Module 3 Guidance Notes

C++ Basics

ENGG1340

Computer Programming II

Before We Start

- We will deal with C++ only in this module, and will leave the C counterparts on I/O (i.e., input/output) handling to the next module.
- **Important:** We will be using the C++ 11 standard, so make sure that your compiler option is set appropriately. We suggest to use the following command to compile your C++ program:

```
g++ -pedantic-errors -std=c++11 your_program.cpp
```

The -pedantic-errors flag is to make sure that your code conforms to the ISO C/C++ standard. We will enforce this in your assignment submission too.
For more information about C/C++ standards, you may read https://en.wikipedia.org/wiki/ANSI_C and https://isocpp.org/std/the-standard

How to Use this Guidance Notes

- This guidance notes aim to lead you through the learning of the C/C++ materials. It also defines the scope of this course, i.e., what we expect you should know for the purpose of this course. (and which should not limit what you should know about C/C++ programming.)
- Pages marked with “Reference Only” means that they are not in the scope of assessment for this course.
- The corresponding textbook chapters that we expect you to read will also be given. The textbook may contain more details and information than we have here in this notes, and these extra textbook materials are considered references only.

How to Use this Guidance Notes

- We suggest you to copy the code segments in this notes to the coding environment and try run the program yourself.
- Also, try make change to the code, then observe the output and deduce the behavior of the code. This way of playing around with the code can help give you a better understanding of the programming language.

Textbook Chapters

- C++: How to program (9th edition)
  - Electronic version available from HKU library https://proquestcombo-safaribooksonline-com.eproxy.lib.hku.hk/9780133378795

- Chapters 1, 2, 4, 5

What are we going to learn?

Part I: Basic Operations

- Variables & Constants
- Operators
- Expressions
- Data types & type conversions
- Basic input/output
- Flow Structures

Part II: Flow of Control

- Branching
- Looping

Part I

BASIC OPERATIONS

The First C++ Program

As usual, we will start with the Hello World program

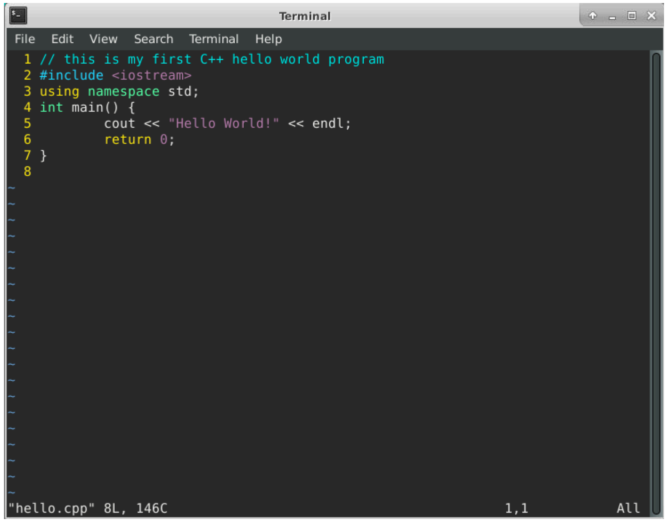
```
// this is my first C++ hello world program
#include <iostream>
using namespace std;

int main() {
  cout << “Hello World!” << endl;
  return 0;
}
```

Now, copy the code and save it in a file named hello.cpp in your home directory.

Program Editing

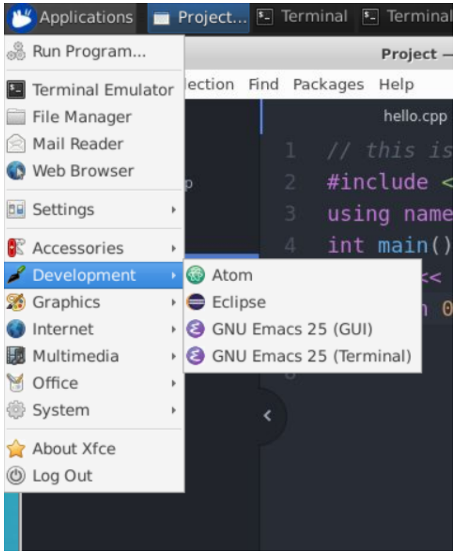
In the Ubuntu (Linux) environment that you have been working on for the previous modules, you may use the vi editor or the Atom editor (https://atom.io/) to edit your program. The Atom editor has a nice graphical user interface (GUI) and can be linked with the gcc compiler to facilitate coding.



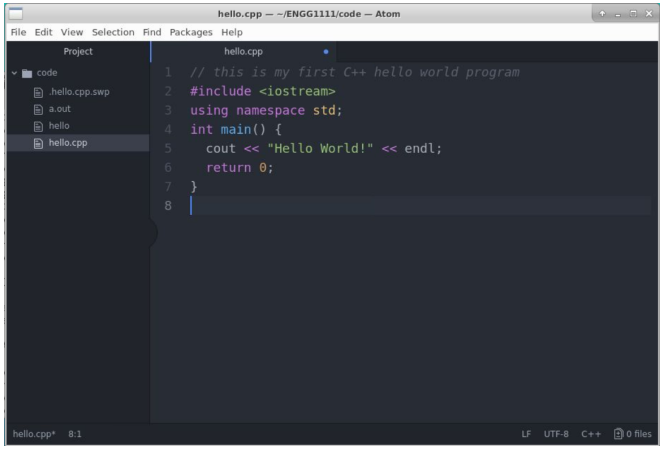
```
// this is my first C++ hello world program
#include <iostream>
using namespace std;
int main() {
        cout << "Hello World!" << endl;
        return 0;
}

"hello.cpp" 8L, 146C                                  1,1          All
```

hello.cpp in the vi editor



Atom is installed in CS server Ubuntu environment



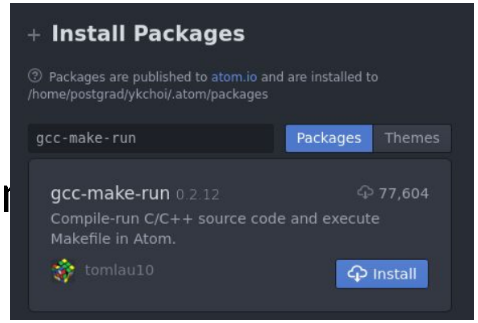
```
// this is my first C++ hello world program
#include <iostream>
using namespace std;
int main() {
  cout << "Hello World!" << endl;
  return 0;
}
```

hello.cpp in the Atom editor

Compiling and Execution

With the Atom editor

1. We need to install the gcc-make-run package so we car compile and execute a C/C++ program from within Atom
2. To do so, in the Atom editor, choose “Packages” -> “Settings View” -> “Install Packages/Themes” from the menu, and search for the “gcc-make-run” package.
3. Click “Install” and after installation is done, click on “Settings”

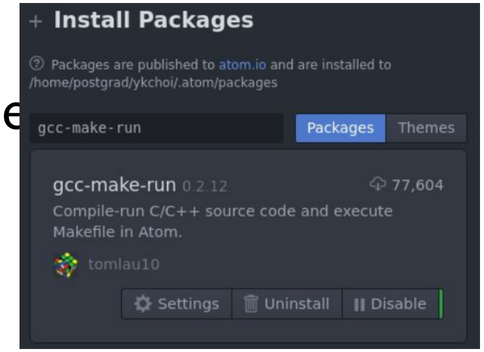


Packages are published to atom.io and are installed to /home/postgrad/ykchoi/.atom/packages

gcc-make-run 0.2.12 77,604

Compile-run C/C++ source code and execute Makefile in Atom.

tomlau10



Packages are published to atom.io and are installed to /home/postgrad/ykchoi/.atom/packages

gcc-make-run 0.2.12 77,604

Compile-run C/C++ source code and execute Makefile in Atom.

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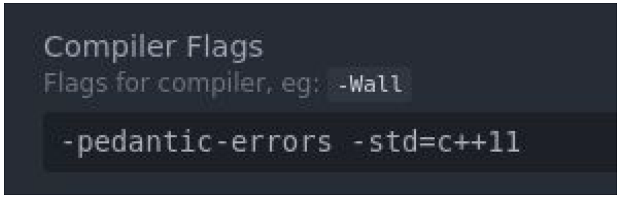
4. Under Compiler Flags, put down “-pedantic-errors -std=c++11”. This is the compiler options that we would use.

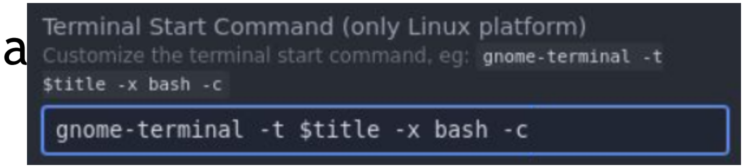


Compiler Flags

Flags for compiler, eg: `-Wall`

```
-pedantic-errors -std=c++11
```

5. Under Terminal Start Command, put down “gnome-terminal -t $title -x bash -c” so tha the terminal will fire up while executing your program for standard I/O.



Terminal Start Command (only Linux platform)

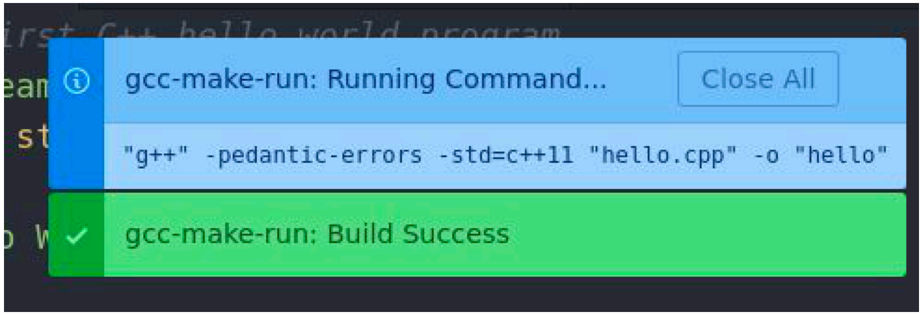
Customize the terminal start command, eg: `gnome-terminal -t $title -x bash -c`

```
gnome-terminal -t $title -x bash -c
```

Compiling and Execution

With the Atom editor

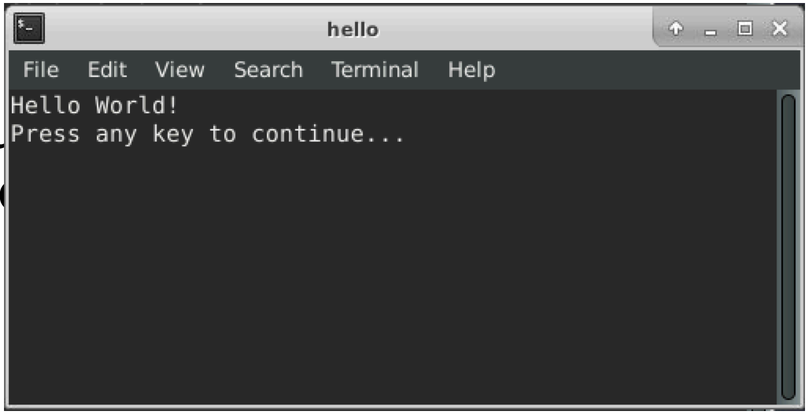
1. Open hello.cpp.
2. Press F6 to compile and run the program.
3. Note that the g++ command line with the flags will be displayed.
4. A terminal with the program outpu will be popped up if the compilati is successful.



gcc-make-run: Running Command...

```
"g++" -pedantic-errors -std=c++11 "hello.cpp" -o "hello"
```

gcc-make-run: Build Success

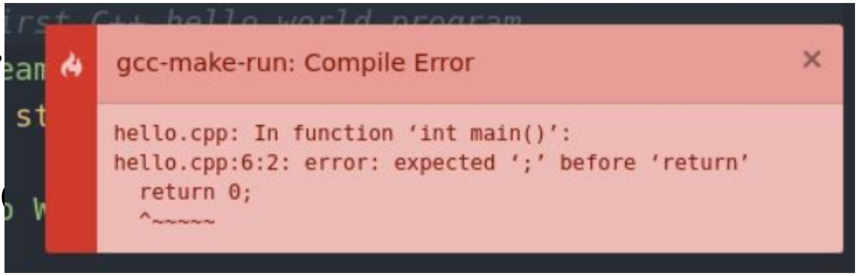


```
Hello World!
Press any key to continue...
```

Now try to remove “;” after “endl” in line 5.
Compile and run the program again. What will happen?

Compiling and Execution

1. You should get a compilation error.
2. Take a look at the error message.
3. It says "hello.cpp:6:2:", so the err
   around line 6.
4. Read further and it says "expected ';'", so you probably know that is about a missing ';'
5. Now fix the error in the program and compile & run again.



gcc-make-run: Compile Error

```
hello.cpp: In function 'int main()':
hello.cpp:6:2: error: expected ';' before 'return'
  return 0;
  ^~~~~~
```

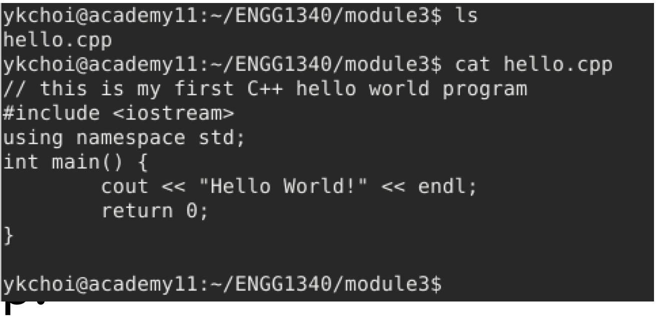
Note: Sometimes the error message is not as "understandable" and "helpful" as this one. We'll have some hints for you about debugging a C/C++ program.

Compiling and Execution

With command line:

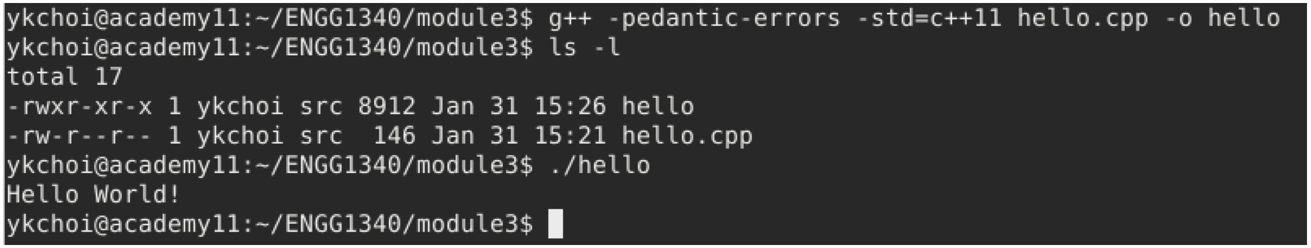
Sometimes you don’t have a nice GUI environment to work with, and you will have to rely on command line (via the terminal) for compiling and executing your program.

Now, suppose you already have hello.cpp in your current working directory.



```
ykchoi@academy11:~/ENGG1340/module3$ ls
hello.cpp
ykchoi@academy11:~/ENGG1340/module3$ cat hello.cpp
// this is my first C++ hello world program
#include <iostream>
using namespace std;
int main() {
        cout << "Hello World!" << endl;
        return 0;
}

ykchoi@academy11:~/ENGG1340/module3$
```

1. Use this command line to compile hello.cpp:
   ```
   g++ –pedantic–errors –std=c++11 hello.cpp –o hello
   ```
2. If the compilation is successful, you should find another file “hello” in the working directory.
3. Run the executable “hello” by typing “./hello” at the prompt



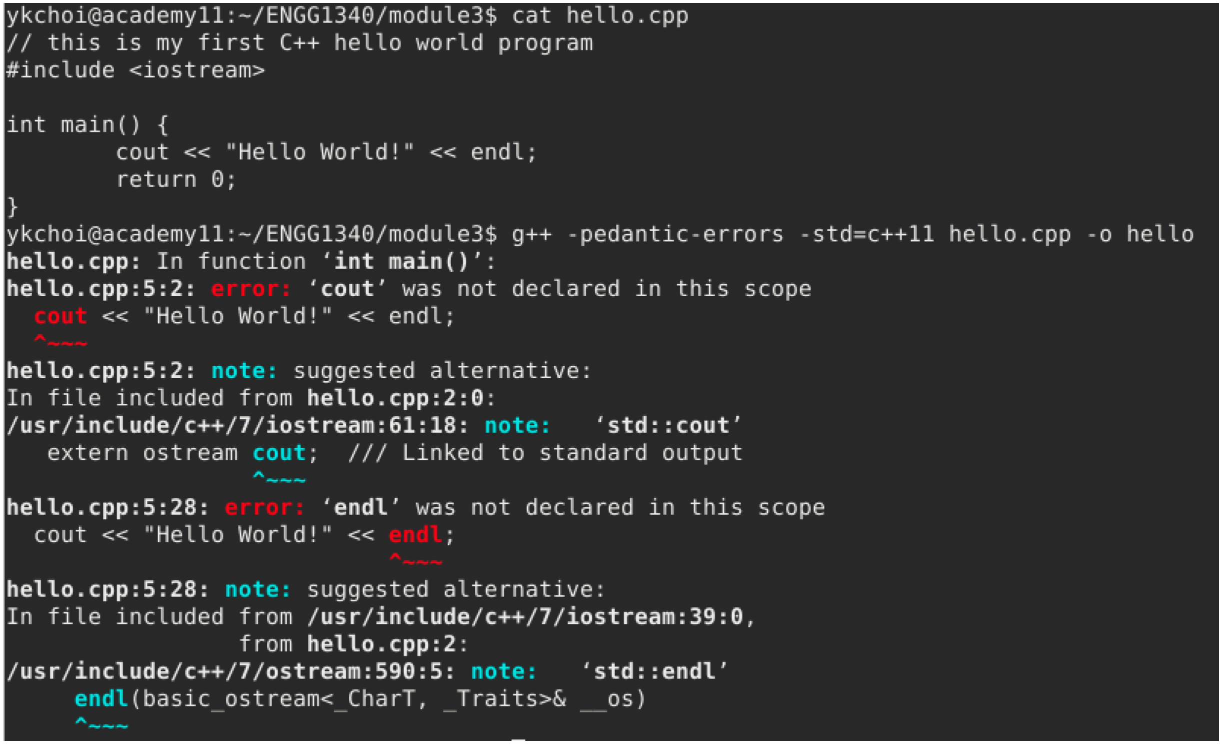
```
ykchoi@academy11:~/ENGG1340/module3$ g++ -pedantic-errors -std=c++11 hello.cpp -o hello
ykchoi@academy11:~/ENGG1340/module3$ ls -l
total 17
-rwxr-xr-x 1 ykchoi src 8912 Jan 31 15:26 hello
-rw-r--r-- 1 ykchoi src  146 Jan 31 15:21 hello.cpp
ykchoi@academy11:~/ENGG1340/module3$ ./hello
Hello World!
ykchoi@academy11:~/ENGG1340/module3$ 
```

Compiling and Execution

With command line:

Now try again to mess up with your code.

1. Delete line 3 “using namespace std;”
2. Compile and run the executable, and note what the error message is.



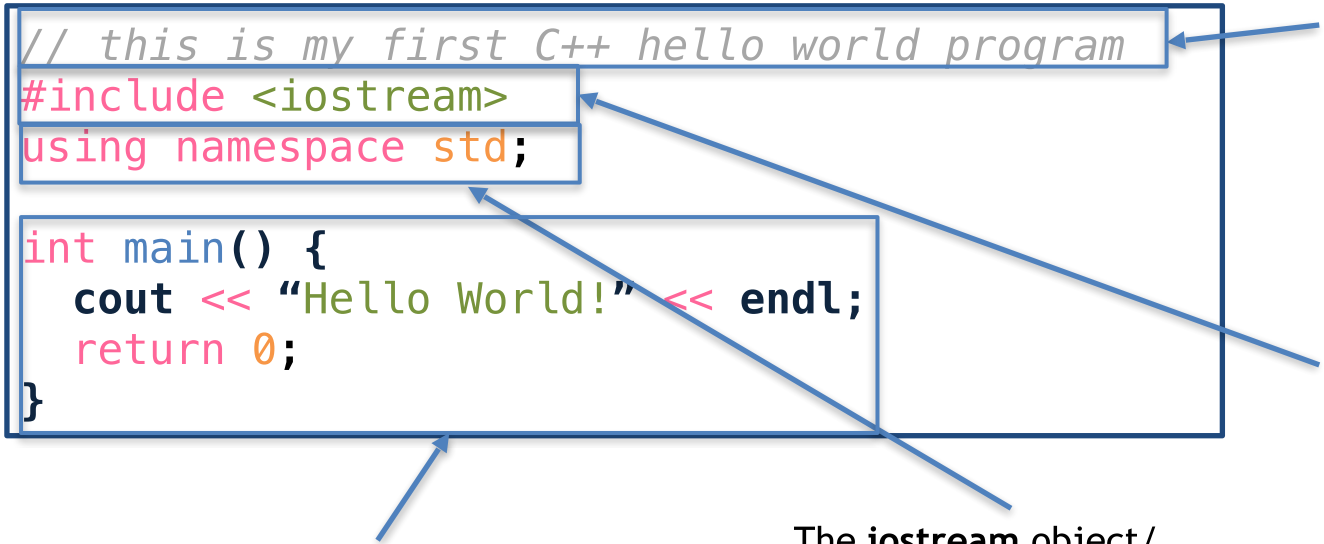
```
ykchoi@academy11:~/ENGG1340/module3$ cat hello.cpp
// this is my first C++ hello world program
#include <iostream>

int main() {
        cout << "Hello World!" << endl;
        return 0;
}
ykchoi@academy11:~/ENGG1340/module3$ g++ -pedantic-errors -std=c++11 hello.cpp -o hello
hello.cpp: In function ‘int main()’:
hello.cpp:5:2: error: ‘cout’ was not declared in this scope
  cout << "Hello World!" << endl;
  ^~~~
hello.cpp:5:2: note: suggested alternative:
In file included from hello.cpp:2:0:
/usr/include/c++/7/iostream:61:18: note:   ‘std::cout’
   extern ostream cout;  /// Linked to standard output
                  ^~~~
hello.cpp:5:28: error: ‘endl’ was not declared in this scope
  cout << "Hello World!" << endl;
                            ^~~~
hello.cpp:5:28: note: suggested alternative:
In file included from /usr/include/c++/7/iostream:39:0,
                 from hello.cpp:2:
/usr/include/c++/7/ostream:590:5: note:   ‘std::endl’
     endl(basic_ostream<_CharT, _Traits>& __os)
     ^~~~
```

Hints on Debugging

- Hint 1: The line number of an error reported by the compiler may be incorrect. It is possible that the error is located before the reported line. After all, the compiler can only try its best to guess what you meant to write down
- Hint 2: For the same above reason, the nature of an error reported by the compiler may be incorrect
- Hint 3: If your source code has multiple errors, always fix the first error and recompile, and repeat the process until the compilation is successful. This is because error messages subsequent to the first one have a higher likelihood of being incorrect

The First C++ Program

The Hello World program gives the basic structure of a C++ program.



```
// this is my first C++ hello world program
#include <iostream>
using namespace std;

int main() {
   cout << “Hello World!” << endl;
   return 0;
}
```

A line starting with // is called a **comment line**, any text after // till the end of line is ignored by the compiler

This is the **main function** which contains the main body of the C++ program. In this case, we have two statements “**cout…**” and “**return ..**” in the main body. The main function is also the starting point of the program execution of all C++ program: the program is executed statement by statement starting from the first statement in this main function

The **iostream** object/operation **cout** and **endl** are under the **namespace std**. If this line is removed, then you will need to write **std::cout** and **std::endl** without raising a compilation error.
(You can try and look for the error yourselves.)

This is the **include directive** which tells the compiler where to find information about certain routines used by the program;
iostream is the name of a library that contains the declarations of the routines (**cout**/**endl**) that handle input from the keyboard and output to the screen;
Later, you may also use other libraries (e.g., the math library by #include <math>

The First C++ Program

```
// this is my first C++ hello world program
#include <iostream>
using namespace std;

int main() {
  cout << “Hello World!” << endl;
  return 0;
}
```

By looking at the output of this program, you probably can guess what this program does. How would you change the program so that it can output
Hello ENGG1340!
on the screen?

The last statement return 0; in the main function indicates (to the operating system) that the program ended successfully. Note that on C++ compilers and more recent C compilers (C99 onwards), the compiler will add this statement for you if you omit it.

The First C++ Program

```
// this is my first C++ hello world program
#include <iostream>
using namespace std;

int main() {
  cout << “Hello World!” << endl;
  return 0;
}
```

cout is the standard output stream object defined in the iostream library. The standard output is the screen by default.

We will come back to the basic I/O afterwards.

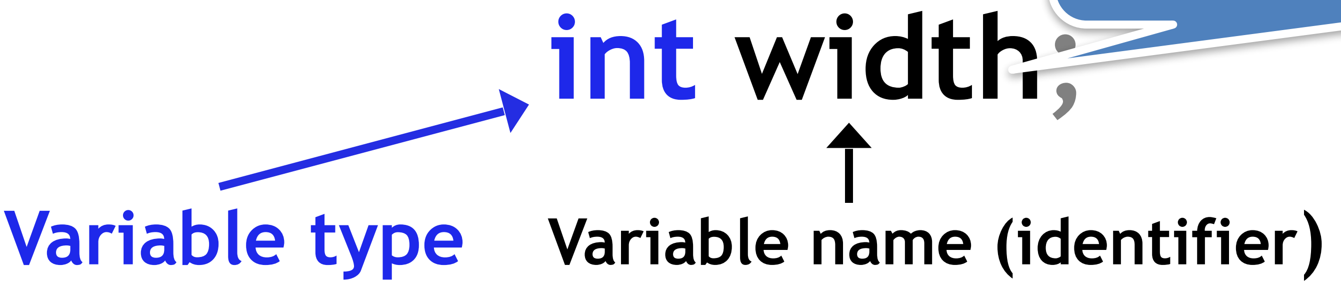
www.cplusplus.com is a good place to look for the definition and usage of the C++ constructs and functions.

You are highly recommended to go through the related topics in their tutorial as well: http://www.cplusplus.com/doc/tutorial/

Variables

Let’s start with how a variable can be defined in C/C++.
Suppose we need a variable named “width”
which is to store an integer.

This statement is called a **declaration.**



```
int width;
```

Variable type

Variable name (identifier)

- Used to store data.
- Data stored in a variable may change over time.
- When we declare a variable, the computer will assign an appropriate number of memory cells in the main memory to each variable according to the type of data to be stored

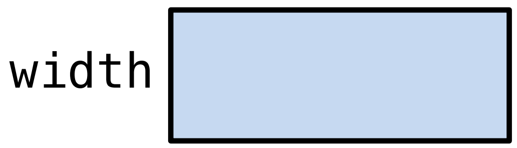
Variables

What happens in the computer?

1

```
int main ( ) {
     int width;
     int height;
     …
     return 0;
}
```

Main Memory

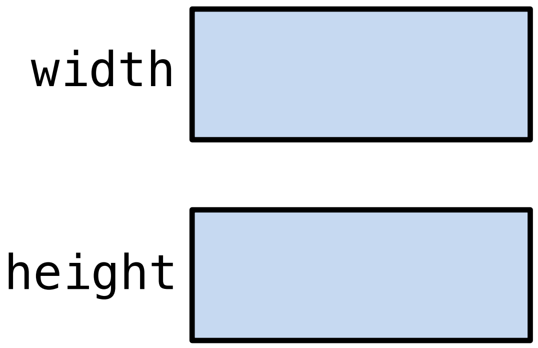

width

A memory chunk for storing an integer will be created in the main memory and associated with the name “width”

2

```
int main ( ) {
     int width;
     int height;
     …
     return 0;
}
```

Main Memory


width

height

Recall that the execution starts from the main() function

Identifiers (Variable names)

- An identifier must start with either
  - a letter (i.e., A to Z, and a to z), or
  - the underscore symbol (i.e., _)
- The rest of the characters may be
  - letters (i.e., A to Z, and a to z),
  - digits (i.e., 0 to 9), or
  - the underscore symbol (i.e., _)
- Meaningful identifiers make a program more readable

```
int area;
int length;
int area = length*length;
```

vs.

```
int a;
int b;
int b= a*a;
```

- C++ is case-sensitive
  - e.g., radius, RADIUS, Radius, etc., are different
- Cannot be a **keyword** in C++

C++ Keywords

- **Reserved** words in C++ with predefined meanings.
- CANNOT be used as names for variables or anything else.

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

You are not required to memorize all these names. You will get to recognize most of them later on.

Valid identifiers

- Which of the following identifiers are valid in C++?

`a_man`	✓	`2008`	✗	`program.cc`	✗
`const`	✗	`year1-student`	✗	`_o0Oo_`	✓
`an integer`	✗	`change%2`	✗	`ABCx123`	✓
`string`	✓	`Days_of_Week`	✓	`friend`	✗
`cout`	✓	`delete`	✗	`cos`	✓

Words like `cin`, `cout`, `string`, and `cos` are NOT keywords in C++. They are defined in libraries required by the C++ language standard. Redefining these words, though allowed, can be confusing and thus should be avoided.

Data Type of a Variable

Data type is an important concept when using a variable.

- Tells the computer how to interpret the data stored in a variable
- Determines the size of storage needed to store the data
- Some basic data types in C++:

Name	Description	Size	Range
`char`	Character or small integer	1 byte	0 to 255
`bool`	Boolean value	1 byte	True(1) or False(0)
`int`	Integer	4 bytes	-2147483648 to 2147483648
`double`	Double precision floating point number	8 bytes	1.7e-308 to 1.7e+308 (~15 digits) -1.7e-308 to -1.7e+308 (~15 digits)

**The size and range of a particular data type depend on the system under which a program is compiled. The values shown above are those found on most 32-bit systems

Declarations

- All variables must be declared before use
- A declaration specifies a type, and contains a list of one or more variables of that type

Syntax

```
    type_name     variable_name;
    type_name     variable_name_1, variable_name_2,
    …;
```

- Examples:

To declare two integer variables named “age” and “steps”

```
        int age, steps;
        char c;
        bool win;
        double height, width,
length;
```

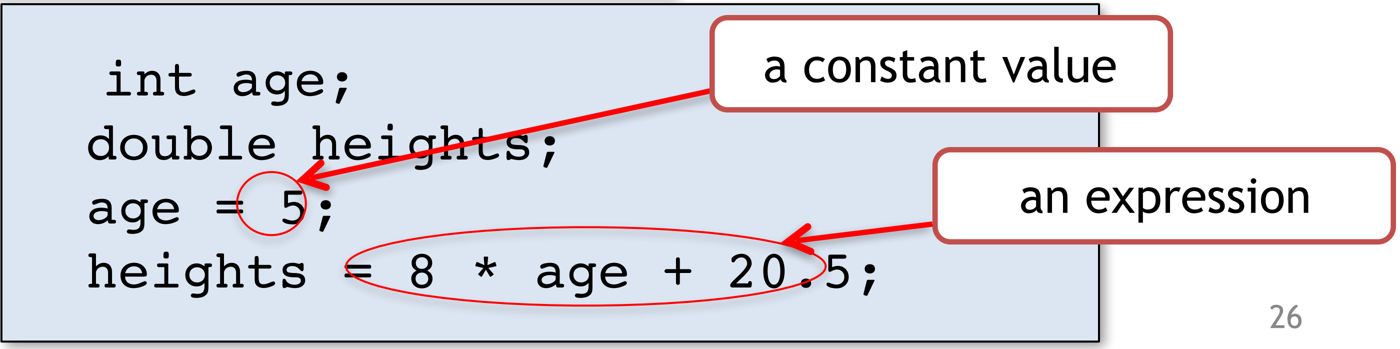
Assignment Statement

- A variable may be initialized or its value can be changed at a later time after its declaration using an assignment statement
- An assignment statement consists of a variable on the left-hand side of an equal sign, and a value or an expression on the right-hand side

Syntax

variable_name = expression;

Example



```
 int age;
double heights;
age = 5;
heights = 8 * age + 20.5;
```

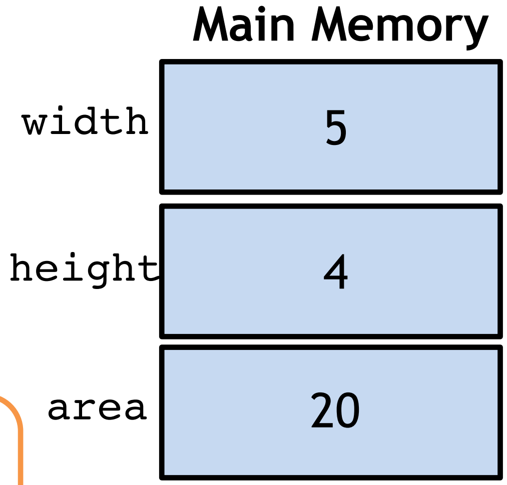
a constant value

an expression

Assigning Values to Variables

1

```
int main ( ) {
  int width, height, area;
  width =  5;
  height =  4;
  area = width * height;
  return 0;
}
```



Main Memory

width 5

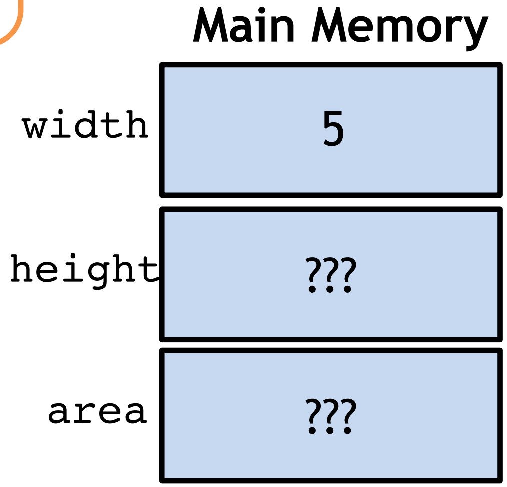
height 4

area 20

The variable **height** is **uninitialized** before use and the result is unpredictable.

2

```
int main ( ) {
  int width, height, area;
  width =  5;
  area = width * height;
  return 0;
}
```



Main Memory

width 5

height ???

area ???

Initializations

- A variable that has not been given a value is said to be uninitialized, and will simply contain some "garbage value"
- Using uninitialized variables in computations will give unexpected results, and thus should be avoided
- A variable may be initialized in its declaration:

```
int age = 5, steps = age + 10;
char c = 'Y';
bool win = true;
double height = 120.5, length = 1.5e3;
```

A character constant is written as a character within **single quotes**.

Scientific notation

(floating point notation)

1.5e3 = 1.5 * 10^3 = 1500

Strings – the Very Basics

- Very often we need to work on textual information and this can be done in C++ using strings (C has a different handling of strings and we will discuss that later)
- A string variable is just a variable containing a sequence of characters
- Strings are not the one of the fundamental C++ data types but are so frequently needed that they are defined as a class within the standard library.
- Include the <string> header when using strings in your program.

Sometimes you got no compilation error even if you don't include the <string> header; it's because it might be included in some standard libraries already, however, this depends on the implementation of the standard libraries and so it's always a good practice to include it when using strings.

Strings – the Very Basics

```
#include <iostream>
#include <string>
using namespace std;

int main() {
  string greeting = “Hi”,  name = “ENGG1340”;
  cout << greeting << “ “ << name << endl;
  greeting = “Good morning”;
  cout << greeting << “ “ << name << endl;
  return 0;
}
```

Can you guess what the output is?

```
Hi ENGG1340
Good morning ENGG1340
```

We will come back to the more interesting operations of strings later.

Constants

- Constants are expressions with a fixed value
- **Integers**: `65` (decimal), `0101` (octal), `0x41` (hexadecimal)
- **Floating point numbers**: `3.14159`, `6e23`, `1.6e–19`, `3.0`
- **Characters**: `‘A’`, `‘z’`,
  `‘\n’` (newline), `‘’’` (’), `‘\\’` (\), `‘\?’` (?),
  `‘\101’` (‘A’, octal ASCII code),
  `‘\x41’` (‘A’, hex ASCII code)
- **Strings**: `“This is a string”`, `“”` (empty string)
- **Boolean**: `true`, `false`

For more details: http://www.cplusplus.com/doc/tutorial/constants/

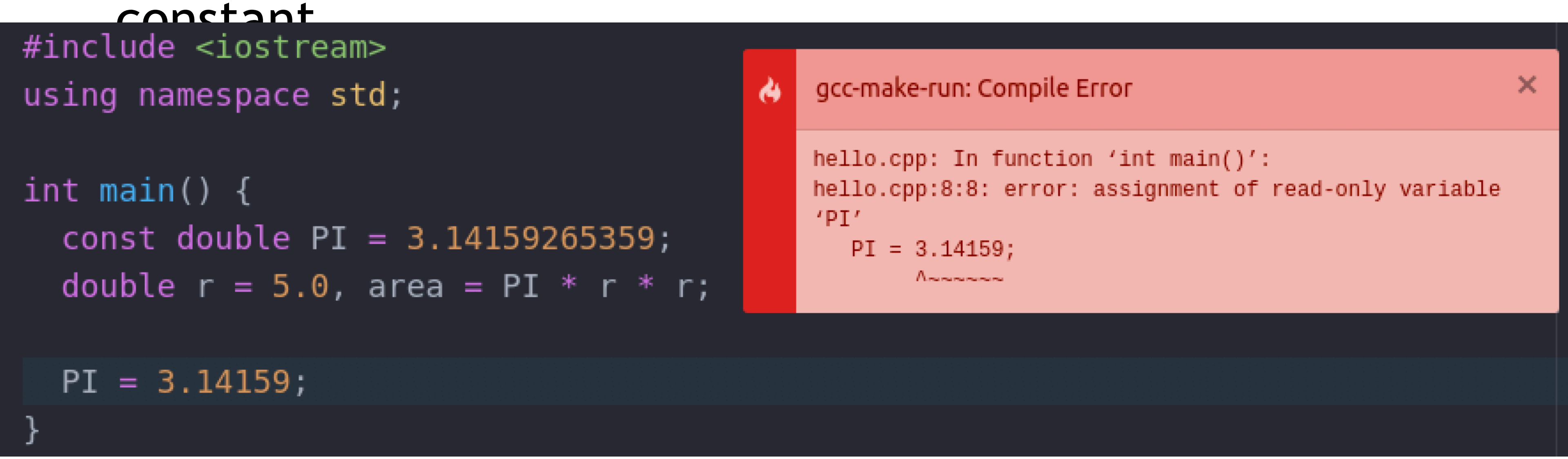
Note that a character is enclosed within the single quotes ‘ ’ while a string is enclosed by the double quotes “ ”. We will come back to the differences between characters and strings in later modules. For now, you may think of a character as a single letter and a string as a sequence of letters.

Constant Variables

- Sometimes we want to assign a fixed value to a variable

```
double PI = 3.14159265359;
```

- Add a **constant** **modifier** in front of a variable declaration
- The compiler will make sure that the variable remains a constant



```
#include <iostream>
using namespace std;

int main() {
  const double PI = 3.14159265359;
  double r = 5.0, area = PI * r * r;

  PI = 3.14159;
}
```

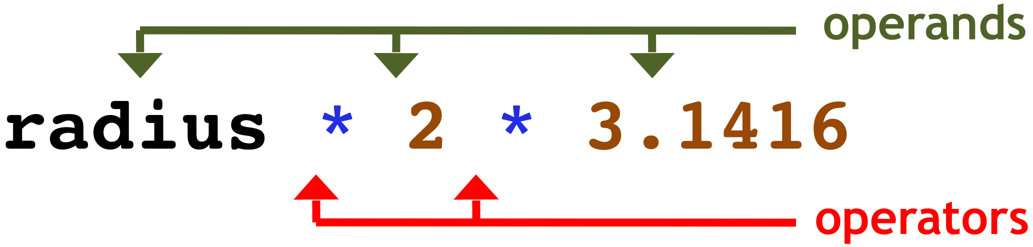
gcc-make-run: Compile Error

```
hello.cpp: In function ‘int main()’:
hello.cpp:8:8: error: assignment of read-only variable
‘PI’
   PI = 3.14159;
        ^~~~~~~
```

Line 8 “PI = 3.14159;” generates a compile error since PI is declared as a constant variable in line 5, but here we attempt to change its value
You can see that this helps to ensure the value of a variable will not be changed accidentally.

Expressions

- Combine variables and constants to produce new values (i.e., to evaluate an expression)
- Composed of **operators** (instructions) and **operands** (data)



operands

```
radius * 2 * 3.1416
```

operators

- Operators
  - Specify what is to be done on the operands
  - E.g., arithmetic operators, relational operators, logical operators
- Operands
  - Data on which the computation is performed
  - May be variables and/or constants

Operators

- Arithmetic operators (+, –, *, /, %)
- Relational operators (>, >=, <, <=, ==, !=)
- Logical operators (&&, ||, !)
- Increment and decrement operators (++, --)
- Assignment operators (=, +=, -=, *=, /=)

Arithmetic Operators

Arithmetic Operators	Sign in the expression
Addition	+
Subtraction	–
Multiplication	∗
Division	/
Modulus	%

- The modulus operator % produces the remainder.
  - E.g., 13 % 3 results in 1
    because 13 = (3 * 4) + 1

Arithmetic Operators

- Note: when both operands of the / operator are of integer types, the / operator performs **integer division** which truncates any fractional part of the division result.

```
  int a = 3, b = 2;
  int c = a / b, d = 8 / 3;
  cout << "The value of c is " << c <<
endl ;
  cout << "The value of d is " << d <<
endl ;
```

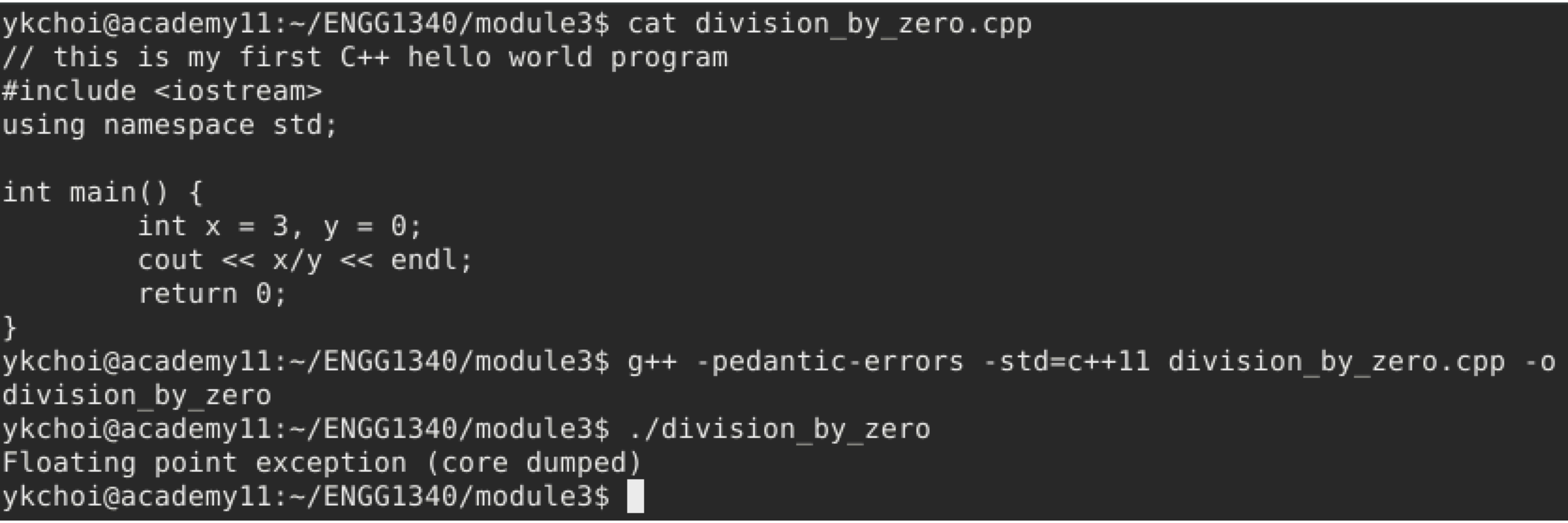
What is the screen output?

```
The value of c is 1
The value of d is 2
```

- The operator % cannot be applied to double (i.e., floating point numbers).

Division by Zero

- If the divisor of the / operator is 0, a division by zero error will be generated **during runtime**.



```
ykchoi@academy11:~/ENGG1340/module3$ cat division_by_zero.cpp
// this is my first C++ hello world program
#include <iostream>
using namespace std;

int main() {
        int x = 3, y = 0;
        cout << x/y << endl;
        return 0;
}
ykchoi@academy11:~/ENGG1340/module3$ g++ -pedantic-errors -std=c++11 division_by_zero.cpp -o
division_by_zero
ykchoi@academy11:~/ENGG1340/module3$ ./division_by_zero
Floating point exception (core dumped)
ykchoi@academy11:~/ENGG1340/module3$ 
```

Note that no compilation error will be generated.

Precedence

- In evaluating an expression with mixed operators, those operators with a **higher priority** will be carried out before those with a **lower priority**.

```
1 + 2 * 3
```

Result: ✗9 or ✓7?

- The operator **`*`** has a higher precedence than the operator **`+`**.
- The order of evaluation is equivalent to `1 + (2 * 3)`.

Precedence

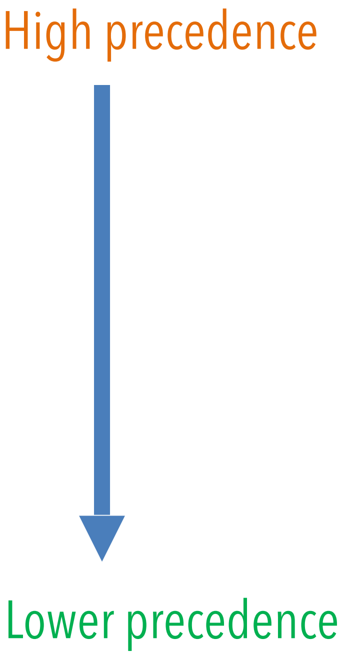
- In evaluating an expression with mixed operators, those operators with a **higher priority** will be carried out before those with a **lower priority**.

12 - 11 % 3 Result: ✗1 or ✓10?

- The operator % has a higher precedence than the operator -.
- The order of evaluation is equivalent to 12 – (11 % 3).

Precedence & Associativity

Operator types	Operators	Associativity
unary	`+, –, ++, --, !`	-
binary arithmetic	`*, /, %`	left to right
binary arithmetic	`+, –`	left to right
relational	`<, <=, >, >=`	left to right
relational	`==, !=`	left to right
logical	`&&`	left to right
logical	`||`	left to right
assignment	`=, +=, –=, *=, /=, %=`	right to left


High precedence

Lower precedence

- by inserting
  - e.g., (1 + 2) * 3 = 9

Arithmetic Operator for Characters

We may perform arithmetic operation with characters. In this case, the numerical representation as in the ASCII code for each character will be used in the calculation.
The following program also shows a common technqiues in converting a letter from upper case to lower case.

```
#include <iostream>
using namespace std;
int main()
{
     char c = ‘Y’;
     // convert a letter from upper case to lower case
     c = c – ‘A’ + ‘a’;
     cout << "1: " << c << endl;

     // advance to the next character
     c = c + 1;
     cout << "2: " << c << endl;
     return 0;
}
```

```
1:  y
2:  z
```

Screen output

Can you convert a letter from lower case to upper case then?

The ASCII table:

www.asciitable.com

Relational Operators

Relational Operators	Sign in the expression
Greater than	>
Greater than or equal	>=
Smaller than	<
Smaller than or equal	<=
Equal	==
Not equal	!=

same
higher precedence

lower precedence

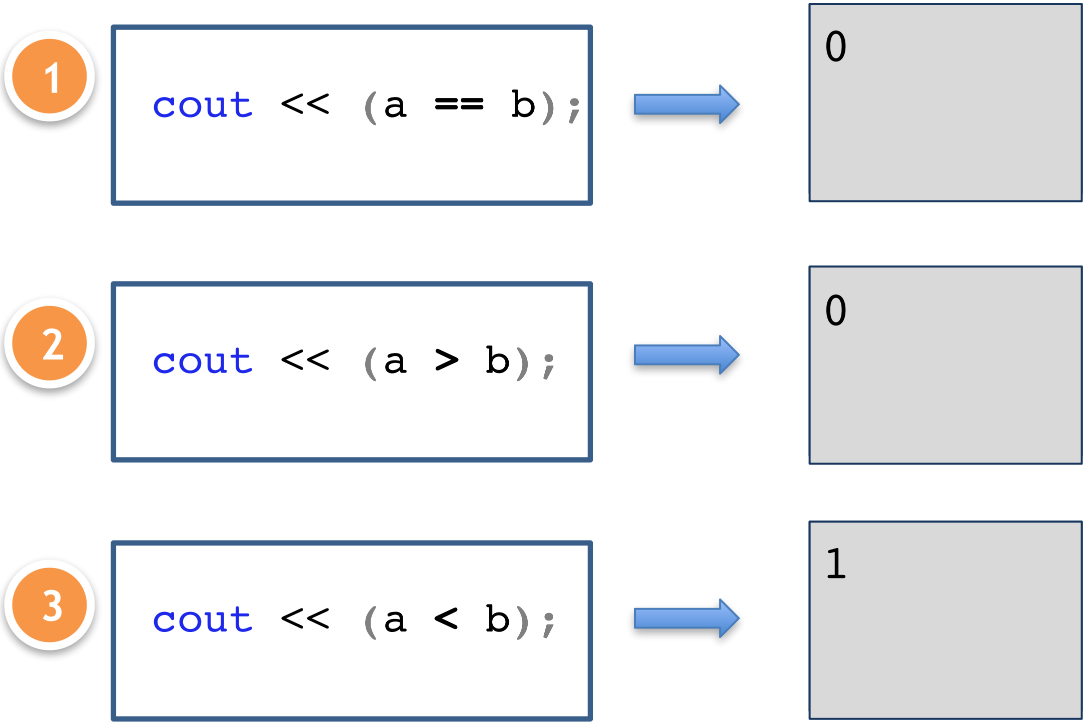
- For comparing the operands.

Relational Operators

- In C/C++, the numeric value of a relational or logical expression is 1 if the relation is **true**, and 0 if the relation is **false**.

Suppose all 3 examples start with:

```
int a = 1, b = 2;
```



1

```
cout << (a == b);
```

```
0
```

2

```
cout << (a > b);
```

```
0
```

3

```
cout << (a < b);
```

```
1
```

Relational Operators

4

```
int i = 1, lim = 2;
cout << (i < lim – 2) ;
```

```
0
```

The "–" operator is of **higher** precedence than the "<" operator, so "`lim – 2`" is executed first

5

```
int i = 1, lim = 2;
cout << ( (i < lim) – 2 );
```

```
-1
```

The bracket `( )` **overrides** precedence and associativity, hence `(i < lim)` is first evaluated to yield the intermediate result **1**

Logical Operators

Operands		AND (&&)	OR (||)	NOT (!)
A	B	A && B	A || B	! A
0	0	0	0	1
0	1	0	1	
1	0	0	1	0
1	1	1	1	

0: False
1: True

- Precedence: (High) **!** > **&&** > **||** (Low)
- C++ treats any non-zero value as true, and zero as false
  - Hence (3 && 0) is false, and (-5 || 0) is true
- The unary **negation** operator ! converts a non-zero operand into 0, and a zero operand into 1 (e.g., **! 3** is evaluated to 0)

Logical Operators

1

```
int x = 5;
bool in_range = ! (x < 0 || x >
50);
cout << in_range << endl;
```

```
1
```

Both expressions connected by || evaluate to a `false` value (`0`)

2

```
bool  i_am_cool =
      (gals != 0) && ((gifts / gals) >=
2);
```

What if **`gals`** is **`0`**? Will **`gifts/gals`** generate a runtime error?

No! Because: C/C++ evaluates a logical expression from left to right, and stops evaluating once the truth or falsehood of the result is known.

(a.k.a. short-circuit evaluation)

Hence, if `gals` is `0`, the expression ((gals != 0) && ???) must be false anyway, so the expression `(gifts / gals) >=2` will NOT be evaluated, and thus not generating a runtime error.

There is similar short-circuit evaluation for the || operator:

```
bool omg = (gals == 0) || ((gifts / gals) <
2);
```

Increment & Decrement Operators

Assignment Operators	Sign in the expression
Increment	++
Decrement	--

- The increment operator ++ **adds 1** to its operand.

```
int i = 0;
++i ;
```

is equivalent to

```
int i = 0;
i = i + 1;
```

- The decrement operator -- **subtracts 1** from its operand.

```
int i = 0;
--i ;
```

is equivalent to

```
int i = 0;
i = i – 1;
```

Increment & Decrement Operators

- The operators ++ and -- may be used either as **prefix** (e.g., **`++i`**) or **postfix** (e.g., **`i++`**) operators.
  - When used as **prefix**, increment/decrement is done **before** the value is used.

```
int c = 0, i =
0;
c = ++i ;
```

is equivalent to

```
int c = 0, i =
0;
i = i + 1;
c = i;
```

c = ???
i = ???

  - When used as **postfix**, increment/decrement is done **after** the value is used.

```
int c = 0, i =
0;
c = i++;
```

is equivalent to

```
int c = 0, i = 0;
c = i;
i = i + 1;
```

c = ???
i = ???

Assignment Operators

- Expression such as `i=i+2` in which the variable on the left-hand side is repeated immediately on the right can be written in the **compressed form** `i+=2`
- Most binary operators have a corresponding compound assignment operator, e.g., `-=`, `*=`, `/=`, and `%=`

Examples

```
x *= y + 1;
```

is equivalent to

```
x = x * (y +
1);
```

```
x %= y % 3;
```

is equivalent to

```
x = x % (y %
3);
```

Type Conversions

- When an operator has operands of different types, they are converted to a **common type** according to a small number of rules.

1 “lower” type promoted to “higher” type

```
3.0 / 2;
```

2 (int) is promoted to **2.0** (double), and the result is **1.5**

Important: Compare this with

```
3 / 2;
```

No type conversion because both 3 and 2 are integers, therefore integer division is carried out, and the result is **1**

Type Conversions

2

In assignment statements, the value of the right side is converted to the type of the left

```
double x = 5;
```

x stores the value 5.0

```
int x = 2.8;
```

Converting a double value to an int value causes truncation of any fractional part
x stores the value 2

* The compiler may issue a warning as there is information loss.

```
   int x = (int)
2.8;
```

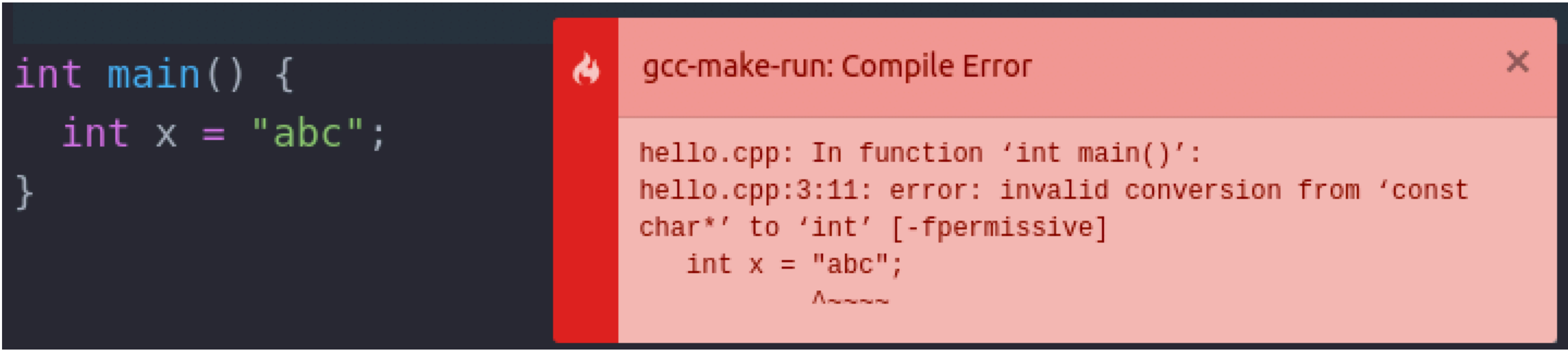
Explicit type casting tells the compiler it is an intended type conversion and prevents the compiler from producing a warning.
x stores the value 2
* The compiler generates no warning

This also shows that you, as the programmer, can control how values are stored.

Type Conversions

3 Type conversions that don’t make sense are not allowed.

e.g., assigning a string literal to an int variable generates a compilation error:



```
int main() {
  int x = "abc";
}
```

gcc-make-run: Compile Error

```
hello.cpp: In function ‘int main()’:
hello.cpp:3:11: error: invalid conversion from ‘const
char*’ to ‘int’ [-fpermissive]
   int x = "abc";
           ^~~~~
```

Basic I/O (Input/Output)

- A **stream** is an object where a program can either **insert** or **extract** characters to/from it.
- We may use **streams** to perform input and output operations in sequential media such as the screen or the keyboard.
- The standard **C++ library** includes the header file iostream where the standard input and output stream objects are declared.
- We need to include the header file by the #include directives before using any objects and functions in the iostream library.

Include the **iostream** library to use **cin** and **cout**. The **iostream** library is some existing object codes developed by others. As this is so useful, it is regarded as standard C++ library.

```
#include
<iostream>
using namespace
std;

int main () {
    …
}
```

Basic I/O

```
#include <iostream>
using namespace std;

int main () {
    cout << “Hello!” <<
endl;
}
```

This statement is **important**! Because `cout` and `endl` are provided under the namespace (i.e., a container of names) `std`. Their names are indeed `std::cout` and `std::endl`.

✗

```
#include <iostream>

int main () {
    cout << “Hello!” <<
endl;
}
```

✓

```
#include <iostream>

int main () {
    std::cout <<
“Hello!”
         << std:: endl;
}
```

```
a.cpp: In function int main():
a.cpp:4: error: 'cout' was not declared in this
scope
a.cpp:4: error: 'endl' was not declared in this
```

Compiler error

Standard Output

- By default, the standard output of a program is the screen, and the C++ stream object defined to access it is **`cout`**.
- The **insertion operator <<** is used to insert data into the stream, which may be used more than once in a single statement.

```
int a = 1 , b= 2, c = 3;
cout << “Hello ”;
cout << “World!” << endl;
cout << 1 << a << endl;
cout << “b = ” << b << “ and c = ”
   << c << endl;
```

```
Hello World!
11
b = 2 and c =
3
```

Screen output

Note that there is no line break after “Hello ” and “World!”

Also there is no space between 1 and the value of a in the 2nd output line.

Reference Only

Standard Output

- There are some **escape sequences** that have special usage in the output.

\a	alert (bell) character	\v	vertical tab
\b	backspace	\\	backslash
\n	newline	\?	question mark
\r	carriage return	\’	single quote
\t	horizontal tab	\”	double quote

```
cout << a << endl;
cout << “Hi!” << endl;
```

is equivalent to

```
cout << a << ‘\n’;
cout << “Hi!\n”;
```

Try out these escape sequences in a program and see the result!

Standard Input

- From time to time, we need to obtain user input to our program.
- The standard input device is usually the keyboard, and the C++ stream object defined to access it is **`cin`**.
- The **extraction operator >>** is used to extract data from the stream
- The type of the variable will determine the type of data that is e the stre

```
int x;
cin >> x;
```

An integer is expected to be input

vs.

```
char x;
cin >> x;
```

A character is expected to be input

- Note that `cin` can only process the input from the keyboard once the **RETURN** key has been pressed.

A Sample Program on I/O

Be careful about the directions of the << and >> operators!

```
#include <iostream>
using namespace std;
int main(){
  int age;
  double height, weight;
  cout << "Please input your age, height and weight: 
";
  cin >> age >> height >> weight;
  cout << endl << "Your age is " << age << endl;
  cout << "Your height is " << height << endl;
  cout << "Your weight is " << weight << endl;
  return 0;
}
```

Screen output

```
Please input your age, height and weight:
```

A Sample Program on I/O

```
#include <iostream>
using namespace std;
int main(){
  int age;
  double height, weight;
  cout << "Please input your age, height and weight:
";
  cin >> age >> height >> weight;
  cout << endl << "Your age is " << age << endl;
  cout << "Your height is " << height << endl;
  cout << "Your weight is " << weight << endl;
  return 0;
}
```

user input from keyboar

```
Please input your age, height and weight: 20 175.5
132
```

Screen output

A Sample Program on I/O

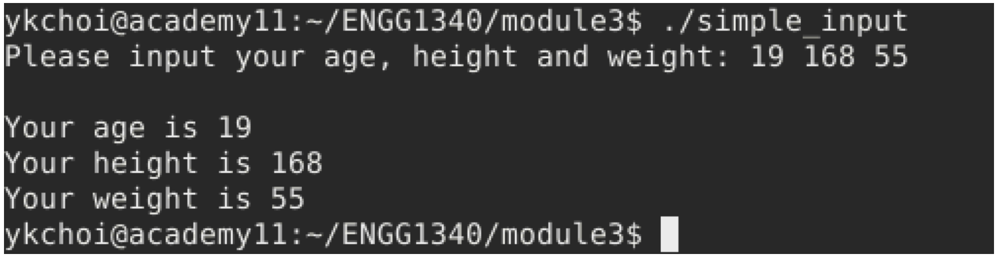
```
#include <iostream>
using namespace std;
int main(){
  int age;
  double height, weight;
  cout << "Please input your age, height and weight: 
";
  cin >> age >> height >> weight;
  cout << endl << "Your age is " << age << endl;
  cout << "Your height is " << height << endl;
  cout << "Your weight is " << weight << endl;
  return 0;
}
```

Screen output

```
Please input your age, height and weight: 20 175.5
132

Your age is 20
Your height is 175.5
Your weight is 132
```

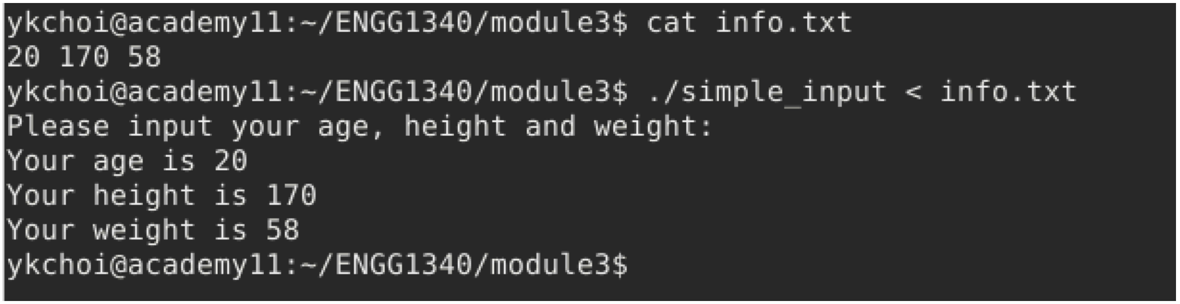
Using File Redirection as Standard Input to Your Program

- Sometimes it is just too tiring to enter the input values to your program again and again, especially during the testing and debugging stages. In this case, you may execute your program using command line and file redirection so that the contents of a file will be fed into your program as if they are from the standard input (i.e., by default the keyboard)



```
ykchoi@academy11:~/ENGG1340/module3$ ./simple_input
Please input your age, height and weight: 19 168 55

Your age is 19
Your height is 168
Your weight is 55
ykchoi@academy11:~/ENGG1340/module3$ 
```

User input from keyboard



```
ykchoi@academy11:~/ENGG1340/module3$ cat info.txt
20 170 58
ykchoi@academy11:~/ENGG1340/module3$ ./simple_input < info.txt
Please input your age, height and weight:
Your age is 20
Your height is 170
Your weight is 58
ykchoi@academy11:~/ENGG1340/module3$
```

User input stored in a file “info.txt” and use file redirection to fed file contents to the program as input.

Part II

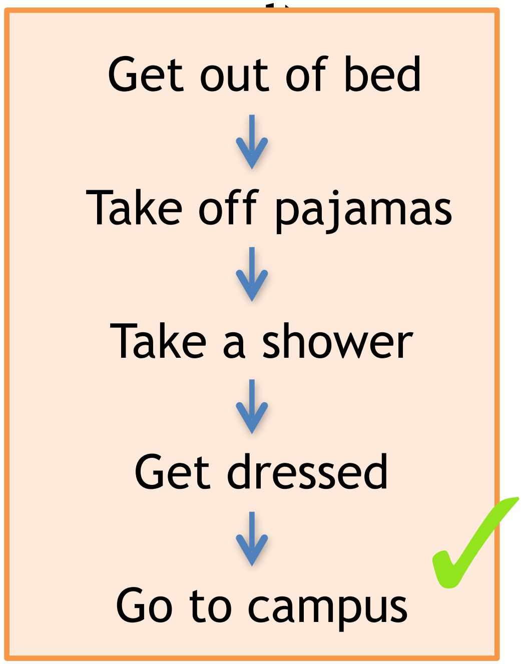
FLOW OF CONTROL

What we are going to learn?

- Making decisions in your program (**branching**)
  - the **if** selection statement
  - the **if…else** double selection statement
  - the **switch** multiple-selection statement
- Doing something repeatedly (**looping**)
  - **while** loop
  - **for** loop
  - **break** and **continue** in loops

Algorithms

- An **algorithm** is a procedure for solving a problem in terms of
  - the **actions** to execute and
  - the **order** in which the actions execute (**flow of**



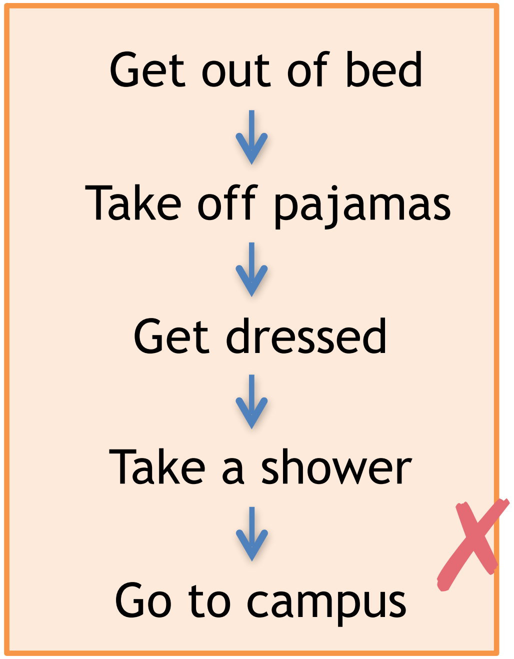
Get out of bed

Take off pajamas

Take a shower

Get dressed

Go to campus ✓



Get out of bed

Take off pajamas

Get dressed

Take a shower

Go to campus ✗

Flow of control is important. The **correctness** of your algorithm determines whether you can get the desired result.

Reference Only

Pseudocode

- “fake” code—An artificial and informal language similar to everyday English for developing an algorithm
- Helps you think out a program without worrying the syntax of a programming language.

Problem: Adding two input integers

Pseudocode

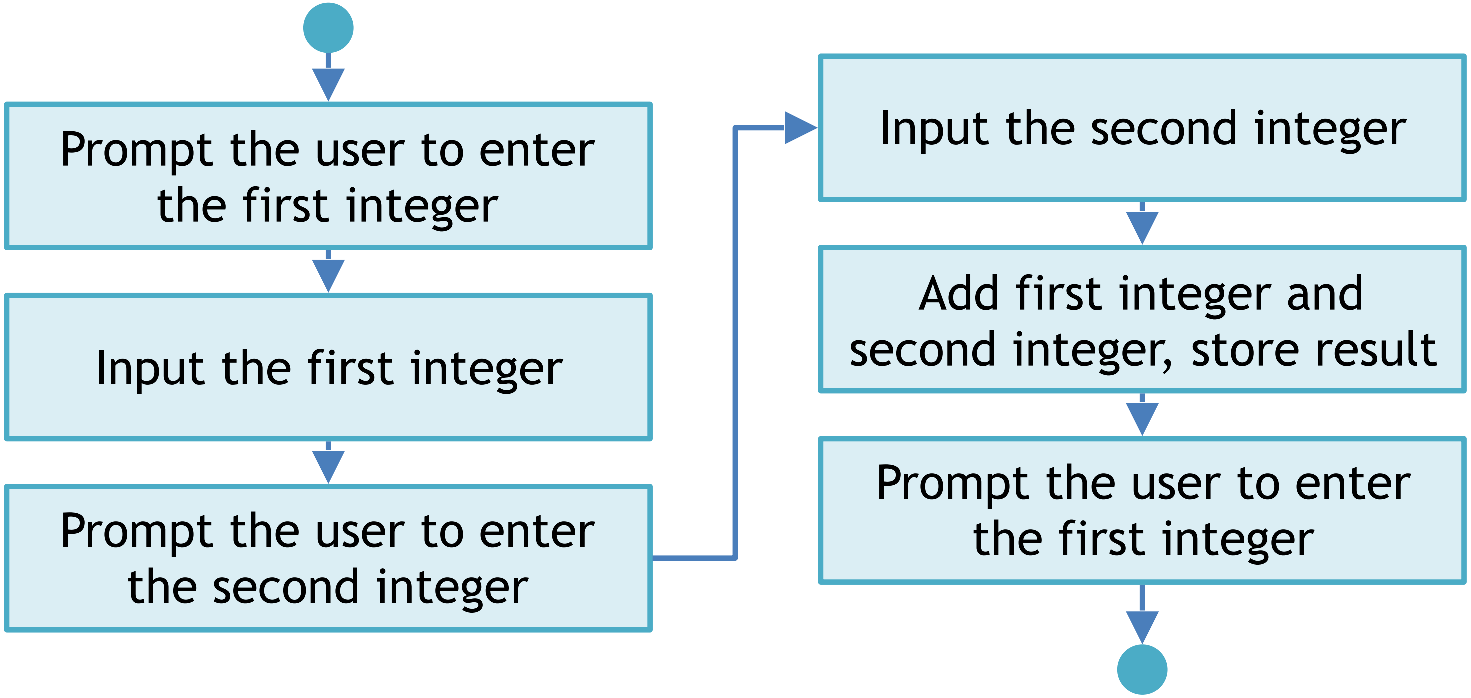
```
Prompt the user to enter the 1st integer
Input the 1st integer

Prompt the user to enter the 2nd integer
Input the 2nd integer

Add 1st integer and 2nd integer, store
result
Display result
```

A C++ Program

```
cout << “Please input the 1st
integer:”;
cin >> x;

cout << “Please input the 2nd
integer:”;
cin >> y;

int res = x + y;
cout << res << endl;
```

Flowchart

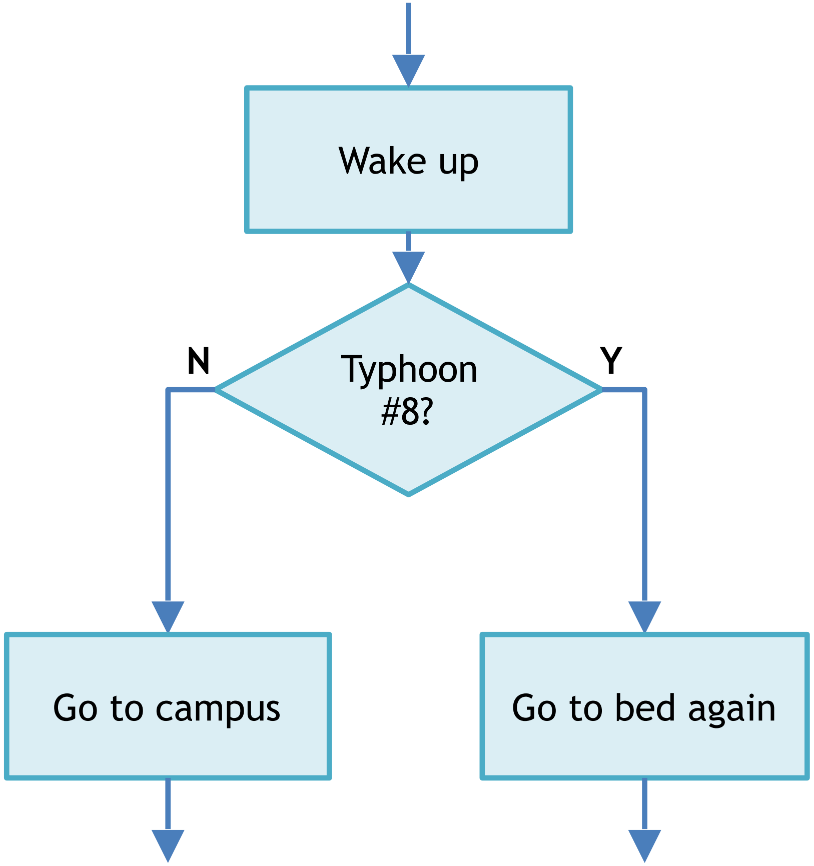
- A diagram to illustrate program flow (program logic).
- Used in **analyzing**, **designing**, **documenting** or **managing** a program.


Prompt the user to enter the first integer
Input the first integer
Prompt the user to enter the second integer
Input the second integer
Add first integer and second integer, store result
Prompt the user to enter the first integer

Flow of Control

- Recall that statements in the main function are executed **sequentially**.
- In more complex programs, however, it is often necessary to alter the order in which statements are executed, e.g.,
  - Choosing between two alternative actions – **branching**
  - Repeating an action a number of times – **looping**
- The order in which statements are executed is often referred to as **flow of control**

Branching & Looping



Wake up

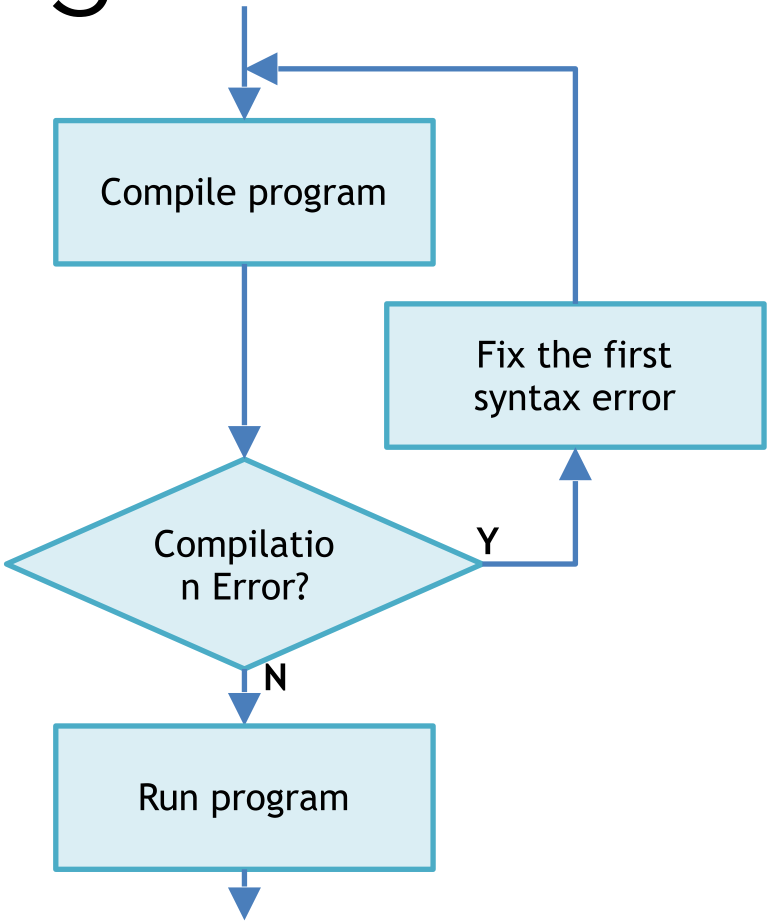
Typhoon #8?

N

Y

Go to campus

Go to bed again



Compile program

Fix the first syntax error

Compilatio n Error?

Y

N

Run program

Branching

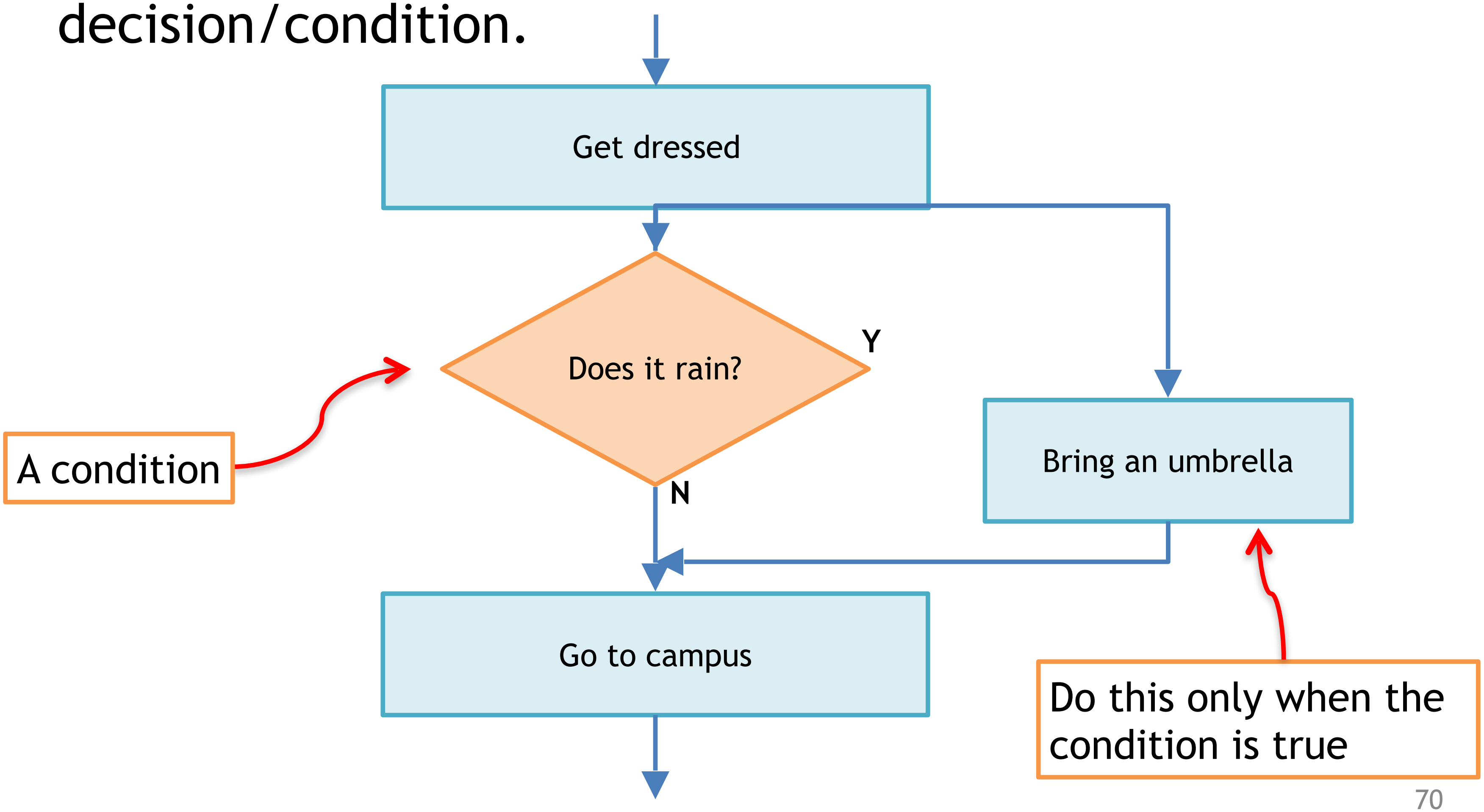
Looping

Make a decision

BRANCHING

Making a Decision

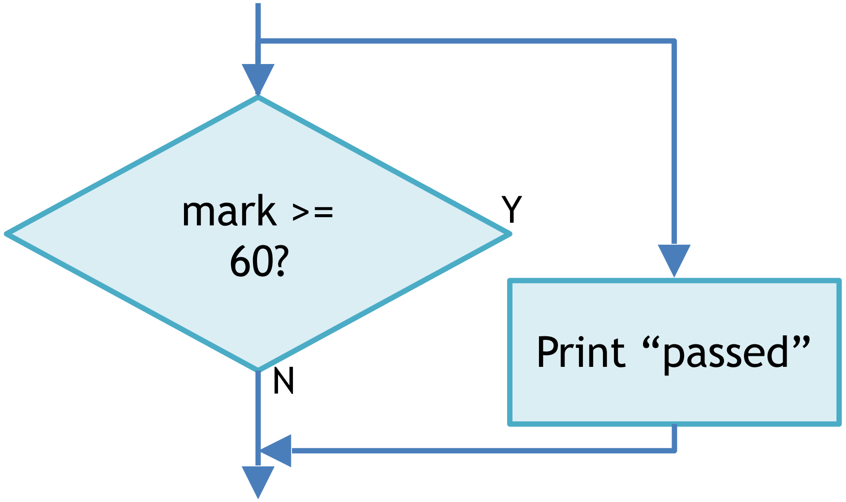
- Sometimes an action is taken **selectively** based on a decision/condition.



The **if** statement

Pseudocode

```
If student’s mark is greater than or equal to 60
    print “passed”
```



Flowchart

C++ code

```
if (mark >= 60)
  cout << “passed”;
```

The **if** statement

Syntax

```
    if (condition)   statement;
```

- **condition**: an expression that evaluates to **true** or **false**

mark > 60

‘A’ == ‘a’

3 – 2 != 0

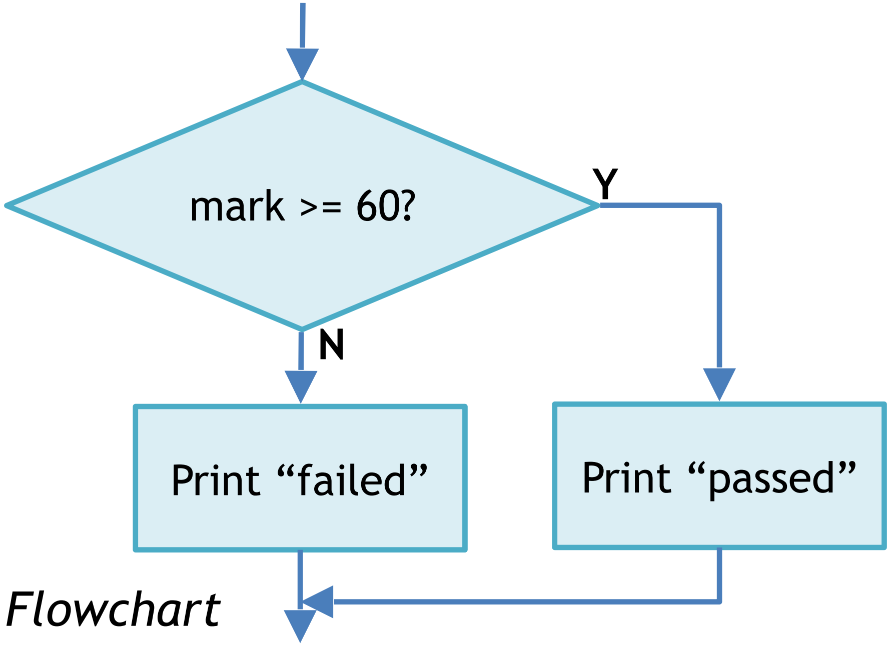
3 - 2

- **statement**: a statement to execute if condition is true

The **if…else** statement

Pseudocode

```
If student’s mark is greater than or equal
to 60
        print “passed”
Else
        print “failed”
```



Flowchart

C++ code

```
if (mark >= 60)
  cout << “passed”;
else
  cout << “failed”;
```

The **if...else** statement

Syntax

```
    if (condition)
        statement1;
    else
        statement2;
```

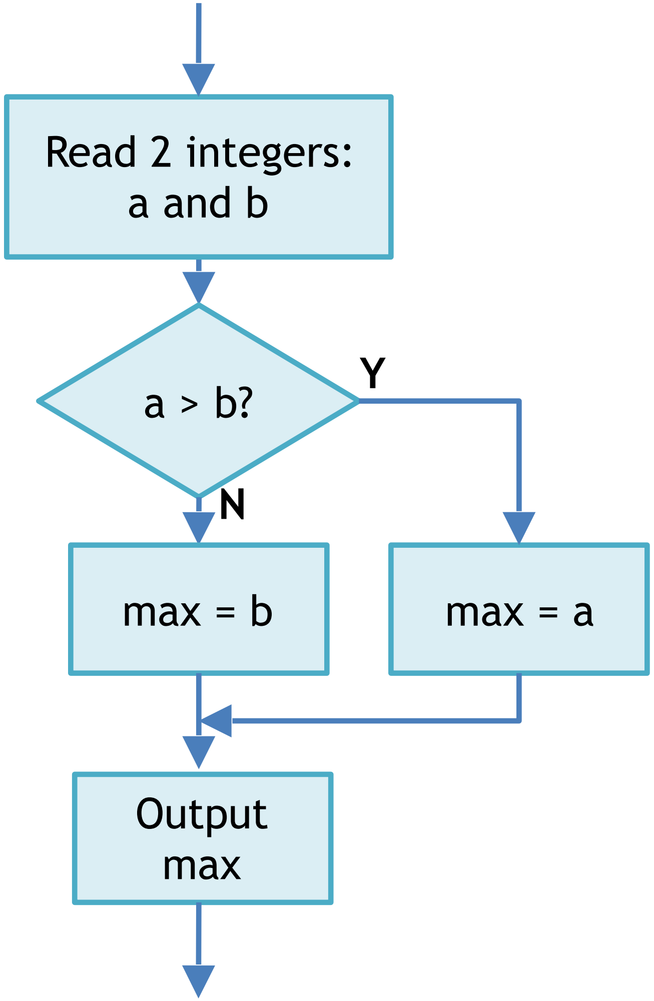
- **condition**: an expression that evaluates to **true** or **false**
- **statement1** is executed if condition is true; and if condition is false, **statement2** is executed.

Example 1

- Write a program that reads 2 input integers and outputs the bigger one.

```
#include <iostream>
using namespace std;
int main() {









  return 0;
}
```

Always start with this template for writing a program with standard I/O



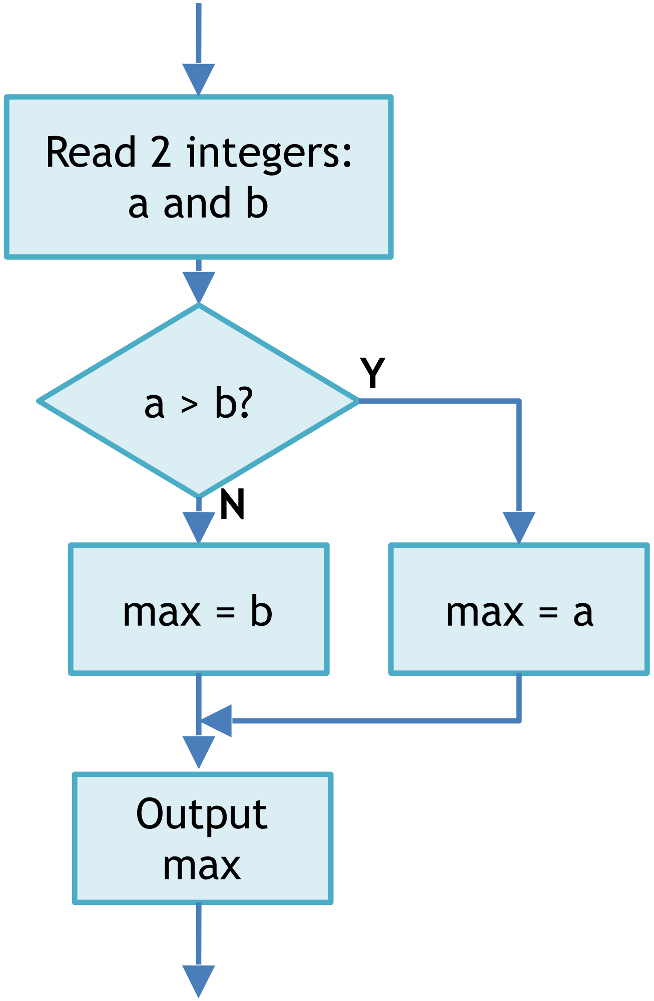
Example 1

- Write a program that reads 2 input integers and outputs the bigger one.

```
#include <iostream>
using namespace std;
int main() {


  return 0;
}
```

Now think about it:
How many variables do you need?
What are their data types?

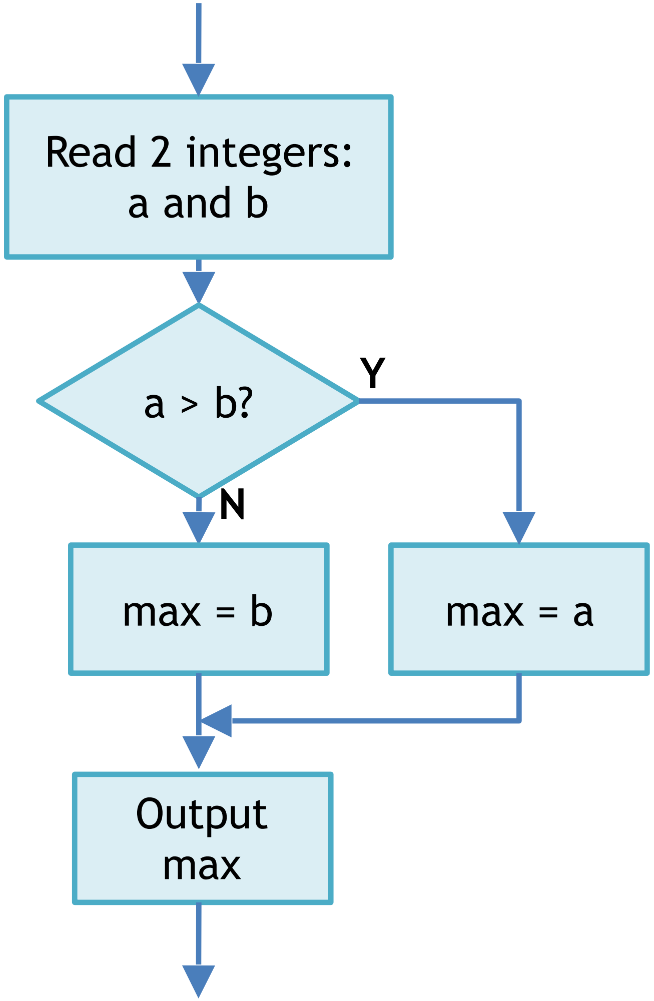
Remember to declare and initialize the variables before using them.



Example 1

- Write a program that reads 2 input integers and outputs the bigger one.

```
#include <iostream>
using namespace std;
int main() {
  int a, b, max;

  cin >> a >> b;

  if (a > b)
    max = a;
  else
    max = b;

  cout << max;
  return 0;
}
```

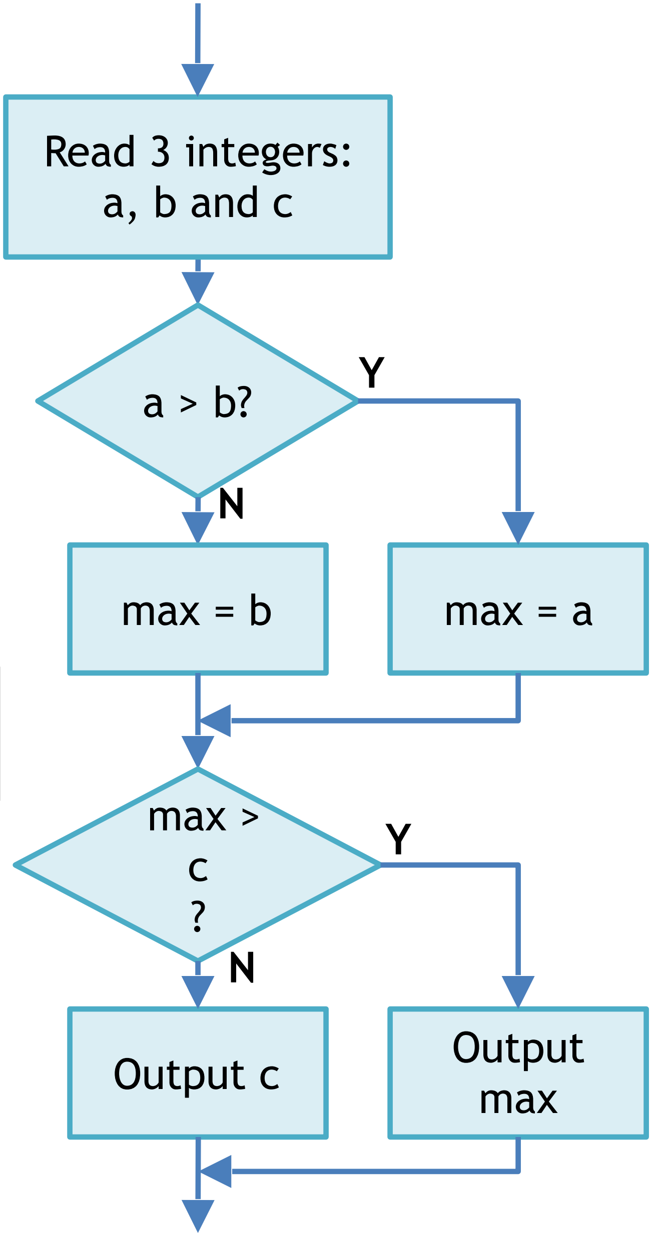


Example 2

- Write a program that reads 3 input integers and outputs the maximum one

```
#include <iostream>
using namespace std;
int main() {



  return 0;
}
```

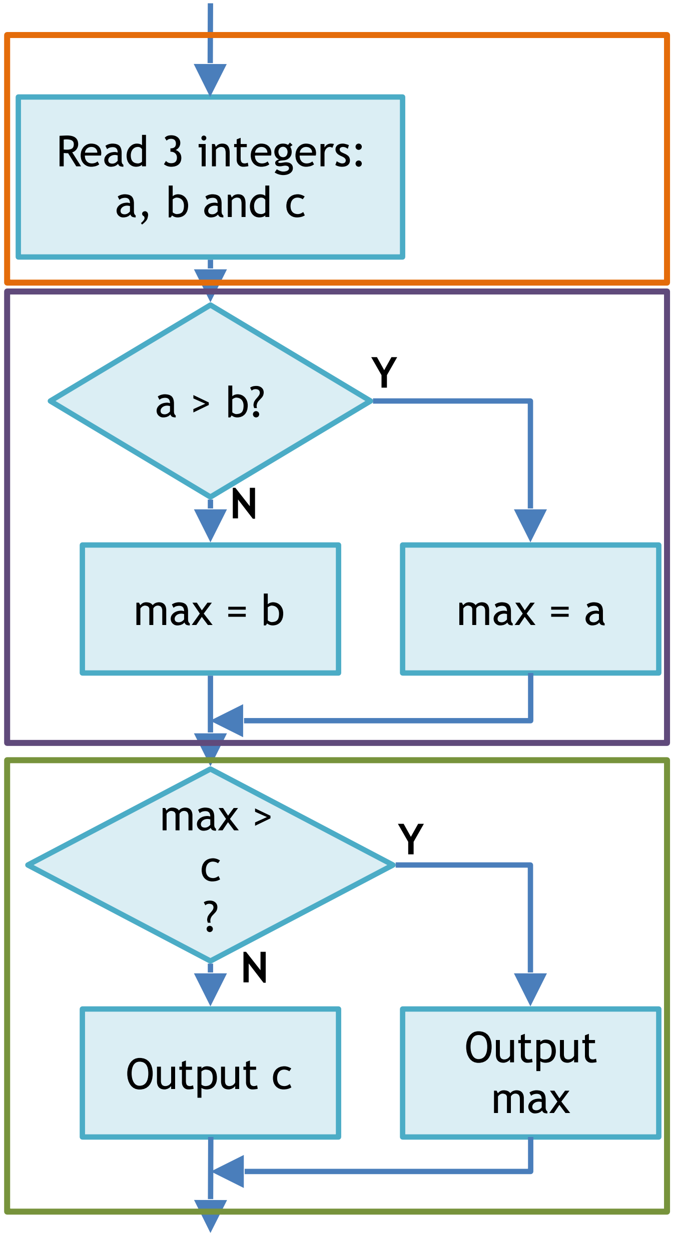
Let’s first come up with an algorithm to solve the problem.



Example 2

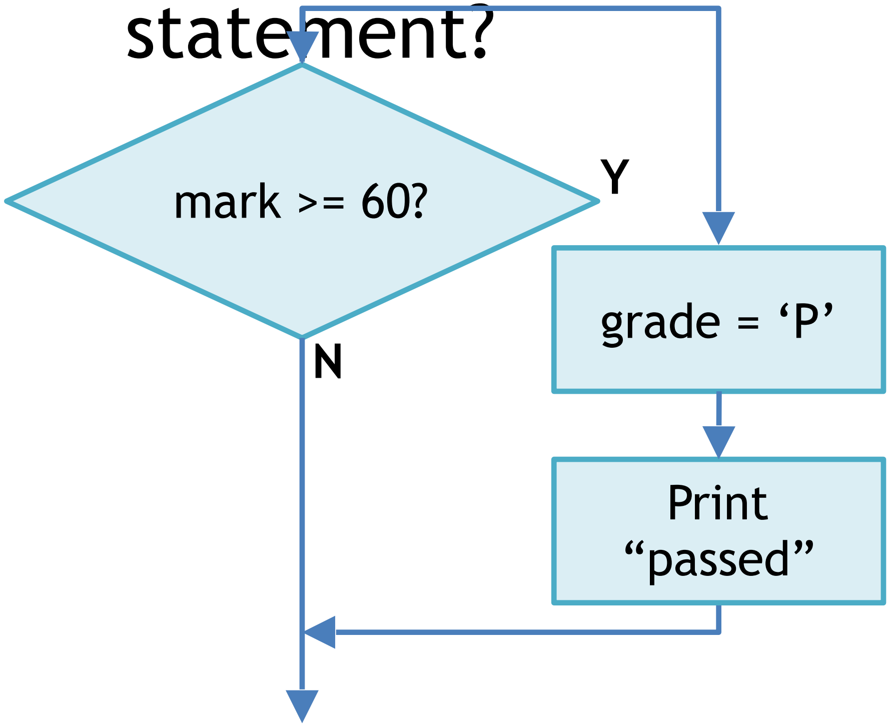
- Write a program that reads 3 input integers and outputs the maximum one

```
#include <iostream>
using namespace std;
int main() {
  int a, b, c, max;
  cin >> a >> b >> c;
  if (a > b)
    max = a;
  else
    max = b;
  if (max > c)
    cout << max << endl;
  else
    cout << c << endl;
  return 0;
}
```



Compound Statements

- What if an action involves more than one statement?



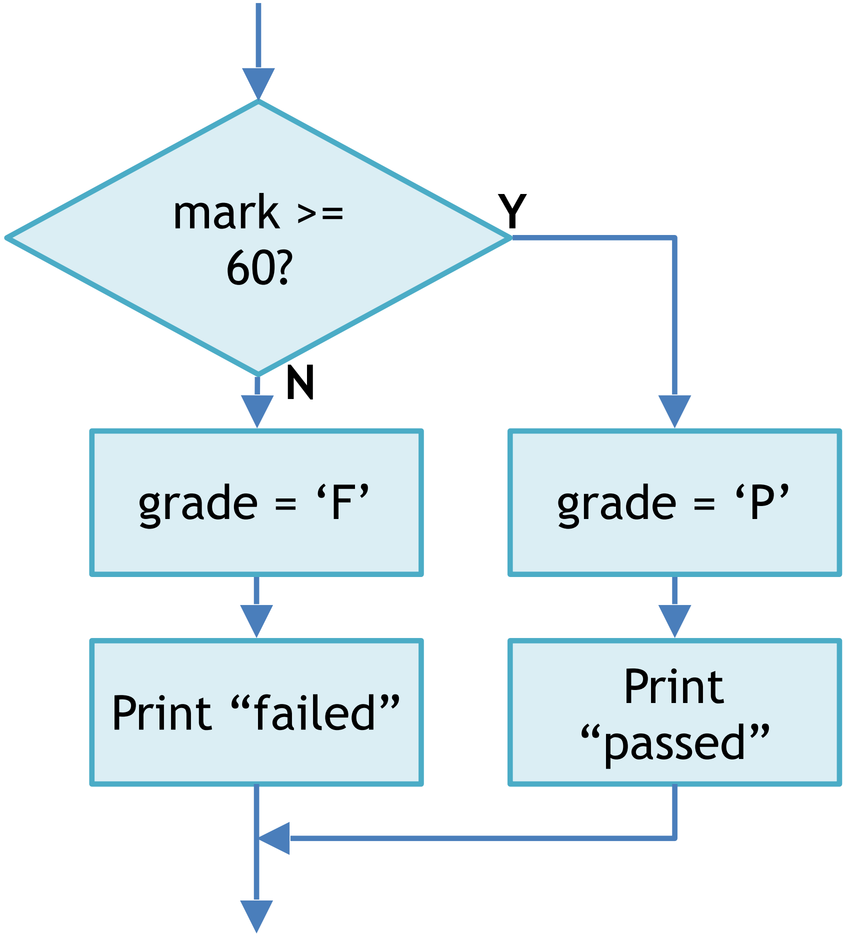
Syntax

```
        if (condition)
statement;
```

a statement can also be a **compound statement** or a **block of statements** enclosed in { and }

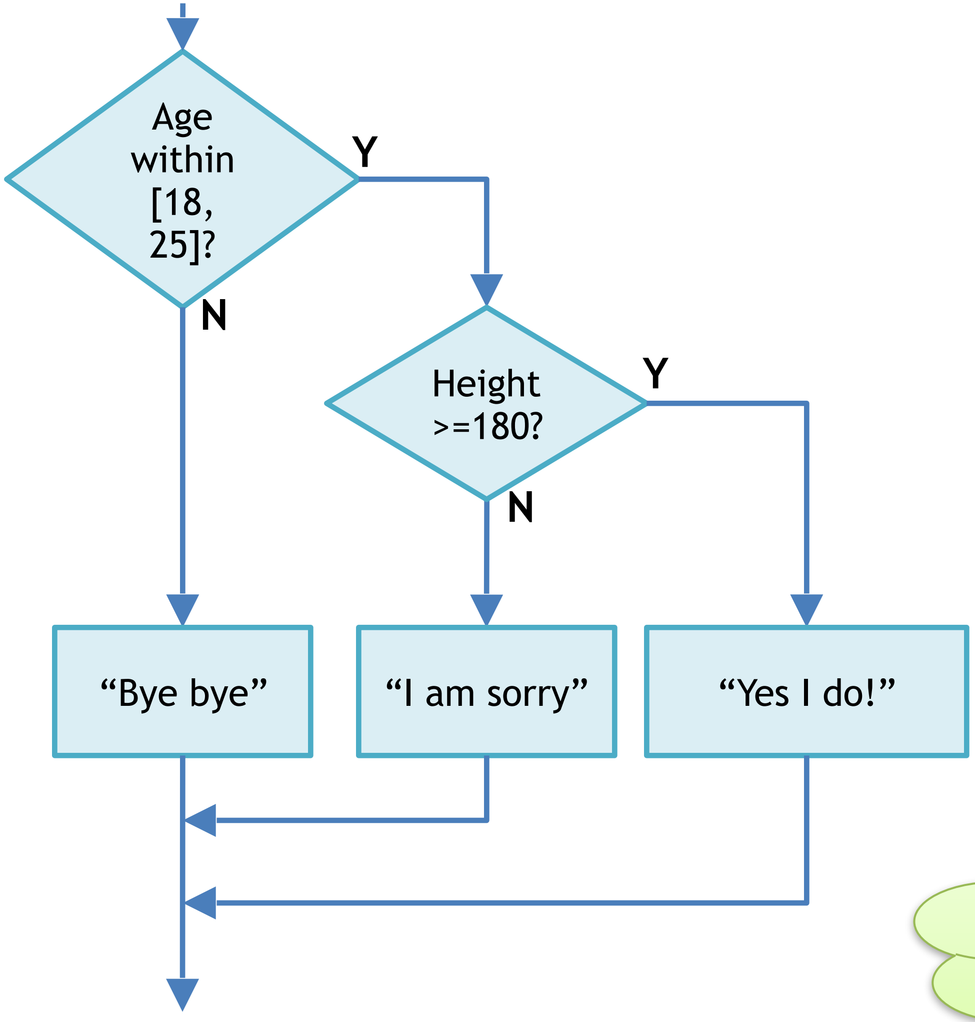
```
if (mark >= 60) {
  grade = ‘P’;
  cout << “passed”;
}
```

Compound Statements



```
if (mark >= 60) {
   grade = ‘P’;
   cout << “passed”;
}
else {
   grade = ‘P’;
   cout << “failed”;
}
```

Nested **if...else** Statements



- An **if-else** statement can be nested within another **if-else** statement

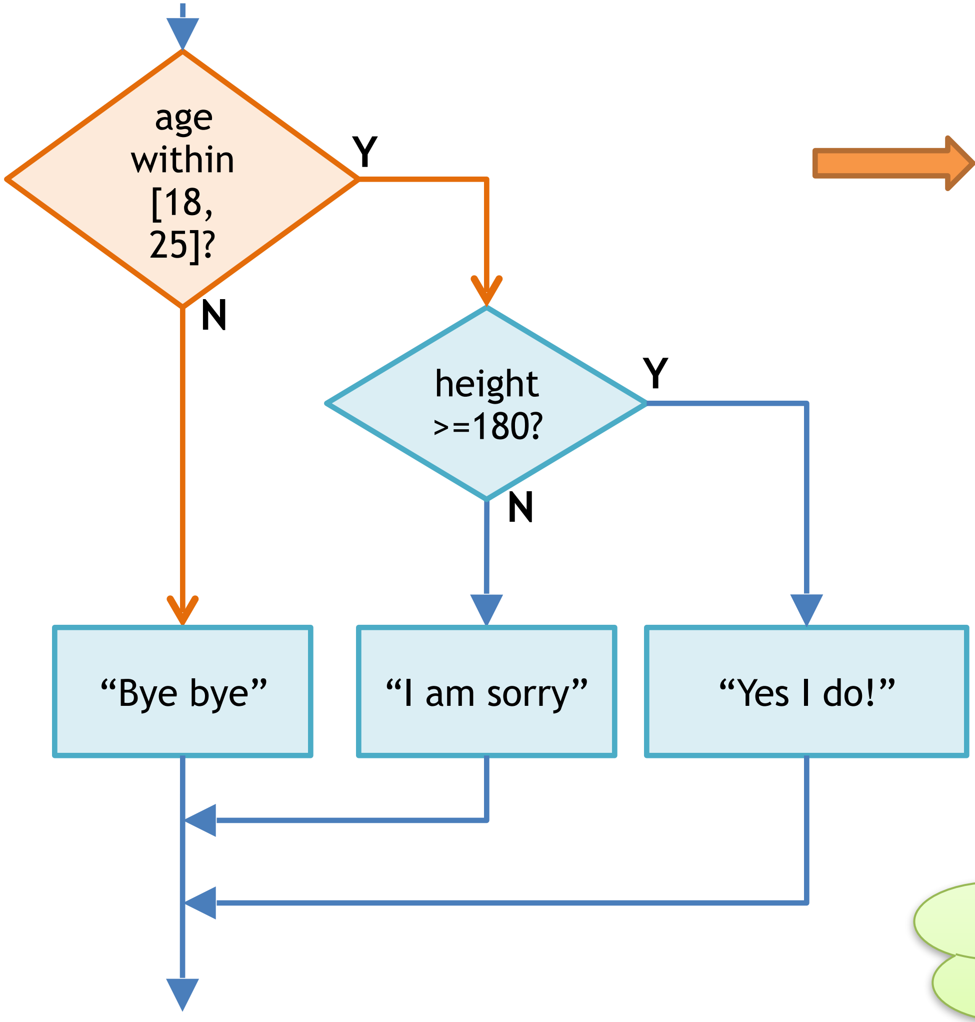
My Mr. Right…

1. 18 to 25 years old,

AND

2. Height: 180 cm or above

Nested **if…else** Statements



```
…
if (age >= 18 && age <=25)
{
  // the Yes part to
  // be dealt with here



}
else {
     cout << "Bye bye.";
}
…
```

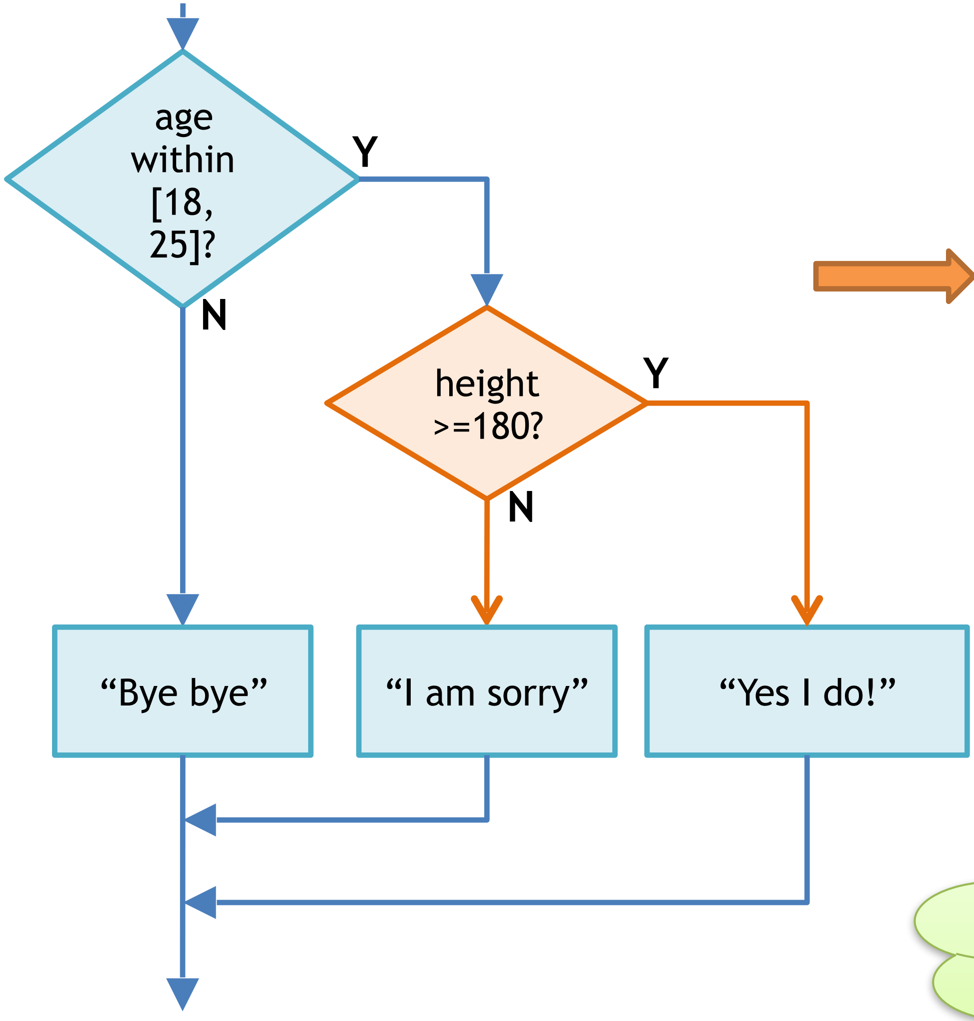
My Mr. Right…

1. 18 to 25 years old,

AND

2. height: 180 cm or above

Nested **if…else** Statements



```
…
if (age >= 18 && age <=25)
{
  if (height >= 180)
    cout << "Yes I do!";
  else
    cout << "I am sorry.";
}
else {
    cout << "Bye bye.";
}
…
```

My Mr. Right…

1. 18 to 25 years old,

AND

2. height: 180 cm or above

Coding Hints

- Visualize the logic of the program before writing the code.
- When writing the code, follow the logic in the diagram, implement the processes in the diagram **one at a time**.
- Use proper **indentation** (spacing) to make your program more readable.

Dangling-Else Problem

Unlike Python, indentation does NOT determine blocks of statements in C/C++!

The following program segments are treated the same by the C/C++ compiler, although they have different indentations as appear to us. So how would the C/C++ treat it? Should the **else** be paired with the 1st **if** or the 2nd **if**?

```
if ( x > 5 )
  if ( y > 5 )
    cout << “x and y are > 5”;
else
  cout << “x is <= 5”;
```

Looks as if:
1st **cout** is executed when x > 5 and y > 5,
2nd **cout** is executed when x <= 5

```
if ( x > 5 )
  if ( y > 5 )
    cout << “x and y are > 5”;
  else
    cout << “x is <= 5”;
```

✓

Looks as if:
1st **cout** is executed when x > 5 and y > 5,
2nd **cout** is executed when x > 5 and y <= 5

▼❊✼▲ ✼▲◗❊❀▼ ▼❊❄ ❃❏○❐✼●❄

Dangling-Else Problem

- Recall that C++ is a free formatting language
  - The compiler will ignore any whitespaces, including indentations
- The compiler always pairs an **else** with the nearest previous **if** that is not already paired with some **else**
- To avoid the dangling else problem, use braces { } to tell the compiler how to group the statements

Dangling-Else Problem

```
if ( x > 5 )
  if ( y > 5 )
    cout << “x and y are >
5”;
  else
    cout << “x is <= 5”;
```

is
equivalent
to

```
if ( x > 5 ) {
   if ( y > 5 )
     cout << “x and y are >
5”;
   else
     cout << “x is <= 5”;
 }
```

- If you want the 2nd **cout** to be executed when x <= 5:

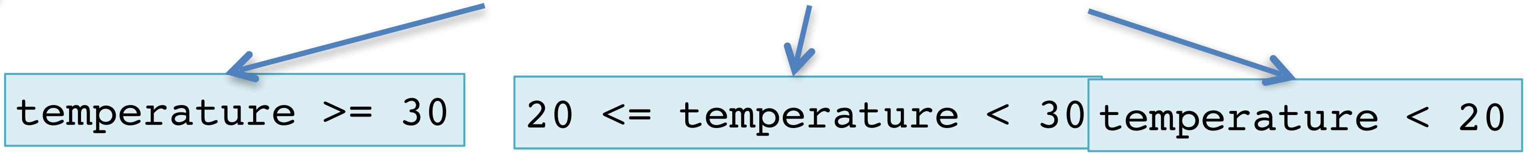
```
if ( x > 5 ) {
  if ( y > 5 )
    cout << “x and y are >
5”;
}
else
  cout << “x is <= 5”;
```

A Dangling-Else Example

```
  if ( temperature >= 20 )
    if ( temperature >= 30 )
      cout << "good day for swimming" <<
endl;
    else
      cout << "good day for golfing" <<
endl;
  else
    cout << "good day to play tennis";
```

1 How to pair up the **if**'s and **else**'s?

2 Conditions for swimming, golfing & tennis?

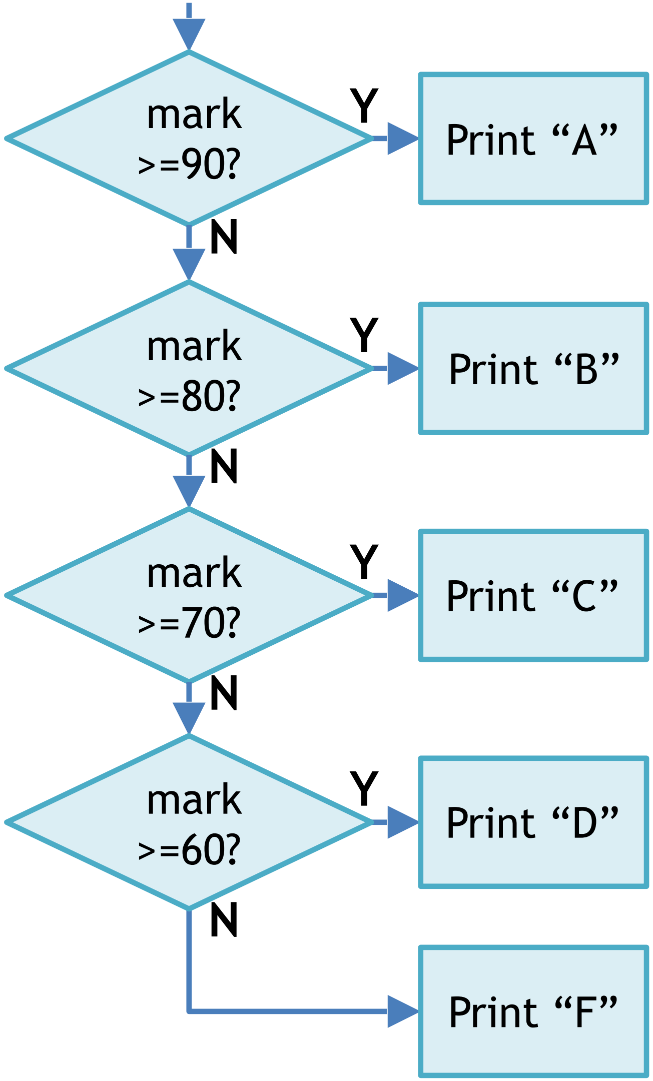


`temperature >= 30`

`20 <= temperature < 30`

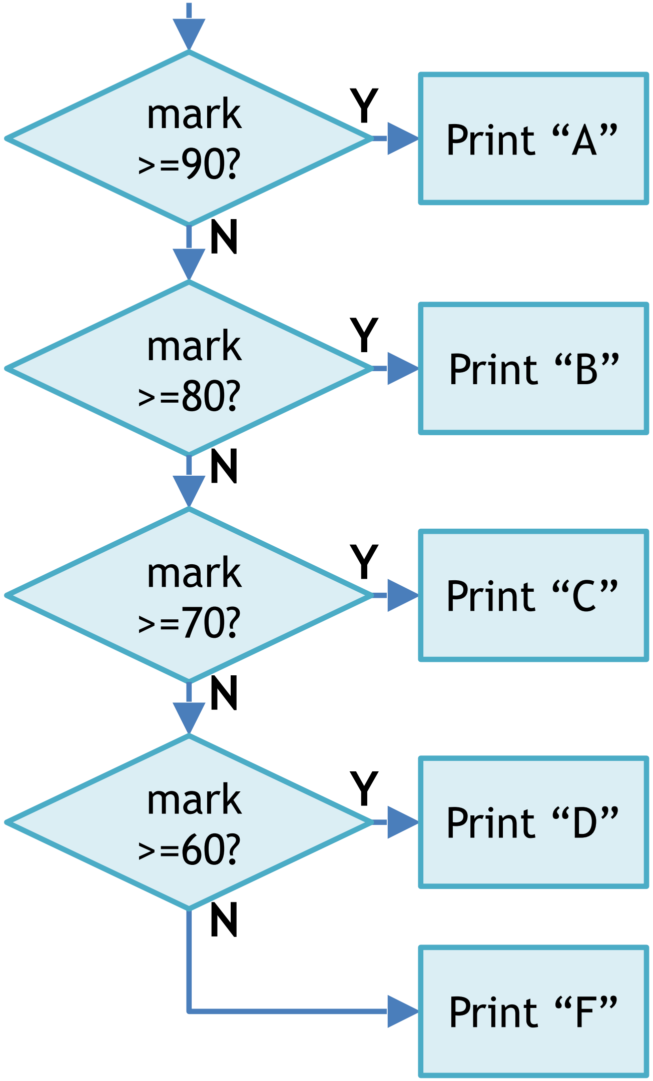
`temperature < 20`

Multi-way **if-else** Statement



```
if ( mark >= 90 )  // 90 and above gets
"A"
  cout << "A";
else
  if ( mark >= 80 )   // 80-89 gets "B"
    cout << "B";
  else
    if (mark >= 70 )   // 70-79 gets "C"
      cout << "C";
    else
      if (mark >= 60 )  // 60-69 gets
"D"
        cout << "D";
      else              // less than 60 gets
"F"
        cout << "F";
```

Multi-way **if-else** Statement



A more compact style is preferred

```
if ( mark >= 90 )   // 90 and above gets
"A"
  cout << "A";
else if (mark >= 80 )   // 80-89 gets
"B"
  cout << "B";
else if (mark >= 70 )   // 70-79 gets
"C"
  cout << "C";
else if (mark >= 60 )   // 60-69 gets
"D"
  cout << "D";
else        // less than 60 gets "F"
  cout << "F";
```

Series of **if** vs. Multi-way **if-else**

- What’s the difference between the following two program segments?

```
if (mark >= 90 )
   cout << "A";
else if (mark >= 80 )
   cout << "B";
else if (mark >= 70 )
   cout << "C";
else if (mark >= 60 )
   cout << "D";
else
   cout << "F";
```

```
if ( mark >= 90 )
   cout << "A";
if ( mark < 90 && mark >=
80 )
   cout << "B";
if ( mark < 80 && mark >=
70 )
   cout << "C";
if ( mark < 70 && mark >=
60 )
   cout << "D";
if ( mark < 60 )
   cout << "F";
```

Faster, skip remaining if testing once hitting a true condition

Slower, needs to test all conditions even though only one of them can be true

Same program outcome but different performance!

switch Statement

Syntax

```
    switch (controlling_expression)
{
        case constant_1:
            statement_1;
            break;
        case constant_2:
            statement_2;
            break;
        …
        case constant_n:
            statement_n;
            break;
        default:
            default_statement;
    }
```

- A multi-way branching action can also be achieved using a **switch** statement

The controlling expression in a switch statement must return either a **Boolean value, an integer or a character**

optional

switch Statement

```
char grade;
cin >> grade;
switch ( grade )
{
case ‘A’:
     cout << "grade point is 4.0";
     break;
case ‘B’:
     cout << "grade point is 3.0";
     break;
case ‘C’:
     cout << "grade point is 2.0";
     break;
case ‘D’:
     cout << "grade point is 1.0";
     break;
case ‘F’:
     cout << "grade point is 0.0";
     break;
default:
     cout << "grade is invalid";
}
```

1 When a **switch** statement is executed, the controlling_expression is evaluated, the value of which must be one of Boolean, integer or character types

2 The constants given after the **case** keywords are checked in order until the first that equals the value of the controlling_expression is found, and then the following statements are executed

3 The **switch** statement ends when a **break** statement is encountered

4 If none of the constants matches the value of the controlling_expression, then the default_statement is executed

switch Statement

```
char grade;
cin >> grade;
switch ( grade )
{
case ‘A’:
   cout << "grade point is 4.0";
   break;
case ‘B’:
   cout << "grade point is 3.0";
   break;
case ‘C’:
   cout << "grade point is 2.0";
   break;
case ‘D’:
   cout << "grade point is 1.0";
   break;
case ‘F’:
   cout << "grade point is 0.0";
   break;
default:
   cout << "grade is invalid";
}
```

is equivalent to

```
char grade;
cin >> grade;
if (grade == ‘A’)
   cout << "grade point is 4.0";
else if (grade == ‘B’)
   cout << "grade point is 3.0";
else if (grade == ‘C’)
   cout << "grade point is 2.0";
else if (grade == ‘D’)
   cout << "grade point is 1.0";
else if (grade == ‘F’)
   cout << "grade point is 0.0";
else
   cout << "grade is invalid";
```

The switch statement is sometimes preferably especially when it can show clearly the flow of control depends on the value of `grade` only.

switch Statement more examples

```
    switch ( mark / 10 ) {
        case 0:    case 1:
        case 2:    case 3:
        case 4:    case 5:
            grade = ‘F’;
            break;
        case 6:
            grade = ‘D’;
            break;
        case 7:
            grade = ‘C’;
            break;
        case 8:
            grade = ‘B’;
            break;
        case 9:
        case 10:
            grade = ‘A’;
            break;
        default:
            cout << “invalid
mark";
    }
```

Assuming that `mark` is of type `int` with range 0 to 100. Note that this is an integer division which results in an integer value.

What is the range of mark for grade to be assigned ‘A’? 90-100

for grade to be assigned ‘B’? 80-89

for grade to be assigned ‘C’? 70-79

for grade to be assigned ‘D’? 60-69

for grade to be assigned ‘F’? 0-59

What if mark is out of the range 0 to 100?

The program will output “invalid mark” on screen

switch Statement more examples

```
switch ( age >= 18 ) {
case 1:
  cout << “Old enough to vote";
    break;
case 0:
  cout << “Not old enough to vote";
    break;
}
```

What is the program output?

If age >= 18 is true, then output “Old enough to vote” to screen;
Otherwise output “Not old enough to vote” to screen

switch Statement

more examples

```
int main()
{
  int mark;
  cout << “Enter the mark: ”;
  cin >> mark;

  switch ( mark / 10 ) {
  case 0:   case 1:
  case 2:   case 3:
  case 4:   case 5:
    cout << “The grade is F.” << endl;
    break;
  case 6:
    cout << “The grade is D.” << endl;
    break;
  case 7:
    cout << “The grade is C.” << endl;
    break;
  case 8:
    cout << “The grade is B.” << endl;
    break;
  case 9:
  case 10:
    cout << “The grade is A.” << endl;
    break;
  default:
    cout << “Invalid mark.“ << endl;
  }

  return 0;
}
```

A recap

What is the output of the program segment if the input mark is 75?

```
Enter the mark:   75
The grade is C.
```

switch Statement more examples

```
int main()
{
  int mark;
  cout << “Enter the mark: ”;
  cin >> mark;

  switch ( mark / 10 ) {
  case 0:   case 1:
  case 2:   case 3:
  case 4:   case 5:
    cout << “The grade is F.” << endl;
  case 6:
    cout << “The grade is D.” << endl;
  case 7:
    cout << “The grade is C.” << endl;
  case 8:
    cout << “The grade is B.” << endl;
  case 9:
  case 10:
    cout << “The grade is A.” << endl;
  default:
    cout << “Invalid mark.“ << endl;
  }

  return 0;
}
```

Pay ATTENTION!
The break; statements are missing!

What is the output of the program segment if the input mark is 75?

```
Enter the mark:   75
The grade is C.
The grade is B.
The grade is A.
Invalid mark.
```

Common Mistakes

- Below are some common mistakes in the Boolean condition of an **if** or **if…else** statement:
  - Using an assignment instead of the equality operator, e.g.,

```
if (a = 10)
```
✗

```
if (a == 10)
```
✓

  - Using bitwise AND/OR instead of logical AND/OR operator, e.g.,

```
if (a != 0 & b > 0)
if (a != 0 | b > 0)
```
✗

```
if (a != 0 && b > 0)
if (a != 0 || b > 0)
```
✓

  - Using strings of inequalities, e.g.,

```
if (a < b < c)
```
✗

```
if (a < b && b > c)
```
✓

- These are all legal expressions in C++ and hence the compiler will not report any syntax error

Reference Only

Condition Operator (**?:**)

- A ternary operator that takes three operands:

condition **?** expr1 **:** expr2

- A conditional expression that evaluates to a value:
  - if condition is **true**, **expr1** is the value of the expression
  - if condition is **false**, **expr2** is the value of the expression

```
if (mark >= 60)
     cout <<
"passed";
else
     cout <<
"failed";
```

is equivalent to

```
cout << (mark >= 60)? "passed" :
"failed";
```

Note: **if…else** is a statement,
?: is an operator that forms an expression

Doing something repeatedly

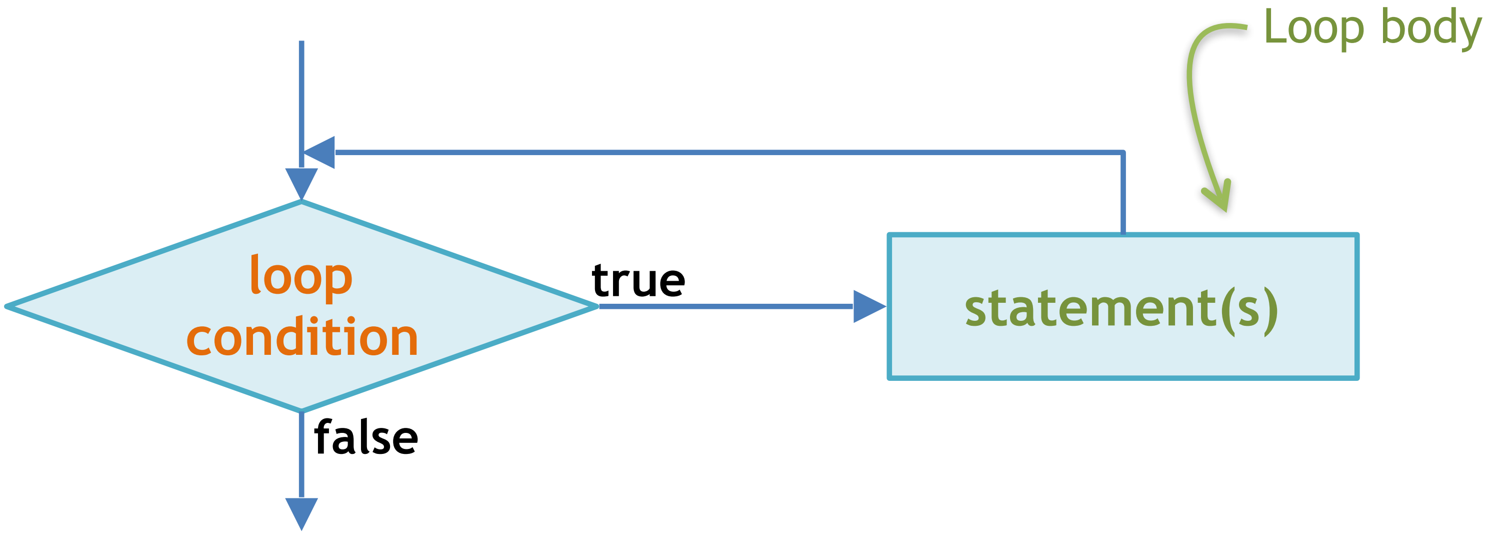
LOOPING

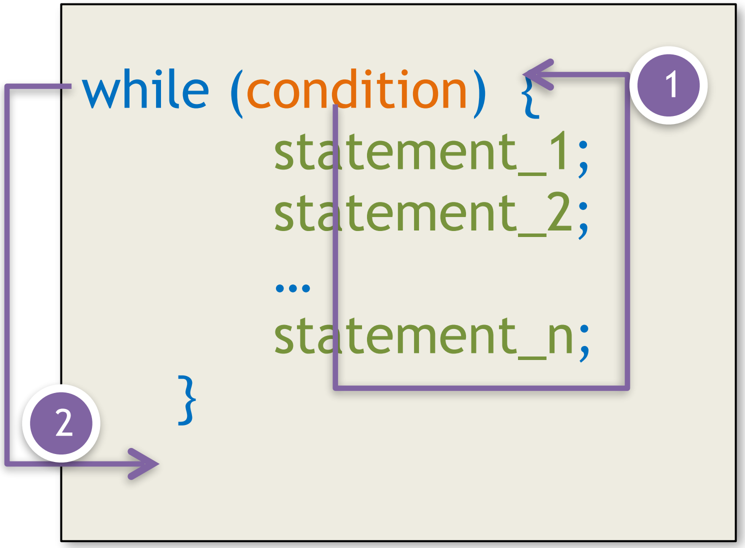
Loop

- A loop is any program construction that repeats a statement (or a compound statement) a number of times
- The statement to be repeated in a loop is called the body of the loop
- Each repetition of the loop body is called an iteration
- In C++, looping can be achieved using either a while statement or a for statement

Note: There is also the **do…while** statement, but we will leave it for you interest only.

while Statement





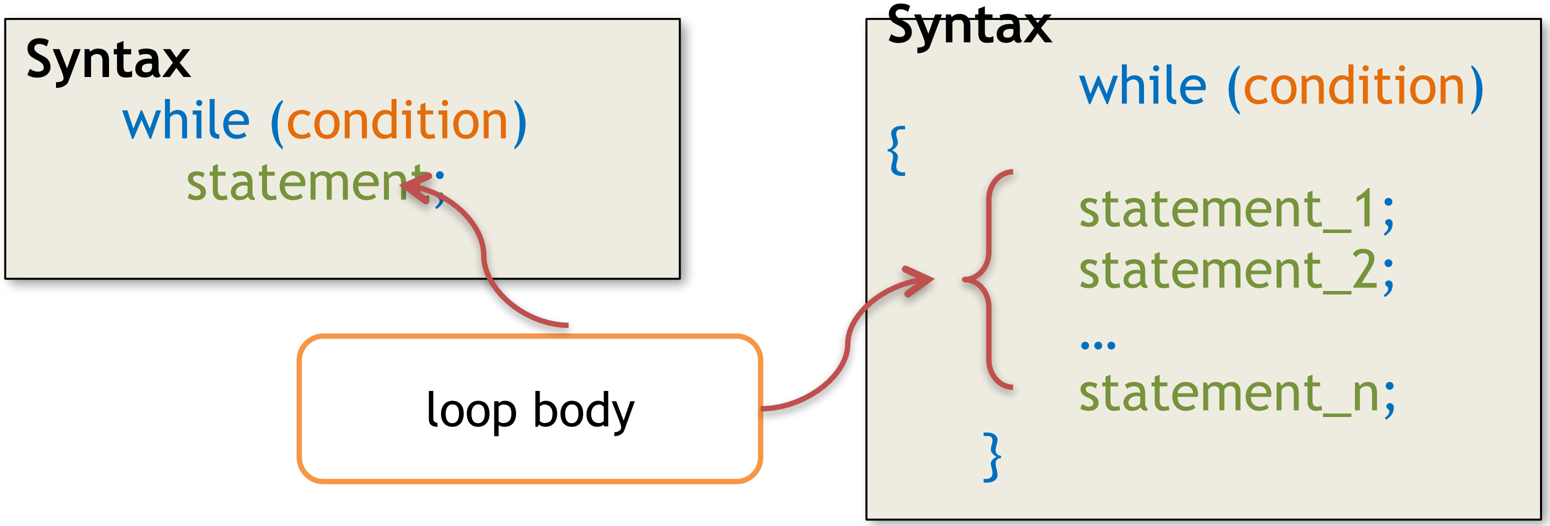
```
while (condition) {
          statement_1;
          statement_2;
          …
          statement_n;
    }
```

The while statement controls whether to repeat a loop body depending on a condition.
Essentially, the loop body is executed repeatedly as long as condition is true

1 execution path when condition is true

2 execution path when condition is false

while Statement



Syntax

```
while (condition)
    statement;
```

loop body

Syntax

```
            while (condition)
{
            statement_1;
            statement_2;
            …
            statement_n;
    }
```

- When a while statement (aka **while loop**) is executed, the condition is evaluated
  - If it returns true, the loop body is executed once (i.e., one iteration)
  - If it returns false, the loop ends without executing its body
- After each iteration, condition will be evaluated again and the process repeats

while Statement

```
#include <iostream>
using namespace std;

int main()
{
   int answer = 0;

   while (answer != 4) {
      cout << “2 * 2 = ”;
      cin >> answer;
   }

   cout << “Correct!” << endl;

   return 0;
}
```

What does this program do?

Asks the user to answer 2 * 2 repeatedly until the user inputs the correct answer

What if the user keeps giving a wrong answer?

The program will keep asking again.

while Statement

```
#include <iostream>
using namespace std;

int main()
{
   int answer = 0;
   int trials = 0;

   while (answer != 4) {
      cout << “2 * 2 = ”;
      cin >> answer;
      trials++;
   }

   cout << “Correct!” << endl;
   cout << “You’ve tried ” << trials << “ times.” << endl;

   return 0;
}
```

We may use a loop variable (or counter), which is of integer type, to count the number of iteration (i.e., how many times the loop body is executed).

What is the loop variable in this example?

`trials`

while Statement

Sentinel-controlled while loops

to use a **special value** to indicate end of loop

```
#include <iostream>
using namespace std;

int main()
{
  int x = 0, total = 0;
  cout << "Enter a negative num to end." << endl;

  while (x >= 0) {
    total += x;
    cout << "Total = " << total << endl;
    cout << "next number? ";
    cin >> x;
  }

  cout << "Program ends." << endl;

  return 0;
}
```

In this example, the special value is any negative number. Also, the number of times the loop body is executed is determined at run time only (loops until user inputs a negative number).

Screen output?

```
Enter a negative number to end.
Total = 0
next number? 4 ↵
Total = 4
next number? 3 ↵
Total = 7
next number? 2↵
Total = 9
next number? 1↵
Total = 10
next number? -1 ↵
Program ends.
```

Note that the loop condition depends on the value of x, and hence **it is important** to make sure that the value of x will be updated within the loop body (as in cin >> x) in order for the condition (x >= 0) to change to false to exit the loop.

while Statement

Counter-controlled while loops
by decrementing a counter

```
#include <iostream>
using namespace std;

int main()
{
  int x = 0, total = 0, n;
  cout << "Enter the number of values to be added: ";
  cin >> n;

  while (n > 0) {
    cout << "next number? ";
    cin >> x;
    total += x;
    cout << "Total = " << total << endl;
    n--;
  }

  return 0;
}
```

How many times will the loop body be executed?

n

```
Enter the number of values to be added: 3↵
next number? 4↵
Total = 4
next number? 3↵
Total = 7
next number? 2↵
Total = 9
```

Screen output?

Again note that how the value of n is updated within the loop body to control loop repetition

while Statement

```
#include <iostream>
using namespace std;

int main()
{
  int x = 0, total = 0, i, n;
  cout << "Enter the number of values to be added: ";
  cin >> n;

  i = 0;
  while (i < n) {
    cout << "next number? ";
    cin >> x;
    total += x;
    cout << "Total = " << total << endl;
    i++;
  }

  return 0;
}
```

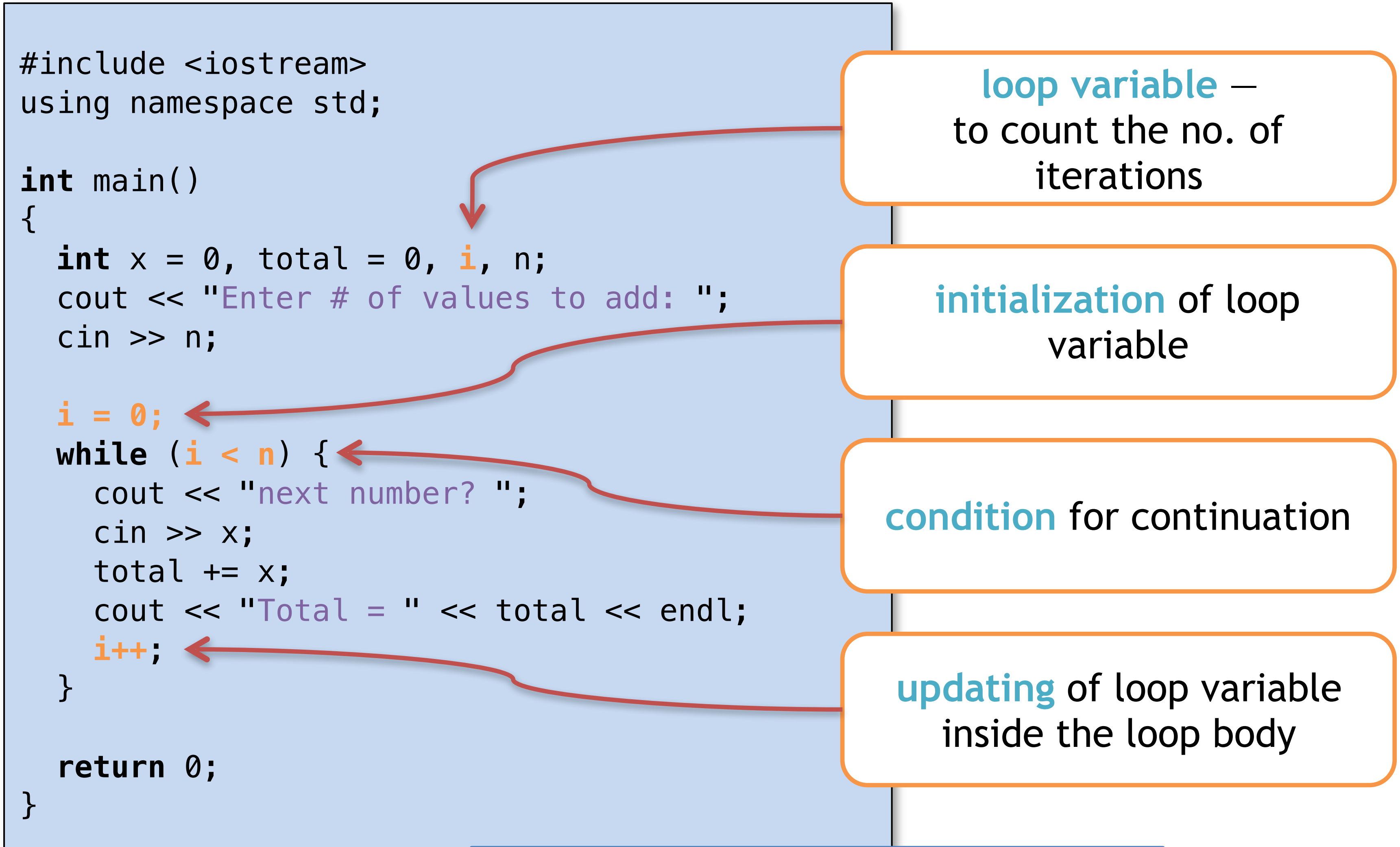
Counter-controlled while loops
by incrementing a counter

How many times will the loop body be executed? n

```
Enter the number of values to be added: 3↵
next number? 4↵
Total = 4
next number? 3↵
Total = 7
next number? 2↵
Total = 9
```

Screen output?

Typical Structure of a Counter-Controlled Loop



```
#include <iostream>
using namespace std;

int main()
{
  int x = 0, total = 0, i, n;
  cout << "Enter # of values to add: ";
  cin >> n;

  i = 0;
  while (i < n) {
    cout << "next number? ";
    cin >> x;
    total += x;
    cout << "Total = " << total << endl;
    i++;
  }

  return 0;
}
```

loop variable – to count the no. of iterations

initialization of loop variable

condition for continuation

updating of loop variable inside the loop body

What if you forgot to update the loop variable?

while Statement

```
#include <iostream>
using namespace std;

int main()
{
  int num = 23;
  int guess;
  bool isGuessed;

  isGuessed = false;

  while (!isGuessed) {
    cout << "Make a guess (0-99)? ";
    cin >> guess;

    if (guess == num) {
      cout << "Correct!" << endl;
      isGuessed = true;
    }
    else if (guess < num)
      cout << "Too small.  Guess again!" << endl;
    else
      cout << "Too large.  Guess again!" << endl;
  }
  return 0;
}
```

Flag-controlled while loops
use a **bool** variable to control the iterations

What is the flag in this example?

`isGuessed`

Screen output?

```
Make a guess (0-99)? 48 ↵
Too large. Guess again? 20 ↵
Too small. Guess again? 35 ↵
Too large. Guess again? 23 ↵
Correct!
```

while Statement

What's wrong here?

```
int i = 0, n = 10;

while (i < n);
{
  cout << "next number? ";
  cin >> x;
  total += x;
  cout << "Total = " << total << endl;
  i++;
}
```

Never put a semicolon after the parenthesis as it is equivalent to introducing an empty statement (aka null statement) as the loop body.
Essentially, this while statement contains an empty loop body

Will the loop counter be updated?
So what will happen? Try it!

Quick Exercise 1

Write a complete C++ program that outputs the numbers 1 to 20, one per line, using a **while loop**

Answer

for Statement

- The for statement (aka for loop) in C++ provides a compact way of expressing a loop structure

Output 1 to 20, one number of a line, using a for loop (i.e., same program outcome as quick exercise 1).

```
#include <iostream>
using namespace std;

int main()
{
  int i;

  for (i = 1; i <= 20; ++i)
    cout << i << endl;

  return 0;
}
```

Now, take a close look at the three statement inside the round brackets () after the for keyword:

`i = 1;`

this statement is for initialization, i.e., it will only be executed once before the loop begins for the first time

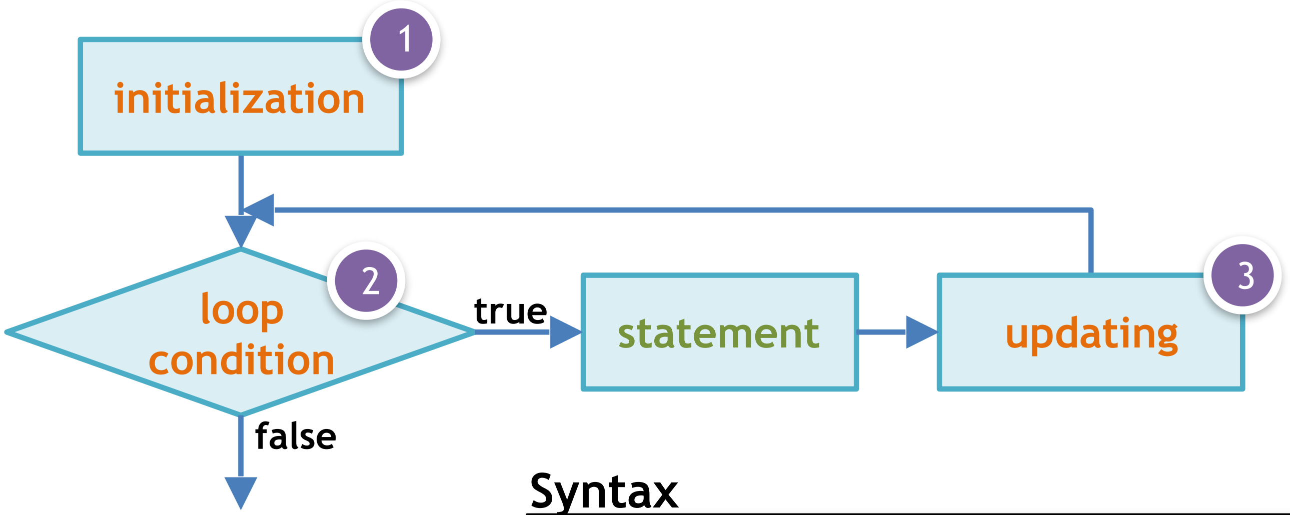
`i <= 20;`

this statement is the loop condition for deciding whether to continue to loop. The loop body will be executed only if it is true.

`++i`

this statement is the updating statement which will be executed after each iteration of the loop. It usually updates the loop control variable (in this case `i`).

for Statement



1 initialization

2 loop condition

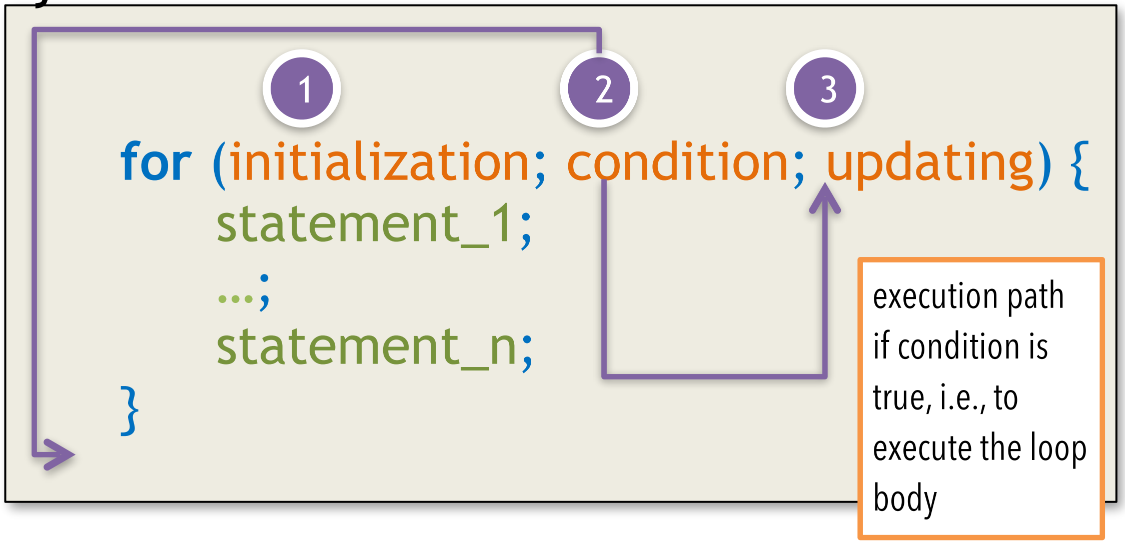
true

statement

updating 3

false

Syntax



```
      1                    2             3
for (initialization; condition; updating) {
    statement_1;
    …;
    statement_n;
}
```

execution path if condition is false, i.e. to exit the loop

execution path if condition is true, i.e., to execute the loop body

for Statement

- When a **for** statement is executed

  1. The initialization is performed
     - Generally it sets the initial value of the loop variable
     - The initialization is executed only once
  2. The condition is evaluated
     - If it is true, the loop body is executed once (i.e., one iteration)
     - If it is false, the loop ends without executing its body
  3. After each iteration, the updating of loop variable is performed and the loop continues at Step 2

for Statement

- Most while loops can be implemented as a for loop

```
#include <iostream>
using namespace std;

int main()
{
   int answer = 0;
   int trials;

   for (trials = 0; answer != 4; trials++) {
      cout << “2 * 2 = ”;
      cin >> answer;
   }

   cout << “Correct!” << endl;
   cout << “You’ve tried ” << trials << “ times.” << endl;

   return 0;
}
```

Compare this program to this previous while loop example.

for vs. **while**

```
#include <iostream>
using namespace std;

int main()
{
  int x = 0, total = 0, i, n;
  cout << “How many numbers to add? ”;
  cin >> n;

  // for loop
  for (i = 0; i < n; i++) {
    cout << “next number? ”;
    cin >> x;
    total += x;
    cout << “Total = ” << total << endl;
  }

  return 0;
}
```

```
#include <iostream>
using namespace std;

int main()
{
  int x = 0, total = 0, i, n;
  cout << “How many numbers to add? ”;
  cin >> n;

  // while loop
  i = 0;
  while (i < n) {
    cout << “next number? ”;
    cin >> x;
    total += x;
    cout << “Total = ” << total << endl;
    i++;
  }

  return 0;
}
```

Compare the above two programs which have the program behaviour.

Quick Exercise 2

Write a program that outputs 9 8 7 6 5 4 3 2 1 0 in a single line using a **for** loop.

Answer

Quick Exercise 3

Write a program that calculates the sum of odd numbers between 1 and 20 using a **for** loop.

Answer

break Statement

- The break statement can be used to exit a loop from inside a loop body
- When a break statement is executed
  - The loop ends immediately
  - The execution continues with the statement following the loop
- The break statement may be used in both **while** loop and **for** loop
- Note: Avoid using a break statement to end a loop unless absolutely necessary because it might make it hard to understand your code
  - A proper way to end a loop is using the condition for continuation

break Statement

Yes, you may declare and initialize the counter variable at the same time in the initialize statement in the for loop

```
#include <iostream>
using namespace std;

int main()
{
  for (int i = 0; i >= 0; i++) {
    if (i == 15) break;
    cout << i << “ ”;
  }

  return 0;
}
```

As the condition is always true, this will be an infinite loop

The break statement is used here to exit the infinite loop when i == 15

Screen output?

```
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
```

Can you rewrite the program so that it produces the same output without using the break statement?

continue Statement

- The continue statement is used to terminate the current iteration of a loop
- When a **continue** statement is executed
  - Any loop body statements after it will be skipped
  - The loop continues by starting the next iteration
- Like the break statement, the **continue** statement may be used in both **while** loop and **for** loop

continue Statement

```
#include <iostream>
using namespace std;

int main()
{
    for (int i = 0; i < 20; ++i) {
        if (i % 2 == 0) continue;
        cout << i << “ ”;
    }

    cout << endl;

    return 0;
}
```

The continue statement is used here to skip those i’s which are even

When the continue statement is executed, the succeeding cout statement are skipped. The next iteration begins by updating the loop variable and checking the condition.

Screen output?

```
1 3 5 7 9 11 13 15 17 19
```

Can you rewrite the program so that it produces the same output without using the continue statement?

Examples on **break** and **continue**

```
int count;
for ( count = 1; count <= 10; ++count) {
  if (count == 5) break;

  cout << count << " ";
}
cout << endl << "Broke out of loop at count = " << count << endl;
```

Screen output?

```
1 2 3 4
Broke out of loop at count =
5
```

```
for ( int count = 1; count <= 10; ++count) {
  if (count == 5) continue;
  cout << count << " ";
}
```

Screen output?

```
1 2 3 4 6 7 8 9 10
```

Answer to Quick Exercise 1

Write a complete C++ program that outputs the numbers 1 to 20, one per line, using a **while loop**

```
#include <iostream>
using namespace std;

int main()
{
  int i = 1, n = 20;

  while (i <= n) {
    cout << i << end;
    i++;
  }

  return 0;
}
```

A shorter version

```
#include <iostream>
using namespace std;

int main()
{
  int i = 1, n = 20;

  while (i <= n)
    cout << i++ << end;

  return 0;
}
```

We can't use ++i here. Using ++i will output 2 to 21 instead. Why? Review how the prefix and postfix operators work here.

Answer to Quick Exercise 2

Write a program that outputs 9 8 7 6 5 4 3 2 1 0 in a single line using a **for** loop.

```
#include <iostream>
using namespace std;

int main()
{
  int i;

  for (i = 9; i >= 0; --i)
    cout << i << ‘ ‘;

  return 0;
}
```

Try to repeat this exercise with a while loop.

Answer to Quick Exercise 3

Write a program that calculates and outputs the sum of odd numbers between 1 and 20 using a **for** loop

```
#include <iostream>
using namespace std;

int main()
{
  int i, sum = 0;

  for (i = 1; i <= 20; ++i)
    sum += i;

  cout << sum << endl;

  return 0;
}
```

A compact version **(for your interest only)**

```
#include <iostream>
using namespace std;

int main()
{
  int i, sum;

  for (i = 1, sum = 0; i <= 20; sum += i++) ;

  cout << sum << endl;

  return 0;
}
```

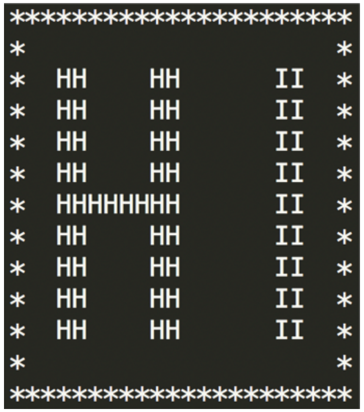
This is essentially a for loop with an empty loop body!

Check http://www.cplusplus.com/doc/tutorial/control/ under the for loop section for why this is so.

PROBLEMS

Problem 1

Write a program that prints HI in large block letters inside a border of *. The output should appear as follows:

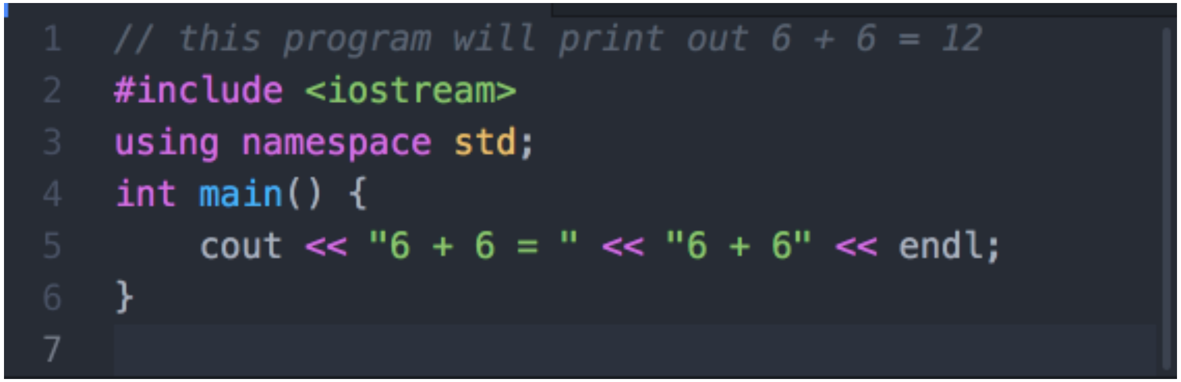


```
**********************
*                    *
*  HH    HH      II  *
*  HH    HH      II  *
*  HH    HH      II  *
*  HH    HH      II  *
*  HHHHHHHH      II  *
*  HH    HH      II  *
*  HH    HH      II  *
*  HH    HH      II  *
*  HH    HH      II  *
*                    *
**********************
```

Problem 2

The following program is supposed to print out 6 + 6 = 12

Unfortunately, it doesn't. Can you fix the problem?

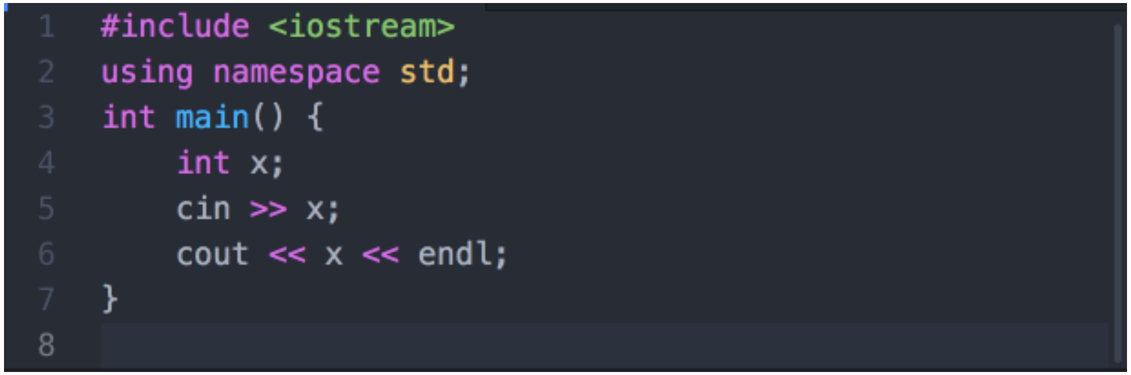


```
// this program will print out 6 + 6 = 12
#include <iostream>
using namespace std;
int main() {
    cout << "6 + 6 = " << "6 + 6" << endl;
}

```

Problem 3

The following C++ program reads in an integer (int) and then output it to screen.

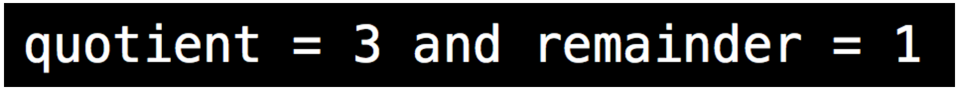
Can you make change to the program so that it reads in two integers, and output both their sum and their product?



```
#include <iostream>
using namespace std;
int main() {
    int x;
    cin >> x;
    cout << x << endl;
}

```

Problem 4

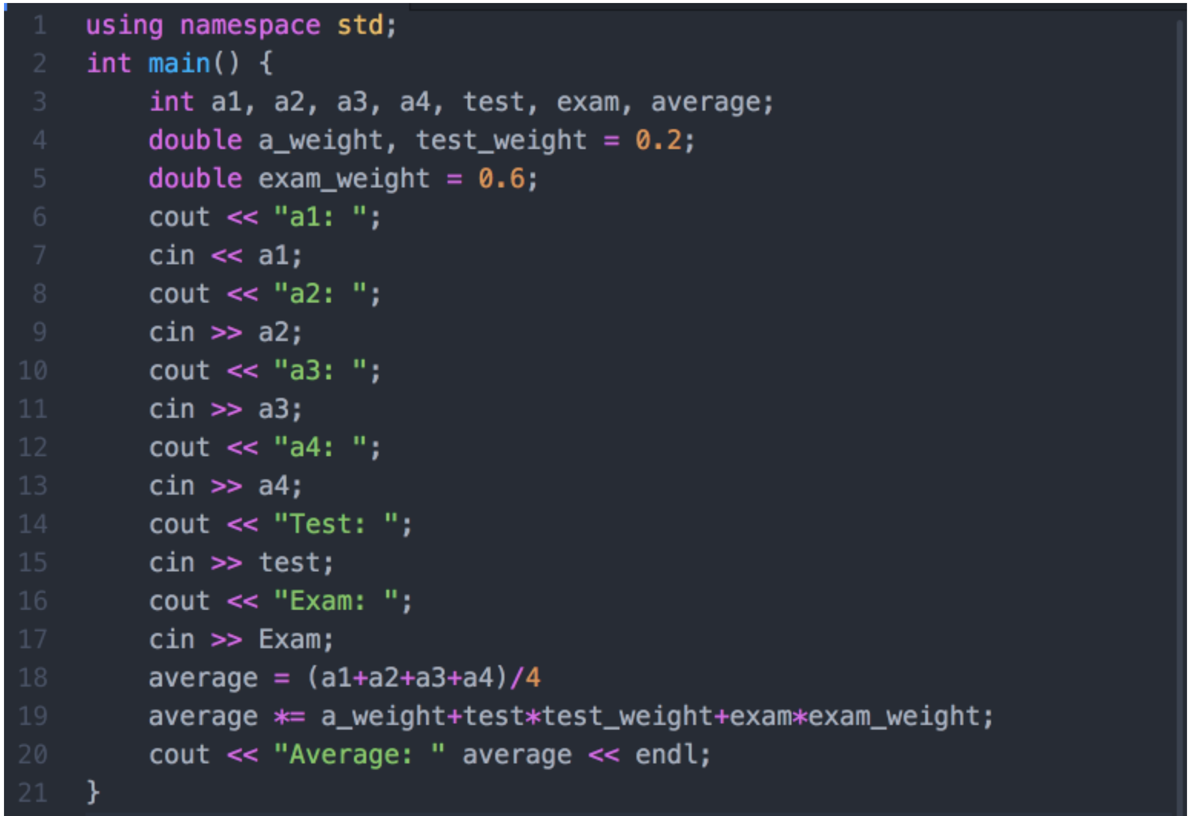
Write a complete C++ program that reads two integers into two int variables a and b, and outputs both the quotient and the remainder when a is divided by b. For example, if a = 10 and b = 3, then the output should be as follows.



```
quotient = 3 and remainder = 1
```

Problem 5

What are the problems in the following program? Can you fix them? (hint: first guess what this program wants to achieve)



```
using namespace std;
int main() {
    int a1, a2, a3, a4, test, exam, average;
    double a_weight, test_weight = 0.2;
    double exam_weight = 0.6;
    cout << "a1: ";
    cin << a1;
    cout << "a2: ";
    cin >> a2;
    cout << "a3: ";
    cin >> a3;
    cout << "a4: ";
    cin >> a4;
    cout << "Test: ";
    cin >> test;
    cout << "Exam: ";
    cin >> Exam;
    average = (a1+a2+a3+a4)/4
    average *= a_weight+test*test_weight+exam*exam_weight;
    cout << "Average: " average << endl;
}
```

Optional.

For those who would like to challenge yourselves.
Even for those of you who are beginners in C++ programming, it’s highly recommended for you to take a look at these problems and try to tackle them as well.

You are welcome to discuss these problems in the Moodle forum.

CHALLENGES

Challenge 1
Modulo operations & overflow

Consider the following line of code:

int product = 654321*123456;

What is the output? Try it in a program. Does it match your expectations?

=====

This unexpected behaviour is called “arithmetic overflow”, which occurs when the size of number is larger than a certain upper-bound. For **int**, this is $2^{32} - 1 \approx 2 * 10^9$.

To resolve this issue, you can try these approaches:

Use a larger data type, eg: “**long long**”, “**double**” etc.

Use modulo operations - Sometimes it is likely that you are just interested in the N least significant figures. For example, to calculate the 9-th least significant figures of the product, you can do:

```
int product = 1LL*654321*123456%1000000000
```

Try to figure out what the prefix “1LL” does.

Challenge 2

You may know that **a = a + b** can be written as **a += b** instead, but what if we use “chain” them together?

Some examples:

i. a += b += c

ii. a *= b *= c

iii. a += b %= c

iv. (a += b) *= c

If the initial values for the variables of **a**, **b** and **c** are **a = 4**, **b = 3**, **c = 2**, then what will be the value of each of the above example expressions after going through each operation? Can you explain the reason behind it?

Challenge 3

Write a program in C++ to find the average of 5 numbers using 2 variables only.

Challenge 4

Write a program in C++ to take in a 3-digit number, and output the reverse of the digits.

For example,

if the input is 136, the output should be 631

if the input is 401, the output should be 104