

CS106L Lecture 7:

Classes



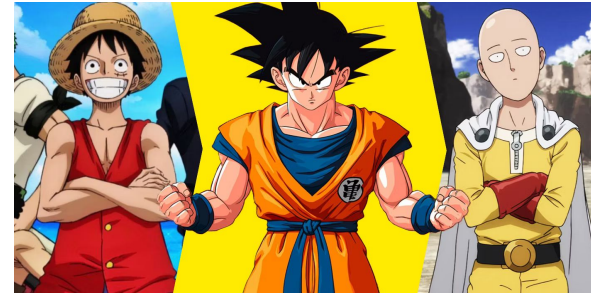
Autumn 2024

Fabio Ibanez, Jacob Roberts-Baca

Attendance



tinyurl.com/classesF24



Today's Agenda

1. Classes
2. Inheritance

Why classes?

- C has no **objects**

Why classes?

- C has no **objects**
- No way of **encapsulating** data and the functions that operate on that data

Why classes?

- C has no **objects**
- No way of **encapsulating** data and the functions that operate on that data
- No ability to have object-oriented programming (OOP) design patterns

What is object-oriented-programming?

- Object-oriented-programming is centered around **objects**

What is object-oriented-programming?

- Object-oriented-programming is centered around **objects**
- Focuses on design and implementation of classes!

What is object-oriented-programming?

- Object-oriented-programming is centered around **objects**
- Focuses on design and implementation of classes!
- Classes are the **user-defined types** that can be declared as an object!

Surprise!

Containers are classes defined in the STL!



Comparing 'struct' and 'class'

classes containing a sequence of objects of various types, a set of functions for manipulating these objects, and a set of restrictions on the access of these objects and function;

structures which are classes without access restrictions;

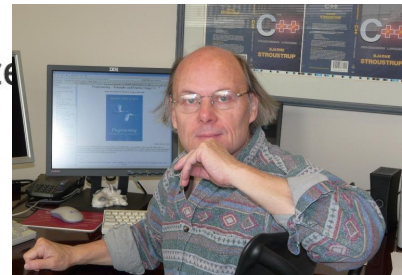
Bjarne Stroustrup, The C++ Programming Language – Reference
Manual, §4.4 Derived types

Comparing 'struct' and 'class'

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structures which are classes without access restrictions;

Bjarne Stroustrup, The C++ Programming Language – Reference Manual, §4.4 Derived types



Recall the 'struct'

```
struct StudentID {  
    std::string name; // these are fields!  
    std::string sunet;  
    int idNumber;  
};
```

```
Student s;  
s.name = "Fabio Ibanez";  
s.sunet = "fabioi";  
s.idNumber = 01243425;
```

Recall the 'struct'

```
struct StudentID {  
    std::string name; // these are fields!  
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```

All these fields are public,
i.e. can be changed by the
user

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Student s;  
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```

All these fields are public,
i.e. can be changed by the
user

```
Student s;  
s.name = "Fabio Ibanez";  
s.sunet = "fabioi";  
s.idNumber = 01243425;  
s.idNumber = -123451234512345; // 🦴 ?
```

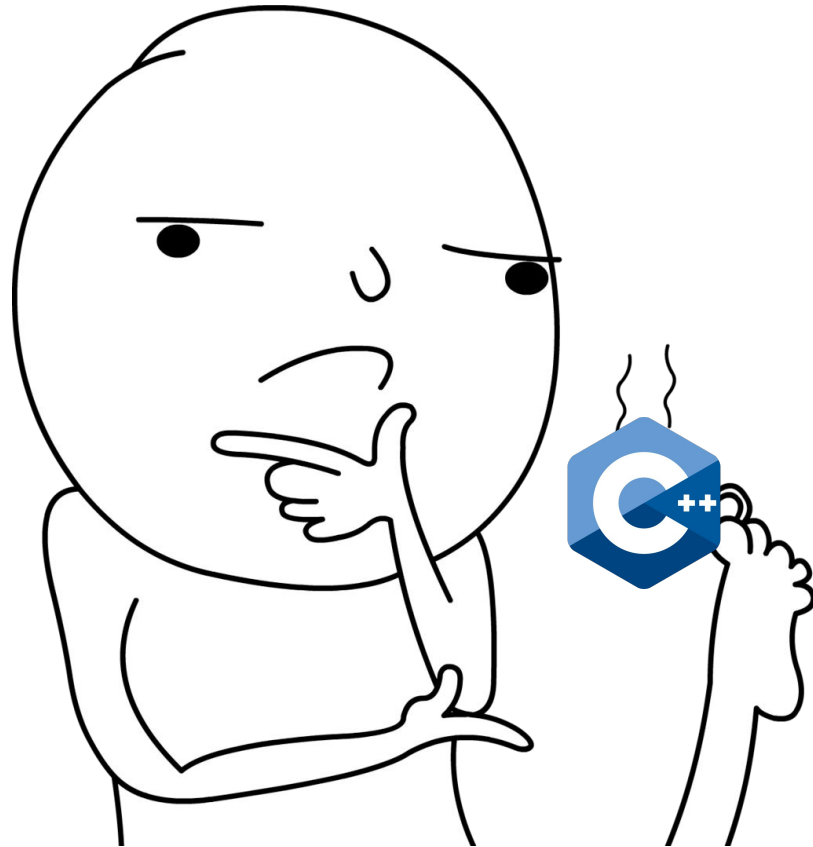
Recall the 'struct'

```
struct StudentID {  
    std::string name; // these are fields!  
    std::string sunet;  
    int idNumber;  
};
```

```
Student s;  
s.name = "Fabio Ibanez";  
s.sunet = "fabioi";  
s.idNumber = 01243425;  
s.idNumber = -12345123451234
```

There are no direct
access controls while
using structs

What questions do we have?



As you might have guessed

```
class ClassName {  
private:
```



```
public:
```



```
}
```

Classes have **public** and **private** sections!

User can access the **public**

```
class ClassName {  
private:
```



```
public:
```



```
}
```

Classes have **public** and **private** sections!

A user can access the **public** stuff

User is restricted from **private**

```
class ClassName {  
private:
```



```
public:
```



```
}
```

Classes have **public** and **private** sections!

A user can access the **public** stuff

But is restricted from accessing the private stuff

A backpack



A backpack

Struct



Class



Daily Meme



**Let's make a StanfordID class based
on our struct!**

Recall from Jacob's lecture!

```
struct StanfordID {  
    string name;           // These are called fields  
    string sunet;         // Each has a name and type  
    int idNumber;  
};  
  
StanfordID id;           // Access fields with '.'  
id.name = "Jacob Roberts-Baca";  
id.sunet = "jtrb";  
id.idNumber = 6504417;
```

Header File (.h) vs Source Files (.cpp)

	Header File (.h)	Source File (.cpp)
Purpose	Defines the interface	Implements class functions
Contains	Function prototypes, class declarations, type definitions, macros, constants	Function implementations, executable code
Access	This is shared across source files	Is compiled into an object file
Example	<code>void someFunction();</code>	<code>void someFunction() {...};</code>

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Access	This is shared across source files	Is compiled into an object file
Example	<code>void someFunction();</code>	<code>void someFunction() {...};</code>

prog2_vecintrin > C CS149intrin.h > ...

```
28 // Declare an integer vector register with __cs149_vec_int
29 #define __cs149_vec_int __cs149_vec<int>
30
31 //*****
32 /* Function Definition *
33 //*****
34
35 // Return a mask initialized to 1 in the first N lanes and 0 in the others
36 __cs149_mask _cs149_init_ones(int first = VECTOR_WIDTH);
37
38 // Return the inverse of maska
39 __cs149_mask _cs149_mask_not(__cs149_mask &maska);
40
41 // Return (maska | maskb)
42 __cs149_mask _cs149_mask_or(__cs149_mask &maska, __cs149_mask &maskb);
43
44 // Return (maska & maskb)
45 __cs149_mask _cs149_mask_and(__cs149_mask &maska, __cs149_mask &maskb);
46
47 // Count the number of 1s in maska
48 int _cs149_cntbits(__cs149_mask &maska);
49
50 // Set register to value if vector lane is active
51 // otherwise keep the old value
52 void _cs149_vset_float(__cs149_vec_float &vecResult, float value, __cs149_mask &mask);
53 void _cs149_vset_int(__cs149_vec_int &vecResult, int value, __cs149_mask &mask);
54 // For user's convenience, returns a vector register with all lanes initialized to value
55 __cs149_vec_float _cs149_vset_float(float value);
56 __cs149_vec_int _cs149_vset_int(int value);
57
```

Class design

- **A constructor**
- Private member functions/variables
- Public member functions (interface for a user)
- Destructor

Constructor

- The constructor initializes the state of newly created objects

Constructor

- The constructor initializes the state of newly created objects
- For our **StudentID** class what do our objects need?

Constructor

- The constructor initializes the state of newly created objects
- For our **StudentID** class what do our objects need?

```
s.name = "Fabio Ibanez";
```

```
s.sunet = "fabioi";
```

```
s.idNumber = 01243425;
```

Constructor

.h file

```
class StudentID {  
    private:  
        ?  
  
    public:  
        ?  
  
}
```

Constructor

.h file

```
class StudentID {  
private:  
    std::string name;  
    std::string sunet;  
    int idNumber;  
  
public:  
    // constructor for our student  
    StudentID(std::string name, std::string sunet, int idNumber);  
}
```

Constructor

.h file

```
class StudentID {  
private:  
    std::string name;  
    std::string sunet;  
    int idNumber;  
  
public:  
    // constructor for our student  
    StudentID(std::string name, std::string sunet, int idNumber);  
}
```

The syntax for the constructor is just
the name of the class

Constructor

.h file

```
class StudentID {  
private:  
    std::string name;  
    std::string sunet;  
    int idNumber;  
  
public:  
    // constructor for our StudentID  
    StudentID(std::string name, std::string sunet, int idNumber);  
    // method to get name, sunet, and idNumber, respectively  
    std::string getName();  
    std::string getSunet();  
    int getID();  
}
```

Parameterized Constructor

!! .cpp file!! (implementation)

```
#include "StudentID.h"
#include <string>

StudentID::StudentID(std::string name, std::string sunet, int idNumber) {
    name = name;
    sunet = sunet;
    idNumber = idNumber;
}
```

Parameterized Constructor

.cpp file (implementation)

```
#include "StudentID.h"
```

```
#include <string>
```

```
StudentID::StudentID(std::string name, std::string sunet, int idNumber) {  
    name = name;  
    sunet = sunet;  
    idNumber = idNumber;  
}
```

Remember namespaces, like `std::`

Parameterized Constructor

.cpp file (implementation)

```
#include "StudentID.h"  
#include <string>
```

```
StudentID::StudentID(std::string name, std::string sunet, int idNumber) {  
    name = name;  
    sunet = sunet;  
    idNumber = idNumber;  
}
```

Remember namespaces, like **std::**

In our **.cpp** file we need to use our class as our namespace when defining our member functions

Parameterized Constructor

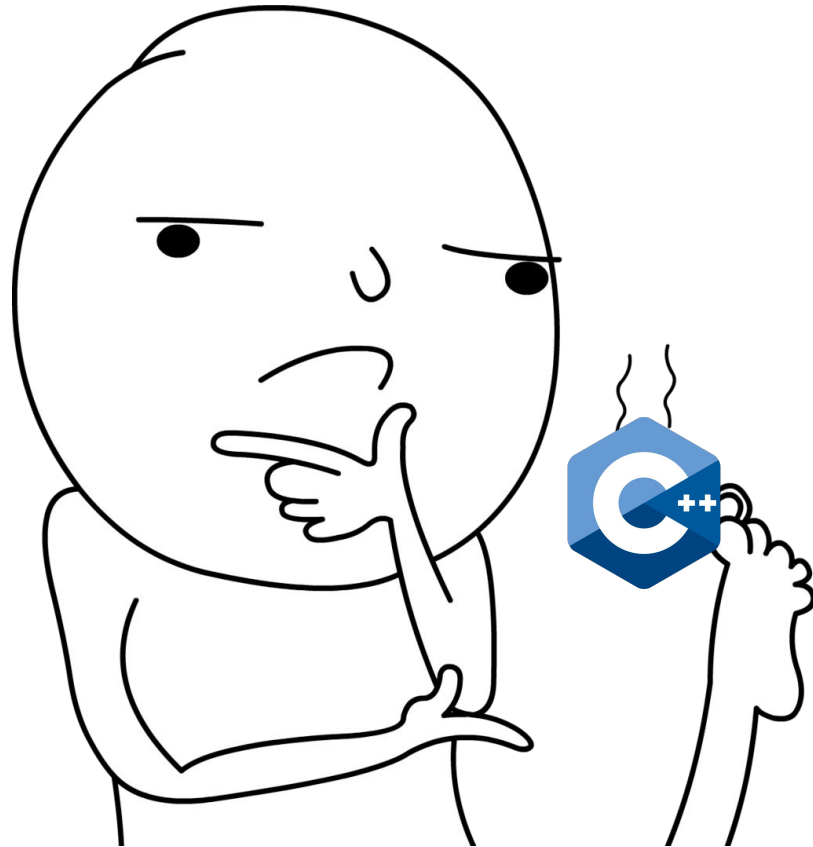
.cpp file (implementation)

```
#include "StudentID.h"
#include <string>

StudentID::StudentID(std::string name, std::string sunet, int idNumber) {
    name = name;
    sunet = sunet;
    if ( idNumber > 0 ) idNumber = idNumber;
}
```

We can now also enforce checks on the values that we initialize or modify our members to!

What questions do we have?



Parameterized Constructor

.cpp file (implementation)

```
#include "StudentID.h"  
#include <string>
```

```
StudentID::StudentID(std::string name, std::string sunet, int idNumber) {  
    name = name;  
    sunet = sunet;  
    if ( idNumber > 0 ) idNumber = idNumber;  
}
```

Does anyone see a problem here?

Parameterized Constructor

.cpp file (implementation)

```
#include "StudentID.h"
```

```
#include <string>
```

```
StudentID::StudentID(std::string name, std::string sunet, int idNumber) {  
    name = name;  
    sunet = sunet;  
    if ( idNumber > 0 ) idNumber = idNumber;  
}
```

Does anyone see a problem here?

Our .h definition

.h file

```
#include <string>
class StudentID {
private:
    std::string name;
    Std::string sunet;
    int idNumber;

public:
    // constructor for our student
    StudentID(std::string name, std::string sunet, int idNumber);
    // method to get name, sunet, and idNumber, respectively
    std::string getName();
    Std::string getSunet();
    int getID();
}
```

Use the **this** keyword

.cpp file (implementation)

```
#include "StudentID.h"
#include <string>

StudentID::StudentID(std::string name, std::string sunet, int idNumber) {
    this->name = name;
    this->state = state;
    this->age = age;
}
```

Use this **this** keyword to disambiguate which 'name' you're referring to.

List initialization constructor (C++11)

.cpp file (implementation)

```
#include "StudentID.h"
#include <string>

// list initialization constructor
StudentID::StudentID(std::string name, std::string sunet, int idNumber): name{name},
sunet{sunet}, idNumber{idNumber} {};
```

Recall, uniform initialization,
this is similar but not quite!

Default constructor

.cpp file (implementation)

```
#include "StudentID.h"
#include <string>

// default constructor
StudentID::StudentID() {
    name = "John Appleseed";
    sunet = "jappleseed";
    idNumber = 00000001;
}
```

If we call our constructor without parameters we can set default ones!

Constructor Overload

.cpp file (implementation)

```
#include "StudentID.h"  
#include <string>
```

```
// default constructor
```

```
StudentID::StudentID() {  
    name = "John Appleseed";  
    sunet = "jappleseed";  
    idNumber = 00000001;  
}
```

```
// parameterized constructor
```

```
StudentID::StudentID(std::string name, std::string sunet, int idNumber) {  
    this->name = name;  
    this->state = state;  
    this->age = age;  
}
```

Our compilers will know
which one we want to use
based on the inputs!

Back to our class definition

.h file

```
class StudentID {  
private:  
    std::string name;  
    std::string sunet;  
    int idNumber;  
  
public:  
    /// constructor for our student  
    StudentID(std::string name, std::string sunet, int idNumber);  
    /// method to get name, sunet, and ID, respectively  
    std::string getName();  
    std::string getSunet();  
    int getID();  
}
```

Let's implement them

.cpp file (implementation)

```
#include "StudentID.h"
#include <string>

std::string StudentID::getName() {
}

std::string StudentID::getSunet() {
}

int StudentID::getID() {
}
```

Implemented members

.cpp file (implementation)

```
#include "StudentID.h"
#include <string>

std::string StudentID::getName() {
    return this->name;
}

std::string StudentID::getSunet() {
    return this->sunet;
}

int StudentID::getID() {
    return this->idNumber;
}
```

Implemented members (setter functions)

.cpp file (implementation)

```
#include "StudentID.h"
#include <string>

void StudentID::setName(std::string name) {
    this->name = name;
}

void StudentID::setSunet(std::string sunet) {
    this->sunet = sunet;
}

void StudentID::setID(int idNumber) {
    if (idNumber >= 0){
        this->idNumber = idNumber;
    }
}
```

The destructor

.cpp file (implementation)

```
#include "StudentID.h"  
#include <string>  
  
StudentID::~~StudentID() {  
    // free/deallocate any data here  
}
```

The destructor

.cpp file (implementation)

```
#include "StudentID.h"
#include <string>

StudentID::~StudentID() {
    // free/deallocate any data here
}
```

In our **StudentID** class we are not dynamically allocating any data by using the **new** keyword

The destructor

.cpp file (implementation)

```
#include "StudentID.h"  
#include <string>  
  
StudentID::~~StudentID() {  
    // free/deallocate any data here  
}
```

Nonetheless destructors are an important part of an object's lifecycle.

The destructor

.cpp file (implementation)

```
#include "StudentID.h"
#include <string>

StudentID::~StudentID() {
    /// free/deallocate any data here

    delete [] my_array; /// for illustration
}
```

The destructor is not explicitly called, it is automatically called when an object goes out of scope

Some other cool class stuff

Type aliasing - allows you to create synonymous identifiers for types

```
template <typename T>
class vector {
    using iterator = T*;

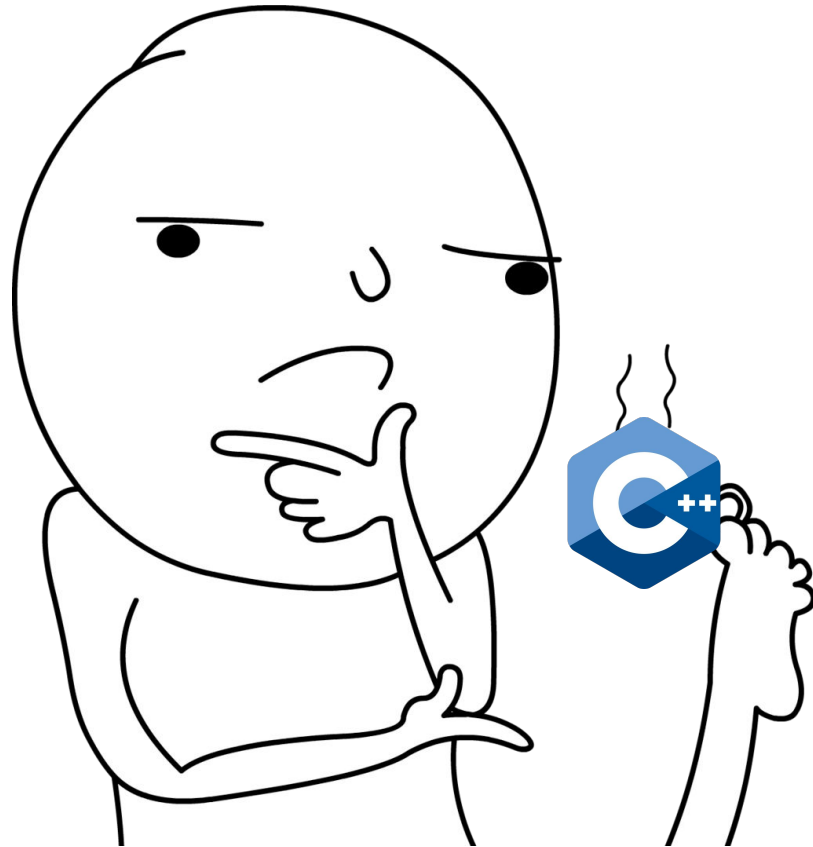
    // Implementation details...
};
```

Back to our class definition

.h file

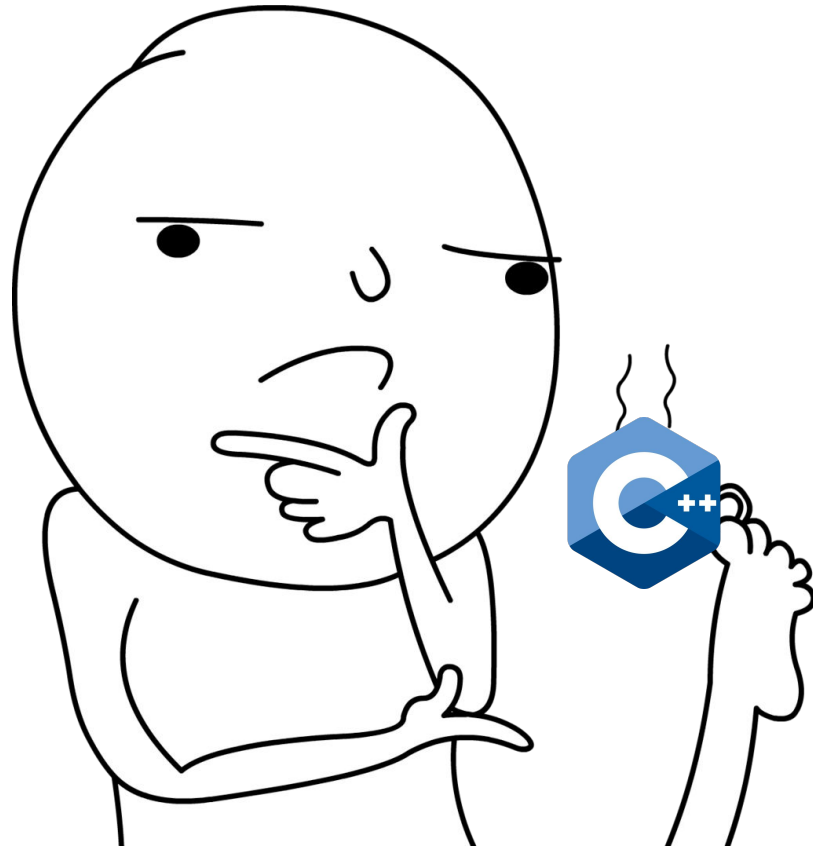
```
class StudentID {  
private:  
    // An example of type aliasing  
    using String = std::string;  
    String name;  
    String sunet;  
    int idNumber;  
  
public:  
    // constructor for our student  
    Student(String name, String sunet, int idNumber);  
    // method to get name, state, and age, respectively  
    String getName();  
    String getSunet();  
    int getID();  
}
```

What questions do we have?



Taking a look at the StudentID class

What questions do we have?

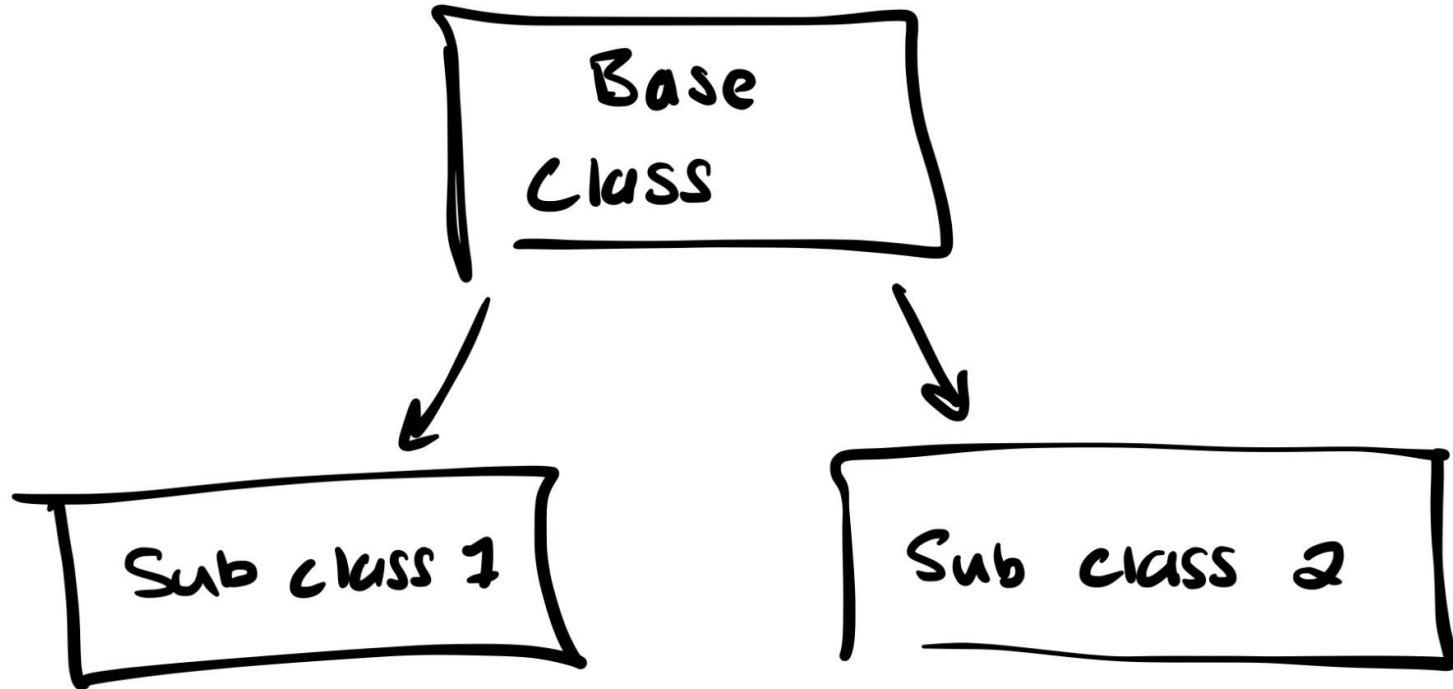


Plan

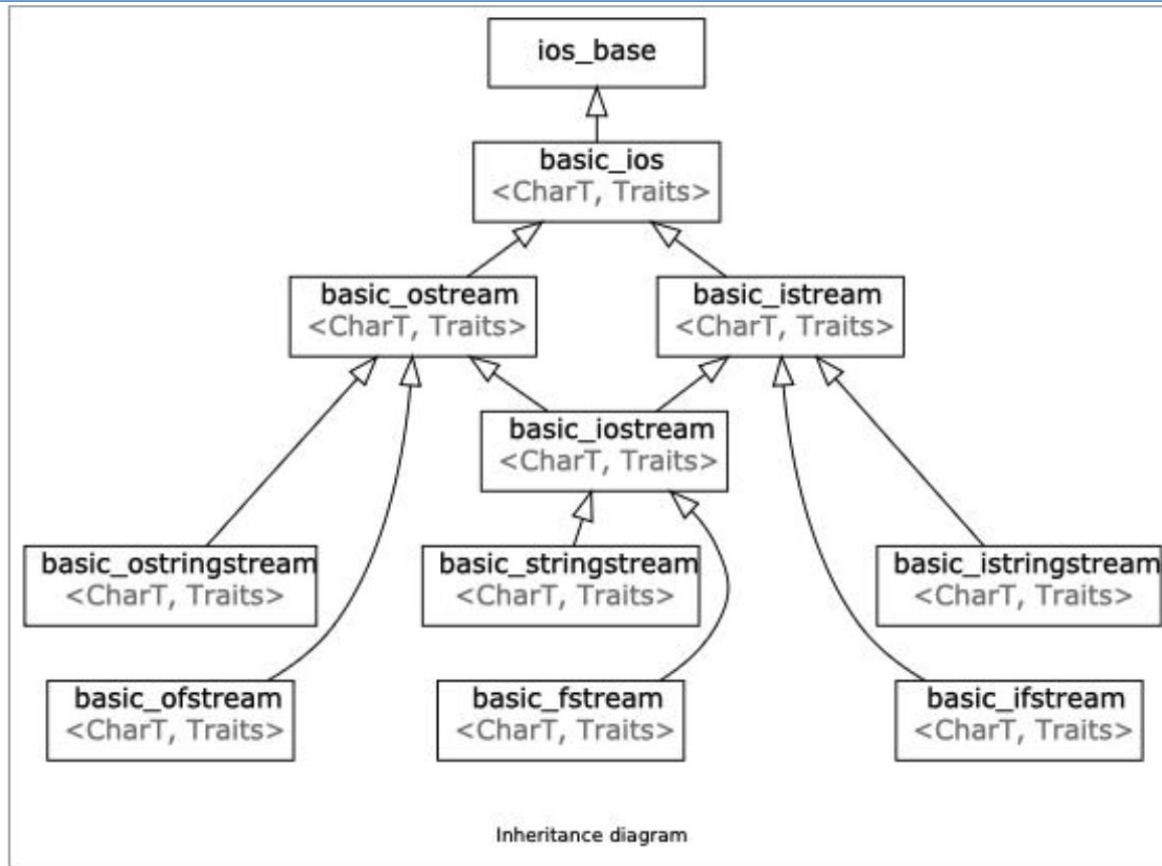
1. Classes

2. Inheritance

(Class) Inheritance



Circling back to this diagram



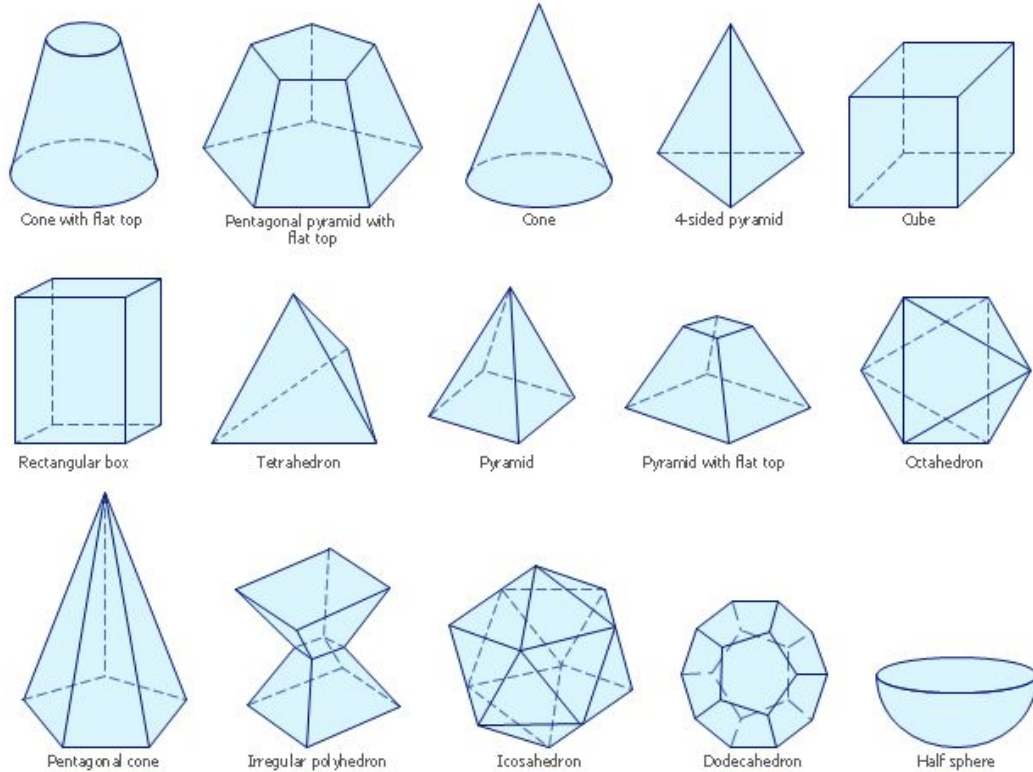
Inheritance

- **Dynamic Polymorphism:** Different types of objects may need the same interface

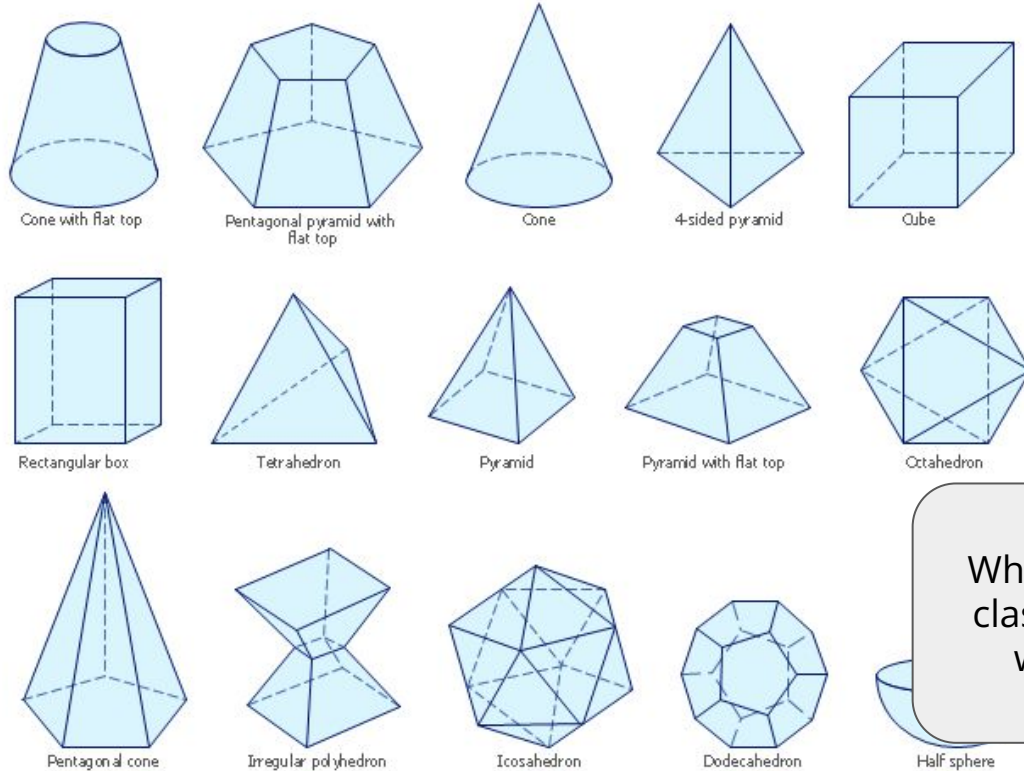
Inheritance

- **Dynamic Polymorphism:** Different types of objects may need the same interface
- **Extensibility:** Inheritance allows you to extend a class by creating a subclass with specific properties

Inheritance in practice



Inheritance in practice



What if we had a **shape** class, what do we think we would include?

Shapes have

- Area

Shapes have

- Area
- Radius? Or height? Or Width?

Shapes have

- Area
- Radius? Or height? Or Width?
- Anything else?

Shape class definition

.h file

```
class Shape {  
public:  
    virtual double area() const = 0;  
};
```

Pure virtual function: it is instantiated in the base class but overwritten in the subclass.

(Dynamic Polymorphism)

Shape class definition

.h file

```
class Shape {  
public:  
    virtual double area() const = 0;  
};  
  
class Circle : public Shape {  
public:  
    // constructor  
    Circle(double radius): _radius{radius} {};  
    double area() const {  
        return 3.14 * _radius * _radius;  
    }  
private:  
    double _radius;  
};
```

Let's break this down step by step

Circle class definition

.h file

```
class Shape {  
public:  
    virtual double area() const = 0;  
};  
  
class Circle : public Shape {  
public:  
    // constructor  
    Circle(double radius): _radius{radius} {};  
    double area() const {  
        return 3.14 * _radius * _radius;  
    }  
private:  
    double _radius;  
};
```

Here we declare the **Circle** class which inherits from the **Shape** class

Circle class definition

.h file

```
class Shape {  
public:  
    virtual double area() const = 0;  
};  
  
class Circle : public Shape {  
public:  
    // constructor  
    Circle(double radius): _radius{radius} {};  
    double area() const {  
        return 3.14 * _radius * _radius;  
    }  
private:  
    double _radius;  
};
```

This is a virtual function we declare in our base class, **Shape**

Circle class definition

.h file

```
class Shape {  
public:  
    virtual double area() const = 0;  
};  
  
class Circle : public Shape {  
public:  
    // constructor  
    Circle(double radius): _radius{radius} {};  
    double area() const {  
        return 3.14 * _radius * _radius;  
    }  
private:  
    double _radius;  
};
```

constructor using list
initialization
construction

Circle class definition

.h file

```
class Shape {  
public:  
    virtual double area() const = 0;  
};  
  
class Circle : public Shape {  
public:  
    // constructor  
    Circle(double radius): _radius{radius} {};  
    double area() const {  
        return 3.14 * _radius * _radius;  
    }  
private:  
    double _radius;  
};
```

Here we are overwriting
the base class function
area() for a circle

Circle class definition

.h file

```
class Shape {
public:
    virtual double area() const = 0;
};

class Circle : public Shape {
public:
    // constructor
    Circle(double radius): _radius{radius} {};
    double area() const {
        return 3.14 * _radius * _radius;
    }
private:
    double _radius;
};
```

Another pro of inheritance is the **encapsulation** of class variables.

Rectangle class definition

.h file

```
class Shape {
public:
    virtual double area() const = 0;
};
. . .
class Rectangle: public Shape {
public:
    // constructor
    Rectangle(double height, double width): _height{height}, _width{width}
    {};
    double area() const {
        return _width * _height;
    }
private:
    double _width, _height;
};
```


Shape subclass definitions

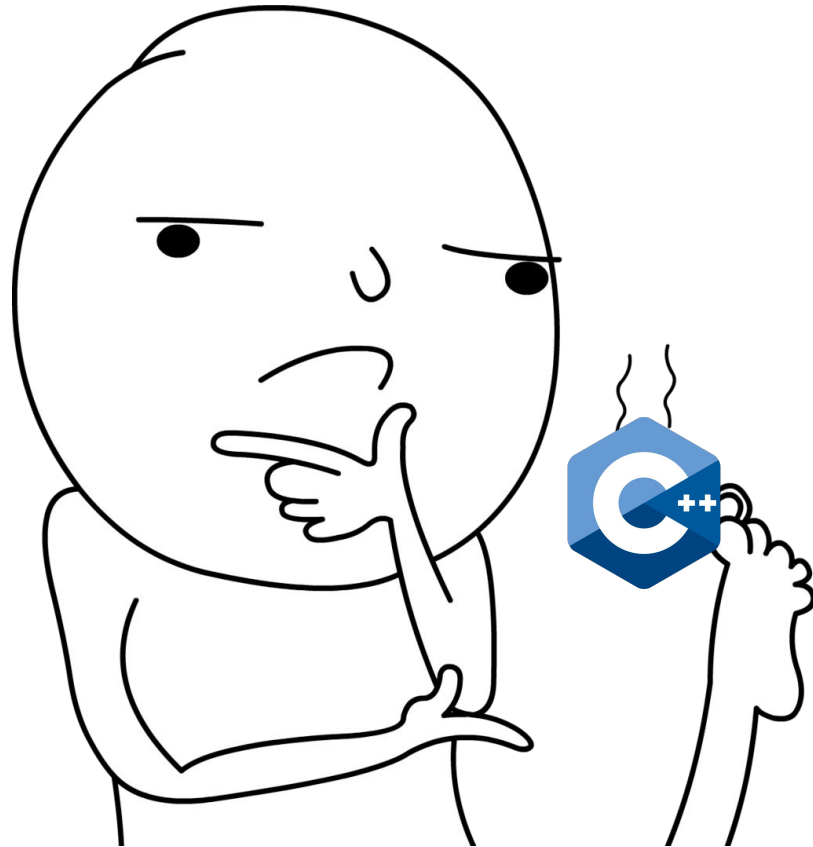
.h file

```
class Rectangle: public Shape {
public:
    // constructor
    Rectangle(double height, double
width): _height{height},
_width{width} {};

    double area() const {
        return _width * _height;
    }
private:
    double _width, _height;
};
```

```
class Circle : public Shape {
public:
    // constructor
    Circle(double radius):
        _radius{radius} {};
    double area() const {
        return 3.14 * _radius *
_radius;
    }
private:
    double _radius;
};
```

What questions do we have?



Types of inheritance

Type	public
Example	<code>class B: public A {...}</code>
Public Members	Are public in the derived class
Protected Members	Protected in the derived class
Private Members	Not accessible in derived class

Types of inheritance

Type	public	protected
Example	<code>class B: public A {...}</code>	<code>class B: protected A {...}</code>
Public Members	Are public in the derived class	Protected in the derived class
Protected Members	Protected in the derived class	Protected in the derived class
Private Members	Not accessible in derived class	Not accessible in derived class

Types of inheritance

Type	public	protected	private
Example	class B: public A {...}	class B: protected A {...}	class B: private A {...}
Public Members	Are public in the derived class	Protected in the derived class	Privated in the derived class
Protected Members	Protected in the derived class	Protected in the derived class	Private in the derived class
Private Members	Not accessible in derived class	Not accessible in derived class	Not accessible in derived class

Person class

.h file

```
class Person {  
protected:  
    std::string name;  
  
public:  
    Person(const std::string& name) : name(name) {}  
    std::string getName();  
}
```

Student class

.h file

```
class Student : public Person {
protected:
    std::string idNumber;
    std::string major;
    std::string advisor;
    uint16_t year;
public:
    Student(const std::string& name, ...);
    std::string getIdNumber() const;
    std::string getMajor() const;
    uint16_t getYear() const;
    void setYear(uint16_t year);
    void setMajor(const std::string& major);
    std::string getAdvisor() const;
    void setAdvisor(const std::string& advisor);
};
```

The constructor has all of the protected members. For the sake of space I've omitted them here.

Employee class

.h file

```
class Employee : public Person {  
protected:  
    double salary;  
public:  
    Employee(const std::string& name);  
    virtual std::string getRole() const = 0;  
    virtual double getSalary() const = 0;  
    virtual void setSalary() const = 0;  
    virtual ~Employee() = default;  
};
```

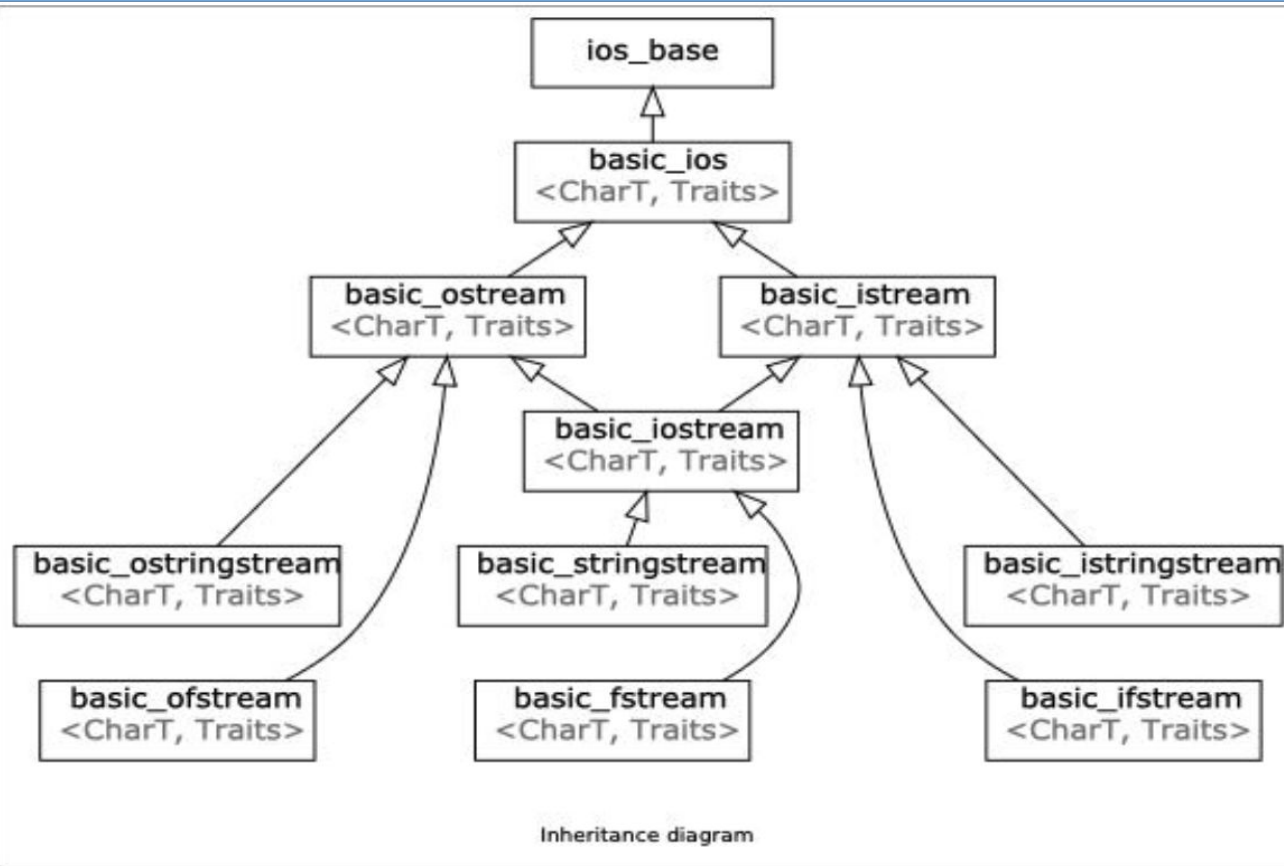

SectionLeader class

.h file

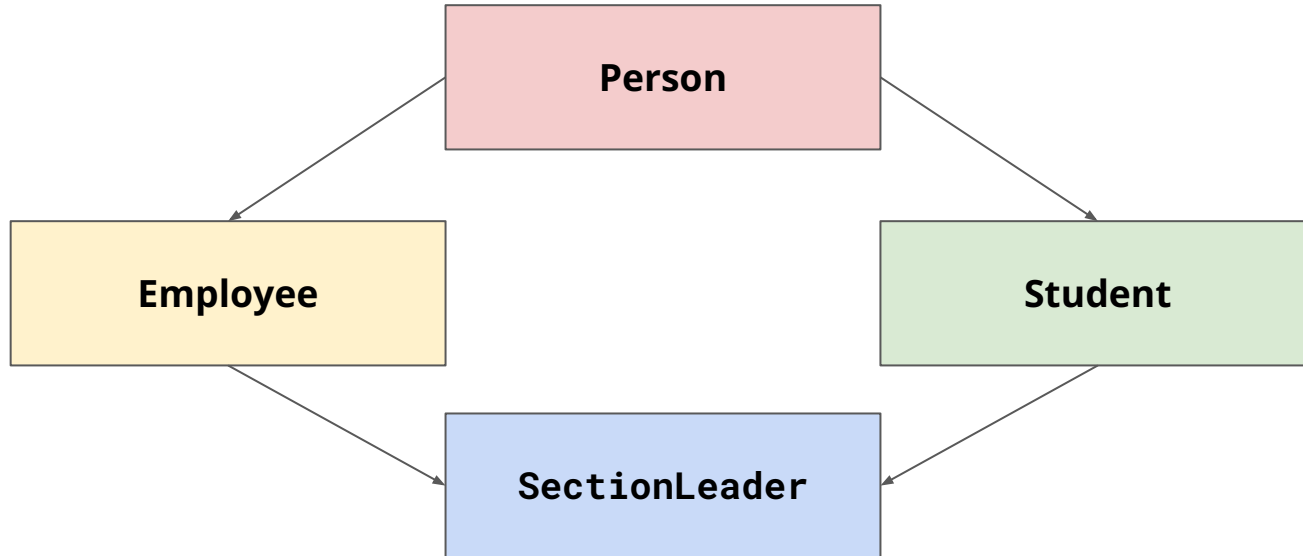
```
class SectionLeader : public Person, public Employee {  
protected:  
    std::string section;  
    std::string course;  
    std::vector<std::string> students;  
public:  
    Student(const std::string& name, ...);  
    std::string getSection() const;  
    std::string getCourse() const;  
    void addStudent(const std::string& student);  
    void removeStudent(const std::string& student);  
    std::vector<std::string> getStudents() const;  
    std::string getRole() const override;  
    double getSalary() const override;  
    void setSalary(double salary) override;  
};
```

And the destructor
~SectionLeader()

Inheritance Diagram?

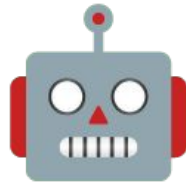


Inheritance Diagram?

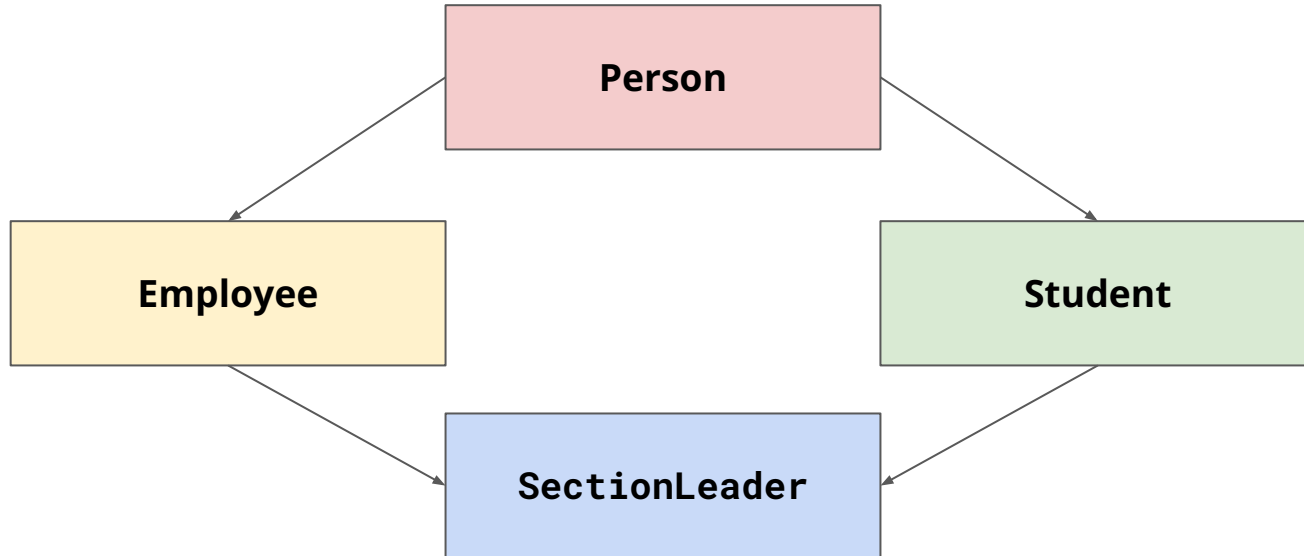


Lets implement a vector class for `ints`!

Let's look at code!

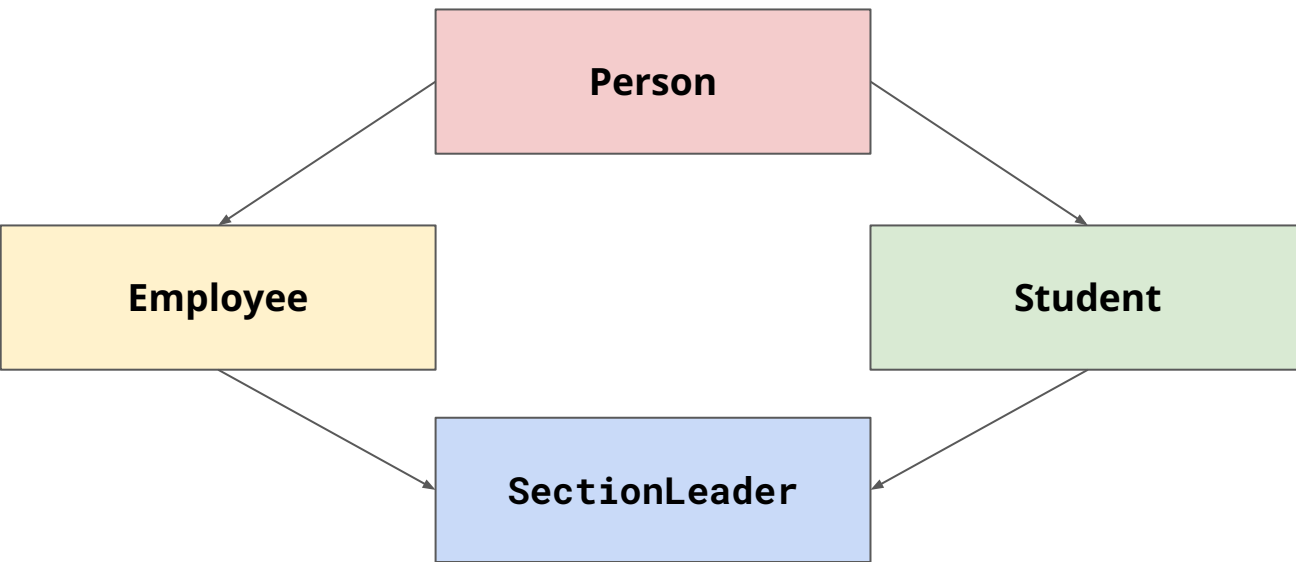


The Diamond Problem



The Diamond Problem

Since both **Student** and **Employee** inherit from **Person**, they each call the constructor of **Person**.



SectionLeader ends up with two copies of **Person**. One from **Student** another from **Employee**

The Diamond Problem

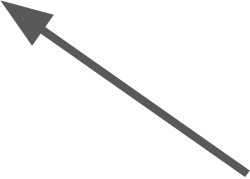
The way to fix this is to make **Employee** and **Student** inherit from **Person** in a **virtual way**.

Virtual inheritance means that a derived class, in this case **SectionLeader**, should only have a single instance of base classes, in this case **Person**.

Student class

.h file

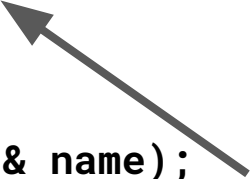
```
class Student : public virtual Person {  
protected:  
    std::string idNumber;  
    std::string major;  
    std::string advisor;  
    uint16_t year;  
public:  
    Student(const std::string& name, ...);  
    std::string getIdNumber() const;  
    std::string getMajor() const;  
    uint16_t getYear() const;  
    void setYear(uint16_t year);  
    void setMajor(const std::string& major);  
    std::string getAdvisor() const;  
    void setAdvisor(const std::string& advisor);  
};
```



Employee class

.h file

```
class Employee : public virtual Person {  
protected:  
    double salary;  
public:  
    Employee(const std::string& name);  
    virtual std::string getRole() const = 0;  
    virtual double getSalary() const = 0;  
    virtual void setSalary() const = 0;  
    virtual ~Employee() = default;  
};
```



The Diamond Problem

The way to fix this is to make **Employee** and **Student** inherit from **Person** in a **virtual way**.

Inheritance virtually just means that a derived class, in this case **SectionLeader**, should only have a single instance of base class **Person**.

! This requires the derived class to initialize the base class! !

Recap

1. Classes allow you to encapsulate functionality and data with access protections
2. Inheritance allows us to design powerful and versatile abstractions that can help us model complex relationships in code.
3. These concepts are tricky – this lecture *really* highlights the power of C++