Introduction to Programming (CS 101)

Spring 2024

Lecture 7:

More about data types, floating point

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Based on material developed by Prof. Abhiram Ranade and Prof. Manoj Prabhakaran

Recap-I: `bool` and `int` types

What is the output of the following program?

`1,32`

`1,1`

`32,32`

```
main_program {
  bool b = 32;
  int i = b;
  cout << b << "," << i << endl;
}
```

Recap-II: `char` arithmetic

What is the output of the following program?

9

18

57 (ASCII code of '9')

48 (ASCII code of '0')

```
main_program {
  char c = '9' + '9' – '0' – '0';
  cout << int(c) << endl;
}
```

Recap-III: Palindrome

Fill in the blanks below to check whether a non-negative integer **n** is a palindrome or not, i.e. is the number the same when read either in forward or backward directions. E.g., 2332 is a palindrome, but 432 is not.

```
main_program {
  unsigned int n, r = 0;
  cin >> n;

  for(int q = n;        ;q =        ){
     r =
  }

  if(n == r) cout << "Palindrome" << endl;
  else cout << "Not Palindrome" << endl;
}
```

Recap-III: Palindrome

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```
main_program {
  unsigned int n, r = 0;
  cin >> n;

  for(int q = n; q > 0; q = q/10){
     r = (r * 10) + (q % 10);
  }

  if(n == r) cout << "Palindrome" << endl;
  else cout << "Not Palindrome" << endl;
}
```

An aside: lvalues and rvalues

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lvalues and rvalues

- lvalue always has a defined region of memory, so you can refer to it.
  - Most common example of lvalue expressions are variable names (including `const` variables). E.g., `int a;`
  - Only an lvalue can appear on the left side of an assignment. E.g., `a = 5;`
  - `a = b`, `a += b`, and other assignment operations are lvalue expressions
  - `a, b` (comma expression) where `b` is an lvalue
- rvalue refer to expressions that evaluate to a value (an rvalue is not an lvalue!)
  - `bool`, `char`, `int` literals such as `false`, `'A'`, `42`, etc.
  - arithmetic expressions (`a + b`), logical expressions (`a && b`), comparison expressions (`a != b`)
  - `a, b` (comma expression) where `b` is an rvalue
- `++a`, `--a` are lvalue expressions, but `a++`, `a--` are not. (More about this when we learn about references.)

Data types and their representations (contd)

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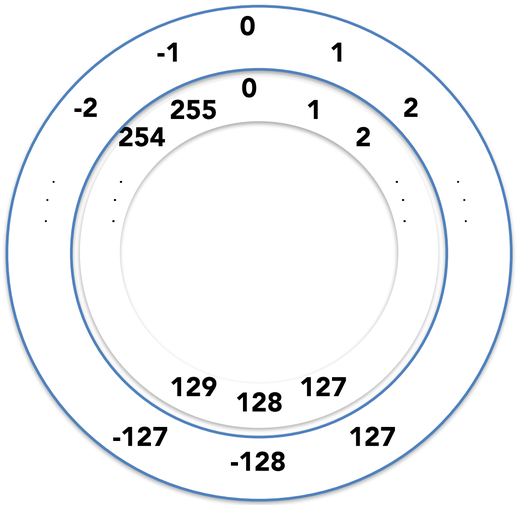
Recap: Binary representations, `bool`, `int`

- Binary representation using `n` bits (two's complement format for signed numbers). Recall the *circular* schematic to help visualize this format.

- The bit representation $b_{n-1} \ldots b_1 b_0$ stands for the signed number: $-b_{n-1}*2^{n-1} + \ldots + b_1*2^1 + b_0*2^0$ (note the sign applies only to the most significant bit b_{n-1})

- Type casting: You can explicitly *cast* one data type to another.
  - E.g. `int x; bool b = bool(x);`
  - `int` can be converted to `char` by mod 256

- Bitwise operations (`&, |, ~, ^`) act bitwise on byte sequences



`int`: Literal formats

- `int` literal is an integer constant written in a program. E.g., `int a = -1, b = 4;`
- `int` literals are typically in decimal. But literals can also be represented in binary, by starting the literal with `0b`. E.g., `0b11010 == 26`
- `int` literals can also be represented in octal (base 8, starting with `0`) or hexadecimal (base 16, starting with `0x`) formats
  - `032 == 26` ($d_{n-1}*8^{n-1} + \ldots + d_1*8^1 + d_0*8^0$)
  - `0x1a == 26` ($d_{n-1}*16^{n-1} + \ldots + d_1*16^1 + d_0*16^0$)

Why do coders confuse Halloween with Christmas? Because oct 31 ≡ dec 25! 🤷🏾‍♀️

- Hexadecimal format allows for compact representation of long binary sequences.
  - The byte `00011010` can be written as `0x1a` (or `0x1A`)
  - `a,b,c,d,e,f` in hexadecimal format correspond to the numbers `10,11,12,13,14,15` respectively
- Note: `cin` reads decimal integers

Internal representations are binary

- Binary representation of integers
  - An n-bit binary representation $b_{n-1} \ldots b_1 b_0$ stands for the number $b_{n-1}*2^{n-1} + \ldots + b_1*2^1 + b_0*2^0$
  - Example: Binary **110** represents the number 6 (**1***2^2 + **1***2^1 + **0***2^0)

- Binary representation of fractions
  - $b_{n-1} \ldots b_1 b_0 . b_{-1} b_{-2} \ldots b_{-m}$ stands for the number $b_{n-1}*2^{n-1} + \ldots + b_1*2^1 + b_0*2^0 + b_{-1}/2^1 + b_{-2}/2^2 + \ldots + b_{-m}/2^m$
  - Example: Binary **110.101** represents the number 6 (**1***2^2 + **1***2^1 + **0***2^0) + ⅝ (**1**/2 + **0**/2^2 + **1**/2^3)

`float` and `double` type

- `float` represents floating point numbers that correspond to `4` bytes, i.e., `32` bits

- While representing a real number as a floating point number, we will use some bits for precision, and some for scale (both signed)
  - E.g.: In decimal, $7.8234 \times 10^2 = 782.34$ has 5 digits of precision, and its scale given by the exponent 2 is such that it is between 100 and 999

- 1 bit for sign. Precision of `24` bits (23 bits stored, a leading 1 is implicit). Scale stored using 8-bits: 2^{-126} to 2^{127} (two values of the exponent are used for indicating special values such as `nan`, `inf`, etc.).
  - E.g.: In binary, $\texttt{0b1.1} \times 2^{-3} = \texttt{0b0.0011}$

- `double` (for double precision floating number) uses `8` bytes i.e., `64` bits
  - 1 bit for sign, 53 bits for precision (one implicit), 11 bits for scale.

`float` literals

- Format for floating point literals (numbers appearing in the programs) and also as used by `cin`/`cout`
  - E.g.: We write `num E exp` (with no spaces) to mean `num` × $10^{\texttt{exp}}$, where `num` can optionally have a decimal point
  - Note: Exponent is for `10`. Also, the number is in decimal.
  - Examples: `314E-2`, `-0.01`, etc. `E` is optional if . present.
  - `6.023e23` (can use either e or E), `1.5e+2` (+ sign is optional)
- By default, the literal is taken to be a `double`. Suffix f or F to force `float`, if you want.

Working with real numbers

- For the sake of better precision, use `double` instead of `float`
  - Using `double` can be a little less efficient in large applications: more memory needed, and (hence) slower

- When comparing, allow a “tolerance” (and be prepared for false positives)
  - Instead of `a == b`, check that absolute value of `(a - b)` is less than or equal to `epsilon`
  - Choice of the tolerance value `epsilon` will be application dependent

Floating point arithmetic: Precision issues

- Order matters

```
float f = 5e7; // 50 million > 2^24
cout << 1 + f - f << endl; // What is the output?
cout << f - f + 1 << endl; // What is the output?
```

output

Produces 0 as output!

output

Produces 1 as expected

- Internal representations are binary

```
cout << 1 + 0.001F - 1 << endl; // What is the output?
cout << 1 + 0.03125 - 1 << endl; // What is the output?
```

output

Not equal to 0.001F!

output

Equal to 0.03125!

Bit shift operators

- Recall that the operators `&, |, ^ and ~` can be used for bit-level manipulations
- Bit shift operators `<<` and `>>` operate on an integral type (`char`, `int`, etc.) variable, and takes a number (how much to shift by) as an additional input
- `(a << n)` shifts the bits in `a` by `n` positions to the left; `n` most significant bits fall off, and `n` least significant bits are set to `0`.
  - Essentially `(a << n)` is the same as `a*2*..*2` (`n` times) done more efficiently
- Similarly `(a >> n)` shifts the bits in `a` by `n` positions to the right; `n` least significant bits fall off, and `n` most significant bits are set to `0` (for unsigned or non-negative `a`) or `1` (for negative signed `a`)
  - Essentially `(a >> n)` is the same as `a/(2*..*2)` (`n` times) if `a` is unsigned or non-negative; for negative `a`, division rounds towards `0`, while `>>` rounds away from `0`

Example: << operator

- Demo in class of code to convert an integer to binary format

Common C++ Errors

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Some common C++ errors (based on concepts studied so far)

- Using = (assignment) instead of == (equal to)
- Not enclosing a multiple-statement body within parenthesis `{ }`
- Dangling else
- Variable scope issues
- Integer division when floats/doubles are required
- Operator precedence; use parentheses whenever precedence is unclear
- Lossy type casting. E.g., `int i = 32; bool b = i;`
- Loop limits being off by one (e.g., using `i = 0 → n` instead of `i = 0 → n-1` for `n` iterations)
- Division by zero
- Sequentially address compiler errors; errors could compound

Next class: Practice Session

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