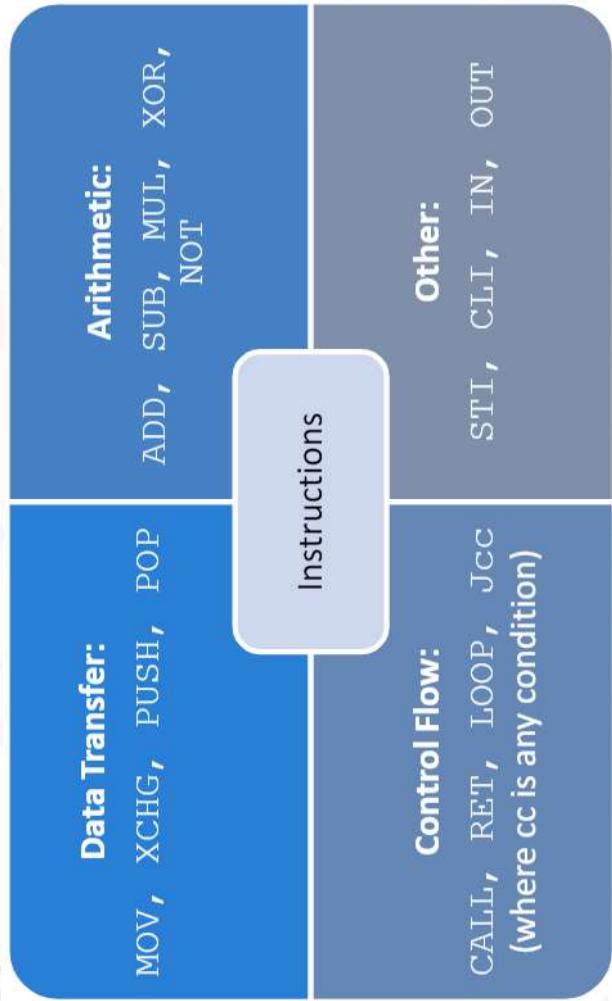
2.4.2 ASM Basics

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Most instructions have two operands and fall into one of the following classes:



2.4.2 ASM Basics

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The following is an example of a simple assembly code that sums two numbers:



```
MOV EAX,2      ; store 2 in EAX
MOV EBX,5      ; store 5 in EBX
ADD EAX,EBX    ; do EAX = EAX + EBX operation
                ; now EAX contains the results
```

2.4.2 ASM Basics



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As you already know, **ASM** deals directly with the registers and memory locations, and there are certain rules for each assembly language.

For example, each opcode is represented in one line and contains the instruction (ex: **MOV**, **ADD**, etc.) and the operands used by the opcode. The number of operands may vary depending on the instruction.

2.4.2.1 Intel vs AT&T



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More importantly, depending on the architectural syntax, instructions and rules may vary. For example, the source and the destination operands may be in different position.

Here's an example:

	Intel (Windows)	AT&T (Linux)
Assembly	MOV EAX, 8	MOVL \$8, %EAX
Syntax	<instruction><destination><source>	<instruction><source><destination>

2.4.2.1 Intel vs AT&T



As you can see, AT&T puts a percent sign (%) before registers names and a dollar sign (\$) before numbers.

Another thing to notice is that AT&T adds a suffix to the instruction, which defines the operand size: Q (quad – 64 bits), L (long – 32 bits), W (word -16 bits), B (byte – 8 bits).

2.4.2.2 PUSH Instruction



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In the previous module, we introduced two very important assembly instructions that allow us to work with the stack: **PUSH** and **POP**.

Since these are very important operations, let us inspect them more in details.

2.4.2.2 PUSH Instruction

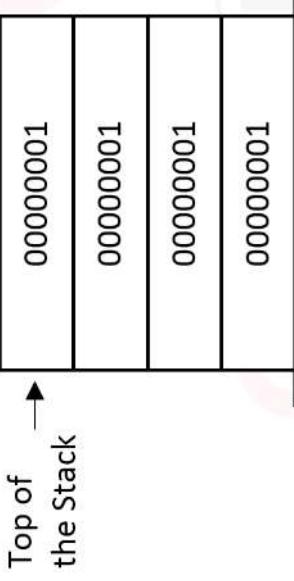
32



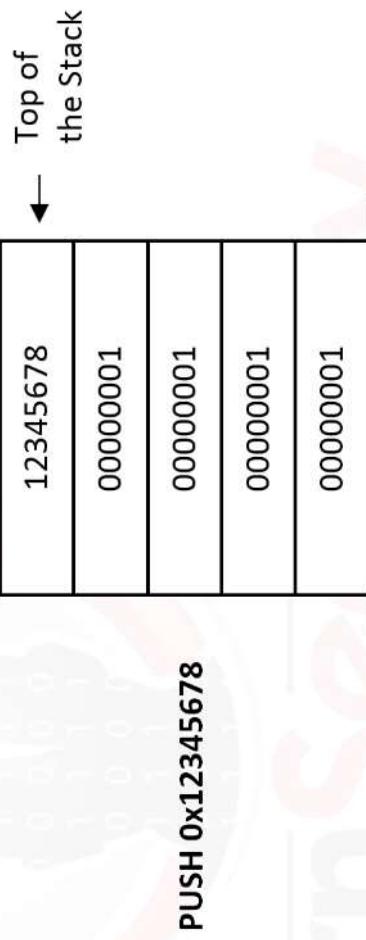
PUSH stores a value to the top of the stack, causing the stack to be adjusted by -4 bytes (on 32 bit systems): -0x04.

Before PUSH

Lower memory addresses



Lower memory addresses



Higher memory addresses

Higher memory addresses

2.4.2.2 PUSH Instruction

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Another interesting fact is that the same operation (PUSH 0x12345678) can be achieved in a different way.

For example, we can use the following two instructions:



```
        SUB ESP, 4           ; subtract 4 to ESP -> ESP=ESP-4  
        MOVE [ESP], 0x12345678 ; store the value 0x12345678 to the location  
                                ; pointed by ESP. Square brackets indicates to  
                                ; address pointed by the register.
```

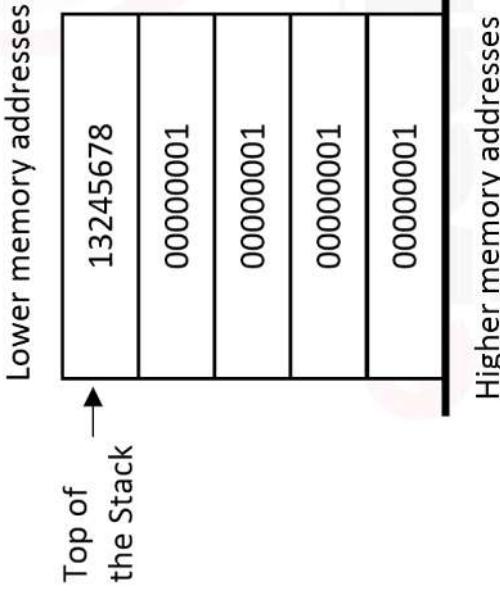
2.4.2.3 POP Instruction

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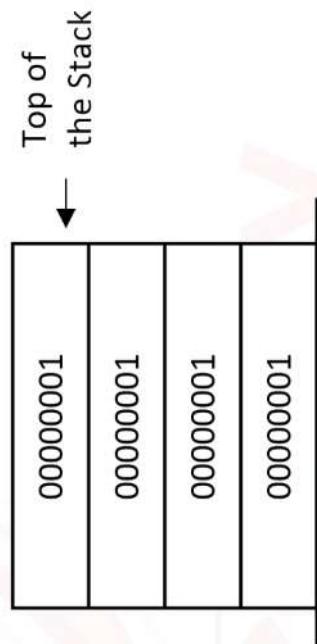


POP reads the value from the top of the stack, causing the stack to be adjusted +0x04.

Before PUSH



POP EAX



After PUSH

2.4.2.3 POP Instruction

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**MAP** **REF**

The POP operation can also be done in several other instructions:



```
MOV EAX, [ESP] ; store the value pointed by ESP into EAX  
; the value at the top of the stack  
ADD ESP, 4      ; Add 4 to ESP - adjust the top of the stack
```

2.4.2.4 CALL instruction



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Subroutines are implemented by using the **CALL** and **RET** instruction pair.

The **CALL** instruction pushes the current instruction pointer (**EIP**) to the stack and jumps to the function address specified. Whenever the function executes the **RET** instruction, the last element is popped from the stack, and the CPU jumps to the address.

2.4.2.4 CALL instruction

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Here is an example of a CALL in assembly:

```
MOV EAX, 1          ; store 1 in EAX
MOV EBX, 2          ; store 2 in EBX
CALL ADD_sub        ; call the subroutine named ADD_sub
INC EAX            ; Increment EAX: now EAX holds "4"
                    ; 2 (EBX) +1 (EAX) +1 (INC)

JMP end_sample

ADD_sub:
ADD EAX, EBX
RETN               ; Function completed so return
                    ; back to the caller function

end_sample:
```

2.4.2.4 CALL instruction

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The following is an example of how to call a procedure. This example begins at proc_2:

```
<> proc proc_1  
Locals none  
MOV ECX, [EBP+8] ;ebp+8 is the  
PUSH ECX ;function argument  
POP ECX  
endproc  
proc proc_2  
Locals none  
invoke proc_1, 5 ;invoke proc_1 proc  
endproc
```

2.4.2.4 CALL instruction



Teaching the assembly language is out of the scope of this course, but the previous example will help you to get familiar with it.

There are tons of additional resources on the web if you are interested in learning more.

2.5 Tools Arsenal



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TOOLS ARSENAL

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2.5 Tools Arsenal



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During this course, we will use different tools and software. The most important are the C/C++ compilers and the debuggers. Although we will not go into great details about the compiler, we will closely inspect the debuggers and their features.

Moreover, we will give you different tool options, so you are free to use the one that best fits your needs.

2.5.1 Compilers



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Since we will write some C and C++ code, you will need a compiler. If you are not confident in programming in C or C++, don't worry. The coding we will do will not be that complicated, and as long as you follow along and understand the concepts, you will do fine.

To make things easier, we will use an IDE to manage all the files.

2.5.1 Compilers



We have different options, such as the commercial Microsoft Visual C/C++ (Visual Studio) or free software like Orwell Dev-C++, or Code::Blocks and so on.

Ideally, it should be one that you are familiar with, but they perform the same functions.

<https://www.microsoft.com/en-us/download/details.aspx?id=48145>
<http://orwelldevcpp.blogspot.com/>

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2.5.1 Compilers



For our purposes, Dev-C++ is enough. It offers a good IDE and all the required compiling and decompiling tools.

Although compiling an application from the IDE is very simple and straightforward, you can also compile an application from the command line. As you will see, this will be very useful later with exploit and payloads.

2.5.1 Compilers



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REF

Dev-C++ creates a directory named **MingW64** where all the compiling tools are stored.

MingW64 is an improved version of the **MingW** (Minimalist GNU compiler for Windows), which provides programming tools for developing native MS-Windows applications.

<http://mingw-w64.org/doku.php>
<http://mingw.org/>

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2.5.1 Compilers



Once you install Orwell Dev-C++, remember to add the bin folder to your windows environment variables so that you can run gcc from any path in the command prompt.

To compile .c or .cpp files we can use the gcc .exe compiler found in the bin folder:

Name	Date
g++.exe	12/7/2
gcc.exe	12/7/2
gcc-ar.exe	12/7/2

<http://orwelldevcpp.blogspot.com/>

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2.5.1 Compilers



Once the environment variables are set, extract the file

- HelloStudents.c
contained in the 2_Assembler_Debuggers_Tools.rar
package from the **Members area** and save it locally.

To compile the C file using gcc we can run the following command:

```
gcc -m32 HelloStudents.c -o HelloStudents.exe
```

2.5.1 Compilers



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With the previous command, we are telling the compiler (gcc) to compile the file HelloStudent.s.c for 32-bit environments (-m32) and then output the compiled version to a file named HelloStudent.exe.

2.5.1 Compilers



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If the command succeeds, you should be able to run the executable from your command prompt and see the following message:

```
Command Prompt  
C:\samples>gcc -m32 HelloStudents.c -o helloStudents.exe  
C:\samples>helloStudents.exe  
Hello students!  
C:\samples>_
```

2.5.1 Compilers



While all the compiling options are out of the scope of this course, you can check the [gcc manual here](#), to learn about all the different possibilities.

It is important to know that every compiler will produce a slightly different output. Therefore, the same source code compiled with different compilers (such as *Microsoft Visual Studio*, *MinGW*, *GCC*, etc.) may produce different machine codes.

<https://gcc.gnu.org/onlinedocs/>

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2.5.2 Debuggers



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A debugger is a program which runs other programs, in a way that we can exercise control over the program itself. In our specific case, the debugger will help us to write exploits, analyze programs, reverse engineer binaries and much more. As we will see, the debugger allows us to:

- Stop the program while it is running
- Analyze the stack and its data
- Inspect registers
- Change the program or program variables and more

2.5.2 Debuggers



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There are several debugs available. During this course, we will use Immunity Debugger. It is a good suggestion to have a general overview of a couple of these debuggers because some companies may prefer one over another. Here is a small list of some of the most popular ones:

- IDB (Windows, Linux, MacOS) • WinDBG (Windows)
- GDB (Unix, Windows) • OllyDBG (Windows)
- X64DBG (Windows) • Hopper (MacOS, Linux)
- EDB (Linux)

<https://www.immunityinc.com/products/debugger/>
<https://www.hex-rays.com/products/ida/>
<https://www.gnu.org/software/gdb/>

<https://docs.microsoft.com/en-us/windows-hardware/drivers/download-the-wdk>
<http://www.ollydbg.de/>
<https://www.hopperapp.com/>

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2.5.2 Debuggers



First, we'll give you a quick breakdown of how the Immunity Debugger GUI looks and operates. We will then use the GUI by running the samples previously built and provided by the Immunity Debugger.

This will help you understand how programs are interpreted on your system, which is the main prerequisite for enjoying real exploitation.

2.5.2 Debuggers



In the following slide we will examine the Immunity Debugger GUI and the meaning of each panel:

The screenshot shows the Immunity Debugger interface with four panels visible:

- Registers (CPU):** Shows CPU register values. A red circle labeled "1" highlights the EIP register, which has the value `004014E0`.
- Registers (FPU):** Shows FPU register values.
- Stack:** Shows memory dump from address `004014E0` to `004014F0`. A red circle labeled "2" highlights the value `A9C84660` at address `004014E0`.
- Dump:** Shows memory dump from address `004014E0` to `004014F0`. A red circle labeled "3" highlights the value `75067C04` at address `004014E4`.
- Registers (CPU):** Shows CPU register values again. A red circle labeled "4" highlights the EIP register, which has the value `0028F84`.

2.5.2 Debuggers



Panel 1

The Disassembler Panel is not only the main window, but it is the most important panel. Here is where all the Assembler code is produced or viewed when you are debugging a module.

- In the **first column** is the address location
- In the **second column** is the machine code
- In the **third column** is the assembly language
- In the **fourth column** is the debugger comments

2.5.2 Debuggers

Panel 1



```

0040100C  ⊞ $ 55      PUSH EBP
0040100D  : 89E5      MOV EBP,ESP
0040100F  : 89E0      MOV EAX,ESP
00401011  . 07        AND EAX,7
00401014  . 74 06      JE SHORT sample_1.0040101C
00401016  : 83EC 08      SUB ESP,8
00401019  ; 83E4 F8      AND ESP,FFFFFFF8
0040101C  > 6A 05      PUSH 5
0040101E  : E8 DFFFFF  CALL sample_1.00401000
00401023  . 89EC      MOV EBP,EAX
00401025  . 5D         POP EBP
00401026  . C3         RETN
00401027  . 00         DB 00
00401028  . 00         DB 00
00401029  . 00         DB 00
0040102A  . 00         DB 00
0040102B  . 00         DB 00
0040102C  . 00         DB 00
0040102D  . 00         DB 00
0040102E  . 00         DB 00
EBP=0018FF94

```

A quick review of the assembly language column should provide you with some familiar terms: **PUSH**, **MOV**, **CALL**, **POP**, and **RETN**.

2.5.2 Debuggers



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Panel 2

The Register Panel holds information on standard registers. Here you can see:

- Names of registers
- Their content
- If a register points to an ASCII string, the value of the string

2.5.2 Debuggers

Panel 2

You can think of this as working similar to a train or plane schedule.

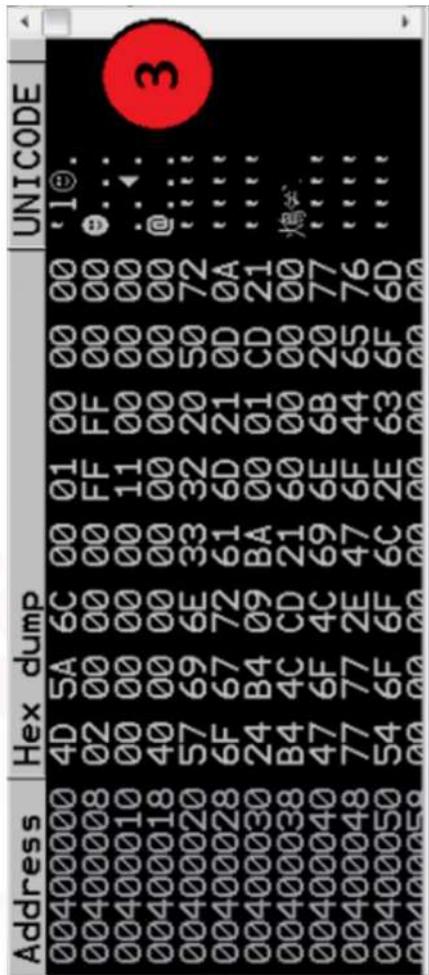
As the program progresses and registers are changed or updated, it is easily noted and observed in this panel.

```
Registers (FPU)
EAX 76A43388 kernel32.BaseThreadInitThunk
ECX 00000000
EDX 0040100C sample_1.<ModuleEntryPoint>
EBX 7EFDE000
ESP 0018FF8C
EBP 0018FF94
ESI 00000000
EDI 00000000
EIP 0040100C sample_1.<ModuleEntryPoint>
CS 0 ES 002B 32bit 0(FFFFFF)
P 1 SS 0023 32bit 0(FFFFFF)
A 0 DS 002B 32bit 0(FFFFFF)
Z 1 FS 0053 32bit 7EFDD000(FFF)
S T 0 GS 002B 32bit 0(FFFFFF)
D 0 LastErr ERROR_SUCCESS (00000000)
EFL 00000246 (NO, NB, E, BE, NS, PE, GE, LE)
ST0 empty 0.0000000000000000
ST1 empty a.0000000000000000
```

2.5.2 Debuggers

Panel 3

The Memory Dump Panel shows the memory locations and relative contents in multiple formats (i.e., hex, UNICODE, etc.).



Address	Hex dump	UNICODE
0040000000	4D 5A 6C 00 01 00 00 FF 00 00 00 00 00 00 00	'1@.
0040000008	02 00 00 00 00 11 00 00 00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
0040000100	00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
0040000180	40 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
0040000200	57 69 6E 33 32 20 50 72 6D 21 0D 0A 00 00 00 00	72 6D 21 0D 0A 00 00 00 00 00 00 00 00 00 00 00
0040000280	6F 67 72 61 6D 21 0D 0A 00 01 CD 21 60 00 00 00 00	67 72 61 6D 21 0D 0A 00 01 CD 21 60 00 00 00 00
0040000300	24 B4 09 BA 00 01 CD 21 60 00 00 00 00 00 00 00 00	24 B4 09 BA 00 01 CD 21 60 00 00 00 00 00 00 00 00
0040000380	B4 4C 0D 21 60 00 00 00 00 00 00 00 00 00 00 00 00 00	B4 4C 0D 21 60 00 00 00 00 00 00 00 00 00 00 00 00 00
0040000400	47 6F 4C 69 6E 6B 20 77 7E 47 6F 6C 44 65 63 6F 6D 00	47 6F 4C 69 6E 6B 20 77 7E 47 6F 6C 44 65 63 6F 6D 00
0040000480	77 6F 6C 44 65 63 6F 6D 00 00 00 00 00 00 00 00 00 00	77 6F 6C 44 65 63 6F 6D 00 00 00 00 00 00 00 00 00 00
0040000500	54 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00	54 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00

2.5.2 Debuggers



Panel 4

The Stack Panel shows the current thread stack.

- In the **first column** is the addresses
- In the **second column** is the value on the stack at that address
- In the **third column** is an explanation of the content (if it's an address or a UNICODE string, etc.)
- In the **fourth column** is the debugger comments

2.5.2 Debuggers



Now that you know the main parts of Immunity Debugger, we can proceed with the analysis of one of our samples:

- Compile the file *demo1.asm* (located in the NASMX folder)
- Watch the following video that will show you how to load and inspect files in Immunity Debugger.
- Load *exe* file in Immunity Debugger
- Explore, question, think and finally, understand how it works on your machine.

Video: Immunity Debugger



If you have a FULL or ELITE plan you can click
on the image on the left to start the video

2.5.3 Decompiling



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The last topic in this module is how to decompile applications. So far we have seen how to compile and assemble applications. But, in order to be a successful pen tester, you need to have the knowledge to reverse that operation.

What do you do if you are given an executable and asked how it works? How can you disassemble it in order to obtain the assembly code?

2.5.3 Decompiling



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We have different options and tools that allow us to do this. In the same Dev-C++ folder where the gcc executable is located, is a file called objdump.exe.

The purpose of this file is to disassemble executable programs.

2.5.3 Decompiling



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Decompiling example:

File: HelloStudents.exe (file we compiled earlier)

Command:

```
objdump -d -Mintel HelloStudents.exe > disasm.txt
```

Switches:

- -d option tells the tool to disassemble the input file
- -Mintel is a disassembler option that allows us to select disassembly for the given architecture (Intel in our case)
- > tells the command what the output file is to be called

2.5.3 Decompiling



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If the command succeeds, we should have a new file named `dissasm.txt`, containing the assembly code of the program.

This will be very useful later to identify the parts of the program that you want to test or exploit.

2.5.3 Decompiling



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Notice that this is something that a debugger like Immunity Debugger automatically does. The following is the assembly code of the function main () in HelloStudent.

The first column contains the addresses in memory, the second column contains the opcodes (machine code), while the third column contains the assembly code.

2.5.3 Decompiling



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The following image shows what we obtain:

```
00401500 < _main>:
401500: 55          push    ebp
        89 e5        mov     esp,ebp
401501: 83 e4 f0    and    esp,0xfffffff0
401503: 83 ec 10    sub    esp,0x10
401506: 83 72 09 00  call   401e80 < _main>
401509: e8 04 24 00  mov    DWORD PTR [esp],0x404000
40150e: c7 00 40 00  call   4025f8 < _puts>
401515: e8 de 10 00  mov    eax,0x0
40151a: b8 00 00 00  leave
40151f: c9          ret
401520: c3          ret
```

2.5.3 Decompiling



Congrats on making it through the fundamentals required to work with executables, debuggers, ASM languages.

We can finally get our hands dirty and start working on buffer overflows!

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