COMP 2012H Honors Object-Oriented Programming and Data Structures

Topic 2: Fundamentals of C++

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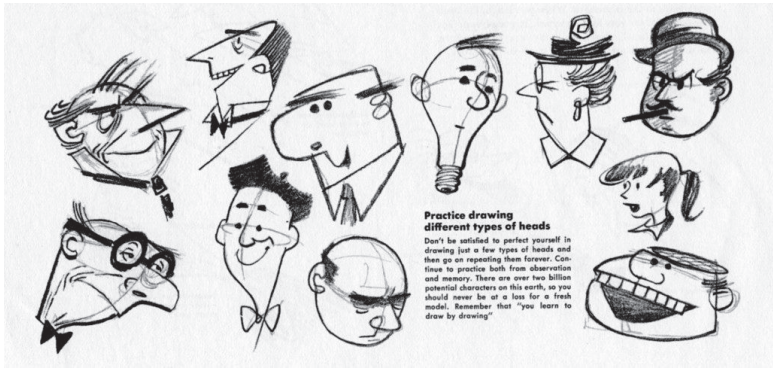
Part I

Simple C++ Data Types



Data Types: Introduction

- A computer program has to deal with different types of data. In a programming language, data are categorized into different types.
- Each data type comes with a set of operations for manipulating its values. Operations on basic data types are built into a programming language.

C++ Basic Types

Types	Common Size(#bytes on a 32-bit machine)	Value Range
bool	1	{ true, false }
char	1	[-128, 127]
short	2	[-32768, 32767]
int	4	$[-2^{31}, 2^{31}-1]$
long	4	$[-2^{31}, 2^{31}-1]$
float	4	± [1.17549E-38, 3.40282E+38]
double	8	± [2.22507E-308, 1.79769E+308]

- Not all numbers of a type can be represented by a computer.
- It depends on how many bytes you use to represent it: with more bytes, more numbers can be represented.

Find Out Their Sizes using sizeof

```
#include <iostream>     /* File: value.cpp */
using namespace std;

int main()
{
    cout << "sizeof(bool) = " << sizeof(bool) << endl;
    cout << "sizeof(char) = " << sizeof(char) << endl;
    cout << "sizeof(short) = " << sizeof(short) << endl;
    cout << "sizeof(int) = " << sizeof(int) << endl;
    cout << "sizeof(long) = " << sizeof(long) << endl;
    cout << "sizeof(long long) = " << sizeof(long long) << endl;
    cout << "sizeof(float) = " << sizeof(float) << endl;
    cout << "sizeof(double) = " << sizeof(double) << endl;
    cout << "sizeof(long double) = " << sizeof(long double) << endl;

    return 0;
}
```


Size of Basic Types on 2 Computers

on a 32-bit machine

```
sizeof(bool) = 1
sizeof(char) = 1
sizeof(short) = 2
sizeof(int) = 4
sizeof(long) = 4
sizeof(long long) = 8
sizeof(float) = 4
sizeof(double) = 8
sizeof(long double) = 12
```

on a 64-bit machine

```
sizeof(bool) = 1
sizeof(char) = 1
sizeof(short) = 2
sizeof(int) = 4
sizeof(long) = 8
sizeof(long long) = 8
sizeof(float) = 4
sizeof(double) = 8
sizeof(long double) = 16
```

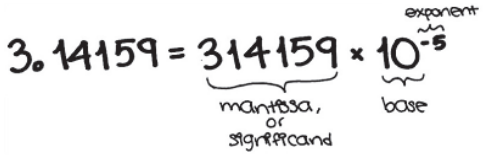
- Note that the figures may be different on your computer.
- A 32(64)-bit machine uses CPUs of which the data bus width and memory address width are 32 (64) bits.

Integers

- Type names: short (int), int, long (int), long long (int)
- Their sizes depend on the CPU and the compiler.
- ANSI C++ requires:
  size of short $\leq$ size of int $\leq$ size of long $\leq$ size of long long
- e.g., What are the numbers that can be represented by a 2-byte short int?
- Each integral data type has 2 versions:
  - signed version: represents both +ve and -ve integers.
    e.g. signed short, signed int, signed long
  - unsigned version: represents only +ve integers.
    e.g. unsigned short, unsigned int, unsigned long
- signed versions are the default.
- Obviously unsigned int can represent 2 times more +ve integers than signed int.

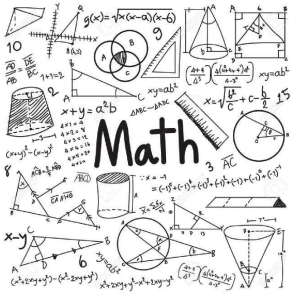
Floating-Point Data Types

- Floating-point numbers are used to represent real numbers and very large integers (which cannot be held in long long).
- Type names:
  - float for single-precision numbers.
  - double for double-precision numbers.
- Precision: For decimal numbers, if you are given more decimal places, you may represent a number to higher precision.
  - for 1 decimal place: 1.1, 1.2, 1.3, ... etc.; can't get 1.03.
  - for 2 decimal places: 1.01, 1.02, 1.03, ... etc.; can't get 1.024.
- In scientific notation, a number has 2 components. e.g. 5.16E-02
  - mantissa: 5.16
  - exponent: -2
- More mantissa bits $\Rightarrow$ higher precision.
- More exponent bits $\Rightarrow$ larger real number.



Integer Arithmetic and Floating-Point Arithmetic

- Arithmetic expressions involving only integers use integer arithmetic.
- Arithmetic expressions involving only floating-point numbers use floating-point arithmetic.
- For $+$, -, $\times$ operations, results should be what you expect.
- However, integer division and floating-point division may give different results. e.g.,
  - $10/2 = 5$ and $10.0/2.0 = 5.0$
  - $9/2 = 4$ and $9.0/2.0 = 4.5$
  - $4/8 = 0$ and $4.0/8.0 = 0.5$



Integers, Characters, Character Strings

- Integers
  - Examples: ..., -2, -1, 0, 1, 2, ...
  - C++ type name: int
- Characters
  - Examples: 'a', 'b', '4'
  - Represent a single character by delimiting it in single quotes.
  - For special characters, use the escape character \. e.g.

'\t'	=	tab	'\n'	=	newline
'\b'	=	backspace	'\0'	=	null character

  - C++ type name: char
- Character Strings
  - Examples: "hkust", "How are you?", "500 dollars"
  - Character strings are not a basic data type in C++.
  - They are sequences of basic char data.

Note: There is a string library that defines string objects which are more than a character string. (More about it later.)

Relation between Characters and Integers

- In C++, a char datum is represented by 1 byte (8 bits).
- Question: How many different characters can 8 bits represent?
- Put it in another way, a char datum is encoded by one of the possible 8-bit patterns.
- The most common encoding scheme is called ASCII (American Standard Code for Information Interchange).
- Since a computer only recognizes bits, a char datum may also be interpreted as an integer!

Character	ASCII Code	Integral Value
'0'	00110000	48
'1'	00110001	49
'9'	00111001	57
'?'	00111111	63
'A'	01000001	65
'B'	01000010	66
'Z'	01011010	90
'a'	01100000	97
'b'	01100001	98
'z'	01111010	122

Boolean Data Type

- Type name: bool.
- Used to represent the truth value, true or false of logical (boolean) expressions like:

$$a > b \qquad x + y == 0 \qquad \text{true \&\& false}$$

- Since C++ evolves from C, C++ follows C's convention:
  - zero may be interpreted as false.
  - non-zero values may be interpreted as true.
- However, since internally everything is represented by 0's and 1's,
  - false is represented as 0.
  - true is represented as 1.
- Even if you put other values to a bool variable, its internal value always is changed back to either 1 or 0.

Example: Output Boolean Values

```
#include <iostream>     /* File: boolalpha.cpp */
using namespace std;

int main()
{
    bool x = true;
    bool y = false;

    // Default output format of booleans
    cout << x << " && " << y << " = " << (x && y) << endl << endl;

    cout << boolalpha;   // To print booleans in English
    cout << x << " && " << y << " = " << (x && y) << endl << endl;

    cout << noboolalpha; // To print booleans in 1 or 0
    cout << x << " && " << y << " = " << (x && y) << endl;

    return 0;
}
```


Underflow and Overflow in Integral Data Types

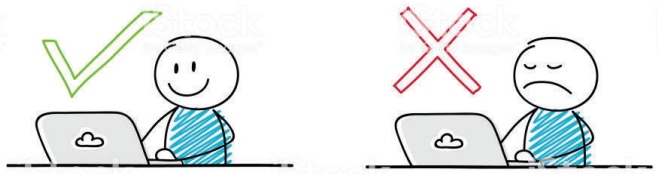
- Overflow: occurs when a data type is used to represent a number larger than what it can hold. e.g.
  - if you use a short int to store HK's population.
  - when a short int has its max value of 32767, and you want to add 1 to it.
- Underflow: occurs when a data type is used to represent a number smaller than what it can hold. e.g.
  - use an unsigned int to store a -ve number.

Underflow and Overflow in Floating-Point Data Types

- Underflow: when the -ve exponent becomes too large to fit in the exponent field of the floating-point number.
- Overflow: when the +ve exponent becomes too large to fit in the exponent field of the floating-point number.
- To prevent these from happening, use double if memory space allows.
- In fact, all floating literals (e.g., 1.23) is treated as double unless explicitly specified by a suffix (e.g., 1.23f).

Part II

Type Checking and Type Conversion



Type Checking and Coercion

- For most languages, data types have to be matched during an operation ⇒ type checking.
- However, sometimes, a type is made compatible with a different type ⇒ coercion.

Operand Coercion

Coercion is the automatic conversion of the data type of operands during an operation.

- Example: $3 + 2.5$ ⇒ int + double.
- The C++ compiler will automatically change it to
  $3.0 + 2.5$ ⇒ double + double
- Thus, the integer 3 is coerced to the double 3.0.

Example: Convert a Small Character to Capital Letter

```
char small_y, big_y;
cin >> small_y;                 // Character in small case
big_y = small_y + 'A' - 'a'; // Character in big case
```

Here big_y, small_y, 'A', and 'a' are "coerced" by "promoting" it to int before addition. The result is converted back (or coerced) to char.

Priority Rules for the Usual Arithmetic Conversions for Binary Operations (Simplified Version)

- If either operand is of type long double, convert the other operand also to long double.
- If either operand is of type double, convert the other operand also to double.
- If either operand is of type float, convert the other operand also to float.
- Otherwise, the integral promotions shall be performed on both operands.
  - Similar rules are used for integral promotion of the operands.
  - Compute using integer arithmetic.

Question: What is the result of 3/4?

Automatic Type Conversion During Assignment

Examples

```
float x = 3.2;          // Initialize x with 3.2 by assignment
double y = 5.7;         // Initialize y with 5.7 by assignment

short k = x;            // k = ?
int n;
n = y;                  // n = ?
```

- Since float|double can hold numbers bigger than short | int, the assignment of k and n in the above program will cause the compiler to issue a warning — not an error.

Compiler Warnings

a.cpp:9: warning: converting to 'short int' from 'float'
a.cpp:11: warning: converting to 'int' from 'double'

Automatic Type Conversion During Assignment ..

- A narrowing conversion changes a value to a data type that might not be able to hold some of the possible values.
- A widening conversion changes a value to a data type that can accommodate any possible value of the original data.
- C++ uses truncation rather than rounding in converting a float | double to short | int | long.

Manual Type Conversion (Casting)

```
int k = 5;
int n = 2;
float x = n/k;          // What is the value of x?
```

- In the above example, one can get x = 0.4 by manually converting n and/or k from int to float | double.

Syntax: static_cast for manual type casting

static_cast<data-type> (value)

- No more warning messages on narrowing conversion.

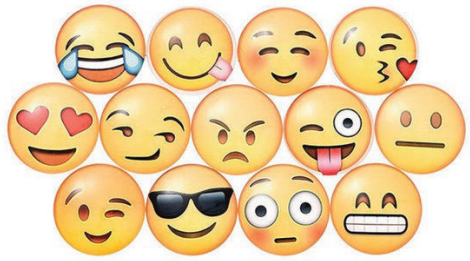
```
int k = 5, n = 2;
float x = static_cast<double>(n)/k;
float y = n/static_cast<double>(k);
float z = static_cast<double>(n)/static_cast<double>(k);
```


Part III

Constants

Literal Constants

- Constants represent fixed values, or permanent values that cannot be modified (in a program).
- Examples of literal constants:
  - char constants: 'a', '5', '\n'
  - string constants: "hello world", "don't worry, be happy"
  - int constants: 123, 456, -89
  - double constants: 123.456, -2.90E+11



Symbolic Constants

- A symbolic constant is a named constant with an identifier name.
- The rule for identifier names for constants is the same as that for variables. However, by convention, constant identifiers are written in capital letters.
- A symbolic constant must be defined and/or declared before it can be used. (Just like variables or functions.)
- Once defined, symbolic constants cannot be changed!

Syntax: Constant Definition

const <data-type> <identifier> = <value> ;

Example

```
const char BACKSPACE = '\b';
const float US2HK = 7.80;
const float HK2RMB = 0.86;
const float US2RMB = US2HK * HK2RMB;
```


Why Symbolic Constants?

Compared with literal constants, symbolic constants are preferred because they are

- more readable. A literal constant does not carry a meaning. e.g. the number 67 cannot tell you that it is the enrollment quota of COMP2012H in 2020.

```
const int COMP2012H_QUOTA = 67;
```

- more maintainable. In case we want to increase the quota to 100, we only need to make the change in one place: the initial value in the definition of the constant COMP2012H_QUOTA.

```
const int COMP2012H_QUOTA = 100;
```

- type-checked during compilation.

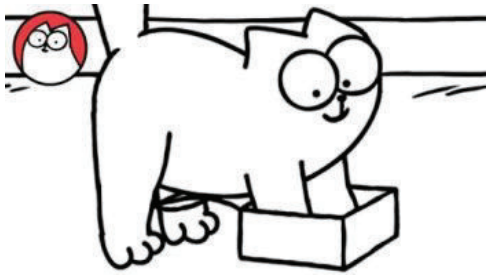
Remark: Unlike variable definitions, memory is not allocated for constant definitions with only few exceptions.

Example: Use of Symbolic Constants

```
#include <iostream>     /* File: symbolic-constant.cpp */
#include <cmath>        // For calling the ceil() function
using namespace std;

int main()
{
    const int COMP2012H_QUOTA = 67;
    const float STUDENT_2_PROF_RATIO = 100.0;
    const float STUDENT_2_TA_RATIO = 40.0;
    const float STUDENT_2_ROOM_RATIO = 100.0;

    cout << "COMP2012H requires "
         << ceil(COMP2012H_QUOTA/STUDENT_2_PROF_RATIO)
         << " instructors, "
         << ceil(COMP2012H_QUOTA/STUDENT_2_TA_RATIO)
         << " TAs, and "
         << ceil(COMP2012H_QUOTA/STUDENT_2_ROOM_RATIO)
         << " classrooms" << endl;

    return 0;
}
```


Part IV

C++ Variables



Identifiers

$$f(x) = x^2 + c$$

where

- f : name of a function
- x : name of a variable
- c : name of a constant

In programming languages, these "names" are called identifiers.

Rules for Making up Identifier Names

- Only the following characters may appear in an identifier:

  0–9, a–z, A–Z, _

- The first character cannot be a digit (0–9).
- C++ keyword — reserved words — are not allowed.
- Examples: amount, COMP2012H, _myname_
- C++ identifiers are case-sensitive: lowercase and uppercase letters are considered different.

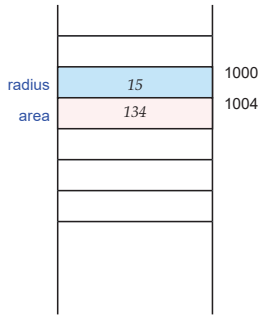
  ⇒ hkust, HKUST, HkUst, HKust are different identifiers.
- Examples of illegal C++ identifiers:
- Guidelines:
  - use meaningful names. e.g. amount instead of a
  - for long names consisting of several words, use '_' to separate them or capitalize them. e.g. num_of_students or numOfStudents instead of numofstudents.
  - usually identifiers starting with '_' are used for system variables.

Reserved Words in C++

asm	auto	bool	break	case
catch	char	class	const	const_cast
continue	default	delete	do	double
dynamic_cast	else	enum	explicit	extern
false	float	for	friend	~~goto~~
if	inline	int	long	mutable
namespace	new	operator	private	public
protected	register	reinterpret	return	short
signed	sizeof	static	static_cast	struct
switch	template	this	throw	true
try	typedef	typeid	typename	union
unsigned	using	virtual	void	volatile
wchar_t	while			

Variables

A variable is a named memory location for a value that we can write to, retrieve from, and manipulate.



- It can be thought of as a container/box for a value.
- A variable must be declared and/or defined before it can be used.

Syntax: Variable Definition

<data-type> <identifier> ;

Examples

```
int radius = 10, sum = 0;
```

Variable Declaration/Definitions

Syntax: Defining Several Variables of the Same Type at Once

<data-type> <identifier1>, <identifier2>, ··· ;

Examples

```
int radius, num_of_words;
char choice, gender, pass_or_fail;
```

- When a variable is defined, the compiler allocates memory for it.
- The amount of memory is equal to the size of its data type.

** Some books will call this variable declaration. Actually there is a big difference between variable declaration and variable definition. We'll talk about that later. When a variable is defined, it is also declared. The other way is not true.

Variable Initialization

Syntax: Initialize Variables While they Are Defined

<data-type> <identifier> = <value> ;

- Several variables of the same type may also be initialized at the same time. e.g.

```
int radius = 10, sum = 0;
```

- A variable may also be initialized by a separate assignment statement after it is defined: e.g.

```
int radius;     // Variable definition
radius = 5;     // Initialization by assignment
```

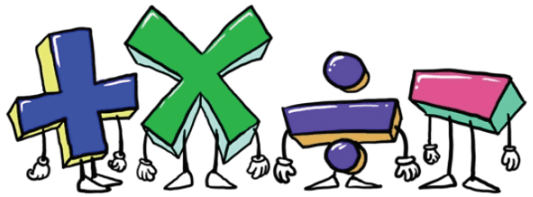
- ANSI C++ does not require compilers to initialize variables.
- Thus, in general, if you do not explicitly initialize variables while you are defining them, their initial contents may be garbage. (Global variables are an exception.)

Example: Addition of 2 Numbers Using Variables

```
#include <iostream>     /* File: add-var.cpp */
using namespace std;

int main()              // Program's entry point
{
    int x, y;           // Define 2 variables to hold the int values to add

    cin >> x;           // You may also shorten the 2 statements into one:
    cin >> y;           // cin >> x >> y;

    cout << x << " + " << y << " = " << x+y << endl;

    return 0;           // A nice ending
}
```

Part V

Operators



Assignment Operator

Syntax: Assignment

<variable> = <value> ;

- In C++, the "=" sign is used to assign a value to a variable; it is the assignment operator.

Examples

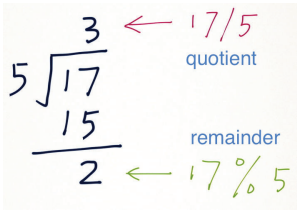
```
int a, b, x = 2, y = 3, z = 4;

a = 10*x;
b = a - (100*y - 1000*z);
a = a + b;
```

- Don't try to understand the assignment statement: `a = a + b;` using normal math notation, otherwise, it doesn't make sense.
- Nor should you treat it as a boolean relational "equality" sign.

Arithmetic Operators

Operation	operator
unary minus	−
addition	+
subtraction	−
multiplication	*
division	/
modulus	%
increment	++
decrement	−−

Modulo Arithmetic



- mod is used to get the remainder in an integer division.

$$\text{mod}(17, 5) = 17 \bmod 5 = 17\%5 = 2$$

- Strictly speaking, $m \bmod n$ is defined only if n is +ve.
- Most programming languages support -ve divisor and different languages may give you different results!
- In C++, the modulo arithmetic is supported by the remainder operator % which allows -ve divisor.

Question: What are the results of (-17)%5, 17%(-5), or (-17)%(-5)?

Pre- and Post- Increment, Decrement

- The unary increment operator ++ add 1 to its operand.
- The unary decrement operator −− subtract 1 from its operand.
- However, there are 2 ways to call them: pre-increment or post-increment. e.g.

$$++x \quad x++ \quad --x \quad x--$$

- If used alone, they are equivalent to: $x = x + 1$ and $x = x - 1$.
- But if used with other operands, then there is a big difference:
  - $++x \Rightarrow$ add 1 to x, and use the result for further operation.
  - $x++ \Rightarrow$ use the current value of x for some operation, and then add 1 to x.

```
cout << ++x;
/* same as */
x = x + 1;
cout << x;
```

```
cout << x++;
/* same as */
cout << x;
x = x + 1;
```

Example: %, ++, --

```
#include <iostream>     /* File: inc-mod.cpp */
using namespace std;

int main()
{
    int x = 100, y = 100; // Variable definitions and initialization
    int a = 10, b = 10, c = 10, d = 10;

    cout << ++x << "\t"; cout << "x = " << x << endl; // Pre-increment
    cout << y++ << "\t"; cout << "y = " << y << endl; // Post-increment

    a = ++b; cout << "a = " << a << "\t" << "b = " << b << endl;
    c = d++; cout << "c = " << c << "\t" << "d = " << d << endl;

    cout << 17%5 << endl; // Trickiness of the mod function
    cout << (-17)%5 << endl;
    cout << 17%(-5) << endl;
    cout << (-17)%(-5) << endl;

    return 0;
}
```


Shorthand Assignment Operators

SHORTHAND NOTATION	NORMAL NOTATION
$n += 2$	$n = n + 2$
$n -= 2$	$n = n - 2$
$n *= 2$	$n = n * 2$
$n /= 2$	$n = n / 2$
$n \%= 2$	$n = n \% 2$

Precedence and Associativity

OPERATOR	DESCRIPTION	ASSOCIATIVITY
$-$ $++$ $--$	minus increment decrement	Right-to-Left
$*$ $/$ $\%$	multiply divide mod	Left-to-Right
$+$ $-$	add subtract	Left-to-Right
$=$	assignment	Right-to-Left

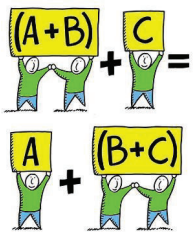
Precedence

Example: $1/2 + 3 * 4 = (1/2) + (3 * 4)$
because $*$, $/$ has a higher precedence over $+$, $-$.

- Precedence rules decide which operators run first.
- In general,

$$x\ P\ y\ Q\ z \quad = \quad x\ P\ (\ y\ Q\ z\ )$$

if operator Q is at a higher precedence level than operator P.



Associativity: Binary Operators

Example: $1 - 2 + 3 - 4 = ((1 - 2) + 3) - 4$
because $+$, $-$ are left associative.

- Associativity decides the grouping of operands with operators of the same level of precedence.
- If binary operator P, Q are of the same precedence level
  - if operator P, Q are both right associative, then

$$x\ P\ y\ Q\ z \quad = \quad x\ P\ (\ y\ Q\ z\ )$$

  - if operator P, Q are both left associative, then

$$x\ P\ y\ Q\ z \quad = \quad (\ x\ P\ \ y\ )\ Q\ z$$

Cascading Assignments

- C++ allows assigning the same value to multiple variables at once.

Examples

```
int w, x, y, z;

y = z = 5;          // Same as y = (z = 5);
w = x = y + z;      // Same as w = (x = (y+z));
```

Expression and Statement

- An expression has a value which is the result of some operation(s) on its(theirs) operands.
- Expression examples:

  4 x - y 2 - a - (b * c)
- A statement is a sentence that acts as a command.
  - It does not have a value.
  - It always ends in a ';'.
- Statement examples:
  - Input statement: cin $\gg$ x;
  - Output statement: cout $\ll$ x;
  - Assignment statement: x = 5;
  - Variable definition: int x;
- For the first 3 statement examples above, if we take out the ending ';', they become input/output/assignment expressions! (More about this later.)

That's all!

Any questions?