# Summary of C++ Constructs

Jan Faigl

Department of Computer Science
Faculty of Electrical Engineering
Czech Technical University in Prague

Lecture 12

**PRG – Programming in C**



## Overview of the Lecture







# Part I

## Part 1 – Summary of C++ Constructs





## Resources – Books


The C++ Programming Language, *Bjarne Stroustrup*, Addison-Wesley Professional, 2013, ISBN 978-0321563842

Programming: Principles and Practice Using C++, *Bjarne Stroustrup*, Addison-Wesley Professional, 2014, ISBN 978-0321992789

Effective C++: 55 Specific Ways to Improve Your Programs and Designs, *Scott Meyers*, Addison-Wesley Professional, 2005, ISBN 978-0321334879






## Objects Oriented Programming (OOP)

**OOP is a way how to design a program to fulfill requirements and make the sources easy maintain.**

- **Abstraction** – concepts (templates) are organized into classes
  - Objects are instances of the classes
- **Encapsulation**
  - Object has its state hidden and provides **interface** to communicate with other objects by sending messages (function/method calls)
- **Inheritance**
  - Hierarchy (of concepts) with common (general) properties that are further specialized in the derived classes
- **Polymorphism**
  - An object with some interface could replace another object with the same interface





## C++ for C Programmers

- C++ can be considered as an "extension" of C with additional concepts to create more complex programs in an easier way
- It supports to organize and structure complex programs to be better manageable with easier maintenance
- **Encapsulation** supports "locality" of the code, i.e., provide only public interfance and keep details "hidden"
  - Avoid unintentional wrong usage because of unknown side effects
  - Make the implementation of particular functionality compact and easier to maintain
  - Provide relatively complex functionality with simple to use interface
- Support a tighter link between data and functions operating with the data, i.e., classes combine data (properties) with functions (methods)





## From `struct` to `class`

- `struct` defines complex data types for which we can define particular functions, e.g., allocation(), deletion(), initialization(), sum(), print() etc.
- `class` defines the data and function working on the data including the initialization (**constructor**) and deletion (**destructor**) in a compact form
  - Instance of the class is an object, i.e., a variable of the class type

```
typedef struct matrix {
   int rows;
   int cols;
   double *mtx;
} matrix_s;

matrix_s* allocate(int r, int c);
void release(matrix_s **matrix);
void init(matrix_s *matrix);
void print(const matrix_s *matrix);

matrix_s *matrix = allocate(10, 10);
init(matrix);
print(matrix);
release(matrix);
```

```
class Matrix {
   const int ROWS;
   const int COLS;
   double *mtx;
   public:
   Matrix(int r, int c);
   ~Matrix(); //destructor
   void init(void);
   void print(void) const;
};
{
   Matrix matrix(10, 10);
   matrix.init();
   matrix.print();
} // will call destructor
```





## Dynamic allocation

- `malloc()` and `free()` and standard functions to allocate/release memory of the particular size in C

```
matrix_s *matrix = (matrix_s*)malloc(sizeof(matrix_s));
matrix->rows = matrix->cols = 0; //inner matrix is not allocated
print(matrix);
free(matrix);
```

- C++ provides two keywords (operators) for creating and deleting objects (variables at the heap) `new` and `delete`

```
Matrix *matrix = new Matrix(10, 10); // constructor is called
matrix->print();
delete matrix;
```

- `new` and `delete` is similar to `malloc()` and `free()`, but
  - Variables are strictly typed and constructor is called to initialize the object
  - For arrays, explicit calling of `delete[]` is required

```
int *array = new int[100]; // aka (int*)malloc(100 * sizeof(int))
delete[] array; // aka free(array)
```





## Reference

- In addition to variable and pointer to a variable, C++ supports references, i.e., a reference to an existing object
- Reference is an **alias** to existing variable, e.g.,

```
int a = 10;
int &r = a; // r is reference (alias) to a
r = 13; // a becomes 13
```

- It allows to pass object (complex data structures) to functions (methods) without copying them

*Variables are passed by value*

```
int print(Matrix matrix)
{// new local variable matrix is allocated
 // and content of the passed variable is copied
}
int print(Matrix *matrix) // pointer is passed
{
   matrix->print();
}
int print(Matrix &matrix)
{
   // reference is passed - similar to passing pointer
   matrix.print(); //but it is not pointer and .  is used
}
```

## Class

Describes a set of objects – it is a model of the objects and defines:

- Interface – parts that are accessible from outside
  public, protected, private
- Body – implementation of the interface (methods) that determine the ability of the objects of the class
  *Instance vs class methods*
- Data Fields – attributes as basic and complex data types and structures (objects)
  *Object composition*
  - Instance variables – define the state of the object of the particular class
  - Class variables – common for all instances of the particular class

```
// header file - definition of the class
    type
class MyClass {
   public:
      /// public read only
      int getValue(void) const;
   private:
      /// hidden data field
      /// it is object variable
      int myData;
};

// source file - implementation of the
    methods
int MyClass::getValue(void) const
{
   return myData;
}
```





## Object Structure

- The value of the object is structured, i.e., it consists of particular values of the object data fields which can be of different data type
  *Heterogeneous data structure unlike an array*
- Object is an abstraction of the memory where particular values are stored
  - Data fields are called attributes or instance variables
- Data fields have their names and can be marked as hidden or accessible in the class definition
  *Following the encapsulation they are usually hidden*

**Object**:

- Instance of the class – can be created as a variable declaration or by dynamic allocation using the **new** operator
- Access to the attributes or methods is using . or -> (for pointers to an object)





## Creating an Object – Class Constructor

- A class instance (object) is created by calling a **constructor** to initialize values of the instance variables
  *Implicit/default one exists if not specified*
- The name of the constructor is identical to the name of the class

Class definition

```
class MyClass {
   public:
      // constructor
      MyClass(int i);
      MyClass(int i, double d);

   private:
      const int _i;
      int _ii;
      double _d;
};
```

Class implementation

```
MyClass::MyClass(int i) : _i(i)
{
   _ii =  i * i;
   _d = 0.0;
}
// overloading constructor
MyClass::MyClass(int i, double d) : _i(i)
{
   _ii =  i * i;
   _d = d;
}
```

```
{
   MyClass myObject(10); //create an object as an instance of MyClass
} // at the end of the block, the object is destroyed
MyClass *myObject = new MyClass(20, 2.3); //dynamic object creation
delete myObject; //dynamic object has to be explicitly destroyed
```





## Relationship between Objects

- Objects may contain other objects
- Object aggregation / composition
- Class definition can be based on an existing class definition – so, there is a relationship between classes
  - Base class (super class) and the derived class
  - The relationship is transferred to the respective objects as instances of the classes

  *By that, we can cast objects of the derived class to class instances of ancestor*
- Objects communicate between each other using methods (interface) that is accessible to them





## Access Modifiers

- Access modifiers allow to implement **encapsulation** (information hiding) by specifying which class members are private and which are public:
  - **public:** – any class can refer to the field or call the method
  - **protected:** – only the current class and subclasses (derived classes) of this class have access to the field or method
  - **private:** – only the current class has the access to the field or method

| Modifier | Access | | |
|---|---|---|---|
| | Class | Derived Class | "World" |
| public | ✓ | ✓ | ✓ |
| protected | ✓ | ✓ | ✗ |
| private | ✓ | ✗ | ✗ |





## Constructor and Destructor

- **Constructor** provides the way how to initialize the object, i.e., allocate resources
  Programming idiom – Resource acquisition is initialization (RAII)
- **Destructor** is called at the end of the object life
  - It is responsible for a proper cleanup of the object
  - Releasing resources, e.g., freeing allocated memory, closing files
- Destructor is a method specified by a programmer similarly to a constructor
  *However, unlike constructor, only single destructor can be specified*
  - The name of the destructor is the same as the name of the class but it starts with the character ∼ as a prefix





## Constructor Overloading

- An example of constructor for creating an instance of the complex number
- Only a real part or both parts can be specified in the object initialization

```
class Complex {
   public:
      Complex(double r)
      {
         re = r;
      }
      Complex(double r, double i)
      {
         re = r;
         im = i;
      }
      ~Complex() { /* nothing to do in destructor */ }
   private:
      double re;
      double im;
};
```

Both constructors shared the duplicate code, which we like to avoid!





## Example – Constructor Calling 1/3

- We can create a dedicated initialization method that is called from different constructors

```
class Complex {

   public:
      Complex(double r, double i) { init(r, i); }
      Complex(double r) { init(r, 0.0); }
      Complex() { init(0.0, 0.0); }

   private:

      void init(double r, double i)
      {
         re = r;
         im = i;
      }

   private:
      double re;
      double im;
};
```





## Example – Constructor Calling 2/3

- Or we can utilize default values of the arguments that are combined with initializer list here

```
class Complex {
   public:
      Complex(double r = 0.0, double i = 0.0) : re(r), im(i) {}
   private:
      double re;
      double im;
};

int main(void)
{
   Complex c1;
   Complex c2(1.);
   Complex c3(1., -1.);
   return 0;
}
```

## Example – Constructor Calling 3/3

- Alternatively, in C++11, we can use delegating constructor

```
class Complex {
   public:
      Complex(double r, double i)
      {
         re = r;
         im = i;
      }
      Complex(double r) : Complex(r, 0.0)  {}
      Complex() : Complex(0.0, 0.0) {}

   private:
      double re;
      double im;
};
```





## Constructor Summary

- The name is identical to the class name
- The constructor does not have return value

*Not even* `void`

- Its execution can be prematurely terminated by calling `return`
- It can have parameters similarly as any other method (function)
- We can call other functions, but they should not rely on initialized object that is being done in the constructor
- Constructor is usually **public**
- (**private**) constructor can be used, e.g., for:
  - Classes with only class methods

*Prohibition to instantiate class*

  - Classes with only constants
  - The so called singletons

*E.g., "object factories"*





## Relationship between Objects

- Objects can be in relationship based on the
  - Inheritance – is the relationship of the type **is**

*Object of descendant class **is** also the ancestor class*

    - One class is derived from the ancestor class

*Objects of the derived class extends the based class*

    - Derived class contains all the field of the ancestor class

*However, some of the fields may be hidden*

    - New methods can be implemented in the derived class

*New implementation **override** the previous one*

    - Derived class (objects) are specialization of a more general ancestor (super) class
- An object can be part of the other objects – it is the **has** relation
  - Similarly to compound structures that contain other struct data types as their data fields, objects can also compound of other objects
  - We can further distinguish
    - **Aggregation** – an object is a part of other object
    - **Composition** – inner object exists only within the compound object





## Example – Aggregation/Composition

- Aggregation – relationship of the type "**has**" or "**it is composed**
  - Let ***A*** be aggregation of ***B*** ***C***, then objects ***B*** and ***C*** are contained in ***A***
  - It results that ***B*** and ***C*** cannot survive without ***A***

*In such a case, we call the relationship as composition*

Example of implementation

```
class GraphComp { // composition
   private:
      std::vector<Edge> edges;
};

class GraphComp { // aggregation
   public:
      GraphComp(std::vector<Edge>& edges) : edges(
       edges) {}
   private:
      const std::vector<Edge>& edges;
};
```

```
struct Edge {
   Node v1;
   Node v2;
};

struct Node {
   Data data;
};
```





## Categories of the Inheritance

- Strict inheritance – derived class takes all of the superclass and adds own methods and attributes. All members of the superclass are available in the derived class. It strictly follows the **is-a** hierarchy
- Nonstrict inheritance – the subclass derives from the a superclass only certain attributes or methods that can be further redefined
- Multiple inheritance – a class is derived from several superclasses





## Inheritance – Summary

- Inheritance is a mechanism that allows
  - Extend data field of the class and modify them
  - Extend or modify methods of the class
- Inheritance allows to
  - Create hierarchies of classes
  - "Pass" data fields and methods for further extension and modification
  - Specialize (specify) classes
- The main advantages of inheritance are
  - It contributes essentially to the code reusability

*Together with encapsulation!*

  - Inheritance is foundation for the **polymorphism**





## Polymorphism

- Polymorphism can be expressed as the ability to refer in a same way to different objects

*We can call the same method names on different objects*

- We work with an object whose actual content is determined at the runtime
- Polymorphism of objects - Let the class ***B*** be a subclass of ***A***, then the object of the ***B*** can be used wherever it is expected to be an object of the class ***A***
- Polymorphism of methods requires dynamic binding, i.e., static vs. dynamic type of the class
  - Let the class ***B*** be a subclass of ***A*** and redefines the method `m()`
  - A variable `x` is of the static type ***B***, but its dynamic type can be ***A*** or ***B***
  - Which method is actually called for *x.m()* depends on the dynamic type





## Virtual Methods – Polymorphism and Inheritance

- We need a dynamic binding for polymorphism of the methods
- It is usually implemented as a **virtual method** in object oriented programming languages
- Override methods that are marked as **virtual** has a dynamic binding to the particular dynamic type





## Example – Overriding without Virtual Method 1/2

```
#include <iostream>
using namespace std;
class A {
   public:
      void info()
      {
         cout << "Object of the class A" << endl;
      }
};
class B : public A {
   public:
      void info()
      {
         cout << "Object of the class B" << endl;
      }
};
A* a = new A(); B* b = new B();
A* ta = a; // backup of a pointer
a->info(); // calling method info() of the class A
b->info(); // calling method info() of the class B
a = b; // use the polymorphism of objects
a->info(); // without the dynamic binding, method of the class A is called
delete ta; delete b;
```

```
clang++ demo-novirtual.cc
./a.out
Object of the class A
Object of the class B
Object of the class A
```

lec12/demo-novirtual.cc

## Example – Overriding with Virtual Method 2/2

```
#include <iostream>
using namespace std;
class A {
   public:
      virtual void info() // Virtual !!!
      {
         cout << "Object of the class A" << endl;
      }
};
class B : public A {
   public:
      void info()
      {
         cout << "Object of the class B" << endl;
      }
};
A* a = new A(); B* b = new B();
A* ta = a; // backup of a pointer
a->info(); // calling method info() of the class A
b->info(); // calling method info() of the class B
a = b; // use the polymorphism of objects
a->info(); // the dynamic binding exists, method of the class B is called
delete ta; delete b;
```

lec12/demo-virtual.cc

```
clang++ demo-virtual.cc
./a.out
Object of the class A
Object of the class B
Object of the class B
```





## Derived Classes, Polymorphism, and Practical Implications

- Derived class inherits the methods and data fields of the superclass, but it can also add new methods and data fields
  - It can extend and specialize the class
  - It can modify the implementation of the methods
- An object of the derived class can be used instead of the object of the superclass, e.g.,
  - We can implement more efficient matrix multiplication without modification of the whole program

    *We may further need a mechanism to create new object based on the dynamic type, i.e., using the `newInstance` virtual method*
- **Virtual** methods are important for the **polymorphism**
  - It is crucial to use a virtual **destructor** for a proper destruction of the object

    *E.g., when a derived class allocate additional memory*





## Example – Virtual Destructor 1/4

```
#include <iostream>
class Base {
   public:
      Base(int capacity) {
         std::cout << "Base::Base -- allocate data" << std::endl;
         data = new int[capacity];
      }
      virtual ~Base() { // virtual destructor is important
         std::cout << "Base::~Base -- release data" << std::endl;
         delete[] data;
      }
   protected:
      int *data;
};
```

lec12/demo-virtual_destructor.cc





## Example – Virtual Destructor 2/4

```
class Derived : public Base {
   public:
      Derived(int capacity) : Base(capacity) {
         std::cout << "Derived::Derived -- allocate data2" << std::endl;
         data2 = new int[capacity];
      }
      ~Derived() {
         std::cout << "Derived::~Derived -- release data2" << std::endl;
         delete[] data2;
      }
   protected:
      int *data2;
};
```

lec12/demo-virtual_destructor.cc





## Example – Virtual Destructor 3/4

- Using `virtual` destructor all allocated data are properly released

```
std::cout << "Using Derived " << std::endl;
Derived *object = new Derived(1000000);
delete object;
std::cout << std::endl;

std::cout << "Using Base" << std::endl;
Base *object = new Derived(1000000);
delete object;
```

lec12/demo-virtual_destructor.cc

```
clang++ demo-virtual_destructor.cc && ./a.out
```

```
Using Derived
Base::Base -- allocate data
Derived::Derived -- allocate data2
Derived::~Derived -- release data2
Base::~Base -- release data
```

```
Using Base
Base::Base -- allocate data
Derived::Derived -- allocate data2
Derived::~Derived -- release data2
Base::~Base -- release data
```

*Both desctructors `Derived` and `Base` are called*





## Example – Virtual Destructor 4/4

- Without `virtual` destructor, e.g,,

```
class Base {
   ...
   ~Base(); // without virtualdestructor
};
Derived *object = new Derived(1000000);
delete object;
Base *object = new Derived(1000000);
delete object;
```

- Only both constructors are called, but only destructor of the `Base` class in the second case `Base *object = new Derived(1000000);`

```
Using Derived
Base::Base -- allocate data
Derived::Derived -- allocate data2
Derived::~Derived -- release data2
Base::~Base -- release data
```

```
Using Base
Base::Base -- allocate data
Derived::Derived -- allocate data2
Base::~Base -- release data
```

*Only the desctructor of `Base` is called*





## Inheritance and Composition

- A part of the object oriented programming is the object oriented design (OOD)
  - It aims to provide "a plan" how to solve the problem using objects and their relationship
  - An important part of the design is identification of the particular objects
  - their generalization to the classes
  - and also designing a class hierarchy
- Sometimes, it may be difficult to decides
  - What is the common (general) object and what is the specialization, which is important step for class hierarchy and applying the inheritance
  - It may also be questionable when to use composition
- Let show the inheritance on an example of geometrical objects





## Example – Is Cuboid Extended **Rectangle**? 1/2

```
class Rectangle {
   public:
      Rectangle(double w, double h) : width(w), height(h) {}
      inline double getWidth(void) const { return width; }
      inline double getHeight(void) const { return height; }
      inline double getDiagonal(void) const
      {
         return sqrt(width*width + height*height);
      }

   protected:
      double width;
      double height;
};
```





## Example – Is Cuboid Extended **Rectangle**? 2/2

```
class Cuboid : public Rectangle {
   public:
      Cuboid(double w, double h, double d) :
         Rectangle(w, h), depth(d) {}
      inline double getDepth(void) const { return depth; }
      inline double getDiagonal(void) const
      {
         const double tmp = Rectangle::getDiagonal();
         return sqrt(tmp * tmp + depth * depth);
      }

   protected:
      double depth;
};
```

## Example – Inheritance Cuboid Extend Rectangle

- Class `Cuboid` extends the class `Rectangle` by the `depth`
  - `Cuboid` inherits data fields `width` a `height`
  - `Cuboid` also inherits „getters" `getWidth()` and `getHeight()`
  - Constructor of the `Rectangle` is called from the `Cuboid` constructor
- The descendant class `Cuboid` extends (override) the `getDiagonal()` methods

*It actually uses the method `getDiagonal()` of the ancestor `Rectangle::getDiagonal()`*

- We create a "specialization" of the `Rectangle` as an extension `Cuboid` class

**Is it really a suitable extension?**

What is the cuboid area? What is the cuboid circumference?





## Example – Inheritance – Rectangle is a Special **Cuboid** 1/2

- Rectangle is a cuboid with zero depth

```
class Cuboid {

   public:
      Cuboid(double w, double h, double d) :
         width(w), height(h), depth(d) {}

      inline double getWidth(void) const { return width; }
      inline double getHeight(void) const { return height; }
      inline double getDepth(void) const { return depth; }

      inline double getDiagonal(void) const
      {
         return sqrt(width*width + height*height + depth*depth);
      }

   protected:
      double width;
      double height;
      double depth;
};
```





## Example – Inheritance – Rectangle is a Special **Cuboid** 2/2

```
class Rectangle : public Cuboid {

   public:
      Rectangle(double w, double h) : Cuboid(w, h, 0.0) {}
};
```

- Rectangle is a "cuboid" with zero depth
- `Rectangle` inherits all data fields: `with`, `height`, and `depth`
- It also inherits all methods of the ancestor

*Accessible can be only particular ones*

- The constructor of the `Cuboid` class is accessible and it used to set data fields with the zero `depth`
- Objects of the class `Rectangle` can use all variable and methods of the `Cuboid` class





## Should be Rectangle Descendant of Cuboid or Cuboid be Descendant of Rectangle?

1. Cuboid is descendant of the rectangle
   - "Logical" addition of the depth dimensions, but methods valid for the rectangle do not work of the cuboid

*E.g., area of the rectangle*

2. Rectangle as a descendant of the cuboid
   - Logically correct reasoning on specialization

"All what work for the cuboid also work for the cuboid with zero depth"

   - Inefficient implementation – every rectangle is represented by 3 dimensions

Specialization is correct

*Everything what hold for the **ancestor** have to be valid for the **descendant***

*However, in this particular case, usage of the inheritance is questionable.*





## Relationship of the Ancestor and Descendant is of the type "**is-a**"

- Is a straight line segment descendant of the point?
  - Straight line segment does not use any method of a point

is-a?: segment is a point ? → **NO** → segment is not descendant of the point

- Is rectangle descendant of the straight line segment?

is-a?: **NO**

- Is rectangle descendant of the square, or vice versa?
  - Rectangle "extends" square by one dimension, but it is not a square
  - Square is a rectangle with the width same as the height

*Set the width and height in the constructor!*





## Substitution Principle

- Relationship between two derived classes
- Policy
  - Derived class is a specialization of the superclass

*There is the **is-a** relationship*

  - Wherever it is possible to sue a class, it must be possible to use the descendant in such a way that a user cannot see any difference

*Polymorphism*

  - Relationship **is-a** must be permanent





## Composition of Objects

- If a class contains data fields of other object type, the relationship is called **composition**
- Composition creates a hierarchy of objects, but not by inheritance

*Inheritance creates hierarchy of relationship in the sense of descendant / ancestor*

- Composition is a relationship of the objects – **aggregation** – **consists** / **is compound**
- It is a relationship of the type "**has**"





## Example – Composition 1/3

- Each person is characterized by attributes of the `Person` class
  - `name` (string)
  - `address` (string)
  - `birthDate` (date)
  - `graduationDate` (date)
- Date is characterized by three attributes Datum (class `Date`)
  - `day` (`int`)
  - `month` (`int`)
  - `year` (`int`)





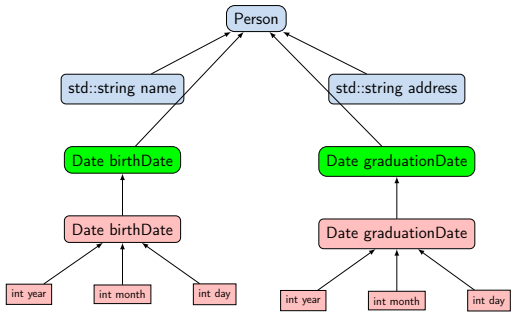
## Example – Composition 2/3

```
#include <string>

class Person {
   public:
   std::string name;
   std::string address;
   Date birthDate;
   Date graduationDate;
};
```

```
class Date {
   public:
      int day;
      int month;
      int year;
};
```

## Example – Composition 3/3








## Inheritance vs Composition

- Inheritance objects:
  - Creating a derived class (descendant, subclass, derived class)
  - Derived class is a specialization of the superclass
    - May add variables (data fields) *Or overlapping variables (names)*
    - Add or modify methods
  - Unlike composition, inheritance changes the properties of the objects
    - New or modified methods
    - Access to variables and methods of the ancestor (base class, superclass) *If access is allowed (public/protected)*
- Composition of objects is made of attributes (data fields) of the object type *It consists of objects*
- A distinction between composition an inheritance
  - „Is" test – a symptom of inheritance (**is-a**)
  - „Has" test – a symptom of composition (**has**)





## Inheritance and Composition – Pitfalls

- Excessive usage of composition and also inheritance in cases it is not needed leads to complicated design
- Watch on literal interpretations of the relationship **is-a** and **has**, sometimes it is not even about the inheritance, or composition *E.g., Point2D and Point3D or Circle and Ellipse*
- Prefer composition and not the inheritance *One of the advantages of inheritance is the **polymorphism***
- Using inheritance violates the **encapsulation** *Especially with the access rights set to the `protected`*





# Part II

# Part 2 – Standard Template Library (STL)





## Templates

- Class definition may contain specific data fields of a particular type
- The data type itself does not change the behavior of the object, e.g., typically as in
  - Linked list or double linked list
  - Queue, Stack, etc.
  - *data containers*
- Definition of the class for specific type would be identical except the data type
- We can use **templates** for later specification of the particular data type, when the instance of the class is created
- Templates provides `compile-time polymorphism` *In constrast to the run-time polymorphism realized by virtual methods.*





## Example – Template Class

- The template class is defined by the **template** keyword with specification of the type name

```
template <typename T>
class Stack {
   public:
      bool push(T *data);
      T* pop(void);
};
```

- An object of the template class is declared with the specified particular type

```
Stack<int> intStack;
Stack<double> doubleStack;
```





## Example – Template Function

- Templates can also be used for functions to specify particular type and use type safety and typed operators

```
template <typename T>
const T & max(const T &a, const T &b)
{
   return a < b ? b : a;
}

double da, db;
int ia, ib;

std::cout << "max double: " << max(da, db) << std::endl;

std::cout << "max int: " << max(ia, ib) << std::endl;

//not allowed such a function is not defined
std::cout << "max mixed " << max(da, ib) << std::endl;
```





## STL

- Standard Template Library (STL) is a library of the standard C++ that provides efficient implementations of the data **containers**, algorithms, functions, and iterators
- High efficiency of the implementation is achieved by templates with compile-type polymorphism
- Standard Template Library Programmer's Guide – `https://www.sgi.com/tech/stl/`





## std::vector – Dynamic "C" like array

- One of the very useful data containers in STL is `vector` which behaves like C array but allows to add and remove elements

```
#include <iostream>
#include <vector>

int main(void)
{
   std::vector<int> a;

   for (int i = 0; i < 10; ++i) {
      a.push_back(i);
   }

   for (int i = 0; i < a.size(); ++i) {
      std::cout << "a[" << i << "] = " << a[i] << std::endl;
   }

   std::cout << "Add one more element" << std::endl;
   a.push_back(0);

   for (int i = 5; i < a.size(); ++i) {
      std::cout << "a[" << i << "] = " << a[i] << std::endl;
   }
   return 0;
}
```

lec12/stl-vector.cc

# Summary of the Lecture





## Topics Discussed

- Classes and objects
- Constructor/destructor
- Templates and STL
- Relationship between objects
  - Aggregation
  - Composition
- Inheritance – properties and usage in C++
- Polymorphism – dynamic binding and virtual methods
- Inheritance and Composition