

بِسْمِ اللّٰهِ الرَّحْمٰنِ الرَّحِيْمِ



## مقام معظم رهبری:

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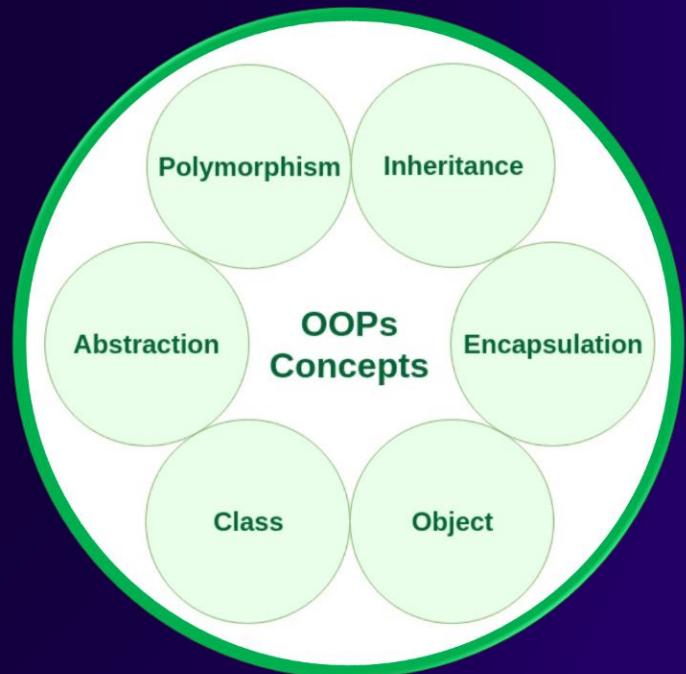


# Qt Training in C++

Lecturer: Ali Panahi

## Object Oriented

- Object-oriented programming aims to implement real-world entities like inheritance, hiding, polymorphism, etc. in programming. The main aim of OOP is to bind together the data and the functions that operate on them so that no other part of the code can access this data except that function.
- Basic concepts:
  - Class
  - Objects
  - Encapsulation
  - Abstraction
  - Polymorphism
  - Inheritance
  - Dynamic Binding
  - Message Passing



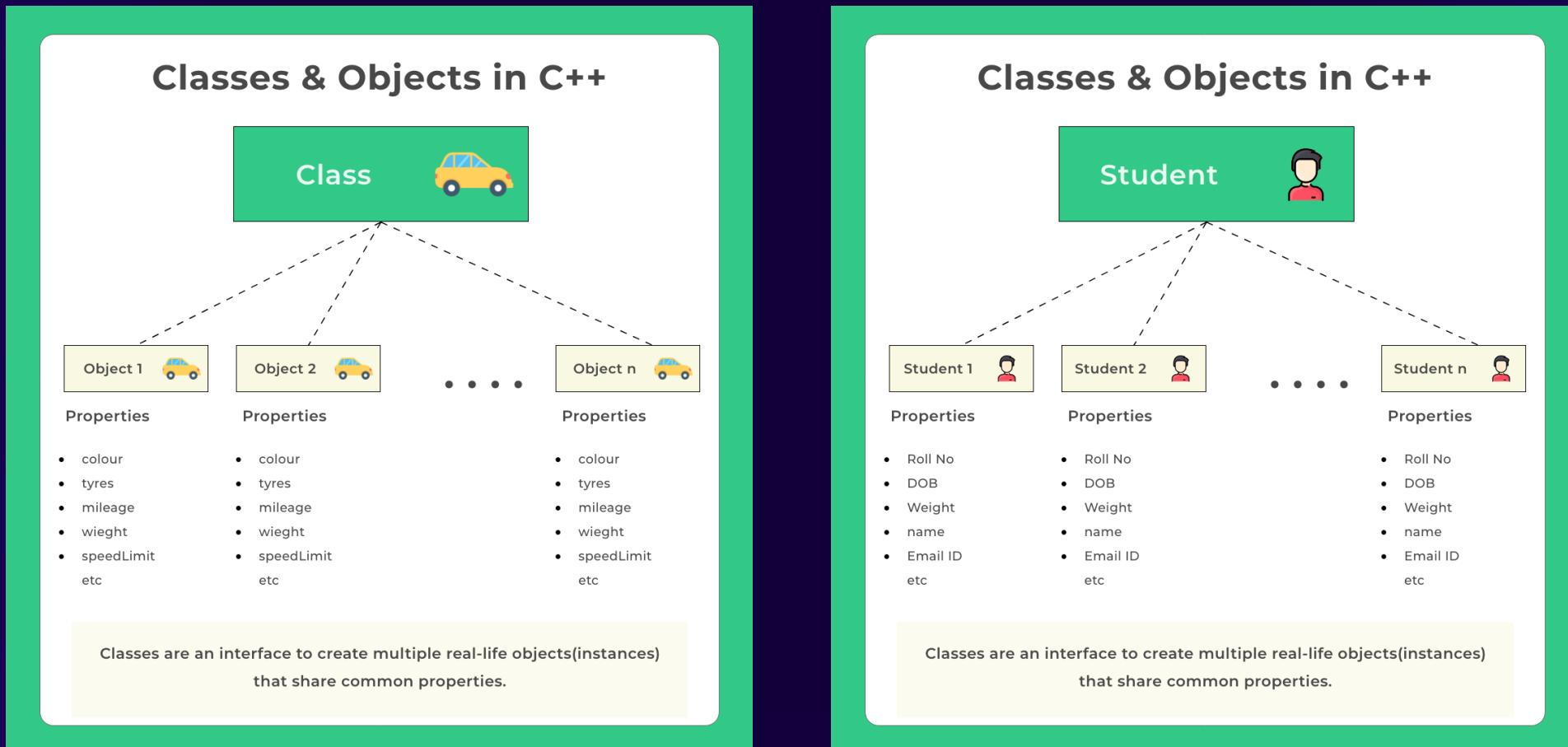
## Class

- A Class is a user-defined data type that has data members and member functions.
- Data members are the data variables and member functions are the functions used to manipulate these variables together these data members and member functions define the properties and behavior of the objects in a Class.
  - For Example: Consider the Class of Cars. There may be many cars with different names and brands but all of them will share some common properties like all of them will have 4 wheels, Speed Limit, Mileage range, etc. So here, the Car is the class, and wheels, speed limits, and mileage are their properties.

## Object

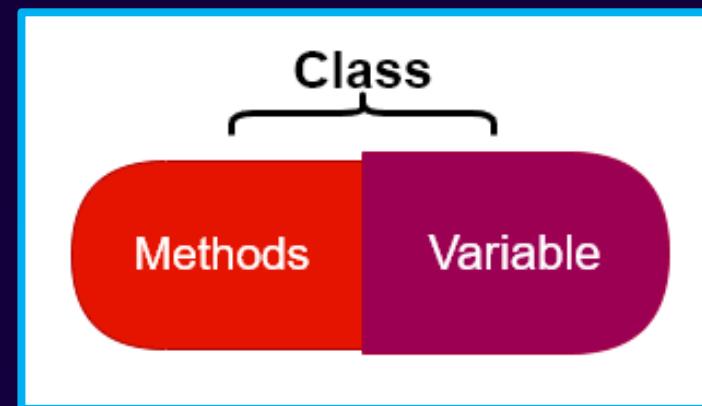
- An Object is an identifiable entity with some characteristics and behavior. An Object is an instance of a Class. When a class is defined, no memory is allocated but when it is instantiated (i.e. an object is created) memory is allocated.
- When a program is executed the objects interact by sending messages to one another. Each object contains data and code to manipulate the data. Objects can interact without having to know details of each other's data or code, it is sufficient to know the type of message accepted and the type of response returned by the objects.

## Class vs Object



## Encapsulation

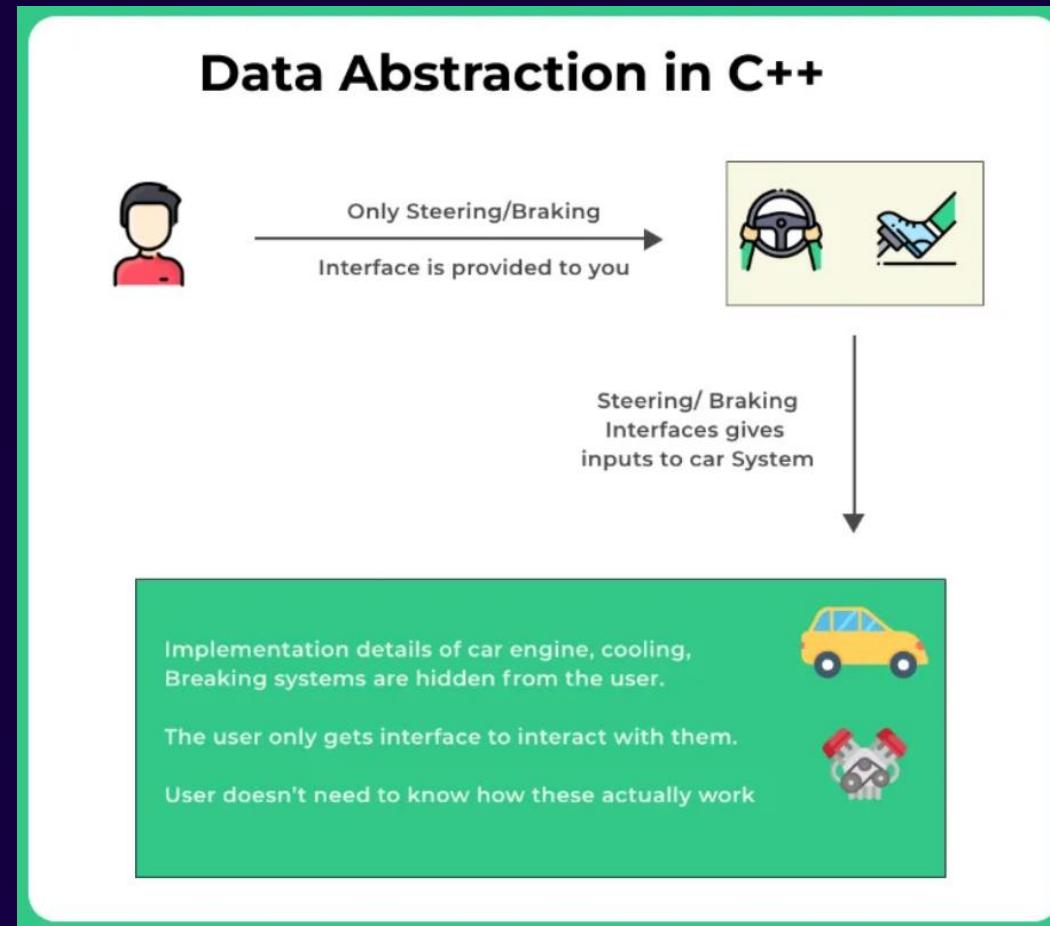
- Encapsulation is an Object Oriented Programming concept that binds together the data and functions that manipulate the data, and that keeps both safe from outside interference and misuse. Data encapsulation led to the important OOP concept of data hiding.
- Data encapsulation is a mechanism of bundling the data, and the functions that use them and data abstraction is a mechanism of exposing only the interfaces and hiding the implementation details from the user.



## Abstraction

- Data abstraction is one of the most essential and important features of object-oriented programming in C++. Abstraction means displaying only essential information and hiding the details. Data abstraction refers to providing only essential information about the data to the outside world, hiding the background details or implementation.
  - **Abstraction using Classes:** We can implement Abstraction in C++ using classes. The class helps us to group data members and member functions using available access specifiers. A Class can decide which data member will be visible to the outside world and which is not.
  - **Abstraction in Header files:** One more type of abstraction in C++ can be header files. For example, consider the `pow()` method present in `math.h` header file. Whenever we need to calculate the power of a number, we simply call the function `pow()` present in the `math.h` header file and pass the numbers as arguments without knowing the underlying algorithm according to which the function is actually calculating the power of numbers.

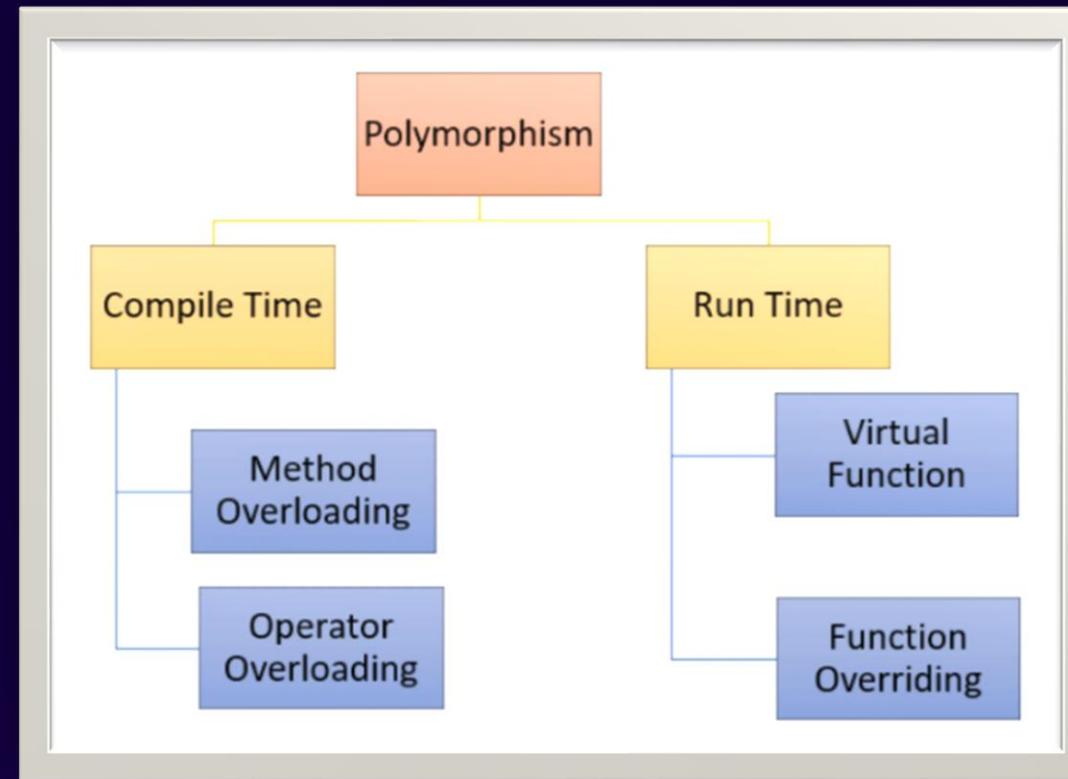
## Abstraction



## Polymorphism

- Polymorphism in C++ means, the same entity (function or object) behaves differently in different scenarios.
  1. **Compile Time Polymorphism**
    - Function Overloading
    - Operator Overloading
  2. **Runtime Polymorphism**
    - Function overriding
    - Virtual Function

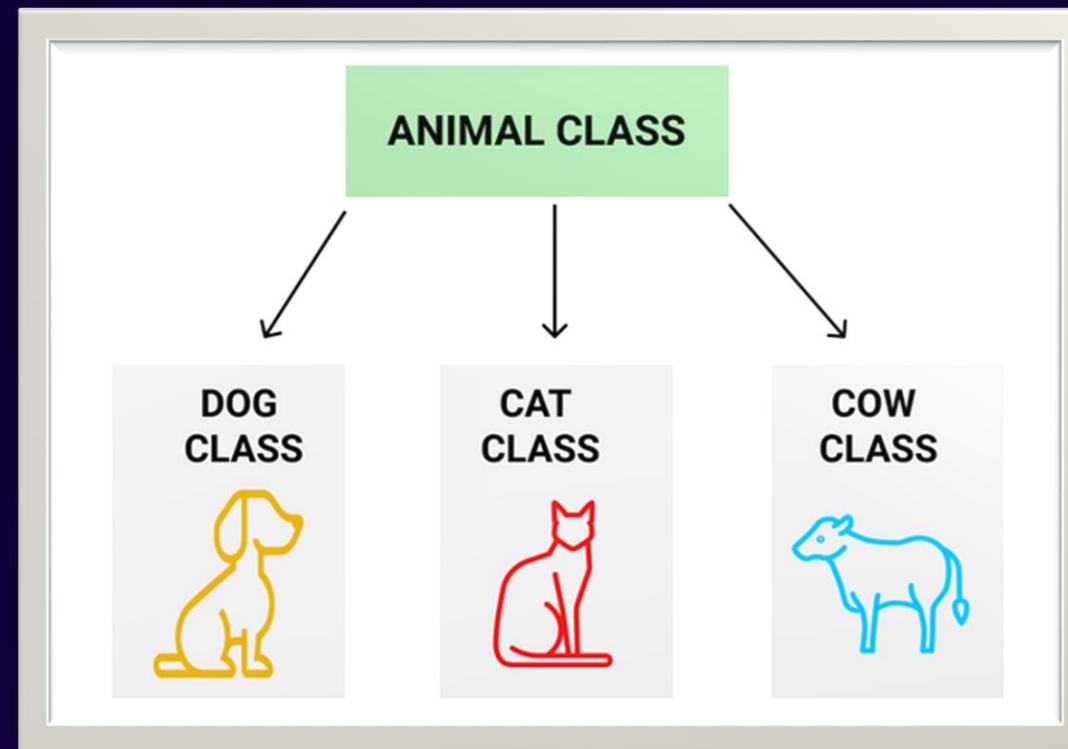
## Polymorphism



## Inheritance

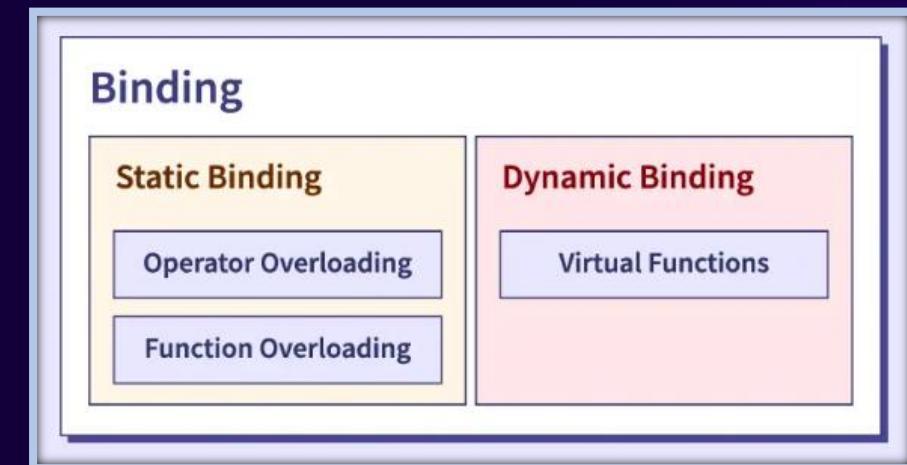
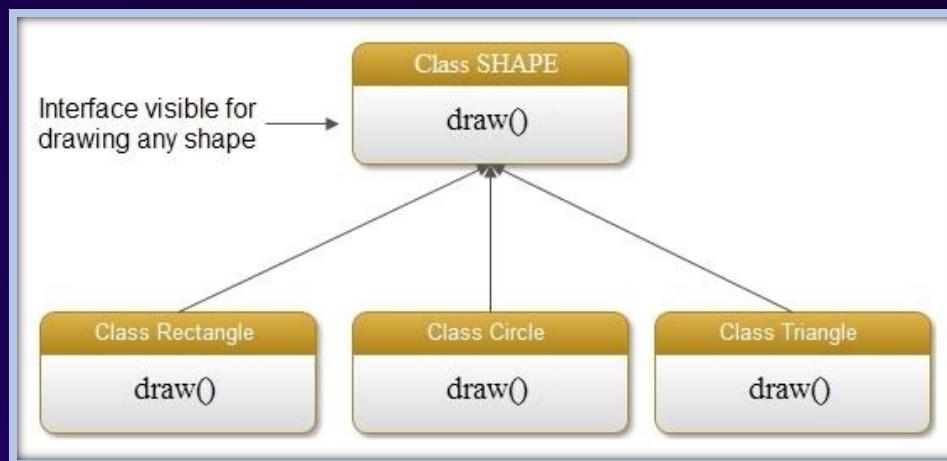
- The capability of a class to derive properties and characteristics from another class is called Inheritance. Inheritance is one of the most important features of Object-Oriented Programming.
  - **Sub Class:** The class that inherits properties from another class is called Sub class or Derived Class.
  - **Super Class:** The class whose properties are inherited by a sub-class is called Base Class or Superclass.
  - **Reusability:** Inheritance supports the concept of “reusability”, i.e. when we want to create a new class and there is already a class that includes some of the code that we want, we can derive our new class from the existing class. By doing this, we are reusing the fields and methods of the existing class.

## Inheritance



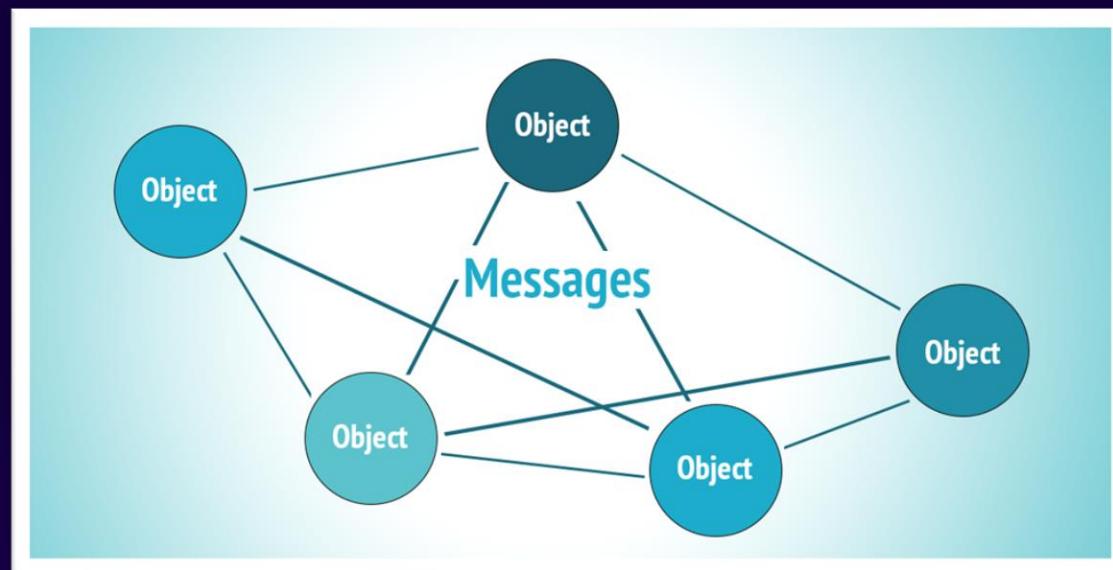
## Dynamic Binding

- In dynamic binding, the code to be executed in response to the function call is decided at runtime. C++ has virtual functions to support this. Because dynamic binding is flexible, it avoids the drawbacks of static binding, which connected the function call and definition at build time.



## Message Passing

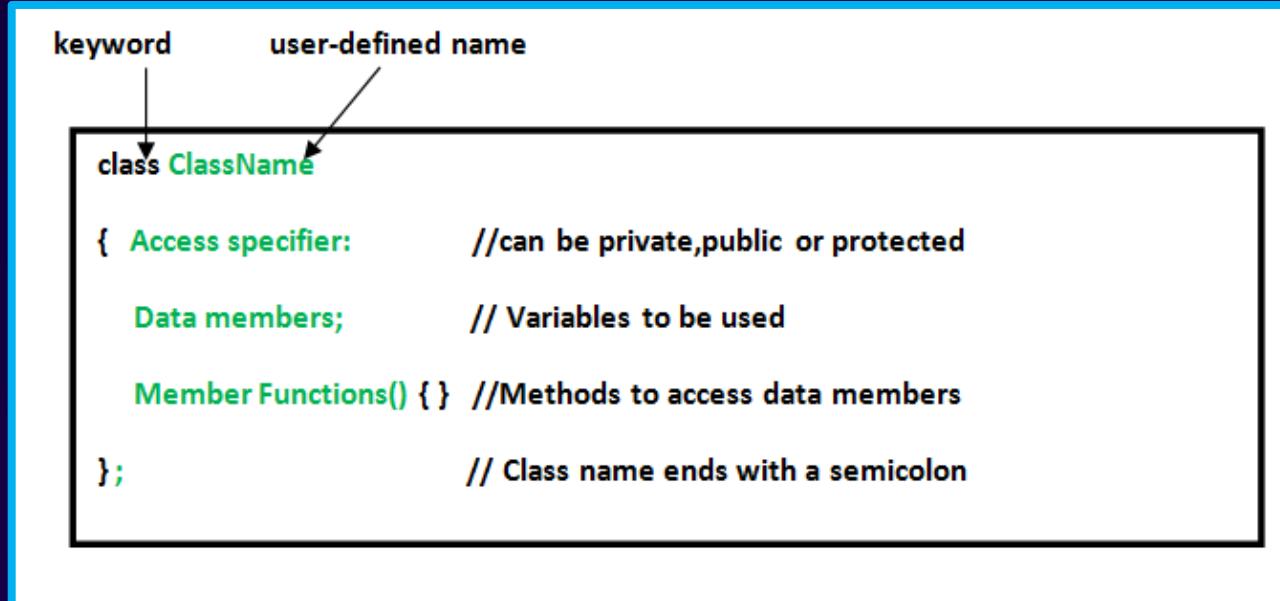
- Objects communicate with one another by sending and receiving information. A message for an object is a request for the execution of a procedure and therefore will invoke a function in the receiving object that generates the desired results. Message passing involves specifying the name of the object, the name of the function, and the information to be sent.



## Classes and Objects

- Defining Class and Declaring Objects

- A class is defined in C++ using the keyword `class` followed by the name of the class. The body of the class is defined inside the curly brackets and terminated by a semicolon at the end. Default modifier is private.



## Classes and Objects

- Declaring Objects
  - When a class is defined, only the specification for the object is defined; no memory or storage is allocated. To use the data and access functions defined in the class, you need to create objects.

```
ClassName ObjectName;
```

- Accessing data members and member functions
  - The data members and member functions of the class can be accessed using the dot('.') operator with the object. For example, if the name of the object is obj and you want to access the member function with the name printName() then you will have to write obj.printName().
  - The public data members are also accessed in the same way given however the private data members are not allowed to be accessed directly by the object. Accessing a data member depends solely on the access control of that data member. This access control is given by Access modifiers in C++. There are three access modifiers: public, private, and protected.

## Classes and Objects

- Member Functions in Classes
  - There are 2 ways to define a member function:
    - ✓ Inside class definition
    - ✓ Outside class definition
  - To define a member function outside the class definition we have to use the scope resolution:: operator along with the class name and function name.
- Constructors
  - Constructors are special class members which are called by the compiler every time an object of that class is instantiated. Constructors have the same name as the class and may be defined inside or outside the class definition. There are 3 types of constructors:
    - ✓ Default Constructors
    - ✓ Parameterized Constructors
    - ✓ Copy Constructors

Note: A Copy Constructor creates a new object, which is an exact copy of the existing object. The compiler provides a default Copy Constructor to all the classes.

```
class-name (class-name &) { }
```

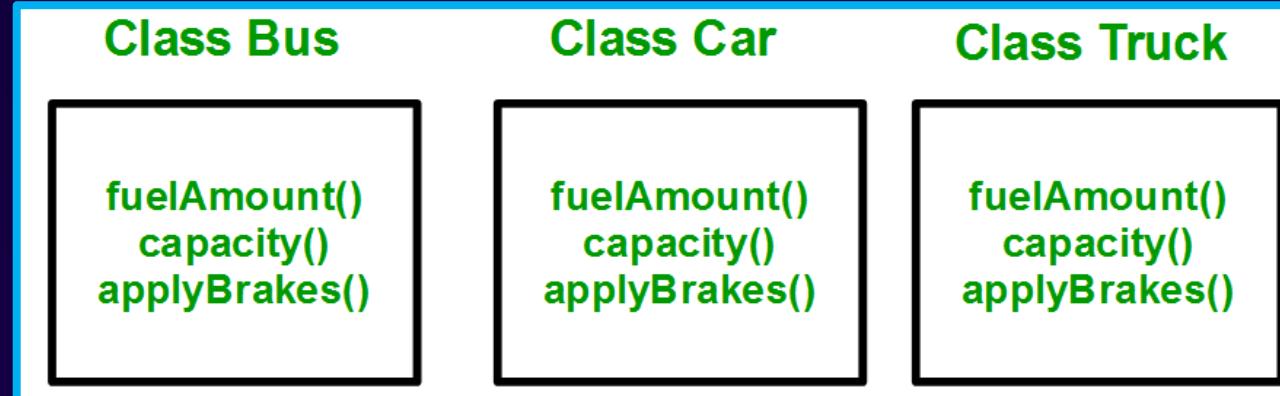
## Classes and Objects

- **Destructors**
  - Destructor is another special member function that is called by the compiler when the scope of the object ends.
- **Interesting Fact (Rare Known Concept)**
  - Many people might say that it's a basic syntax and we should give a semicolon at the end of the class as its rule defines in cpp. But the main reason why semicolons are there at the end of the class is compiler checks if the user is trying to create an instance of the class at the end of it.
  - Yes just like structure and union, we can also create the instance of a class at the end just before the semicolon. As a result, once execution reaches at that line, it creates a class and allocates memory to your instance.

## Inheritance in C++

- Why and when to use inheritance?

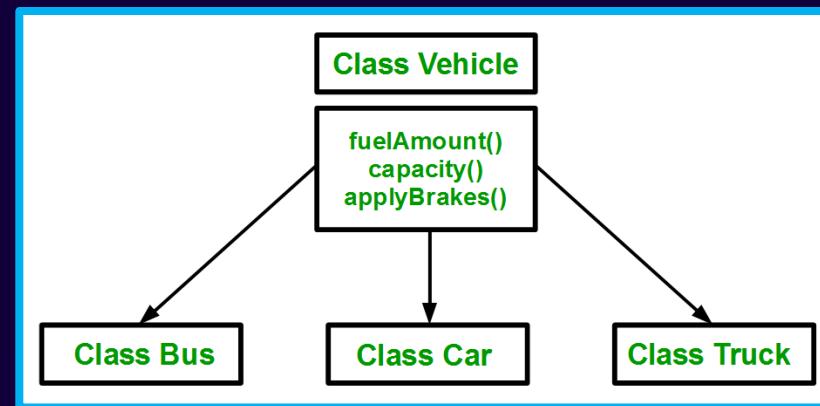
- Consider a group of vehicles. You need to create classes for Bus, Car, and Truck. The methods fuelAmount(), capacity(), applyBrakes() will be the same for all three classes. If we create these classes avoiding inheritance then we have to write all of these functions in each of the three classes as shown below figure:



## Inheritance in C++

- Why and when to use inheritance?

- You can clearly see that the above process results in duplication of the same code 3 times. This increases the chances of error and data redundancy. To avoid this type of situation, inheritance is used.



- Using inheritance, we have to write the functions only one time instead of three times as we have inherited the rest of the three classes from the base class (Vehicle).

## Inheritance in C++

- **Implementing inheritance in C++**
  - access-specifier either of private, public or protected. If neither is specified, PRIVATE is taken as default.

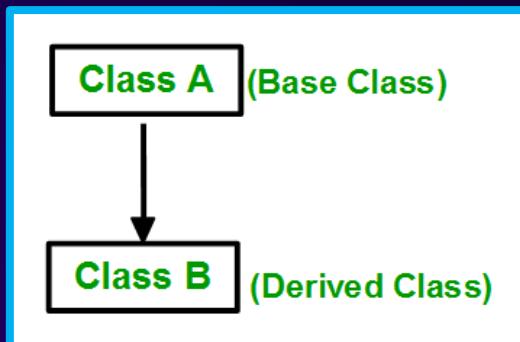
```
class <derived_class_name> : <access-specifier> <base_class_name>
{
    // body
}
```

- Note: When a base class is privately inherited by the derived class, public members of the base class becomes the private members of the derived class and therefore, the public members of the base class can only be accessed by the member functions of the derived class.
- **Modes of Inheritance**

Base class member access specifier	Type of Inheritance		
	Public	Protected	Private
Public	Public	Protected	Private
Protected	Protected	Protected	Private
Private	Not accessible (Hidden)	Not accessible (Hidden)	Not accessible (Hidden)

## Inheritance in C++

- Types Of Inheritance:
  1. Single inheritance
  2. Multilevel inheritance
  3. Multiple inheritance
  4. Hierarchical inheritance
  5. Hybrid inheritance
  6. Multipath inheritance
- Single Inheritance: In single inheritance, a class is allowed to inherit from only one class. i.e. one subclass is inherited by one base class only.

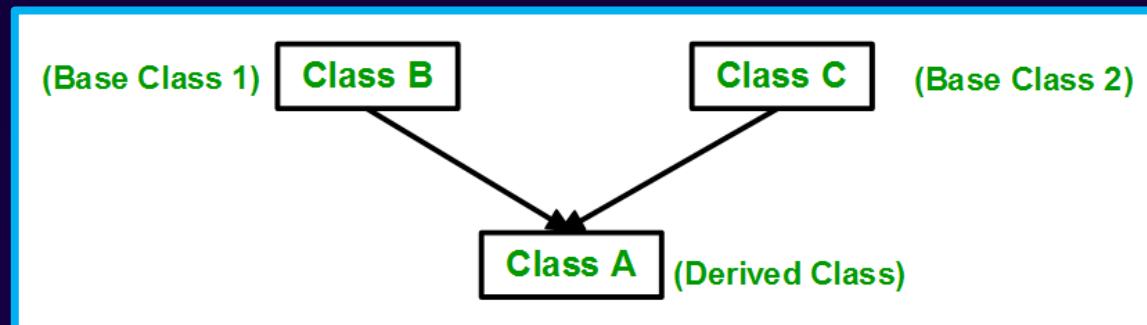


```
class subclass_name : access_mode base_class
{
    // body of subclass
};
```

## Inheritance in C++

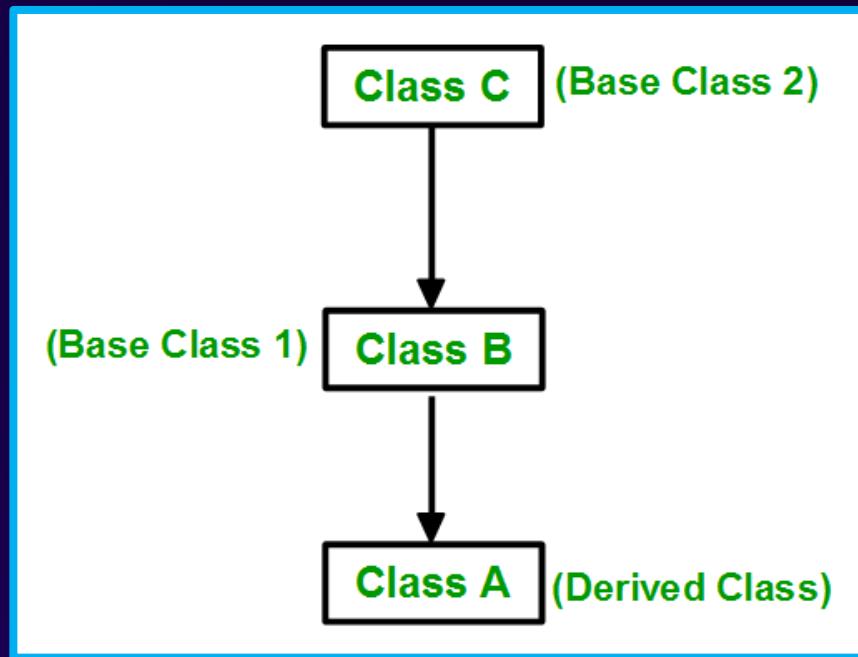
- **Multiple Inheritance:** Multiple Inheritance is a feature of C++ where a class can inherit from more than one class. i.e one subclass is inherited from more than one base class.

```
class subclass_name : access_mode base_class1, access_mode base_class2, ....  
{  
    // body of subclass  
};
```



## Inheritance in C++

- Multilevel Inheritance: In this type of inheritance, a derived class is created from another derived class.



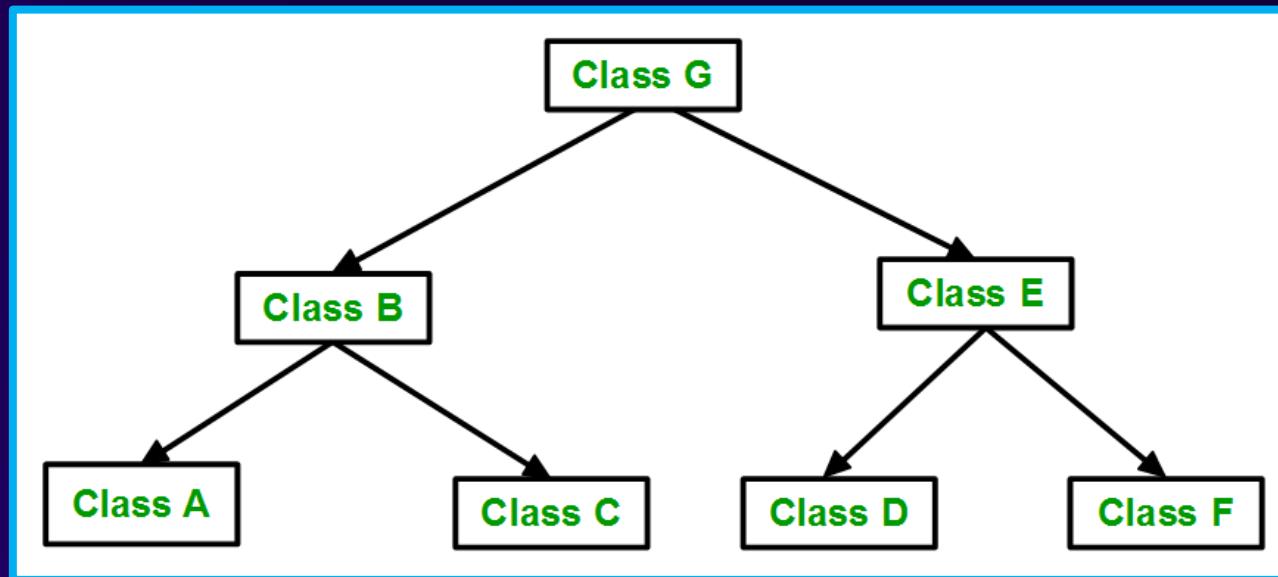
```
class C
{
...
};

class B:public C
{
...
};

class A: public B
{
...
};
```

## Inheritance in C++

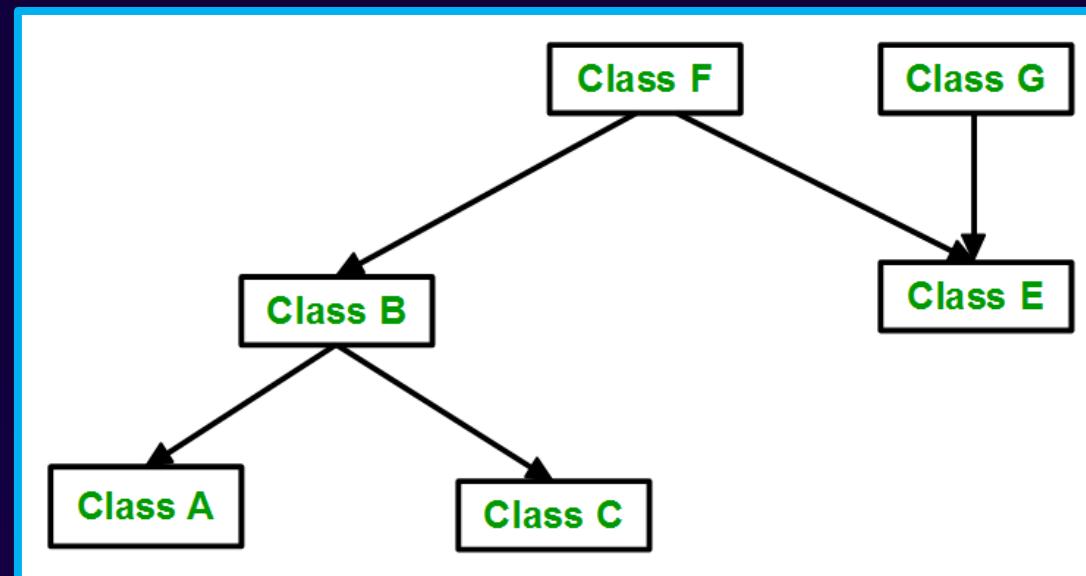
- **Hierarchical Inheritance:** In this type of inheritance, more than one subclass is inherited from a single base class. i.e. more than one derived class is created from a single base class.



```
class A
{
    // body of the class A.
}
class B : public A
{
    // body of class B.
}
class C : public A
{
    // body of class C.
}
class D : public A
{
    // body of class D.
}
```

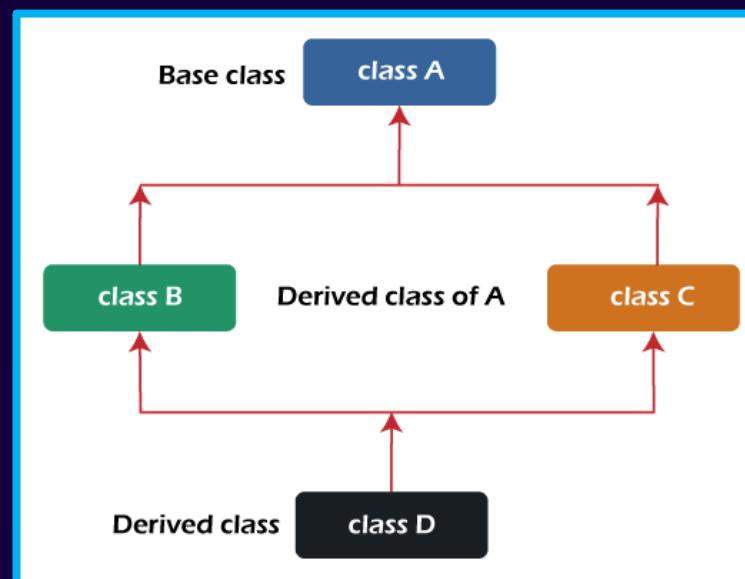
## Inheritance in C++

- Hybrid (Virtual) Inheritance: Hybrid Inheritance is implemented by combining more than one type of inheritance. For example: Combining Hierarchical inheritance and Multiple Inheritance. Below image shows the combination of hierarchical and multiple inheritances:



## Inheritance in C++

- Multipath inheritance (A special case of hybrid inheritance): A derived class with two base classes and these two base classes have one common base class is called multipath inheritance. Ambiguity can arise in this type of inheritance.



## Inheritance in C++

- Multipath inheritance (A special case of hybrid inheritance)
  - There are 2 Ways to Avoid this Ambiguity:
    1. Avoiding ambiguity using the scope resolution operator: In this case there are multiple copies of the parent class
    2. Avoiding ambiguity using the virtual base class: In this case there is a copy of the parent class.

```
class A
{
    member;
}
class B : public A {}
class C : public A {}
class D : public B, public C {}

D d;
d.B::member = x;
d.C::member = x;
```

```
class A
{
    member;
}
class B : virtual public A {}
class C : virtual public A {}
class D : public B, public C {}

D d;
d.member = x;
```

## Compile-Time Polymorphism

- **Function Overloading**
  - When there are multiple functions with the same name but different parameters, then the functions are said to be overloaded, hence this is known as Function Overloading. Functions can be overloaded by changing the number of arguments or/and changing the type of arguments.
- **Operator Overloading**
  - C++ has the ability to provide the operators with a special meaning for a data type, this ability is known as operator overloading. For example, we can make use of the addition operator (+) for string class to concatenate two strings. We know that the task of this operator is to add two operands. So a single operator '+', when placed between integer operands, adds them and when placed between string operands, concatenates them.

## Runtime Polymorphism

- Function Overriding or Virtual Function
  - A virtual function is a member function that is declared in the base class using the keyword `virtual` and is re-defined (Overridden) in the derived class.
    - Virtual functions are Dynamic in nature.
    - They are defined by inserting the keyword “`virtual`” inside a base class and are always declared with a base class and overridden in a child class
    - A virtual function is called during Runtime
  - The function in the parent class must be defined as `virtual`.
- Runtime Polymorphism with Data Members
  - Runtime Polymorphism can be achieved by data members in C++.

## Constructor

- A constructor is a member function of a class that has the same name as the class name. It helps to initialize the object of a class. It can either accept the arguments or not.

```
ClassName ()  
{  
    //Constructor's Body  
}
```

## Destructor

- Like a constructor, Destructor is also a member function of a class that has the same name as the class name preceded by a tilde(~) operator. It helps to deallocate the memory of an object. It is called while the object of the class is freed or deleted.

```
~ClassName ()  
{  
    //Destructor's Body  
}
```

## Virtual Destructor

- Deleting a derived class object using a pointer of base class type that has a non-virtual destructor results in undefined behavior. To correct this situation, the base class should be defined with a virtual destructor.

## Pure Virtual Destructor

- The inclusion of a pure virtual destructor in a C++ program has no negative consequences. Pure virtual destructors must have a function body because their destructors are called before those of base classes; if one is absent, object destruction will fail since there won't be anything to call when the object is destroyed. Making a pure virtual destructor with its definition allows us to create an abstract class easily.

**Note:** Only Destructors can be Virtual. Constructors cannot be declared as virtual.

## Pure Virtual Functions and Abstract Classes in C++

- Sometimes implementation of all function cannot be provided in a base class because we don't know the implementation. Such a class is called abstract class. For example, let Shape be a base class. We cannot provide implementation of function draw() in Shape, but we know every derived class must have implementation of draw(). Similarly an Animal class doesn't have implementation of move() (assuming that all animals move), but all animals must know how to move. We cannot create objects of abstract classes.
- A pure virtual function (or abstract function) in C++ is a virtual function for which we can have implementation, But we must override that function in the derived class, otherwise the derived class will also become abstract class.
  - Some Interesting Facts:
    1. A class is abstract if it has at least one pure virtual function.
    2. We can have pointers and references of abstract class type.
    3. If we do not override the pure virtual function in derived class, then derived class also becomes abstract class.
    4. An abstract class can have constructors.
    5. An abstract class in C++ can also be defined using struct keyword.

## static\_cast

- `static_cast` is used for ordinary typecasting. It is responsible for the implicit type of coercion and is also called explicitly. We should use it in cases like converting the int to float, int to char, etc.

## dynamic\_cast

- In C++, we can treat the derived class's reference or pointer as the base class's pointer. This method is known as upcasting in C++. But its opposite process is known as downcasting, which is not allowed in C++. So, the `dynamic_cast` in C++ promotes safe downcasting. We can only perform this in polymorphic classes, which must have at least one virtual function.
- `dynamic_cast` is useful when you don't know what the dynamic type of the object is. It returns a null pointer if the object referred to doesn't contain the type casted to as a base class (when you cast to a reference, a `bad_cast` exception is thrown in that case).

## Copy Constructor

- A copy constructor is a member function that initializes an object using another object of the same class. In simple terms, a constructor which creates an object by initializing it with an object of the same class, which has been created previously is known as a copy constructor.

```
ClassName (const ClassName &old_obj);
```

- Characteristics of Copy Constructor**

- The copy constructor is used to initialize the members of a newly created object by copying the members of an already existing object.
- Copy constructor takes a reference to an object of the same class as an argument.
- The process of initializing members of an object through a copy constructor is known as copy initialization.
- It is also called member-wise initialization because the copy constructor initializes one object with the existing object, both belonging to the same class on a member-by-member copy basis.
- The copy constructor can be defined explicitly by the programmer. If the programmer does not define the copy constructor, the compiler does it for us.

## Copy Constructor

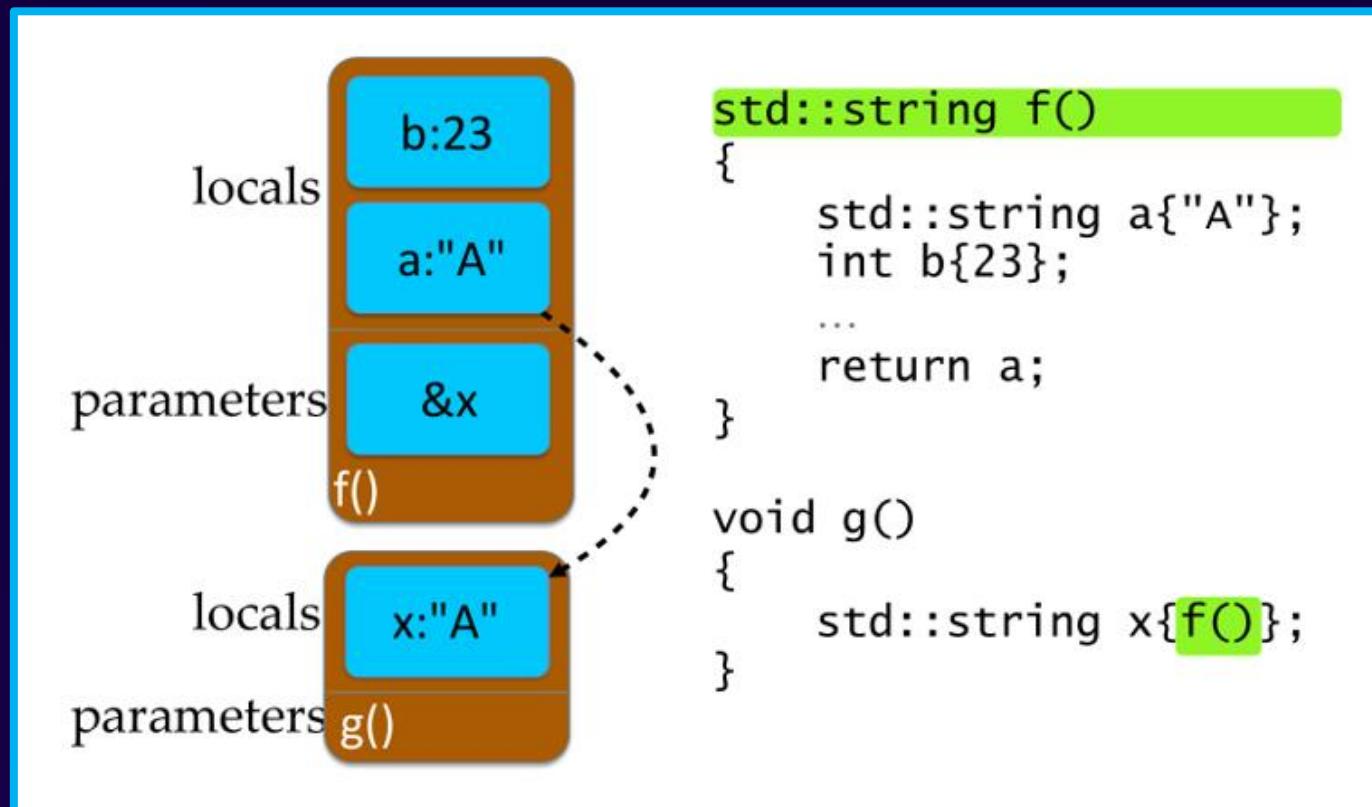
- Types of Copy Constructors
  1. Default Copy Constructor
  2. User Defined Copy Constructor
- When is the copy constructor called? In C++, a Copy Constructor may be called in the following cases:
  1. When an object of the class is returned by value.
  2. When an object of the class is passed (to a function) by value as an argument.
  3. When an object is constructed based on another object of the same class.
  4. When the compiler generates a temporary object.

Note: It is, however, not guaranteed that a copy constructor will be called in all these cases, because the C++ Standard allows the compiler to optimize the copy away in certain cases, one example is the return value optimization (sometimes referred to as RVO).

- Copy Elision
- In copy elision, the compiler prevents the making of extra copies which results in saving space and better the program complexity(both time and space); Hence making the code more optimized.

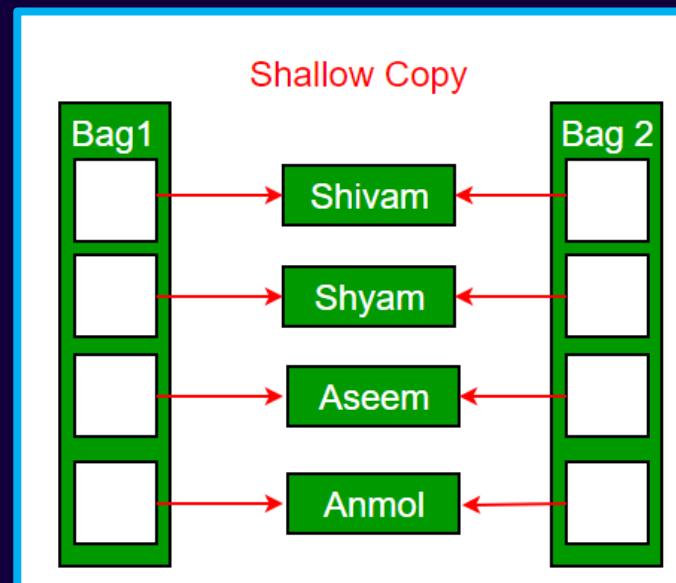
## Copy Constructor

- RVO



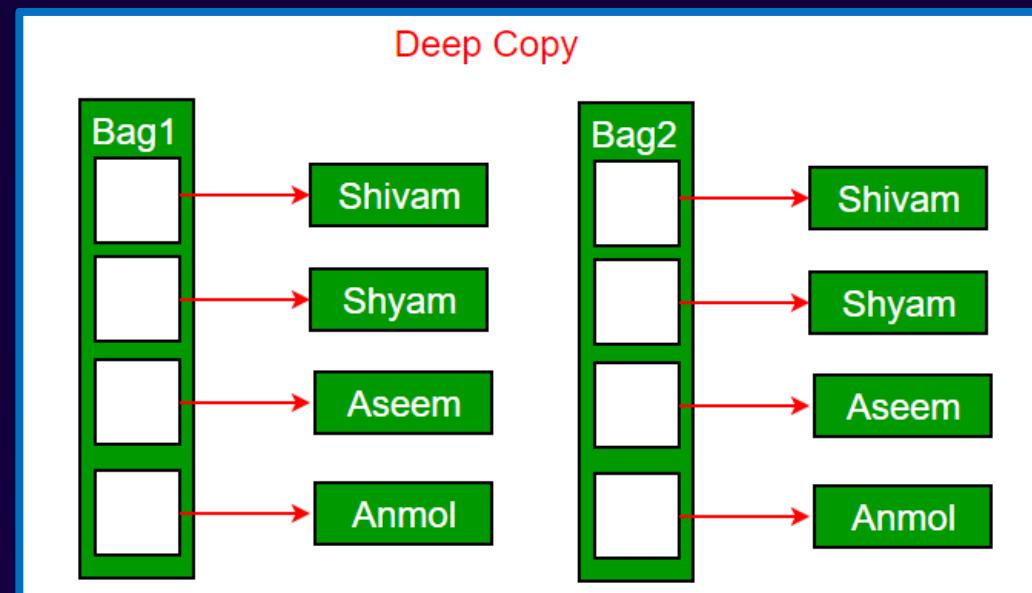
## Copy Constructor

- When is a user-defined copy constructor needed?
  - If we don't define our own copy constructor, the C++ compiler creates a default copy constructor for each class which does a member-wise copy between objects. The compiler-created copy constructor works fine in general. We need to define our own copy constructor only if an object has pointers or any runtime allocation of the resource like a file handle, a network connection, etc.
  - The default constructor does only shallow copy.



## Copy Constructor

- When is a user-defined copy constructor needed?
  - Deep copy is possible only with a user-defined copy constructor. In a user-defined copy constructor, we make sure that pointers (or references) of copied objects point to new memory locations.



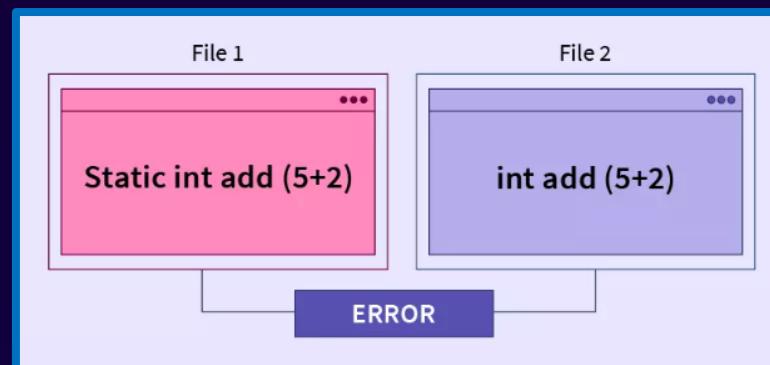
## Copy Constructor

- Copy constructor vs Assignment Operator
  - The main difference between Copy Constructor and Assignment Operator is that the Copy constructor makes a new memory storage every time it is called while the assignment operator does not make new memory storage.
  - A copy constructor is called when a new object is created from an existing object, as a copy of the existing object. The assignment operator is called when an already initialized object is assigned a new value from another existing object. In the bellow example (1) calls the copy constructor and (2) calls the assignment operator. See this for more details.

```
MyClass t1, t2;  
MyClass t3 = t1; // ----> (1)  
t2 = t1;         // -----> (2)
```

## static

- The static keyword has different meanings when used with different types. We can use static keywords with:
  - **Static Functions in C:** The “static” keyword before a function name makes it static.
  - **Static Variables:** Variables in a function, Variables in a class.
  - **Static Members of Class:** It is used for functions inside the class.
- **Static Functions in C**
  - Unlike global functions in C, access to static functions is restricted to the file where they are declared. Therefore, when we want to restrict access to functions, we make them static. Another reason for making functions static can be reuse of the same function name in other files.

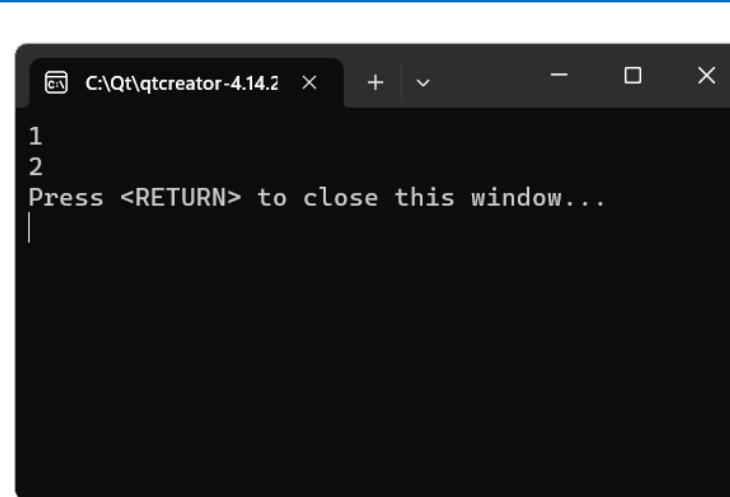


## static

- Static Variables

- When a variable is declared as static, space for it gets allocated for the *lifetime* of the program. Even if the function is called multiple times, space for the static variable is allocated only once and the value of the variable in the previous call gets carried through the next function call.
- Static variables must be initialized. Initialization is done only once.

```
5 int fun()
6 {
7     static int count = 0;
8     count++;
9     return count;
10 }
11
12 int main()
13 {
14     cout << fun() << endl;
15     cout << fun() << endl;
16     return 0;
17 }
```



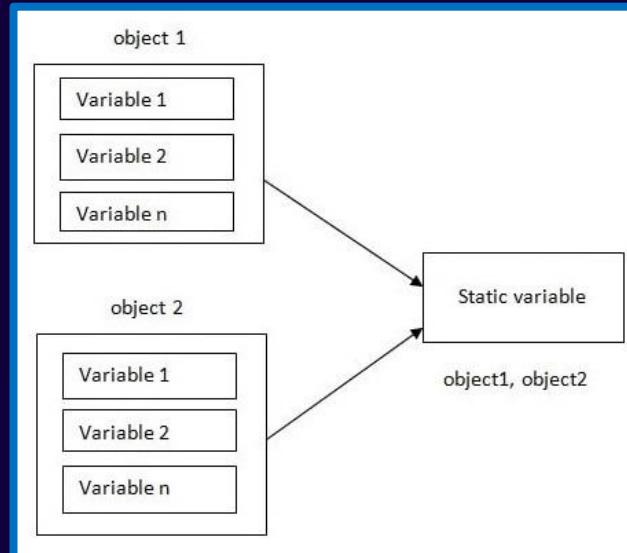
The terminal window shows the following output:

```
C:\Qt\qtcreator-4.14.2> 1
2
Press <RETURN> to close this window...
```

## static

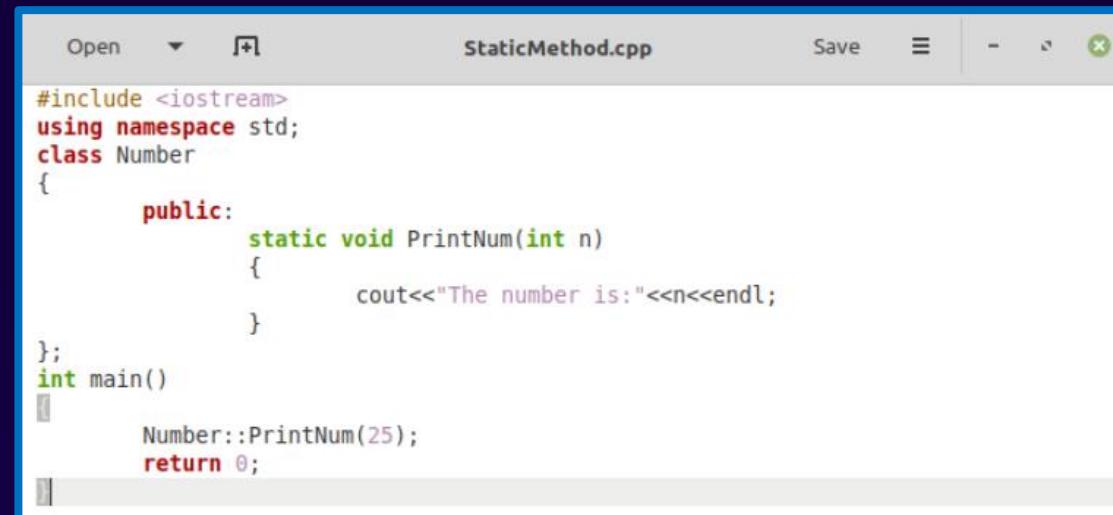
- Static Member Variables (Static variables in a class)
  - The static variables in a class are **shared** by the objects. There can not be multiple copies of the same static variables for different objects. Also because of this reason static variables **can not be initialized** using constructors.
  - The static variable must be initialized as follows:

```
type Class::variable = value;
```



## static

- Static Member Functions (Static functions in a class)
  - Static member functions also do not depend on the object of the class. We are allowed to invoke a static member function using the object and the '.' operator but it is recommended to invoke the static members using the class name and the scope resolution operator.
  - Static member functions are allowed to access only the **static data members or other static member functions**, they can not access the **non-static data members or member functions** of the class.



The screenshot shows a code editor window titled "StaticMethod.cpp". The code defines a class "Number" with a static member function "PrintNum". The "main" function calls this static function with the argument 25.

```
#include <iostream>
using namespace std;
class Number
{
public:
    static void PrintNum(int n)
    {
        cout<<"The number is:"<<n<<endl;
    }
};
int main()
{
    Number::PrintNum(25);
    return 0;
}
```

## const

- Whenever const keyword is attached with any method(), variable, pointer variable, and with the object of a class it prevents that specific object/method()/variable to modify its data items value.
  - Constant Variables
  - Constant Pointer
  - Constant Methods
- Constant Variables
  - There are a certain set of rules for the declaration and initialization of the constant variables:
    - The const variable cannot be left un-initialized at the time of the definition.
    - It cannot be assigned value anywhere in the program.
    - Explicit value needed to be provided to the constant variable at the time of declaration of the constant variable.

### How to Declare Constants

<code>const int var;</code>	X
<code>const int var; var=5</code>	X
<code>Const int var = 5;</code>	✓

## const

- Constant Pointer
  - Pointers can be declared with a const keyword.
    - When the *pointer variable point to a const value*:

```
const data_type* var_name;
```

- When *const pointer variable point to the value*:

```
data_type* const var_name;
```

- When *const pointer pointing to a const variable*:

```
const data_type* const var_name;
```

## const

- Constant Pointer
  - Note: Pass const-argument value to a non-const parameter of a function cause error.

```
1 #include <iostream>
2 using namespace std;
3
4 int foo(int* y)
5 {
6     return *y;
7 }
8
9 // Driver code
10 int main()
11 {
12     int z = 8;
13     const int* x = &z;
14     cout << foo(x);
15     return 0;
16 }
```

- Output: The compile-time error that will appear as if const value is passed to any non-const argument of the function then the following compile-time error will appear.

## const

- Constant Methods (A `const` member function of the class)
  - Constant member functions are those functions which are denied permission to change the values of the data members of their class. To make a member function constant, the keyword “`const`” is appended to the function prototype and also to the function definition header.

```
class
{
    void foo() const
    {
        //.....
    }
}
```

- When a function is declared as `const`, it can be called on any type of object, `const` object as well as non-`const` objects.
- Whenever an object is declared as `const`, it needs to be initialized at the time of declaration. however, the object initialization while declaring is possible only with the help of constructors.

## const

- Constant Objects
  - An object declared as const cannot be modified and hence, can invoke only const member functions as these functions ensure not to modify the object.

```
const Class_Name Object_name;
```

- When a function is declared as const, it can be called on any type of object, const object as well as non-const objects.
- Whenever an object is declared as const, it needs to be initialized at the time of declaration. However, the object initialization while declaring is possible only with the help of constructors.

## const

- Constant Function Parameters
  - A function() parameters and return type of function() can be declared as constant. Constant values cannot be changed as any such attempt will generate a compile-time error.
- Constant Return Type
  - The value of a return type that is declared const cannot be changed. This is especially useful when giving a reference to a class's internals.

## mutable

- In Class Member
  - Sometimes there is requirement to modify one or more data members of class/struct through const function even though you don't want the function to update other members of class/struct. This task can be easily performed by using mutable keyword.
- In Lambda Expression
  - Since C++11 mutable can be used on a lambda to denote that things captured ***by value*** are ***modifiable*** (they aren't by default).

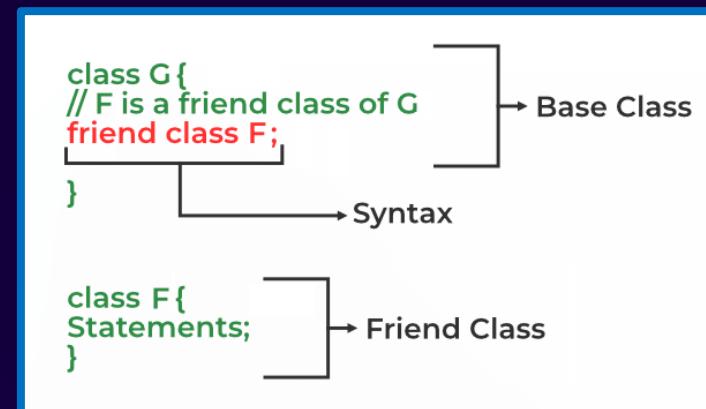
## friend

- **Friend Class**

- A friend class can access private and protected members of other classes in which it is declared as a friend. It is sometimes useful to allow a particular class to access private and protected members of other classes. For example, a `LinkedList` class may be allowed to access private members of `Node`.

```
friend class class_name;      // declared in the base class
```

- Note: We can declare friend class or function anywhere in the base class body whether its private, protected or public block. It works all the same.



## friend

- Friend Function

- A friend function can be granted special access to private and protected members of a class in C++. They are the non-member functions that can access and manipulate the private and protected members of the class for they are declared as friends. A friend function can be:

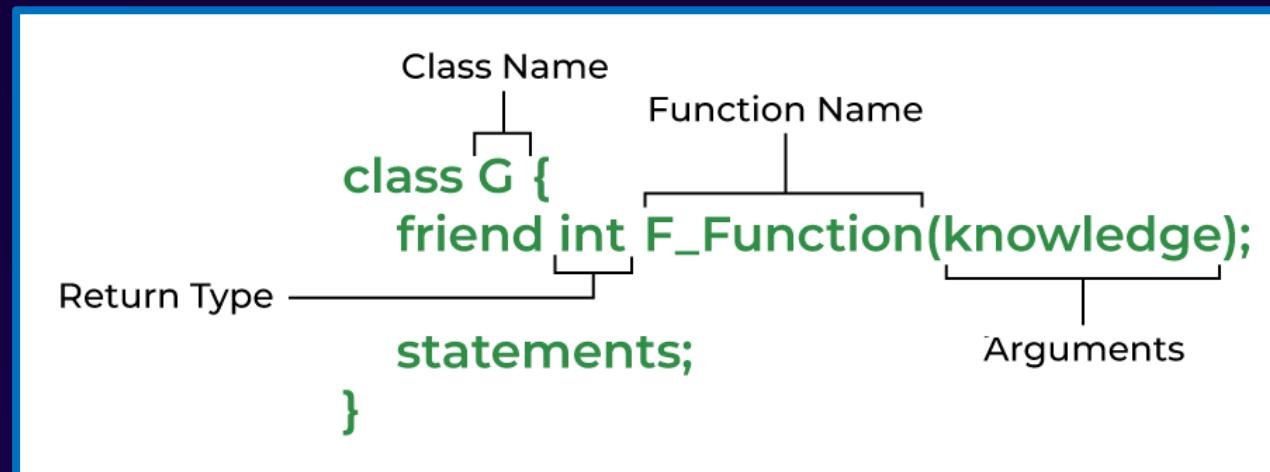
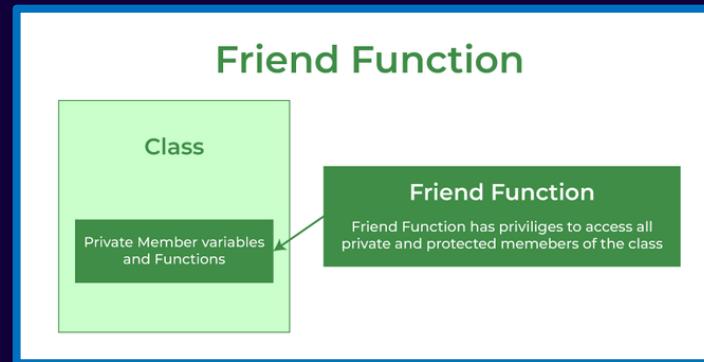
- A global function
- A member function of another class

```
// for a global function
friend return_type function_name (arguments);
```

```
// for a member function of another class
friend return_type class_name::function_name (arguments);
```

## friend

- Friend Function



## friend

- Friend Function
  - Advantages of Friend Functions
    - A friend function is able to access members without the need of inheriting the class.
    - The friend function acts as a bridge between two classes by accessing their private data.
    - It can be used to increase the versatility of overloaded operators.
    - It can be declared either in the public or private or protected part of the class.
  - Disadvantages of Friend Functions
    - Friend functions have access to private members of a class from outside the class which violates the law of data hiding.
    - Friend functions cannot do any run-time polymorphism in their members.
  - Important Points About Friend Functions and Classes
    - Friends should be used only for limited purposes. Too many functions or external classes are declared as friends of a class with protected or private data access lessens the value of encapsulation of separate classes in object-oriented programming.
    - Friendship is not mutual. If class A is a friend of B, then B doesn't become a friend of A automatically.
    - Friendship is not inherited.
    - The concept of friends is not in Java.

## References

- **Concept**
  - When a variable is declared as a reference, it becomes an alternative name for an existing variable. A variable can be declared as a reference by putting '&' in the declaration.

```
data_type &ref = variable;
```

- **Applications of Reference in C++**
  1. Modify the passed parameters in a function
  2. Avoiding a copy of large structures
  3. In For Each Loop to modify all objects
  4. For Each Loop to avoid the copy of objects

## References vs Pointers

- Both references and pointers can be used to change the local variables of one function inside another function. Both of them can also be used to save copying of big objects when passed as arguments to functions or returned from functions, to get efficiency gain.
- Despite the above similarities, there are the following differences between references and pointers:
  - A pointer can be declared as void but a reference can never be void

```
int a = 10;
void* aa = &a; // it is valid
void& ar = a; // it is not valid
```

- The pointer variable has n-levels/multiple levels of indirection i.e. single-pointer, double-pointer, triple-pointer. Whereas, the reference variable has only one/single level of indirection.
- Reference variables cannot be updated.
- Reference variable is an internal pointer.
- Declaration of a Reference variable is preceded with the ‘&’ symbol (but do not read it as “address of”).

## References vs Pointers

- **Limitations of References**
  1. Once a reference is created, it cannot be later made to reference another object; it cannot be reset. This is often done with pointers.
  2. References cannot be NULL. Pointers are often made NULL to indicate that they are not pointing to any valid thing.
  3. A reference must be initialized when declared. There is no such restriction with pointers.
- **Advantages of using References**
  1. Safer: Since references must be initialized, wild references like wild pointers are unlikely to exist.
  2. Easier to use: References don't need a dereferencing operator to access the value. They can be used like normal variables. The '&' operator is needed only at the time of declaration. Also, members of an object reference can be accessed with the dot operator ('.'), unlike pointers where the arrow operator ('->') is needed to access members.

## References vs Pointers

	References	Pointers
<b>Reassignment</b>	The variable cannot be reassigned in Reference.	The variable can be reassigned in Pointers.
<b>Memory Address</b>	It shares the same address as the original variable.	Pointers have their own memory address.
<b>Work</b>	It is referring to another variable.	It is storing the address of the variable.
<b>Null Value</b>	It does not have null value.	It can have value assigned as null.
<b>Arguments</b>	This variable is referenced by the method pass by value.	The pointer does it work by the method known as pass by reference.

## Declaration vs Definition

- Declaration: Declaration of a **variable** or **function** or **class** simply declares that the variable or function exists somewhere in the program, but the memory is **not allocated** for them. The declaration of a variable or function serves an important role—it tells the program what its type is going to be. In the case of function declarations, it also tells the program the **arguments**, their **data types**, the **order of those arguments**, and the **return type** of the function. So that's all about the declaration.
- Definition: When we define a variable or function, in addition to everything that a declaration does, it also **allocates memory** for that variable or function or class. Therefore, we can think of the definition as a superset of the declaration (or declaration as a subset of the definition).

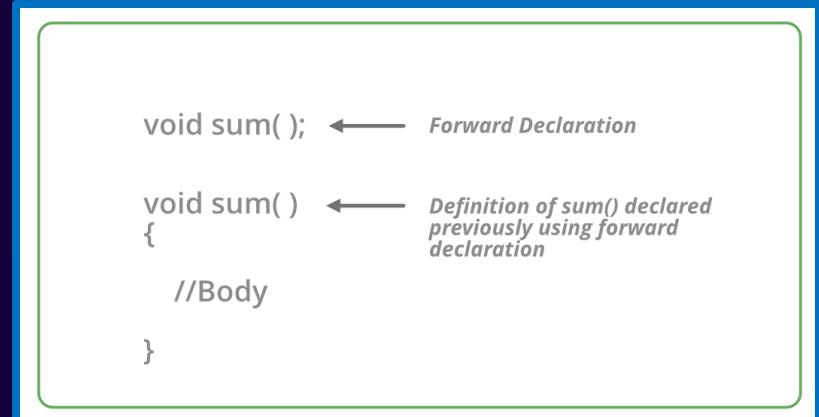
```
void sum(); ← Declaration  
void sum() ← Definition of sum() declared  
{  
    //Body  
}
```

## Forward Declaration

- Forward Declaration refers to the beforehand declaration of the syntax or signature of an identifier, variable, function, class, etc. prior to its usage (done later in the program).

Note: Forward declarations in C++ are useful to save in compile time as the compiler does not need to check for translation units in the included header. Also it has other benefits such as preventing namespace pollution, allowing to use PImpl idiom and it may even reduce the binary size in some cases.

```
// Forward Declaration class A  
class A;  
  
// Definition of class A  
class A{  
    // Body  
};
```



The diagram shows a code snippet within a light blue-bordered box. On the left, there is a forward declaration of a function `void sum();`. To its right, an arrow points from the declaration to the text *Forward Declaration*. Below it, there is a definition of the same function `void sum() { //Body }`. An arrow points from the definition to the text *Definition of sum() declared previously using forward declaration*.

```
void sum(); ← Forward Declaration  
void sum() { ← Definition of sum() declared  
previously using forward  
declaration  
    //Body  
}
```

## extern

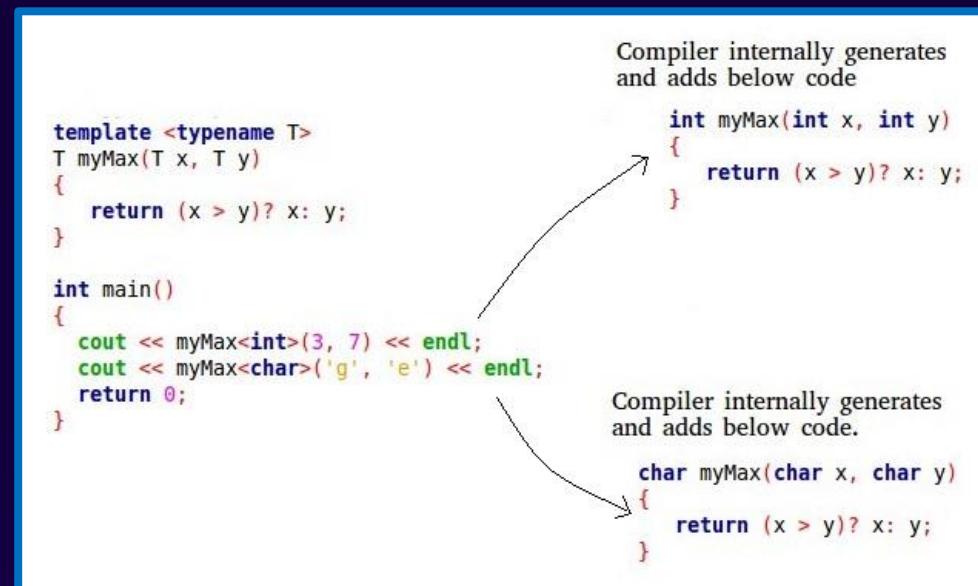
- Basically, the extern keyword extends the visibility of the C variables and C functions.
  - Extern is a short name for external.
  - The extern variable is used when a particular files need to access a variable from another file.

```
extern data_type variable_name;
```

- Properties of extern Variable in C
  - When we write `extern some_data_type some_variable_name;`; ***no memory is allocated***. Only the property of the variable is announced.
  - ***Multiple declarations*** of extern variable is allowed within the file. This is not the case with automatic variables.
  - The extern variable says to the compiler “Go ***outside my scope*** and you will find the definition of the variable that I declared.”
  - The ***compiler*** believes that whatever that extern variable said is true and produces no error. ***Linker*** throws an error when it finds no such variable exists.
  - When an extern variable is initialized, then memory for this is allocated and it will be considered defined.

## Templates

- A template is a simple yet very powerful tool in C++. The simple idea is to pass the data type as a parameter so that we don't need to write the same code for different data types.
- How Do Templates Work?
  - Templates are expanded at compiler time. This is like macros. The difference is, that the compiler does type-checking before template expansion. The idea is simple, source code contains only function/class, but compiled code may contain multiple copies of the same function/class.



## Templates

- Type of Templates:
  - Function Templates
    - We write a generic function that can be used for different data types. Examples of function templates are sort(), max(), min(), printArray().
  - Class Templates
    - Class templates like function templates, class templates are useful when a class defines something that is independent of the data type. Can be useful for classes like LinkedList, BinaryTree, Stack, Queue, Array, etc.
  - Notes:
    - We can specify default arguments to templates.
    - Both function overloading and templates are examples of polymorphism features of OOP. Function overloading is used when multiple functions do quite similar (not identical) operations, templates are used when multiple functions do identical operations.
    - Each instance of a template contains its own static variable. See Templates and Static variables for more details.
    - Template specialization allows us to have different codes for a particular data type.
    - We can pass non-type arguments to templates. Non-type parameters are mainly used for specifying max or min values or any other constant value for a particular instance of a template.

## Templates

- Source code organization
  - When defining a class template, you must organize the source code in such a way that the member definitions are visible to the compiler when it needs them. You have the choice of using the inclusion model or the explicit instantiation model. In the inclusion model, you include the member definitions in every file that uses a template. This approach is simplest and provides maximum flexibility in terms of what concrete types can be used with your template. Its disadvantage is that it can increase compilation times. The times can be significant if a project or the included files themselves are large. With the explicit instantiation approach, the template itself instantiates concrete classes or class members for specific types. This approach can speed up compilation times, but it limits usage to only those classes that the template implementer has enabled ahead of time. In general, we recommend that you use the inclusion model unless the compilation times become a problem.

## Templates

- The inclusion model

- The simplest and most common way to make template definitions visible throughout a translation unit, is to put the definitions in the header file itself. Any .cpp file that uses the template simply has to #include the header. This approach is used in the Standard Library.

```
#ifndef MYARRAY
#define MYARRAY
#include <iostream>

template<typename T, size_t N>
class MyArray
{
    T arr[N];
public:
    // Full definitions:
    MyArray(){}
    void Print()
    {
        for (const auto v : arr)
        {
            std::cout << v << " , ";
        }
    }

    T& operator[](int i)
    {
        return arr[i];
    }
};

#endif
```

## Templates

- The explicit instantiation model

- If the inclusion model isn't viable for your project, and you know definitively the set of types that will be used to instantiate a template, then you can separate out the template code into an .h and .cpp file, and in the .cpp file explicitly instantiate the templates. This approach generates object code that the compiler will see when it encounters user instantiations. In the example, the explicit instantiations are at the bottom of the .cpp file. A MyArray may be used only for double or String types.

```
//MyArray.h
#ifndef MYARRAY
#define MYARRAY

template<typename T, size_t N>
class MyArray
{
    T arr[N];
public:
    MyArray();
    void Print();
    T& operator[](int i);
};

#endif
```

```
//MyArray.cpp
#include <iostream>
#include "MyArray.h"

using namespace std;

template<typename T, size_t N>
MyArray<T,N>::MyArray(){}

template<typename T, size_t N>
void MyArray<T,N>::Print()
{
    for (const auto v : arr)
    {
        cout << v << " ";
    }
    cout << endl;
}

template MyArray<double, 5>;
template MyArray<string, 5>;
```

## Exception Handling

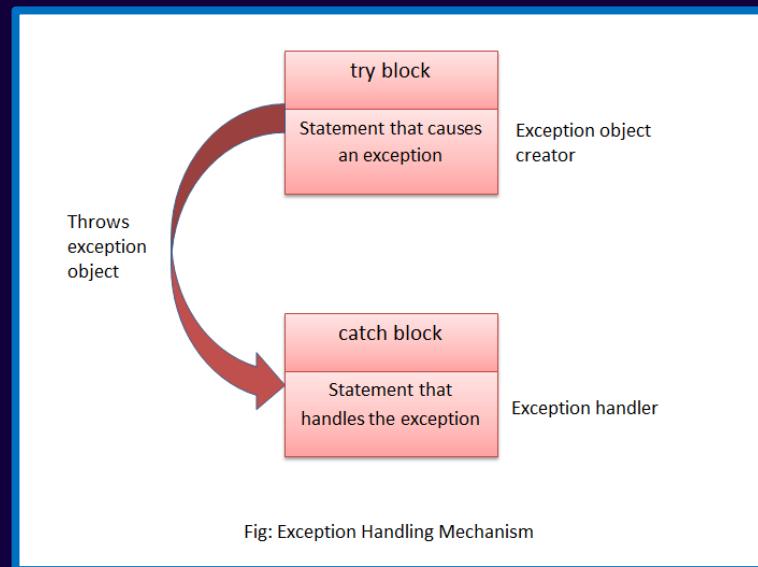
- One of the advantages of C++ over C is Exception Handling. Exceptions are runtime anomalies or abnormal conditions that a program encounters during its execution.
- There are two types of exceptions:
  - **Synchronous:** i.e., exceptions which are beyond the program's control, such as disc failure, keyboard interrupts etc.
  - **Asynchronous:** Out of range, over flow, ...
- Why Exception Handling?
  - Separation of Error Handling code from Normal Code (In traditional error handling codes, there are always if-else conditions to handle errors).
  - Functions/Methods can handle only the exceptions they choose.
  - Grouping of Error Types.

## Exception Handling

- **Synchronous**

There is a way to prevent the use of try, catch blocks.

- try: Represents a block of code that can throw an exception.
- catch: Represents a block of code that is executed when a particular exception is thrown.
- throw: Used to throw an exception. Also used to list the exceptions that a function throws but doesn't handle itself.



## Exception Handling

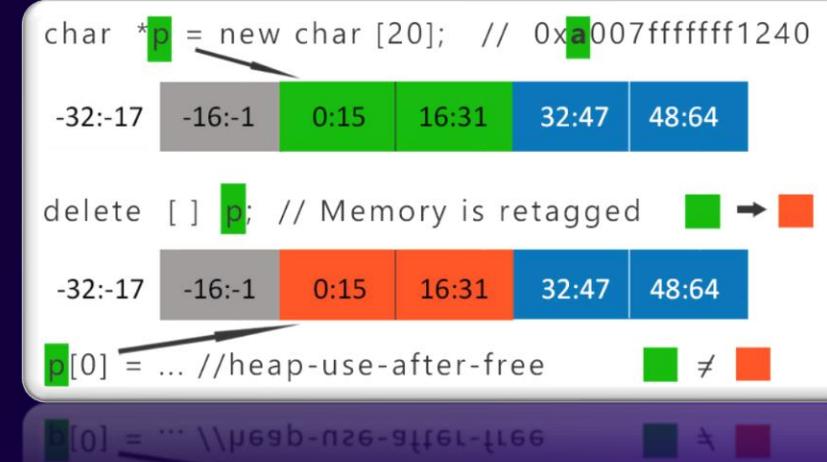
- Synchronous

### Notes:

- There is a special catch block called the ‘catch all’ block, written as `catch(...)`, that can be used to catch all types of exceptions.
- Implicit type conversion doesn’t happen for primitive types (Example: `throw 'a'` not catch by `catch (int x)`).
- If an exception is thrown and not caught anywhere, the program terminates abnormally.
- A derived class exception should be caught before a base class exception.
- Like Java, the C++ library has a standard exception class which is the base class for all standard exceptions.
- Unlike Java, in C++, all exceptions are unchecked (In checked, all classes have error handling).
- In C++, try/catch blocks can be nested. Also, an exception can be re-thrown using “`throw;`“.
- When an exception is thrown, all objects created inside the enclosing try block are destroyed before the control is transferred to the catch block.
- Note : The use of Dynamic Exception Specification has been deprecated since C++11 (Place the `throw` after the function signature).

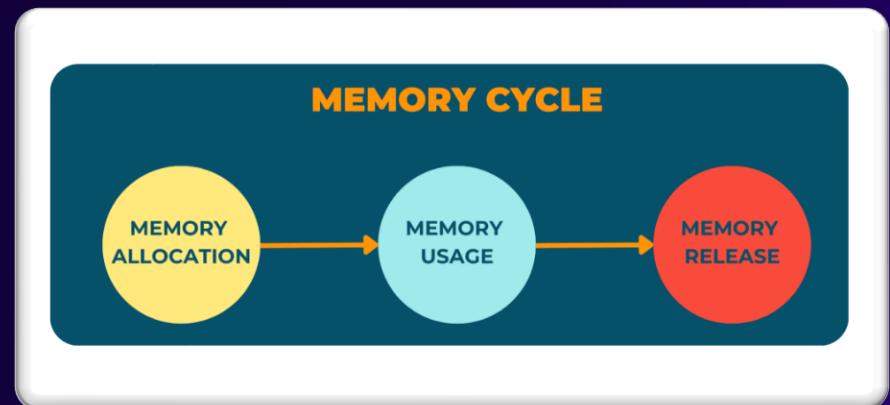
## Memory Corruption

- Memory corruption occurs in a computer program when the contents of a memory location are modified due to programmatic behavior that exceeds the intention of the original programmer or program/language constructs; this is termed as violation of memory safety.
- The main causes of memory corruption:
  - Casting to the wrong type
  - Uninitialized pointers
  - Typo error for -> and .
  - Typo error when using \* and & (or multiple of either)
  - Mixing new [] and new with delete [] and delete
  - Missing or incorrect copy-constructors
  - Pointer pointing to garbage
  - Calling delete multiple times on the same data
  - Polymorphic baseclasses without virtual destructors



## Memory Leak

- A memory leak occurs when a programmer does not allocate a previously allocated memory, resulting in deallocation, which thus causes a memory leak. This is because the program does not require this memory but it is still present in the program.
- There are many forms of leaks:
  - Unmanaged leaks (code that allocates unmanaged code)
  - Resource leaks (code that allocates and uses unmanaged resources, like files, sockets)
  - Extended lifetime of objects
  - Incorrect understanding of how GC and .NET memory management works
  - Bugs in the .NET runtime



## Differences in Stack and Heap Memory



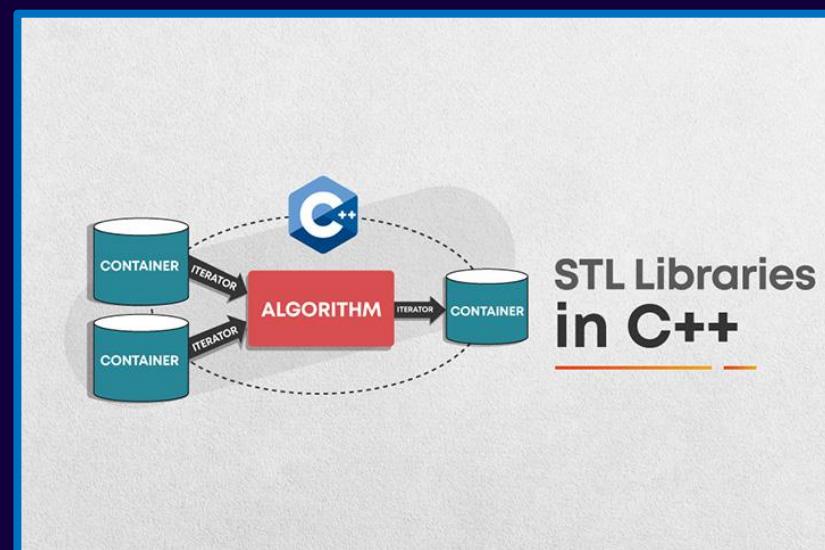
Feature	Stack	Heap
Access Speed	Fast	Slow
Memory Allocation	Handled automatically by runtime	Only automatically handled in high level languages
Performance Cost	Less	More
Size	Fixed Size	Dynamic Size
Variable Access	Local variables only	Global variable access
Data Structure	Linear data structure (stack)	Hierarchical Data Structure (array/tree)
Main Issue	Small fixed amount of memory (stack overflow risk)	Memory fragmentation over time

# The C++ Standard Template Library (STL)

Qt

## STL

- The Standard Template Library (STL) is a set of C++ template classes to provide common programming data structures and functions such as lists, stacks, arrays, etc. It is a library of container classes, algorithms, and iterators. It is a generalized library and so, its components are parameterized.
- By using the STL, you can simplify your code, reduce the likelihood of errors, and improve the performance of your programs.



# The C++ Standard Template Library (STL)

Qt

## STL

- Some of the key components of the STL include:
  - **Containers:** The STL provides a range of containers, such as vector, list, map, set, and stack, which can be used to store and manipulate data.
  - **Algorithms:** The STL provides a range of algorithms, such as sort, find, and binary\_search, which can be used to manipulate data stored in containers.
  - **Iterators:** Iterators are objects that provide a way to traverse the elements of a container. The STL provides a range of iterators, such as forward\_iterator, bidirectional\_iterator, and random\_access\_iterator, that can be used with different types of containers.
  - **Function Objects:** Function objects, also known as functors, are objects that can be used as function arguments to algorithms. They provide a way to pass a function to an algorithm, allowing you to customize its behavior.
  - **Adapters:** Adapters are components that modify the behavior of other components in the STL. For example, the reverse\_iterator adapter can be used to reverse the order of elements in a container.

## Algorithms

- `sort(first_iterator, last_iterator)` – To sort the given vector.
- `sort(first_iterator, last_iterator, greater<int>())` – To sort the given container/vector in descending order
- `reverse(first_iterator, last_iterator)` – To reverse a vector. ( if ascending -> descending OR if descending -> ascending)
- `max_element (first_iterator, last_iterator)` – To find the maximum element of a vector.
- `min_element (first_iterator, last_iterator)` – To find the minimum element of a vector.
- `accumulate(first_iterator, last_iterator, initial value of sum)` – Does the summation of vector elements
- `count(first_iterator, last_iterator,x)` – To count the occurrences of x in vector.
- `find(first_iterator, last_iterator, x)` – Returns an iterator to the first occurrence of x in vector and points to last address of vector ((name\_of\_vector).end()) if element is not present in vector.
- `binary_search(first_iterator, last_iterator, x)` – Tests whether x exists in sorted vector or not.
- `lower_bound(first_iterator, last_iterator, x)` – returns an iterator pointing to the first element in the range [first,last) which has a value not less than 'x'.
- `upper_bound(first_iterator, last_iterator, x)` – returns an iterator pointing to the first element in the range [first,last) which has a value greater than 'x'.

## Algorithms

- `arr.erase(position to be deleted)` – This erases selected element in vector and shifts and resizes the vector elements accordingly.
- `arr.erase(unique(arr.begin(),arr.end()),arr.end())` – This erases the duplicate occurrences in sorted vector in a single line.
- `next_permutation(first_iterator, last_iterator)` – This modified the vector to its next permutation.
- `prev_permutation(first_iterator, last_iterator)` – This modified the vector to its previous permutation.
- `distance(first_iterator,desired_position)` – It returns the distance of desired position from the first iterator. This function is very useful while finding the index.

# The C++ Standard Template Library (STL)

Qt

## Containers

- vector
- list
- deque
- arrays
- forward\_list (Introduced in C++11)
- queue
- priority\_queue
- stack
- set
- multiset
- map
- multimap

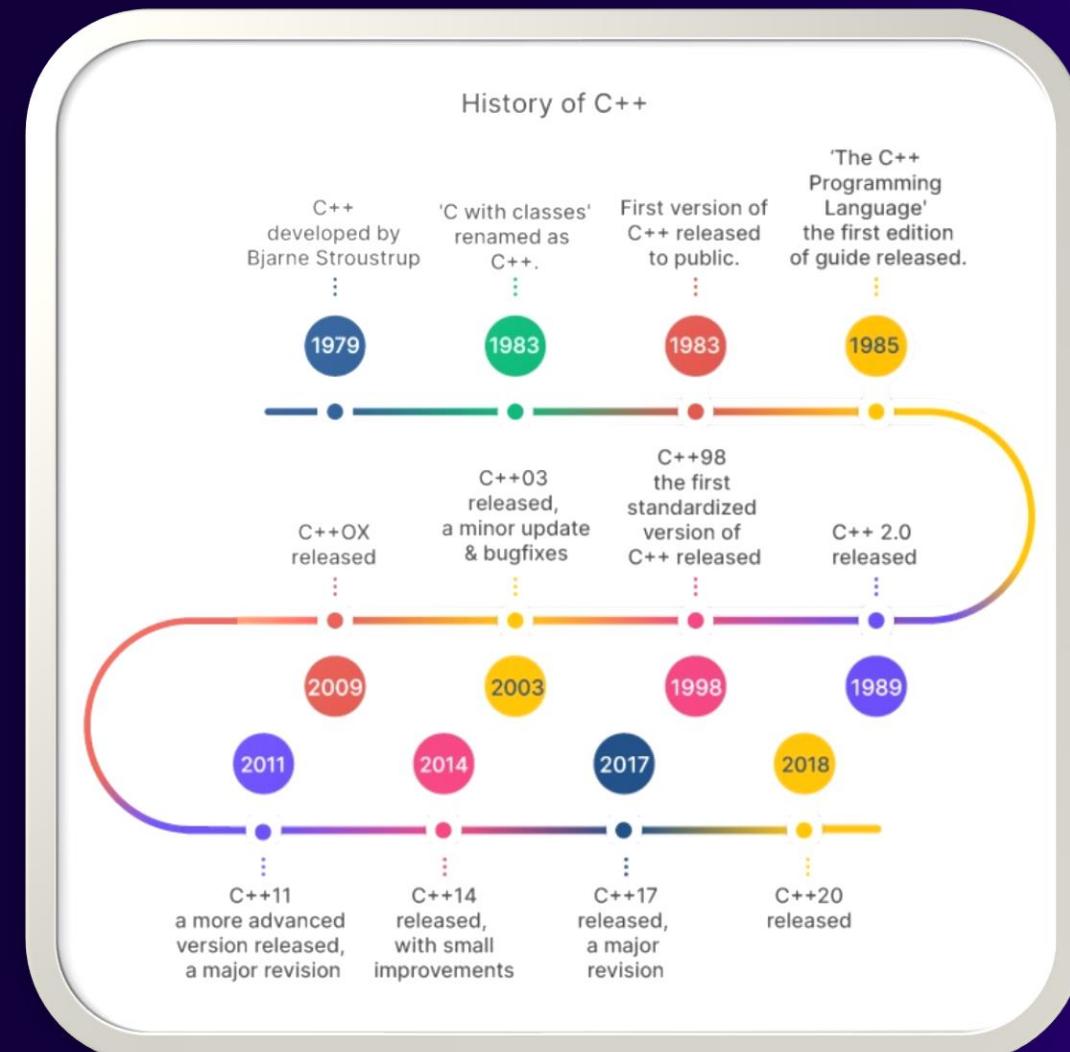
## Containers

- unordered\_set (Introduced in C++11)
- unordered\_multiset (Introduced in C++11)
- unordered\_map (Introduced in C++11)
- unordered\_multimap (Introduced in C++11)

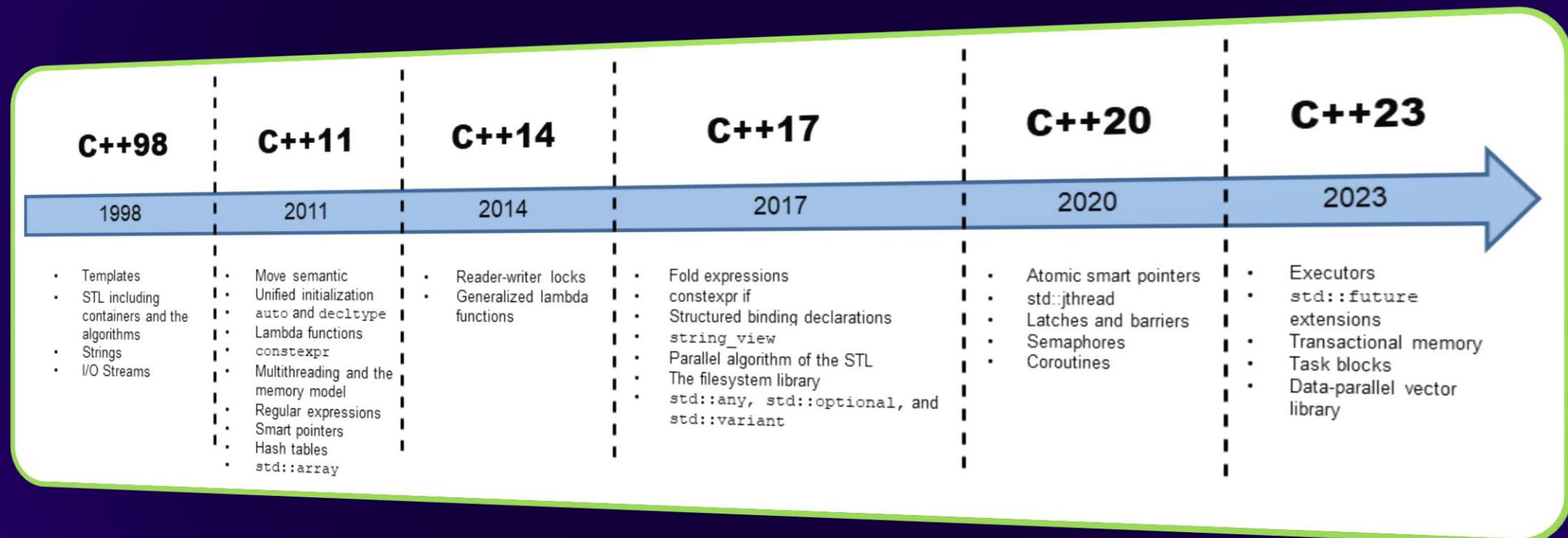
## History Of C++

- Versions with major changes:

- C++ 98
- C++ 11
- C++ 17



## Timeline of C++ Features



## New features in C++11

C++11 was the largest change ever made to C++; and due to the changed release schedule, probably will remain the largest single change. It is a well thought out, mostly backward-compatible change that can completely change the way you write code in C++. It is best thought of as almost a new language, a sort of (C++)++ language.

- **Types**
  - Typing in C++11 is much simpler. If the type is deductible, auto allows you to avoid writing it out.

```
1 // Avoiding double writing on pointers
2 auto pointer = new SomeNamespace::MyLongType(arg1, arg2);
3
4 // Does anyone know the type of an iterator? It's ugly!
5 auto iterator = some_vector.begin();
6
7 // This is useful for prototyping, but probably should be explicitly typed in real code to help coders
8 auto type = function_returns_something();
9
10 // Worst use of auto; don't do this
11 auto a = 1;
```

## New features in C++11

- **Types**
  - The *NULL keyword*, which is equivalent to 0, causes typing issues. A new `nullptr` keyword was added, and is not equivalent to zero. This is significantly better type-safety, and should be used instead of NULL.
  - The definitions of `const` and `mutable` changed a little.
- **Containers and Iterators**
  - While iterators existed in previous versions, using them is now part of the language, with the `iterating for` statement (for each). It allows a unintuitive iteration loop to be written more cleanly and compactly.

```
1  for (vector<double>::iterator iter = vector.begin(); iter != vector.end(); ++iter)
2      *value = 0.0;
3
4  for (auto& value : vector)
5      value = 0.0;
```

## New features in C++11

- **Containers and Iterators**

- A related improvement is the addition of container constructors. C++ also has a variety of different initializers; C++11 added a uniform initializer syntax, so it has even more different initializers.

```
1 std::vector<int> values = { 1,2,3,4,5,6 };
```

- **Functional Programming**

- Functions are now easier to refer to and create. The lambda function allows an inline function definition, with some perks. The syntax is `[](){}, which looks like a normal function definition with the function name and type replaced by the square brackets.`

```
1 auto square = [](double x) -> int { return x * x; };
2 double squared_five = square(5.0);
```

## New features in C++11

- **Functional Programming**

- The lambda function gets interesting when you add something to the square brackets; this is called "capture" and allows you to capture the surrounding variables.

```
1 int i = 0;
2 auto counter = [&i](){ return i++; };
3 counter(); // returns 0
4 counter(); // returns 1
```

- You can capture by value, by reference, etc. If you use [=] or [&], the lambda function will automatically capture (by value or reference, respectively) any variables mentioned inside the function.
  - Syntax used for capturing variables :
    - [&] : capture all external variables by reference
    - [=] : capture all external variables by value
    - [a, &b] : capture a by value and b by reference

## New features in C++11

- **Class Improvements**
  - Default values for members can be declared in the definition now (as I'm sure you've tried to do in older C++ at least once). You can also call a previous constructor in the initializer list (delegating constructors).

```
1  class A {
2      int x = 0, y, z;
3
4  public:
5      A()
6      {
7          x = 0;
8          y = 0;
9          z = 0;
10     }
11
12     // Constructor delegation
13     A(int z) : A()
14     {
15         this->z = z; // Only update z
16     }
17 }
```

## New features in C++11

- **Compile Time Improvements**

- The slow removal of the ugly, error-prone macro programming has started in C++11, with `constexpr`. `constexpr` is a feature added in C++ 11. The main idea is a performance improvement of programs by doing computations at compile time rather than run time. Note that once a program is compiled and finalized by the developer, it is run multiple times by users. The idea is to spend time in compilation and save time at run time (similar to template metaprogramming).

```
1 #include <iostream>
2
3 constexpr int product(int x, int y) { return (x * y); }
4
5 int main()
6 {
7     constexpr int x = product(10, 20);
8     std::cout << x;
9
10 }
```

## New features in C++11

- **Compile Time Improvements**

- A function be declared as `constexpr`:

1. In C++ 11, a `constexpr` function should contain only one return statement. C++ 14 allows more than one statement.
2. `constexpr` function should refer only to constant global variables.
3. `constexpr` function can call only other `constexpr` functions not simple functions.
4. The function should not be of a void type.
5. In C++11, prefix increment (`++v`) was not allowed in `constexpr` function but this restriction has been removed in C++14.

```
1 // C++ program to demonstrate constexpr function to evaluate
2 // the size of array at compile time.
3 #include <iostream>
4
5 constexpr int product(int x, int y) { return (x * y); }
6
7 int main()
8 {
9     int arr[product(2, 3)] = { 1, 2, 3, 4, 5, 6 };
10    std::cout << arr[5];
11    return 0;
12 }
```

## New features in C++11

- **Compile Time Improvements**
  - constexpr with constructors: A constructor that is declared with a `constexpr` specifier is a `constexpr` constructor also. `constexpr` can be used in the making of constructors and objects. A `constexpr` constructor is implicitly inline.
  - Restrictions on constructors that can use `constexpr`:
    - No virtual base class
    - Each parameter should be literal
    - It is not a try block function
- **Std Library Improvements**
  - The powerful `std::shared_ptr` and `std::unique_ptr` remove most of the reasons to fear pointers.
  - A chrono library was added for consistent timekeeping on all platforms.
  - A threading library provides tools that work with the new functional tools and makes threading easy, and also a mutex and atomic library to support it.
  - A regular expression library was added.
  - Random number generation is finally properly supported, with a good set of algorithms and distributions.
  - Several container libraries were added.

## New features in C++11

- **Variadic Templates**
  - Variadic templates allow a function or constructor to take an unlimited number of arguments of any type.

```
1 // To handle base case of below recursive
2 // Variadic function Template
3 void print()
4 {
5 }
6
7 // Variadic function Template that takes
8 // variable number of arguments and prints
9 // all of them.
10 template <typename T, typename... Types>
11 void print(T var1, Types... var2)
12 {
13     cout << var1 << endl;
14     print(var2...);
15 }
16
17 // Driver code
18 int main()
19 {
20     print(1, 2, 3.14, "Hello");
21
22     return 0;
23 }
```

## New features in C++11

- **Move Semantics**
  - One of the more fundamental changes in the language was the promotion of move semantics to a language feature, as well as stronger guidelines on auto-optimization.

```
Object item = Object_returning_function();
```

- Here, you create a Object inside the function, and then copy it to a new object item, then delete the old object. It's horribly wasteful in both time and memory; if you don't have enough memory for two separate copies of Object, you can crash your program. In C++11, not only is the idea of a move instead of a copy added, the compiler is generally recommended to do that for you if it can. So the value will simply be moved, with no changes to either the function or the line above, as long as there are no references retained to the object inside the function (through globals, members, parameters, etc).

## constexpr vs inline Functions

Constexpr	Inline Functions
It removes the function calls as it evaluates the code/expressions in compile time.	It hardly removes any function call as it performs an action on expression in the run time.
It is possible to assess the value of the variable or function at compile time.	It is not possible to assess the value of the function or variable at compile time.
It does not imply external linkage.	It implies external linkage.

## constexpr vs const

- constexpr is mainly for optimization while const is for practically const objects like the value of Pi.
- Both of them can be applied to member methods. Member methods are made const to make sure that there are no accidental changes in the method.
- On the other hand, the idea of using constexpr is to compute expressions at compile time so that time can be saved when the code is run.
- const can only be used with non-static member functions whereas constexpr can be used with member and non-member functions, even with constructors but with condition that argument and return type must be of literal types.

## Literals

- Literals are the Constant values that are assigned to the constant variables. Literals represent fixed values that cannot be modified. Literals contain memory but they do not have references as variables. For example, "const int = 5;", is a constant expression and the value 5 is referred to as a constant integer literal.
- Literal Types
  - Integer literal
  - Float literal
  - Character literal
  - String literal
  - Boolean Literals
- Integer Literals
  - Integer literals are used to represent and store the integer values only. Integer literals are expressed in two types i.e.
    - Prefixes
    - Suffixes

## Literals

- Integer Literals
  - Prefixes

- a. **Decimal-literal(base 10):** A non-zero decimal digit followed by zero or more decimal digits(0, 1, 2, 3, 4, 5, 6, 7, 8, 9).

Example: 56, 78

- b. **Octal-literal(base 8):** a 0 followed by zero or more octal digits(0, 1, 2, 3, 4, 5, 6, 7).

Example: 045, 076, 06210

- c. **Hex-literal(base 16):** 0x or 0X followed by one or more hexadecimal digits(0, 1, 2, 3, 4, 5, 6, 7, 8, 9, a, A, b, B, c, C, d, D, e, E, f, F).

Example: 0x23A, 0Xb4C, 0xFEAE

- d. **Binary-literal(base 2):** 0b or 0B followed by one or more binary digits(0, 1).

Example: 0b101, 0B111

## Literals

- Integer Literals
  - Suffixes: The Suffix of the integer literal indicates the type in which it is to be read. For example: 12345678901234LL indicates a long long integer value 12345678901234 because of the suffix LL.

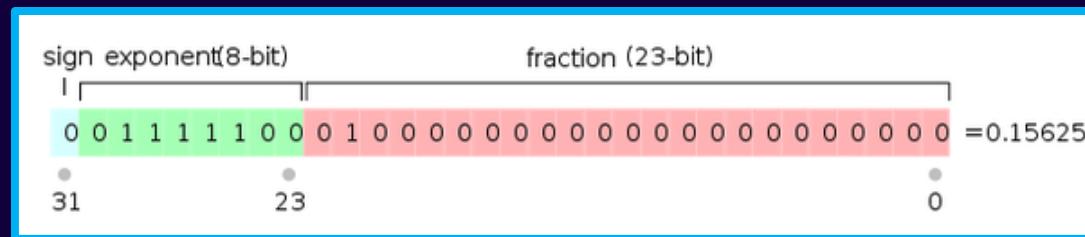
Example: 12345678901234LL

- a. int: No suffix is required because integer constant is by default assigned as an int data type.
- b. unsigned int: character **u** or **U** at the end of an integer constant.
- c. long int: character **l** or **L** at the end of an integer constant.
- d. unsigned long int: character **ul** or **UL** at the end of an integer constant.
- e. long long int: character **ll** or **LL** at the end of an integer constant.
- f. unsigned long long int: character **ull** or **ULL** at the end of an integer constant.

## Literals

- **Floating-Point Literals**

- These are used to represent and store real numbers. The real number has an integer part, real part, fractional part, and exponential part.



- Valid Floating Literals:
    - 10.125
    - 1.215-10L
    - 10.5E-3
  - Invalid Floating Literals:
    - 123E
    - 1250f
    - 0.e879

## Literals

- **Character Literal**
  - This refers to the literal that is used to store a single character within a single quote. To store multiple characters, one needs to use a character array.
    - a. **char type:** This is used to store normal character literal or narrow-character literals. This is supported by both C and C++.

```
Example: char chr = 'G';
```

- **wchar\_t type:** This is used to store normal character literal or narrow-character literals. This is supported by both C and C++.

```
Example: wchar_t chr = L'G';
```

## Literals

- **Character Literal**
  - This refers to the literal that is used to store a single character within a single quote. To store multiple characters, one needs to use a character array.
    - a. **char type:** This is used to store normal character literal or narrow-character literals. This is supported by both C and C++.

```
Example: char chr = 'G';
```

- **wchar\_t type:** This is used to store normal character literal or narrow-character literals. This is supported by both C and C++.

```
Example: wchar_t chr = L'G';
          wchar_t chr = L'\x3b1';
```

## Literals

- **String Literals**
  - String literals are similar to character literals, except that they can store multiple characters and uses a double quote to store the same.

```
Example: string stringVal = "MyValue"
```

- **Boolean Literals**
  - This literal is provided only in C++ and not in C.

```
Example: bool var = true/false;
```

## Literals

- User Defined Literals (UDL)
  - A literal is used for representing a fixed value in a program. A literal could be anything in a code like a, b, c2., 'ACB', etc.

```
// Examples of classical literals for built-in types.  
42          // int  
2.4         // double  
3.2F        // float  
'w'         // char  
32ULL       // Unsigned long long  
0xD0        // Hexadecimal unsigned  
"cd"        // C-style string(const char[3])
```

- UDLs are treated as a call to a literal operator. Only suffix form is supported. The name of the literal operator is operator "" followed by the suffix (operator "" suffix-identifier c++11).

## Obfuscation

- In software development, obfuscation is the act of creating source or machine code that is difficult for humans or computers to understand. Other approaches include stripping out potentially revealing metadata, replacing class and variable names with meaningless labels and adding unused or meaningless code to an application script.
- Obfuscation techniques:
  - *Renaming*: The obfuscator alters the methods and names of variables. The new names may include unprintable or invisible characters.
  - *Packing*: This compresses the entire program to make the code unreadable.
  - *Control flow*: The decompiled code is made to look like spaghetti logic, which is unstructured and hard to maintain code where the line of thought is obscured. Results from this code are not clear, and it's hard to tell what the point of the code is by looking at it.

## Obfuscation

- Obfuscation techniques:
  - *Instruction pattern transformation:* This approach takes common instructions created by the compiler and swaps them for more complex, less common instructions that effectively do the same thing.
  - *Dummy code insertion:* Dummy code can be added to a program to make it harder to read and reverse engineer, but it does not affect the program's logic or outcome.
  - *Metadata or unused code removal:* Unused code and metadata give the reader extra information about the program, much like annotations on a Word document, that can help them read and debug it. Removing metadata and unused code leaves the reader with less information about the program and its code.

## Obfuscation

- Obfuscation techniques:
  - *Opaque predicate insertion:* A predicate in code is a logical expression that is either true or false. Opaque predicates are conditional branches -- or if-then statements -- where the results cannot easily be determined with statistical analysis. Inserting an opaque predicate introduces unnecessary code that is never executed but is puzzling to the reader trying to understand the decompiled output.
  - *Anti-debug:* Legitimate software engineers and hackers use debug tools to examine code line by line. With these tools, software engineers can spot problems with the code, and hackers can use them to reverse engineer the code. IT security pros can use anti-debug tools to identify when a hacker is running a debug program as part of an attack. Hackers can run anti-debug tools to identify when a debug tool is being used to identify the changes they are making to the code.
  - *Anti-tamper:* These tools detect code that has been tampered with, and if it has been modified, it stops the program.

## Obfuscation

- Obfuscation techniques:
  - *Anti-tamper*: These tools detect code that has been tampered with, and if it has been modified, it stops the program.
  - *String encryption*: This method uses encryption to hide the strings in the executable and only restores the values when they are needed to run the program. This makes it difficult to go through a program and search for particular strings.
  - *Code transposition*: This is the reordering of routines and branches in the code without having a visible effect on its behavior.

## Obfuscator tools

- Stunnix C/C++ Obfuscator
- Mangle-It C++ Code Obfuscator
- CodeMorph
- Online Offuscator (<https://picheta.me/obfuscator>)
- TinyObfuscate
- Themida
  - Themida is a powerful software protection system designed for software developers who wish to protect their applications against advanced reverse engineering and software cracking. Themida uses the SecureEngine® protection system to achieve its goals, making it really difficult to break using the traditional and newest cracking tools.

## Windows

- Portable Executable (PE) Format

## Linux

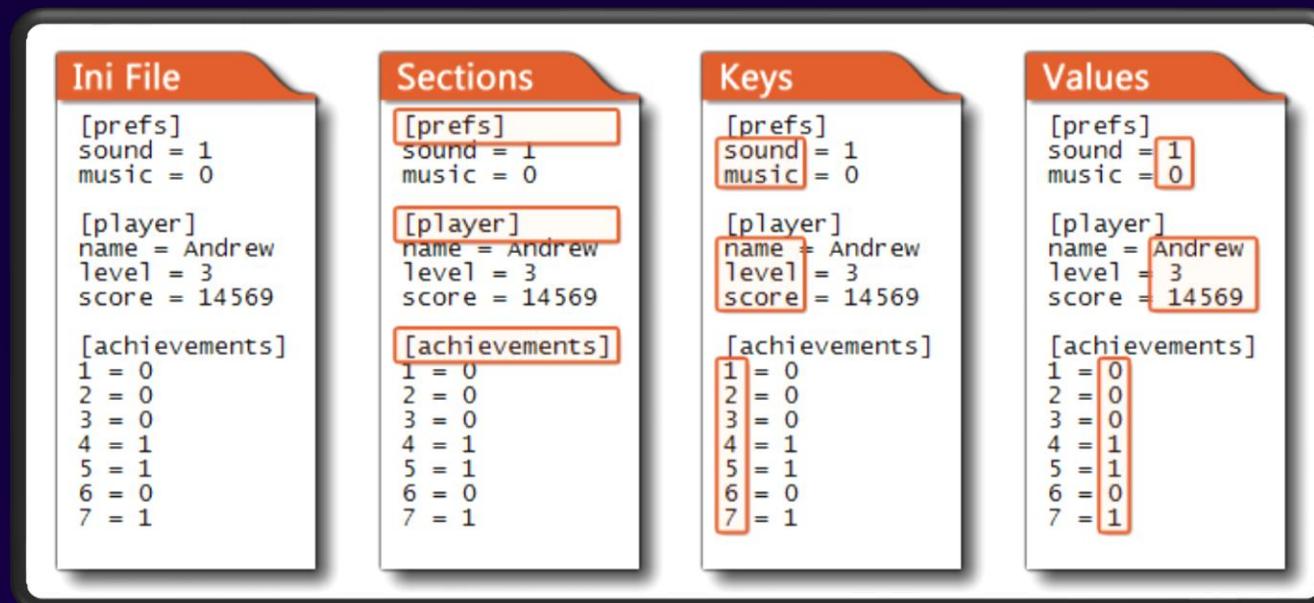
- Linkable (ELF) Format

## Binary file viewing and editing tools

- Resource Hacker
- ResEdit
- PE Explorer
- PE-bear
- PE Viewer
- XN Resource Editor

## INI file

- An INI file (INInitialization file) is a configuration file for computer software that consists of a text-based content with a structure and syntax comprising **key-value** pairs for properties, and sections that organize the properties.



↳ = T  
0 = 0  
2 = T

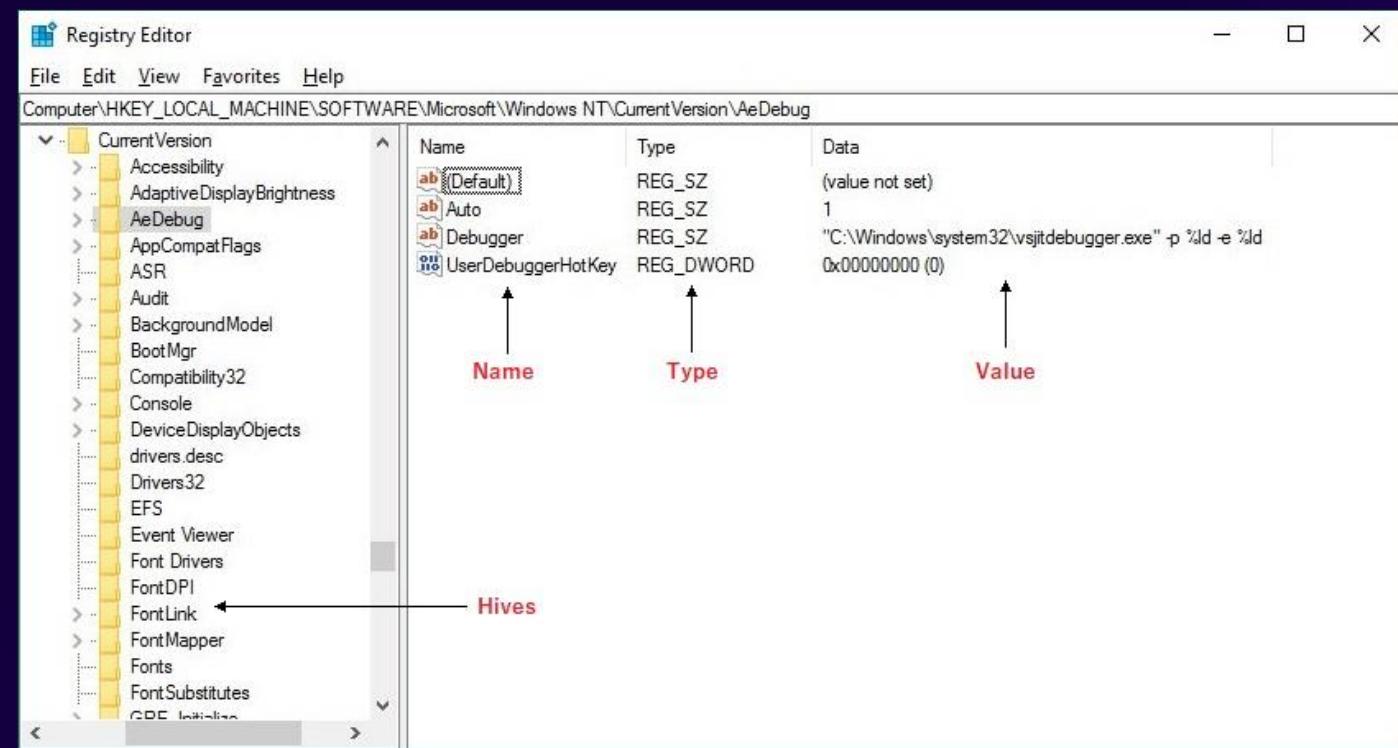
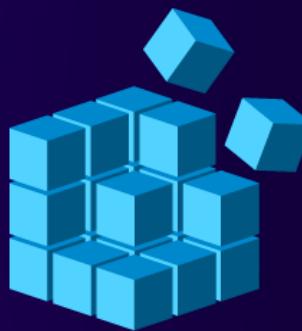
↳ = T  
0 = 0  
2 = T

↳ = T  
0 = 0  
2 = T

↳ = T  
0 = 0  
2 = T

## Registry

- The Windows Registry is a hierarchical database that stores low-level settings for the Microsoft Windows operating system and for applications that opt to use the registry. The kernel, device drivers, services, Security Accounts Manager, and user interfaces can all use the registry.



## QVariant

- The QVariant class acts like a union for the most common Qt data types.
- A QVariant object holds a **single value** of a single typelid() at a time. (Some types are multi-valued, for example a string list.) You can find out what type, T, the variant holds, convert it to a different type using convert(), get its value using one of the toT() functions (e.g., toSize()), and check whether the type can be converted to a particular type using canConvert().
- The methods named toT() (e.g., toInt(), toString()) are const. If you ask for the stored type, they return a copy of the stored object. If you ask for a type that can be generated from the stored type, toT() copies and converts and leaves the object itself unchanged. If you ask for a type that cannot be generated from the stored type, the result depends on the type.

Header: #include <QVariant>

qmake: QT += core

## QVariant

```
QDataStream out(...);
QVariant v(123);                      // The variant now contains an int
int x = v.toInt();                     // x = 123
out << v;                            // Writes a type tag and an int to out
v = QVariant(tr("hello"));            // The variant now contains a QString
int y = v.toInt();                     // y = 0 since v cannot be converted to an int
QString s = v.toString();              // s = tr("hello") (see QObject::tr())
out << v;                            // Writes a type tag and a QString to out
...
QDataStream in(...);                  // (opening the previously written stream)
in >> v;                            // Reads an Int variant
int z = v.toInt();                     // z = 123
qDebug("Type is %s",
       v.typeName());                 // prints "Type is int"
v = v.toInt() + 100;                  // The variant now holds the value 223
v = QVariant(QStringList());          // The variant now holds a QStringList
```

## QSettings

- The `QSettings` class provides persistent platform-independent application settings. Users normally expect an application to remember its settings (window sizes and positions, options, etc.) across sessions. This information is often stored in the system registry on Windows, and in property list files on macOS and iOS. On Unix systems, in the absence of a standard, many applications (including the KDE applications) use INI text files.

## Methods

- `QSettings(QSettings::Scope scope, QObject *parent = nullptr);`
  - This enum specifies whether settings are user-specific or shared by all users of the same system.
- `QSettings(const QString &fileName, QSettings::Format format, QObject *parent = nullptr);`
  - If `format` is `QSettings::NativeFormat`, the meaning of `fileName` depends on the platform. On Unix, `fileName` is the name of an INI file. On macOS and iOS, `fileName` is the name of a .plist file. On Windows, `fileName` is a path in the system registry.
  - If `format` is `QSettings::IniFormat`, `fileName` is the name of an INI file.

Warning: This function is provided for convenience. It works well for accessing INI or .plist files generated by Qt, but might fail on some syntaxes found in such files originated by other programs.

Header:	#include <QSettings>
qmake:	QT += core

## Methods

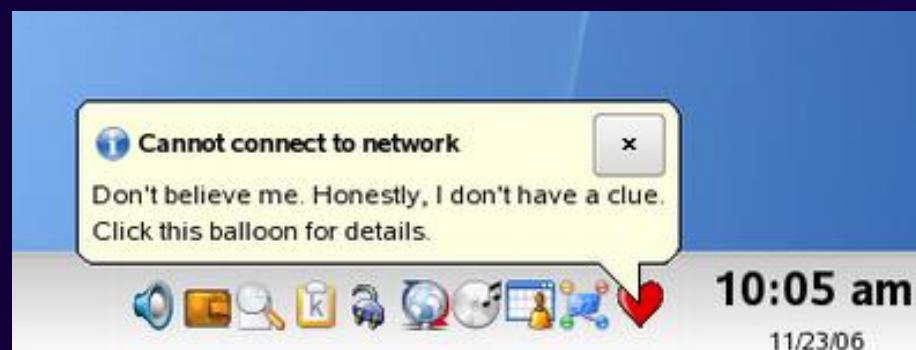
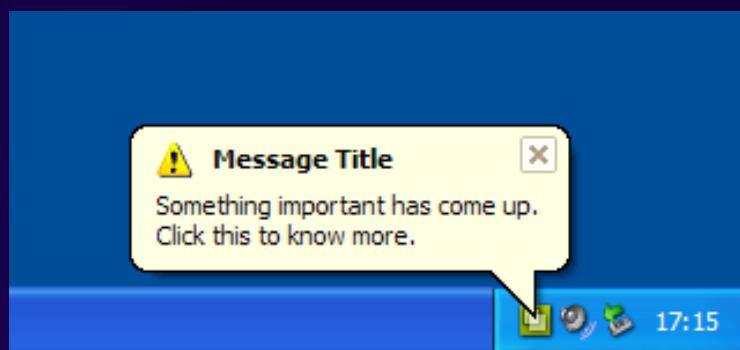
- `QSettings(QSettings::Format format, QSettings::Scope scope, const QString &organization, const QString &application = QString(), QObject *parent = nullptr);`
  - If scope is `QSettings::UserScope`, the `QSettings` object searches user-specific settings first, before it searches system-wide settings as a fallback. If scope is `QSettings::SystemScope`, the `QSettings` object ignores user-specific settings and provides access to system-wide settings.
  - If format is `QSettings::NativeFormat`, the native API is used for storing settings. If format is `QSettings::IniFormat`, the INI format is used.
  - If no application name is given, the `QSettings` object will only access the organization-wide locations.
- `QSettings(QSettings::Scope scope, const QString &organization, const QString &application = QString(), QObject *parent = nullptr);`
  - If scope is `QSettings::UserScope`, the `QSettings` object searches user-specific settings first, before it searches system-wide settings as a fallback. If scope is `QSettings::SystemScope`, the `QSettings` object ignores user-specific settings and provides access to system-wide settings.
  - The storage format is set to `QSettings::NativeFormat` (i.e. calling `setDefaultFormat()` before calling this constructor has no effect).
  - If no application name is given, the `QSettings` object will only access the organization-wide locations.

## Methods

- `void QSettings::setValue(const QString &key, const QVariant &value);`
  - Sets the value of setting key to value. If the key already exists, the previous value is overwritten.  
Note that the Windows registry and INI files use case-insensitive keys, whereas the CFPrefrences API on macOS and iOS uses case-sensitive keys.
- `QVariant QSettings::value(const QString &key, const QVariant &defaultValue = QVariant()) const;`
  - Returns the value for setting key. If the setting doesn't exist, returns defaultValue.
  - If no default value is specified, a default QVariant is returned.  
Note that the Windows registry and INI files use case-insensitive keys, whereas the CFPrefrences API on macOS and iOS uses case-sensitive keys.
- `void QSettings::beginGroup(const QString &prefix);`
  - The current group is automatically prepended to all keys specified to QSettings. In addition, query functions such as childGroups(), childKeys(), and allKeys() are based on the group. By default, no group is set.
- `void QSettings::endGroup();`
  - Resets the group to what it was before the corresponding beginGroup() call.

## QSystemTrayIcon

- The QSystemTrayIcon class provides an icon for an application in the system tray.
- Modern operating systems usually provide a special area on the desktop, called the system tray or notification area, where long-running applications can display icons and short messages.



```
Header: #include <QSystemTrayIcon>
```

```
qmake: QT += widgets
```

## Methods

- `void setContextMenu(QMenu *menu);`
  - Sets the specified menu to be the context menu for the system tray icon.
  - The menu will pop up when the user requests the context menu for the system tray icon by clicking the mouse button.

Note: The system tray icon does not take ownership of the menu. You must ensure that it is deleted at the appropriate time by, for example, creating the menu with a suitable parent object.
- `void setIcon(const QIcon &icon);`
  - This property holds the system tray icon.
  - On Windows, the system tray icon size is 16x16; on X11, the preferred size is 22x22. The icon will be scaled to the appropriate size as necessary.
- `void showMessage(const QString &title, const QString &message, QSystemTrayIcon::MessageIcon icon = QSystemTrayIcon::Information, int millisecondsTimeoutHint = 10000);`
  - Shows a balloon message for the entry with the given title, message and icon for the time specified in millisecondsTimeoutHint. title and message must be plain text strings.

## QSignalMapper

- This class collects a set of parameterless signals, and re-emits them with integer, string or widget parameters corresponding to the object that sent the signal. Note that in most cases you can use lambdas for passing custom parameters to slots.

## Signals

- `void mappedInt(int i);`
- `void mappedObject(QObject *object);`
- `void mappedString(const QString &text);`

## Methods

- `void setMapping(QObject *sender, int id);`
- `void setMapping(QObject *sender, const QString &text);`
- `void setMapping(QObject *sender, QObject *object);`

Header: `#include <QSignalMapper>`

qmake: `QT += core`

## Sender (QObject::sender())

- Returns a pointer to the object that sent the signal, if called in a slot activated by a signal; otherwise it returns nullptr. The pointer is valid only during the execution of the slot that calls this function from this object's thread context.

**Note:** The pointer returned by this function becomes invalid if the sender is destroyed, or if the slot is disconnected from the sender's signal.

**Warning:** This function violates the object-oriented principle of modularity. However, getting access to the sender might be useful when many signals are connected to a single slot.

**Warning:** As mentioned above, the return value of this function is not valid when the slot is called via a Qt::DirectConnection from a thread different from this object's thread. Do not use this function in this type of scenario.

## Dynamic Properties (in QObjects)

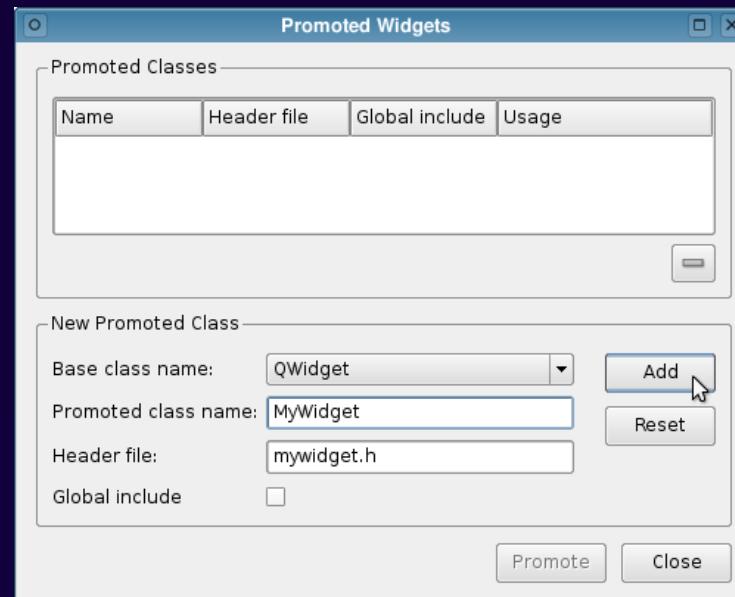
- From Qt 4.2, dynamic properties can be added to and removed from QObject instances at run-time. Dynamic properties do not need to be declared at compile-time, yet they provide the same advantages as static properties and are manipulated using the same API - using property() to read them and setProperty() to write them.
- From Qt 4.3, dynamic properties are supported by Qt Designer, and both standard Qt widgets and user-created forms can be given dynamic properties.

## Methods

- `bool QObject::setProperty(const char *name, const QVariant &value);`
  - Sets the value of the object's name property to value.
- `QVariant QObject::property(const char *name) const;`
  - Returns the value of the object's name property.
  - If no such property exists, the returned variant is invalid.
- `QList<QByteArray> QObject::dynamicPropertyNames() const;`
  - Returns the names of all properties that were dynamically added to the object using setProperty().

## Types of promotion

- Programmatically promote
- With Qt Designer
  - Qt Designer can display custom widgets through its extensible plugin mechanism, allowing the range of designable widgets to be extended by the user and third parties. Alternatively, it is possible to use existing widgets as placeholders for widget classes that provide similar APIs.



## Third party libraries (External libraries)

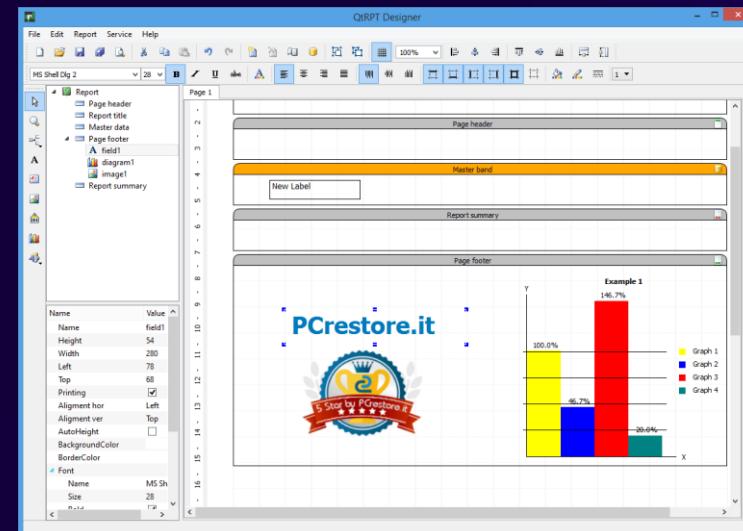
- **Source:** <https://github.com/qtproject/qt-solutions>
  - **QtSingleApplication**
    - The QtSingleApplication class provides an API to detect and communicate with running instances of an application.
    - This class allows you to create applications where only one instance should be running at a time. I.e., if the user tries to launch another instance, the already running instance will be activated instead. Another usecase is a client-server system, where the first started instance will assume the role of server, and the later instances will act as clients of that server.
  - **QtService**
    - The QtService is a convenient template class that allows you to create a service for a particular application type.
    - A Windows service or Unix daemon (a "service"), is a program that runs "in the background" independently of whether a user is logged in or not. A service is often set up to start when the machine boots up, and will typically run continuously as long as the machine is on.

## Third party libraries (External libraries)

- **Source:** <https://github.com/qt-project/qtrpt>

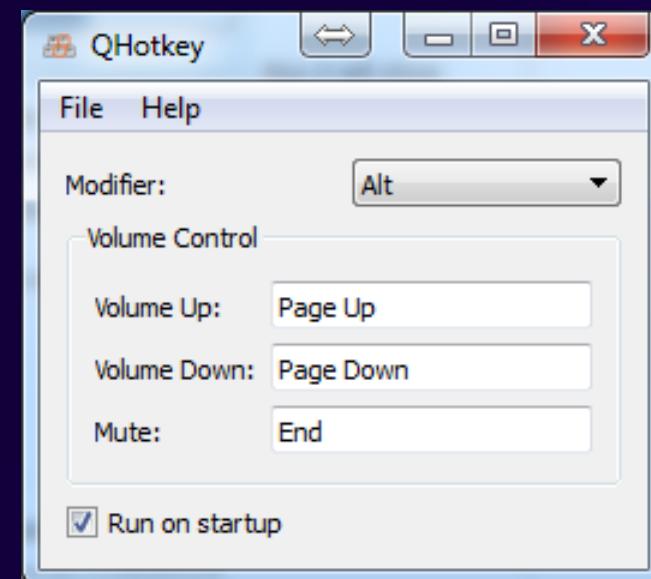
- **QtRPT (Report)**

- QtRPT is the easy-to-use report engine written in C++ QtToolkit. It allows combining several reports in one XML file. For separately taken field, you can specify some condition depending on which this field will display in different font and background color, etc. The project consists of two parts: report library QtRPT and report designer application QtRptDesigner. Report file is a file in XML format. The report designer makes easy to create report XML file.



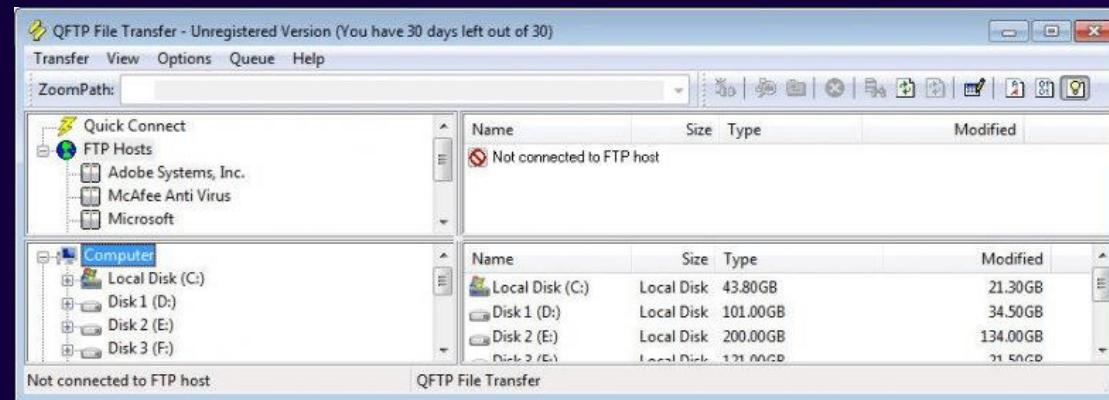
## Third party libraries (External libraries)

- Source: <https://github.com/Skycoder42/QHotkey>
  - QHotkey
    - A global shortcut/hotkey for Desktop Qt-Applications.
    - The QHotkey is a class that can be used to create hotkeys/global shortcuts, aka shortcuts that work everywhere, independent of the application state. This means your application can be active, inactive, minimized or not visible at all and still receive the shortcuts.



## Third party libraries (External libraries)

- [Source: https://github.com/qt/qtftp](https://github.com/qt/qtftp)
  - QtFtp
    - The QFtp class provides an implementation of the client side of FTP protocol.
    - This class provides a direct interface to FTP that allows you to have more control over the requests. However, for new applications, it is recommended to use QNetworkAccessManager and QNetworkReply, as those classes possess a simpler, yet more powerful API.
    - The class works asynchronously, so there are no blocking functions. If an operation cannot be executed immediately, the function will still return straight away and the operation will be scheduled for later execution. The results of scheduled operations are reported via signals. This approach depends on the event loop being in operation.



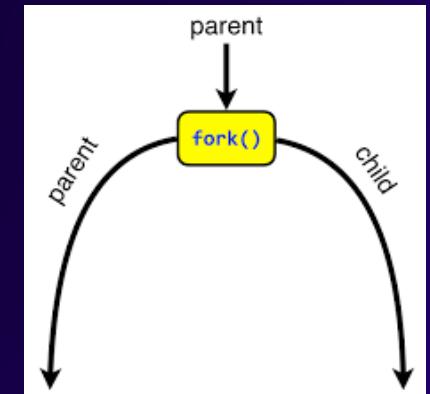
## fork

- fork() is a system call that creates a child process from the parent process. Whenever we call fork() from the parent program, a child process is created that has the exact copy of the address space. The important thing to remember is it shares the copy of the address space, not the copy itself.

```
#include <unistd.h>

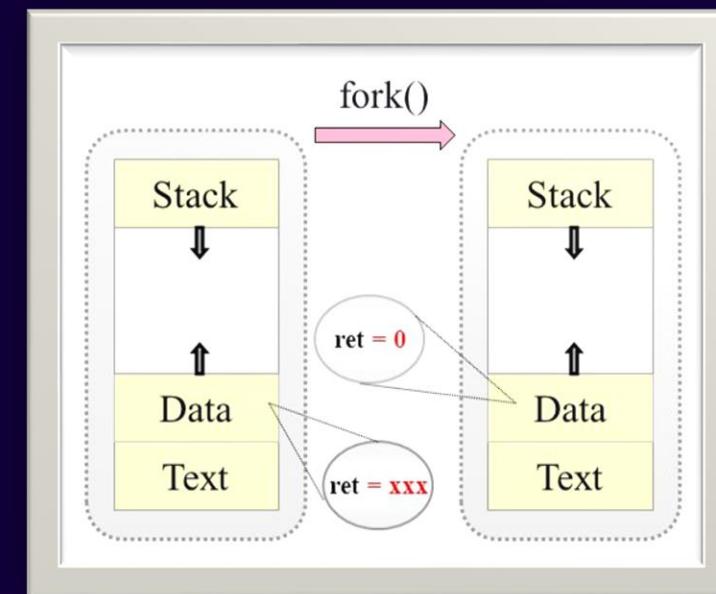
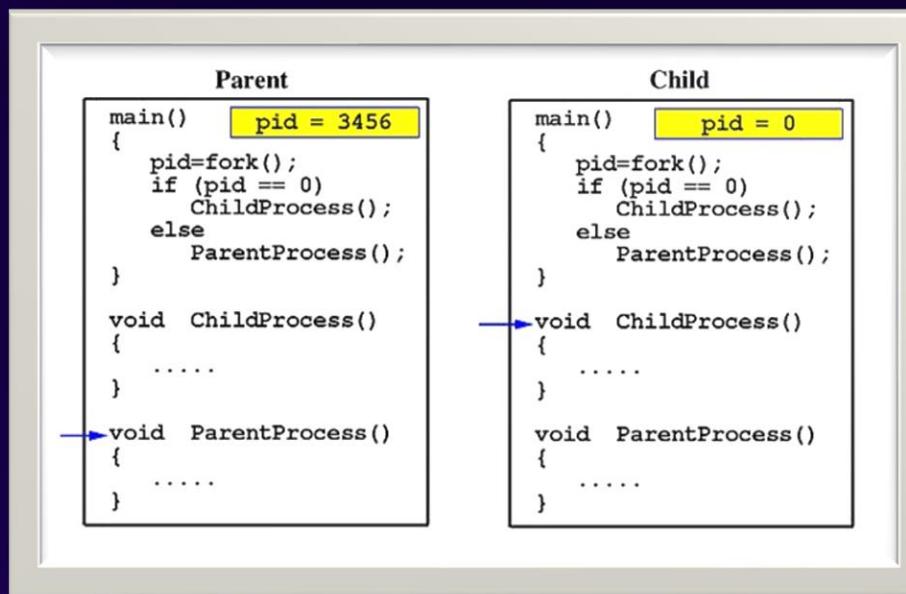
pid_t fork(void);
```

- Current process split into 2 process: parent, child
  - Return -1 if unsuccessful
  - Return 0 in the child
  - Return the child's identifier in the parent



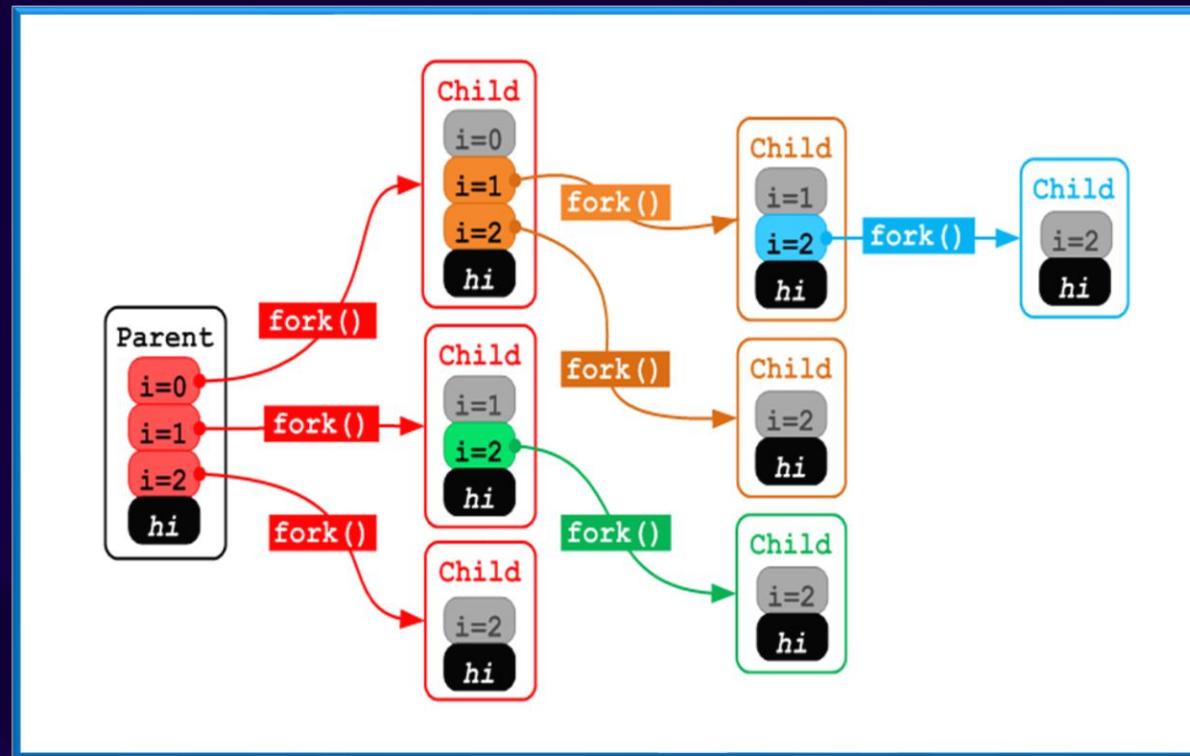
## fork

- Significance:
  - Both the parent and child processes are two separate threads that execute in different address space
  - Threads are similar to the process except that they share the address space
  - fork function can run concurrently in the same program or can run an executable from the file system
  - It helps to distinguish parent and child processes using pid. It returns 0 for the child process and a positive integer for the parent



## fork

- When a parent forks a child, there are two processes, parent and child. But when a child creates another child, the number increases in the power of 2. For example, when there are two forks( ) calls, n=2 and the total number of processes is  $2^2 = 4$ .

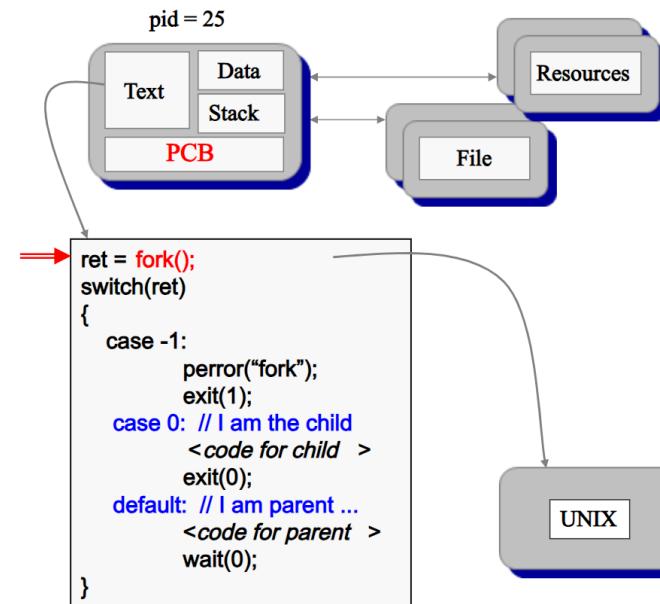


# Linux Advanced Programming >> System Calls

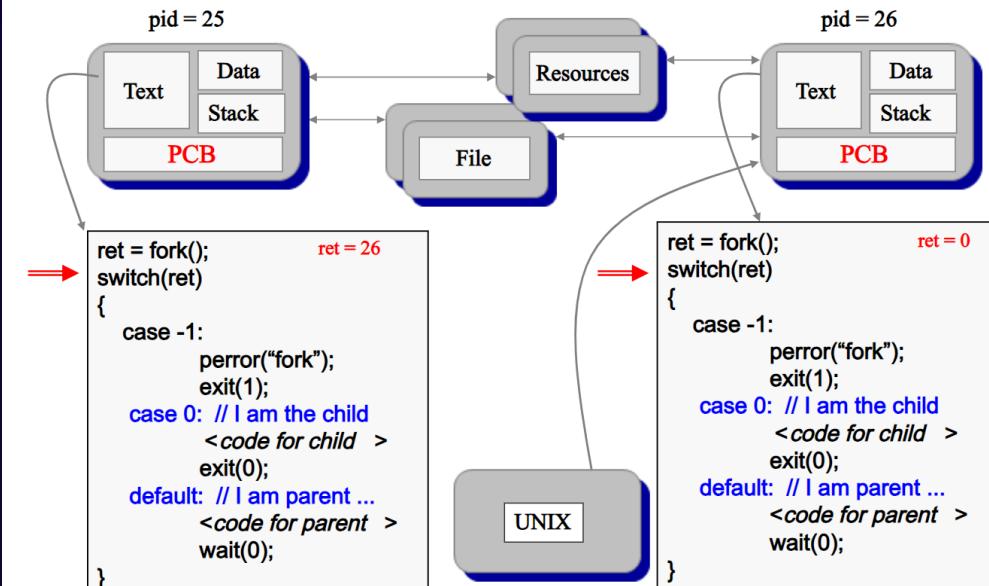
Qt

fork

1



2

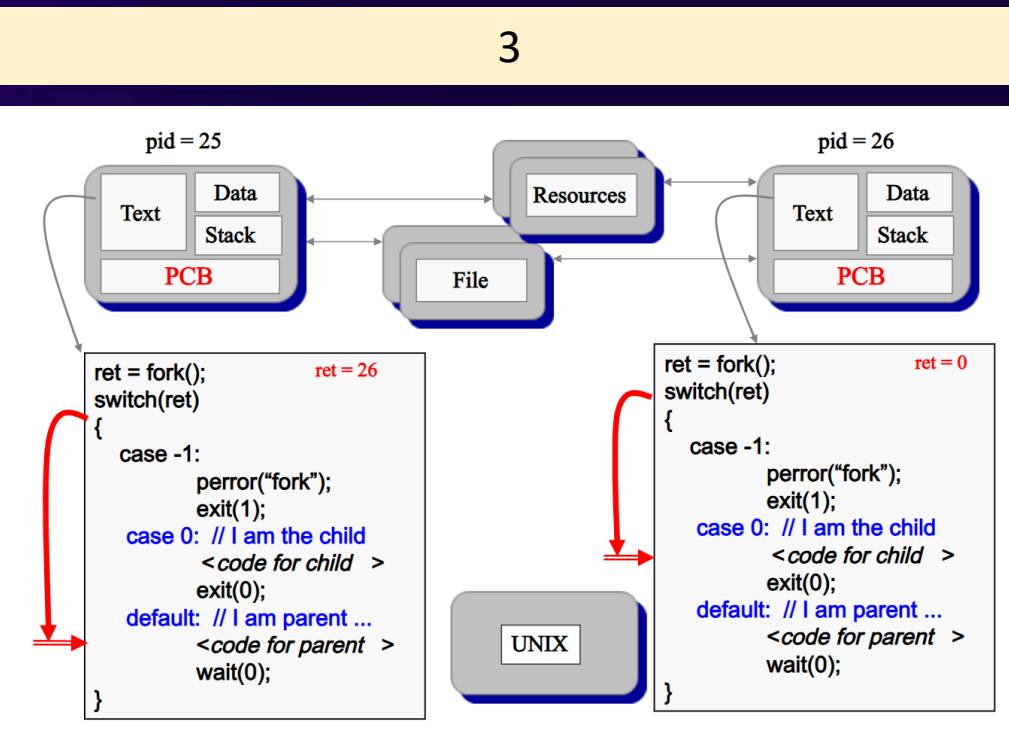


# Linux Advanced Programming >> System Calls

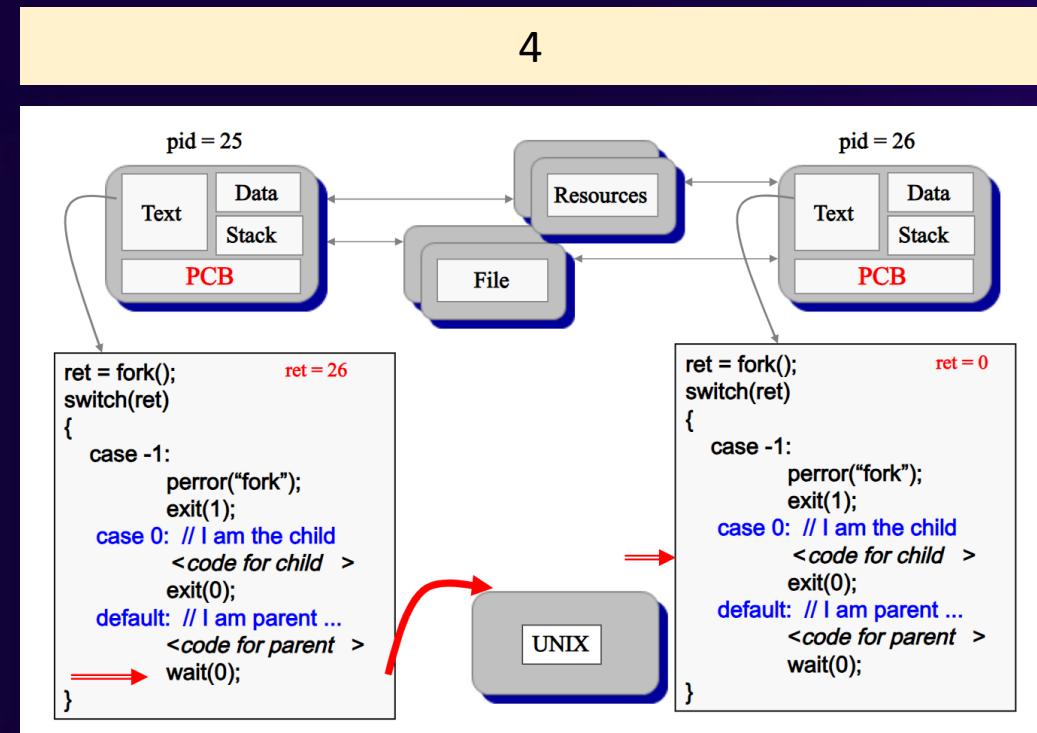
Qt

## fork

3



4

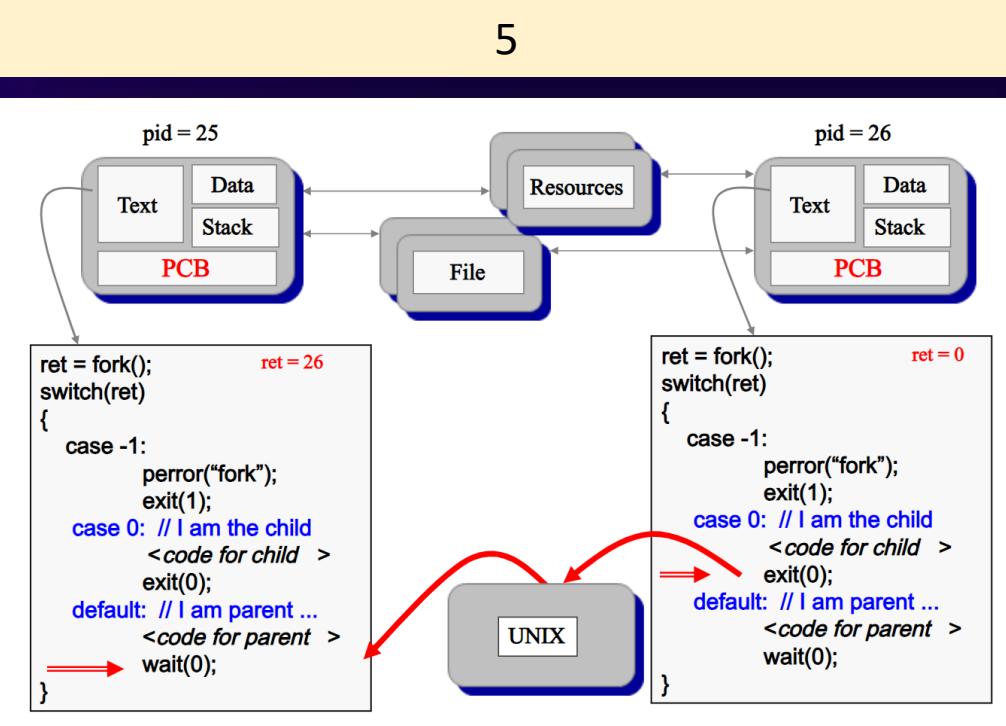


# Linux Advanced Programming >> System Calls

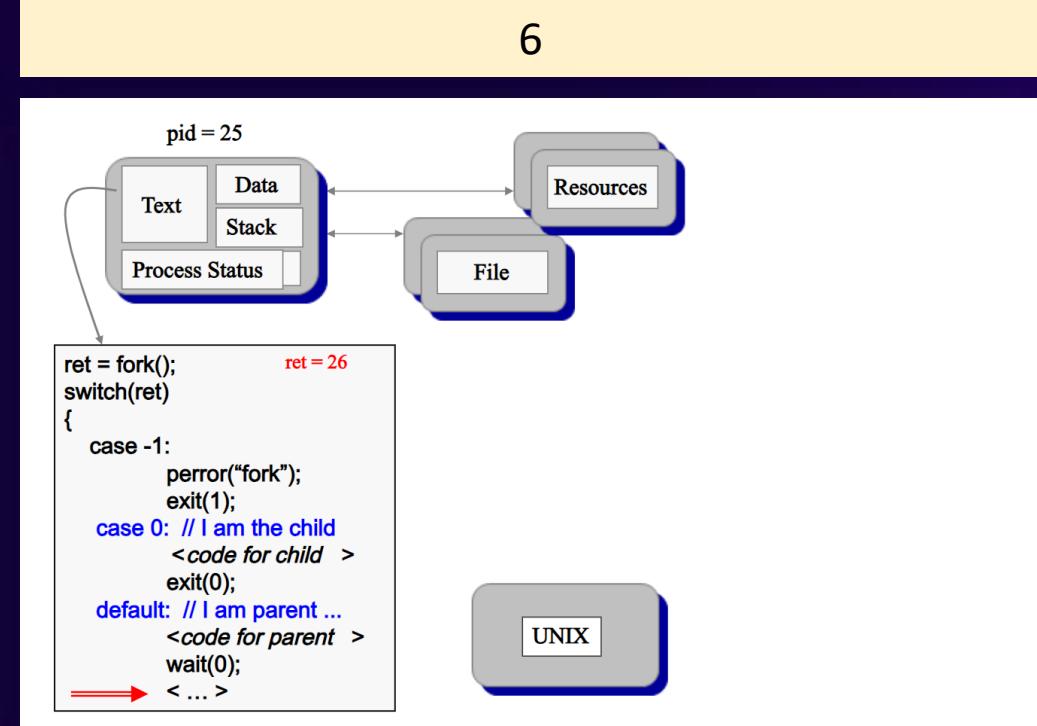
Qt

## fork

5



6



## wait

- A call to `wait()` blocks the calling process until one of its child processes exits or a signal is received. After child process terminates, parent continues its execution after `wait` system call instruction.

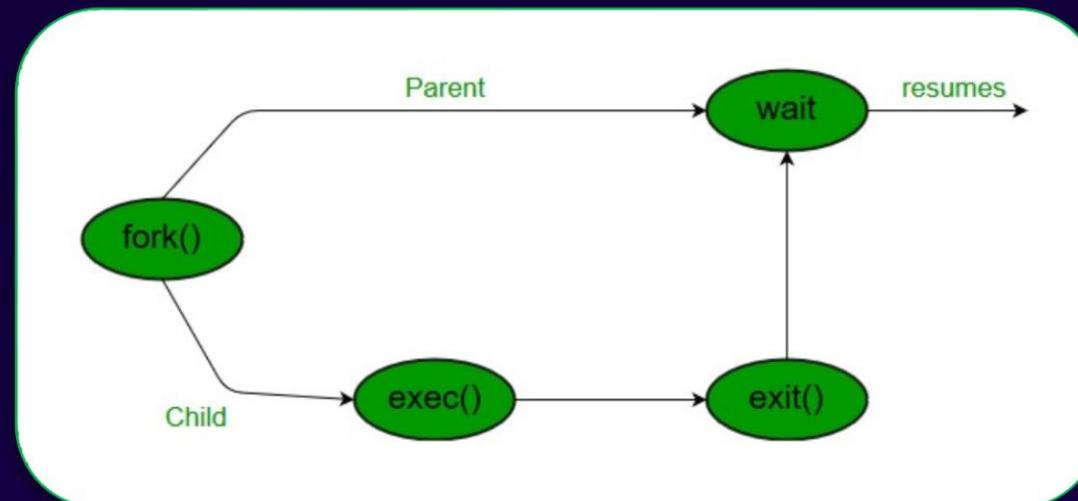
```
<sys/wait.h>

// take one argument status and returns
// a process ID of dead children.
pid_t wait(int *stat_loc);
```

- Child process may terminate due to any of these:
  - It calls `exit();`
  - It returns (an int) from `main`
  - It receives a signal (from the OS or another process) whose default action is to terminate.

## wait

- If any process has more than one child processes, then after calling wait(), parent process has to be in wait state if no child terminates.
- If only one child process is terminated, then return a wait() returns process ID of the terminated child process.
- If more than one child processes are terminated than wait() reap any arbitrarily child and return a process ID of that child process.
- When wait() returns they also define exit status (which tells our, a process why terminated) via pointer, If status are not NULL.
- If any process has no child process then wait() returns immediately “-1”.



## wait

- For find information about status, we use WIF....macros:
  - **WIFEXITED(status)**: child exited normally.
    - **WEXITSTATUS(status)**: return code when child exits.
  - **WIFSIGNALED(status)**: child exited because a signal was not caught.
    - **WTERMSIG(status)**: gives the number of the terminating signal.
  - **WIFSTOPPED(status)**: child is stopped.
    - **WSTOPSIG(status)**: gives the number of the stop signal.
- We know if more than one child processes are terminated, then **wait()** reaps any arbitrarily child process but if we want to reap any specific child process, we use **waitpid()** function.

```
pid_t waitpid (child_pid, &status, options);
```

## wait

- Options Parameter:
  - If 0 means no option parent has to wait for terminates child.
  - If **WNOHANG** means parent does not wait if child does not terminate just check and return **waitpid()**.(not block parent process)
  - If **child\_pid** is -1 then means any arbitrarily child, here **waitpid()** work same as **wait()** work.
- Return value of **waitpid()**
  - pid of child, if child has exited
  - 0, if using **WNOHANG** and child hasn't exited.

## exit

- To finish execution, a child may call `exit(number)`.
- This system call:
  - Unblock waiting parent
  - Orderly program termination
  - Saves result (argument of `exit`).
  - Closes all open files, connections.
  - Deallocates memory.
  - Checks if parent is alive.
  - If parent is alive, holds the result value until the parent requests it (With `wait`); in this case, the child process does not really die, but it enters a zombie/defunct state.
  - If parent is not alive, the child terminates (dies).

## signal

- A signal is a message or notification issued to your program by the operating system or another application (or one of its threads). Each signal is assigned a number between 1 and 31. Signals are devoid of argument, and most of the time, their names are self-explanatory. For instance, signal number 9 or SIGKILL notifies the program that it is being attempted to be killed.
- Types of Signals:
  - **SIGHUP:** This signal indicates that the controlling terminal has been killed. HUP is an abbreviation meaning “hang up.” Locate the terminal to be controlled or hang up on the control process’s demise. This signal is obtained when the process is performed from the terminal and that terminal abruptly terminates.
  - **SIGINT:** This is the signal generated when a user presses Ctrl + C from the keyboard.
  - **SIGQUIT:** This is the signal generated when a user presses Ctrl + D from the keyboard.
  - **SIGILL:** Signal for illegal instruction. This is an exception signal provided by the operating system to your application when it detects unlawful instruction within your program. For example, if some code is not understandable by your machine or if your program’s executable file is corrupted. Another possibility is that your program loads a corrupted dynamic library.

## signal

- Types of Signals:
  - **SIGABRT**: Abort signal indicates that you used the `abort()` API within your program. It is used to end a program. `abort()` generates the SIGABRT signal, which terminates your program (unless handled by your custom handler).
  - **SIGFPE**: Exception for floating point numbers. Another exception signal is generated by the operating system when your program causes an exception.
  - **SIGPIPE**: Broken pipe. When there is nothing to read on the other end, write to the pipe.
  - **SIGSEGV**: This is also an exception signal. When a program tries to access memory that does not belong to it, the operating system gives that application this signal.
  - **SIGALRM**: Alarm Signal sent through the `alarm()` system function to your program. The `alarm()` system call essentially acts as a timer that allows you to receive SIGALRM after a set amount of time. Although there are other timer APIs that are more accurate, this can be useful.

## signal

- Types of Signals:
  - **SIGTERM**: This signal instructs your program to quit. While SIGKILL is an abnormal termination signal, think of this as a signal to cleanly shut down.
  - **SIGCHLD**: Informs you that a child's process of your program has ended or stopped. This is useful if you want to synchronize your process with one that has children.
  - **SIGUSR1** and **SIGUSR2**: SIGUSR1 and SIGUSR2 are two undefined signals that are provided for your consideration. These signals can be used to communicate with or synchronize your software with another program.
- Signal Handler

```
signal(SIGINT, sig_handler);
```

- Command to raise signal

```
$top -c -p $(pgrep -d -f [Process Name])  
$kill -s [Signal Name] [Pid] | kill -n [Signal Number] [Pid] # kill -9 [Pid] // Force
```

## signal

- Signal as interrupt
  - Signals disrupt your program in addition to being instructive.
  - For example, one of the threads in your application must briefly switch to signal handler mode in order to process a signal.
  - As of the Linux kernel version 2.6, it should be noted that most signals only interrupt one thread, as opposed to the previous practice of interrupting the entire application.
  - Additionally, a signal handler itself may be halted by a different signal.
- Signal masks
  - Each signal has one of three possible states:
  - For the signal, we might have our own signal handler.
  - The default handler may be used to handle a signal. Each signal has a default handler job that it performs. For instance, your application will be terminated by the SIGINT default handler.
  - The signal could be overlooked. Signal blocking is another name for ignoring a signal.

**Warning:** Invoking the `longjmp()` function from within a signal handler can lead to undefined behavior if it results in the invocation of any non-asynchronous-safe functions. Consequently, neither `longjmp()` nor the POSIX `siglongjmp()` functions should ever be called from within a signal handler.

## raise

- csignal header file declared the function raise() to handle a particular signal. Signal learns some unusual behavior in a program, and calls the signal handler. It is implemented to check if the default handler will get called or it will be ignored.

```
int raise ( int signal_ );
```

- Parameter: The function accepts a single parameter sig which specifies the signal which is artificially raised. It can take any of the 6 C standard signals.
- Defined Signal Types:
  - **SIGILL**
  - **SIGINT**
  - **SIGSEGV**
  - **SIGTERM**
  - **SIGABRT**
  - **SIGFPE**

**Warning:** There is a nested call to the raise() function, which is undefined behavior.

Signal secure coding: <https://wiki.sei.cmu.edu/confluence/display/c/>

## umask

- **Command**
  - Umask (short for user file-creation mode mask) is used by UNIX-based systems to set default permissions for newly created files and directories. It does this by masking or subtracting these permissions.
- **System Call**
  - umask() sets the calling process's file mode creation mask (umask) to mask & 0777.

```
#include <sys/types.h>
#include <sys/stat.h>

mode_t umask(mode_t mask);
```

- The umask is used by open, mkdir, and other system calls that create files to modify the permissions placed on newly created files or directories. Specifically, permissions in the umask are turned off from the mode argument to open and mkdir.
- Alternatively, if the parent directory has a default ACL, the umask is ignored, the default ACL is inherited, the permission bits are set based on the inherited ACL, and permission bits absent in the mode argument are turned off.

## umask

- Command

Permissions	Octal Value	Binary Value	Description
---	0	000	No permission
--x	1	001	only permission to execute
-w-	2	010	only permission to write
-wx	3	011	permission to write and execute
r--	4	100	only permission to read
r-x	5	101	permission to read and execute
rw-	6	110	permission to read and write
rwx	7	111	permission to do all three, i.e. read, write and execute

## umask

- **Command**
  - Simplification:
    - The bit for the respective mode, i.e. in 3-bit number, the first bit(leftmost) is for read, then write and execute respectively.
    - Each digit here is for different classes of users, there are a total of 3 classes of users in Linux:
      1. The owner
      2. Group members
      3. Everyone else
  - umask values for files and directories
    - File -> The full permission set for a file is **666** (read/write permission for all) (full permissions for file) – (umask value) i.e.  $666 - 543 = 123$
    - Directory -> The full permission set for a directory is **777** (read/write/execute) (full permissions for directory) – (umask value) i.e.  $777 - 543 = 234$



## umask

- **System Call**

- The typical default value for the process umask is S\_IWGRP | S\_IWOTH (octal 022). In the usual case where the mode argument to open() is specified as:

```
S_IRUSR | S_IWUSR | S_IRGRP | S_IWRGRP | S_IROTH | S_IWOTH
```

- (octal 0666) when creating a new file, the permissions on the resulting file will be:

```
S_IRUSR | S_IWUSR | S_IRGRP | S_IROTH
```

- (because  $0666 \& \sim 022 = 0644$ ; i.e., rw-r--r--).
  - This system call always succeeds and the previous value of the mask is returned.

## chmod

- In Unix and Unix-like operating systems, chmod is the command and system call used to change the access permissions and the special mode flags of file system objects. Collectively these were originally called its modes, and the name chmod was chosen as an abbreviation of change mode.
- To change file/directory permissions for everyone, use “***u***” for users, “***g***” for group, “***o***” for others, and “***ugo***” or “***a***” (for all).
- Example:
  - chmod +rwx filename to add permissions
  - chmod -rwx directoryname to remove permissions.
  - chmod +x filename to allow executable permissions.
  - chmod -wx filename to take out write and executable permissions.
  - chmod ugo+rwx foldername to give read, write, and execute to everyone.
  - chmod a=r foldername to give only read permission for everyone.

## Special-Permissions

- The **"chmod g+s"** command sets the "set group ID" (setgid) mode bit on the current directory. This means that all new files and subdirectories created within the current directory inherit the group ID of the directory, rather than the primary group ID of the user who created the file.

```
ubuntu@itslinuxfoss:~$ ls -l testfile2
-rw-rw-r-- 1 ubuntu ubuntu 0 Dec 29 15:00 testfile2
ubuntu@itslinuxfoss:~$ chmod g+s testfile2
ubuntu@itslinuxfoss:~$ ls -l testfile2
-rw-rwsr-- 1 ubuntu ubuntu 0 Dec 29 15:00 testfile2
ubuntu@itslinuxfoss:~$
```

## chdir

- The `chdir` command is a system function (system call) that is used to change the current working directory. On some systems, this command is used as an alias for the shell command `cd`. `chdir` changes the current working directory of the calling process to the directory specified in `path`.

```
int chdir(const char *path);
```

- Errors:**

There can be errors that can be returned. These depend on the filesystem.

- EACCES:** If the search permission is denied for one of the components of the path.
- EFAULT:** If the path points lie outside the accessible address space.
- EIO:** If there is an I/O error occurred.
- ELOOP:** If there are too many symbolic links encountered in the resolving path.
- ENAMETOOLONG:** If the path is too long.
- ENOENT:** If the file does not exist.
- ENOMEM:** If there is insufficient kernel memory available.
- ENOTDIR:** If the component of the path is not a directory.

## sysconf

- The `sysconf()` function provides a method for the application to determine the current value of a configurable system limit or option (variable).

```
#include <unistd.h>

long sysconf(int name);
```

- Return Value**
  - If `name` is invalid, `-1` is returned, and `errno` is set to `EINVAL`. Otherwise, the value returned is the value of the system resource and `errno` is not changed.
- Example compatible values:**
  - `CHILD_MAX - _SC_CHILD_MAX`: The max number of simultaneous processes per user ID.
  - `HOST_NAME_MAX - _SC_HOST_NAME_MAX`: Max length of a hostname, not including the terminating null byte.
  - `OPEN_MAX - _SC_OPEN_MAX`: The maximum number of files that a process can have open at any time.
  - `PAGESIZE - _SC_PAGESIZE`: Size of a page in bytes. Must not be less than 1 (Some systems use `PAGE_SIZE` instead).

## /dev

- In the Linux file system, everything is a file or a directory. Even devices are accessed as files. Your hard drive partitions, pendrive, speakers, for all of these, there exists a file from which these are accessed.
- A device like a speaker can input data to produce sound, a hard disk can be used to read and write data, a printer takes the input to print files, etc. Files and devices are similar in this way.
- /dev is a directory that stores all the physical and virtual devices of a Linux system. Physical devices are easy to understand, they are tangible devices like pen-drive, speakers, printers, etc. A Linux system also has virtual devices which act as a device but represent no physical device.

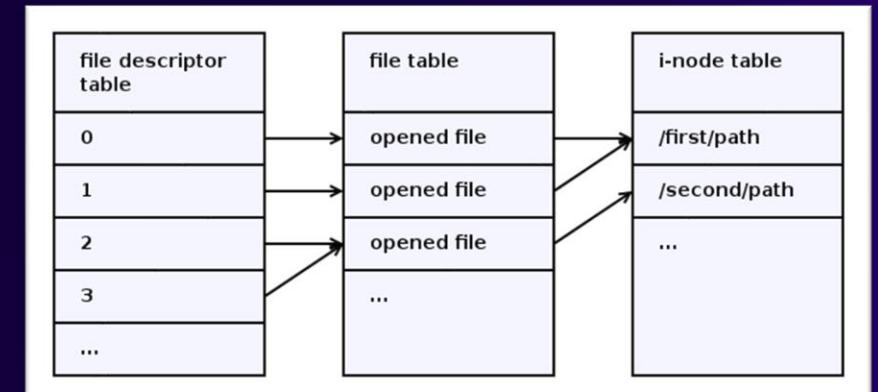
## /dev/null

- It is a **virtual device**, which has a special property: Any data written to /dev/null vanishes or disappears. Because of this characteristic, it is also called bitbucket or blackhole.

```
$ls "dir" > /dev/null          # redirects stdout to null and stderr to console  
$ls 2> /dev/null              # redirects stdout to console and stderr to null  
$ls "dir" > /dev/null 2>&1    # redirects both stdout and stderr to null
```

## File locking in Linux

- File locking is a mutual-exclusion mechanism for files. Linux supports two major kinds of file locks:  
**Advisory locks** and **Mandatory locks**
- **Advisory locks**
  - Traditionally, locks are advisory in Unix. They work only when a process explicitly acquires and releases locks, and are ignored if a process is not aware of locks.
  - Advisory locking will work, only if the participating process are cooperative. Advisory locking sometimes also called as “unenforced” locking.
  - There are several types of advisory locks available in Linux:
    1. BSD locks (`flock`)
    2. POSIX record locks (`fcntl`, `lockf`)
    3. Open file description locks (`fcntl`)



## File locking in Linux

- Mandatory locks
  - Linux has limited support for mandatory file locking. A mandatory lock is activated for a file when all of these conditions are met:
    1. The partition was mounted with the `mand` option.
    2. The set-group-ID bit is on and group-execute bit is off for the file.
    3. A POSIX record lock is acquired.
  - When a mandatory lock is activated, it affects regular system calls on the file:
    - When an exclusive or shared lock is acquired, all system calls that modify the file (e.g. `open()` and `truncate()`) are blocked until the lock is released.
    - When an exclusive lock is acquired, all system calls that read from the file (e.g. `read()`) are blocked until the lock is released.
  - Mandatory locking doesn't require cooperation from the participating processes. Mandatory locking causes the kernel to check every open, read, and write to verify that the calling process isn't violating a lock on the given file.

## unlink

- `unlink()` deletes a name from the filesystem. If that name was the last link to a file and no processes have the file open the file is deleted and the space it was using is made available for reuse.
- If the name was the last link to a file but any processes still have the file open the file will remain in existence until the last file descriptor referring to it is closed.
- If the name referred to a symbolic link the link is removed. If the name referred to a socket, fifo or device the name for it is removed but processes which have the object open may continue to use it.

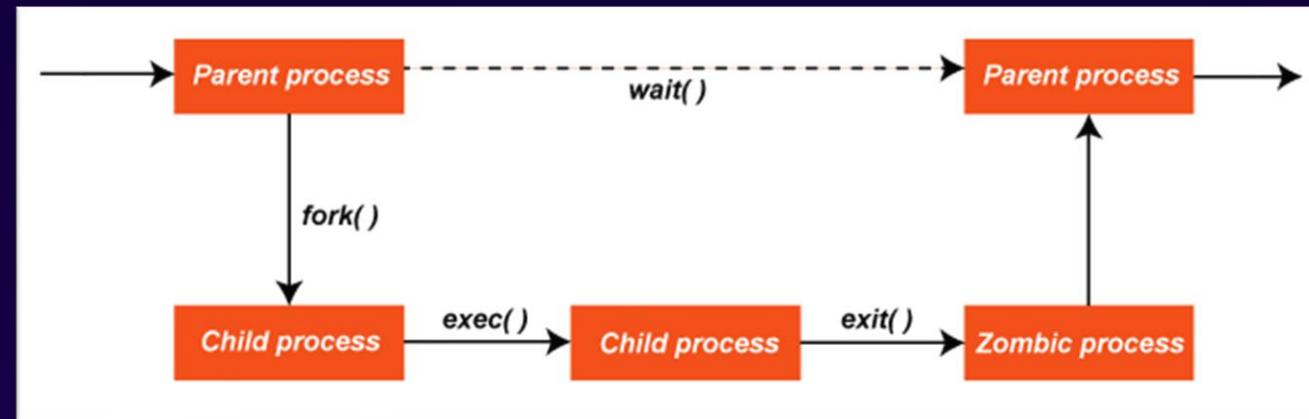
```
#include <unistd.h>

int unlink(const char *pathname);
```

- **Return Value**
  - On success, zero is returned. On error, -1 is returned, and `errno` is set appropriately.

## Zombie Process

- A zombie process or defunct process is a process that has completed execution (via the exit system call) but still has an entry in the process table: it is a process in the "Terminated state". This occurs for the child processes, where the entry is still needed to allow the parent process to read its child's exit status: once the exit status is read via the wait system call, the zombie's entry is removed from the process table and it is said to be "reaped". A child process always first becomes a zombie before being removed from the resource table. In most cases, under normal system operation zombies are immediately waited on by their parent and then reaped by the system – processes that stay zombies for a long time are generally an error and cause a resource leak, but the only resource they occupy is the process table entry – process ID.
- In the term's metaphor, the child process has "died" but has not yet been "reaped". Also, unlike normal processes, the kill command has no effect on a zombie process.

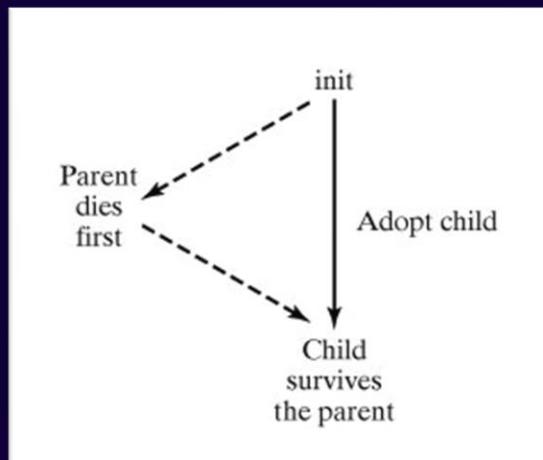


## Zombie Process

- Preventions to Zombie Process
  - sing wait() system call
  - By ignoring the SIGCHLD signal
  - By using a signal handler

## Orphan Process

- An orphan process is a computer process whose parent process has finished or terminated, though it remains running itself.
- In a Unix-like operating system any orphaned process will be immediately adopted by an implementation-defined system process: the kernel sets the parent to this process. This operation is called re-parenting and occurs automatically. Even though technically the process has a system process as its parent, it is still called an orphan process since the process that originally created it no longer exists. In other systems orphaned processes are immediately terminated by the kernel. Most Unix systems have historically used init as the system process to which orphans are reparented, but in modern DragonFly BSD, FreeBSD, and Linux systems, an orphan process may be reparented to a "subreaper" process instead of init.



## Init Daemon

- The init daemon is the first process executed by the Linux Kernel and its process ID (PID) is always **1**. Its purpose is to initialize, manage and track system services and daemons. In other words, the init daemon is the parent of all processes on the system.

## Init

- Init (also known as System V init, or SysVinit) is an init daemon, created in the 1980s, that defines six run-levels (system states) and maps all system services to these run-levels. This allows all services (defined as scripts) to be started in a pre-defined sequence. The next script is executed only if the current script in the sequence is executed or timed out if it gets stucked. In addition to unexpected wait during execution timeouts, starting services serially makes the system initialization process inefficient and relatively slow.
- To create a service, you will need to write a script and store it in [`/etc/init.d`](#) directory. You would write a service script [`/etc/init.d/myService`](#).
- Once you have your script, you can use the `service` command to `start`, `stop`, and `restart` your service.

## Init

```
#!/bin/bash
# chkconfig: 2345 20 80
# description: Description comes here.....
# Source function library.
. /etc/init.d/functions

start() { # TODO: code to start app comes here }
stop() { # TODO: code to stop app comes here }

case "$1" in
    start)
        start
        ;;
    stop)
        stop
        ;;
    restart)
        stop
        start
        ;;
    status)
        # TODO: code to check status of app comes here
        ;;
    *)
        echo "Usage: $0 {start|stop|restart|status}"
esac
exit 0
```

## Systemd

- Systemd (system daemon) is an init daemon used by modern systems and starts system services in parallel which remove unnecessary delays and speeds up the initialization process. What do I mean by parallel? Systemd uses Unit Dependencies to define whether a service wants/requires other services to run successfully, and Unit Order to define whether a service needs other services to be started before/after it.
- To create a service, you will need to write a .service file stored in the [/etc/systemd/system](#) directory. You would write a file [/etc/systemd/system/myService.service](#).
- Once you have your service file, you can start, stop and restart your service using the `systemctl` command.

```
[Unit]
Description=Some Description
Requires=syslog.target
After=syslog.target

[Service]
ExecStart=/usr/sbin/<command-to-start>
ExecStop=/usr/sbin/<command-to-stop>

[Install]
WantedBy=multi-user.target
```

## Init vs Systemd

- Init and Systemd are both init daemons but it is better to use the latter since it is commonly used in recent Linux Distros. Init uses service whereas Systemd uses systemctl to manage Linux services.
- **Init**

```
sudo service <service-name> <command>
```

Or

```
sudo /etc/init.d/<service-name> <command>
```

- **Systemd**

```
sudo systemctl <command> <service-name>
```

## QML

- QML is an acronym that stands for ***Qt Meta-object Language***. It is a declarative programming language that is part of the Qt framework. QML's main purpose is fast and easy creation of user interfaces for desktop, mobile and embedded systems. QML allows seamless integration of JavaScript, either directly in the QML code or by including JavaScript files.



## QML

- QML and Javascript are ***interpreted*** languages. This means that they do not have to be processed by a compiler before being executed. Instead, they are being run inside an execution engine. However, as interpretation is a costly operation, various techniques are used to improve performance.
- The QML engine uses ***just-in-time (JIT)*** compilation to improve performance. It also caches the intermediate output to avoid having to recompile. This works seamlessly for you as a developer. The only trace of this is that files ending with qmlc and jsc can be found next to the source files.

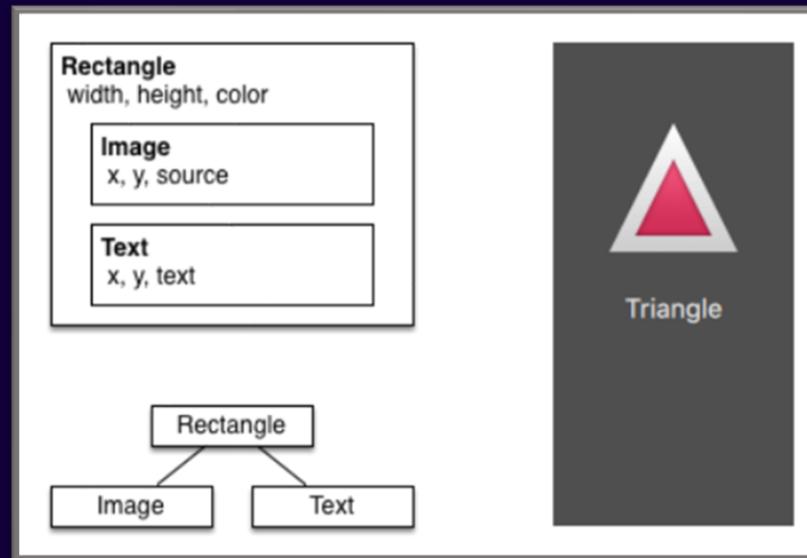
## Qt Quick

- Qt Quick is the standard library of QML types and functionality for QML. It includes visual types, interactive types, animations, models and views, particle effects and shader effects. A QML application developer can get access to all of that functionality with a single import statement.
- Qt Quick is a framework built on QML.



## QML Syntax

- In its simplest form, QtQuick lets you create a hierarchy of elements. Child elements inherit the coordinate system from the parent. An x,y coordinate is always relative to the parent.



- The import statement imports a module. An optional version in the form of `<major>.<minor>` can be added (e.g. `2.15` ).

## QML Syntax

- Comments can be made using `//` for single line comments or `/* */` for multi-line comments. Just like in C/C++ and JavaScript.
- Every QML file needs to have exactly one root element, like HTML An element is declared by its type followed by `{}`.
- Elements can have properties, they are in the form `name: value` and `<Element>.property: value` method is used for access it.
- Arbitrary elements inside a QML document can be accessed by using their id (*an unquoted identifier*).
- Elements can be nested, meaning a parent element can have child elements. The parent element can be accessed using the parent keyword.
- Several properties can be separate with *semi colon* (i.e. `height: 10; width: 20`).
- A property can depend on one or many other properties. This is called *binding*. A bound property is updated when its dependent properties change.

## QML Syntax

- Adding new properties to an element is done using the property qualifier followed by the type, the name and the optional initial value (**property <type> <name> : <value>**). If no initial value is given, a default initial value is chosen.
- Another important way of declaring properties is using the alias keyword (**property alias <name>: <reference>**). The alias keyword allows us to forward a property of an object or an object itself from within the type to an outer scope.
- Some properties are **grouped properties**. This feature is used when a property is more structured and related properties should be grouped together. Another way of writing grouped properties is `font { family: "Ubuntu"; pixelSize: 24 }` or `font.family: "Ubuntu"; font.pixelSize: 24`.
- For every property, you can provide a **signal handler**. This handler is called after the property changes **on<Property>Changed:** (i.e. `onHeightChanged:()`).

## Scripting

- QML and JavaScript (also known as ECMAScript) are best friends.
- Syntax:
  - For every property, you can provide a *signal handler*. This handler is called after the property changes `on<Property>Changed:` (i.e. `onHeightChanged:`).
  - Use arrow function: `(text) => {}`
  - Definition of a JavaScript function in the form of `function <name> (<parameters>) { ... }`
  - Direct function assignment: `event: {}`

**WARNING:** An element id should only be used to reference elements inside your document (e.g. the current file). QML provides a mechanism called "***dynamic scoping***", where documents loaded later on overwrite the element IDs from documents loaded earlier. This makes it possible to reference element IDs from previously loaded documents if they have not yet been overwritten. It's like creating global variables. Unfortunately, this frequently leads to really bad code in practice, where the program depends on the order of execution. Unfortunately, this can't be turned off.

## Binding

- The difference between the QML : (binding) and the JavaScript = (assignment) is that the binding is a contract and keeps true over the lifetime of the binding, whereas the JavaScript assignment ( = ) is a one time value assignment. The lifetime of a binding ends when a new binding is set on the property or even when a JavaScript value is assigned to the property.
- Example:
  - `text: "value is: " + num // If the value of the num changes, it will be updated here (binding).`
  - `label.text = " // Assignment`

## Elements

- Elements can be grouped into ***visual*** and ***non-visual*** elements. A visual element (like the Item , Rectangle , Text , Image and MouseArea) has a geometry and normally presents an area on the screen. A non-visual element (like a Timer) provides general functionality, normally used to manipulate the visual elements.

## Item Element

- Item is the base element for all visual elements as such all other visual elements inherits from Item.
  - **Geometry:** **x** and **y** to define the top-left position, **width** and **height** for the expansion of the element, and **z** for the stacking order to lift elements up or down from their natural ordering.
  - **Layout handling:** anchors (**left**, **right**, **top**, **bottom**, **vertical** and **horizontal center**) to position elements relative to other elements with optional margins.

## Item Element

- Item is the base element for all visual elements as such all other visual elements inherits from Item.
  - Key handling: attached `Key` and `KeyNavigation` properties to control key handling and the `focus` property to enable key handling in the first place.
  - Transformation: `scale` and `rotate` transformation and the generic `transform` property list for x,y,z transformation, as well as a `transformOrigin` point.
  - Visual: `opacity` to control transparency, `visible` to show/hide elements, `clip` to restrain paint operations to the element boundary, and `smooth` to enhance the rendering quality.
  - State definition: `states` list property with the supported list of states, the current `state` property, and the `transitions` list property to animate state changes.

## Core Elements

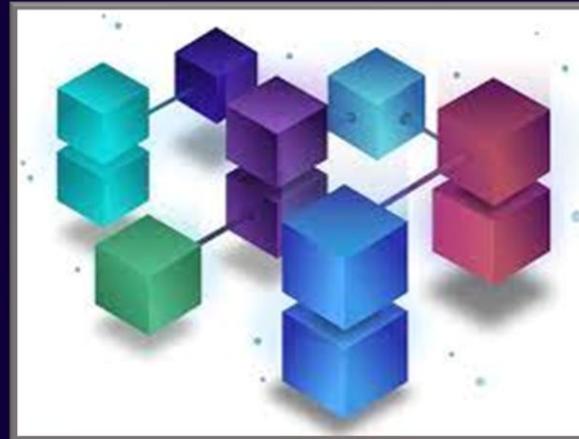
- **Rectangle Element**
  - Rectangle extends Item and adds a fill color to it. Additionally it supports borders defined by `border.color` and `border.width`. To create rounded rectangles you can use the `radius` property.
- **Text Element**
  - To display `text`, you can use the Text element. Its most notable property is the `text` property of type `string`. The element calculates its initial width and height based on the given text and the font used. The font can be influenced using the font property group (e.g. `font.family` , `font.pixelSize` , ...). To change the `color` of the text just use the `color` property.

## Core Elements

- **Image Element**
  - An **Image** element is able to display images in various formats (e.g. **PNG** , **JPG** , **GIF** , **BMP** , **WEBP**). Besides the **source** property to provide the image URL, it contains a **fillMode** which controls the resizing behavior.
- **MouseArea Element**
  - To interact with these elements you will often use a **MouseArea**. It's a rectangular invisible item in which you can capture mouse events. The mouse area is often used together with a visible item to execute commands when the user interacts with the visual part.

## Components

- A component is a reusable element. QML provides different ways to create components. the simplest form - a **file-based** component. A file-based component is created by placing a QML element in a file and giving the file an element name (e.g. Button.qml). You can use the component like every other element from the Qt Quick module.

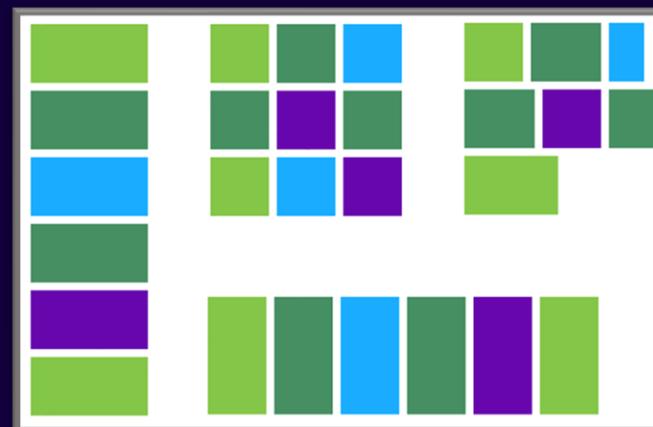


## Transformations

- A transformation manipulates the geometry of an object. QML Items can, in general, be ***translated***, ***rotated*** and ***scaled***. There is a simple form of these operations and a more advanced way.

## Positioning Elements

- There are a number of QML elements used to position items. These are called positioners, of which the Qt Quick module provides the ***Row*** , ***Column*** , ***Grid*** and ***Flow***.



## Why to Integrate QML and C++?

- There is no doubt that QML is a pretty, nice and even seductive comparing it to other programming languages including C++. Plenty of features common in today's applications could be implemented using QML only.
- Logic implemented in C++ class,

## Benefits of integrating QML and C++?

- You have a clean division between your application's QML UI native code and the application's logic in C++. This means improved maintainability.
- You have access to a wide range of Qt modules and features that are accessible only from C++ API.
- You can access platform-specific features by integrating C++ with Android, Objective-C or C.
- You can use plain C and C++ libraries in Qt wrappers to implement specific features.
- You have application of higher performance. Especially when you use C++ and multi-threading for intensive operations. However, it must be said that QML is well optimized.



## Access Property of C++ Class in QML

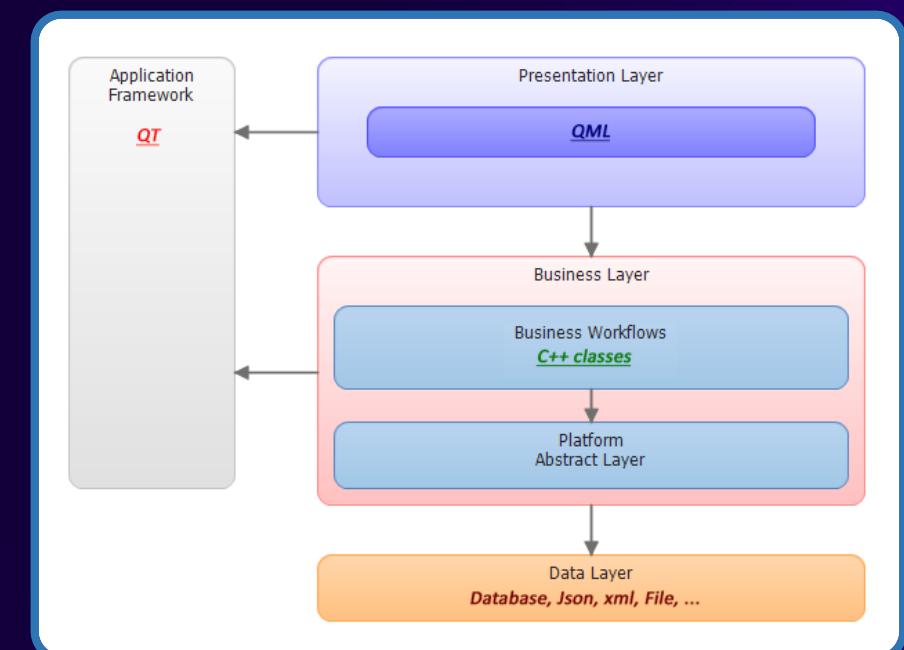
The logic layer is implemented in C++ and the user interface layer is implemented in Qml.

- 1- First you need to create a new class that will extend ***QObject*** class and use ***Q\_OBJECT*** macro.
- 2- Add properties using ***Q\_PROPERTY*** macro.

```
Q_PROPERTY(bool isNightMode READ isNightMode WRITE setIsNightMode NOTIFY isNightModeChanged)
```

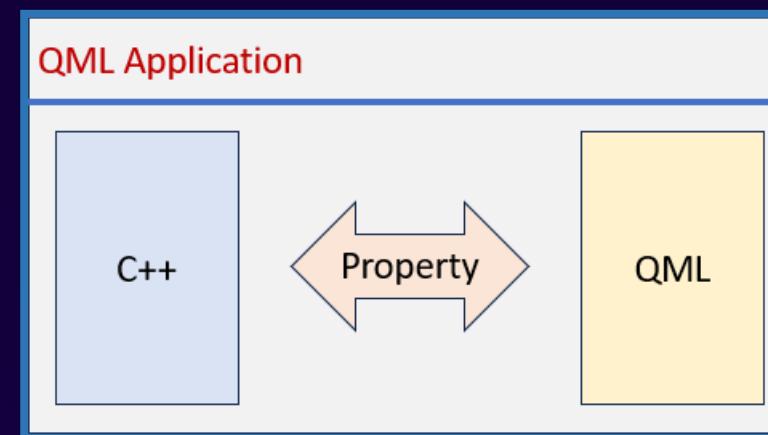
Note: Just put your cursor on the property and hit ***Alt + Enter*** on your keyboard to trigger the refactor menu.

There you should see an option to automatically generate missing property members.



## Access Property of C++ Class in QML

- 3- Instantiate your class object and expose it in main.cpp file (or wherever you have access to QML engine) using ***QQmlContext::setContextProperty(const QString &name, QObject \*value)*** method on the engine's root context. You must pass a name under which the object will be accessible and the pointer to a QML object. This pair is the so-called context property.
- 4- All you need to do is execute ***setContextProperty()*** method. From this point, your C++ object is accessible from QML.



## Execute a Method and Handle a Signal of C++ Object

In order to be able to run a method on a C++ object, you need to inform the meta-object system about the fact that this method exists. You can do that either by putting the method declaration under **public slots** scope or by marking the method with **`Q_INVOKABLE`** macro. The signal needs to be under **signals scope** in class definition.

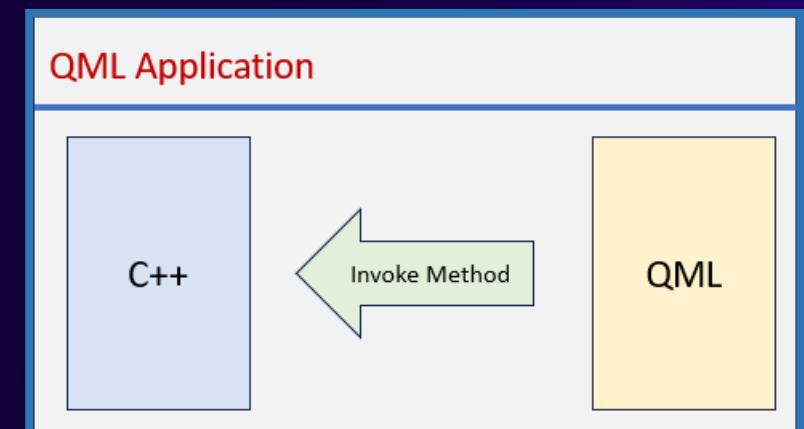
- 1- Invoke synchronous
- 2- Invoke asynchronous

Connections: When connecting to signals in QML, the usual way is to create an "on<Signal>" handler that reacts when a signal is received, like this:

```
Connections {  
    function onClicked(mouse) { foo(mouse) }  
}
```

More generally, the Connections object can be a child of some object other than the sender of the signal:

```
MouseArea {  
    Connections { function onClicked(mouse) { foo(mouse) } }  
}
```



## Register C++ Class to QML

- The C++ class can be registered in QML type system in order to use that type as data type in QML code. Also without doing that, Qt Creator won't display any hints about class properties and members, so your programmer's life is going to be way more difficult.

- Register Instantiable C++ Class to QML – Method 1:

- To be able to use your C++ class as QML type, you need to put the QML\_ELEMENT or QML\_NAMED\_ELEMENT macro in class definition. You will get the macro by including <qqml.h>. The macro was introduced in Qt 5.15 and it actually made registering C++ classes more straightforward (Qt 5.15 and later).
    - Add Below lines to \*.pro:

```
CONFIG += qmltypes
QML_IMPORT_NAME = [ModuleName]
QML_IMPORT_MAJOR_VERSION = 1
```

- Register Instantiable C++ Class to QML – Method 2:

- Use qmlRegisterType macro (Qt 5.14 and before):

```
template<typename T>
int qmlRegisterType(const char *uri, int versionMajor, int versionMinor, const char *qmlName);
```

## Register C++ Class to QML

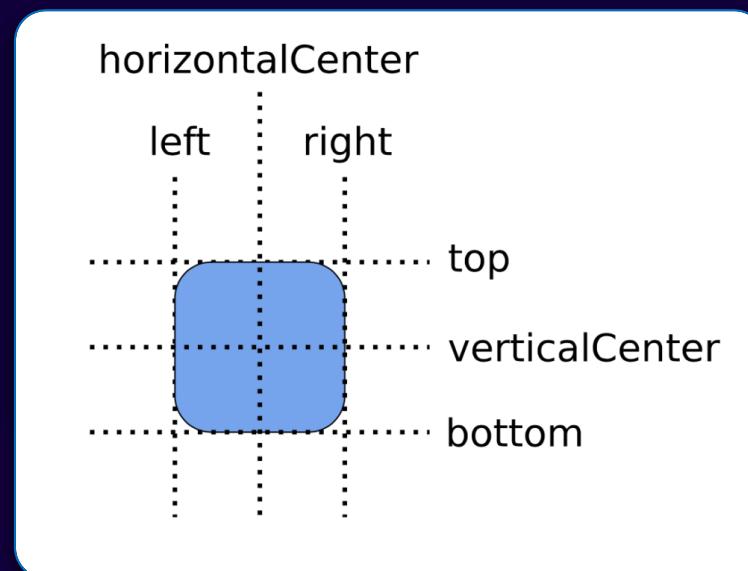
- Register Non-instantiable C++ Class to QML

- There are cases when you wouldn't want C++ classes to be instantiable as QML types. However, you would like to still benefit from recognizing them. You must use the following macro:

```
QML_UNCREATABLE(reason)
```

## Layout Items

- QML provides a flexible way to layout items using anchors. The concept of anchoring is fundamental to **Item**, and is available to all **Visual QML elements**.
- An element has 6 major anchor lines (**top**, **bottom**, **left**, **right**, **horizontalCenter**, **verticalCenter**).
- Additionally, there is the baseline anchor for text in Text elements. Each anchor line comes with an offset. In the case of the top, bottom, left and right anchors, they are called margins. For horizontalCenter, verticalCenter and baseline they are called offsets.



## Input Elements

- **TextInput**
  - TextInput allows the user to enter a line of text. The element supports input constraints such as `validator`, `inputMask`, and `echoMode`.
  - The user can click inside a TextInput to change the focus. To support switching the focus by keyboard, we can use the `KeyNavigation` attached property.
  - Note: The `KeyNavigation` attached property supports a preset of navigation keys where an element id is bound to switch focus on the given key press.
- **TextEdit**
  - The `TextEdit` is very similar to `TextInput`, and supports a multi-line text edit field. It doesn't have the text constraint properties, as this depends on querying the content size of the text (`contentHeight`, `contentWidth`).

## Focus Scope

- To support switching the focus by keyboard, we can use the **KeyNavigation** attached property.
- A focus scope declares that the last child element with `focus: true` receives the focus when the focus scope receives the focus. So it forwards the focus to the last focus-requesting child element.
- In nested objects (component) for example: `TextInput` in `Rectangle` the simple use of `focus: true` is not sufficient. The problem is that when the focus was transferred to the `TextInput` element, the top-level item inside the nested item (`Rectangle`) received focus, and did not forward the focus to the `TextInput`. To prevent this, QML offers the **FocusScope**.

## Keys Element

- The attached property `Keys` allows executing code based on certain key presses.

## Animations

- Animations are applied to property changes. An animation defines the interpolation curve from one value to another value when a property value changes. These animation curves create smooth transitions from one value to another.

## Animation Elements

- There are several types of animation elements, each optimized for a specific use case. Here is a list of the most prominent animations:
  - **PropertyAnimation** - Animates changes in property values
  - **NumberAnimation** - Animates changes in qreal-type values
  - **ColorAnimation** - Animates changes in color values
  - **RotationAnimation** - Animates changes in rotation values

## Animation Elements

- Besides these basic and widely used animation elements, Qt Quick also provides more specialized animations for specific use cases:
  - **PauseAnimation** - Provides a pause for an animation
  - **SequentialAnimation** - Allows animations to be run sequentially
  - **ParallelAnimation** - Allows animations to be run in parallel
  - **AnchorAnimation** - Animates changes in anchor values
  - **ParentAnimation** - Animates changes in parent values
  - **SmoothedAnimation** - Allows a property to smoothly track a value
  - **SpringAnimation** - Allows a property to track a value in a spring-like motion
  - **PathAnimation** - Animates an item alongside a path
  - **Vector3dAnimation** - Animates changes in QVector3d values

## Animation Elements

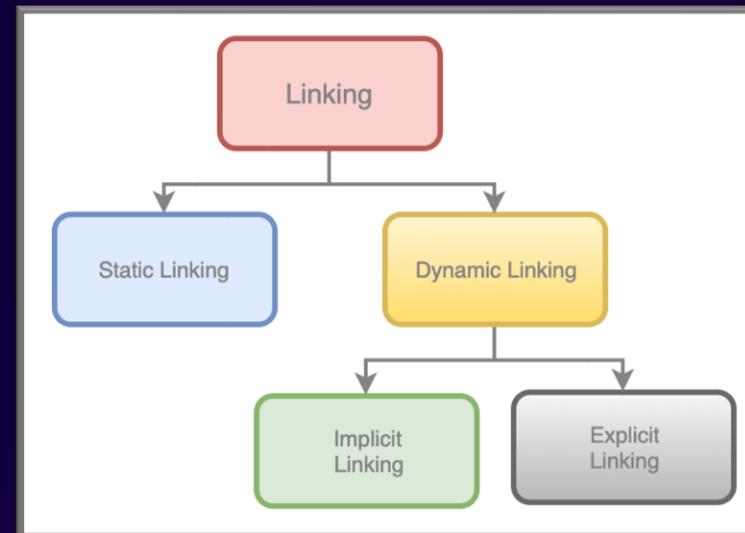
- While working on more complex animations, there is sometimes a need to change a property or to run a script during an ongoing animation. For this Qt Quick offers the action elements, which can be used everywhere where the other animation elements can be used:
  - **PropertyAction** - Specifies immediate property changes during animation
  - **ScriptAction** - Defines scripts to be run during an animation

## Applying Animations

- Animation can be applied in several ways:
  - **Animation on property** - runs automatically after the element is fully loaded
  - **Behavior on property** - runs automatically when the property value changes
  - **Standalone Animation** - runs when the animation is explicitly started using `start()` or `running` is set to true (e.g. by a property binding)

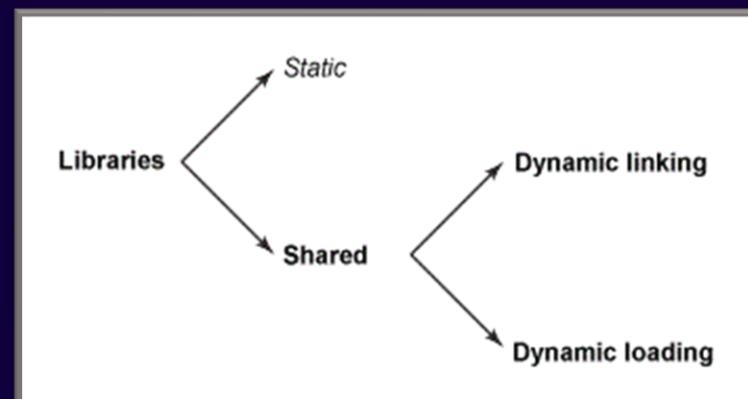
## Types of Library

- Depends on the programming language
  - Dynamic
    - Implicit
    - Explicit
  - Static
- Independent of the programming language
  - Dynamic Explicit



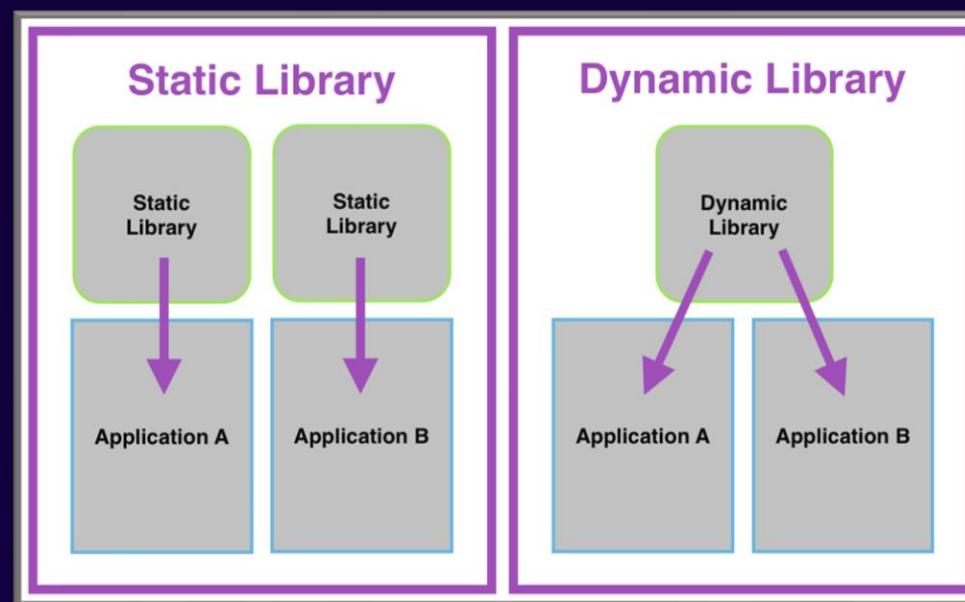
## Types of Library

- Depends on the programming language
  - Static
  - Shared
    - Dynamic Linking
    - Dynamic Loading
- Independent of the programming language
  - Dynamic Loading



## Static and Dynamic Libraries

- When a C/C++ program is compiled, the compiler generates object code. After generating the object code, the compiler also invokes linker. One of the main tasks for linker is to make code of library functions (eg `printf()`, `scanf()`, `sqrt()`, ..etc) available to your program. A linker can accomplish this task in two ways, by copying the code of library function to your object code, or by making some arrangements so that the complete code of library functions is not copied, but made available at run-time.



## Static Libraries

- Static Linking and Static Libraries is the result of the linker making copy of all used library functions to the executable file. Static Linking creates larger binary files, and need more space on disk and main memory. Examples of static libraries (libraries which are statically linked) are, .a files in Linux and .lib files in Windows.

## Dynamic Libraries

- Dynamic linking and Dynamic Libraries Dynamic Linking doesn't require the code to be copied, it is done by just placing name of the library in the binary file. The actual linking happens when the program is run, when both the binary file and the library are in memory. Examples of Dynamic libraries (libraries which are linked at run-time) are, .so in Linux and .dll in Windows.

## Dynamic Linking Types

- **Implicit** Dynamic linking is done by the loader at the loading time of the process. Loader checks import symbols (dysym) and import libraries and loads individual shared objects accordingly. If one or more objects are already loaded then they need not to be loaded again and only shared code section will be linked to the process. It will populate import table(dysym) and resolves all external symbols from the shared object. Once linking is done process can execute shared function directly.
- Another way is loading the symbol during run time **explicitly**. Operating system provides system calls to load a dynamic library and finding import symbol location, unloading the library etc. This way programmer can explicitly load a library and find out a symbol/function entry and execute that and then can unload that.

## What are the advantages and disadvantages of libraries

- **Dynamic**
  - No need to rewrite code or copy paste.
  - It saves a lot of editing time.
  - The compiled code is already tested so we can rely on it. Not at first, but when we have already used it in several different applications, so the errors have been corrected.
- **Static**
  - A program compiled with static libraries is bigger, since it copies everything we need.
  - A program compiled with static libraries can be taken to another computer without taking the libraries.

## What are the advantages and disadvantages of libraries

- Dynamic vs Static
  - A program compiled with static libraries is, in principle, faster to execute. When we call a library function, we have it in the code, so we don't have to go read the dynamic library file to find the function and execute it.
  - If we change a static library, the executable is not affected. If we change a dynamic, the executable is affected. This is an advantage if we have changed the library to correct an error (it is automatically corrected in all executable), but it is a drawback if touching that makes us change the executable (for example, we have added one more parameter to a function of the library , ready-made executable stop working).

## Linux static library

- C/C++ Language
  - Create Library
    1. Create library header & source file.
    2. Create object file:

```
$gcc | g++ -c -Wall -Werror -fPIC mylib.c
```

3. Now make a archive or static lib with the object file:

```
$ar rc -o libmylib.a mylib.o
```

## Linux static library

- **C/C++ Language**
  - To use this static library in a application we need to do the following steps:
    1. Compile and link the application code (place mylib.h in include folder):

```
$gcc | g++ -L. -Wall -o app app.c -lmylib
```

2. Run the application:

```
$ ./app
```

## Linux implicit dynamic library

- C/C++ Language
  - Create Library
    1. Create library header & source file.
    2. Create object file:

```
$gcc|g++ -c -Wall -Werror -fPIC mylib.c
```

3. Creating a shared library object file:

```
$gcc|g++ -shared -o libmylib.so mylib.o
```

## Linux implicit dynamic library

- **C/C++ Language**
  - To use this dynamic library in a application we need to do the following steps:
    1. Compile and link the application code (place mylib.h in include folder):

```
$gcc | g++ -L. -Wall -o app app.c -lmylib
```

2. Making the library available at runtime:

```
$export LD_LIBRARY_PATH=.:$LD_LIBRARY_PATH
```

3. Run the application

```
$ ./app
```

**Note:** In Linux, if you do not export the changes to an environment variable, they will not be inherited by the child processes (such as "LD\_LIBRARY\_PATH=.:\$LD\_LIBRARY\_PATH") or copy so file in "/usr/lib" path.

**Note:** Use the "\$unset LD\_LIBRARY\_PATH" command to delete the registered variable.

## Linux implicit dynamic library

- **C/C++ Language**
  - To use this dynamic library in a application we need to do the following steps:

**Using rpath:** Rpath, or the run path, is a way of embedding the location of shared libraries in the executable itself, instead of relying on default locations or environment variables. We do this during the linking stage.

```
$gcc | g++ -L. -Wl,-rpath=. -Wall -o app app.c -lmylib
```

**Note:** Show app dependencies:

```
$ldd app
```

**Note:** path vs. LD\_LIBRARY\_PATH:

There are a few downsides to rpath, however. First, it requires that shared libraries be installed in a fixed location so that all users of your program will have access to those libraries in those locations. That means less flexibility in system configuration. Second, if that library refers to a NFS mount or other network drive, you may experience undesirable delays - or worse - on program startup.

## Linux explicit dynamic library

- C/C++ Language
  - Create Library
    1. Create library header & source file.
    2. Create object file:

```
$gcc|g++ -c -Wall -Werror -fPIC mylib.c
```

3. Creating a shared library object file:

```
$gcc|g++ -shared -o libmylib.so mylib.o
```

## Linux explicit dynamic library

- **C/C++ Language**
  - To use this dynamic library in a application we need to do the following steps:
    1. Compile and link the application code:

```
$gcc | g++ -Wall -o app app.c -ldl
```

2. Run the application

```
$ ./app
```

- **difcn library**
  - **dlopen()**: Loads a dynamic link binary.
  - **dlsym()**: Returns the function pointer if found the function entry.
  - **dlclose()**: Unloads the dynamic link binary.

## important Notes

- Static and Dynamic Implicit libraries can only be used in the language in which they were developed.
- C Dynamic Libraries can be used Dynamic Explicit form in the C++ and other languages. Except for C language, this case can only be done for language C++ with an exception. Only by using Name Unmangling.
- In standard libraries, only function is exported.

## Function Overloading

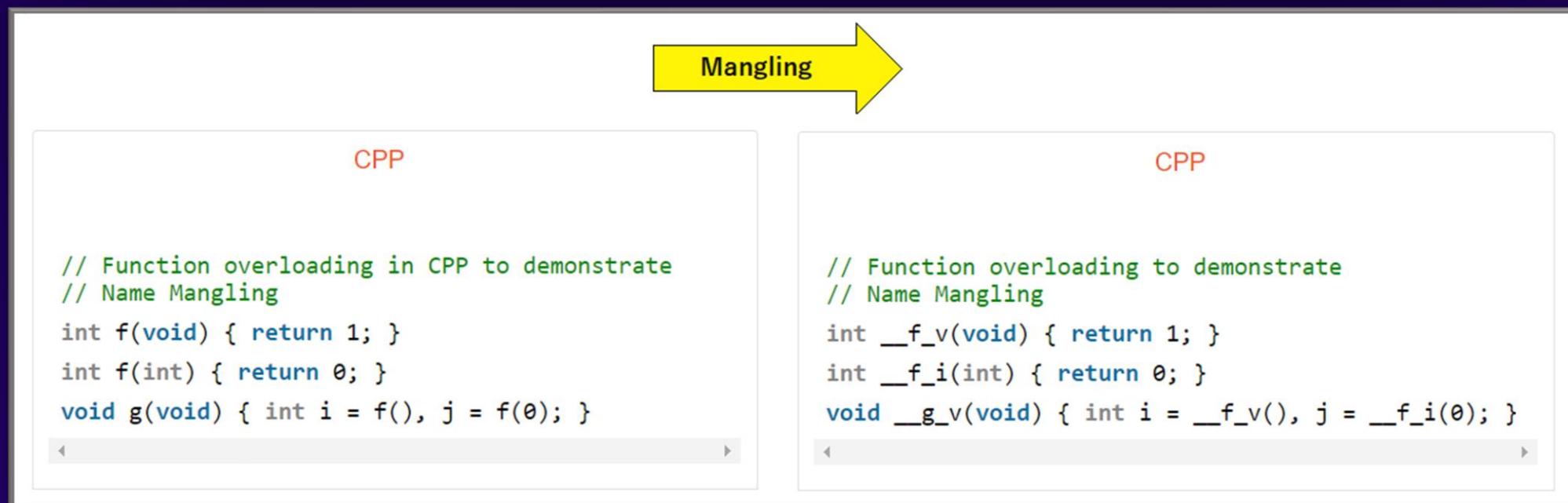
- is a very well-known concept used in object-oriented languages having many functions with the same name and different parameters in a single code. The object-oriented programming languages which support function overloading include Java and C++.

## Name Mangling

- Name mangling is the encoding of function and variable names into unique names so that linkers can separate common names in the language. Type names may also be mangled. Name mangling is commonly used to facilitate the overloading feature and visibility within different scopes.
- C++ supports function overloading, i.e., there can be more than one function with the same name but, different parameters. How does the C++ compiler distinguish between different functions when it generates object code – it changes names by adding information about arguments. This technique of adding additional information to function names is called Name Mangling. C++ standard doesn't specify any particular technique for name mangling, so different compilers may append different information to function names.

## Name Mangling

- In C, names may not be mangled as it doesn't support function overloading. So how to make sure that name of a symbol is not changed when we link a C code in C++.



## extern "C" in C++

- When some code is put in the extern "C" block, the C++ compiler ensures that the function names are un-mangled – that the compiler emits a binary file with their names unchanged, as a C compiler would do.

```
#ifdef __cplusplus
extern "C" {
#endif
// Declarations of this file
#ifndef __cplusplus
}
#endif
```

- When we want to use the functions of C++ in the C source code, we must use extern "C".

## Exported Symbols in Shared Libraries in Linux

- **readelf**
  - We can use the readelf command with the -s flag to view exported symbols:

```
$readelf -s lib.so | binary | lib.a
```
- **objdump**
  - We can also use the objdump command with the -T flag to view exported symbols:

```
$objdump -T lib.so | binary | lib.a
```
  - It doesn't demangle symbols by default, so we must pass the --demangle flag.
- **nm**
  - Finally, we can also use the nm command with the -D flag to view exported symbols. It can demangle names with the --demangle flag just like objdump:

```
$pnm -D --demangle lib.so | binary | lib.a
```

## Windows static library

- C/C++ Language
  - Create Library
    1. Create library header & source file.
    2. Create object file:

```
>cl [/TC:compile as c] /c mylib.c
```

3. Now make a archive or static lib with the object file:

```
>lib mylib.lib
```

## Windows static library

- C/C++ Language
  - To use this static library in a application we need to do the following steps:
    1. Compile the application code (place mylib.h in include folder):

```
>cl [/TC:compile as c] /I . /c app.c
```

2. Link the application code:

```
>link app.obj mylib.lib
```

3. Run the application:

```
>app.exe
```

## Windows implicit dynamic library

- **C/C++ Language**
  - Create Library
    1. Create library header & source file.
    2. Creating a shared library object file:

```
>cl [/TC:compile as c] /LD mylib.c
```

- To use this dynamic library in a application we need to do the following steps:
  1. Compile the application code (place mylib.h in include folder):

```
>cl [/TC:compile as c] /I . /c app.c
```

- 2. Link the application code:

```
>link app.obj mylib.lib
```

- 3. Run the application

```
>app.exe
```

## Windows explicit dynamic library

- **C/C++ Language**
  - Create Library
    1. Create library header & source file.
    2. Creating a shared library object file:

```
>cl [/TC:compile as c] /LD mylib.c
```

- To use this dynamic library in a application we need to do the following steps:
  1. Compile the application code:

```
>cl [/TC:compile /I . as c] app.c
```

- 2. Link the application code:

```
>link app.obj mylib.lib
```

- 3. Run the application

```
>app.exe
```

## Windows explicit dynamic library

- **C/C++ Language**
  - windows library
    - `LoadLibrary()`: Loads and links a input library form the DLL path, or current path.
    - `GetProcAddress()`: Finds the symbol/function address by its name for a loaded DLL.
    - `FreeLibrary()`: Unloads the loaded DLL instance.
    - `__declspec(dllexport)`: The class or function so tagged will be exported from the DLL it is built in. If you're building a DLL and you want an API, you'll need to use this or a separate .DEF file that defines the exports.
    - `__declspec(dllimport)`: The class or function so tagged will be imported from a DLL. This is not actually required - you need an import library anyway to make the linker happy.

## DllMain Entry Point (Windows)

- An optional entry point into a dynamic-link library (DLL). When the system starts or terminates a process or thread, it calls the entry-point function for each loaded DLL using the first thread of the process. The system also calls the entry-point function for a DLL when it is loaded or unloaded using the LoadLibrary and FreeLibrary functions.
- Usage: Initialize semaphores, mutexes, critical sections, classes, COM objects, or any other objects used by the DLL.

```
BOOL WINAPI DllMain(
    HINSTANCE hinstDLL, // handle to DLL module
    DWORD fdwReason,   // reason for calling function
    LPVOID lpvReserved ) // reserved

{
    // Perform actions based on the reason for calling.
    switch( fdwReason )
    {
        case DLL_PROCESS_ATTACH:
            // Initialize once for each new process.
            // Return FALSE to fail DLL load.
            break;

        case DLL_THREAD_ATTACH:
            // Do thread-specific initialization.
            break;

        case DLL_THREAD_DETACH:
            // Do thread-specific cleanup.
            break;

        case DLL_PROCESS_DETACH:
            if (lpvReserved != nullptr)
            {
                break; // do not do cleanup if process termination scenario
            }

            // Perform any necessary cleanup.
            break;
    }
    return TRUE; // Successful DLL_PROCESS_ATTACH.
}
```

## Exporting from a DLL Using DEF Files (Windows)

- A module-definition or DEF file (\*.def) is a text file containing one or more module statements that describe various attributes of a DLL. If you are not using the `_declspec(dllexport)` keyword to export the DLL's functions, the DLL requires a DEF file.
- The EXPORTS statement lists the names and, optionally, the ordinal values of the functions exported by the DLL.

```
LIBRARY BTREE
EXPORTS
    Insert    @1
    Delete    @2
    Member    @3
    Min      @4
```

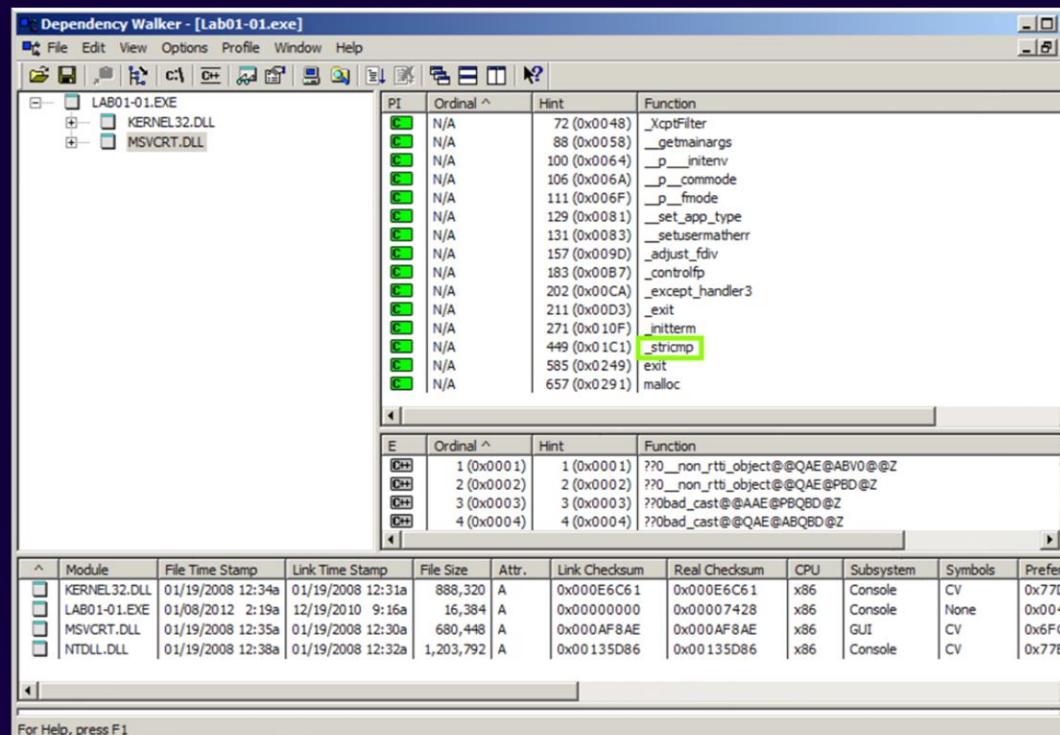
## Exported Symbols in Shared Libraries in Windows

- **dumpbin**
  - To get the decorated form of a function using DUMPBIN, run it on the .OBJ or .LIB file using the /SYMBOLS option:

```
>dumpbin /symbols /exports lib.dll | binary | lib.lib
```

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- **Dependency Walker**
  - The Export Function List View displays the list of export functions for the currently selected module in the Module Dependency Tree View.



Qt

# Thank You

By Ali Panahi

