CS 240 Programming in C

Constants and Variables

September 13, 2022

Schedule

1. Variables
2. Constants
3. Format printing – printf

Decimal-Binary Conversion

Before anything, I want to introduce the decimal-binary number conversion. Because we are familiar with decimal numbers, whereas computer CPUs are dealing with binary numbers.

```
For a number in base 10 for example  15;
```

```
15   =   2 * 7 + 1
7    =   2 * 3 + 1
3    =   2 * 1 + 1
1    =   2 * 0 + 1
```

Thus $15_{10} = 1111_2$. Specifically,

$$15 = 2^3 * 1 + 2^2 * 1 + 2^1 * 1 + 2^0 * 1$$

Decimal-Binary Conversion

Conversion steps:

1. Divide the number by 2.
2. Get the integer quotient for the next iteration.
3. Get the remainder for the binary digit.
4. Repeat the steps until the quotient is equal to 0.

Decimal to binary calculation steps

Divide by the base 2 to get the digits from the remainders:

Division by 2	Quotient	Remainder (Digit)	Bit #
(15)/2	7	1	0
(7)/2	3	1	1
(3)/2	1	1	2
(1)/2	0	1	3

$= (1111)_2$

https://www.rapidtables.com/convert/number/decimal-to-binary.html

Bytes and Bits

Every number in computer is represented by binary number.
The unit representation in memory is 1 Byte which equals 8 bits.
Right now your computer is probably 64 bits, which means the CPU can process 64 bits data each time.
Let's get into today's topics.

Variable

- As we covered before, variables in C are just names to memory addresses.
- And for different data types of a certain variable, the memory allocated for it is different.
- Specifically, there is a void data type of a variable, which only contains an memory address without the information of the amount of memory it owns.
- Void data type is often used in pointer type casting.

Char

- Char type in C takes up only 1 byte of memory
- There are signed char and unsigned char, whose values are range from -128 to 127 or 0 to 255. For example,

```
char c1 = 65;
unsigned c2 = 65;
```

So, a char variable is essentially an one byte integer, why and how it is used to represent a letter?

ASCII Table

- Computers can only understand numbers, so an ASCII code is the numerical representation of a character such as 'a' or '@'.
- To utilize the letter meaning of a char variable, we have to treat it associated with ASCII table.
- In standard library stdio, there are function like putchar and printf which will print out the letter of a char onto screen. Lets see a demo.

ctype.h

Turn to textbook pg 249, there is a list of functions for testing characters defined in <ctype.h>

```
isalnum(c) isalpha(c) or isdigit(c)
isalpha(c) isupper(c) or islower(c)

int tolower(c) convert c to lower case
int toupper(c) convert c to upper case
```

Question: can you write the implemation yourself for tolower and to upper

Integer

Based on how large memory an integer variable can hold, there are 3 types of integer in C:

```
short   2 bytes
int     4 bytes
long    8 bytes
```

These are signed integer types, for each there are also unsigned:

```
unsigned    short   2 bytes
unsigned    int     4 bytes
unsigned    long    8 bytes
```

Integer

1, Things are simple when integers are all positive.

2, Things become complex when there are negative integers.

3, Because CPU calculates the equivalent addition for a subtraction which results computer stores a negative as its 2's complement form.

4, Let's take an example

2's Complement

1, Assume we have an data type of int_4 which contains 4 bits and the first bit is a signed bit, for which 0 stands for positive and 1 for negative. For example:

```
int_4 a =  3; //  0011
int_4 b = -2; //  1010 (without 2's complement form)
```

2's Complement

2, The process of 2's complement for negative integers,

```
-2    1010    (without 2's complement form)
      1101    1's complement form
      1110    2's complement form
```

3, 2's complement of a positive stays the same.

2's Complement

How to calculate 1's complement for a binary number?

The 1's complement can be easily calculated by inverting the 0s & 1s of a given binary number.

How to calculate 2's complement for a binary number?

1. Find the one's complement by inverting 0s & 1s of a given binary number.
2. Add 1 to the one's complement provides the two's complement.

2's Complement Addition

4, let's do a + b with addition of their 2's complement form.

```
variable     value    2's complement form
       a     -2         1110
       b      3      + 0011
              ------------
                    10001
```

2's Complement

5, Since a and b are of int_4 type which only contains 4 bits, the result 10001 will be cut to 0001 which is 1.

6, Thus a + b == 3 - 2 = 1

7, Let's do another example by letting a = -2, b = -1:

2's Complement Addition

Example: a = -2, b = -1

```
variable     value    2's complement form
       a     -2       1110
       b     -1     + 1111
              -----------
                    11101
```

Let's compute -3's 2's complement form:

```
    -3  1011    (without 2's complement form)
        1101    2's complement form
```

Overflow of Integers'

- Arithmetic data types in C has fixed memory storage, which means if the value to be assigned is larger that a variable can hold, it will just discard those highest bits.
- Like in the above demo which 11101 being cut into 1101, we will see some demo in real C.
- The implementation overflow of unsigned integer is defined behavior, however the overflow of signed integer is not, or implementation-defined behaviour.

Undefined Behaviour

- In C, some expressions yield undefined behavior. The standard explicitly chooses to not define how a compiler should behave if it encounters such an expression.
- As a result, a compiler is free to do whatever it sees fit and may produce useful results, unexpected results, or even crash.
- Code that invokes UB may work as intended on a specific system with a specific compiler, but will likely not work on another system, or with a different compiler, compiler version or compiler settings.
- For portability, try avoid them

In memory -0

- In memory -0 means in memory bit level of 1000,0000 for char, and 1000,0000,0000,0000 for short.
- Not the same thing with -0 in your code.
- In memory -0 for a signed integer type, will be treated differently based on machine's architecture. Page 36 in text book.
- It is treated as the least negative number of its data type on a 2's complement machine, for example, -0 for a char type is -128
- So the range of signed char is [-128, 127]. the range of signed integer is $[-2^{31} - 1, 2^{31}]$

Demo of integer overflow

- Integer overflow and initialization are implementation-dependent behaviour.
- Turn to p257 on our text book.
- header <1imits.h> defines constants for the sizes of integral types.

Demo of integer overflow

```
int main(void)
{
  printf("%lu\n",sizeof(int) );
  printf("This if for signed:\n");
  printf("    INT_MAX : %11d\n", INT_MAX);
  printf("1 + INT_MAX : %11d\n", INT_MAX + 1);
  printf("    INT_MIN : %11d\n",INT_MIN);
  printf("INT_MIN - 1 : %11d\n",INT_MIN - 1);
  printf("This if for unsigned:\n");
  printf("    INT_MAX : %11u\n", UINT_MAX);
  printf("1 + INT_MAX : %11u\n", UINT_MAX + 1);
  printf("    INT_MIN : %11u\n",0);
  printf("INT_MIN - 1 : %11u\n", - 1);
  return 0;
}
```

A pitfall

- We have not talk about typecast yet, but it is a good reminder to make here.
- It is usually not a good idea to mix signed and unsigned integers in arithmetic operations.
- It is better practice to first cast unsigned to signed and then do operations.
- It is often wrong to cast negative to an unsigned integer.

What will be printed out ? and Why ?

```
int main(void)
{
  unsigned int a = 1000;
  signed int b = -1;

  if (a > b)
      printf("a is more than b");
  else
      printf("a is less or equal than b");

  return 0;
}
```

What will be printed out ? and Why ?

```
int main(void)
{
  unsigned int a = 1000; // 1111101000
  signed int b = -1;     // 1111111111

  if (a > b)
      printf("a is more than b");
  else
      printf("a is less or equal than b");

  return 0;
}
```

Fixed Width Integer Types

As different implementations may have different width for int or long etc., since c99 the header <stdint.h> provides several fixed-width signed integer type definitions.

The width is explicit with their data type names.

```
/* commonly used types include */

uint32_t u32 = 32; /* exactly 32-bits wide */

uint8_t  u8 = 255; /* exactly 8-bits wide */

int64_t  i64 = -65 /* exactly 64 bit in two's complement
                                        representation */
```

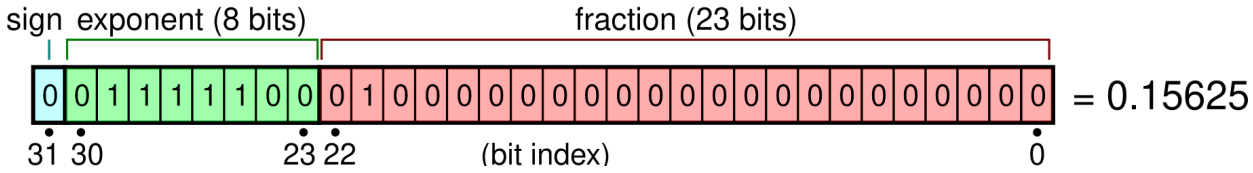
Floating-point Numbers

There are just signed floating point data type. For example,

Type	Storage	Value range			Precision
float	4 byte	1.2E-38	to	3.4E+38	6 decimal
double	8 byte	2.3E-308	to	1.7E+308	15 decimal
long double	10 byte	3.4E-4932	to	1.1E+4932	19 decimal

Single-precision floating-point format

Now Let's take a look how C stores floating-point number with float type.



- radix is 2, 1 sign bit, 8 exponent bits and 24 for mantissa bits (one implicit bit and 23 fraction bits)
- More: `https://en.wikipedia.org/wiki/Single-precision_floating-point_format`

The real value assumed by a given 32-bit binary data is computed as:

$$(-1)^{b_{31}} \times 2^{(b_{30}b_{29}\ldots b_{23})_2 - 127)} \times (1.b_{22}b_{21}\ldots b_0)_2$$

which gives :

$$(-1)^{sign} \times 2^{(e-127)} \times (1 + \sum_{i=1}^{23} b_{23-i}2^{-i})_2$$

Constants of Floats

Turn to Page 257 in which you will see:

```
FLT_RADIX       2          radix of exponent representation
FLT_ROUND       1          floating-point rounding mode for addition
FLT_DIG         6          decimal digits of precision
FLT_EPSILO      1E-05      smallest number x such that 1.0 + x <> 1.0

FLT_MANT_DIG    24         number of base FLT_RADIX digits in mantissa
FLT_MAX         1E+37      maximum floating-point number
FLT_MAX_EXP     128        maximum n such that FLT_RADIX^n-1 is
                           re-presentable
FLT_MIN         1E-37      minimum normalized floating-point number
FLT_MIN_EXP     -125       minimum n such that 10^n is a normalized
                           number
```

math.h

Turn to textbook pg 250, there is a list of functions for testing characters defined in <math.h>

Constants

- Constants or literals are fixed value in a C program.
- There are four basic constant data types in C:
  1. Integer constant/literal
  2. Floating number constant/literal
  3. Character constant/literal
  4. String constant/literal

Integer Constant

- An integer literal can be a decimal, octal, or hexadecimal constant.
- A prefix specifies the base or radix: 0x or 0X for hexadecimal, 0 for octal, and nothing for decimal.
- An integer literal can also have a suffix that is a combination of U/u and L/l, for unsigned and long, respectively.
- The suffix is not case sensitive.

Integer Constant Example!

```
10,         -10             /* decimal/int */
010,        -010            /* octal       */
0x1A,       -0x1A,          /* hexadecimal */
10u                         /* unsigned int */
10l,        -010l           /* long */
10ul,       10lu            /* unsigned long */
```

```
Note:
1, the relative position of l and u does not matter.
2, for an signed number the first left bit is the sign bit,
   if it is 1 means negative if it is 0 means positive.
3, for example,
            signed char   memory
                    1     0000,0001
                   -1     1000,0001
```

Illegal Constant Number Expressions

For example: 078

What's wrong with this expression?

Illegal Constant Number Expressions

```
For example:        078
```

```
    Decimal:        {0,1,2,...,9}
    Octal   :       {0,1,2,...,7}
    Hexadecimal   : {0,1,2,...,9, A,..,F}
```

Floating-point Constants

decimal form	exponential form
3.1415926,	31425927E-5 or 31425927e-5 (denotes double)
3.1415926f,	31425927E-5f or 31425927e-5f (denotes float)

0, The e/E denoted radix of 10.

1, Floating number literals without suffix "f" will be treated as double.

2, For the decimal floating number, we have to have the dot part with other parts.

3, For the exponential form, we must include the integer part, the e/E and the exponent part.

Floating-point Constants

```
324, 314E are illegal floating numbers.

Try them, see what will happen.
    printf("%f\n", 314);
    printf("%f\n", 314e);

.1 and 1. are legal
```

Character Constants

- Character constants are enclosed in single quotes, e.g., 'x'.
- There are plain character like 'x', and also escape character '\n'
- 0 and '0' are different. '0' represents the ASCII integer value of '0'.
- Page 37. Character literal can also be specified by octal or hexadecimal digits within this form:

```
#define VTAB '\013'
#define BELL '\007'
#define VTAB '\xb'
#define BELL '\x7'
```

- '0' and "0" are also different things in C.

Character Constants

Here is a list of escape character:

\\	\ character
\'	' character
\"	" character
\?	? character
\a	Alert or bell
\b	Backspace
\f	Form feed
\n	Newline
\r	Carriage return
\t	Horizontal tab
\v	Vertical tab
\ooo	Octal number of one to three digits
\xhh...	Hexadecimal number of one or more digits

String Constants

- String constants are enclosed in double quotes, like "hello world".
- And they are just a sequence of character constants
- String constants can be concatenated at compile time:

```
        "hello," " world"
is equivalent to
        "hello, world".
```

- The internal representation of a string has a null character '\0' at the end, so the physical storage required is one more than the number of characters written between the quotes
- We will cover string more later.

printf

- On page 154.