15 FIRST DATES WITH ASSEMBLY PROGRAMMING

(Assembly Programming for Hackers)

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GARAGE 4 HACKERS

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15 First Dates with Assembly Programming

10th March 2011
Ver. 0.1

Few words…

This document is an attempt to provide some supplements to those who are new to assembly language programming and finding it hard to start the venture of shell coding and/or exploitation techniques.

Motive behind developing this document is:

1. To keep notes handy for authors own reference.
2. To provide a good supplement for beginners to play with registers, memory and our beloved stack (before smashing it down ;).
3. To teach the basics of assembly programming which are required to learn Shell coding (yeah those weird \x series of characters), and developing Exploitation skills by presenting 15 easy to understand assembly programs.

An attempt has been made to introduce and code/collect some very basic programs in assembly language. With each program, the reader would find himself more comfortable playing with registers, memory and stack (building blocks for Shell coding and Exploitation).

Although all programs have been coded on Linux, but emphasize has been given on the basic concepts of developing assembly programs instead of the platform.
Most of the tutorials you would find for Win32 Assembly basically teach you coding assembly programs for Win32 GUI instead of revealing the background scene of the state of computer memory, registers and stack. So here is an attempt to present the background process of "assembly programs" irrespective of the platform.

This document, by no means, is any reference guide or the author is pro in assembly. I reiterate, it's just an attempt to provide supplements to those who are learning assembly and find it hard to code assembly programs.

The readers might ask here and in fact they do; "Is it necessary to learn assembly for developing exploitation skill set?" The answer is: YES. This knowledge will help at almost every stage of exploitation, right from the level at which user use the public shell codes trusting them the way there are promised to work. It could not be better justified than the arguments proposed by H. D. Moore under the section "Penetration Testing: Learn Assembly?" in metasploit blog. Have a look at that and surely you would be convinced.

The document is in version 0.1 only and I understand the vast scope of improvement in it. The next version of it would cover things in more depth and breadth.

Thanks to:
My wife (for being understanding and supporting all the time)

Greetz to:
All my well wishers, friends and members @ www.garage4hackers.com (especially Eby, Punter, Vinnu, Fb1h2s, the_empty, Neo, Prashant)

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1. Wake-Up Call

The readers of this document would be broadly categorized into two categories per the prerequisites:

1. Those who understand the basics of assembly and are familiar with assembly instructions, memory layout etc.
2. Those who are totally new to this subject.

For those who fall under category 2, it's strongly suggested to grab the video series "Assembly Primer for Hackers" by Vivek Ramachandran. He has done an awesome job by creating such a simple to understand video tutorials on assembly programming. There are 11 video, each of 10-30 minutes time duration. That would give a kick start in understanding the basics of assembly programming language, the memory layout, registers and stack.

See the "Reference" section for the links to the awesome resources on the same subject.

Those falling under the category 1 can start with the following as refreshing morning walk! Or directly jump to the program examples section and shall refer to the introductory text when needed.

Development Platform: Linux
Assembler: GAS (The GNU Assembler)
Linker: ld
Compiler: GCC
Debugger: GDB
Operation on 32-bit registers on Intel architecture

Some one-liners to refresh your concepts:

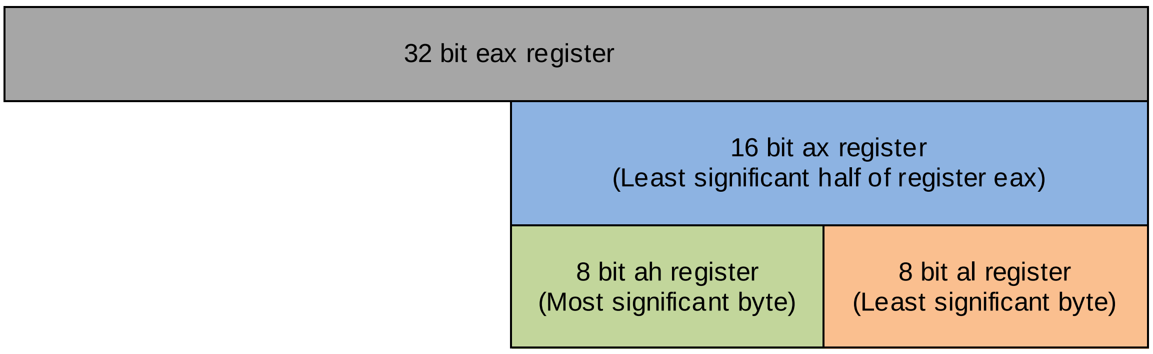
1. **GAS terminology**: *movl source, destination*

addl S, D	→	Add source to destination and store in destination
subl S, D	→	Subtract source from destination and store in destination
imull S, D	→	Multiply source by the destination and store in destination
idivl number	→	Dividend has to be in register eax, "number" is the divisor, quotient is then transferred to eax and the remainder to eds. The divisor can be any register or memory location

2. **Moving the values between registers**:

movl %eax, %ebx	→	Moving a double-word value (4 bytes) from the register eax into register ebx. The value in eax remains the same
movw %ax, %bx	→	Moving a word value (2 bytes) from the register ax into register bx
movb %ah, %bh	→	Moving a byte value (1 byte) from the register ah into register bh

The breakdown of a 32-bit register is as follows:



Hence you can perform operations on either of the following:

- The whole 32 bit register, as we did in the first mov statement by appending the character 'l' (small L) and fetching 32-bit registers, or
- The lower 16 bits of the register, as we did in the second mov statement by appending the character 'w' (word) and fetching 16-bit registers, or
- Either of the lowest 8-bits by addressing them as ah and al using movb (b ~ byte) instruction.

Please note that just for the sake of example the register "eax" has been taken. It could have been ebx or ecx or edx.

Word = 2 bytes
Dword = 4 bytes
Short = 16 bit
Int = 32 bit

The mov instruction is useful for transferring data along any of the following paths:

- To a register from memory
- To memory from a register
- Between general registers
- Immediate data to a register
- Immediate data to a memory

The mov instruction cannot move from memory to memory. Memory-to-memory moves can be performed, however, by the string move instruction MOVSx series discussed later in the document.

3. **Some Jump instructions**:

   cmpl %eax, %ebx

je	→ Jump if the values under comparison are equal
jg	→ Jump if the 2nd value is greater than the 1st value
jge	→ Jump if the 2nd value is greater than equal to the 1st value
jl	→ Jump if the 2nd value is less than the 1st value
jle	→ Jump if the 2nd value is less than equal to the 1st value
jmp	→ Unconditional jump

4. The difference between "call" and "jmp" is that "call" also pushes the return address onto the stack so that the function can return from where it was been called, while the "jmp" does not. This would be clearer with the examples in the later part of the document.

5. A specific integer value is associated with each syscall; this value must be placed into the register eax.
   There are six registers that are used for the arguments that the system call takes. The first argument goes in EBX, the second in ECX, then EDX, ESI, EDI, and finally EBP, if there are so many. If there are more than six arguments, EBX must contain the memory location where the list of argument is stored – but don't worry about this because it's unlikely that you'll use a syscall with more than six arguments.

6. **Moving Strings from one memory location to another (MOVSx series)**

movsb	→	move a byte (8 bits)
movsw	→	move a word (16 bits)

movsl	→	move a double word (32 bits)

Source	→	ESI points to memory location
Destination	→	EDI points to memory location

Interestingly, whenever any of the movsx series instruction is executed, the ESI and EDI are automatically incremented or decremented according to the Direction Flag (DF).

If DF (part of EFLAGS registers) is set i.e. has a value '1', ESI and EDI registers are decremented.
If DF is cleared i.e. has a value '0', ESI and EDI registers are incremented.

We can set DF using the STD instruction and it can be cleared using the CLD instruction.

7. **Moving Strings from memory location into registers (LODSx series)**

lodsb	→	load a byte from memory location into AL
lodsw	→	load a word from memory location into AX
lodsl	→	load a double word from memory location into EAX

The loading is always done into EAX register and the source string has to be pointed to by ESI.

The register ESI would be automatically incremented or decremented based on DF flag after the LODSx instruction executes.

8. **Storing Strings from registers into memory location (STOSx series)**

stosb	→	store a byte from AL into memory location
stosw	→	store a word from AX into memory location
stosl	→	stores a double word from EAX into memory location

The storing is always done from EAX register and the EDI points to the destination memory.

The register EDI would be automatically incremented or decremented based on DF flat after the STOSx instruction executes.

9. Comparing Strings (CMPSx series to compare various strings)

cmpsb	→	compares a byte value
cmpsw	→	compares a word value
cmpsl	→	compares a double word value

For comparison, the ESI should point to the source string and EDI should point to the destination string.

The register ESI and EDI would automatically incremented or decremented based on the DF flag after the CMPSx instruction executes.
When CMPSx instruction executes, it subtracts the destination string from the source string and appropriately sets the Zero Flag (ZF) in EFLAGS register. When the comparison matches, ZF is set to '0', else it is set to '1'.

*Remember that when ZF or DF are 'set', they have a numeral value of '1' and when they are 'not set', they have a numeral value of '0'.

CLD	→	clear the DF (DF = 0). ESI and EDI would get incremented
STD	→	set the DF (DF = 1). ESI and EDI would get decremented

CMPSx → When both of the strings are same, the subtraction of destination from source comes out to be ‘0’ and ZF gets set i.e. it gets a value of ‘1’
CMPSx → When both the strings are different, ZF gets a value of ‘0’ and is not set.

(gdb) info registers → would show only the ‘set’ components of EFLAGS

2. Get Dressed-Up

This section covers Data Accessing Modes along with some examples, the skeleton of an assembly program, and the basics of GDB.

Data Accessing Modes

Data accessing modes or methods are different ways a processor can adopt to access data. This section will deal with how those addressing modes are represented in assembly language instructions.

The general form of memory address references is following:

BaseAddress(%Offset, %Index, DataSize)

Perform the following calculation to calculate the address:

Final_address = BaseAddress + %Offset + (DataSize x %Index)

BaseAddress and DataSize must both be constants, while the other two, i.e. %Offset and %Index, must be registers. If any of the pieces is left out, it is just substituted with zero in the equation.

All of the following discussed addressing modes except immediate addressing mode can be represented in this fashion.

If you are new to this stuff, you might not be able to digest and understand it properly. So just go through them once and do keep referring them while programming.

1. **Immediate Addressing Mode**

Instruction → *movl $10, %eax*

It says; load the value 10 into the register eax. This mode is used to load direct values into registers or memory location. Please pay attention to the $ sign. It's the $ sign which is making it "Immediate Addressing Mode". Without it, the instruction would instruct to load the 'value' present at the memory location 10 into eax rather than the number 10 itself and thus would make it "Direct Addressing Mode" instead of "Immediate Addressing Mode".

2. **Direct Addressing Mode**

Instruction → *movl ADDRESS, %eax*

Hence, this is done by only using the <u>BaseAddress</u> portion, and rests of the fields have been substituted with zero in the equation.

It says; load the value at the ADDRESS into the register eax. This terminology should be quite clear to the readers acquainted with pointers in programming languages.

```
.section .data
        IntValue:
                .int 16
.section .text
        .globl _start
        _start:
                movl IntValue, %eax
```

The above code will pass the value 16 into register eax. Please do not worry about the code if you are not comfortable with it at the current moment. They would be clearer as you proceed with the document.

Another example could be:

movl 1002, %eax.

It is Direct Addressing Mode considering 1002 as some memory address containing some value.

3. Indirect Addressing Mode

Instruction → *movl (%eax), %ebx*

It says; eax is holding some address, and we want to move the value at that address into register ebx. Hence, the "Indirect Addressing Mode" loads a value from the address indicated by a register.

A very nice example of this addressing mode is to obtain the top of the stack without popping out the top value:

movl (%esp), %eax

4. Indexed Addressing Mode

Instruction → *movl BaseAddress(%Offset , %Index, DataSize), %DestinationRegister*

```
.section .data
        IntArray:
                .long 1, 2, 3, 4, 5
.section .text
        .globl _start
        _start:
              movl $0, %esi
              movl $0, %edi
              movl IntArray(%esi,  %edi, 4), %eax
```

This will move the value "1" from the initialized array into the register eax.
Actually the above statement says, "Start at the beginning of IntArray as the %Offset is zero, and take the first item number (because %Index is 0 and the counting of array starts from 0 itself).
Also remember that each number takes up four storage locations (because data type is 'long' i.e. 4 bytes)."
If edi is incremented to 1 i.e. if the %Index holds numeral value 1, the last code statement would move the number '2' from IntArray into eax.

5. Base Pointer Addressing Mode

Instruction → *movl 4(%eax), %ebx*

Base-pointer addressing is similar to indirect addressing, except that it adds a constant value to the address in the register.

movl (%esp), %eax → Indirect addressing mode. It would copy the value on the top of the stack into eax

movl 4(%esp), %eax → Base pointer addressing mode to access the 2nd top value on a stack

movl $9, 4(%edi) → copy the value 9 in the memory pointed out by (edi + 4)

movl $9, -2(%edi) → copy the value 9 in the memory pointed out by (edi – 2)

We would be using base pointer addressing mode very frequently while making programs in this guide.

6. **Register Addressing Mode**

Instruction → *movl %eax, %ebx*

Register mode simply moves data in or out of a register.

Some examples

Being said the above terminology; let us play moving some values in and out of memory/registers for practice.

Instead of taking examples one-by-one at this stage, let us pen down what generally arouses in mind of a newbie programmer.

Before that, we need to declare some memory locations and keep in mind that while "moving" the data from "source" to "destination" does not actually change the value at source. It is simply copied into the destination contrary to the word "move".

```
.section .data

    mem_location:

            .int 10

    IntegerArray:

            .int 10, 20, 30, 40, 50
```

1. How to move a value 15 in register?

   movl $15, %eax → Immediate Addressing Mode

2. How to move a value 15 in the location?
   movl $15, mem_location → This would change the value in mem_location from 10 to 15

3. How to move the value in the mem_location in a register and vice versa?

```
movl mem_location, %eax
movl %eax, mem_location
```

4. What if I need to copy the address of mem_location in a register? i.e. the value stored in the register would be the addess of the mem_location

   movl $mem_location, %eax → Notice the prepended "$" dollar to memory location

   print &mem_location = print /x $eax (Some GDB terminology you would come across later)

   Similarly, movl $mem_location, another_location, will load the address of mem_location to another_location.

5. What if I need to copy something from one register to another?

movl %eax, %ebx	→	To move a 32 bit value
movw %ax, %bx	→	To move a 16 bit value
movb %ah, %bh	→	To move a 8 bit value.

   Bottom line is that both, the source and destination, should be of same size.

6. How to access value in an array?

   BaseAddress(Offset, Index, Data_Size)

   Here the trap is, the "Offset" and "Index" needs to be mentioned in registers. "Data_Size" would be an integer value and it's basically the size of the data type under operation.

   Let us say you want to change the 4th variable of array to 44, following would be the instructions:

```
movl $0, %eax
movl $3, %ebx
movl $44, IntegerArray(%eax, %ebx, 4)
```

7. How to do indirectly (Indirect Addressing Mode)?

movl $mem_location, %eax	→ move the address of label mem_location into register eax
movl (%eax), %ebx	→ move the value at the address stored in register eax into register ebx i.e. mov the value of label mem_location into register ebx
movl $35, (%eax)	→ move the value 35 at the location pointed by the address stored in register eax i.e. here in the current case, the current value of label mem_location would be over written with integer value 35

The Sexy Figure: The Structure of an Assembly Language Program

```
# Start of Program.

# Anything after the symbol "#" is a comment.

# Any assembly program has following three sections and structure:

.section .data

                    } All initialized data goes here

.section .bss

                    } All uninitialized data goes here

.section .text

        .globl _start

        _start:

                Program Instructions

                More Instructions

                Some more Instructions

# End of Program
```

.section .data

Under this section you initialize your data. The initialized data will consume memory and would contribute in the size of executable file. The space is reserved during compile time only. Some examples of declaration could be:

.ascii	→	A non-NULL terminated string
.asciz	→	A NULL terminated string
.byte	→	1 byte value
.short	→	16 bit integer
.int	→	32 bit integer
.float	→	Single precision floating point number
.double	→	Double precision floating point number.
.int 10, 20, 30, 40, 50	→	Declaration of Integer Array
db '/bin/bash'	→	The DB, or define byte directive (it's not technically an instruction), allows us to set aside space in memory for a string

.section .bss

All uninitialized data is stored here. Anything declared in this segment is created at run time. Hence, whatever you declare here is not going to occupy any space inside the executable. Only when the program is loaded into memory, the space actually will be created. Following could be the declaration examples:

.comm buffer, 1000	→	declares a 'buffer' of 1000 bytes. 'buffer' would be the Label_name i.e. it would refer to the location that follows it.
.comm	→	declares common memory area
.lcomm	→	declares local common memory area

This section can reserve storage, but it cannot initialize it. This section is primarily useful for buffers because we do not need to initialize them anyway; we just need to reserve storage.

.section .text

This section comprises of program instructions.

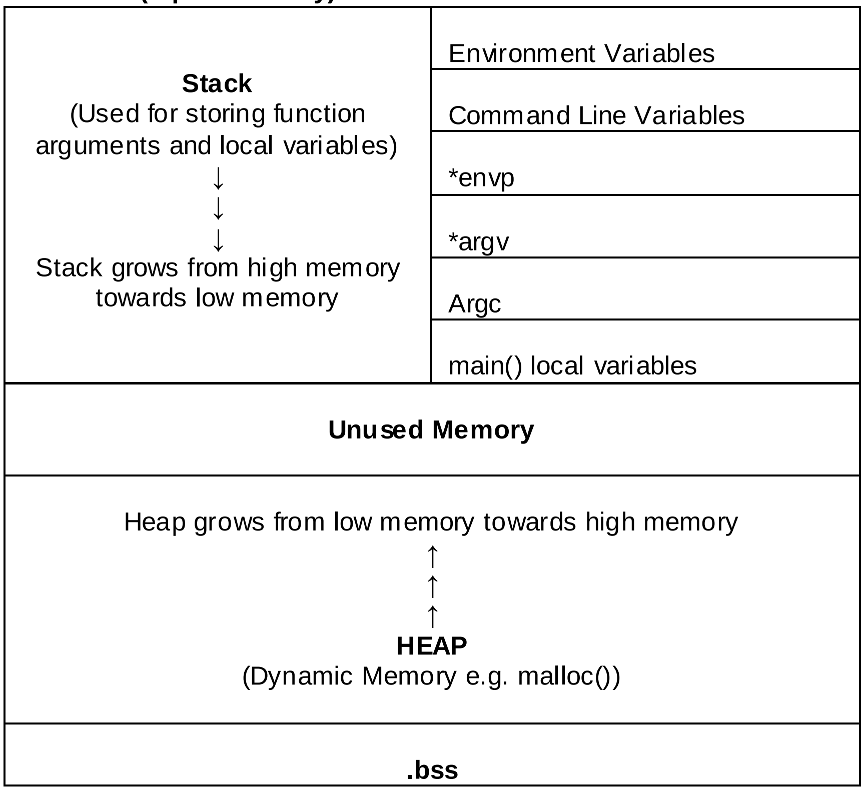
.globl _start
_start:

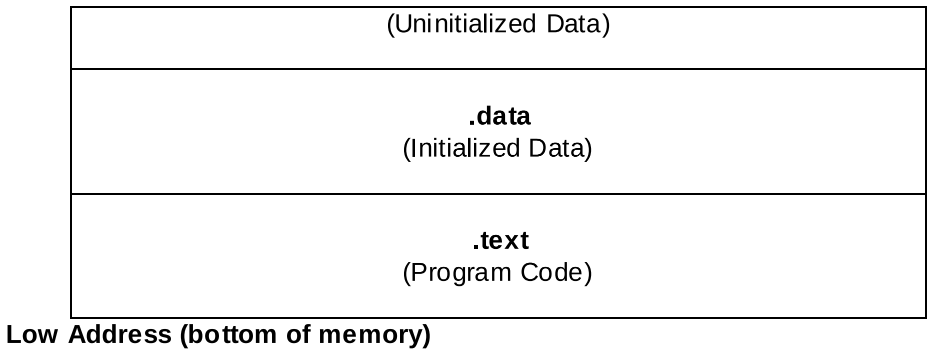
This is somewhat like the "main()" function of 'C' programming language, i.e. assembler would hunt for it to be treated as the start of the program.

We are free to include only that section of program which has some data or significance in our program. For example, if we do not have any uninitialized data in our program, we can exclude the .bss section from our program without any harm.

The process layout map in memory looks like follow:

High Addresses (top of memory)


Stack
(Used for storing function arguments and local variables)
Stack grows from high memory towards low memory
Environment Variables
Command Line Variables
*envp
*argv
Argc
main() local variables
Unused Memory
Heap grows from low memory towards high memory
HEAP
(Dynamic Memory e.g. malloc())
.bss


(Uninitialized Data)
.data
(Initialized Data)
.text
(Program Code)
Low Address (bottom of memory)

Some flirting basics – Essential GDB basics to analyze the code – Essential for debugging

Learn your debugger well to debug the code efficiently. This section comprises of some tricks/commands/short-cuts to use GDB efficiently. To cut it short, it's a cheat sheet for GDB

1. If intending to open compiled 'C' programs using GDB, you need to tell your compiler to compile your code with symbolic debugging information included. E.g.

   # gcc –g –o hello hello.c

   # gcc –ggdb –o hello hello.c

   # g++ -g –o hello hello.c

2. To run the program in GDB, do either of the following:

# gdb ./<binary> [Return Key]	→ This will open up the binary in GDB
# gdb [Return Key]	→ This will open up the debugger without loading any program. On the gdb prompt, pass the command "file <binary_name>" and that will cause the executable to be loaded up:

   (gdb) file <binary_name> [Return Key]

# gdb –tui ./<binary> [Return Key]	→ For console-cum-GUI GDB

3. If arguments as well have to be passed to the program to be loaded into GDB, following options can be opted:

   # gdb <binary> --args arg1 arg2 arg3 …. argN [Return Key]

   Or

   # gdb <binary> [Return Key]

   (gdb) run arg1 arg2 arg3 ….. argN

4. Hitting the 'RETURN' at gdb prompt will repeat the last command entered.

5. **Break Points**

   Use the "break" or "b" command at gdb prompt to specify a location which could be a function name, a line number or a source file and line number.

   Set Break Point

➔ *break main*	to set a break point at the function "main"
➔ *break 5*	to set a break point at the code line number 5
➔ *break hello.c:5*	to set a break point at code line number 5 of imported file hello
➔ *break *_start+1*	include "nop" on the very next line of it to get a break point there

   Check Break Point

➔ *info breakpoints*, to list the current break points (type 'i b' without quotes for shortcut)

Clear Break Point

➔ clear main to clear the break point set at particular function

➔ delete <breakpoint number>

➔ If the program has already been "run" but you forget to set breakpoints, hit CTRL-C and that will stop the program where ever it happens to be and return you to the gdb prompt. At that point, you can set up a proper breakpoint somewhere and 'continue' to that break point.

6. 'next', and 'step' (s for shortcut) to proceed step by step after you have hit the breakpoint. 'continue' (c) to continue until next breakpoint or end of program.
   One shortcut could be just hitting RETURN as it repeats the last command entered. This will save you typing 'next' or's' over and over again.

7. Following and the next point (8) are gdb commands which you would use very frequently while debugging your program:

(gdb) list	To list the source code of executable loaded
(gdb) disassemble <function_name>	To dump the assembly code of function referred
(gdb) help <keyword>	gdb help pages
(gdb) info registers	To see the content and state of all registers
(gdb) info variables	To see all variables and their respective addresses

8. Examine command

(gdb) print variable_name	To see the value of a variable in decimal
(gdb) print /x variable_name	To see the value of a variable in hex
(gdb) print /c variable_name	To see the value of a variable in ASCII
(gdb) print &Label_name	To see the address of Label_name
(gdb) print /x &Label_name	To see the address of Lable_name in better format
(gdb) x/FMT &Label_name	To see the value of variable (useful in case of integers)
(gdb) x/1s &Label_name	To see the whole string in single-shot (useful in case of strings)
(gdb) x/1s $register	To see the whole string in single-shot located at the address stored in register
(gdb) x/1s 0x080000 i.e address	To see the whole string in single-shot at a particular address
(gdb) print /c $eax	To see the value in register in ASCII
(gdb) print /d $eax	To see the value in register in Decimal
(gdb) print /x $eax	To see the value in register in HEX
(gdb) x/FMT Address	Address could be something like 0x08.. or '&Label_name'

→ If there is no Label_name, take the address and fetch to examine command

3. Let's Start Dating

This section is an attempt to produce 15 Assembly programs to help beginners learn Assembly programming.

Date – 1: Know Your "Exit" Before You Say Hello

Purpose	To exit the program "cleanly" and pass the exit code to the Linux kernel
Input	Nothing
Program Flow	• Call the "exit()" function and exit out of program • Check the return code at console
Output	Nothing. Just check the exit code.

```
# Program to explain the way to exit() from a Linux Assembly Program

.section .data

.section .bss

.section .text
            .globl _start

            _start:
                  movl $1, %eax
                  movl $0, %ebx
                  int $0x80

# End of program
```

Let's dissect the program

We have not initialized anything in .data or .bss section as we are only interested in exiting from the program successfully. Hence just for the sake of completeness they have been included; else they can be dropped as well from the program code.

The 'C' programming terminology for exit is:
exit(integer-status)
e.g. exit(0) or exit(1)

As a programmer, we generally pass the integer value '0' on success and integer value '1' on failure. So the program logic is, call the exit function and pass the relevant integer value to it as an exit integer-status.

Following are the steps we need to follow in Assembly language programs.

- Load the system call for relevant function (i.e. call the exit function in current program)
- Load it's parameters (i.e. pass the integer value to it)
- Call Linux kernel interrupt to run the command (i.e. execute the exit function in current program)

The system call is always loaded into the register eax with the instruction:

```
movl $System_Call_Number, %eax
```

In the current case of exit, the System_Call_Number is '1', hence the instruction would be:

```
movl $1, %eax
```

The numbers of parameters required for the successful function call are fetched sequentially into ebx, ecx, edx and so on.

In the current case of exit, only one parameter is required which is either 0 (success status) or 1 (failure status), hence just ebx needs to be loaded:

```
movl $0, %ebx
```

(In the example of read() or write() function call we will see how other parameters are loaded into registers)

Finally the control is handed over to Linux kernel by calling the interrupt *int $0x80* to run the exit command.

```
int $0x80
```

So the following three instructions in assembly language are equivalent to the exit(0) function call in 'C' programming language:

```
movl $1, %eax
movl $0, %ebx
int $0x80
```

For all such calls we need to follow the same pattern i.e. load the system call number into the register eax and start loading the required parameters into ebx, ecx, edx and so on. Finally call the Linux kernel interrupt with the instruction *int $0x80* and run the desired command.

EAX → System Call number
EBX → First argument
ECX → Second argument
EDX → Third argument
ESI → Fourth argument
EDI → Fifth argument

For system calls which require more than 5 arguments, we go ahead and pass a pointer to structures containing those arguments.

Execution	Name the program → `exit.s` Assemble the program → `$ as –gstabs –o exit.o exit.s` Link the program → `$ ld –o exit exit.o` Execute the program → `$ ./exit` Check the output → `$ echo $?` You must get '0' at the console as output. If any of the above commands report error(s), do spell check for the source code and commands. After correcting the source code, you have to re-run all the commands. <u>You must always re-assemble and re-link assembly programs after the source code file has been modified.</u>

Play Ground	Pass a different parameter to exit system call and see the result with echo $?
References	System Calls: /usr/include/asm/unistd.h http://linux.die.net/man/2/syscalls
What we learnt?	The way to call “system calls” (exit in this case) with required number of parameters.

Let’s visit and analyze the “Hello World” program now:

Date – 2: Hello ☺ With A Gentle Smile

Purpose	To print “Hello World” on the console – Let’s follow the programming trend.
Input	Nothing
Program Flow	• Initialize the string “Hello World\n” • Call the write() function to write the string on the console • Exit out of program
Output	”Hello World” string on console

```
# Program to print the string "Hello World" on console
# Anything after the symbol “#” is a comment

.section .data

                HelloWorld:
                              .ascii "Hello World\n"

.section .bss

.section .text
                .globl _start

                _start:
                       # Following is the call to write() function
                        movl $4, %eax
                        movl $1, %ebx
                        movl $HelloWorld, %ecx
                        movl $12, %edx
                        int $0x80

                       # Following is the exit() process call
                        movl $1, %eax
                        movl $0, %ebx
                        int $0x80

# End of program
```

Let's dissect the program

A string "Hello World\n" has been initialized in the .data section. This string would be accessible from anywhere in the program by its label name "HelloWorld". So the HelloWorld label is like a pointer to the string following it.
The .ascii is used to define all ascii strings in assembly.

The space acquired by the string "Hello World\n" i.e. 12 characters, would be a part of the size of executable and would be assigned during compile time.

Contrary to it, in .bss section we just declare the variables and the size they would need in future. They are allocated memory at run time and hence do not add up to the size of executable.

Let's analyze the first half of the .text section. Second half is the call to exit() syscall which we have already discussed in previous example.

In order to write something, be it on console or in a file, we need to call write() syscall:
write(**int** fd, **const** void *buf, **size_t** count)

So by looking at the call to write() syscall, we know that in addition to system call number itself we need to pass three more parameters to it.

The system call number goes into eax register:

```
movl $4, %eax
```

The file descriptor (fd) goes into ebx. In case of console, the fd is '1'. In case of writing data to some file, we need to pass the fd of that file.

```
movl $1, %ebx
```

Next is the buffer from where write syscall needs to read the data. Since the label HelloWorld is a pointer to our string, we shall pass the address of the label HelloWorld into the ecx register:

```
movl $HelloWorld, %ecx
```

The last parameter for a successful write syscall is the number of bytes to be read from the buffer. In our case, the length of the string "Hello World\n" is 12 bytes.

```
movl $12, %edx
```

Here ends the call to write syscall and loading of the required parameters.

The last step is to call the Linux kernel interrupt to finish the job

```
int $0x80
```

After printing out our string on console, the execution will proceed with the second half of the code and will exit gracefully.

Execution	Name the program → `HelloWorld.s` Assemble the program → `$ as –gstabs –o HelloWorld.o HelloWorld.s` Link the program → `$ ld –o HelloWorld HelloWorld.o` Execute the program → `$ ./HelloWorld`

	The string “Hello World” should get displayed at the console as output. If any of the above commands report error(s), do spell check for the source code and commands. After correcting the source code, you have to re-run all the commands. <u>You must always re-assemble and re-link assembly programs after the source code file has been modified.</u>
Play Ground	-
References	File descriptors in Linux: 0 → Standard Input, STDIN 1 → Standard Output, STDOUT 2 → Standard Error, STDERR The system call for write is 4. System Calls: /usr/include/asm/unistd.h http://linux.die.net/man/2/syscalls
What we learnt?	The way to call “system calls” (write in this case) with required parameters.

Date – 3: Did Not Work? Let’s Say Hello 10 Times

Purpose	To print “Hello World” 10 times on console using the concept of looping
Input	Nothing
Program Flow	• Initialize the string “Hello World” • Set the counter to the number of times string has to be printed • Get into a loop of printing the string counter number of times and decrement counter with every successful execution of loop • Exit out of program when counter becomes zero
Output	”Hello World” string printed ten times on console

```
# Program to print "Hello World" 10 times on console using  “jmp” instruction and a counter

.section .data
            HelloWorld:
                        .ascii "Hello World"

.section .bss

.section .text
            .globl _start
```

```
_start:
nop                     # It's just been added to overcome buggy gdb against break point
movl $10, %ecx

PrintHello:
    cmpl $0, %ecx
    je ExitCall

    pushl %ecx

    # Following 5 lines are to print the string on console once with each iteration
    movl $4, %eax
    movl $1, %ebx
    movl $HelloWorld, %ecx
    movl $12, %edx
    int $0x80

    popl %ecx
    decl %ecx

    jmp PrintHello


# Following is the exit() process call
ExitCall:
    movl $1, %eax
    movl $0, %ebx
    int $0x80

# End of program
```

Let's dissect the program

Couple of concepts to discuss here.

We have moved from the "flat" coding to some "segmentation". Now we have a different body for "exit" instruction and a different body for the "PrintHello" loop. They are somewhat analogous to functions in 'C' language, but mind it that none of them is a function. We would see function declaration and usage in examples further down the document.

The program is not complex in any way. The register ecx has been initialized with the count 10, the desired number of times the string should get printed on console.

With every iteration of PrintHello section, the value in register ecx is compared with numeral '0' and is decremented by numeral '1' at the end of section. The iteration of section would last until the value of ecx is greater than 0.

The only thing which could bother a bit to a beginner is the "pushl" and "popl" instructions here.
It is for the sake of protecting the value of ecx register. If you look carefully, our "write" code is using ecx register to load the address of string every time "write" is getting called.
At the same time we wish to use ecx as counter variable as well. Hence before it being modified by "write" call, we are saving its value by pushing on the stack and after it's been used by "write" call, we are popping out its value back into ecx register.

Execution	Name the program → Hello10times.s Assemble the program → $ as –gstabs –o Hello10times.o Hello10times.s

	Link the program → $ ld –o Hello10times Hello10times.o Execute the program → $ ./ Hello10times The declared string would be printed out on console 10 times. If any of the above commands report error(s), do spell check for the source code and commands. After correcting the source code, you have to re-run all the commands. <u>You must always re-assemble and re-link assembly programs after the source code file has been modified.</u>
Play Ground	Open up the executable with GDB and analyze the complete program step by step setting up some break point.
References	-
What we learnt?	A bit of program code management by segregating code into different sections Basics of push and pop operations and the way to retain value of some variable/register.

Date – 4: Did Not Work? Let's Say H3!!0 10 Times in l337 Way – the sm4r7 way

Purpose	To print "Hello World" 10 times on console using the concept of looping
Input	Nothing
Program Flow	• Initialize the string "Hello World" • Set the counter to the number of times string has to be printed • Get into a loop of printing the sting counter number of times and decrement counter with every successful execution of loop • Exit out of program when counter becomes zero
Output	"Hello World" string on console ten times

```
# Program to print "Hello World" 10 times on console using "loop" instruction and ecx counter

.section .data
        HelloWorld:
                .ascii "Hello World"

.section .bss

.section .text
        .globl _start

        _start:
        nop             # It's just been added to overcome buggy gdb against break point
        movl $10, %ecx

        PrintHello:
                cmpl $0, %ecx
                je ExitCall

                pushl %ecx

                # Following 5 lines are to print the string on console once
                movl $4, %eax
                movl $1, %ebx
                movl $HelloWorld, %ecx

                movl $12, %edx

                int $0x80

                popl %ecx

                loop PrintHello


                # Following is the exit() process call
      ExitCall:
                movl $1, %eax
                movl $0, %ebx
                int $0x80

# End of program
```

Let's dissect the program

The program does nothing different than the previous one; it just does in a different way.
Here we have introduced a new instruction "loop".

The instruction "loop" and the register %ecx work together. Whenever "loop" instruction is called, the value of ecx gets decremented by one automatically.

You can observe in our code that "decl %ecx" instruction and "jmp PrintHello" have been removed, using which we coded our previous program.

Execution	Name the program → l33t-h3llo.s Assemble the program → $ as –gstabs –o l33t-h3llo.o l33t-h3llo.s Link the program → $ ld –o l33t-h3llo l33t-h3llo.o Execute the program → $ ./ l33t-h3llo The declared string would be printed out on console 10 times. If any of the above commands report error(s), do spell check for the source code and commands. After correcting the source code, you have to re-run all the commands. You must always re-assemble and re-link assembly programs after the source code file has been modified.

Play Ground	Open up the executable with GDB and analyze the complete program step by step setting up some break point.
References	-
What we learnt?	Another way of "looping".

Date – 5: Hello Worked! Let's Exchange Some Beautiful Words

Purpose	This program copies a string from one memory location to another memory location
Input	Nothing
Program Flow	• Initialize the string "Hello World" • Declare a memory location as destination • Copy string from source to destination • Exit out of program
Output	The defined string gets copied to destination from source

```
# Program to copy the string "Hello World" from one memory location to another

.section .data

                HelloWorld:
                              .ascii "Hello World"

.section .bss
                .lcomm Destination, 50

.section .text
                .globl _start

                _start:
                     nop
                     movl $HelloWorld, %esi
                     movl $Destination, %edi
                     movl $11, %ecx

                     rep movsb

                     # Following is the exit() process call
                     movl $1, %eax
                     movl $0, %ebx
                     int $0x80

  # End of program
```

Let's dissect the program

String's cannot simply be moved like integers.

In the .data section, the string "Hello World" has been initialized. Next, 50 bytes buffer has been declared in .bss section. This 50 byte would be allocated to it during run time and hence it would not contribute to the size of the executable (binary).

The string operations do not deal with mere location names, instead they deal with the registers "esi" and "edi" as well.
The source address has to be loaded into esi and destination address into edi. This has been achieved with the following codes:

```
movl $HelloWorld, %esi
movl $Destination, %edi
```

After that we have moved an integer value 11 into ecx, which you might have guessed correctly the number of characters in our string "Hello World". Here, copying the number of characters in the register ecx has significance and any other register cannot be used. We need a counter to count 11 times and with every count we copy one byte from source to destination with the instruction movsb.

```
rep movsb
```

movsb is an instruction to move just one byte at a time. Its family members, movsw will move 2 bytes and movsl will move 4 bytes at a time.

The instruction "rep" will repeat the instruction "movsb" ecx number of times, i.e., 11 in our case and with every successful operation, the value of ecx would be decremented.

So, the instruction "rep movsb" will execute 11 times and hence 11 bytes would be copied, 1 at a time, copying the whole string from source to destination.

Next follows the "exit" code to exit out of program cleanly.

In all of the above programs, we hard binded the string length value in edx register. It could be made generic with the following code:

```
helloworld:
    .ascii "hello world"
helloworld_end:

.equ helloworld_len, helloworld_end – helloworld

movl $helloworld_len, %edx
```

The .equ notation is covered later in the document.

Execution	Name the program → MoveString.s Assemble the program → $ as –gstabs –o MoveString.o MoveString.s Link the program → $ ld –o MoveString MoveString.o Execute the program → $ ./MoveString The defined string would be copied into the "Destination" If any of the above commands report error(s), do spell check for the source

	code and commands. After correcting the source code, you have to re-run all the commands. <u>You must always re-assemble and re-link assembly programs after the source code file has been modified.</u>
Play Ground	Open up the executable with GDB and analyze the complete program step by step setting up some break point. *(gdb) x/1s &Destination* would show the string stored at Destination Do also notice during the execution that the values of esi and edi will also increment with every successful movsx operation. The amount of increment will depend whether we are copying one byte or two bytes and so on. Actually ESI and EDI could either increment or decrement. The "direction flag" determines whether esi and edi would increment or decrement. If Direction Flag is "clear", they would increment. If Direction Flag is "set", they would decrement. We can clear the "Direction Flag" with the instruction "cld" and we can set the "Direction Flag" with the instruction "std" In GDB, you can see whether the DF flag is "set" or "clear" by running the following command: (gdb)info registers Notice the EFLAGS. If you see "DF" in eflags, it means DF has been set and the value of ESI and EDI would decrement with each iteration of "rep". In our case, since we wish ESI and EDI to increment to point to next memory location, DF has to be cleared if set.
References	-
What we learnt?	String operations are performed using esi and edi registers and the instructions used are: movsb → To move one byte of string movsw → To move two bytes of string (one word) movsl → To move four bytes of string (double word) cld → Clear the Direction Flag std → Set the Direction Flag

Date – 6: Picking the Best Feature – (Finding highest value in an integer array)

Purpose	To find the highest value in an integer array
Input	Nothing
Program Flow	• See in the program explanation
Output	Check the exit status of the program to find the highest value in the supplied integer array # echo $?

```
# Program to find the highest number in an integer array


.section .data
            IntArray:
                        .long 40, 15, 200, 56, 78, 88, 27, 75, 96, 100

.section .bss

.section .text
   .globl _start

            _start:
                        movl $9, %ecx                       # Initialize the counter
                        movl $0, %edi
                        movl IntArray(, %edi, 4), %ebx

                        loop:
                              cmpl %edi, %ecx
                              je ExitCall

                              movl IntArray(, %edi, 4), %eax
                              cmpl %ebx, %eax
                              ja newhighest
                              incl %edi
                              call loop

                        newhighest:
                              movl %eax, %ebx
                              incl %edi
                              call loop

                        ExitCall:
                              movl $1, %eax
                              int $0x80

# End of program
```

Let's dissect the program

In the .data section, an integer array of 10 elements has been declared.

The logic we have implemented in this program is as follows:

1. Initialize a counter equal to the number of elements in integer array.
   `movl $9, %ecx`

2. Use Indexed Addressing Mode to access elements of integer array. Use edi for Index and keep on incrementing it to access elements of array. Exit the program when finished with accessing all the elements of the array.
   `movl IntArray(, %edi, 4), %ebx`

3. Assume the very first element in array to be the highest value present. Store it in ebx. The reason for choosing register ebx for storing highest value is that you can see the output of the program, i.e. the highest integer in array, at command line as the exit status of program
   `# echo $?`
   If we chose some other register for storing the highest element, we need to access and see its value in gdb after program finishes its execution.

   Observe the exclusion of ebx register in ExitCall code.

4. Get into a loop of accessing the next element of array; compare the value obtained with the value in register ebx. If the value is smaller than the value stored in ebx, continue and fetch the next element from the array. Else, if the value is higher than the value stored in ebx, replace the value in ebx with this new higher value.

5. Exit when finished with accessing all the elements of supplied integer array.

Execution	Name the program → `FindHighest.s` Assemble the program → `$ as –gstabs –o FindHighest.o FindHighest.s` Link the program → `$ ld –o FindHighest FindHighest.o` Execute the program → `$ ./ FindHighest` After the successful execution of the program, check the exit status of program to see the highest value in the supplied integer array: `# echo $?` If any of the above commands report error(s), do spell check for the source code and commands. After correcting the source code, you have to re-run all the commands. <u>You must always re-assemble and re-link assembly programs after the source code file has been modified.</u>
Play Ground	Open up the executable with GDB and analyze the complete program step by step setting up some break point. Analyze the flow of the program, the conditional jumps and the changing values in various registers. Tweak the code to find the lowest value in the integer array.
References	-
What we learnt?	Traversing array with Index Addressing Mode.

Date – 7: Be Sm4r7, Believe in TTMM (The Dutch Treat) – (Function call to add two numbers)

Purpose	To add two numbers by making a function call. To analyze the stack closely during function call.
Input	Pass two parameters to be added to function
Program Flow	• Initialize two intergers • Pass interger values as parameters to function • Do addition in the function and return the sum • Exit out of program
Output	The sum of added numbers

```
# Program explaining the way function call is made.

.section .data                                  # initializing data
        Int_1:
                .long 27
        Int_2:
                .long 13

.section .bss

.section .text
  .globl _start

        _start:
                pushl Int_1                     # push first integer
                pushl Int_2                     # push second integer

                call add_func                   # call function

                addl $8, %esp                   # move the stack pointer back
                movl %eax, %ebx                 # pass the function return value into the exit status

                call Exit_call

# The input to the following function is two integer values whose sum has to be calculated.
        .type add_func, @function
        add_func:
                pushl %ebp                      # setting up the stack
                movl %esp, %ebp
                subl $8, %esp

                movl 12(%ebp), %eax             # load first integer value into eax
                movl 8(%ebp), %ebx              # load second integer value into ebx

                addl %ebx, %eax                 # eax hold the sum
                movl %ebp, %esp                 # restore the stack pointer
                popl %ebp                       # restore the base pointer
                ret                             # pop the return address in EIP

        Exit_call:
                movl $1, %eax
                int $0x80
# End of program
```

Let's dissect the program

The .type directive tells the linker that 'add_func' is a function. The next line that says 'add_func:' gives the symbol add_func the storage location of the next instruction. That's how 'call' knew where to go when 'call add_func' is executed.

Execution	Name the program → addition.s Assemble the program → $ as –gstabs –o addition.o addition.s Link the program → $ ld –o addition addition.o Execute the program → $ ./addition After the successful execution of the program, check the exit status of program to see the sum of the supplied integer values: # echo $? If any of the above commands report error(s), do spell check for the source code and commands. After correcting the source code, you have to re-run all the commands. <u>You must always re-assemble and re-link assembly programs after the source code file has been modified.</u>
Play Ground	Try adding three integer values
References	Refer to page 55 and 56 of Programming from Ground Up for stack layout in case of function calls
What we learnt?	When a function is done executing, it does the following: • Returns the value in register %eax • Resets the stack to what it was before call to function • Control is returned back to where ever it was called from. The 'ret' instruction does this by popping out the value of the top of the stack and sets the instruction pointer EIP to that value.

Date – 8: Me ^ Beer + She ^ Vodka – (Compute the value of (a^b + c^d))

Purpose	Further analyze the function calls and stack layout. To compute the value of (2^3 + 4^2)
Input	-
Program Flow	• See in the program explanation
Output	The value of mathematical expression (2^3 + 4^2)

# Program explaining the way function call is made.

```
# Program to do the following:
# ( 2^3 + 4^2 )

.section .data                                  # Initializing data
        Base_1:
                .long 2
        Base_2:
                .long 4
        Power_1:
                .long 3
        Power_2:
                .long 2

.section .bss

.section .text
  .globl _start

        _start:
                nop
                pushl Power_1                   # push power
                pushl Base_1                    # push base

                call raise_func                 # call function

                addl $8, %esp                   # move the stack pointer back
                pushl %eax                      # save the returned value on stack for later use

                pushl Power_2                   # push power for next call to function
                pushl Base_2                    # push base for next call to function

                call raise_func                 # call function

                addl $8, %esp                   # move the stack pointer back
                popl %ebx                       # pop out the value saved in stack earlier

                addl %eax, %ebx                 # eax currently holds the return value of 2nd function call
                call Exit_call


# The input to the following function is “Base” and “Power”. It returns the value of base raise power in %eax
register.

        .type raise_func, @function
        raise_func:
                pushl %ebp                      # Setting up the stack
                movl %esp, %ebp
                movl 12(%ebp), %ecx             # Take “power” into ecx
                movl 8(%ebp), %ebx              # Take “base” into ebx
                movl $1, %eax

                power_loop:
                        cmpl $0, %ecx
                        je Return

                        imull %ebx, %eax

                        loop power_loop          # The value of ecx decrements by ‘1’ with every execution
of ‘loop’ instruction.

                Return:
                        movl %ebp, %esp
                        popl %ebp
                        ret

                Exit_call:
                        movl $1, %eax
                        int $0x80
```

Let’s dissect the program

That’s quite interesting program to learn some new stuff. Agenda is to find the result of mathematical expression (2^3 + 4^2).

Our program is designed the way to make a call to function ‘raise_func’ twice. With each call it would return the result of ‘base^power’.
In current case, during first call to function, the function will return the value of 2^3 and during second call it will return the result of 4^2.
Finally we would add up the return values to get the answer.

The point to notice here is the behavior of register %eax.
Whenever a call is made to a function, the register eax is going to be altered for sure. Actually the return value of any function call by default goes into register eax.
Other registers might also get altered depending on the code. Hence it is advisable to save the values of registers during function calls if the old values of registers would be needed later.

You might have observed by now that inside the section ‘power_loop’ we are keeping the result of multiplication in register eax. Hence during function return, the output of our ‘base^power’ would be in register eax.

After first call to function ‘raise_func’, register eax is holding the return value which is in fact the result of 2^3. It’s been pushed to stack to be popped later as eax is going to be altered soon with the next call to ‘raise_func’.

After the second call to ‘raise_func’, eax is holding the result of 4^2 and we are popping out the earlier result of 2^3 from stack into ebx. The summation of both would produce the desired result into register ebx. One more point to note down: In order to see the result, we keep the answer as exit status of program in register ebx. Mind it, the maximum value for exit status cannot exceed 256.	
Execution	Name the program → raise_power.s Assemble the program → $ as –gstabs –o raise_power.o raise_power.s Link the program → $ ld –o raise_power raise_power.o Execute the program → $ ./raise_power The register %ebx will hold the final answer of summation. If any of the above commands report error(s), do spell check for the source code and commands. After correcting the source code, you have to re-run all the commands. <u>You must always re-assemble and re-link assembly programs after the source code file has been modified.</u>
Play Ground	Create space for local variables and use them for temporary storage instead of registers. In bigger programs there might not be enough registers left to store temporary values in, so practice offloading them into local variables. Open up gdb and analyze the program flow and values in stack and registers.
References	-
What we learnt?	When a function is done executing, it does the following: • Returns the value in register %eax • Resets the stack to what it was before call to function • Control is returned back to where ever it was called from. The ‘ret’ instruction does this by popping out the value of the top of the stack and sets the instruction pointer EIP to that value. 256 is the highest exit status value.

Date – 9: Time to Exaggerate Your Qualities - (Recursive program to find the factorial)

Purpose	To compute the factorial of a number
Input	-
Program Flow	-
Output	The factorial value of the supplied integer number

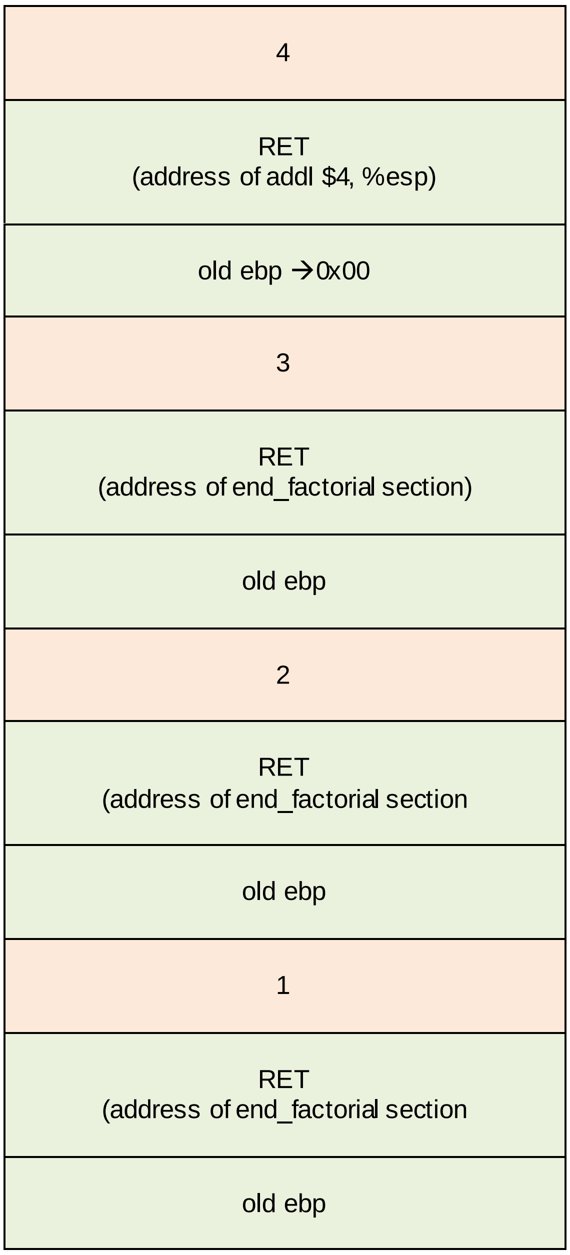
# Program to find the factorial of a number

```
# Program to do the following:
# factorial 4 : 4 * 3 * 2 * 1 = 24

.section .data                              # Initializing data
        Int1:
                .long 4

.section .bss

.section .text
        .globl _start
        _start:
                nop
                pushl Int1                  # push the number

                call factorial              # call function

                addl $4, %esp               # move the stack pointer back
                movl %eax, %ebx             # take the returned factorial value in exit status register

                call exit_call

        exit_call:
                movl $1, %eax
                int $0x80


# The input to the following function is an integer value. It returns the factorial value of that number in %eax register.

        .type factorial, @function
        factorial:
                pushl %ebp                  # Setting up the stack
                movl %esp, %ebp

                movl 8(%ebp), %eax

                cmpl $1, %eax
                jle end_factorial

                decl %eax
                pushl %eax
        call factorial

        end_factorial:
                movl 8(%ebp), %ebx
                imull %ebx, %eax
                movl %ebp, %esp
                popl %ebp
                ret
```

Let's dissect the program

The following would be the layout of stack once the execution of program enters the section 'end_factorial' i.e. after the recursion of factorial function has already taken place:

Bottom of the Stack →→→



4
RET
(address of addl $4, %esp)
old ebp →0x00
3
RET
(address of end_factorial section)
old ebp
2
RET
(address of end_factorial section
old ebp
1
RET
(address of end_factorial section
old ebp

Top of the Stack →→→

By this point, register eax is holding an integer value 1. Loaded with knowledge and experience from previous programs, the reader should be able to analyze the program flow in gdb well. Again please note: The value in register ebx should not exceed 256 while making call to the exit function.	
Execution	Name the program → factorial.s Assemble the program → $ as –gstabs –o factorial.o factorial.s Link the program → $ ld –o factorial factorial.o Execute the program → $ ./factorial The register %ebx will hold the final answer of factorial. If any of the above commands report error(s), do spell check for the source code and commands. After correcting the source code, you have to re-run all the commands. You must always re-assemble and re-link assembly programs after the source code file has been modified.
Play Ground	Open up gdb and analyze the program flow and values in stack and registers.
References	-
What we learnt?	When a function is done executing, it does the following: a) Returns the value in register %eax b) Resets the stack to what it was before call to function c) Control is returned back to where ever it was called from. The 'ret' instruction does this by popping out the value of the top of the stack and sets the instruction pointer EIP to that value. 256 is the highest exit status value.

Date – 10: Let Her Read Your Mind - (File Handling → Copy data from one file to another)	
Purpose	To copy data from one file into another file
Input	The name of the files as command line arguments
Program Flow	• Open first file in "read" mode • Open second file in "write" mode • Loop reading first file and writing it to second until the first file reaches EOF • Close the opened files • exit
Output	A new copy of a file is created

# Program to copy the content of a file to another file, both passed as command line arguments

```
.section .data                                          # Initializing constants
            .equ SYS_EXIT, 1                            # They are linux system calls with fixed value
            .equ SYS_READ, 3
            .equ SYS_WRITE, 4
            .equ SYS_OPEN, 5
            .equ SYS_CLOSE, 6
            .
            .equ SYS_CALL, 0x80

            .equ O_RDONLY, 0
            .equ O_WRONLY, 03101
            .equ END_OF_FILE, 0

.section .bss
            .equ BUFFER_SIZE, 500                       # Reserving a space of 500 bytes to read data from file
            .lcomm BUFFER_DATA, BUFFER_SIZE

.section .text
            .equ SIZE_RESERVE, 8                # Reserve space on stack to hold file descriptors
            .equ FD_IN, -4                      # File descriptor for first file to be opened in "read" mode
            .equ FD_OUT, -8                     # File descriptor for second file to be opened in "write" mode
            .equ ARGC, 0                        # Number of arguments passed
            .equ ARGV_0, 4                      # Program name
            .equ ARGV_1, 8                      # The first command line argument i.e. the first file
            .equ ARGV_2, 12                     # The second command line argument i.e. the second file

            .globl _start
            _start:
                        nop
                        movl %esp, %ebp                 # Setting up the stack
                        subl $SIZE_RESERVE, %esp        # Reserving space on stack for file descriptors

            Open_file:
            Open_fd_in:                                 # Opening first file in Read-Only mode
                        movl $SYS_OPEN, %eax
```

```
                movl ARGV_1(%ebp), %ebx
                movl $O_RDONLY, %ecx
                movl $0666, %edx

                int $SYS_CALL
                movl %eax, FD_IN(%ebp)          # Saving file descriptor on stack as the register %eax
would be overwritten soon

        Open_fd_out:
                movl $SYS_OPEN, %eax            # Opening second file in Write mode
                movl ARGV_2(%ebp), %ebx
                movl $O_WRONLY, %ecx
                movl $0666, %edx

                int $SYS_CALL
                movl %eax, FD_OUT(%ebp)         # Saving file descriptor on stack as the register %eax
would be overwritten soon


        Read_loop:                              # Reading data from the file been opened in RO mode
                movl $SYS_READ, %eax
                movl FD_IN(%ebp), %ebx
                movl $BUFFER_DATA, %ecx
                movl $BUFFER_SIZE, %edx

                int $SYS_CALL

                cmpl $END_OF_FILE, %eax         # Stop reading the file once EOF has reached
                jle End_loop


        Write_File:                             # Writing the read data to second file
                movl %eax, %edx                 # Size of buffer read is returned in %eax
                movl $SYS_WRITE, %eax
                movl FD_OUT(%ebp), %ebx
                movl $BUFFER_DATA, %ecx
                int $SYS_CALL

                jmp Read_loop

        End_loop:
                movl $SYS_CLOSE, %eax           # Clean up work. Closing first file.
                movl FD_IN(%ebp), %ebx
                int $SYS_CALL

                movl $SYS_CLOSE, %eax           # Closing second file
                movl FD_OUT(%ebp), %ebx
                int $SYS_CALL


        Exit_call:
                movl $SYS_EXIT, %eax
                movl $0, %ebx
                int $0x80
```

Let's dissect the program

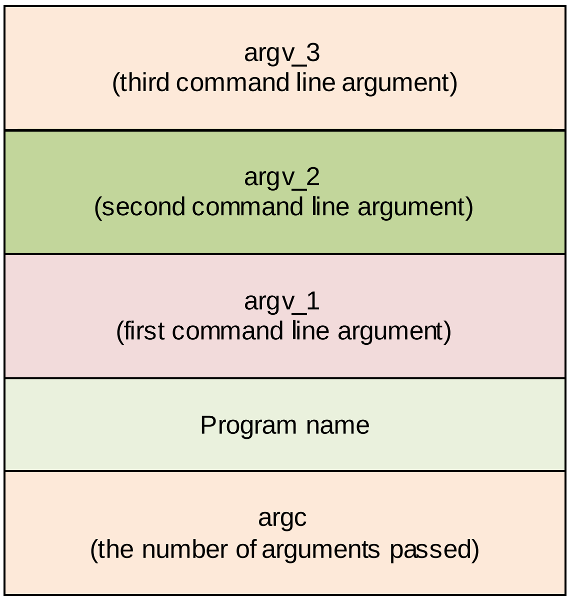
The first point need to be noted is the way command line arguments are placed on stack.

Let's say some xyz program has been executed as follows:

```
# ./xyz   file1.txt   file2.txt   file3.txt
```

The stack would look like:

Top of the stack →


argv_3
(third command line argument)
argv_2
(second command line argument)
argv_1
(first command line argument)
Program name
argc
(the number of arguments passed)

Bottom of the stack →

Now the logic behind the program is:

1. Open the first file in RO mode
2. Open the second file in Write mode
3. Read data from opened file into buffer, 500 bytes at a time. If read 0 i.e. EOF, stop reading and go to step 6
4. Write the data found in buffer to second file
5. Go the step 3
6. Close the files when nothing more has to be read or write
7. Exit the program

The program has been started with the declaration of many constant values. This has been done to make the program more meaningful and to ease the amendment task.

The syntax for the same is:
.equ String_name, value

All the needed system calls, buffer size, stack distance etc. have been declared as constants and throughout the program we just need to refer the values using string constants, making more sense to the reader of the program.

To open a file:

1. Pass the system call number in %eax
2. The address of the file name in %ebx
3. The mode (read/write) in %ecx (its 0 for read-only)
4. Permission value in %edx
5. Call the interrupt

With a successful "open" call, linux will return the file descriptor in %eax.

To read a file:

1. Pass the system call number in %eax
2. File descriptor, obtained during successful "open" system call, in %ebx
3. The address of buffer for storing the data that is read in %ecx
4. Size of the buffer in %edx

The read system call will return the number of characters read from the file in %eax or an error code, which is a negative value, in case of failure.

The write system call requires the same parameters as the read system call, except that the buffer should already be filled with the data to write out. The write system call returns the number of bytes written in %eax or an error code in case of failure.

Also remember that the Linux command line arguments are stored in zero-terminated strings. The pointer to the last argument is followed by 0, which indicates the end of the arguments. This could easily be seen in gdb.

Execution	Name the program → read-write.s Assemble the program → $ as –gstabs –o read-write.o read-write.s Link the program → $ ld –o read-write read-write.o Execute the program → $ ./ read-write first-file second-file The content of first file should get copied into the second file. If any of the above commands report error(s), do spell check for the source code and commands. After correcting the source code, you have to re-run all the commands. <u>You must always re-assemble and re-link assembly programs after the source code file has been modified.</u>
Play Ground	Redirect the "read" content from first file to console instead of second file. The file descriptor for STDOUT is 1
References	To pass command line arguments to GDB, refer to the GDB section
What we learnt?	Basics of file handling

Date – 12: Oops! CAT in Thoughts – (File Handling → Implementing CAT Linux Command)

Purpose	To implement Linux ‘cat’ command through assembly program
Input	Name of the file as command line argument. If none specified, STDIN would be used for input
Program Flow	• See in the program explanation
Output	• Implementation of CAT Linux command

# Program to implement Linux ‘cat’ command through assembly program

```
# Implementation of Linux ‘cat’ command through Assembly program

# Pass the name of the file/files as command line arguments. If nothing is mentioned, read from STDIN

# ./pgm file1.txt file2.txt


.section .data                                   # Initializing constants
        .equ SYS_EXIT, 1                         # They are linux system calls with fixed value
        .equ SYS_READ, 3
        .equ SYS_WRITE, 4
        .equ SYS_OPEN, 5
        .equ SYS_CLOSE, 6

        .equ STDIN, 0                            # This would be required in case of 0 arguments
        .equ STDOUT, 1

        .equ SYS_CALL, 0x80

        .equ O_RDONLY, 0
        .equ END_OF_FILE, 0
        .equ NUM_OF_ARGUMENTS, 0                 # To keep track of the arguments passed

.section .bss
        .equ BUFFER_SIZE, 500
        .lcomm BUFFER_DATA, BUFFER_SIZE          # Reserving a space of 500 bytes to read data from file

.section .text

        .equ SIZE_RESERVE, 4                     # Reserve space on stack to hold file descriptor
        .equ FD_IN, -8                           # File descriptor for the file opened in “read” mode
        .equ ARGC, 0                             # Number of arguments passed
        .equ ARGV_0, 4                           # Program name
        .equ ARGV_1, 8                           # The first command line argument. In the program you
would notice that we do not need to declare more constants in order to access other command line arguments.

        .globl _start
```

```
    _start:
            nop
            movl %esp, %ebp                 # Setting up the stack
            movl (%esp), %ebx               # Collect the number of arguments passed in register ebx
            decl %ebx                          # Decrement the value in order to check whether any
command line argument i.e. files have been passed or not. If no, switch to STDIN to seek for some input, else
proceed with the files been passed as command line arguments.

            cmpl $NUM_OF_ARGUMENTS, %ebx
            jle Read_STDIN                    # Seek STDIN for some input


            jmp Open_Next_File              # Else open the input files


    Open_Next_File:
            pushl %ebx                        # Keep track of number of arguments processed
            subl $SIZE_RESERVE, %esp       # Reserving space on stack for file descriptor

    Open_fd_in:                                # Opening file in Read-Only mode
            movl $SYS_OPEN, %eax
            movl ARGV_1(%ebp), %ebx
            movl $O_RDONLY, %ecx
            movl $0666, %edx

            int $SYS_CALL
            movl %eax, FD_IN(%ebp)          # Saving file descriptor on stack as the register %eax
would be overwritten soon


    Read_loop:                                 # Reading data from the file been opened in RO mode
            movl $SYS_READ, %eax
            movl FD_IN(%ebp), %ebx
            movl $BUFFER_DATA, %ecx
            movl $BUFFER_SIZE, %edx

            int $SYS_CALL

            cmpl $END_OF_FILE, %eax          # Stop reading file once EOF has reached
            jle End_loop

    Write_STDOUT:                              # Writing read data onto console
            movl %eax, %edx                   # Size of buffer read is returned in %eax
            movl $SYS_WRITE, %eax
            movl $STDOUT, %ebx
            movl $BUFFER_DATA, %ecx

            int $SYS_CALL

            jmp Read_loop

    End_loop:
            movl $SYS_CLOSE, %eax            # Clean up work. Closing the file.
            movl FD_IN(%ebp), %ebx
            int $SYS_CALL

            popl %eax                          # Popping out the fd value from stack to throw it away
            popl %ebx                          # Retrieving older value of number of arguments passed
```

```
                decl %ebx
                cmpl $NUM_OF_ARGUMENTS, %ebx           # Checking for more arguments
                jle Exit_call
                popl %eax                      # Pop up one more value from top of the stack so that
the constant ARGV_1 always point to the next argument once program is done with previous argument

                movl %esp, %ebp                # Setting up the stack again to deal with next argument
                jmp Open_Next_File


        Exit_call:
                movl $SYS_EXIT, %eax
                movl $0, %ebx
                int $0x80

        Read_STDIN:                            # Seek STDIN for input i.e. keyboard
        Read_Loop_STDIN:
                movl $SYS_READ, %eax
                movl $STDIN, %ebx
                movl $BUFFER_DATA, %ecx
                movl $BUFFER_SIZE, %edx

                int $SYS_CALL

                cmpl $END_OF_FILE, %eax              # Press "ctrl + c" to exit the STDIN
                jle End_Loop_STDIN

        Write_Loop_STDOUT:                           # Output on STDOUT i.e. console
                movl %eax, %edx
                movl $SYS_WRITE, %eax
                movl $STDOUT, %ebx
                movl $BUFFER_DATA, %ecx

                int $SYS_CALL

                jmp Read_Loop_STDIN

        End_Loop_STDIN:
                jmp Exit_call
```

Let's dissect the program

The logic behind the program is:

1. First check whether any command line argument is passed or not. If passed, go to step 2 else go to step 8
2. If argument is there, open the file in RO mode
3. Read data from opened file into buffer, 500 bytes at a time. If read 0 i.e. EOF, stop reading and go to step 6
4. Write the data read into buffer to console
5. Go to step 3
6. Close the file when nothing more is there to read and look for next command line argument passed
7. If next command line argument found, go to step 2. Else exit out of program
8. When no argument is passed, wait for input from keyboard. Echo the input on console (STDOUT) once it's been received from keyboard.
9. Exit out of program when "ctrl + c" is pressed.

Now let's assume that 3 command line arguments have been passed:
./assembly_cat file1.txt file2.txt file3.txt

The following would be the layout of stack once the execution of program begins.

The first column of table depicts the state of stack while dealing with file1.txt
The second column of table depicts the state of stack while dealing with file2.txt
And the third column of table depicts the state of stack while dealing with file3.txt

You would notice that with each successful completion of traversing a file, we are popping out one argument from stack. This has been done to keep program generic to accept 'n' number of arguments. This would help to reach the argument(file) every time from register ebp with our constant string value ARGV_1 (8)

Bottom of the Stack →→→

Stack while reading 1st file	**Stack while reading 2nd file**	**Stack while reading 3rd file**
argv_3 (3rd command line argument)	argv_3 (3rd command line argument)	argv_3 (3rd command line argument)
Argv_2 (2nd command line argument)	Argv_2 (2nd command line argument)	Argv_2 (2nd command line argument)
Argv_1 (1st command line argument)	Argv_1 (1st command line argument)	Argv_1 (1st command line argument)
Program name	Program name	ebx = 1
argc (the number of arguments passed)	ebx = 2	fd (file descriptor)
ebx = 3	fd (file descriptor)	
fd (file descriptor)		

Top of the Stack →→→

Loaded with knowledge and experience from previous programs, the reader should be able to analyze the program flow in gdb well.

Execution	Name the program Assemble the program Link the program	→ assembly_cat.s → $ as –gstabs –o assembly_cat.o assembly_cat.s → $ ld –o assembly_cat assembly_cat.o

	Execute the program → `$ ./ assembly_cat` If command line argument has been passed, the content of it would get displayed on screen; else the program would sit and wait for some input from keyboard to be echoed back onto console. If any of the above commands report error(s), do spell check for the source code and commands. After correcting the source code, you have to re-run all the commands. <u>You must always re-assemble and re-link assembly programs after the source code file has been modified.</u>
Play Ground	Open up gdb and analyze the program flow and values in stack and registers.
References	Refer the GDB cheat sheet to play around with the code while debugging
What we learnt?	Some more stack manipulation

Date – 14: Plead 100 Times Now – (Print 1-100 on Console Using Shared Libraries)

Purpose	To print the series from 1 to 100 on console using shared libraries
Input	-
Program Flow	• See in the program explanation
Output	A series from 1 to 100 would be printed out on console separated by newlines

```
# Print the numbers from 0 to 100 on console.

.section .data
          format_string:
                    .asciz "%d\n"
.section .text

   .globl _start

          _start:
             movl    $0, %eax                              # Starting value
             movl    $100, %ebx                            # End value


          loop:
          # push them on stack else would be overwritten during call to printf library function
             pushl  %eax
             pushl  %ebx

             # Display the current value i.e. value in register eax on console.
             pushl  %eax
             pushl  $format_string
             call    printf
             addl    $8, %esp

             popl    %ebx
             popl    %eax

             # Check against the ending value.
             cmpl    %eax, %ebx
             je   exit_call

             # Increment the current value.
             incl    %eax
             jmp   loop

          exit_call:
             movl $1, %eax
             movl $0, %ebx
             int $0x80
```

Let's dissect the program

All our earlier programs were statically-linked, as they contained all of the necessary functionality for the program that wasn't handled by the kernel.

The current program is dynamically-linked, which means that not all of the code needed to run the program is actually contained within the program file itself, but in external libraries.

The beginning and the end of the desired result has been initialized and pushed onto the stack. They are kept safe on stack because call to printf library function would return the result in register eax, hence overwrite the previous value. Some other register can definitely be used to avoid push-pop actions.

The following function code is nothing but the 'c' programming way of calling printf routine,

```
pushl   %eax
pushl   $format_string
call    printf
addl    $8, %esp
```

where the arguments passed to printf are first pushed on to the stack in reverse order and then following the number of %s or %d in the string the arguments are taken from the stack.
The format_string is the first parameter to printf, and printf uses it to find out how many parameters it was given, and what kind they are.

In current case, format_string is "%d\n". So the printf function knows that only one value has to be taken from the stack and the nature of value is int (interger).

The stack has been adjusted after every call to printf within loop.

Execution	Name the program → printf_console.s Assemble the program → $ as –gstabs –o printf_console.o printf_console.s Link the program → $ ld -dynamic-linker /lib/ld-linux.so.2 -o printf_console printf_console.o -lc Execute the program → $ ./printf_console A series from 1 to 100 would be printed out on console separated by newlines. If any of the above commands report error(s), do spell check for the source code and commands. After correcting the source code, you have to re-run all the commands. <u>You must always re-assemble and re-link assembly programs after the source code file has been modified.</u>
Play Ground	Print "Hello World" using shared libraries
References	-
What we learnt?	The way shared libraries can be used with the assembly codes

Date – 15: And Everything Smashed! What Else You Expected Moron?

Purpose	To analyze the buffer the way it get overflowed
Input	-
Program Flow	-
Output	-

```
# Program to explain the way buffer gets over flowed and "Saved EBP", "EIP" gets over written.

#include <stdio.h>

void buffer_func(int *num)
{
        int buffer[4];
        int j;
        for(j=0; j<10; j++)
                buffer[j] = *(num + j);
}

void main()
{
        int numbers[10] = {1, 2, 3, 4, 5, 6, 7, 8, 9, 10};
        buffer_func(numbers);

        exit(0);
}
```

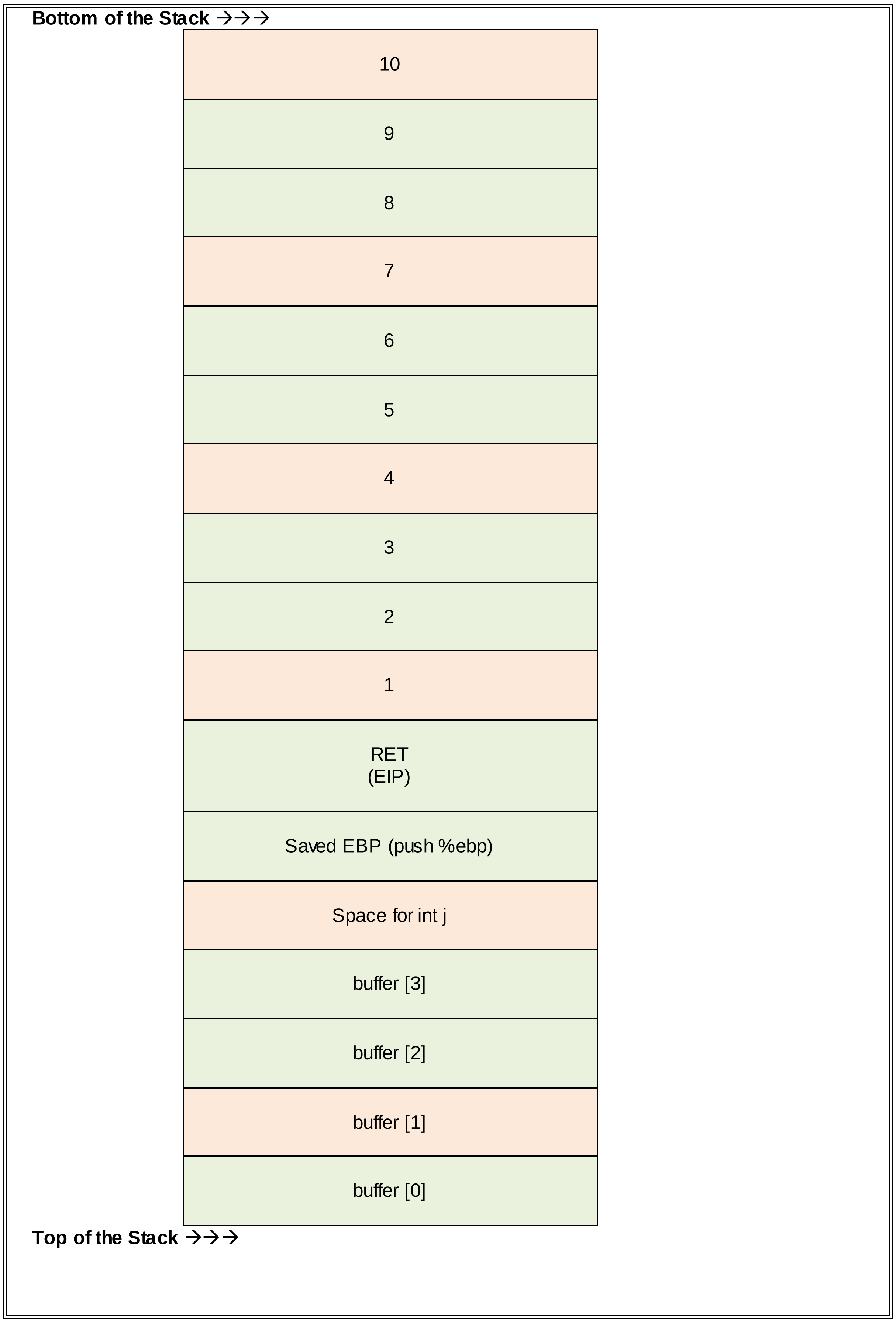
Let's dissect the program

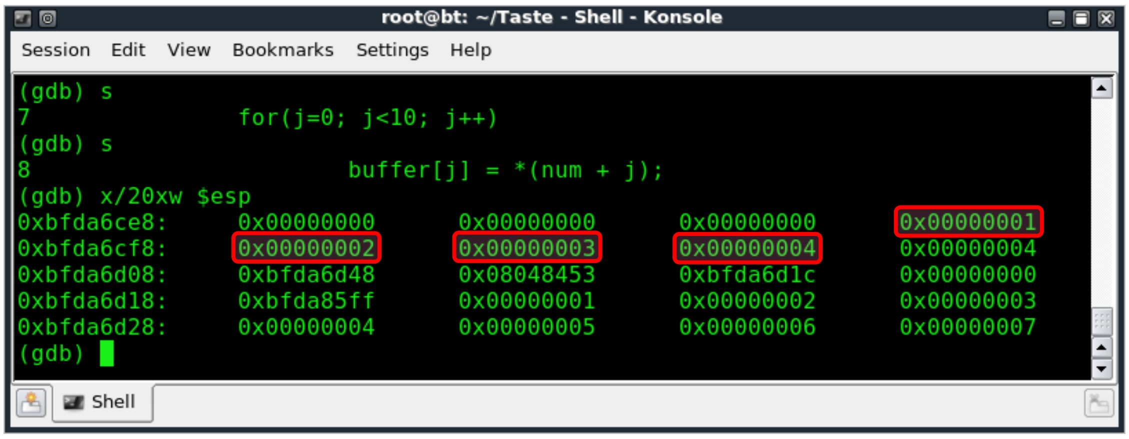
I believe the motive of many of the readers of this supplement is to learn exploitation next. The very first program example of the buffer overflow exploitation could be like the above stated one.

Let me assist those who cannot extract out the crux of the above program properly:

- In the main(), an integer array of 10 elements has been initialized
- Next is the function call with the array address as the argument
- Inside the function a local integer array of size 4 has been declared
- In the loop, we are trying to adjust 10 integers in a space meant for 4 integers. Boom! Stack Smashed!

Let's analyze further:
Forget the libc and call to main (the main function too has been called by someone and definitely will have place on our stack), and just focus on the called function buffer_func and its layout on stack.


Bottom of the Stack →→→
10
9
8
7
6
5
4
3
2
1
RET
(EIP)
Saved EBP (push %ebp)
Space for int j
buffer [3]
buffer [2]
buffer [1]
buffer [0]
Top of the Stack →→→


root@bt: ~/Taste - Shell - Konsole
Session Edit View Bookmarks Settings Help
Shell

```
(gdb) s
7               for(j=0; j<10; j++)
(gdb) s
8                       buffer[j] = *(num + j);
(gdb) x/20xw $esp
0xbfda6ce8:     0x00000000      0x00000000      0x00000000      0x00000001
0xbfda6cf8:     0x00000002      0x00000003      0x00000004      0x00000004
0xbfda6d08:     0xbfda6d48      0x08048453      0xbfda6d1c      0x00000000
0xbfda6d18:     0xbfda85ff      0x00000001      0x00000002      0x00000003
0xbfda6d28:     0x00000004      0x00000005      0x00000006      0x00000007
(gdb) 
```

After four iterations of loop, the highlighted numbers (1, 2, 3, and 4) have been pushed onto the stack. Notice the order they are getting pushed. It started from the top of the stack and now proceeding towards the Saved EBP and EIP (Ret).
Loop has been run 4 times only, so everything is in place. Now if we proceed, it'll start smashing the stack.
With next loop it'll overwrite the place meant for the local variable int j. The next loop will overwrite the Saved EBP and the next one would overwrite the EIP (Ret).
Here 0x08048453 is the EIP.

Execution	-
Play Ground	The journey has just started ;)
References	-
What we learnt?	-

Reference

1. Assembly Primer for Hackers Video Series – by Vivek Ramachandran (http://www.securitytube.net)
2. Programming from the ground up – by Jonathan Bartlett
3. Beej's Quick Guide to GDB
4. Intel 80386 Reference Programmer's Manual (http://pdos.csail.mit.edu/6.828/2006/readings/i386/toc.htm)