Take Home Test 2: Factorial

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Contents

❖1.Objective

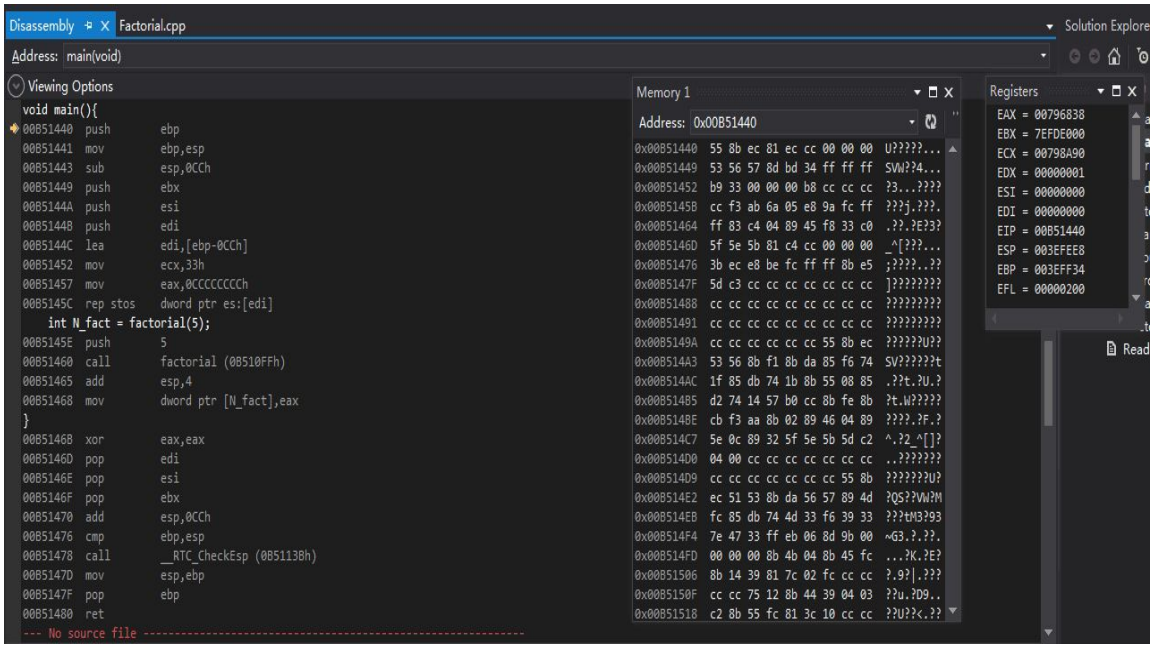
The objective of take home test 2 is going to using the assembly code and C++ code which provide by the professor to analysis in MIPS (assembly compiler which use MARS based on the Java JDK), Microsoft Visual Studio in 32 bit Window(debugger analysis) and GDB/GCC in 64 bit LINUX compiler. This topic of lab is factorial. That require to plot the time of it takes to compute Factorial(N), for N=10,100,1000,10,000.

❖2.Part I Analysis In x86 Intel Of Microsoft's Visual Studio

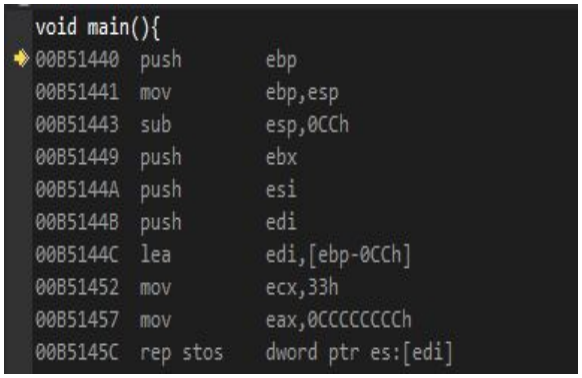
The below is my factorial c++ code and debug in the Visual Studio at Windows.

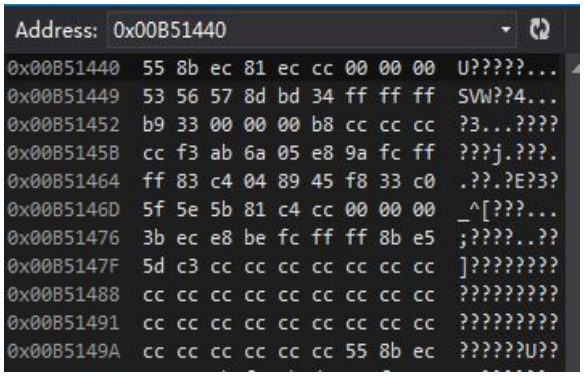
```
int factorial (int N){
    if (N==1)
        return 1;
    return (N*factorial(N-1));
}

void main(){
    int N_fact = factorial(5);
}
```

First we need to take look the ebp in the push process. It's EIP is 0x00B51440. The EIP register always contains the address of the next instruction to be executed. You cannot directly access or change the instruction pointer. However, instructions that control program flow, such as calls, jumps, loops, and interrupts, automatically change the instruction pointer.

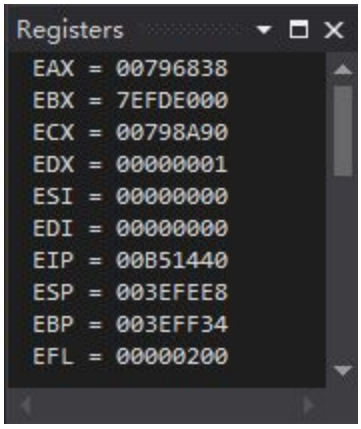


Then we could know the basic memory value is 55 8b ec 81 ec cc 00 00 00. The below memory values also contain other process when the system debug this code in main function. It will lead us to the initial factorial way. That will tell the system to save the value of EBP.

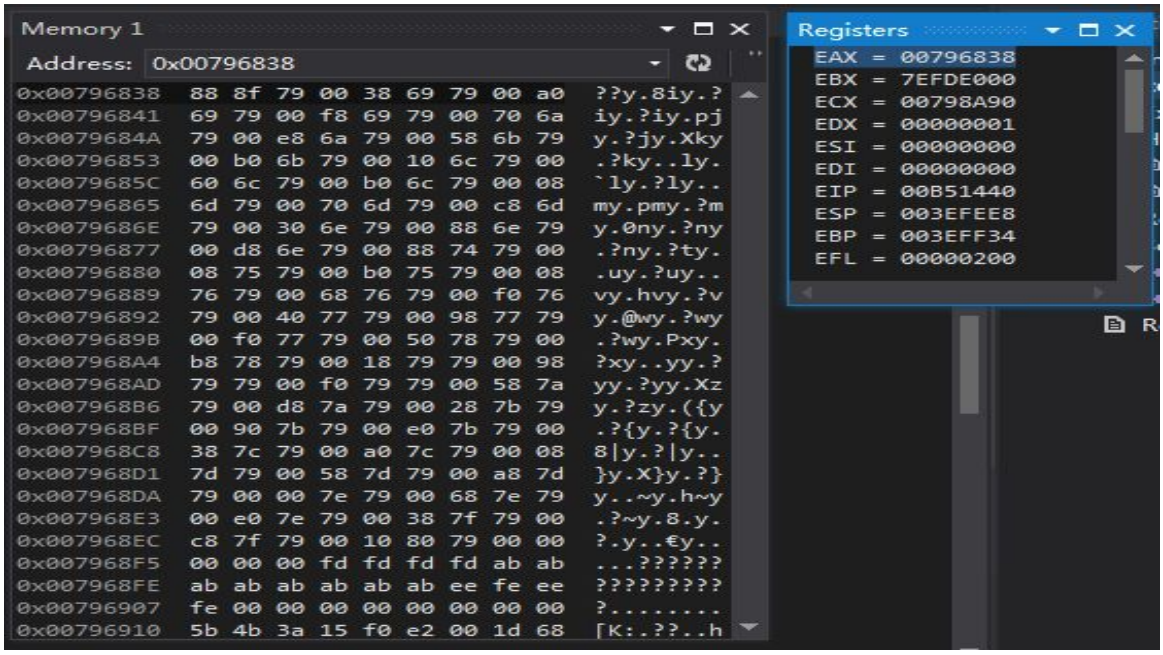




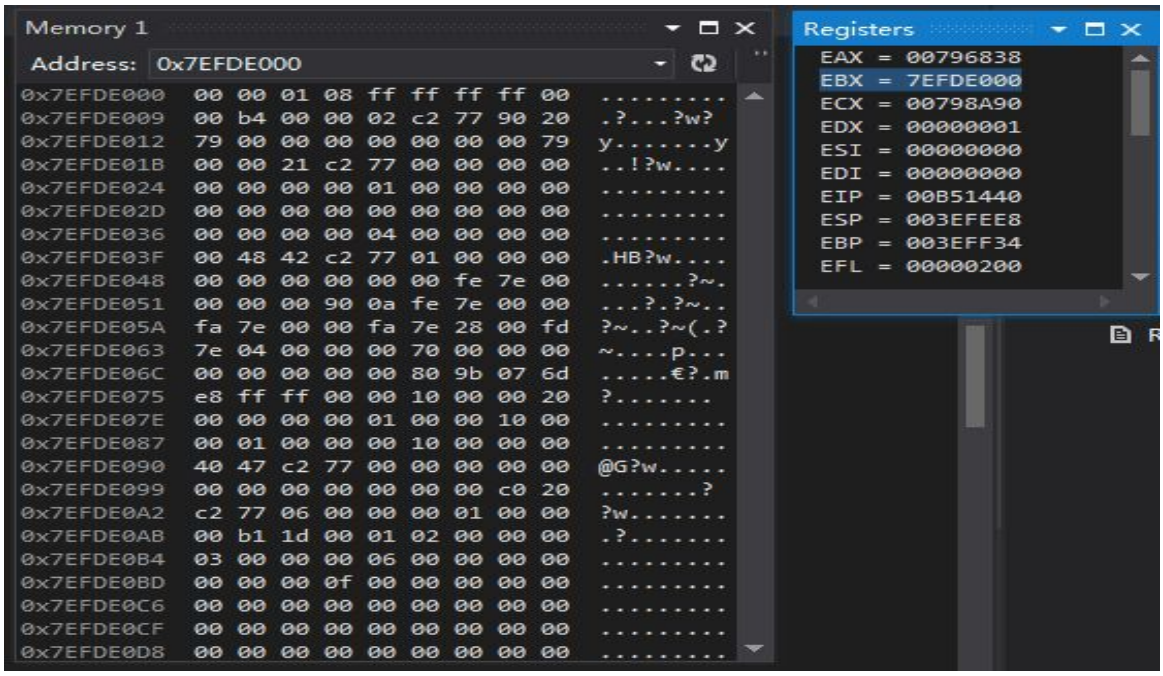
The below is the basic registers address of initial step. The EDI(Electronic Data Interchange) and the ESI(Extended Source Index) are point to 0 memory address.



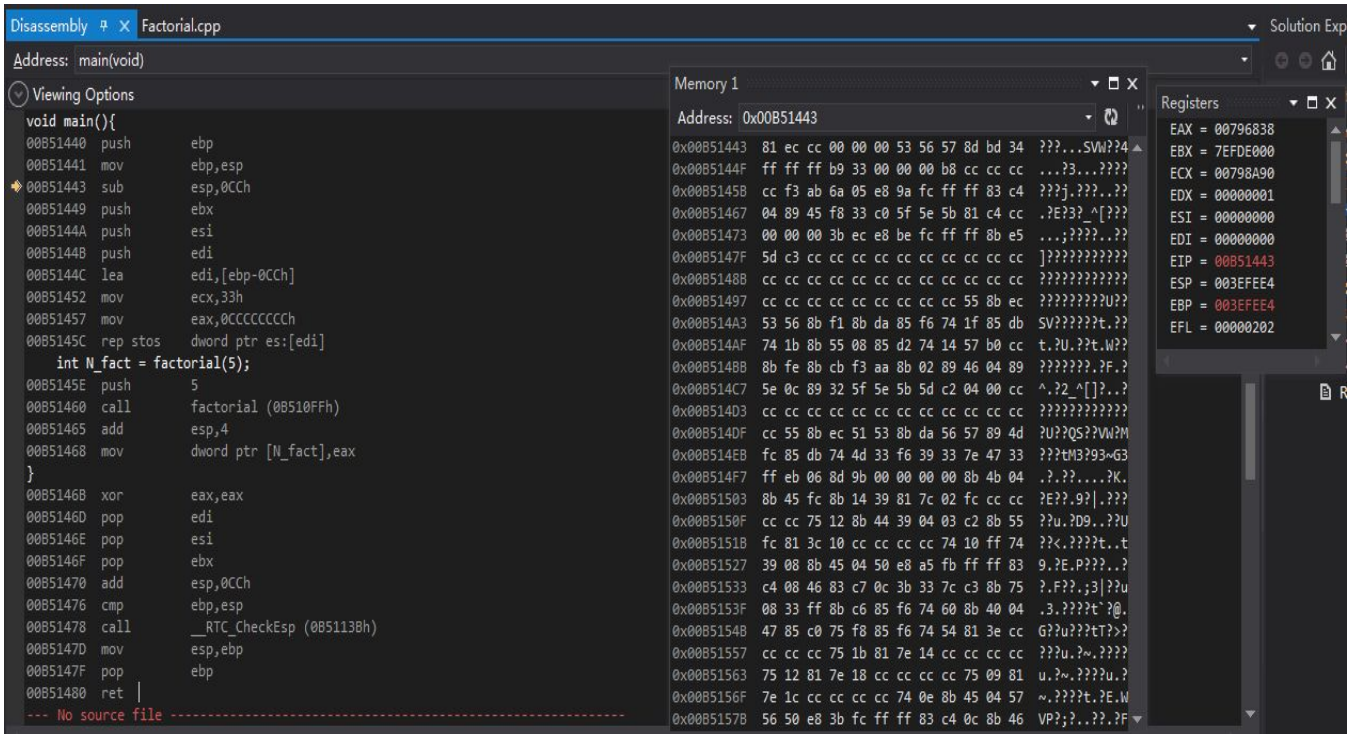
The memory address of EAX is 0x00796838. It's memory value is 88 8f 79 00 38 69 79 00 a0. EAX used to be called the accumulator since it was used by a number of arithmetic operations while the system operate the math formula.



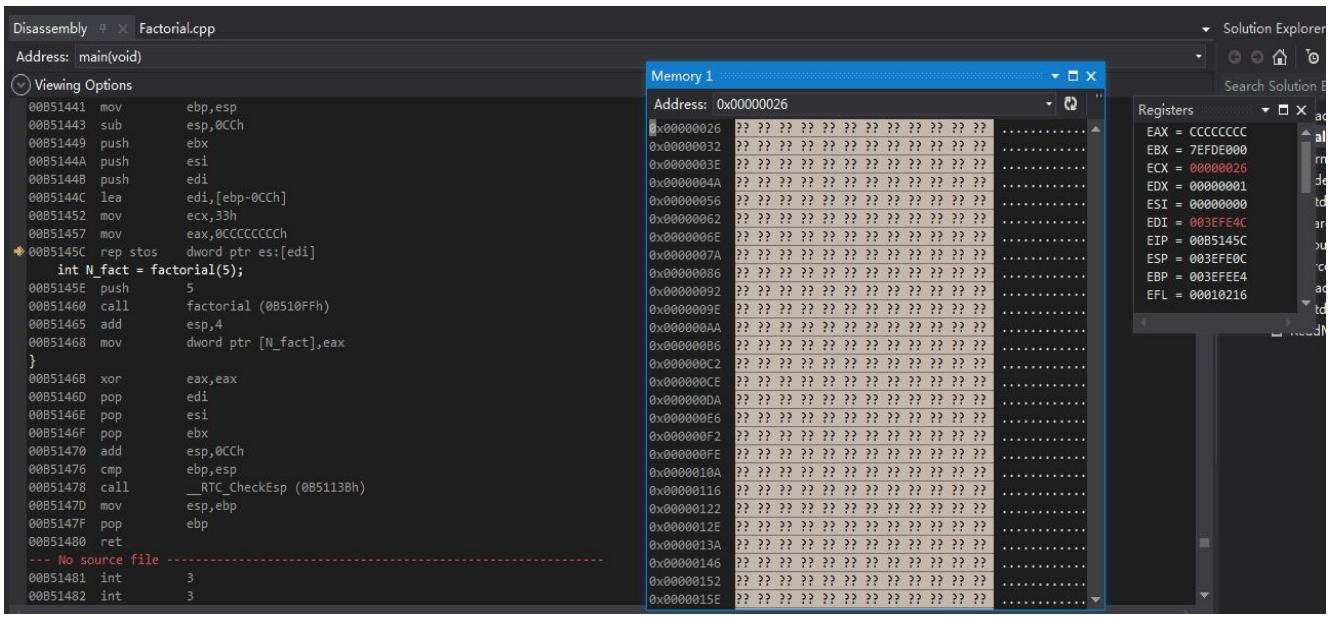
In this register, the EBX is 0x7EFDE000, the memory values are 00 00 01 08 ff ff ff ff. It will has 32 bit in the register memory. It defined as the base register, that the The base address is stored in memory addressing.



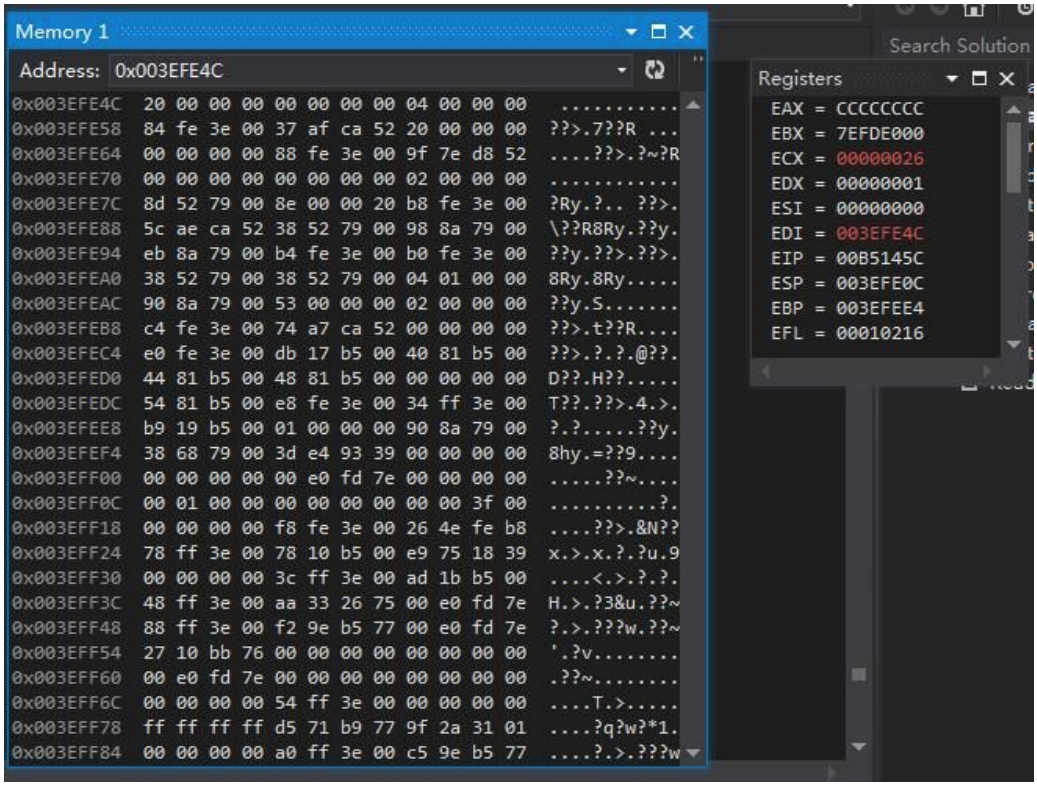
Next, we take look for the sub process. The ESP register which is the current stack pointer. EBP is the base pointer for the current stack frame. When you call a function, typically space is reserved on the stack for local variables. This space is usually referenced via EBP (all local variables and function parameters are a known constant offset from this register for the duration of the function call.) ESP, on the other hand, will change during the function call as other functions are called, or as temporary stack space is used for partial operation results. The register of ESP is 0x003EFEE4, the register of EBP is 0x003EFEE4. In this line, the "sub esp, 0CCh" means space allocated on the stack for the local variables, esb=esb-0CCH.



The EIP is 0x00B5145C, in this step, it will repeat the command from previous. The memory values of ECX is repeat times. The memory register is 0x00000026, that shows lots of question mark in Memory window. In other words, we could say we don't know the times of repeat in factorial function.



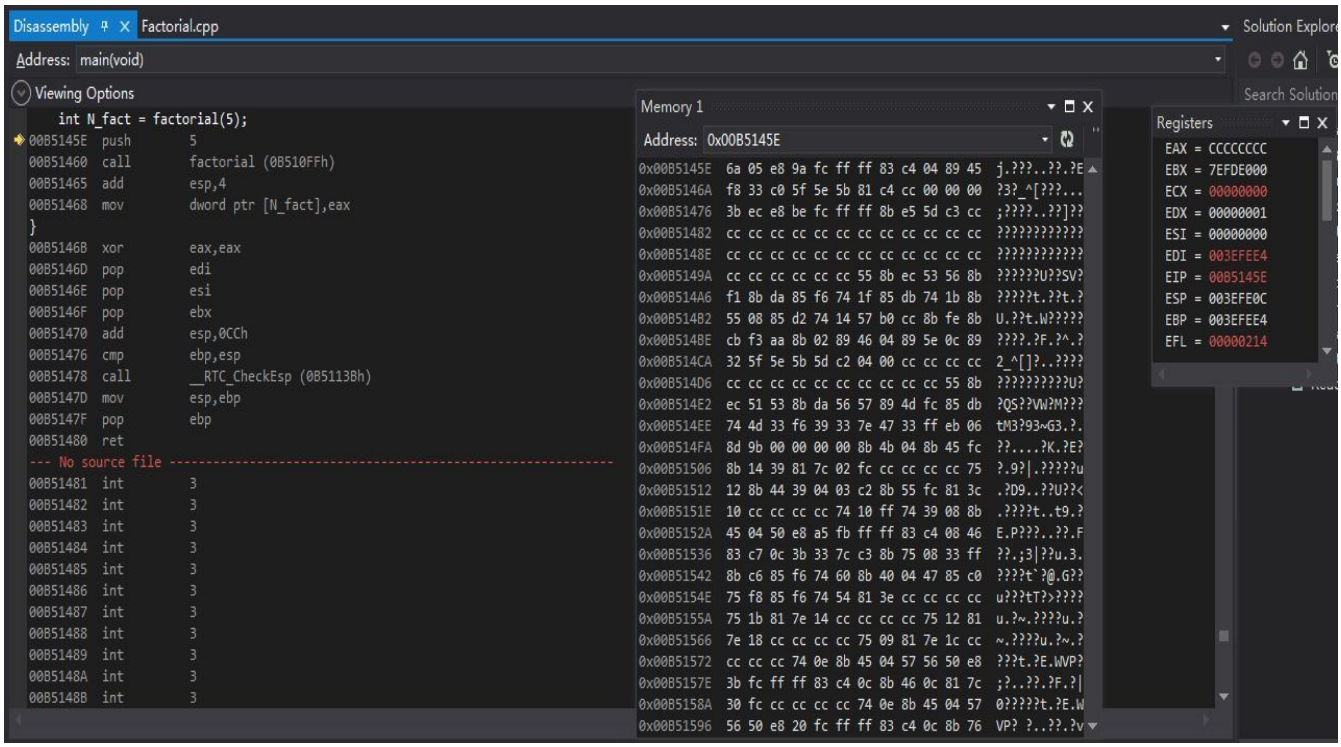
The memory register of EDI is destination index register. This instruction copies the contents of Ax into the memory location whose address is the sum of the Bx and SI. DI stands for destination index, used as a pointer to the current character being written or compared in a string instruction. It is also available as an offset just like SI. The memory register is 0x003EFE4C, and it has memory values are 20 00 00 00 00 00 00 00 04 00 00 00. Then we could know the target string will be much smaller.



The below is the debugging process of factorial 5.

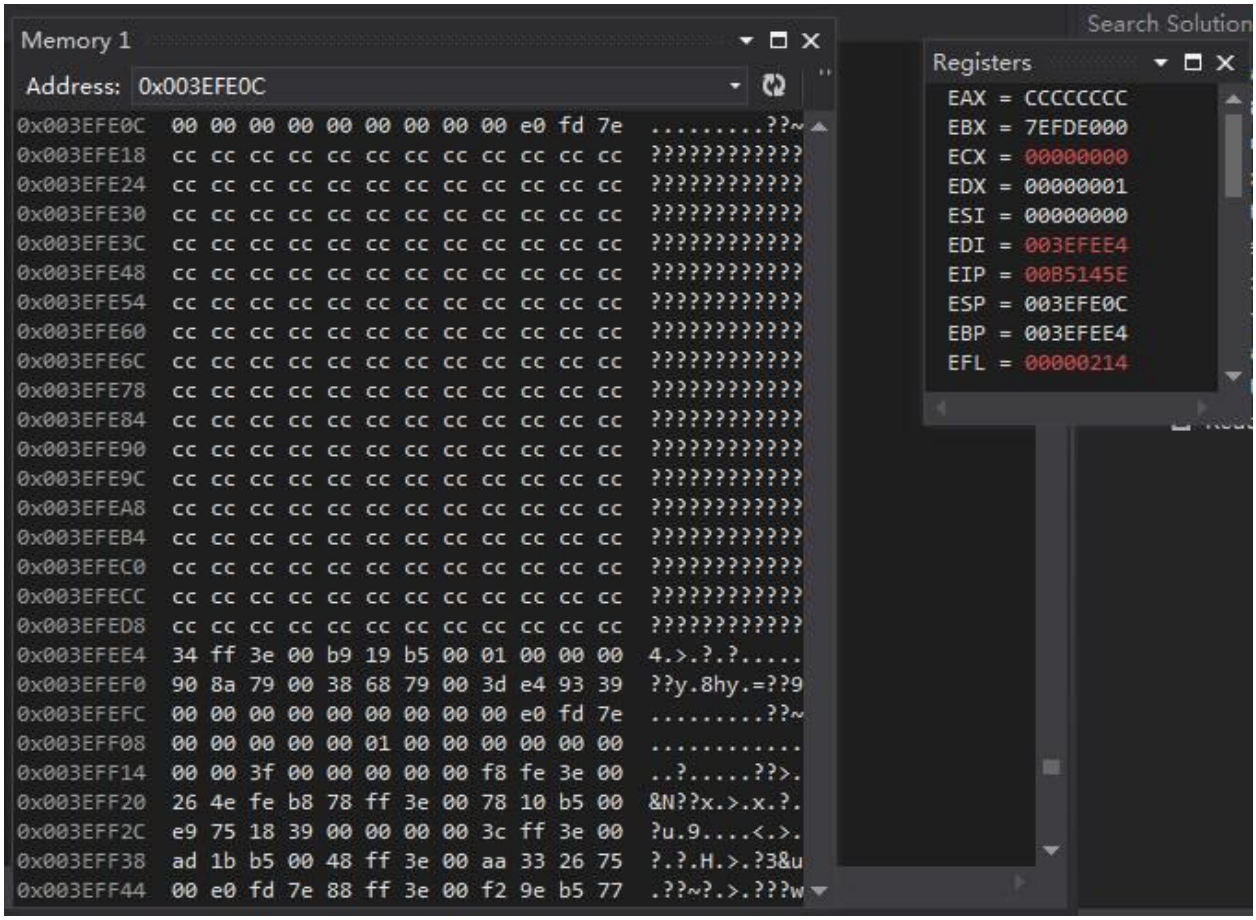
```
    int N_fact = factorial(5);
00B5145E  push        5
00B51460  call        factorial (0B510FFh)
00B51465  add         esp,4
00B51468  mov         dword ptr [N_fact],eax
}
00B5146B  xor         eax,eax
00B5146D  pop         edi
00B5146E  pop         esi
00B5146F  pop         ebx
00B51470  add         esp,0CCh
00B51476  cmp         ebp,esp
00B51478  call        __RTC_CheckEsp (0B5113Bh)
00B5147D  mov         esp,ebp
00B5147F  pop         ebp
00B51480  ret
```

In the initial step, we need to save the value 5. It's EIP is 0x00B5145E. The EIP register always contains the address of the next instruction to be executed. You cannot directly access or change the instruction pointer. However, instructions that control program flow, such as calls, jumps, loops, and interrupts, automatically change the instruction pointer. CPU can not read the following instructions without it. The popular point on the CPU can not be executed each time the corresponding assembly instructions to complete the corresponding eip value will increase.

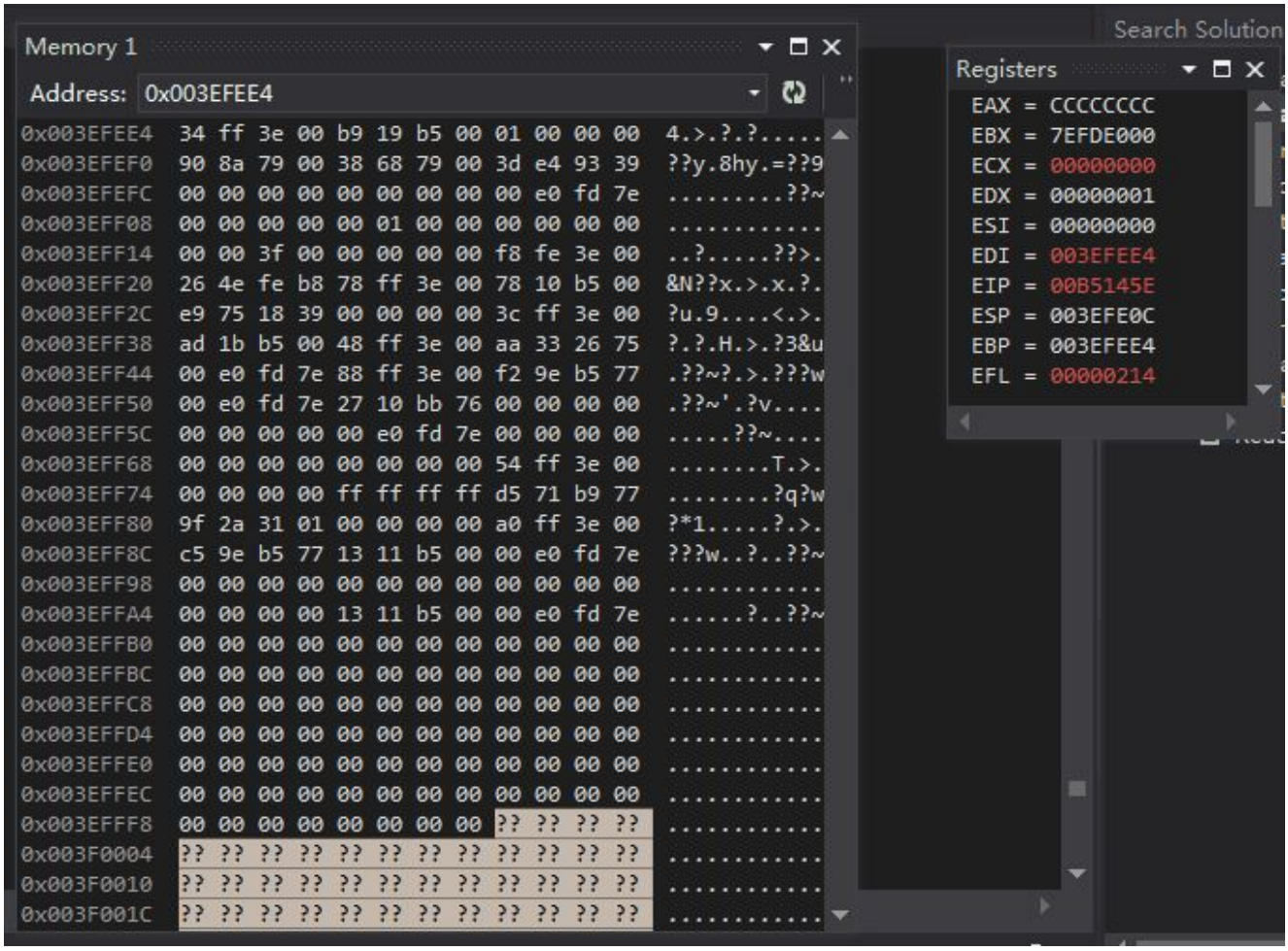


Then we need to search the register ESP. It is the extended stack pointer in the stack pointer. It has memory register is 0x003EFE0C. The esp change or not has nothing to do with ebp, ebp change or not has nothing to do with esp. The esp's point will be with the stack, the stack operation and change, and ebp will not follow the stack, the stack operation and change the

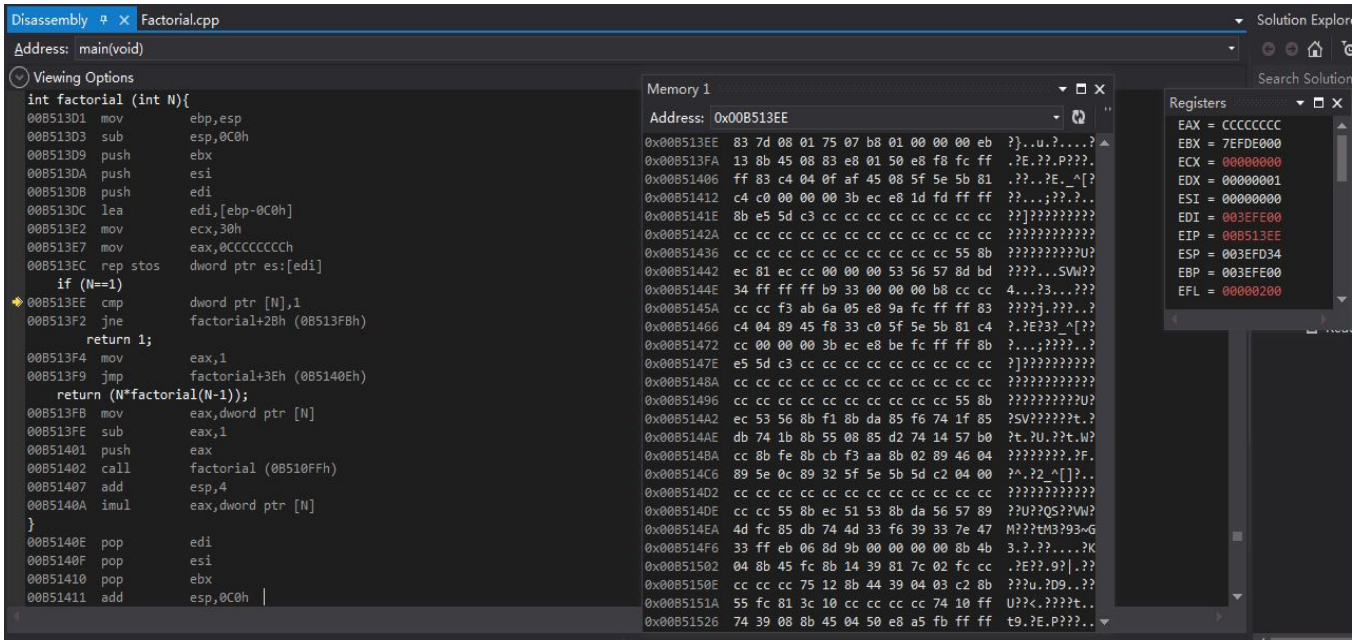
top of the stack will change with the esp point, the top of the stack changes and ebp is irrelevant. The ebp originally pointed to where or where to point, unless the instruction changes ebp value of its point to change only.



The below is the register EBP which is extended base pointer, it contains a pointer to the bottom of a stack frame at the top of the system stack. The ebp only access to a certain moment of esp, this time is to enter a function, the cpu will be assigned to the value of esp to ebp, ebp at this time can operate on the stack, such as access to function parameters, local variables, in fact the system use esp can also implement the function.

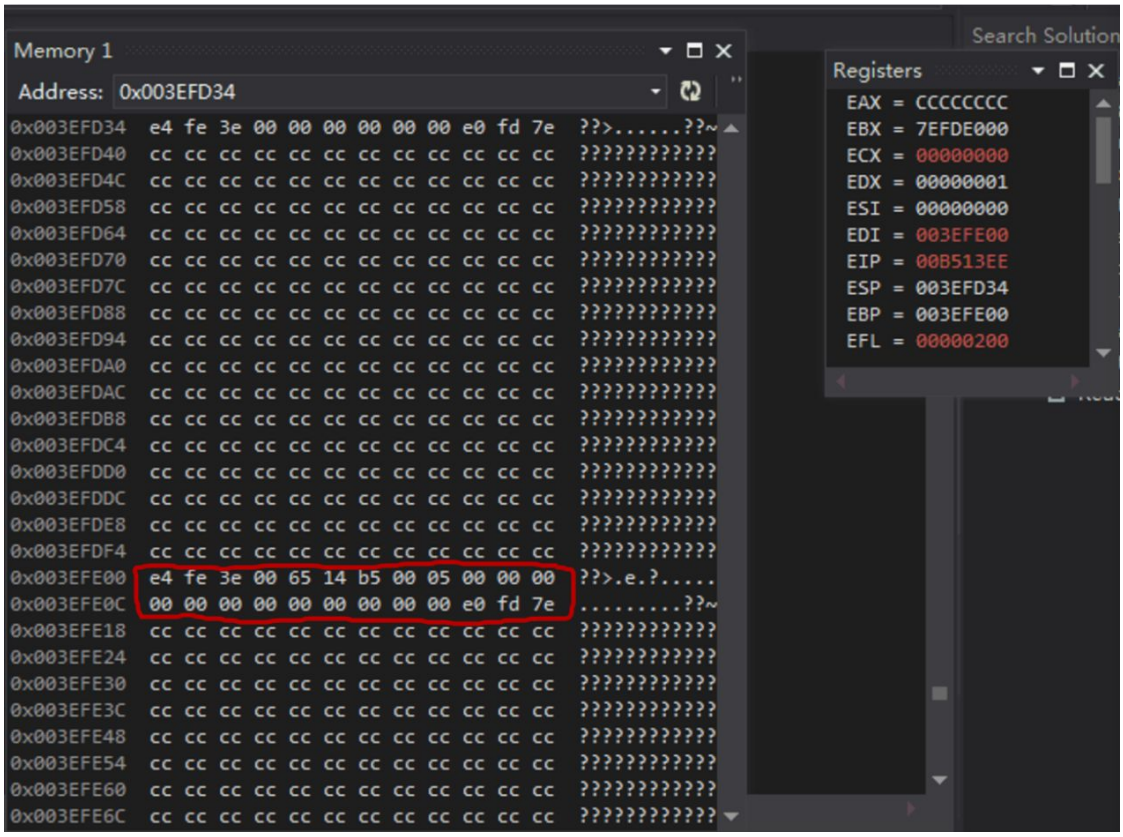


Then we debug over to inductive step of the factorial, N=1. It's memory register EIP is 0x000B513EE. First, the cmp instruction is a comparison instruction that compares the size of the first argument and the second argument. Now the first argument is dword ptr [esp] dword ptr means that this is a double word pointer, that is, the data to be addressed is a double word (4 bytes). And the data in the memory of the address offset is esp this register stored in the content. The It is where the segment is the stack, SS.

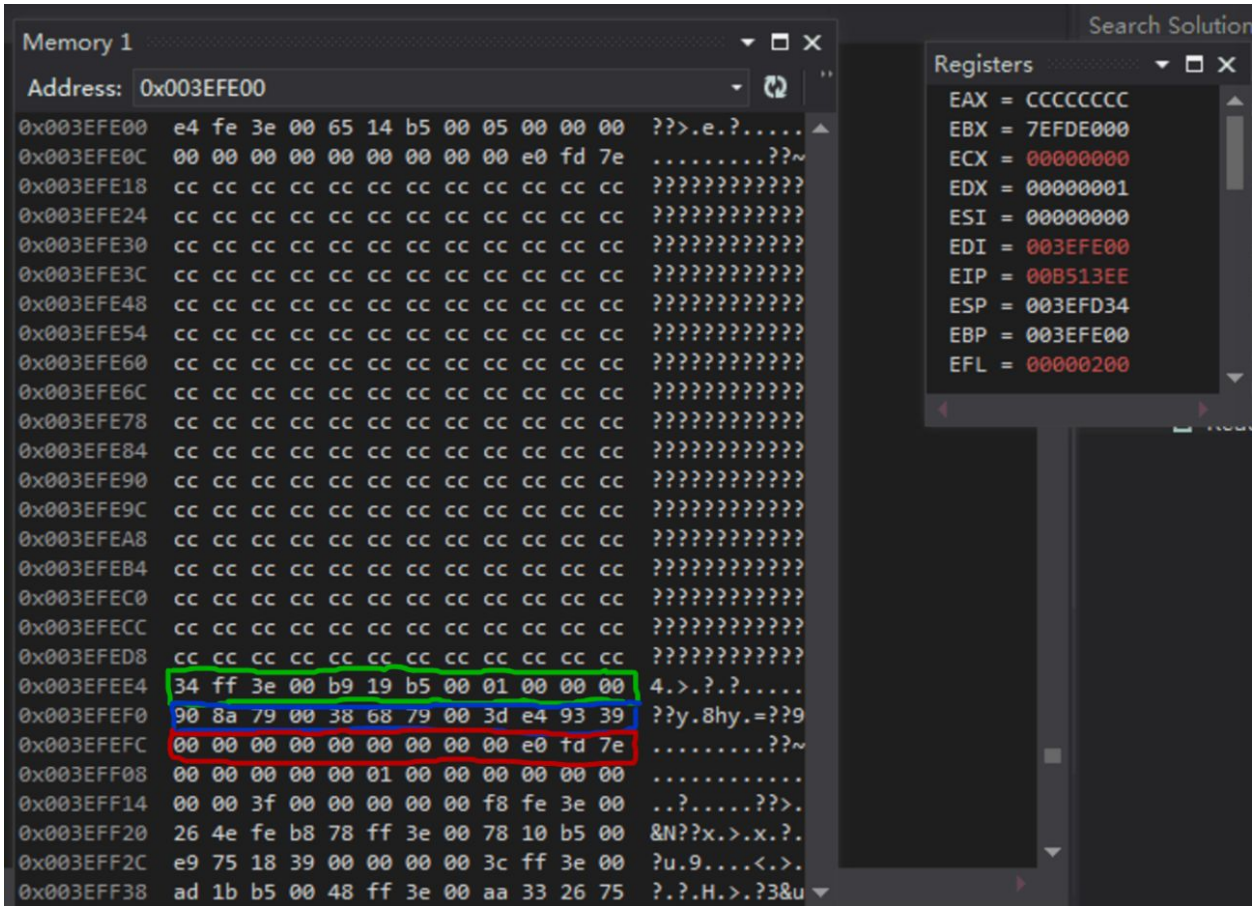


Now it is the debug memory values of register ESP. It has memory register 0x003EFD34.

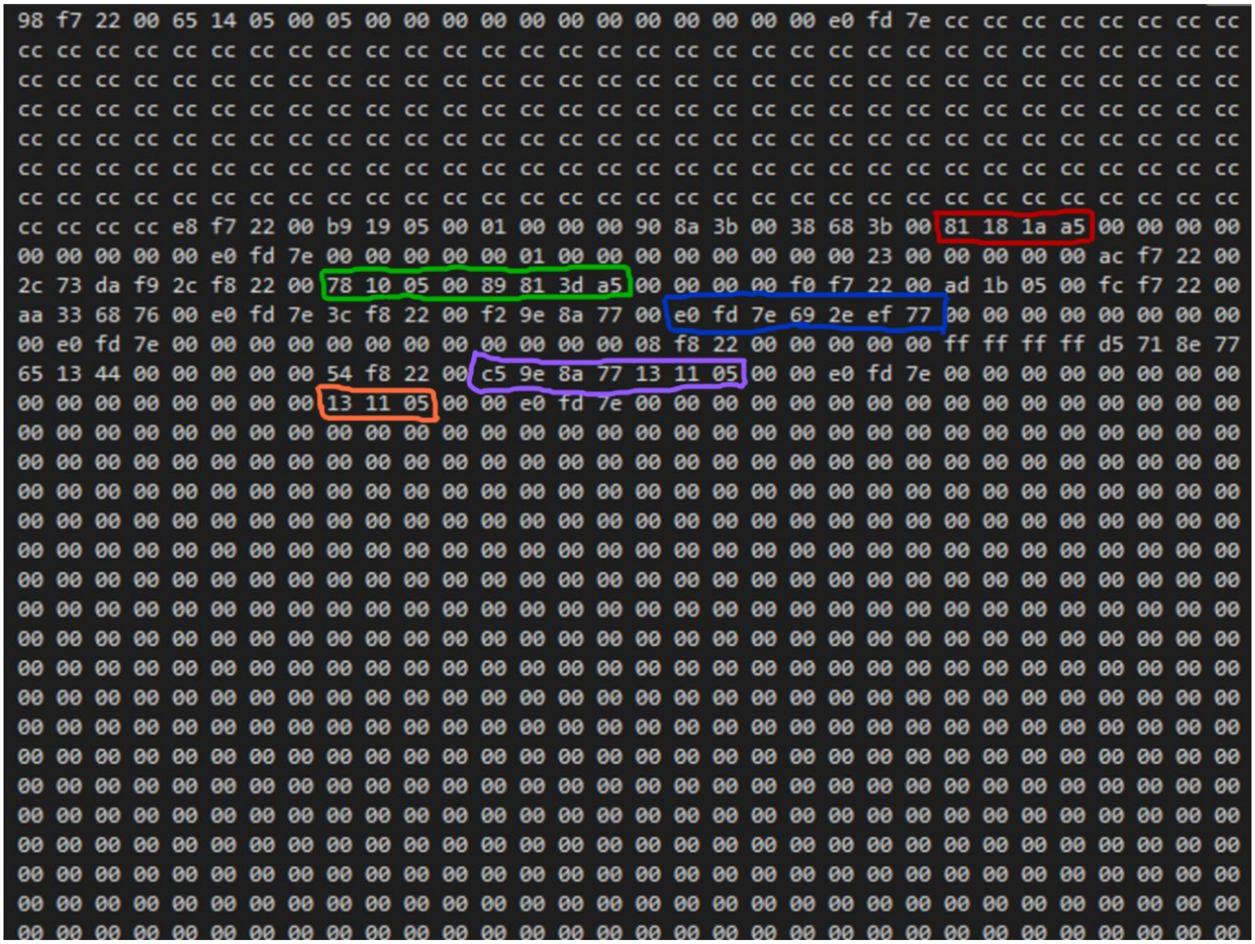
The below red circle is saved ESP of main() and returning address during execution.



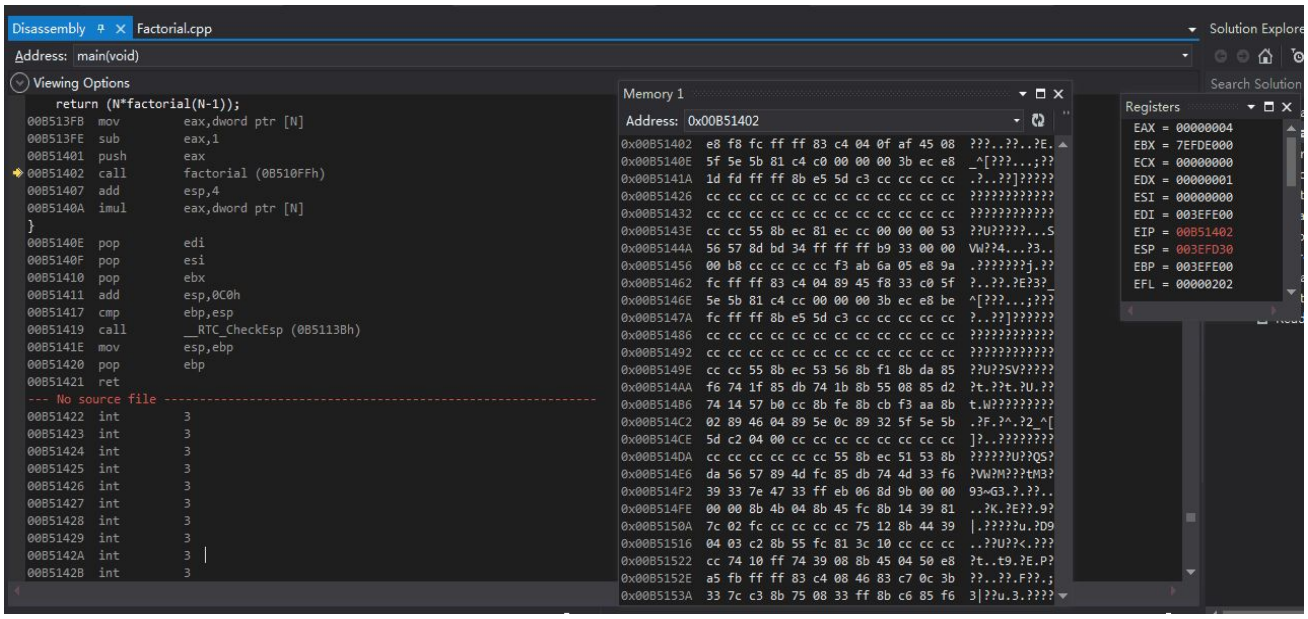
The below is the register memory of EBP which is 0x003EFE00. The green means saved EBP of main(). The blue means return address during execution of factorial(5). The red means argument during execution of factorial(5).



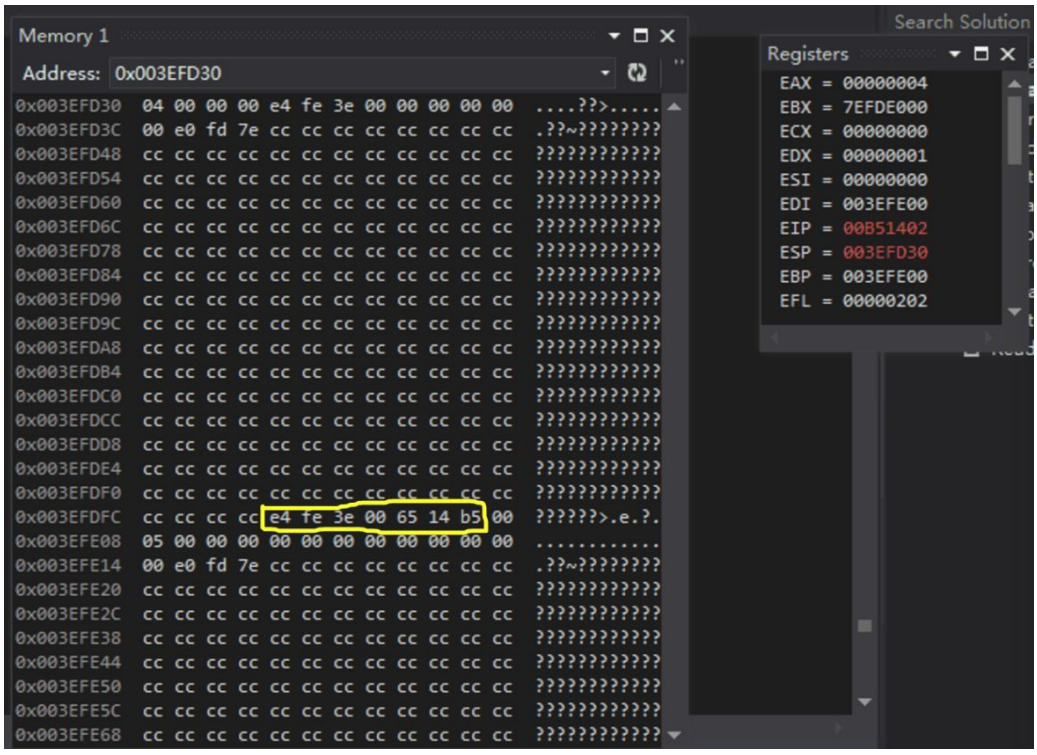
The red means factorial(1), it's value is 81 18 1a a5. The green means factorial(2), it's value is 78 10 05 00 89 81 3d a5. The blue means factorial(3), it's value is e0 fd 7e 69 2e ef 77. The purple means factorial(4), it's value is c5 9e 8a 77 13 11 05. The orange means factorial(5) means factorial(5), it's value is 13 11 05.



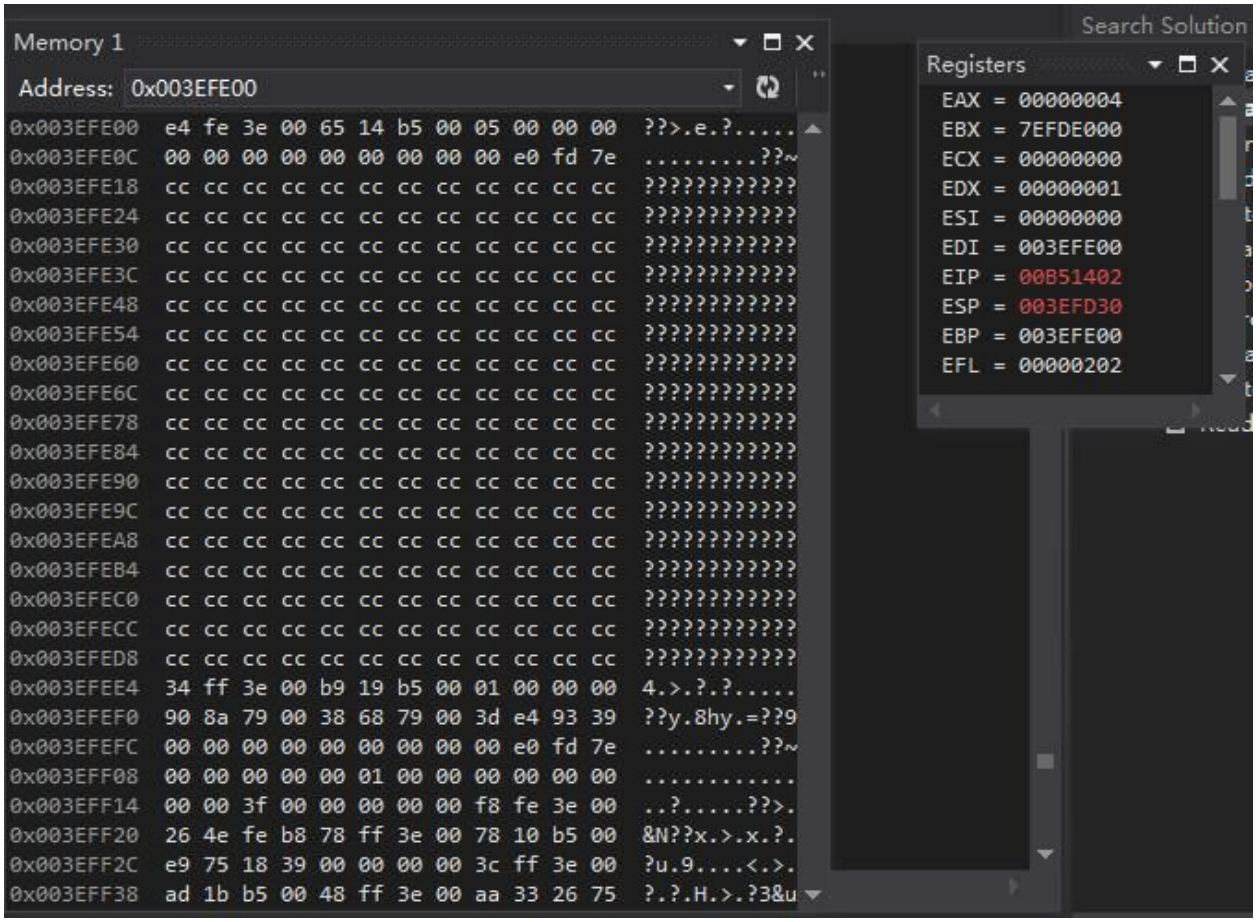
This step is going to call the factorial function. It's memory register EIP is 0x00B51402. The ECX which is called the counter register It is used as a loop counter and for shifts gets some interrupt values. There is 0 register memory and that factorial could not have any loop shift.



The memory register of ESP is 0x003EFD30. After the debugging, the main function call the factorial (0B510FFh) which has the memory value in the below yellow circle.



The ESP, it is the extended stack pointer in the stack pointer. It has memory register is 0x003EFE00. The esp change or not has nothing to do with ebp, ebp change or not has nothing to do with esp. The esp's point will be with the stack, the stack operation and change, and ebp will not follow the stack, the stack operation and change the top of the stack will change with the esp point, the top of the stack changes and ebp is irrelevant.



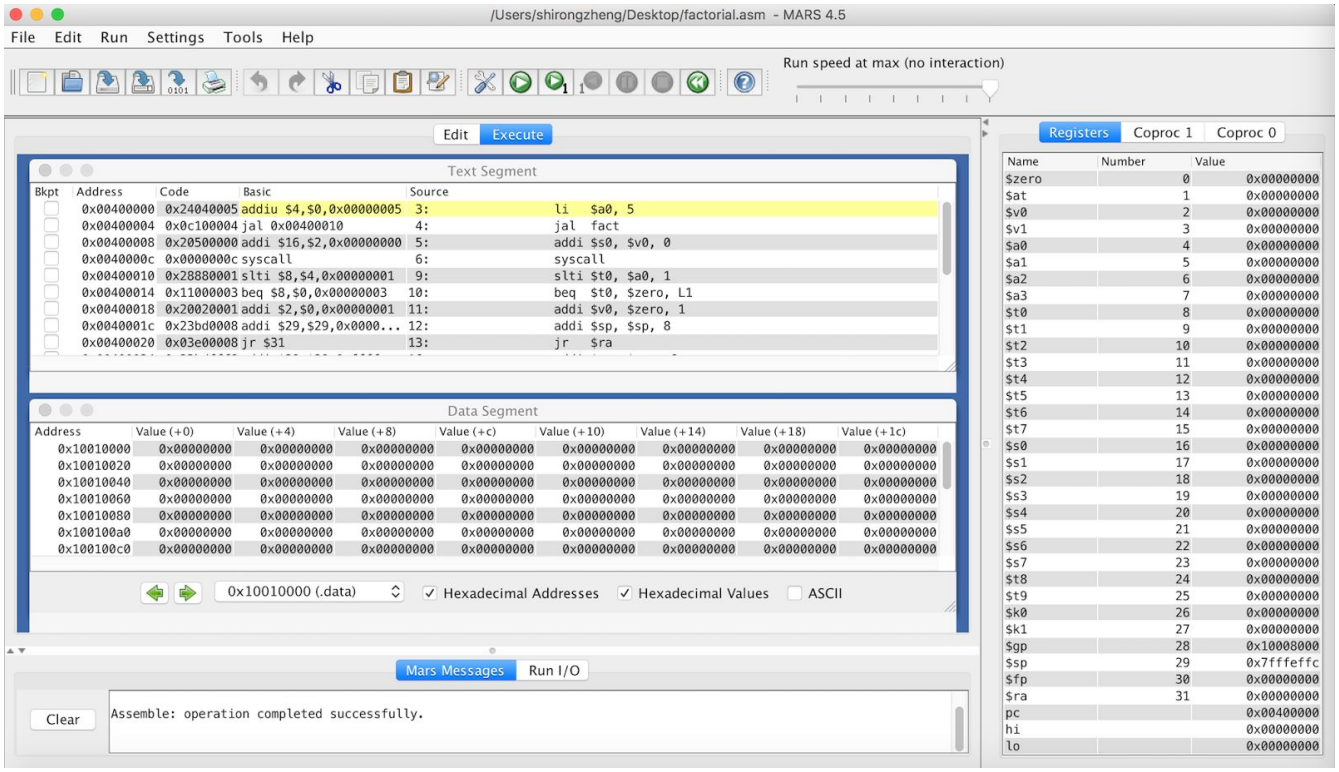
❖3.Part II Analysis In MIPS on MARS Simulator

The below is my factorial assembly code. There are some keywords in this code. For example, In “jal fact” , jal is Jump and Link instructions which are similar to the jump instructions, except that they store the address of the next instruction (the one immediately after the jump) in the return address ($ra; $31) register. This allows a subroutine to return to the main body routine after completion.

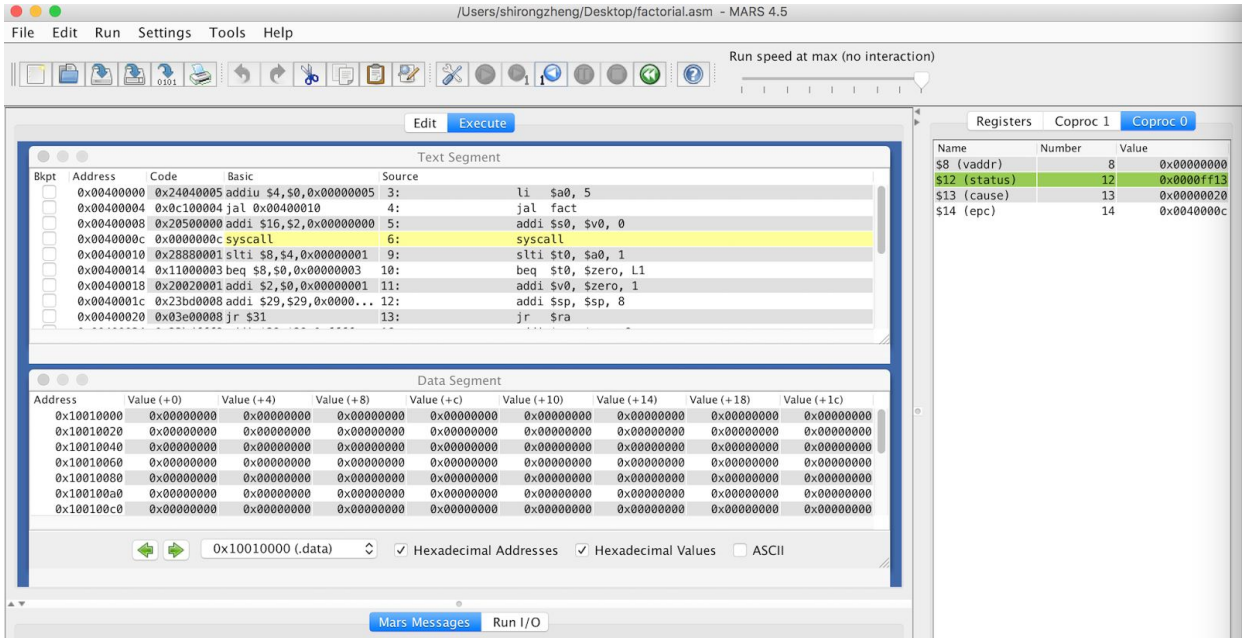
factorial.asm

```
1   .text
2           main:
3                   li   $a0, 5
4                   jal  fact
5                   addi $s0, $v0, 0
6                   syscall
7
8           fact:
9                   slti $t0, $a0, 1
10                  beq  $t0, $zero, L1
11                  addi $v0, $zero, 1
12                  addi $sp, $sp, 8
13                  jr   $ra
14
15          L1:
16                  addi $sp, $sp, -8
17                  sw   $ra, 4($sp)
18                  sw   $a0, 0($sp)
19                  addi $a0, $a0, -1
20                  jal  fact
21                  lw   $a0, 0($sp)
22                  lw   $ra, 4($sp)
23                  addi $sp, $sp, 8
24                  mul  $v0, $a0, $v0
25                  jr   $ra
```

In the initial step, that load immediate value 5 into destination register $a0. The $sp means stack pointer which has value 0x7fffeffc, it points to last location on the stack. The pc is program counter, it shows the current address of text is 0x00400o0 in $a0.



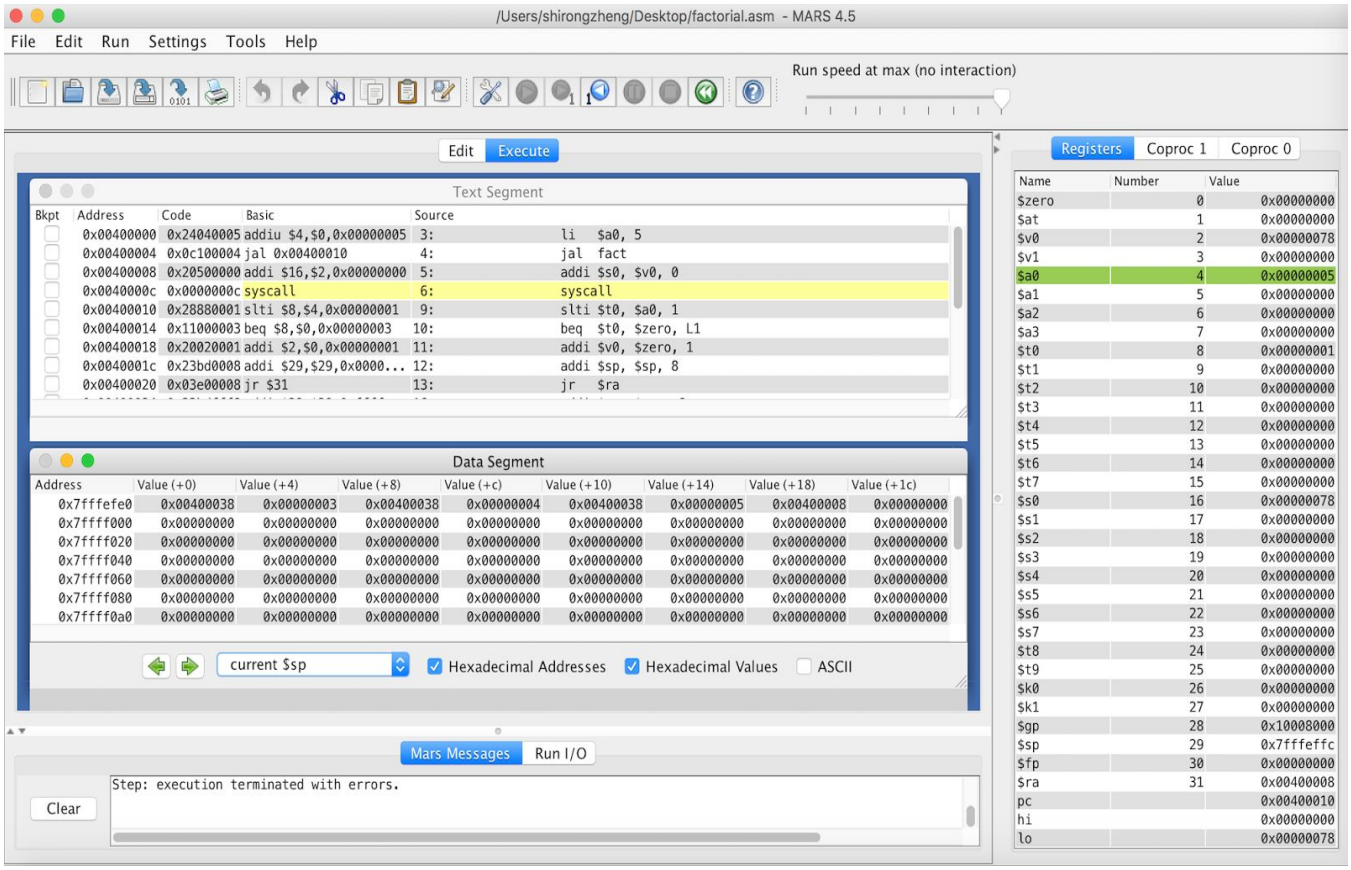
In computing, a system call (syscall) is the programmatic way in which a computer program requests a service from the kernel of the operating system it is executed on. The fundamental interface between an application and the Linux kernel. System calls and library wrapper functions System calls are generally not invoked directly, but rather via wrapper functions in glibc (or perhaps some other library). The $12(status) has memory value is 0x0000ff13.



A stack pointer $sp is a small register that stores the address of the last program request in a stack. A stack is a specialized buffer which stores data from the top down. As new requests come in, they "push down" the older ones. The most recently entered request always resides at the top of the stack, and the program always takes requests from the top. It's memory values is 0x7fffeffc.

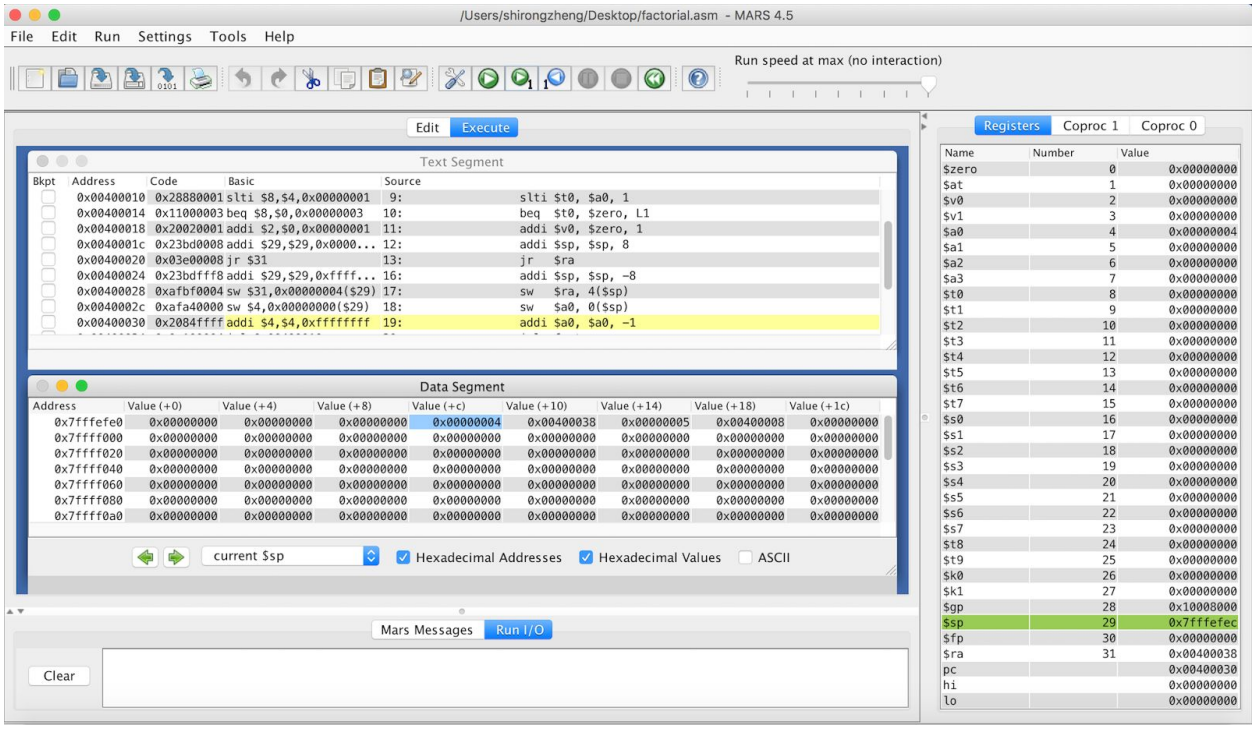
Name	Number	Value
$zero	0	0x00000000
$at	1	0x00000000
$v0	2	0x00000078
$v1	3	0x00000000
$a0	4	0x00000005
$a1	5	0x00000000
$a2	6	0x00000000
$a3	7	0x00000000
$t0	8	0x00000001
$t1	9	0x00000000
$t2	10	0x00000000
$t3	11	0x00000000
$t4	12	0x00000000
$t5	13	0x00000000
$t6	14	0x00000000
$t7	15	0x00000000
$s0	16	0x00000078
$s1	17	0x00000000
$s2	18	0x00000000
$s3	19	0x00000000
$s4	20	0x00000000
$s5	21	0x00000000
$s6	22	0x00000000
$s7	23	0x00000000
$t8	24	0x00000000
$t9	25	0x00000000
$k0	26	0x00000000
$k1	27	0x00000000
$gp	28	0x10008000
$sp	29	0x7fffeffc
$fp	30	0x00000000
$ra	31	0x00400008
pc		0x0040000c
hi		0x00000000
lo		0x00000078

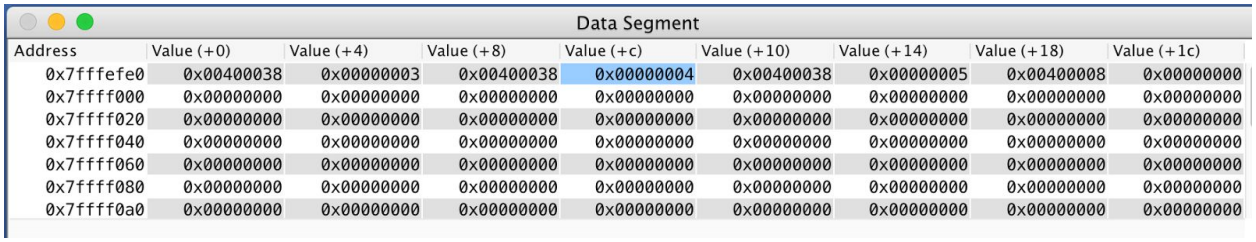
The initial value of $a0 which is factorial(5), it is 0x00000005. Based on the current $sp, +0 value is 0x0040038, +4 value is 0x00000003, +8 value is 0x0040038, +c value is 0x00000004, +10 value is 0x0040038, +14 value is 0x00000005, +18 value is 0x0040008. The $ra means return address, it will return 0x00400008.



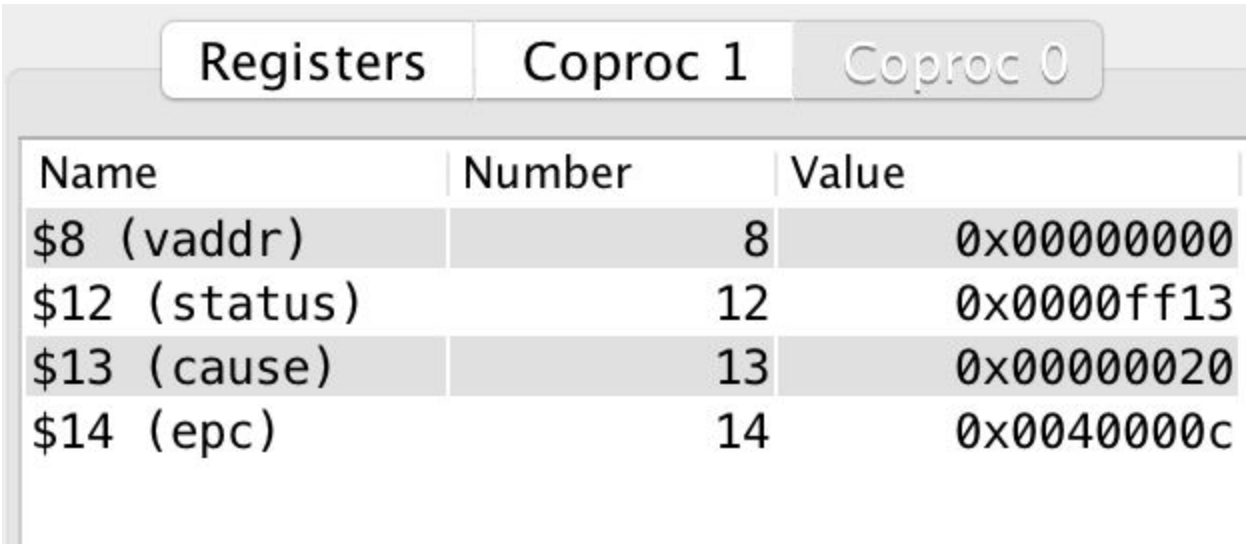
This step is called decrement, the basic signed binary is 0xffffffff, then the factorial (n-1).

Then you could see the $a0 become 0x00000004. The previous “addi $sp, $sp, -8” is subtract 8 bytes from the stack pointer , there is no override to the address of $a0. The math way is 0x7fffeff4 - 8 = 0x0x7fffefec.



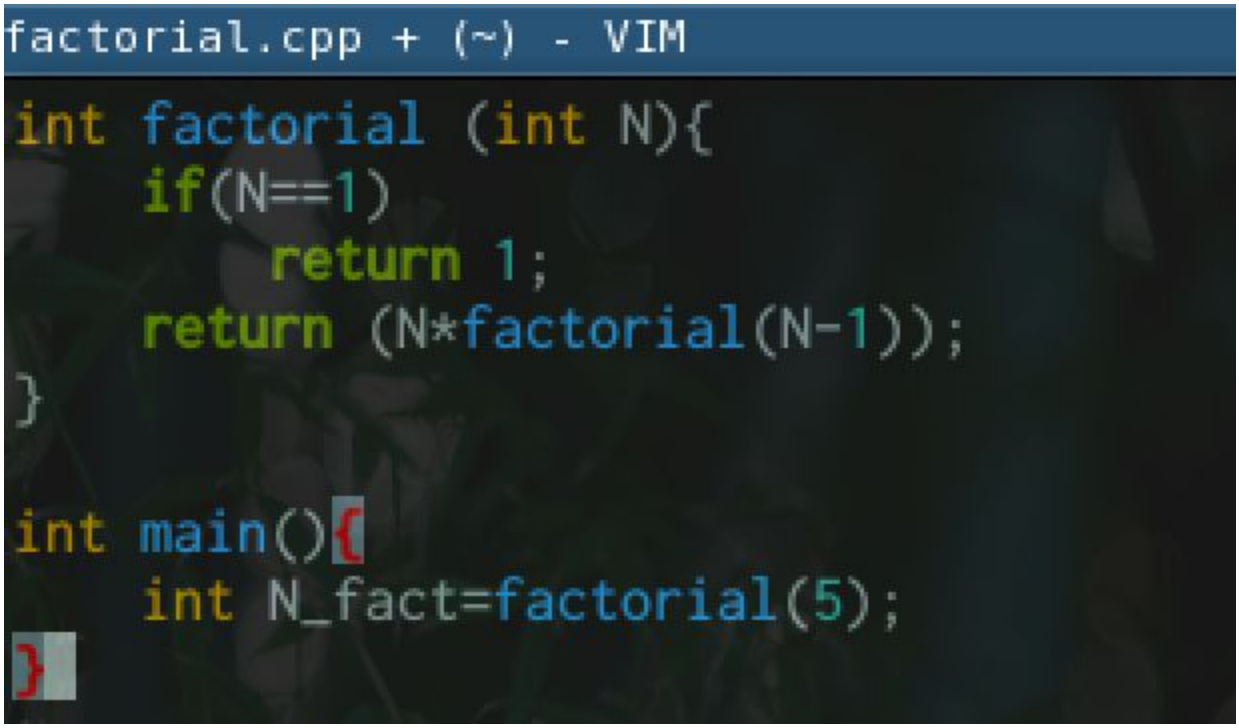


The $14(epc) is exception program counter, It's memory value is 0x0040000c. When a procedure is called using jal, two things happen, 1. control is transferred at the address provided by the instruction, 2. the return address is saved in register $ra. The return address can not be saved in $ra since it may clobber a return address that has been placed in that register before the exception. The Exception Program Counter (EPC) is used to store the address of the instruction that was executing when the exception was generated.

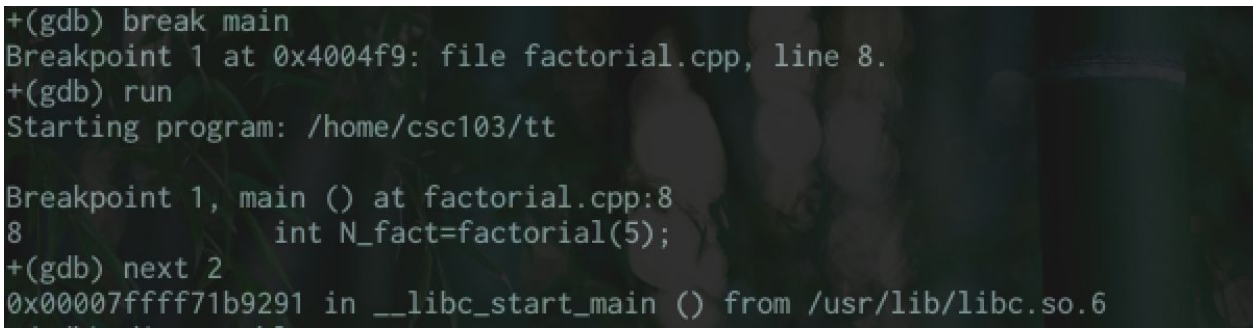


❖4.Part III Analysis In 64-bit Intel Processor gdb/gcc On Linux

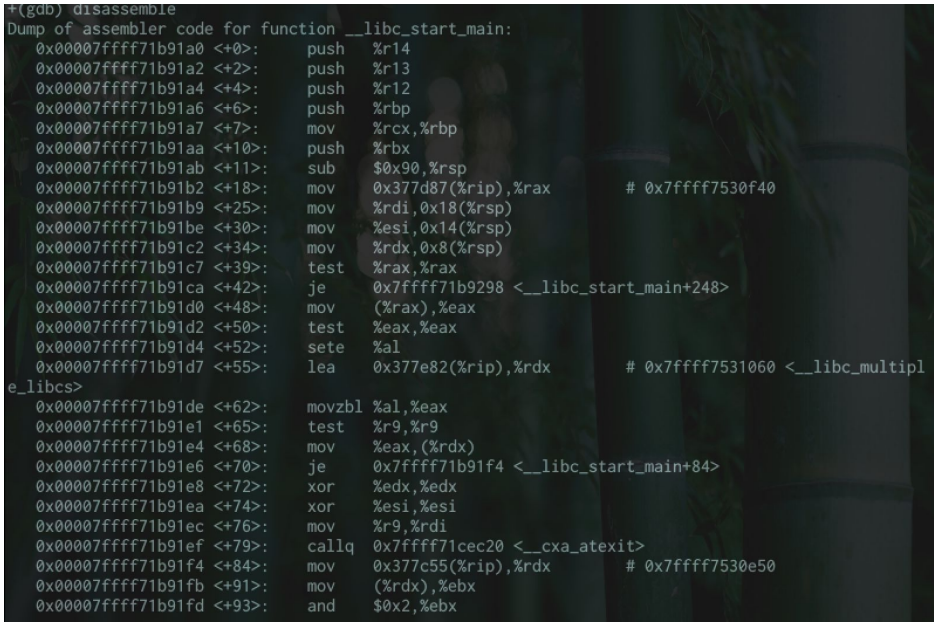
The below is my factorial.cpp which written on VIM of Linux.

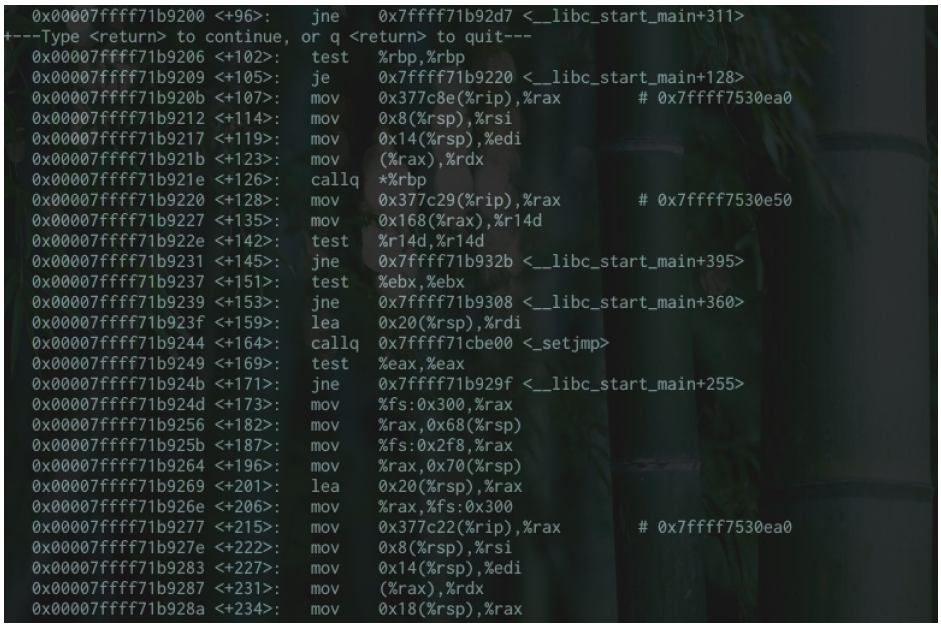


The system will set breakpoint 1 at the entry to the factorial(5) in main function.



The below is debug the code and disassemble the memory address. A disassembler is the exact opposite of an assembler. Where an assembler converts code written in an assembly language into binary machine code, a disassembler reverses the process and attempts to recreate the assembly code from the binary machine code.

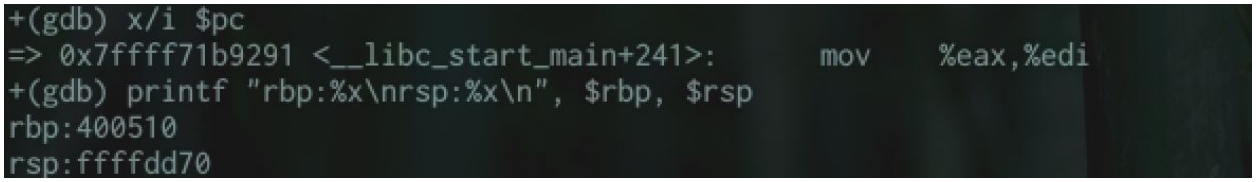




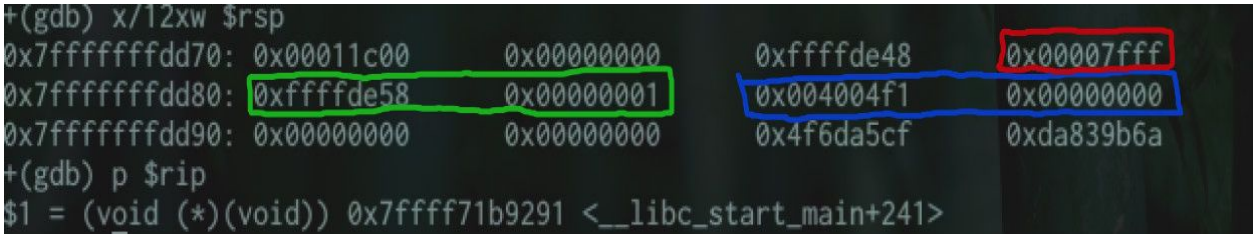
```
   0x00007ffff71b928f <+239>:   callq  *%rax
=> 0x00007ffff71b9291 <+241>:   mov    %eax,%edi
   0x00007ffff71b9293 <+243>:   callq  0x7ffff71ce9d0 <exit>
+---Type <return> to continue, or q <return> to quit---
   0x00007ffff71b9298 <+248>:   xor    %eax,%eax
   0x00007ffff71b929a <+250>:   jmpq   0x7ffff71b91d7 <__libc_start_main+55>
   0x00007ffff71b929f <+255>:   mov    0x37d40a(%rip),%rax        # 0x7ffff75366b0 <__libc_pthread
_functions+400>
   0x00007ffff71b92a6 <+262>:   ror    $0x11,%rax
   0x00007ffff71b92aa <+266>:   xor    %fs:0x30,%rax
   0x00007ffff71b92b3 <+275>:   callq  *%rax
   0x00007ffff71b92b5 <+277>:   mov    0x37d3e4(%rip),%rax        # 0x7ffff75366a0 <__libc_pthread
_functions+384>
   0x00007ffff71b92bc <+284>:   ror    $0x11,%rax
   0x00007ffff71b92c0 <+288>:   xor    %fs:0x30,%rax
   0x00007ffff71b92c9 <+297>:   lock decl (%rax)
   0x00007ffff71b92cc <+300>:   sete   %dl
   0x00007ffff71b92cf <+303>:   test   %dl,%dl
   0x00007ffff71b92d1 <+305>:   je     0x7ffff71b92f3 <__libc_start_main+339>
   0x00007ffff71b92d3 <+307>:   xor    %eax,%eax
   0x00007ffff71b92d5 <+309>:   jmp    0x7ffff71b9291 <__libc_start_main+241>
   0x00007ffff71b92d7 <+311>:   mov    0x8(%rsp),%rax
   0x00007ffff71b92dc <+316>:   lea    0x140992(%rip),%rdi        # 0x7ffff72f9c75
   0x00007ffff71b92e3 <+323>:   mov    (%rax),%rsi
   0x00007ffff71b92e6 <+326>:   xor    %eax,%eax
   0x00007ffff71b92e8 <+328>:   callq  *0x110(%rdx)
   0x00007ffff71b92ee <+334>:   jmpq   0x7ffff71b9206 <__libc_start_main+102>
   0x00007ffff71b92f3 <+339>:   mov    $0x3c,%edx
   0x00007ffff71b92f8 <+344>:   nopl   0x0(%rax,%rax,1)
   0x00007ffff71b9300 <+352>:   xor    %edi,%edi
```

```
   0x00007ffff71b9302 <+354>:   mov    %edx,%eax
   0x00007ffff71b9304 <+356>:   syscall
   0x00007ffff71b9306 <+358>:   jmp    0x7ffff71b9300 <__libc_start_main+352>
   0x00007ffff71b9308 <+360>:   mov    0x8(%rsp),%rax
   0x00007ffff71b930d <+365>:   mov    0x377b3c(%rip),%rdx        # 0x7ffff7530e50
+---Type <return> to continue, or q <return> to quit---
   0x00007ffff71b9314 <+372>:   lea    0x140974(%rip),%rdi        # 0x7ffff72f9c8f
   0x00007ffff71b931b <+379>:   mov    (%rax),%rsi
   0x00007ffff71b931e <+382>:   xor    %eax,%eax
   0x00007ffff71b9320 <+384>:   callq  *0x110(%rdx)
   0x00007ffff71b9326 <+390>:   jmpq   0x7ffff71b923f <__libc_start_main+159>
   0x00007ffff71b932b <+395>:   mov    0x160(%rax),%r13
   0x00007ffff71b9332 <+402>:   mov    0x377a97(%rip),%rax        # 0x7ffff7530dd0
   0x00007ffff71b9339 <+409>:   xor    %r12d,%r12d
   0x00007ffff71b933c <+412>:   mov    (%rax),%rbp
   0x00007ffff71b933f <+415>:   add    $0x470,%rbp
   0x00007ffff71b9346 <+422>:   mov    0x18(%r13),%rax
   0x00007ffff71b934a <+426>:   test   %rax,%rax
   0x00007ffff71b934d <+429>:   je     0x7ffff71b9354 <__libc_start_main+436>
   0x00007ffff71b934f <+431>:   mov    %rbp,%rdi
   0x00007ffff71b9352 <+434>:   callq  *%rax
   0x00007ffff71b9354 <+436>:   add    $0x1,%r12d
   0x00007ffff71b9358 <+440>:   add    $0x10,%rbp
   0x00007ffff71b935c <+444>:   mov    0x40(%r13),%r13
   0x00007ffff71b9360 <+448>:   cmp    %r12d,%r14d
   0x00007ffff71b9363 <+451>:   jne    0x7ffff71b9346 <__libc_start_main+422>
   0x00007ffff71b9365 <+453>:   jmpq   0x7ffff71b9237 <__libc_start_main+151>
End of assembler dump.
```

The “x/i $pc” can be set to run all the time using the usual configuration mechanism. The debug system will move the value of %edi to the store place of $eax. In the second debug command, It is pointed to by rbp, the "base pointer," and is used in combination with an offset to reference all local variables. Every time a function is called, RBP is updated to point to its stack frame. The value of rbp is 400510. The rsp point to the top of the current stack frame, then the value of rsb is ffffdd70.



The green is saved RBP of factorial(2), the blue is return address during factorial(1), the red is argument during factorial(1).

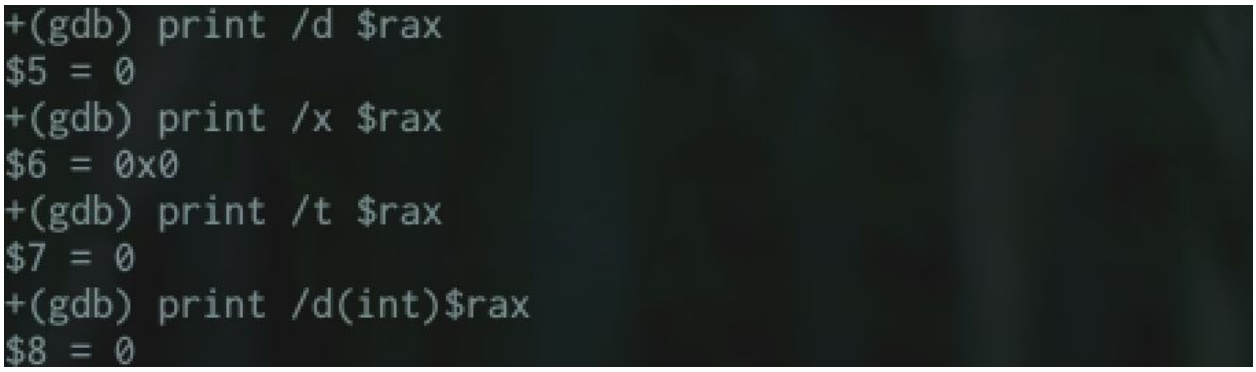


A program counter is a register in a computer processor that contains the address (location) of the instruction being executed at the current time. As each instruction gets fetched, the program counter increases its stored value by 1. ... Within a computer, an address is a specific location in memory or storage.

The first debug command is print /x $rip which print program counter in hex. The second debug command is print /d $rip which print program counter in decimal. The third debug command is print /t $rip which print program counter in binary.

The first debug command is print /d $rax which print contents of %rax in decimal. The second debug command is print /x $rax which print contents of %rax in hex. The first debug command is print /t $rax which print contents of %rax in binary. The first debug command is print /d(int) $rax which print contents of %rax in decimal after sign-extending lower 32-bits. If there is some number below the 32-bit is 0xffffffff, then the $8 is equal to -1.

The contents of %rax is data which is 0 in this debug system.



The first debug command is print 0x100 which is print decimal representation of 100. The value is 256. The second debug command is print /x($rsp+8) which is print (contents of $rsp) +8 in hex. The original contents of $rsp is 0x7fffffffdd70, then plus 8 is 0x7fffffffdd78. The third debug command is print *(int *) ($rsp+8) which print integer at address %rsp + 8, then it is -8632.

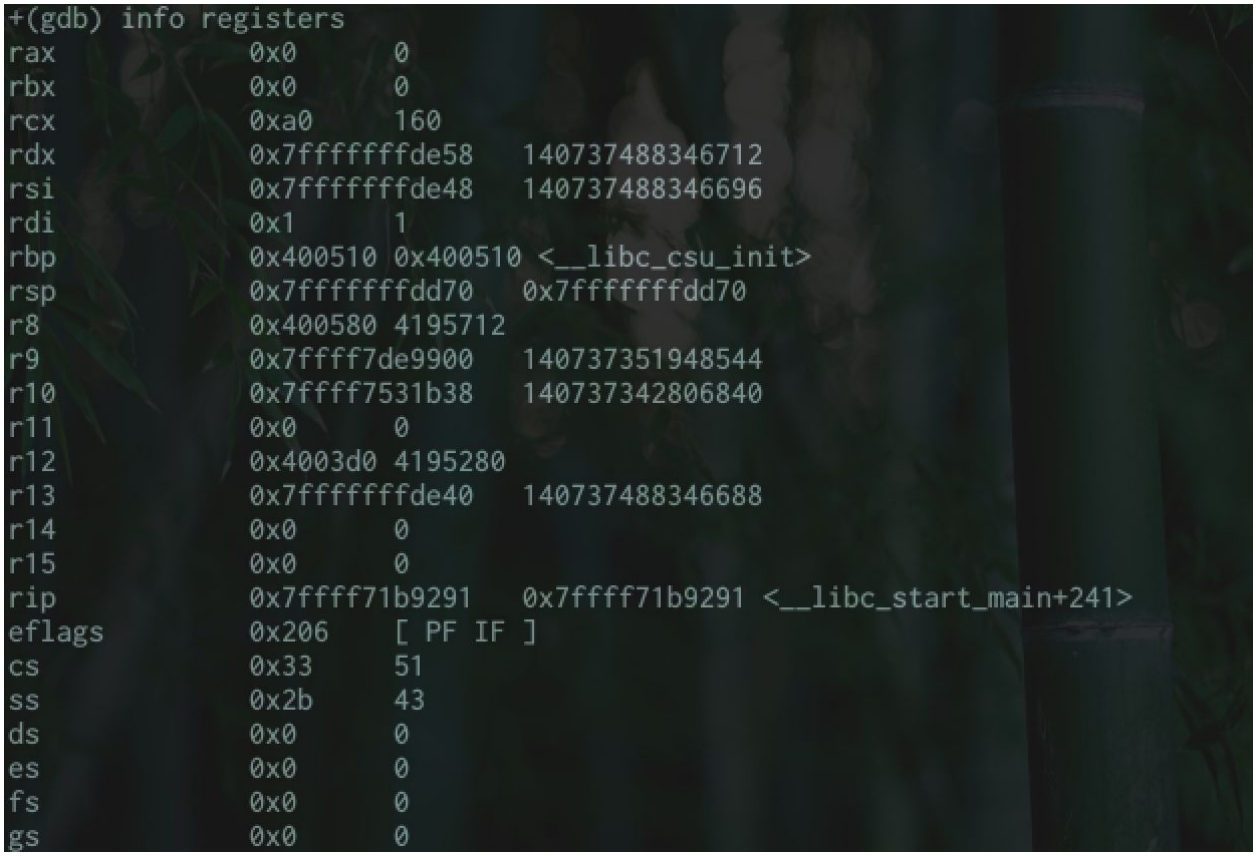
```
+(gdb) print /x $rsp
$1 = 0x7fffffffdd70
```

```
+(gdb) print 0x100
$9 = 256
+(gdb) print /x($rsp+8)
$10 = 0x7fffffffdd78
+(gdb) print *(int *) ($rsp+8)
$11 = -8632
```

The first debug command is x/2wd $rsp which examine two (4-byte) words starting at address in $rsp, then print in decimal. The second debug command is x/gd $rsp which examine (8-byte) word starting at address in $rsp, then print in decimal. Because sum of two 4-byte words is equal to one 8-byte word, so they have same memory address and values.

```
+(gdb) x/2wd $rsp
0x7fffffffdd70: 72704   0
+(gdb) x/gd $rsp
0x7fffffffdd70: 72704
```

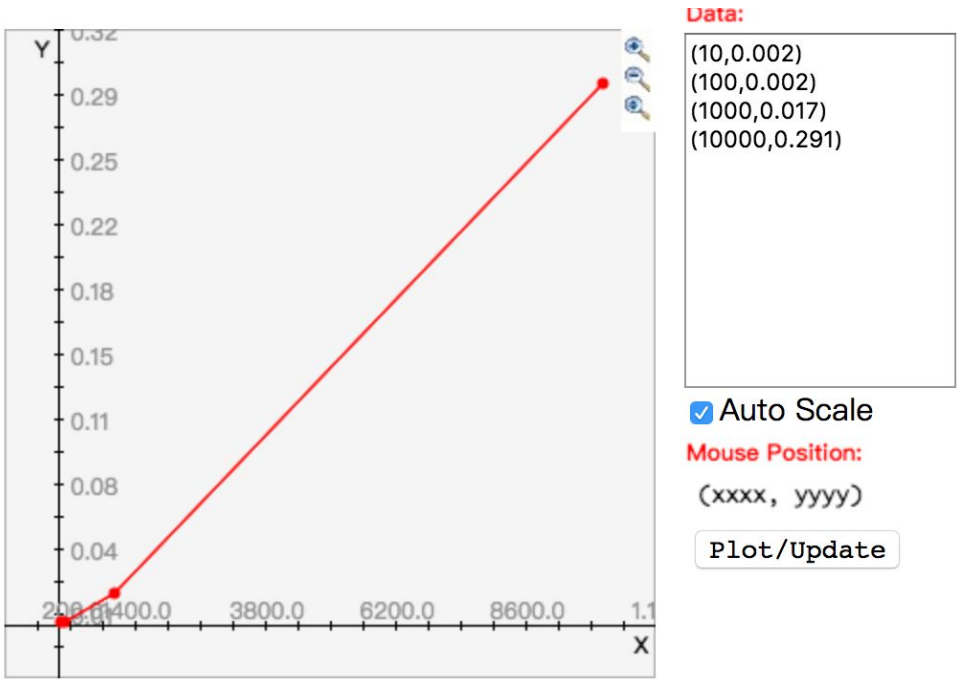
The below are register and their contents. That print the names and values of all registers except floating-point and vector registers (in the selected stack frame). GDB always considers the contents of an ordinary register as an integer when the register is examined in this way. Some machines have special registers which can hold nothing but floating point; these registers are considered to have floating point values. There is no way to refer to the contents of an ordinary register as floating point value (although you can print it as a floating point value with 'print/f $regname').



❖5. The Factorial Running Time

The factorial 10 has running time 0.002s, the factorial 100 has running time 0.002s, the factorial 1000 has running time 0.017s, the factorial 10000 has running time 0.291s. The line will directly going straight up, that means big factorial number cost lots of time.

```
Last login: Tue Mar 28 00:41:02 on ttys000
ShirongdeMBP:~ shirongzheng$ cd Desktop
ShirongdeMBP:Desktop shirongzheng$ g++ factorialTime.cpp
ShirongdeMBP:Desktop shirongzheng$ ./a.out
factorial(10) time: 0.002
ShirongdeMBP:Desktop shirongzheng$ g++ factorialTime.cpp
ShirongdeMBP:Desktop shirongzheng$ ./a.out
factorial(100) time: 0.002
ShirongdeMBP:Desktop shirongzheng$ g++ factorialTime.cpp
ShirongdeMBP:Desktop shirongzheng$ ./a.out
factorial(1000) time: 0.017
ShirongdeMBP:Desktop shirongzheng$ g++ factorialTime.cpp
ShirongdeMBP:Desktop shirongzheng$ ./a.out
factorial(10000) time: 0.291
ShirongdeMBP:Desktop shirongzheng$
```



❖6. Conclusions

In the conclusion, I learned how to debugging in MIPS, MS Visual Studio and GDB in Linux. This take home test is going to debug factorial function. We should to compare the similarity and difference of all threes. That cause each debug system, whatever the Windows X32 bit or Linux X64 bit will debugging or compiling each function. In the end, this assignment required to find out the cost time of each factorial. I spent more than 10 hours to finish all the sections. In the suggestion, it is better to do the efficiently work in less time.