Polymorphism

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Today's Plan

Inheritance Recap
Polymorphism

Announcements

Q: Why use dynamic memory allocation?

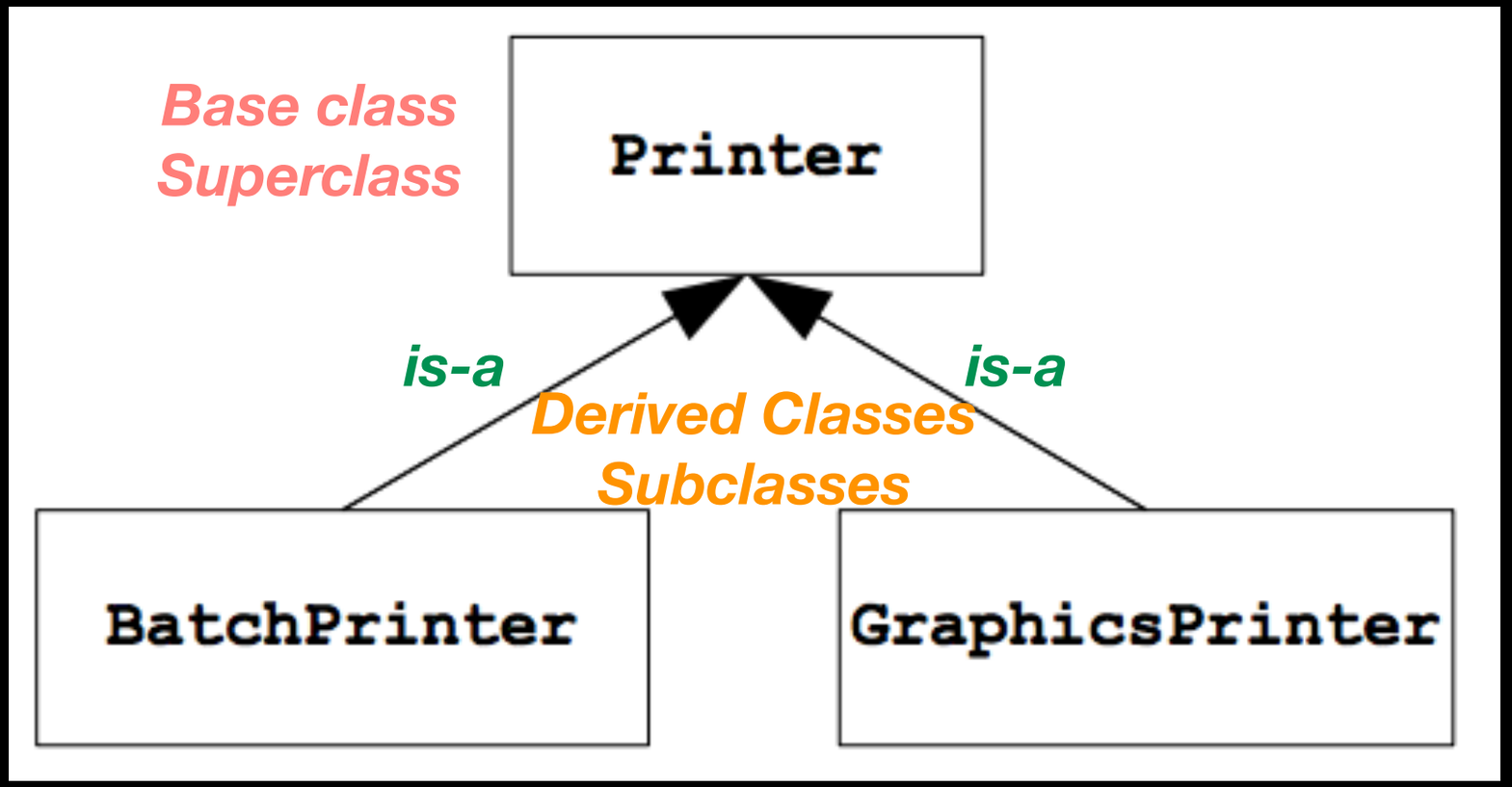
Inheritance Recap

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

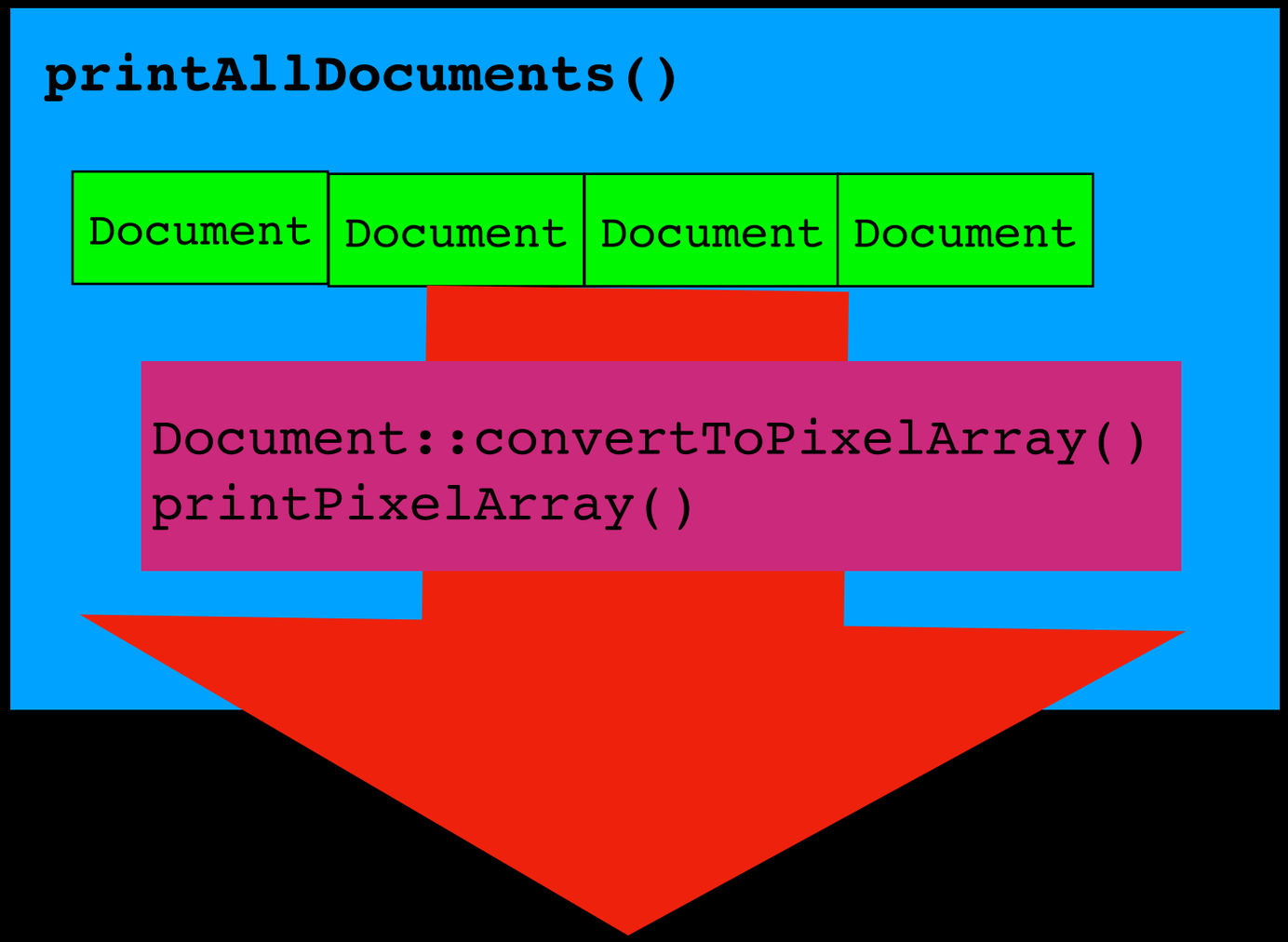
We would like to print all kinds of documents not just text
`documents` **should be able to store different types of documents**

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**

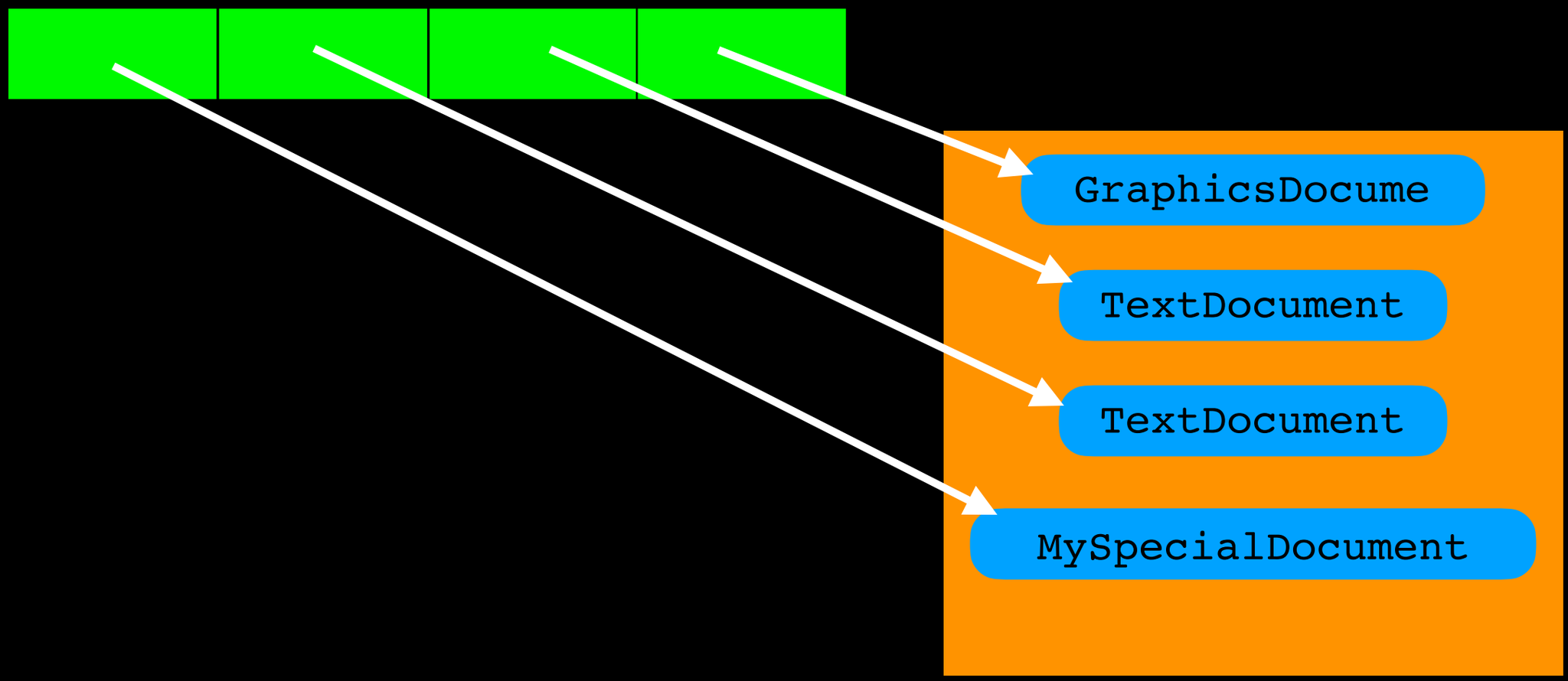
I'll explain this next

**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 = new Document;//Error!
```

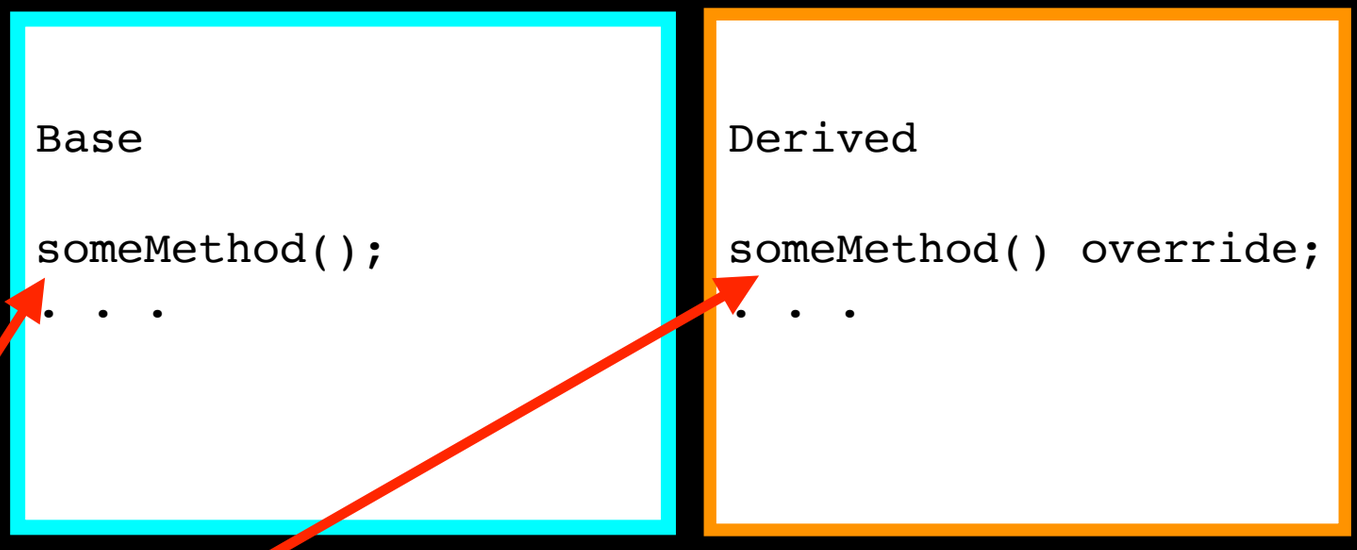
"The curious =0 syntax was chosen over the obvious alternative of introducing a new keyword `pure` or `abstract` because at the time I saw no chance of getting a new keyword accepted. Had I suggested `pure`, Release 2.0 would have shipped without abstract classes, I chose abstract classes. Rather than 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;
. . .
```

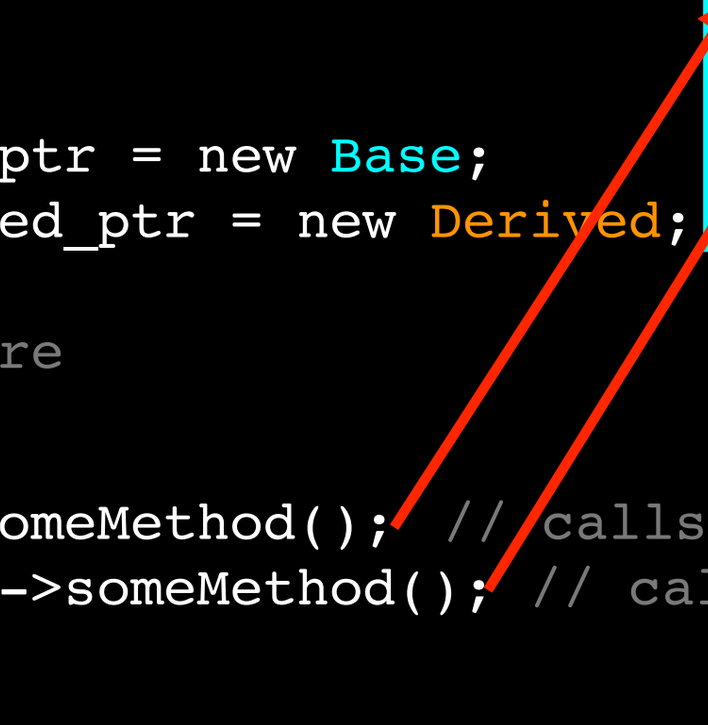
Recap Polymorphism

main()

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

// stuff here


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

```
Base

someMethod();
. . .
```

```
Derived

someMethod() override;
. . .
```



Recap Polymorphism

main()

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

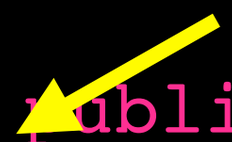
`private`

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

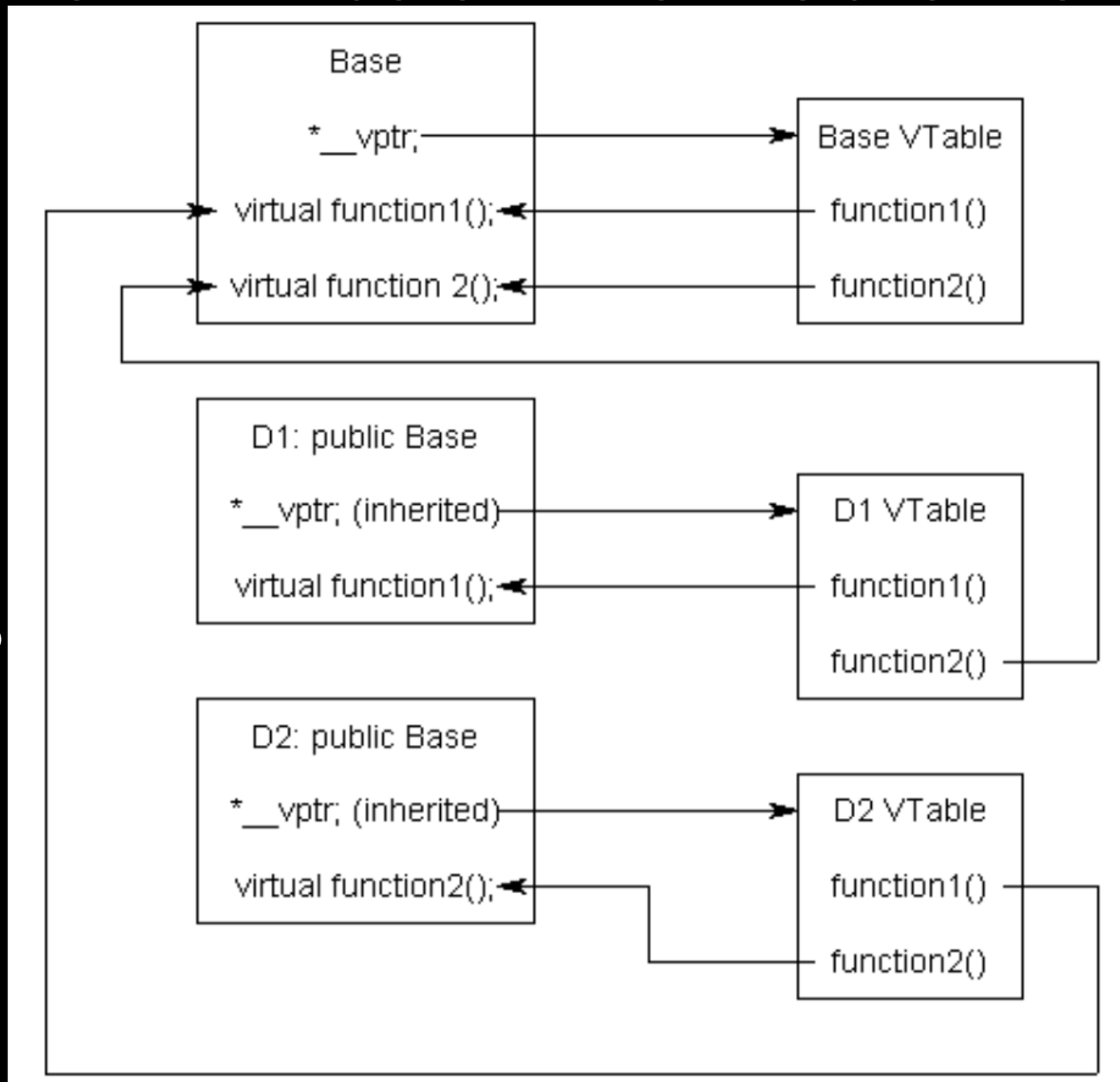
- C++ maintains ***virtual function tables*** that store pointers to each virtual function

- 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

Review Questions

Polymorphism Recap

Base-class pointer to Derived class

Determine behavior at runtime (**late binding)**

HOW? `virtual`

WHY? store different type of (Derived) objects in same container and retain access to each object's distinct behavior

Review Questions

What is OOP?

Review Questions

What is an ADT?

Review Questions

Why dynamic memory allocation?

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

Review Questions

What does final mean?

Review Questions

How is basic inheritance different from polymorphism?

Review Questions

Why Inheritance?

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

Review Questions

What is the overhead in Polymorphism?

Review Questions

What is Information hiding?