High Energy Physics

Traineeships in Advanced Computing for High Energy Physics (TAC-HEP)

GPU & FPGA module training

Week 2 : Introduction to C++

Lecture 3 - January 31st 2023

WELCOME BACK
TO THAT MAGICAL PLACE CALLED
TAC-HEP GPU training module
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What we learnt in the previous lecture

- Hardware accelerators can be used in combination with CPUs to executing specific tasks more efficiently
- GPUs are hardware accelerators that follow the SIMT paradigm
    - Have thousands of cores and therefore can provide massive parallelization
    - Can provide more FLOPS/watt that CPUs
- The next decades will pose a significant computing challenge for HEP experiments
    - Many HEP experiments are already exploring the use of accelerators and heterogeneous computing

Today : Some brushing up of C++

- History of C++
- Core syntax
- Variables & Operators
- Control instructions
- Functions

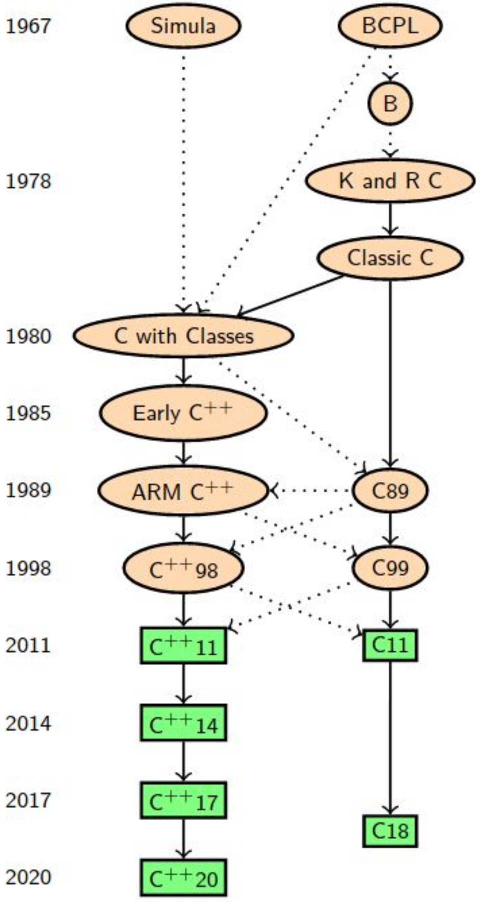


Image taken from [3]

History of C++

C inventor

C++ inventor

- Multi-paradigm programming language that supports object-oriented programming
- Based on C language developed by Dennis Ritchie
- Designed at Bell labs in the late 70s by Bjarne Stroustrup

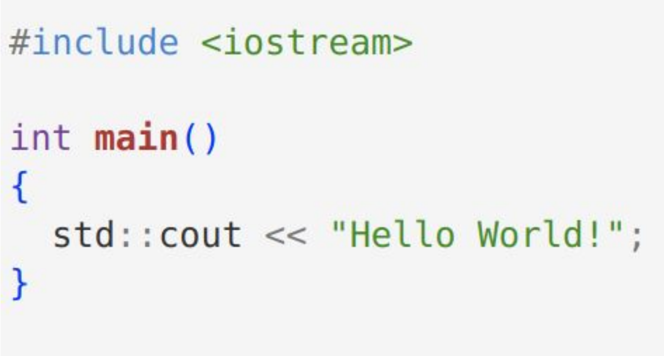
Why is C++ so widely used

- **Fast**
  - C++ is a compiled language unlike other languages e.g. python / Java which are interpreted
- **Object oriented**
  - Modular and reusable code
- **Low level**
  - Closer to hardware / allows low level optimization
- **Many available libraries**
  - Standard Template Library (STL) provides template that can be used from the developer and make coding faster

Core syntax

Structure of a C++ program

Let's look into the main structure and components of a C++ program by checking out a simple program that print out “Hello world” :



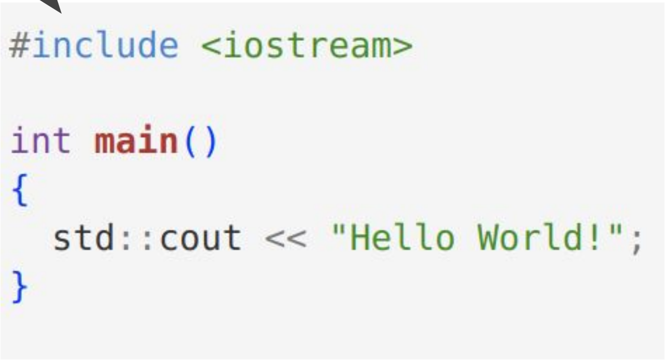
```
#include <iostream>

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

Structure of a C++ program

#include <iostream>

- Special lines interpreted before compilation
- Instruct the preprocessor to include a section of standard C++ code
- e.g *iostream* allows standard I/O operations



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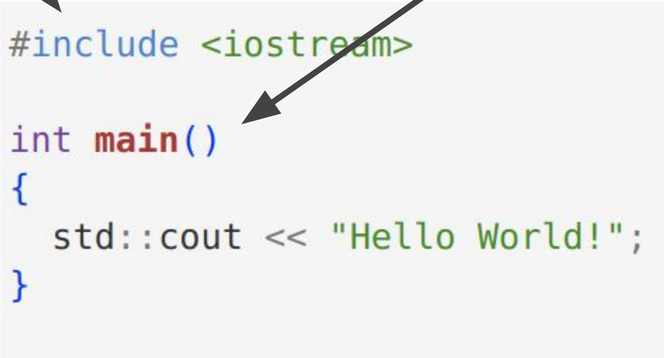

```
#include <iostream>

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

int main()

- Special C++ function
- All C++ programs start execution from main

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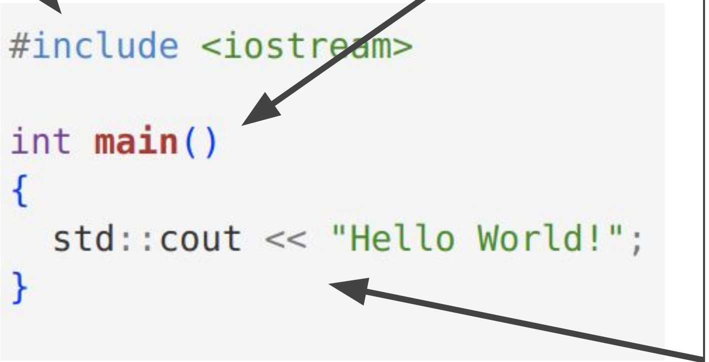

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int main()
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int main()

- Special C++ function
- All C++ programs start execution from main

std::cout << "Hello World";

- C++ statement :
  - std::cout **st**andar**d** **c**haracter **out**put
  - **"Hello World"** string of characters that will be outputted
  - **<<** insertion operator
  - **;** every statement should end with a semi-colon

Structure of a C++ program

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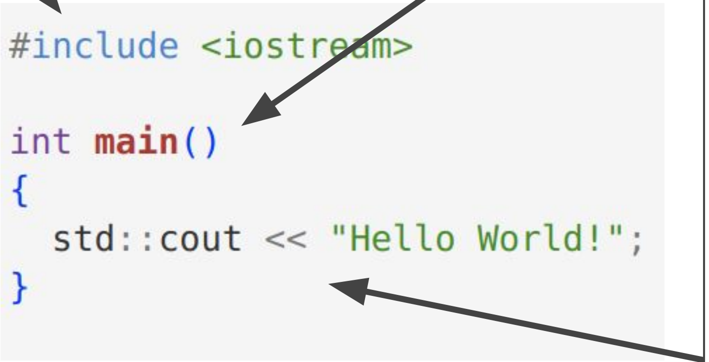

```
#include <iostream>

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

{.........}

Curly braces enclose the body of a function

std::cout << "Hello World";

- C++ statement :
  - std::cout **st**andar**d** **c**haracter **out**put
  - **"Hello World"** string of characters that will be outputted
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Comments in C++

Line comment

```
// This is a line comment
```

Block comment

```
/* This is a block comment
It can span on more than 1 lines
*/
```

Useful and important tool since it makes code more readable and easier to share

doxygen compatible comments : tool for generating documentation from annotated C++ sources [documentation]

```
/**
* doxygen compatible comments
* \fn bool isOdd(int i)
* \brief checks whether i is odd
* \param i input
* \return true if i is odd, otherwise false
*/
```

Variables and operators

Variables

- **Variable** → portion of memory used to store a value.
- Name of variable →**Identifier**
  - Combination of letters, digits, or underscore characters
  - C++ keywords cannot be used

Size	Number
8-bit	2^{8}
16-bit	2^{16}
32-bit	2^{32}
64-bit	2^{64}

Variable types	Names	Example

Character	char
	char16_t
	char32_t
		`char c = 'a'`
		`16-bit wide`
		`32-bit wide`

Integer	int
	(un)signed char
	(un)signed int
	short/long (int)
		`int i = 2023`
		`8-bit wide`
		`32-bit wide`
		`16-bit wide`

Floating-point	float
	double
		`float f = 2.023f`
		`32-bit wide`
		`double d = 2.023`
		`64-bit wide`

Boolean	bool	`bool a = true`
		`bool b = false`

Operators

Operators can operate on variables

There are many types some of which are summarized in the table

Types	Operators	Usage
Assignment operator	=	Assign value to variable
Arithmetic operators	+, -, *, /, %	Mathematical operations
Compound assignment	+=, -=, *=, /=, %=, >>=, <<=, &=, ^=, |=	modify the current value by performing an operation
Increment and decrement	++,--	equivalent to +=1 & -=1
Relational and comparison	==, !=, >, <, >=, <=	Comparisons of two expressions
Logical	!, &&, ||	not / and / or
Conditional ternary operator	?	Returns different value if expression is true or false Syntax : condition ? result1 : result2
Bitwise operators	&, |, ^, ~, <<, >>	modify variables considering the bit patterns

Operators

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

int main ()
{
     int a,b,c;
     bool d;

     // Assignment & arithmetic
     a=2;
     b=7+3;
     // Assignment, logical & comparison
     d = !(7 == 5);
     // Conditional & relational
     c = (a>b) ? a : b;
     // Compound assignment & increment
     a+=2;
     b = ++a;
     // What is the value of each variable?
     cout <<" a : " << a << '\n';
     cout <<" b : " << b << '\n';
     cout <<" c : " << c << '\n';
     cout <<" d : " << d << '\n';
}
```

What are the values of variables a,b,c & d?

Let's check using onlinegdb

Operators

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

int main ()
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      int a,b,c;
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      a+=2;
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      cout <<" a : " << a << '\n';
      cout <<" b : " << b << '\n';
      cout <<" c : " << c << '\n';
      cout <<" d : " << d << '\n';
}
```
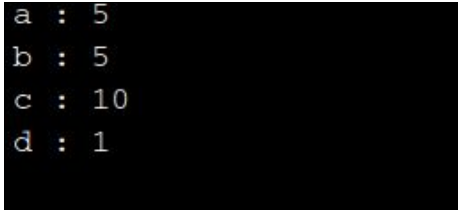



```
a : 5
b : 5
c : 10
d : 1
```

Control flow

Flow control instructions

Statement :

- Individual instructions of the program
- End with a semicolon (;)
- Executed in the order in which they appear in the program

Control instructions :

- Redirect the flow of a program
- Many types - some include :
  - if/else
  - Conditional operator (**?**)
  - switch
  - for loop / range based loops / while loops

if...else

```
if (x > 0)
 cout << "x is positive";
else if (x < 0)
 cout << "x is negative";
else
 cout << "x is 0";
```

- **Syntax :** if (*condition*) statement
  - *condition* is evaluated
  - If *condition* true, statement is executed
- `else` and `else if` are optional
- `else if` can be repeated
- braces are optional if there is a single instruction

switch

```
switch (oper) {
 case '+':
   cout << a + b;
   break;
 case '-':
   cout << a - b;
   break;
 case '*':
   cout << a * b;
   break;
 case '/':
   cout << a / b;
   break;
 default:
   cout << "Incorrect operator";
   break;
}
```

Let's add this to our code on onlinegdb

- **Syntax :**

  switch(*identifier*) {
   case c1 : *instructions1*; break;
   case c2 : *instructions2*; break;
   …
   default : *instructionsd*; break;
  }
- switch evaluates expression / checks if it is equivalent to case c1
- If true, *instructions1* are executed
- After break the program jumps to the end of switch
- Execution carries on with the next case if no break is present
- Default is optional

for loop

```
 for (int n=10; n>0; n--) {
  cout << n << ", ";
 }
```

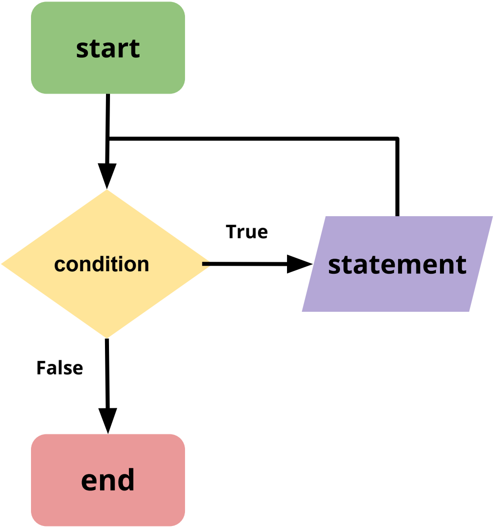
```
for ( n=0, i=100 ; n!=i ; ++n, --i ){
 cout << "n="<< n << " and i=" << i << "\n";
}
```

```
for(int i = 0, j = 0 ; i < 10 ; i++, j = 2*i)
  cout << "2*" << i << " is " << j << "\n";
```

Syntax :

for(initializations; condition; increments) {statement}

- Initializations and increments are separated by a comma
- Initializations can contain declarations



Range based loop

```
string str {"Hello World!"};
for (char c : str)
{
 cout << "[" << c << "]";
}
```

Syntax :

for (type iterator : container) statement;

- iterates over all the elements in the container
- simplifies loops tremendously especially with STL container

Range based loop

```
string str {"Hello World!"};
for (char c : str)
{
 cout << "[" << c << "]";
}
```

Syntax :

for (type iterator : container) statement;

- iterates over all the elements in the container
- simplifies loops tremendously especially with STL container

Exercise : Lets try this out!

- Open a new window in **onlinegdb**
- Create an array with 5 elements - your favorite integer numbers
- Calculate their sum using a range based loop and print out the result!

While loop

```
int n = 10;
while (n>0) {
  cout << n << ", ";
  --n;
}
```

```
int n = 10;
do {
 cout << n << ", ";
 --n;
} while (n>0);
```

Syntax :

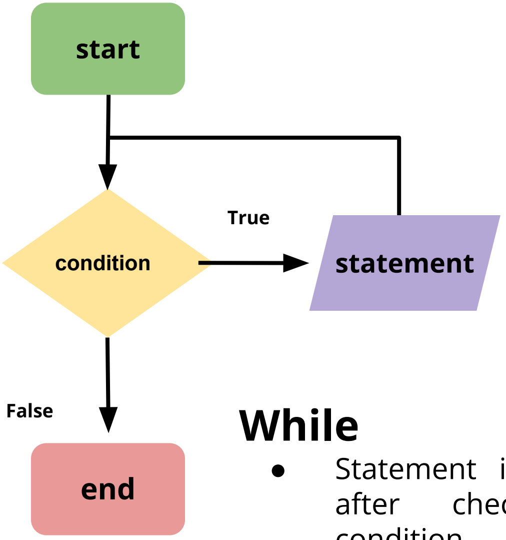
while (*condition*) statement

- Condition evaluated **before** first iteration

do statement while (*condition*);

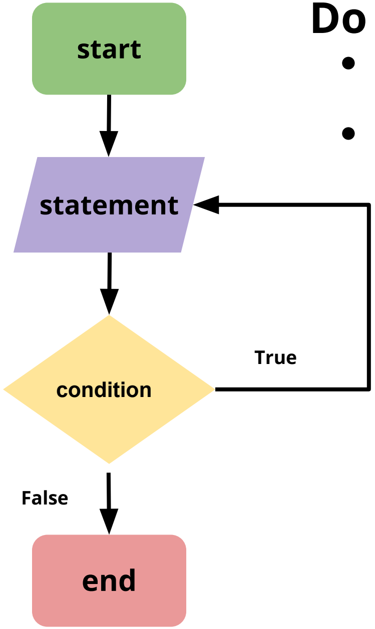
- Condition evaluated **after** first iteration

While loop



While

- Statement is executed after checking the condition
- Similar to for loop flowchart



Do — While

- Statement is always executed once
- Condition is checked after the statement is executed

Functions

What is a function

- Group of statements that is given a name and can be called from some point of the program
- Allow to structure programs in segments of code
- Make code reusable

Syntax :

```
type name ( parameter1, parameter2, ...) { statements }
```

- **type** : type of the value returned by the function.
- **name** : function identifier
- **parameters** : type followed by an identifier, (e.g. int parameter1) arguments are passed to the function from the location where the function is called from.
- **statements** : block of statements surrounded by curly braces

Some examples of functions

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

int addition (int a, int b)
{
 int r;
 r=a+b;
 return r;
}

void print (int a)
{
 cout<<"The number is " <<a<<endl;
}

int main ()
{
 int z;
 z = addition (5,3);
 print(z);
}
```

Function that takes two arguments and returns an integer

Function that takes one arguments and returns nothing (void)

main function → program always starts from main

Function parameters

Function parameters can be passed :

- **By value**
- **By reference**

```
int addition (int a, int b)
{
 int r;
 r=a+b;
 return r;
}
```

```
int addition (int &a, int &b)
{
 int r;
 r=a+b;
 return r;
}
```

Function parameters

- **Passed by value :**
    - Parameters are copied into the variables represented by the function parameters
    - Modifications of these variables within the function has no effect on the values of the variables outside the function
    - By default arguments are passed by value (= copy, good for small types, e.g. numbers)

```
int addition (int a, int b)
{
 int r;
 r=a+b;
 return r;
}
```

Function parameters

- **Passed by reference :**
  - also called pass by address
  - The parameters a and b are still local to the function, but they are *reference* variables (i.e. nicknames to the original variables passed
  - Allows the function to modify a variable without having to create a copy of it
  - references are preferred to avoid copies
  - **const** can be used for safety e.g.
    - `int addition (const int &a)`
    - Ensures that variable cannot be changed

```
int addition (int &a, int &b)
{
 int r;
 r=a+b;
 return r;
}
```

Function parameters

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Exercise : Lets try this out!

- Write a function that takes two integer arguments and returns nothing
- Change the value of each variable to its square
- Print the values of the argument in the main function
- Try passing the variables by value and by reference - what do you observe?
- Try making a variable const. What do you observe?

Wrapping-up

Overview of today's lecture

- Learnt about the history of C++ and why it is widely used
- Brushed up C++ core syntax
- Went through the different variables types & operators
- Were reminded of C++ flow control instructions & functions

Tomorrow

- We will continue with :
  - Scopes / namespaces
  - Compound data types
  - Object Orientation
  - The C++ compilation chain

Back-up

Resources

1. cplusplus docs link
2. cppreference docs link
3. CERN C++ course link