1 The basics of C++

“Hello world” in C++

- Lets start with a very simple C++ program

```
// my first program in C++
#include <iostream>

int main () {
  std::cout << "Hello World!" << std::endl;
  return 0;
}
```

“Hello world” in C++

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```
// my first program in C++
#include <iostream>

int main () {
  std::cout << "Hello Worl[illegible]< std::endl;
  return 0;
}
```

Anything on line after // in C++ is considered a comment

“Hello world” in C++

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int main () {
  std::cout << "He
  return 0;
}
```

Lines starting with # are directives for the preprocessor

Here we include some standard function and type declarations of objects defined by the ‘iostream’ library

- The preprocessor of a C(++) compiler processes the source code before it is passed to the compiler. It can:
  - Include other source files (using the #include directive)
  - Define and substitute symbolic names (using the #define directive)
  - Conditionally include source code (using the #ifdef, #else, #endif directives)

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int main () {
  std::cout << "Hello World!" << std::endl;
  return 0;
}
```

Beginning of the main() function declaration.

- The main() function is the default function where all C++ programs begin their execution.
  - In this case the main function takes no input arguments and returns an integer value
  - You can also declare the main function to take arguments which will be filled with the command line options given to the program

“Hello world” in C++

- Lets start with a very simple C++ program

```
// my first program
#include <iostream>

int main () {
  std::cout << "Hello World!" << std::endl;
  return 0;
}
```

Use iostream library objects to print string to standard output

- The names **`std::cout`** and **`std::endl`** are declared in the ‘header file’ included through the ‘#include <iostream>’ preprocessor directive.
- The std::endl directive represents the ‘carriage return / line feed’ operation on the terminal

"Hello world" in C++

- Lets start with a very simple C++ program

```
// my first program in C++
#include <iostream>

int main () {
  std::cout << "Hello World!" << std::endl;
  return 0;
}
```

The return statement passes the return value back to the calling function

- The return value of the main() function is passed back to the operating system as the 'process exit code'

Compiling and running 'Hello World'

- Example using Linux, (t)csh and g++ compiler

```
unix> g++ -o hello hello.cc

unix> hello
Hello World!

unix> echo $status
0
```

Convert c++ source code into executable

Run executable 'hello'

Print exit code of last run process (=hello)

Outline of this section

- Jumping in: the 'hello world' application

- Review of the basics
  - **Built-in data types**
  - **Operators on built-in types**
  - **Control flow constructs**
  - **More on block {} structures**
  - Dynamic Memory allocation

```
int main() {
   int a  = 3 ;
   float b = 5 ;

   float c = a * b + 5 ;

   if ( c > 10) {
      return 1 ;
   }

   return 0 ;
}
```

Review of the basics – built-in data types

- C++ has only few built-in data types

type name	type description
`char`	ASCII character, 1 byte
`int`, `signed int`, `unsigned int`, `short int`, `long int`	Integer. Can be signed, unsigned, long or short. Size varies and depends on CPU architecture (2,4,8 bytes)
`float`, `double`	Floating point number, single and double precision
`bool`	Boolean, can be true or false (1 byte)
`enum`	Integer with limited set of named states `enum fruit { apple,pear,citrus }`, or `enum fruit { apple=0,pear=1,citrus}`

- More complex types are available in the 'Standard Library'
  - A standard collection of tools that is available with every compiler
  - But these types are not fundamental as they're implement using standard C++
  - We will get to this soon

Defining data objects – variables

- Defining a data object can be done in several ways

```
int main() {
   int j ;     // definition – initial value undefined
   int k = 0 ; // definition with assignment initialization
   int l(0) ;  // definition with constructor initialization

   int m = k + l ; // initializer can be any valid C++ expression

   int a,b=0,c(b+5); // multiple declaration – a,b,c all integers
}
```

- Data objects declared can also be declared constant

```
int main() {
   const float pi = 3.14159268 ; // constant data object
   pi = 2 ; // ERROR – doesn't compile
}
```

Defining data objects – variables

- Const variables must be initialized

```
int main() {
   const float pi ;       // ERROR – forgot to initialize

   const float e = 2.72; // OK
   const float f =  5*e ;// OK – expression is constant
}
```

- Definition can occur at any place in code

```
int main() {
   float pi = 3.14159268 ;
   cout << “pi = “ << pi << endl ;

   float result = 0; // ‘floating’ declaration OK
   result = doCalculation() ;
}
```

  – Style tip: always declare variables as close as possible to point of first use

Literal constants for built-in types

- Literal constants for integer types

```
int j = 16 ;    // decimal
int j = 0xF ;   // hexadecimal (leading 0x)
int j = 020 ;   // octal (leading 0)

unsigned int k = 4294967280U ; // unsigned literal
```

  - Hex, octal literals good for bit patterns (hex digit = 4 bits, octal digit = 3 bits)
  - Unsigned literals good for numbers that are too large for signed integers (e.g. between 2^32/2 and 2^32-1)

- Literal constants for character types

```
char ch = ‘A’ ; // Use single quotes
```

  - Escape sequences exist for special characters →

`\n`	newline
`\r`	carriage return
`\t`	tabulation
`\v`	vertical tabulation
`\b`	backspace
`\f`	page feed
`\a`	alert (beep)
`\'`	single quotes (')
`\"`	double quotes (")
`\?`	question (?)
`\\`	inverted slash (\)

Auto declaration type **(C++ 2011)**

- In C++ 2011, you can also omit an explicit type in declarations of objects that are immediately initialized
- In these cases the type is deduced from the initializer

```
auto j = 16 ;   // j is integer
auto j = 2.3 ;  // j is double
auto j = true ;  // j is bool
```

Arrays

- C++ supports 1-dimensional and N-dimensional arrays
  - Definition

```
Type name[size] ;
Type name[size1][size2]…[sizeN] ;
```

  - Array dimensions in definition must be constants

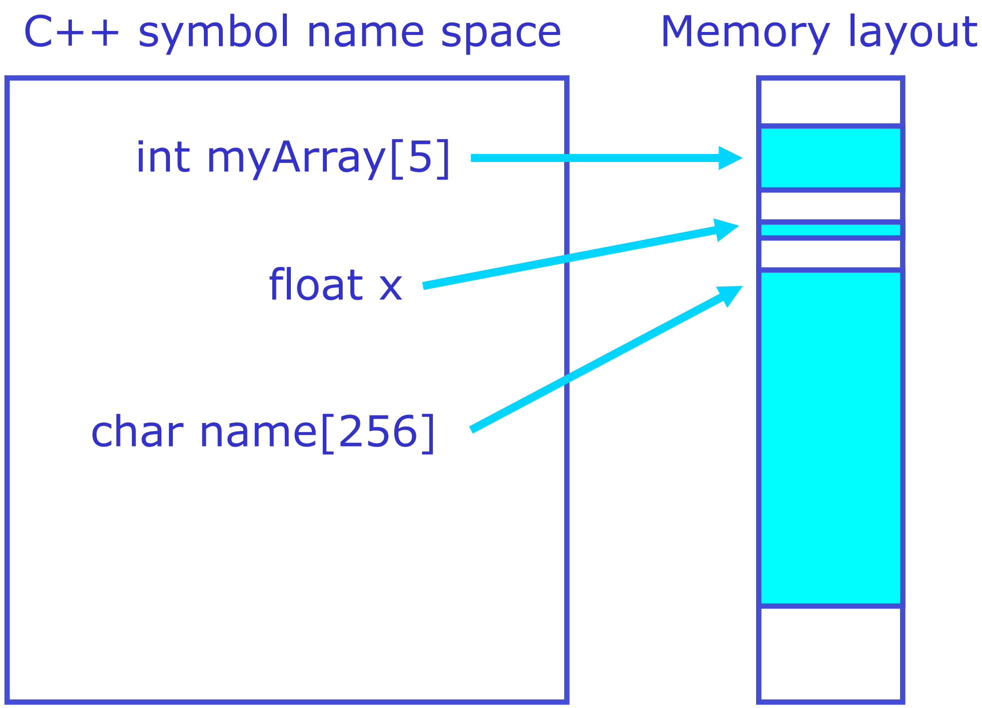
```
float x[3] ;     // OK

const int n=3 ;
float x[n] ;     // OK

int k=5 ;
float x[k] ;     // ERROR!
```

  - *First element's index is always **0***
  - Assignment initialization possible

```
float x[3]      = { 0.0, 5.7 , 2.3 } ;
float y[2][2]   = { 0.0, 1.0, 2.0, 3.0 } ;
float y[3]      = { 1.0 } ; // Incomplete initialization OK
```

Declaration versus definition of data

- Important fine point: definition of a variable is two actions
  1. Allocation of memory for object
  2. Assigning a symbolic name to that memory space



  - C++ symbolic name is a way for programs to give understandable names to segments of memory
  - But it is an artifact: no longer exists once the program is compiled

References

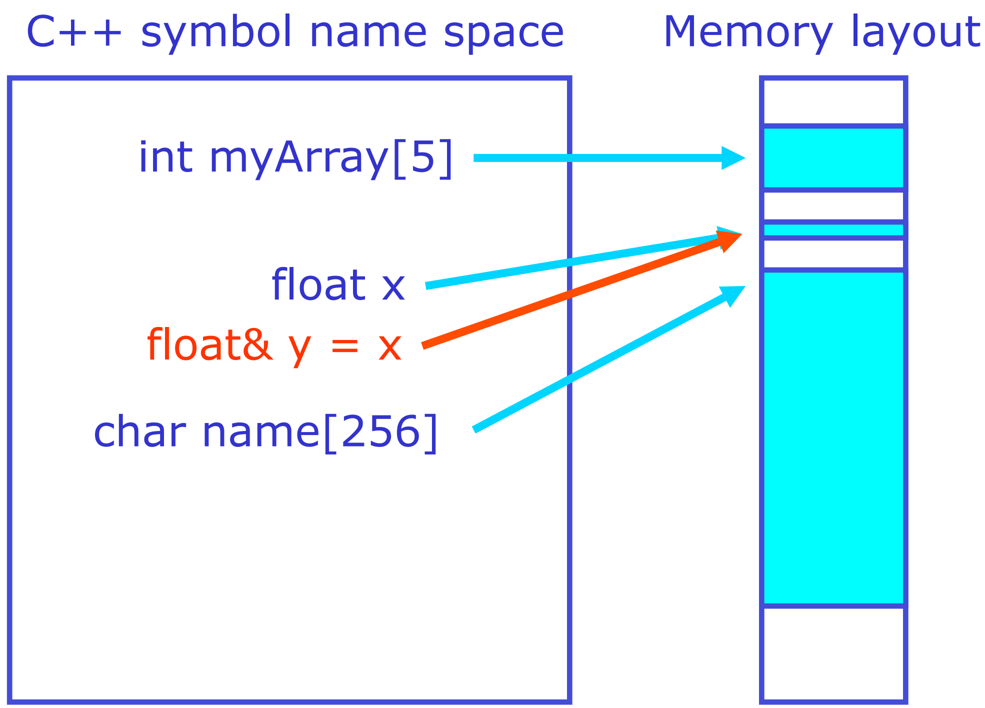
- C++ allows to create 'alias names', a different symbolic name referencing an already allocated data object
  - Syntax: '`Type& name = othername`'
  - References do not necessarily allocate memory
- Example

```
int x ;        // Allocation of memory for int
               // and declaration of name 'x'
int& y = x ;   // Declaration of alias name 'y'
               // for memory referenced by 'x'

x = 3 ;
cout << x << endl ; // prints '3'
cout << y << endl ; // also prints '3'
```

  - Concept of references will become more interesting when we'll talk about functions

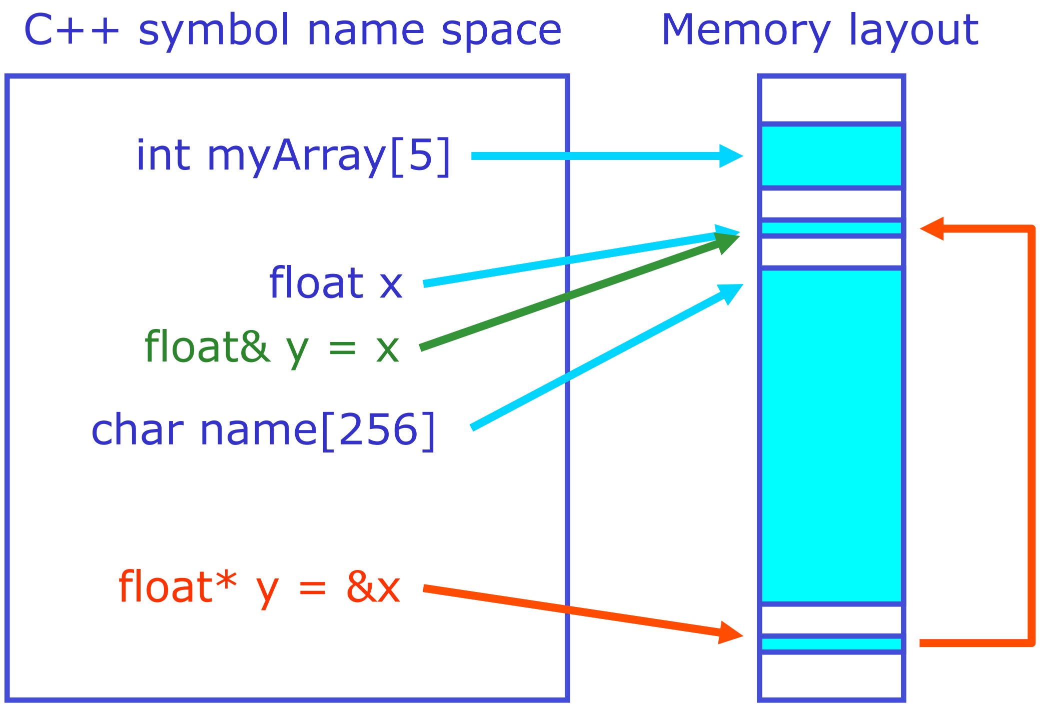
References

- Illustration C++ of reference concept
  - Reference is symbolic name that points to same memory as initializer symbol



Pointers

- Pointer is a variable that contains a memory address
  - Somewhat similar to a reference in functionality, but fundamentally different in nature: a pointer is always an object in memory itself
  - Definition: '**`TYPE* name`**' makes pointer to data of type TYPE



Pointers

- Working with pointers
  - Operator & takes memory address of symbol object (=pointer value)
  - Operator * turns memory address (=pointer value) into symbol object
- Creating and reading through pointers

```
int x = 3, y = 4 ;
int* px ;              // allocate px of type 'pointer to integer'
px = &x ;              // assign 'memory address of x' to pointer px

cout << px << endl ; // Prints 0x3564353, memory address of x
cout << *px << endl ;// Prints 3, value of x, object pointed to by px
```

- Modifying pointers and objects pointed to

```
*px = 5 ;              // Change value of object pointed to by px (=x) ;
cout << x << endl ;   // Prints 5 (since changed through px)
px = &y ;              // Reseat pointer to point to symbol named 'y'

cout << px << endl ; // Prints 0x4863813, memory address of y
cout << *px << endl ;// Prints 4, value of y, object pointed to by px
```

Pointers continued

- Pointers are also fundamentally related to arrays

```
int a[3]  = { 1,2,3} ; // Allocates array of 3 integers
int* pa   = &a[0] ;    // Pointer pa now points to a[0]

cout << *pa << endl ;      // Prints '1'
cout << *(pa+1) << endl ; // Prints '2'
```

- Pointer (pa+1) points to next element of an array
  – This works regardless of the type in the array
  – In fact **`a`** itself is a pointer of type **`int*`** pointing to **`a[0]`**

- The **Basic Rule** for arrays and pointers
  – **`a[i]` is equivalent to `*(a+i)`**

Pointers and arrays of char – strings

- Some special facilities exist for arrays of `char`
  - char[] holds strings and is therefore most commonly used array

- Initialization of character arrays:
  - String literals in double quotes are of type 'char *', i.e.

```
const char* blah = “query”;
```

is equivalent to

```
const char tmp[7] = {‘q’,’w’,’e’,’r’,’t’,’y’,0} ;
const char* blah = tmp ;
```

  - Recap: single quoted for a single char, double quotes for a const pointer to an array of chars

- Termination of character arrays
  - Character arrays are by convention ended with a null char (\0)
  - Can detect end of string without access to original definition
    - For example for strings returned by “a literation expression”

Strings and string manipulation

- Since char[] strings are such a common object
  - the ‘Standard Library’ provides some convenient manipulation functions

- Most popular char[] manipulation functions

```
//  Length of string
int strlen(const char* str) ;

// Append str2 to str1 (make sure yourself str1 is large enough)
char* strcat(char* str1, const char* str2) ;

// Compares strings, returns 0 if strings are identical
int strcmp(const char* str1, const char* str2) ;
```

- Tip: Standard Library also provides ‘class string’ with superior handling
  - We’ll cover class string later
  - But still need ‘const char*’ to interact with operating system function calls (open file, close file, etc)

Reading vs. Writing – LValues and RValues

- C++ has two important concepts to distinguish read-only objects and writeable objects
  - An **LValue** is writable and can appear on the left-hand side of an assignment operation
  - An **RValue** is read-only and may only appear on the right-hand side of assignment operations

- Example

```
int i;
char buf[10] ;

i = 5 ; // OK, i is an lvalue
5 = i ; // ERROR, 5 is not an lvalue
        // (it has no memory location)

buf[0] = ‘c’ ;    // OK buf[0] is an lvalue
buf = “qwerty” ; // ERROR, buf is immutably tied to char[10]
```

Operators and expressions – arithmetic operators

- Arithmetic operators overview

Name	Operator
Unary minus	**-x**
Multiplication	**x * y**
Division	**x / y**

Name	Operator
Modulus	**x % y**
Addition	**x + y**
Subtraction	**x - y**

- Arithmetic operators are evaluated from **left to right**
  - `40 / 4 * 5 = (40 / 4) * 5 = 50` (not 2)

- In case of mixed-type expressions compiler automatically converts integers up to floats

```
int i = 3, j = 5 ;
float x = 1.5 ;

float y = i*x ; // = 4.5 ; int i promoted to float
float z = j/i ; // = 1.0 ; '/' has precedence over '='
```

Operators and expressions – increment/decrement operators

- In/Decrement operators

Name	Operator
Prefix increment	**++x**
Postfix increment	**x++**
Prefix decrement	**--x**
Postfix decrement	**x--**

- Note difference
  - ***Prefix*** operators return value ***after*** operation
  - ***Postfix*** operators return value ***before*** operation
- Examples

```
int x=0 ;
cout << x++ << endl ; // Prints 0
cout << x << endl ;   // Prints 1

cout << ++x << endl ; // Prints 2
cout << x << endl ;   // Prints 2
```

Operators and expressions – relational operators

- Relational operators

Name	Operator
Less than	`x < y`
Less than or equal to	`x <= y`
Greater than or equal to	`x >= y`
Greater than	`x > y`
Equal to	`x == y`
Not equal to	`x != y`

- All relational operators yield `bool` results
- Operators `<`,`<=`,`>=`,`>` have precedence over `==`, `!=`

Operators and expressions – Logical operators

- Logical operators

Name	Operator
Logical NOT	`!x`
Logical AND	`x>3 && x<5`
Logical OR	`x==3 || x==5`

Do not confuse with bit-wise AND (&) and bit-wise OR (|)

- All logical operators take `bool` arguments and return `bool`
  - If input is not `bool` it is *converted* to `bool`
  - Zero of any type maps to `false`, anything else maps to `true`

- Logical operators are evaluated from left to right
  - *Evaluation is **guaranteed to stop** as soon as outcome is determined*

```
float x, y ;
…
if (y!=0. && x/y < 5.2) ; // safe against divide by zero
```

Operators and expressions – Bitwise operators

- Bitwise operators

Name	Operator	Example
Bitwise complement	**~x**	**0011000 → 1100111**
Left shift	**x << 2**	**000001 → 000100**
Right shift	**x >> 3**	**111111 → 000111**
Bitwise AND	**x & y**	**1100 & 0101 = 0100**
Bitwise OR	**x | y**	**1100 | 0101 = 1101**
Bitwise XOR	**x ^ y**	**1100 ^ 0101 = 1001**

- Remarks
  - Bitwise operators cannot be applied to floating point types
  - Mostly used in online, DAQ applications where memory is limited and 'bit packing is common'
  - Do not confuse logical or, and (||,&&) with bitwise or, and (|,&)

Operators and expressions – Assignment operators

- Assignment operators

Name	Operator
Assignment	`x = 5`
Addition update	`x += 5`
Subtraction update	`x -= 5`
Multiplication update	`x *= 5`
Division update	`x /= 5`
Modulus update	`x %= 5`
Left shift update	`x <<= 5`
Right shift update	`x >>= 5`
Bitwise AND update	`x &= 5`
Bitwise OR update	`x |= 5`
Bitwise XOR update	`x ^= 5`

Operators and expressions – Assignment operators

- Important details on assignment operators
  - **Left-hand** arguments must be **lvalues** (naturally)
  - Assignment is evaluated **right to left**
  - Assignment operator **returns left-hand** value of expression

- Return value property of assignment has important consequences
  - **Chain** assignment is possible!

```
x = y = z = 5 ;  // OK! x = ( y = ( z = 5 ))
                 //     x = ( y = 5)
                 //     x = 5
```

  - **Inline** assignment is possible

```
int x[5], i ;
x[i=2] = 3 ; // i is set to 2, x[2] is set to 3
```

Operators and expressions – Miscellaneous

- Inline conditional expression: the ternary `?:` operator
  - Executes inline if-then-else conditional expression

```
int x = 4 ;
cout << ( x==4 ? ”A” : ”B” ) << endl ; // prints “A” ;
```

- The comma operator (`expr1, expr2, expr3`)
  - Evaluates expressions sequentially, returns *rightmost* expression

```
int i=0, j=1, k=2 ;
cout<< (i=5, j=5, k) <<endl ; // Prints ‘2’, but i,j set to 5
```

- The `sizeof` operator
  - Returns size in bytes of operand, argument can be *type* or *symbol*

```
int size1 = sizeof(int) ; // = 4 (on most 32-bit archs)

double x[10] ;
int size2 = sizeof(x) ;   // = 10*sizeof(double)
```

Conversion operators

- Automatic conversion
  - All type conversions that can be done ‘legally’ and without loss of information are done automatically
  - Example: float to double conversion

```
float f = 5 ;
double d = f ; // Automatic conversion occurs here
```

- Non-trivial conversions are also possible, but not automatic
  - Example: `float` to `int`, `signed int` to `unsigned int`
  - If conversion is non-trivial, conversion is not automatic → you must request it with a ***conversion operator***

- C++ has a variety of ways to accomplish conversions
  - C++ term for type conversion is ‘**cast**’
  - Will focus on ‘modern’ methods and ignore ‘heritage’ methods

Conversion operators – Explicit casts

- For conversions that are 'legal' but may result in truncation, loss of precision etc...: **static_cast**

```
float f = 3.1 ;
int i = static_cast<int>(f) ; // OK, i=3 (loss of precision)
int* i = static_cast<int*>(f) ; // ERROR float != pointer
```

- For conversions from 'const X' to 'X', i.e. to override a logical const declaration: **const_cast**

```
float f = 3.1 ;
const float& g = f ;
g = 5.3 ;                        // ERROR not allowed, g is const
float& h = const_cast<float&>(g) ; // OK g and h of same type
h = 5.3 ;                        // OK, h is not const
```

Conversion operators – Explicit casts

- Your last resort: **reinterpret_cast**

```
float* f ;
int* i = reintepret_cast<int*>(f) ; // OK, but you take
                                    // responsibility for the ensuing mess…
```

- You may need more than one cast to do your conversion

```
const float f = 3.1 ;
int i = static_cast<int>(f) ; // ERROR static_cast cannot
                              // convert const into non-const

const float f = 3.1 ;
int i = static_cast<int>( const_cast<float>(f) ) ; // OK
```

  – It may look verbose but it helps you to understand your code as all aspects of the conversion are explicitly spelled out

Control flow constructs – `if/else`

- The `if` construct has three formats
  - Parentheses around expression required
  - Brackets optional if there is only one statement (but put them anyway)

```
if (expr) {
   statements ; // evaluated if expr is true
}
```

```
if (expr) {
  statements ; // evaluated if expr is true
} else {
  statements ; // evaluated if expr is false
}
```

```
if (expr1) {
  statements ;     // evaluated if expr1 is true
} else if (expr2) {
  statements ;     // evaluated if expr2 is true
} else {
  statements ;     // evaluated if neither expr is true
}
```

Intermezzo – coding style

- C++ is free-form so there are no rules
- But style matters for readability, some suggestions
  - One statement per line
  - **Always put {} brackets** even if statement is single line
  - Common indentation styles for {} blocks

```
if (foo==bar) {
    statements ;
} else {
    statements ;
}
```

```
if (foo==bar)
{
    statements ;
}
else
{
    statements ;
}
```

Try to teach yourself this style,
it is more compact and more
readable (especially when you're
more experienced)

Control flow constructs – `while`

- The `while` construct

```
while (expression) {
  statements ;
}
```

  - Statements will be executed if expression is true
  - At end, expression is re-evaluated. If again true, statements are again executed

- The `do/while` construct

```
do {
  statements ;
} while (expression) ;
```

  - Similar to **`while`** construct except that statements are always executed once before expression is evaluated for the first time

Control flow constructs – for

- The for construct

```
for (expression1 ; expression2 ; expression3) {
  statements ;
}
```

  – is equivalent to

```
expression1 ;
while (expression2) {
  statements ;
  expression3 ;
}
```

- Most common looping construct

```
int i ;
for (i=0 ; i<5 ; i++) {
  // Executes with i=0,1,2,3 and 4
}
```

Control flow constructs – for

- Expressions may be empty

```
for (;;) {
  cout << "Forever more" << endl ;
}
```

- Comma operator can be useful to combine multiple operations in expressions

```
int i,j;
for (i=0,j=0 ; i<3 ; i++,j+=2) {
  // execute with i=0,j=0, i=1,j=2, i=2,j=4
}
```

Control flow constructs – break and continue

- Sometimes you need to stop iterating a `do`, `do/while` or `for` loop prematurely
  - Use `break` and `continue` statements to modify control flow

- The `break` statement
  - Terminate loop construct *immediately*

```
int i = 3 ;
while(true) { // no scheduled exit from loop
  i -= 1 ;
  if (i<0) break ; // exit loop
  cout << i << endl ;
}
```

  - Example prints ‘2’, ’1’ and ’0’. Print statement for i=-1 never executed

Control flow constructs – break and continue

- The `continue` statement
  - Continue stops execution of loops statements and *returns to evaluation of conditional expression*

```
char buf[12] = "abc,def,ghi" ;
for (int i=0 ; i<12 ; i++) {
  if (buf[i]==',') continue ; // return to for()
                              // if ',' is encountered
  cout << buf[i] ;
}
cout << endl ;
```

  - Output of example `'abcdefghi'`
  - Do not confuse with FORTRAN 'continue' statement -- Very different meaning!

- Both `break` and `continue` only affect the *innermost* loop
  - When you are using nested loops

Control flow constructs – switch

- The switch construct

```
switch (expr) {
  case constant1:
    statements ; // Evaluated if expr==const1
    break ;

  case constant2:
  case constant3:
    statements ; // Evaluated if expr==const2 or const3
    break ;

  default:
    statements ; // Evaluated expression matched none
    break ;
}
```

  - Most useful for decision tree algorithms

- If break is omitted execution continues with next case evaluation
  - Usually you don’t want this, so watch the breaks

Control flow constructs – switch (example)

- `switch` works very elegantly with `enum` types
  - `enum` naturally has finite set of states

- case expressions must be constant but can be any valid expression
  - Example:

```
enum color { red=1, green=2, blue=4 };
color paint = getcolor() ;
switch (paint) {
  case red:
  case green:
  case blue:
    cout << "primary color" << endl ;
    break ;

  case red+green:
    cout << "yellow" << endl ;
    break ;

  case red+blue:
    cout << "magenta" << endl ;
    break ;

  case blue+green:
    cout << "cyan" << endl ;
    break ;

  default:
    cout << "white" << endl ;
    break ;
}
```

Some details on the block {} statements

- Be sure to understand all consequences of a block {}
  - The lifetime of automatic variables inside the block is limited to the end of the block (i.e up to the point where the } is encountered)

```
int main() {
  int i = 1 ;

  if (x>0) {
    int i = 0 ;
    // code
  } else {
    // code
  }
}
```

Memory for 'int i' allocated

Memory for 'int i' released

  - A block introduces a new scope : it is a separate namespace in which you can define new symbols, even if those names already existed in the enclosing block

Scope – more symbol visibility in {} blocks

- Basic C++ scope rules for variable definitions
  - In given location all variables defined in local scope are visible
  - All variables defined in enclosing scopes are visible
  - Global variables are always visible
  - Example

```
int a ;
int main() {
   int b=0 ;

   if (b==0) {
      int c = 1;
   }

}
```

a, b visible

a, b, c visible

Scoping rules – hiding

- What happens if two variables declared in different scopes have the same name?
  - Definition in inner scope ***hides*** definition in outer scope
  - It is legal to have two variables with the same name defined in different scopes

```
int a ;
int main() {
   int b=0 ;
                          ← 'b' declared in main() visible
   if (b==0) {
LEGAL! → int b = 1;       ← 'b' declared in if() visible
                            'b' declared in main() hidden!
   }

}
```

'b' declared in main() visible

'b' declared in if() visible
'b' declared in main() hidden!

  - NB: It is not legal to have two definitions of the same name in the same scope, e.g.

```
int main() {
  int b ;
  …
  int b ;  ERROR!
}
```

Scoping rules – The :: operator

- Global variables, even if hidden, can always be accessed using ***the scope resolution operator ::***

```
int a=1 ;

int main() {
   int a=0 ;      ← LEGAL, but hides global 'a'

   ::a = 2 ;      ← Changes global 'a'
}
```

- No tools to resolve symbols from intermediate unnamed scope
  - Solution will be to use 'named' scopes: namespaces or classes
  - More on classes later

More on memory use

- By default all objects defined *outside* {} blocks (global objects) are allocated statically
  - Memory allocated before execution of `main()` begins
  - Memory released after `main()` terminates

- By default all defined objects defined *inside* {} blocks are 'automatic' variables
  - Memory allocated when definition occurs
  - Memory released when closing bracket of scope is encountered

```
if (x>0) {
  int i = 0 ;      <-- Memory for 'int i' allocated
  // code
}                  <-- Memory for 'int i' released
```

  - You can override behavior of variables declared in {} blocks to be statically allocated using the `static` keyword

More on memory allocation

- Example of static declaration

```
void func(int i_new) {
   static int i = 0 ;
   cout << "old value = " << i << endl ;
   i = i_new ;
   cout << "new value = " << i << endl ;
}

int main() {
  func(1) ;
  func(2) ;
}
```

  - Output of example

```
old value = 0 ;
new value = 1 ;
old value = 1 ;
new value = 2 ;
```

Value of `static int i` preserved between `func()` calls

Dynamic memory allocation

- Allocating memory at run-time
  - When you design programs you cannot always determine how much memory you need
  - You can allocate objects of unknown size at compile time using the 'free store' of the C++ run time environment

- Basic syntax of runtime memory allocation
  - Operator new allocates single object, returns pointer
  - Operator new[] allocates array of objects, returns pointer

```
// Single object
Type* ptr = new Type ;
Type* ptr = new Type(initValue) ;

// Arrays of objects
Type* ptr = new Type[size] ;
Type* ptr = new Type[size1][size2]…[sizeN] ;
```

Releasing dynamic memory allocation

- Operator delete releases dynamic memory previously allocated with new

```
// Single object
delete ptr ;

// Arrays of objects
delete[] ptr ;
```

  - **Be sure to use delete[] for allocated arrays**. A mismatch will result in an incomplete memory release
  - **The delete operator only deletes memory that the pointer points to, not pointer itself**
  - **Every call to new must be matched with a call to a delete**

- How much memory is available in the free store?
  - As much as the operating system lets you have
  - If you ask for more than is available your program will terminate in the new operator
  - It is possible to intercept this condition and continue the program using ‘exception handling’ (we’ll discuss this later)

Dynamic memory and leaks

- A common problem in programs are memory leaks
  - Memory is allocated but never released even when it is not used anymore
  - Example of leaking code

```
void leakFunc() {
  int* array = new int[1000] ;
  // do stuff with array
}

int main() {
  int i ;
  for (i=0 ; i<1000 ; i++) {
    leakFunc() ; // we leak 4K at every call
  }
}
```

Leak happens right here

we loose the pointer `array` *here and with that our only possibility to release its memory in future*

Dynamic memory and leaks

- Another scenario to leak memory
  - Misunderstanding between two functions

```
int* allocFunc() {
  int* array = new int[1000] ;
  // do stuff with array
  return array ;
}

int main() {
   int i ;
   for (i=0 ; i<1000 ; i++) {
     allocFunc() ;
   }
}
```

allocFunc() allocates memory but pointer as return value memory is not leaked yet

Author of main() doesn't know that it is supposed to delete array returned by allocFunc()

Leak occurs here, pointer to dynamically allocated memory is lost before memory is released

Dynamic memory and ownership

- Avoiding leaks is a matter of good bookkeeping
  - All memory allocated should be released after use

- Memory handling logistics usually described in terms of **ownership**
  - The 'owner' of dynamically allocated memory is responsible for releasing the memory again
  - **Ownership is a 'moral concept'**, not a C++ syntax rule. Code that never releases memory it allocated is legal, but may not work well as program size will increase in an uncontrolled way over time
  - Document your memory management code in terms of ownership

Dynamic memory allocation

- Example of dynamic memory allocation with ownership semantics
  - Less confusion about division of responsabilities

```
int* makearray(int size) {
   // NOTE: caller takes ownership of memory
   int* array = new int[size] ;

   int i ;
   for (i=0 ; i<size ; i++) {
     array[i] = 0 ;
   }
   return array;
}

int main() {
  // Note: We own array
  int* array = makearray(1000) ;

  delete[] array ;
}
```