Basic Assembly Language I (Data Size)

ICS312

Machine-Level and Systems Programming

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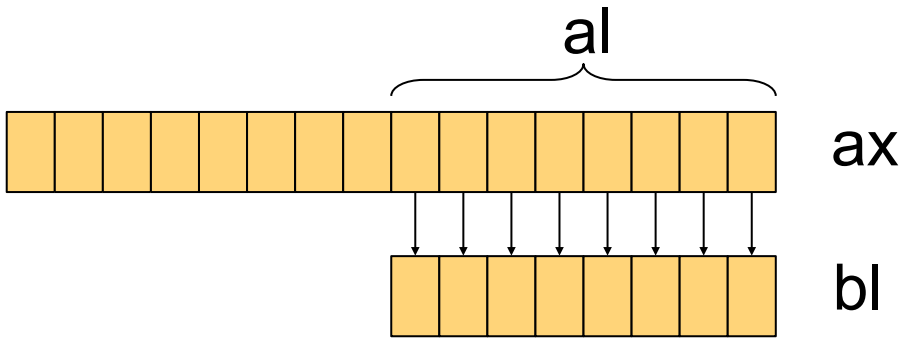
Size of Data

- Labels merely declare an address in the data segment, and do not specify any data size
- Size of data is inferred based on the source or destination register
  - mov eax, [L] ; loads 32 bits
  - mov al, [L] ; loads 8 bits
  - mov [L], eax ; stores 32 bits
  - mov [L], ax ; stores 16 bits
- This is why it's really important to know the names of the x86 registers

Size Reduction

- Sometimes one needs to decrease the data size
- For instance, you have a 4-byte integer, but you needs to use it as a 2-byte integer for some purpose
- We simply uses the the fact that we can access lower bits of some registers independently
- Example:
  - mov ax, [L] ; loads 16 bits in ax
  - mov bl, al ; takes the lower 8 bits of ax and puts them in bl



Size Reduction

- Of course, when doing a size reduction, one loses information
- So the “conversion to integers” may or may not work
- Example that “works”:
  - mov ax, 000A2h ; ax = 162 decimal
  - mov bl, al; ; bl = 162 decimal
  - Decimal 162 is *encodable* on 8 bits (it’s < 256)
- Example that “doesn’t work”:
  - mov ax, 00101h ; ax = 257 decimal
  - mov bl, al; ; bl = 1 decimal
  - Decimal 257 is *not encodable* on 8 bits because > 255

Size Reduction and Sign

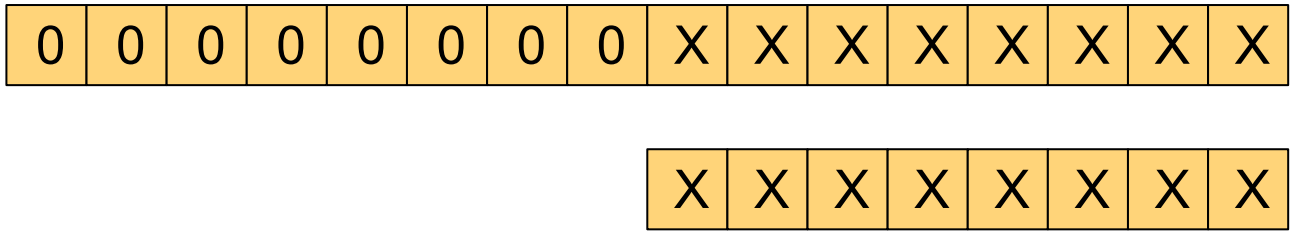
- Consider a 2-byte quantity: FFF4
- If we interpret this quantity as unsigned it is decimal 65,524
  - The computer does not know whether the content of registers/ memory corresponds to signed or unsigned quantities
  - Once again it's the responsibility of the programmer to do the right thing, using the right instructions (more on this later)
- In this case size reduction "does not work", meaning that reduction to a 1-byte quantity will not be interpreted as decimal 65,524 (which is way over 255!), but instead as decimal 244 (F4h)
- If instead FFF4 is a signed quantity (using 2's complement), then it corresponds to -000C (000B + 1), that is to decimal -12
- In this case, size reduction works!

Size Reduction and Sign

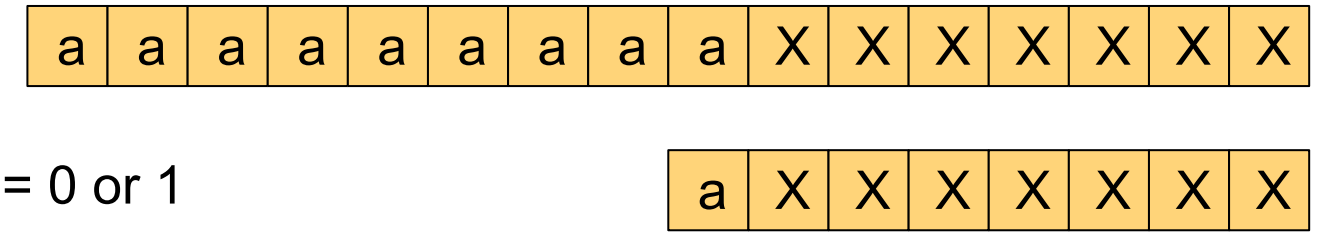
- This does **not** mean that size reduction always works for signed quantities
- For instance, consider FF32h, which is a negative number equal to -00CEh, that is, decimal -206
- A size reduction into a 1-byte quantity leads to 32h, which is decimal +50!
- This is because -206 is not encodable on 1 byte
  - The range of signed 1-byte quantities is between decimal -128 and decimal +127
- So, size reduction may work or not work for signed or unsigned quantities!
  - There will always be “bad” cases

Two Rules to Remember

- For unsigned numbers: size reduction works if all removed bits are 0



- For signed numbers: size reduction works if all removed bits are all 0's or all removed bits are all 1's, AND if the highest bit not removed is equal to the removed bits
  - This highest remaining bit is the new sign bit, and thus must be the same as the original sign bit



Size Increase

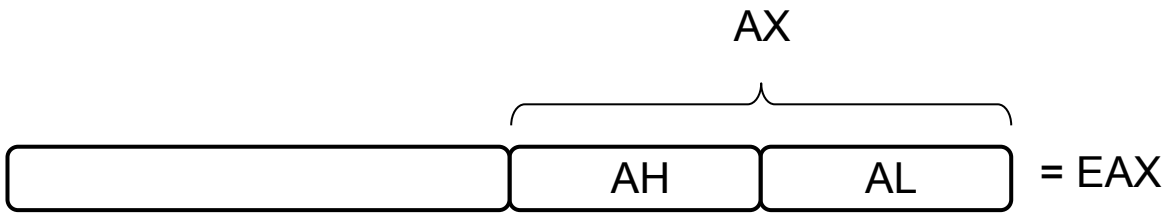
- Size increase for **unsigned** quantities is simple: just add 0s to the left of it
- Size increase for **signed** quantities requires sign extension: the sign bit must be extended, that is, replicated
  - Consider the signed 1-byte number 5A. This is a positive number (decimal 90), and so its 2-byte version would be 005A
  - Consider the signed 1-byte number 8A. This is a negative number (decimal -118), and so its 2-byte version would be FF8A

Unsigned size increase

- Say we want to size increase an unsigned 1-byte number to be a 2-byte unsigned number
- This can be done in a few easy steps, for instance:
  - Put the 1-byte number into al
  - Set all bits of ah to 0
  - Access the number as ax
- Example
  - mov al, 0EDh
  - mov ah, 0
  - mov ..., ax

Unsigned size increase

- How about increasing the size of a 2-byte quantity to 4 byte?
- This cannot be done in the same manner because there is no way to access the 16 highest bit of register eax separately!



- Therefore, there is an instruction called movzx (Zero eXtend), which takes two operands:
  - Destination: 16- or 32-bit register
  - Source: 8- or 16-bit register, or 1 byte in memory, or 1 word in memory
  - The destination must be larger than the source!

Using movzx

- movzx eax, ax ; zero extends ax into eax
- movzx eax, al ; zero extends al into eax
- movzx ax, al ; zero extends al into ax
- movzx ebx, ax ; zero extends ax into ebx
- movzx ebx, [L] ; leads to a "size not specified" error
- movzx ebx, **byte** [L] ; zero extends 1-byte value at address L into ebx
- movzx eax, **word** [L] ; zero extends 2-byte value at address L into eax

Signed Size Increase

- There is no way to use mov or movzx instructions to increase the size of signed numbers, because of the needed sign extension
- Four “old” conversion instructions with implicit operands
  - CBW (Convert Byte to Word): Sign extends AL into AX
  - CWD (Convert Word to Double): Sign extends AX into DX:AX
    - DX contains high bits, AX contains low bits
    - a left-over instruction from the time of the 8086 that had no 32-bit registers
  - CWDE (Convert Word to Double word Extended): Sign extends AX into EAX
  - CDQ (Convert Double word to Quad word): Signs extends EAX into EDX:EAX (implicit operands)
    - EDX contains high bits, EAX contains low bits
    - This is really a 64-bit quantity (and we have no 64-bit register)
- The much more popular MOVSX instruction
  - Works just like MOVZX, but does sign extension
  - CBW equiv. to MOVSX ax, al
  - CWDE equiv. to MOVSX eax, ax

Example

```
mov al 0A7h       ; as a programmer, I view this
                  ; as a unsigned, 1-byte quantity
                  ; (decimal 167)
mov bl 0A7h       ; as a programmer, I view this
                  ; as a signed 1-byte
                  ; quantity (decimal -89)

movzx eax, al;    ; extend to a 4-byte value
                  ; (000000A7)
movsx ebx, bl;    ; extend to a 4-byte value
                  ; (FFFFFFA7)
```

Signed/Unsigned in C

- In the C (and C++) language (not in Java!) one can declare variables as signed or unsigned
  - Motivation: if I know that a variable never needs to be negative, I can extend its range by declaring it unsigned
  - Often one doesn't do this, and in fact one often uses 4-byte values (int) when 1-byte values would suffice
    - e.g., for loop counters
- Let's look at a small C-code example

Signed/Unsigned in C

- Declarations:

```
unsigned char    uchar = 0xFF;
signed char      schar = 0xFF; // "char"="signed char"
```

- I declared these variables as 1-byte numbers, or chars, because I know I don't need to store large numbers
  - Often used to store ASCII codes, but can be used for anything

```
char x;
for (x=0; x<30; x++)  {  ... }
```

- Let's say now that I have to call a function that requires a 4-byte int as argument (by default "int" = "signed int")
- We need to extend 1-byte values to 4-byte values
- This is done in C with a "cast"

```
int a = (int) uchar;     // the compiler will use MOVZX to do this
int b = (int) schar;     // the compiler will use MOVSX to do this
```

Signed/Unsigned in C

```
unsigned char       uchar = 0xFF;
signed char         schar = 0xFF;
int                 a = (int)uchar;
int                 b = (int)schar;

printf("a = %d\n",a);
printf("b = %d\n",b);
```

- Prints out:
  - a = 255 (a = 0x000000FF)
  - b = -1 (b = 0xFFFFFFFF)

printf in C

- So, by declaring variables as “signed” or “unsigned” you define which of movsx or movzx will be used when you have a cast in C
- Printf can print signed or unsigned interpretation of numbers, regardless of how they were declared:
  - “%d”: signed
  - “%u”: unsigned
- Arguments to printf are automatically size extended to 4-byte integers!
  - Unless you specify “short” as in “%hd” or “%hu”
- Good luck understanding this if you have never studied assembly at all...
- Let’s try this out (this is overkill, but if you understand it, then you understand much more than the average C developer!)

Understanding printf

```
unsigned short      us = 259;  // 0x0103
signed short        ss = -45;  // 0xFFD3

printf("%d %d\n",us, ss);
printf("%u %u\n",us, ss);
printf("%hd %hd\n",us, ss);
print("%hu %hu\n",us, ss);
```

- Let's together try to understand what will be printed.....

Understanding printf

```
unsigned short      us = 259;  // 0x0103
signed short        ss = -45;  // 0xFFD3

printf("%d %d\n",us, ss);
printf("%u %u\n",us, ss);
printf("%hd %hd\n",us, ss);
print("%hu %hu\n",us, ss);
```

```
259    -45
259    4294967251
259    -45
259    65491
```

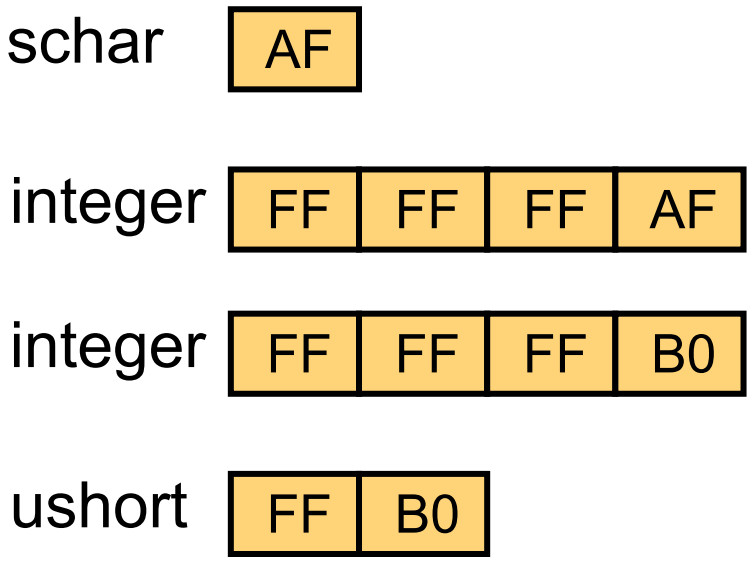
Example

```
unsigned short      ushort;    // 2-byte quantity
signed   char       schar;     // 1-byte quantity
int                 integer;   // 4-byte quantity

schar = 0xAF;
integer = (int) schar;
integer++;
ushort = integer;

printf("ushort = %d\n",ushort);
```

- What does this code print?
  - Or at least what's the hex value of the decimal value it prints?

Example

```
unsigned short      ushort;
signed   char       schar;
int                 integer;

schar = 0xAF;

integer = (int) schar;

integer++;

ushort = integer;

printf("ushort = %d\n",ushort);
```



Because printf doesn't specify "h" ushort is size augmented to 4-bytes using movzx (because declared as unsigned): 00 00 FF B0
The number is then printed as a signed integer ("%d"): 65456

More Signed/Unsigned in C

- On page 32 of the textbook there is an interesting example about the use of the fgetc() function
  - fgetc reads a 1-byte character from a file but returns it as a 4-byte quantity!
- This is a good example of how understanding low-level details can be necessary to understand high-level constructs
- Let's go through the example...

The Trouble with fgetc()

- The fgetc() function in the standard C I/O library takes as argument a file opened for reading, and returns a character, i.e., an ASCII code
- This function is often used to read in all characters of the file
- The prototype of the function is:

  int fgetc(FILE *)

- One may have expected for fgetc() to return a char rather than an int
- But if the end of the file is reached, fgetc() returns a special value called EOF (End Of File)
  - Typically defined to be -1 (#define EOF -1)
- So fgetc() returns either
  - A character zero-extended into a 4-byte int (i.e., 000000xx), or
  - Integer -1 (i.e., FFFFFFFF)

The Trouble with fgetc()

- Buggy code to compute the sum of ASCII codes in a text file:

```
char c;
while ( (c = fgetc(file)) != EOF) {
        sum += c;
}
```

- In this code we have mistakenly declared c as a char
- C being C (and not Java), it thinks we know what we're doing and does a size-reduction of a 4-byte int into a 1-byte char when doing the assignment into c
- Let's say we just read in a character with ASCII code FF (decimal 255, "ÿ")
- fgetc() returned 000000FF, but it was truncated into 1-byte integer c=FF
  - FF is -1 in decimal
- So we then compare 1-byte value FF to 4-byte value FFFFFFFF
  - C allows comparing signed integer values of different byte sizes, for convenience, by internally sign-extending the shorter value
    - int x=-1; char y=-1; // (x == y) returns TRUE
  - So FF is sign-extended into FFFFFFFF
- Therefore, the above code will "miss" all characters after ASCII code FF and mistake them for an end of file
- Solution: declare c as an int (which may seem counter-intuitive)

Conclusion

- If everything you do is Java, then these issues should never arise
- But being aware of data sizes and of data size extension/reduction behaviors is important when doing low-level development
  - Assembly, C, etc.
- Unfortunately, almost every developer at some point is confronted with data size issues and having studied a bit of assembly is really the way to remove mysteries