1 Working with byte and word data

We are declaring some bytes in the assembly program below:

```
section .data
        num DB 1
        num2 DB 2
        num3 DB 3

section .text
        global _start
        _start:
                MOV ebx, [num]
                MOV ecx, [num2]
                MOV edx, [num3]
                MOV eax, 1
                INT 80h
```

So, everything looks normal(for now). We are just moving the bytes into the registers. Note that these registers are 32-bit registers i.e. 4 byte registers and the variables are just 1 byte each.

So, how will 1 byte be stored in 4 bytes?? Let's find out using GDB.

2 Using GDB to find out how 1 byte is stored in 4 bytes

Eveything is just the same as the previous examples. Let's focus on the main portion.

The assembly layout:

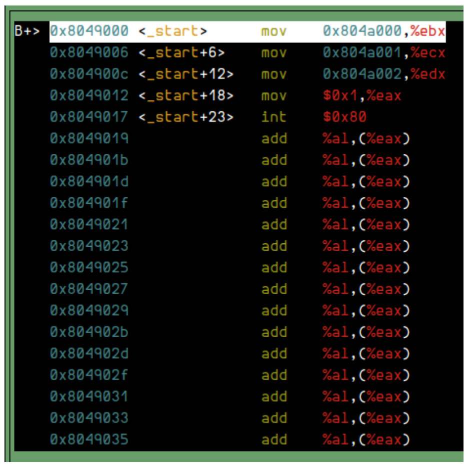


Figure 1: Starting with GDB

Notice the value in **ebx** in the image below:

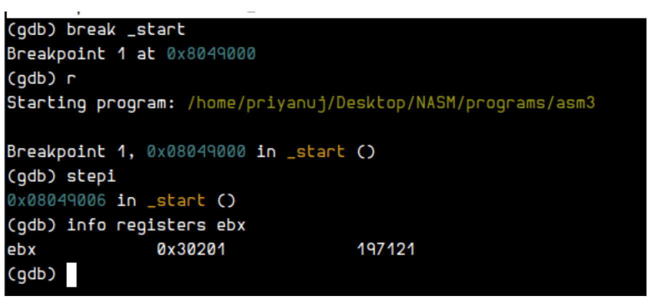


Figure 2: Value in **ebx**

We can see that via the **info registers** command that the value in **ebx** is not 1. Rather it's a very large number.

How??

If we use the **x/x** command then we will get the following:

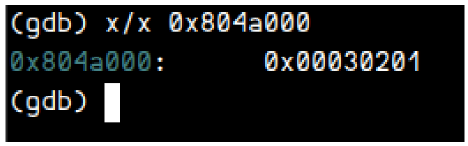


Figure 3: What does **0x804a000** store in it??

So, this tells us that in the address **0x804a000** which is a 32-bit address the value stored in it is **0x00030201**. What is this value?!

If we look at the binary equivalent of this hexadecimal equivalent number:

$$(00030201)_{16} = (00000000\ 00000011\ 00000010\ 00000001)_2$$

We can clearly see that $(00000011)_2$ is $(3)_{10}$ in decimal, $(00000010)_2$ is $(2)_{10}$ in decimal and $(00000001)_2$ is $(1)_{10}$ in decimal.

So, bytes, in a 32-bit register or are stored next to each other.

We have more to see because the number of bytes stored in 4 bytes changes in each of the registers.

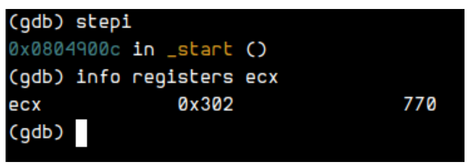


Figure 4: Value in **ecx**(Notice the change)

As we move towards the next instruction using the **stepi** command, we can see that **MOV ecx,** [**num2**] gets executed.

Notice that **ecx** stores a value(look at the hexadecimal value).

We again use the **x/x** command on the next address which is **0x804a001**(also, notice that the addresses **0x804a000**, **0x804a001** and **0x804a002**, all these are 1 byte apart from each other).

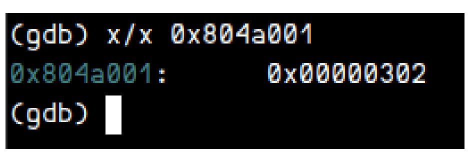


Figure 5: Value of **0x804a001**

We can see that the binary equivalent of **0x00000302** is:

$$(00000302)_{16} = (00000000\ 00000000\ 00000011\ 00000010)_2$$

Now, we again step to the next instruction: **INT 80h** which means that **MOV edx,** [**num3**] has completed execution. Let's see what **edx** has in store:

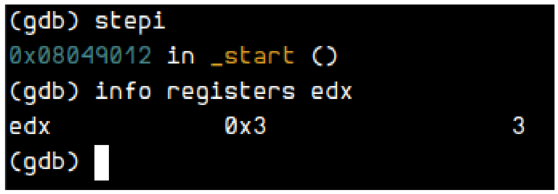


Figure 6: Value in **edx**

So, **edx** stores only 3. Let's see what is in **0x804a002**

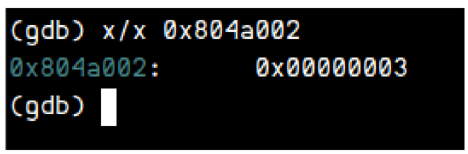


Figure 7: Value in **0x804a002**

$(00000003)_{16}$ in hexadecimal is $(00000000\ 00000000\ 00000000\ 00000011)_2$ in binary.

Why were these numbers stored in the registers like this???

Let's look at the data section again:

```
section .data
        num DB 1
        num2 DB 2
        num3 DB 3
```

If we look at, say, Figure 5 we can see the value(in hex) **0x00000302**. As we know that one hex digit represents 4-bits. So, two hex digits will represent 8-bits or 1 byte. So from the figure we can say that **0x02** represents 1 byte, **0x03** represents 1 byte, **0x00** represents 1 byte and the last(left-most) **0x00** also represents 1 byte. So all total there 4 bytes i.e 32-bits.

3 IMPORTANT

How actually is 1 byte stored in the 32-bit address?

• Let's know a basic concept first: **The memory is like a big array**.

We know that **0x804a000** is a 32-bit long **address**. That doesn't mean that the memory block is 32-bits long. It's like the memory blocks shown in figure Figure 8. So, the length of the address has nothing do with the size of the memory block to which that address is pointing to.

Now, coming to the command **x/x**. Let's understand the meaning of this command:

x/x → This command is used to examine memory at a specified address and display the contents as a **single hexadecimal integer**. The **/x** modifier specifies the **display format** as hexadecimal.

For example:

```
(gdb) x/x 0x804a000
```

This command will basically display the contents of the memory pointed to by this address(**0x804a000**) as a 32-bit hexadecimal integer. This 32 bit hexadecimal integer is not only taken from **0x804a000** but this 32-bit hexadecimal is made up of 3 more memory blocks pointed to by **0x804a001**, **0x804a002** and **0x804a003** each address contributing 1 byte(2 hex digits). **I**n simple words this command displays the contents in the memory starting from **0x804a000** and going all the way till **0x804a003**.

And that's the reason why we see **0x00030201**. Now if we look at this hexadecimal integer, **0x00** is the MSB and **0x01** is LSB. So the byte ordering is *Little Endian* because the LSB is stored in **0x804a000** which is the first address.

Watch this **video**.

Consider this command:

```
(gdb) x/1xb 0x804a000
```

This command displays 1 byte in hexadecimal format. So, in this case only the value in the memory block pointed to by **0x804a000** will be displayed as a hexadecimal byte. See figure Figure 9.

Now, for **x/3xb**

```
(gdb) x/3xb 0x804a000
```

This command displays 3 consecutive bytes in hexadecimal format. The three consecutive bytes will come from **0x804a000**, **0x804a001** and **0x804a002**.

0x804a000 stores 1(hex: **0x01**), **0x804a001** stores 2(hex: **0x02**) and **0x804a002** stores 3(hex: **0x03**). See figure Figure 10.

Note that this command(s) will work in similar way for any address not just for **0x804a000**.

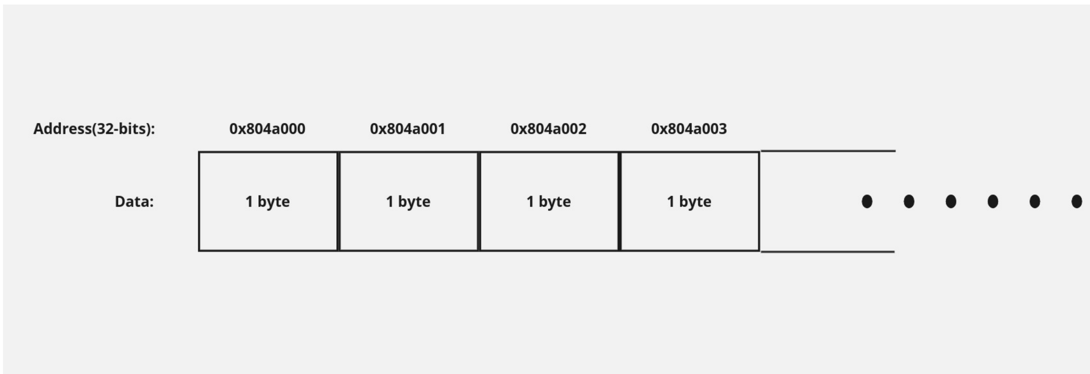
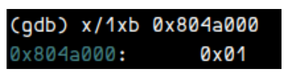
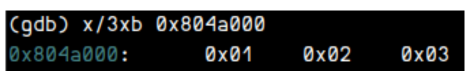


Figure 8: Memory makeup



```
(gdb) x/1xb 0x804a000
0x804a000:      0x01
```

Figure 9: Hexadecimal byte



```
(gdb) x/3xb 0x804a000
0x804a000:      0x01    0x02    0x03
```

Figure 10: 3 hexadecimal bytes

How are registers storing the values?

Now, the registers **ebx**, **ecx** and **edx** are 32-bit registers(see Figure 11).
Now, if we want to see the contents inside of register **ebx**, then we will use the **info registers** command(see Figure 2). We can see that **ebx** stores the value **0x30201**. Why?? Because **ebx** is a 32-bit register. When we execute **MOV ebx, [num]** then since **ebx** is a 32-bit register so the contents of the memory block starting from address **0x804a000** are stored into the register. We know **0x804a000** points a memory block of 1 byte data but **ebx** is 4 bytes long, so we need 3 more bytes to store into **ebx**. So, the memory blocks pointed to by the addresses **0x804a001**, **0x804a002** and **0x804a003** are also stored into the register **ebx**.

Similarly when we execute **MOV ecx, [num2]** then again 4 bytes are stored into register **ecx**. So the contents of the memory block starting from the address **0x804a001** to **0x804a004** are stored into the register. That's why when we run the **info registers** command on **ecx** we get the output that we see in Figure 4 because the address **0x804a001** points to a memory block that contains the byte 2(hex: **0x02**), **0x804a002** points to a memory block that contains the byte 3(hex: **0x03**), **0x804a003** points to a memory block that is uninitialized and so is the case with **0x804a004**.

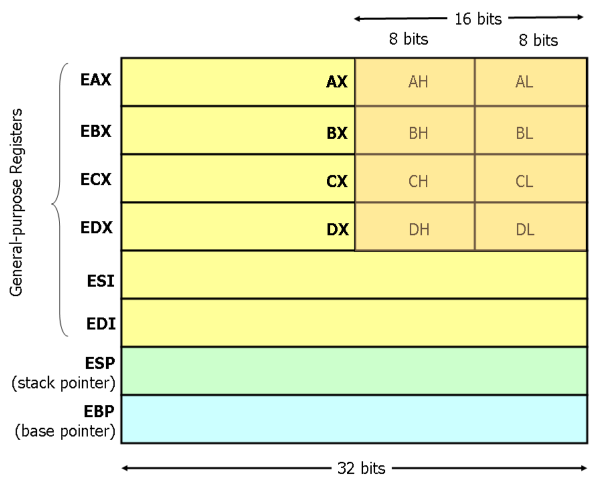


Figure 11: x86 Registers(Image source: Google)

- I found these links helpful:
  - https://cs.stackexchange.com/questions/157633/why-does-a-32-bit-address-only-contain-1-byte-when-32-bits-4-bytes
  - https://www.quora.com/How-does-a-32-bit-address-represent-1-byte-of-memory

4 The solution to the problem

Before starting, this image is important:

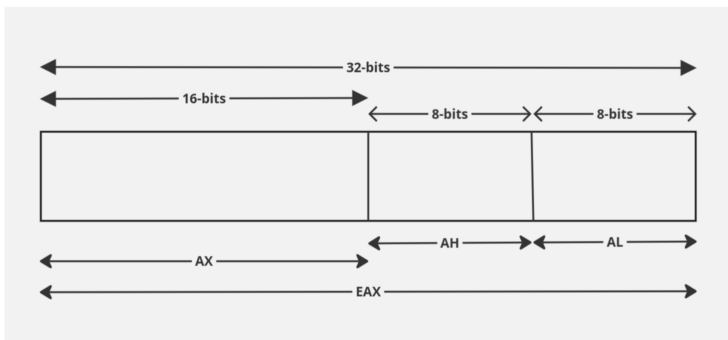


Figure 12: Register sizes

We modified our program:

```
section .data
        num DB 1
        num2 DB 2
        num3 DB 3

section .text
        global _start
        _start:
                MOV bl, [num]
                MOV cl, [num2]
                MOV dl , [num3]
                MOV eax, 1
                INT 80h
```

And again starting debugging using GDB.

NOTE:

Now, from Figure 12, we can say that **EAX** is a 32-bit register, **AX** is a sub-register that is 16-bits, **AH**(high order byte) is another sub-register that is 8-bits in size and **AL**(low order byte) is yet another sub-register whose size equals the size of **AH**. Similarly, for registers **EBX**, **ECX** and **EDX**, we have similar sub-registers as well(letter-wise i.e for **EBX** there are **BX**, **BH**, **BL**).

Now, when we use the command:

```
(gdb) info registers bl
```

This is what we get:

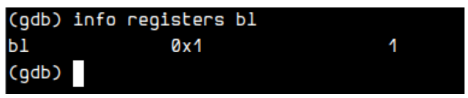


Figure 13: Finally! Some normal output

So, 1 is stored into the lower bits. Register **bl** is 1 byte long and only 1 byte can be stored in it.

But surprisingly, when we type:

```
(gdb) info registers ebx
```

We get the following output:

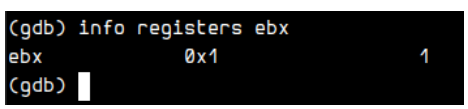


Figure 14: **ebx** stores only 1 now!!

Why did that happen?? Because we know that **bl** is a sub-register of **ebx** and it is 1 byte long and also it is the lower byte of **ebx**. So when we stored the value of **num** into **bl**. Only the lower 8-bits(1 byte) of **ebx** got initialized and the rest 24 bits were uninitialized(0). And the whole register kind of looked like this:

00000000 00000000 00000000 00000001

That is the reason why we see 1 in **ebx**.

5 What will happen if we store the bytes in the higher byte of the registers?

Now, we again modified our program:

```
section .data
        num DB 1
        num2 DB 2
        num3 DB 3

section .text
        global _start
        _start:
                MOV bh, [num]
                MOV ch, [num2]
                MOV dh, [num3]
                MOV eax, 1
                INT 80h
```

We are storing the bytes in the higher bytes of the registers. Let's see what happens then.

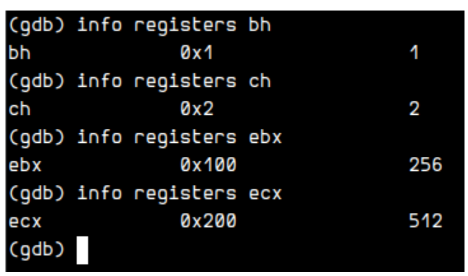


Figure 15: Storing in the higher bytes

One thing is very clear that when we check the values in the registers **bh** and **ch** we can see that the correct values are stored(just like the previously modified code) because these registers are 8 bits in size.

But one thing is different, the value in the 32-bit registers **ebx** and **ecx** are not 1 and 2, they are something else. HOW??

Let's see. In this program we stored the bytes in the high bytes of the registers i.e 1 is stored in the higher bytes of the register **ebx**(see Figure 12).

So for that reason the **ebx** looks kind of like this:

00000000 00000000 00000001 00000000

This binary representation is actually of the decimal number 256(i.e 2^8 if you look at the position of 1).

Similarly, the register **ecx** looks kind of like this:

00000000 00000000 00000010 00000000

This binary representation is of the decimal number 512(i.e 2^9, look at the position of 1).

And that's the reason why we see those values while checking the values in the registers **ebx** and **ecx**.