Polymorphism

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Today's Plan

Inheritance Recap
Polymorphism

Announcements and Syllabus Check

Q: Why use dynamic memory allocation?

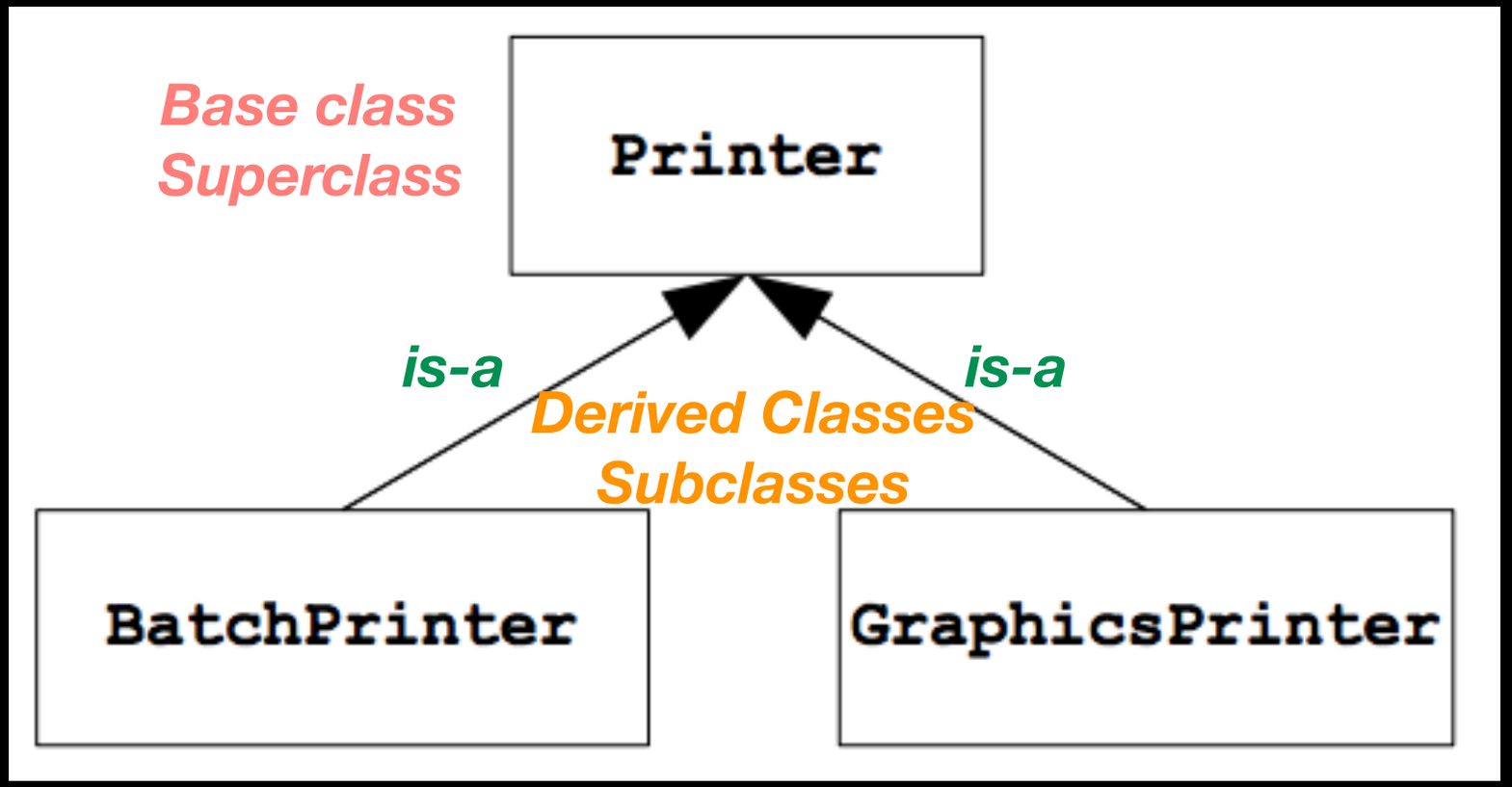
Inheritance Recap

Basic Inheritance

```
class Printer
{
public:
    //Constructor, destructor

    void setPaperSize(const int size);
    void setOrientation(const string& orientation);
    void changeCartridge();
    void printDocument(const string& document);
private:
    // stuff here
}; //end Printer

class BatchPrinter: public Printer // inherit from printer
{
public:
    //Constructor, destructor
    void addDocument(const string& document);
    void printAllDocuments();
private:
    vector<string> documents; //Document queue
}; //end BatchPrinter
```

```
class GraphicsPrinter: public Printer // inherit from printer
{
public:
    //Constructor, destructor
    void changeCartridge();
    void printDocument(const Picture& picture);

private:
    //stuff here
}; //end GraphicsPrinter
```

Basic Inheritance




```
void initializePrinter(Printer& p)
BatchPrinter batch;
initizlizePrinter(batch); //legal because batch is-a printer
```

Think of argument types as specifying minimum requirements

Problem

```
class BatchPrinter: public Printer // inherit from printer
{
public:
    //Constructor, destructor
    void addDocument(const string& document);
    void printAllDocuments();
private:
    vector<string> documents; //Document queue
}; //end BatchPrinter
```

Can’t store different types of documents in printer queue

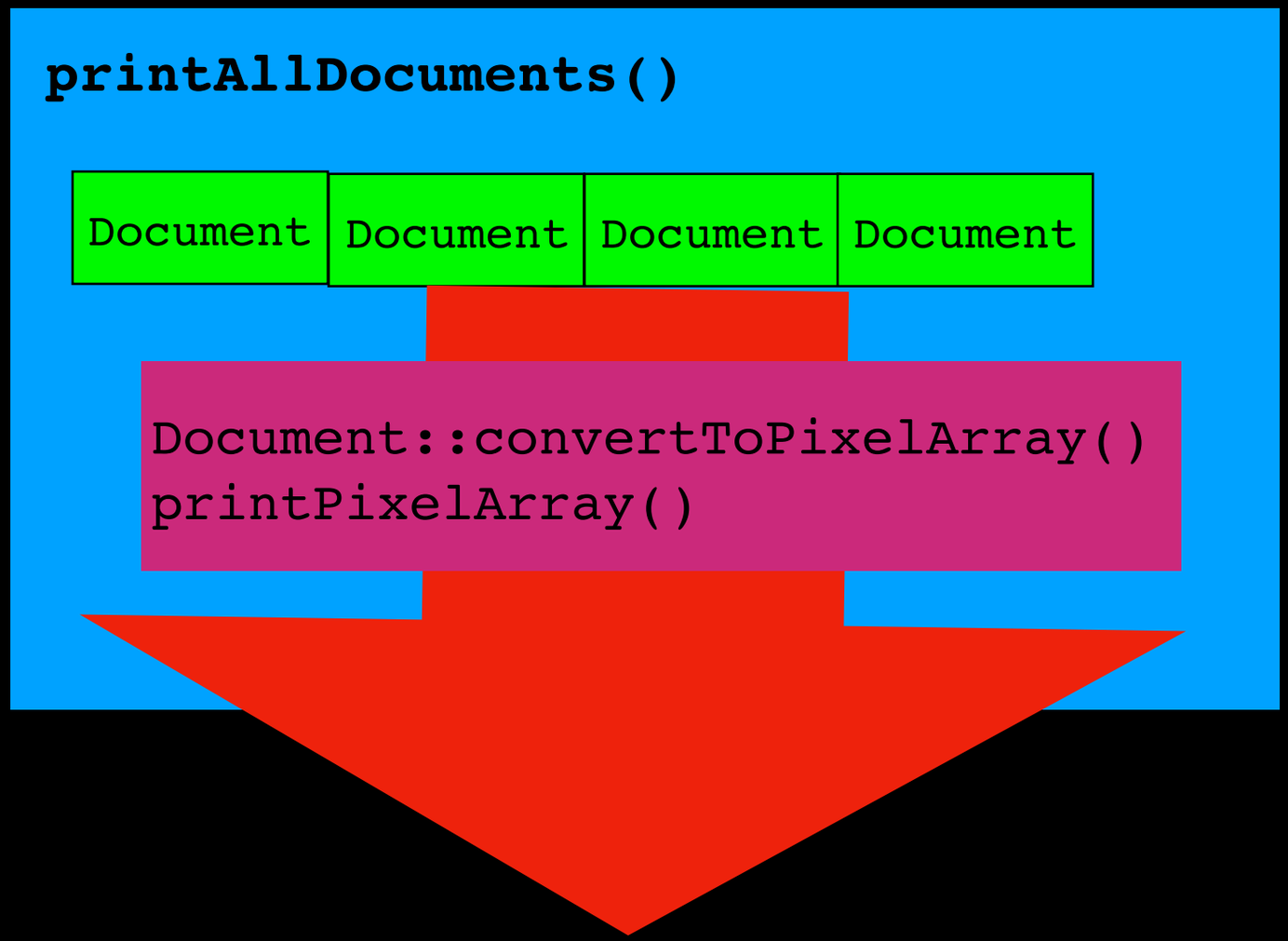
We would like to print all kinds of documents not just text
`documents` **should be able to store different types of documents**

Generalized Document

Whatever the type of document, a printer ultimately prints a grid of pixels

Generalized `Document` should know how to convert itself into a printable format

We want `Document` to be an *interface* => not concerned with implementation details


printAllDocuments()
Document
Document
Document
Document
Document::convertToPixelArray()
printPixelArray()

Polymorphism

```
class BatchPrinter: public Printer // inherit from printer
{
public:
    //Constructor, destructor
    void addDocument(const Document* document);
    void printAllDocuments();
private:
    vector<Document*> documents; //Document queue
}; //end BatchPrinter
```

Abstract Class!

```
class Document:
{
public:
    //Constructor, destructor
    virtual void convertToPixelArray() const = 0;
    virtual int getPriority() const = 0;

private:
    //stuff here
}; //end Document
```

This function has no implementation**

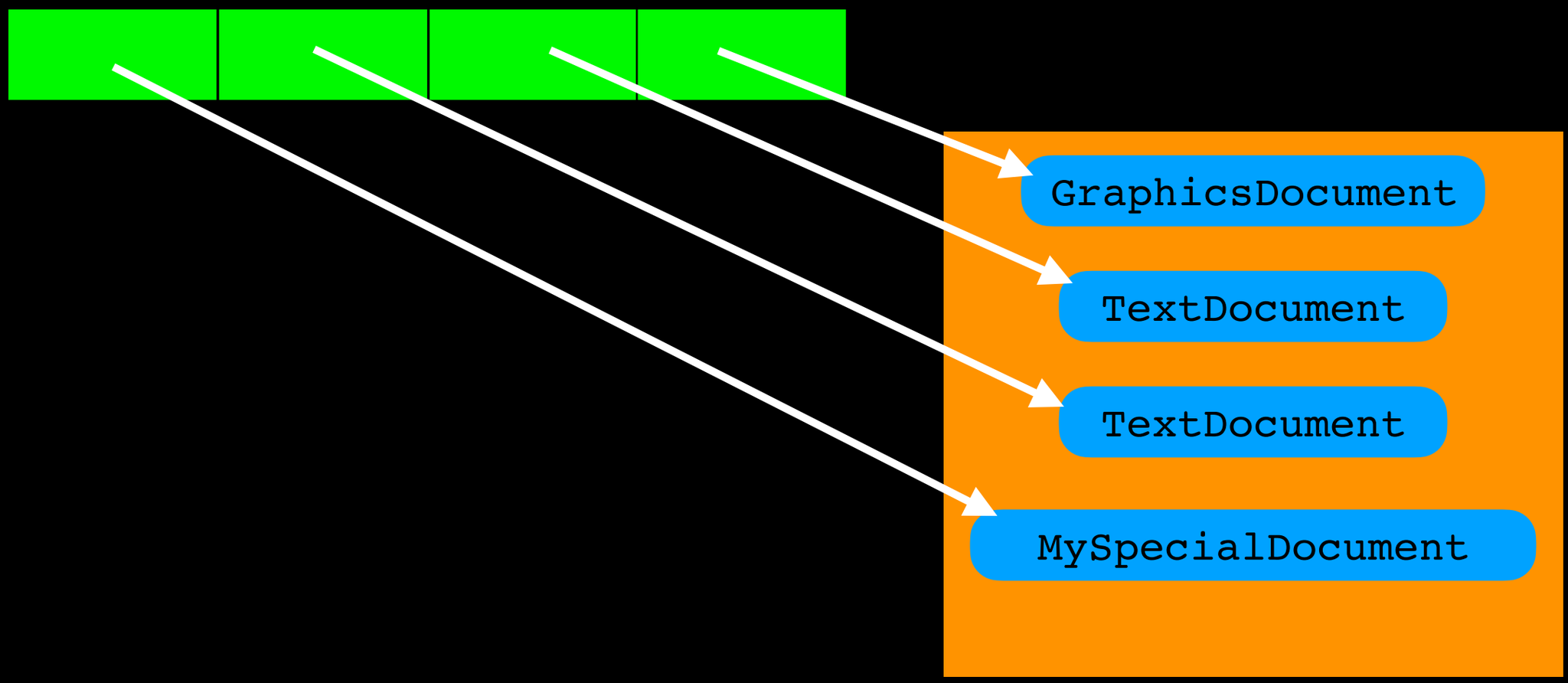
I'll explain this next

**odd syntax due to historical/political reasons, explained in quote later

```
class TextDocument: public Document// inherit from Document
{
public:
    //Constructor, destructor
    virtual void convertToPixelArray() const override;
    virtual int getPriority() const override;

    void setFont(const string& font); //text-specific formatting
    void setSize(int size);

private:
    //stuff here
}; //end TextDocument
```

Have implementation

```
class TextDocument: public Document

class GraphicsDocument: public Document

class PortableFormatDocument: public Document

class SpreadsheetDocument: public Document
```



But how does compiler know whose
`convertToPixelArray()` to call?
`TextDocument::convertToPixelArray?`
`GraphicsDocument::convertToPixelArray?`

Where are we going?

I want to store all kinds of documents in my `BatchPrinter` queue

I want to access the correct `convertToPixelArray()` method specific to each different document type

main()

```
BatchPrinter myBatchPrinter;

Document* myTextDocument = new TextDocument;
Document* myGraphicsDocument = new GraphicsDocument;

//do stuff

myBatchPrinter.addDocument(myTextDocument)
myBatchPrinter.addDocument(myGraphicsDocument)

myBatchPrinter.printAllDocuments();
```

`TextDocument` ***is-a*** `Document`
`GraphicsDocument` ***is-a*** `Document`
We can point to objects of derived class using pointers to base class

We store in printer queue pointers to `Document` but really can access any derived class document

```
    myTextDocument->convertToPixelArray();
    myGraphicsDocument->convertToPixelArray();
```

`convertToPixelArray` **is marked `virtual` so the appropriate function call is determined at runtime**

Late Binding via Virtual Functions

Avoid statically binding function calls at compile time

Must declare functions as `virtual` for **late binding**

Polymorphism

We just saw an example of *polymorphism* (literally many forms)

With `virtual` functions the outcome of an operation is determined at execution time

With basic inheritance we were just saving ourselves the trouble of re-writing code

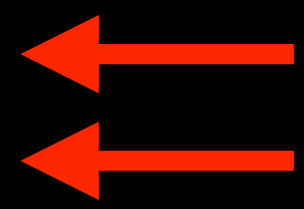
Abstract Class

Pure virtual function (=0) has no implementation

Abstract class

- Has at least one pure virtual function
- Cannot be instantiated because does not have implementation for some/all its member functions

```
Document myDocument;        //Error!
Document* myDocument;       //Error!
```



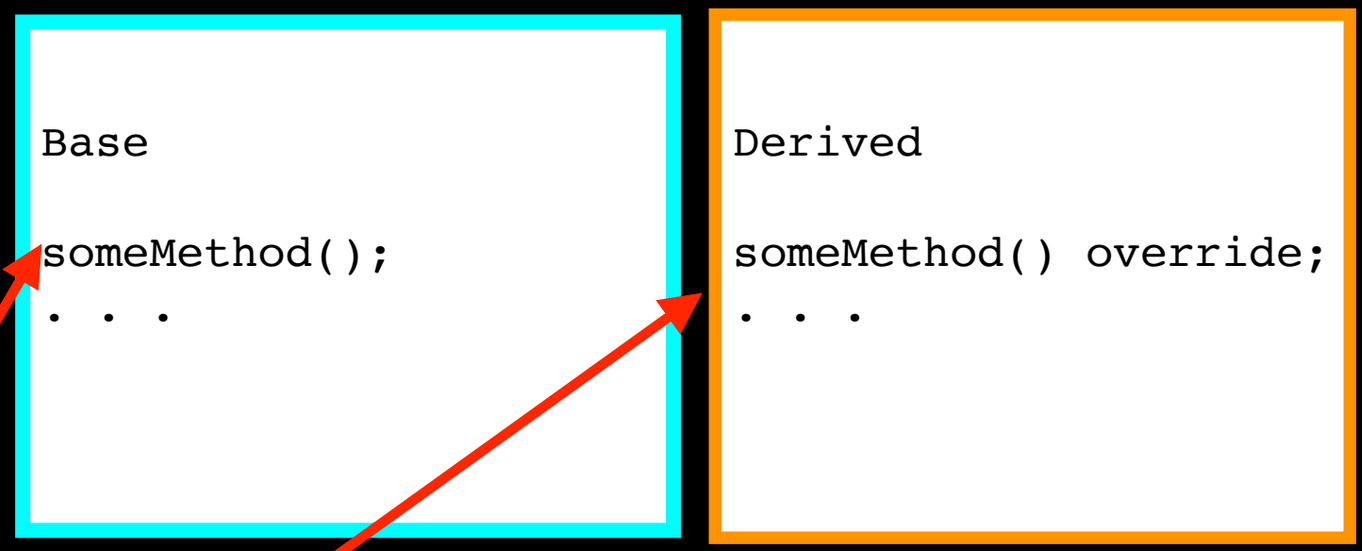
"The curious =0 syntax was chosen over the obvious alternative of introducing a new keyword pure or abstract because at the time I saw no chance of getting a new keyword accepted. Had I suggested pure, Release 2.0 would have shipped without abstract classes, I chose abstract classes. Rather than risking delay and incurring the certain fights over pure, I used the traditional C and C++ convention of using 0 to represent 'not there' "

Bjarne Stroustrup

Recap Basic Inheritance

main()

```
Base base_object;
Derived derived_object;

// stuff here


base_object.someMethod();    //calls Base function
derived_object.someMethod(); // calls Derived function - Overriding!!!
```



Recap Polymorphism

main()

```
Base* base_ptr = new Base;
Base* derived_ptr = new Derived;

// stuff here


base_ptr->someMethod();  //calls Base function
derived_ptr->someMethod(); // ???
```

```
Base

someMethod();
. . .
```

```
Derived

someMethod() override;
. . .
```

Recap Polymorphism

main()

```
Base* base_ptr = new Base;
Base* derived_ptr = Derived;

// stuff here


base_ptr->someMethod();  //calls Base function
derived_ptr->someMethod(); // call Derived function - LATE BINDING!!!!
```

```
Base

virtual someMethod();
. . .
```

```
Derived

someMethod() override;
. . .
```

Recap Abstract Class

This function has no implementation**

```
class Document:
{
public:
    //Constructor, destructor
    virtual void convertToPixelArray() const = 0;
    virtual int getPriority() const = 0;

private:
    //stuff here
}; //end Document
```

Polymorphism without abstraction

Superclass need not be abstract

Virtual functions in superclass need not be pure virtual

Polymorphism without Abstract Classes

```
class Skater
{
public:
    //constructor, destructor
    virtual void slowDown();
    //virtual, not pure

private:
    //stuff here
}; //end Skater
```

```
class InexperiencedSkater:
          public Skater
{
public:
    //constructor, destructor
    virtual void slowDown() override;
private:
    //stuff here
}; //end InexperiencedSkater
```

```
void Skater::slowDown()
{
    applyBreaks();
} //end slowDown
```

```
void InexperiencedSkater
                        ::slowDown()
{
    fallDown();
} //end slowDown
```

implementation does not have **virtual** or **override** keyword

Polymorphism without Abstract Classes

main()

```
Skater* firstSkater = new Skater;
firstSkater->slowDown();    // applyBreaks()

Skater* secondSkater = new InexperiencedSkater;
secondSkater->slowDown();       // fallDown() - LATE BINDING!
```

Polymorphism without Abstract Classes

Need not override non-pure virtual functions

```
class StuntSkater: public Skater
{
public:
    //constructor, destructor - note no mention of slowDown
    void frontFlip();
    void backFlip();
private:
    //stuff here
};  //end StuntSkater


// stuff here


Skater* stunt_skater = new StuntSkater;
stunt_skater->slowDown();       // applyBreaks()
```

Warning

```
class NotVirtual
{
public:
    void notAVirtualFunction();
};  //end NotVirtual
```

When using pointers to base class, to let derived classes override functions in base class must make the base class's function virtual

```
class NotVirtualDerived: public NotVirtual
{
public:
    void notAVirtualFunction() override;
};  //end NotVirtualDerived



NotVirtual* nv = new NotVirtualDerived;
nv->notAVirtualFunction(); // OUCH!!! calls NotVirtual's member
                           // instead of NotVirtualDerived's member
```

More design considerations

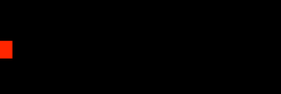
Back to `Document` class

Assume we realize all types of documents have `width` and `height` data members

Makes sense to move them into base class

Don’t want client to have direct access to data members

```
class Document:
{
public:
    //Constructor, destructor
    virtual void convertToPixelArray() const = 0;
    virtual int getPriority() const = 0;

private:
    int width, height; //Problem!!!
    //stuff here
}; //end Document
```



protected Access in Base Class

```
class Document:
{
public:
    //Constructor, destructor
    virtual void convertToPixelArray() const = 0;
    virtual int getPriority() const = 0;

protected:
    int width, height;
    //stuff here

private:
    //stuff here
}; //end Document
```

Access Specifiers Base Class members

`public`

accessible by everyone

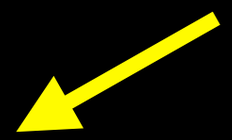
`private`

accessible within class and by friends

`protected`

accessible within class, by friends and by derived classes

Access Specifiers for Inheritance



```
class Derived: public Base
{
public:
    //Stuff here

private:
    //Stuff here


}; //end Derived
```

Inheritance accessibility

Access in Base Class	Inheritance Method	Access in Derived Class
public	public ***is-a***	public
protected		protected
private		**no access**
public	protected ***is-implemented-and-inherited-as***	protected
protected		protected
private		**no access**
public	private ***is-implemented-as***	private
protected		private
private		**no access**

We will not discuss the details of protected and private inheritance in this course

`override` specifier

Explicitly tell compiler you mean to override a function

Compiler will check!

Also self-documenting

```
class BaseClass
{
    virtual void f(int);
};

class DerivedClass: public BaseClass
{
    virtual void f(float) override; //Compile-time error
};
```

`final` specifier

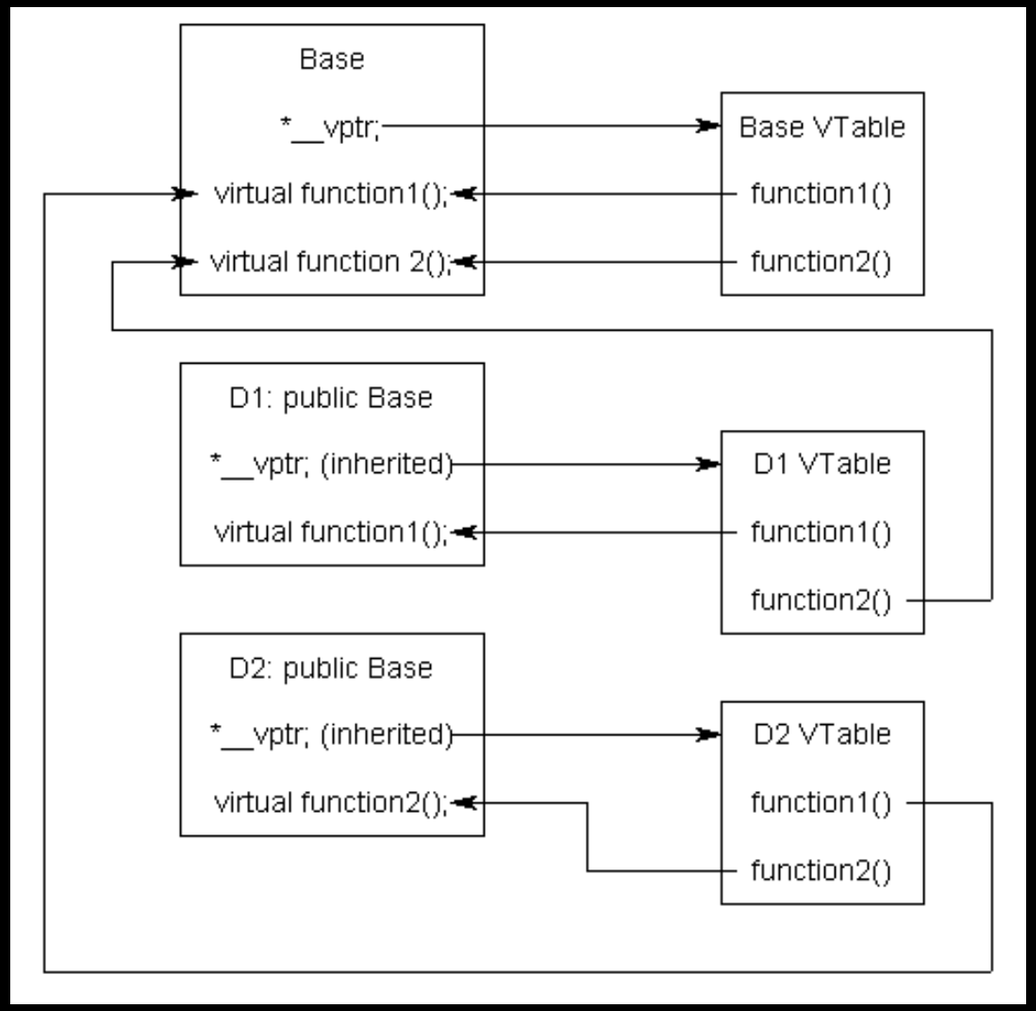
- Prevents inheritance
- Prevents deriving classes from overriding methods

```
class A
{
    virtual void f();
};

class B : public A
{
    void f() final override; //cannot override f()
};

class C: public B final  //cannot inherit from C
{
    void f() override; //Error, f is final!
}

class D: public C{}   //Error C is final!
```

Runtime Costs of Virtual Functions

Function call overhead

- C++ maintains ***virtual function tables*** that store pointers to each virtual function
- Determine which function to call at execution time by looking-up **v-table** of object being pointed to



Clever! But still

Slower

Extra space for v-tables

Overhead ->mark individual functions virtual to take advantage of polymorphism only when appropriate

Fully polymorphic inheritance would be overkill in most cases

Recap

Polymorphism -> virtual functions

Pure vs non-pure virtual functions

Polymorphism with or without abstract classes

`override` and `final`

Overhead

Study Q

Need to pay **extra** attention to **destructors**!!!

With Polymorphism destructor **MUST** always be virtual!!!

```
class BaseClass()
{
public:
    BaseClass();
    ~BaseClass();

}; //end BaseClass
```

```
class DerivedClass:
            public BaseClass
{
public:
    DerivedClass();
    ~DerivedClass();

private:
    char* myString;
}; //end DerivedClass
```

```
DerivedClass::DerivedClass()
{
    //allocate some memory
    myString = new char[128];
}

DerivedClass::~DerivedClass()
{
    //deallocate memory
    delete[] myString;
}
```

```
main()

BaseClass* myClass = new DerivedClass;
delete myClass; //PROBLEM!!!
```

BaseClass destructor is invoked.
Need to allow late binding for destructor!!!

Fix

```
class BaseClass()
{
public:
    BaseClass();
    virtual ~BaseClass();

}; //end BaseClass

class DerivedClass:
            public BaseClass
{
public:
    DerivedClass();
    ~DerivedClass();

private:
    char* myString;
}; //end DerivedClass
```

```
DerivedClass::DerivedClass()
{
    //allocate some memory
    myString = new char[128];
}

DerivedClass::~DerivedClass()
{
    //deallocate memory
    delete[] myString;
}
```

main()

```
BaseClass* myClass = new DerivedClass;
delete myClass; // both destructors
                //invoked
```

Problem fixed! BOTH destructors invoked

Virtual Functions in Constructors and Destructors

Recall

- `BaseClass` constructor invoked before `DerivedClass`'
- `DerivedClass` destructor invoked before `BaseClass`'

If virtual function in constructor/destructor is called polymorphically could try to access uninitialized/deallocated data

C++ prevents this by calling virtual functions in constructors/destructors **non-polymorphically**

```
class BaseClass()
{
public:
    BaseClass()
    {
        someVirtualFunction();
    }
    virtual void someVirtualFunction()
    {
        cout << “Base” << endl;
    }
};  //end BaseClass
```

```
main()

DerivedClass myDerivedClas;
```

Standard output:
Base

```
class DerivedClass: public BaseClass
{
public:

    virtual void someVirtualFunction()
    {
        cout << “Derived” << endl;
    }

};  //end DerivedClass
```

Invoking Virtual Members Non-Virtually

Sometimes may need to call the `BaseClass` version of a virtual function from a `DerivedClass`

```
void DerivedClass::someFunction()
{
    BaseClass::someVirtualFunction(); // no polymorphism
    //do more stuff
}
```

Copy Constructors and Assignment Operators with Inheritance

Can become complicated beasts with inheritance!!!

Must **always call explicitly** BaseClass within DerivedClass

```
class Base()
{
public:
    Base();
    Base(const Base& other);
    Base& operator=(const Base& other);
    virtual ~Base();
    //other public and protected members here that will be inherited

}; //end BaseClass
```

```
class Derived: public Base
{
public:
    Derived();
    Derived(const Derived& other);
    Derived& operator=(const Derived& other);
    virtual ~Derived();
private:
    char* theString;  //a C string
    //generic helper functions
    void copyOther(const Derived& other);
    void clear();
}; //end DerivedClass
```

Derived Implementation

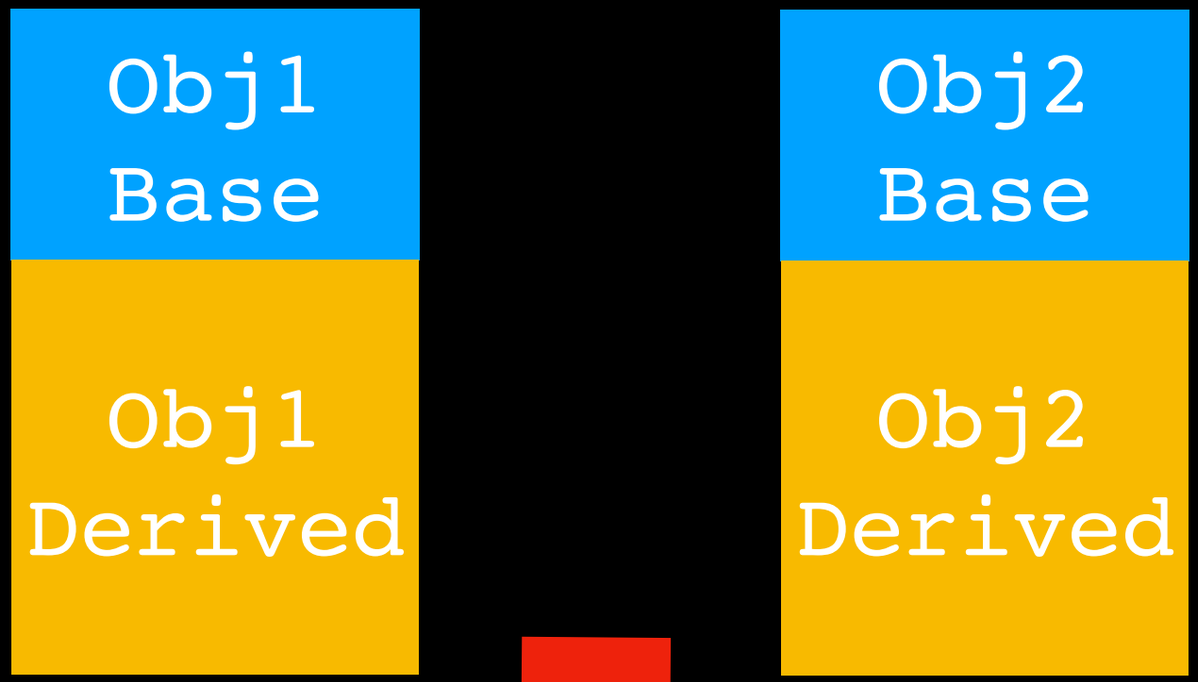
```
//generic “copy other” private member function
void Derived::copyOther(const Derived& other)
{
    theString = new char[strlen(other.theString)+1];
    strcpy(theString, other.theString);
}

// clear out private member function
void Derived::clear()
{
    delete[] theString; //deallocate memory
    theString = NULL;    //avoid dangling pointer
}
```

Derived Incorrect Implementation

```
//copy constructor
Derived::Derived(const Derived& other)
{
    copyOther(other);
}

//assignment operator
Derived& Derived::operator=(const Derived& other)
{
    if(this != other)
    {
        clear();
        copyOther(other);
    }
    return *this;
}
```

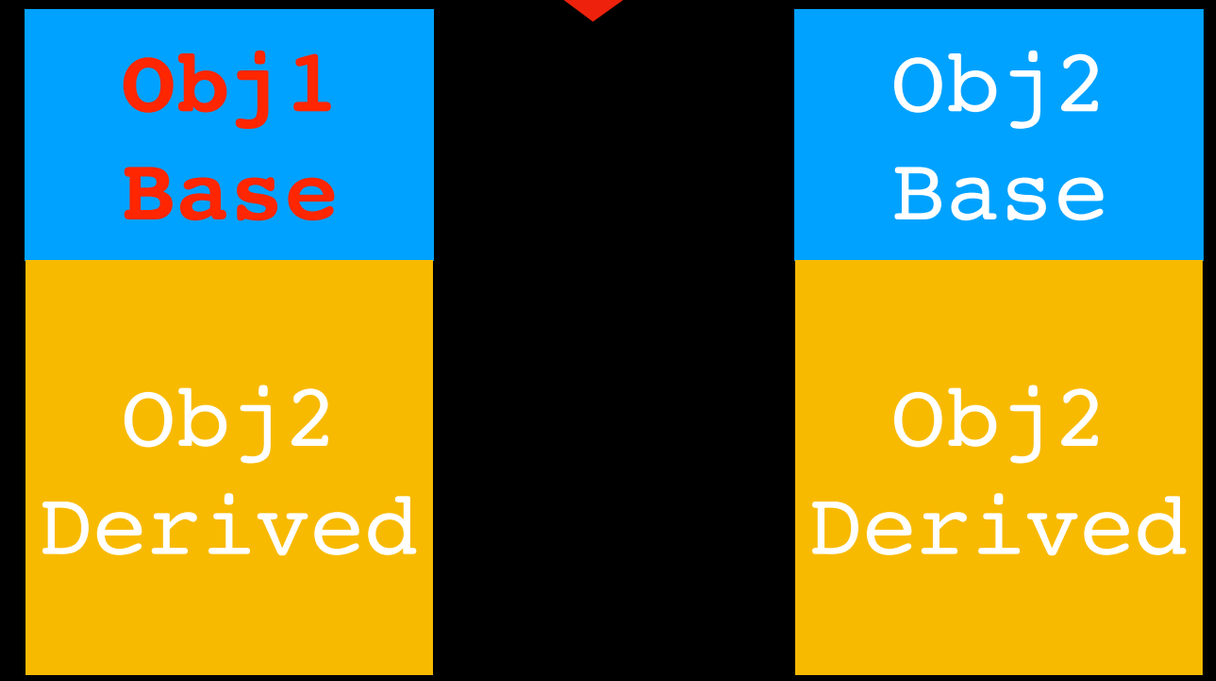
Derived Incorrect Implementation

```
//copy constructor
Derived::Derived(const Derived& other)
{
    copyOther(other);                          //WRONG!!!
}

//assignment operator
Derived& Derived::operator=(const Derived& other)
{
    if(this != other)
    {
        clear();
        copyOther(other);                      //WRONG!!!
    }
    return *this;
}
```



After invoking copy constructor or assignment operator

PROBLEM!!!



Derived Correct Implementation

```
//copy constructor
Derived::Derived(const Derived& other): Base(other) //CORRECT!!!
{
    copyOther(other);
}

//assignment operator
Derived& Derived::operator=(const Derived& other)
{
    if(this != other)
    {
        clear();
        Base::operator= (other);//CORRECT!!!Invoke Base operator=
                                //explicitly
        copyOther(other);
    }
    return *this;
}
```

Slicing

Copy ONLY `BaseClass` portion of object

Opposite of previous case

```
Base* ptr1;
Base* ptr2 = new Derived; // pointer of type Base that points to type Derived
//do stuff

*ptr1 = *ptr2; //copy value pointed to by ptr2 into variable pointed to by
                //ptr1
```

Note potential problem!!!

The above expands into

```
ptr1->operator= (*ptr2);
```

Invoking the `operator=` of the `Base` loosing all data of `Derived` portion

*ptr1
Base

*ptr1
Derived

*ptr2
Base

*ptr2
Derived

***ptr1 = *ptr2**

PROBLEM!!!

Nothing copied here

*ptr2
Base

*ptr2
Derived

Slicing via Copy Constructor

```
void doSomething(Base baseObject)
{
   //do something
}
```

```
Derived myDerived;
doSomething(myDerived);
```

PROBLEM!!! Parameter `baseObject` will be initialized using `Base` copy constructor

Slicing
Ever more insidiously!!!

```
vector<Base> myBaseVector;
Base* myBasePtr = someFunction(); //pointer to Base
//ATTENTION myBasePtr could point to Derived object
myBaseVector.push_back(*myBasePtr);
```

If `someFunction` returns a pointer to an object of type `Derived` calling `push_back` on object of type `Derived` will likely **slice** the object storing only its `Base` data

Possible solution: store pointers in myBaseVector instead of objects

Casting

Forcing one datatype to be converted into another

Up-casting (`Derived` to `Base`) automatically available through inheritance

```
Base* basePtr;
Derived* derivedPtr;
//do stuff
basePtr = derivedPtr; //automatic conversion Derived is-a Base
```

Down-casting (`Base` to `Derived`)

```
Base* basePtr = new Derived; // pointer of type Base points to
Derived
//do stuff
Derived* derivedPtr = (Derived*) basePtr;
```

Casting

Classic C++ cast too powerful => no checks.
Could write something totally nonsensical

```
Base* basePtr;
vector<double>* myVectorPtr = (vector<double>*) basePtr;
//PROBLEM!! Makes no sense, BUT no compiler error


const Base* basePtr = new Derived;
// do stuff
Derived* derivedPtr = (Derived*) basePtr;
//PROBLEM!!! Lost constness of Base object
//derivedPtr  is now free to modify it
```

static_cast

`static_cast` checks at compile time that cast "makes sense”

Allows:

- Converting between primitive types (e.g. `int` to `float`)
- Converting pointers or references of `Derived` type to pointers or references of `Base` type (e.g. `Derived*` to `Base*`) where target is at least as `const` as the source
- Converting pointers or references of `Base` type to pointers or references of `Derived` type (e.g. `Base*` to `Derived*`) where target is at least as `const` as the source

```
Base* basePtr = new Derived;
// do stuff
Derived* derivedPtr = static_cast<Derived*>(basePtr);
```

dynamic_cast

If `Base*` did not point to `Derived` object, `static_cast` would succeed

=> runtime problems

e.g. access `Derived` data members not present in `Base`

```
Base* basePtr = new Base;
Derived* derivedPtr1 = (Derived*)basePtr; //BAD!!!
Derived* derivedPtr2 = static_cast<Derived*>(basePtr); //BAD!!!
Derived* derivedPtr3 = dynamic_cast<Derived*>(basePtr); //GOOD!!!
```

Will return a NULL pointer

Conclusion

Polymorphism is easy, Just put `virtual` everywhere and the compiler will take care of the rest!

Conclusion

Polymorphism is easy, Just put `virtual` everywhere and the compiler will take care of the rest!

Real Conclusion

Overhead! Use it only when useful/necessary

Carefully craft **constructors**

Always make **destructor** **virtual**

Beware of **Slicing** (in all its forms)

Beware of **casting** and use level most appropriate and safe for your situation

Study Q

What is an Abstract Class?

Study Q

Why Polymorphism?

When would you use it? What problems does it solve?

Study Q

What does = 0 mean?

Study Q

What is Encapsulation?

Study Q

What does it mean to override?

Flash Q

What is OOP?

Study Q

Why dynamic memory allocation?

When would you use it? What problems does it solve?

Study Q

What does final mean?

Flash Q

How is basic inheritance different from polymorphism?

Flash Q

Why Inheritance?

When would you use it? What problems does it solve?

Flash Q

What is the overhead in Polymorphism?

Flash Q

What is Information hiding?