Inheritance

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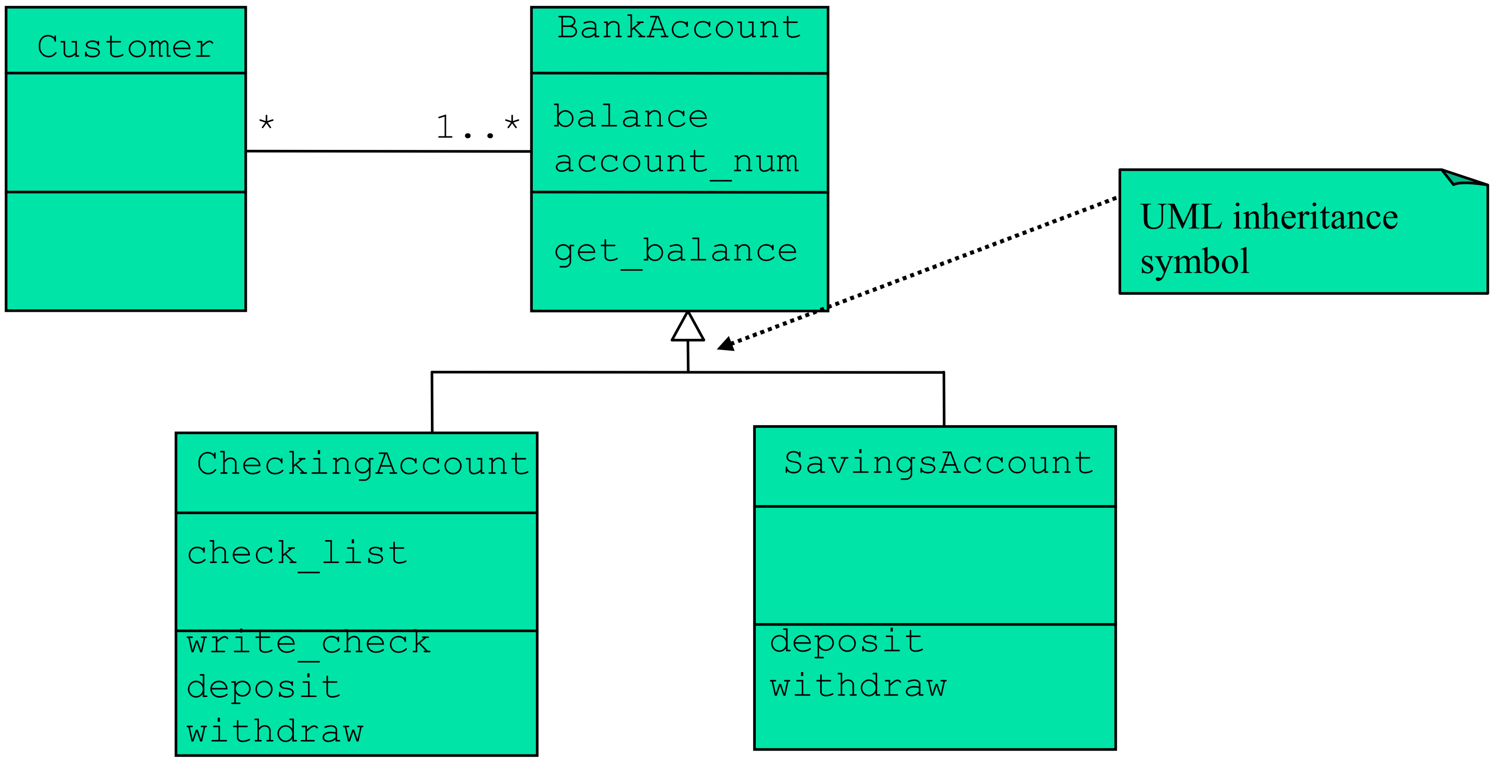
Inheritance in UML

- Inheritance models the object relation "is a kind of"
  - A SavingsAccount is a kind of BankAccount
  - Thus any attribute or method of a BankAccount also applies to a SavingsAccount



Inheritance in C++

```
// File: bankaccount.h
class BankAccount {
private:
   Money balance;
   int account_num;
public:
   Money get_balance(){
      return balance;
   }
   // other members,
   // e.g., constructor
};
```

Money would be typedef'ed in a header file as a decimal type

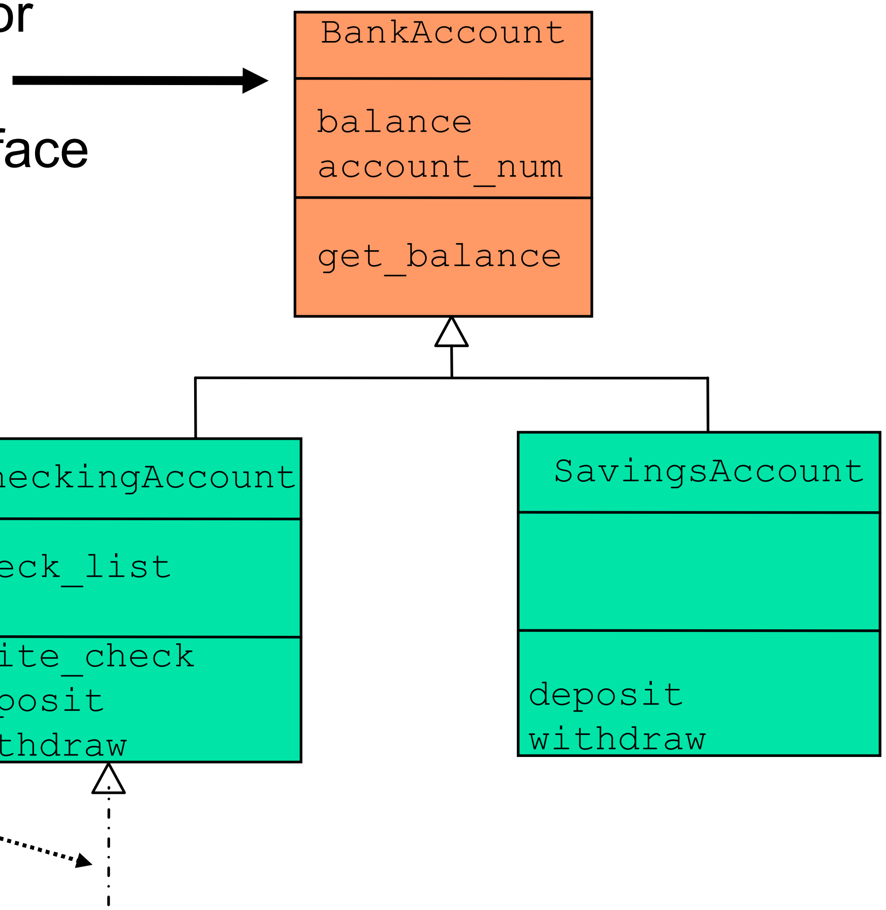
public modifier needed to allow users of the ***derived*** class to access members of the ***base*** class

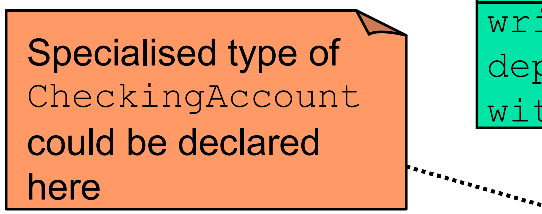
```
#include "bankaccount.h"
...
class CheckingAccount : public BankAccount {
private:
   std::list<Check*> check_list;
public:
   void deposit(Money m){ ... }
   void withdraw(Money m){ ... }
   void write_check(Check* cp){ ... }
   // other members, e.g., constructor
};
```

#include of file containing the base class definition needed. Double quotes are used as this is a user file, not a system file

Derived Classes

- Derived classes are central to reusable software development; they provide the capability to
  - Factor out common behavior in a base class
  - Provide an alternative interface to an existing class
  - Extending or modifying the facilities of other classes





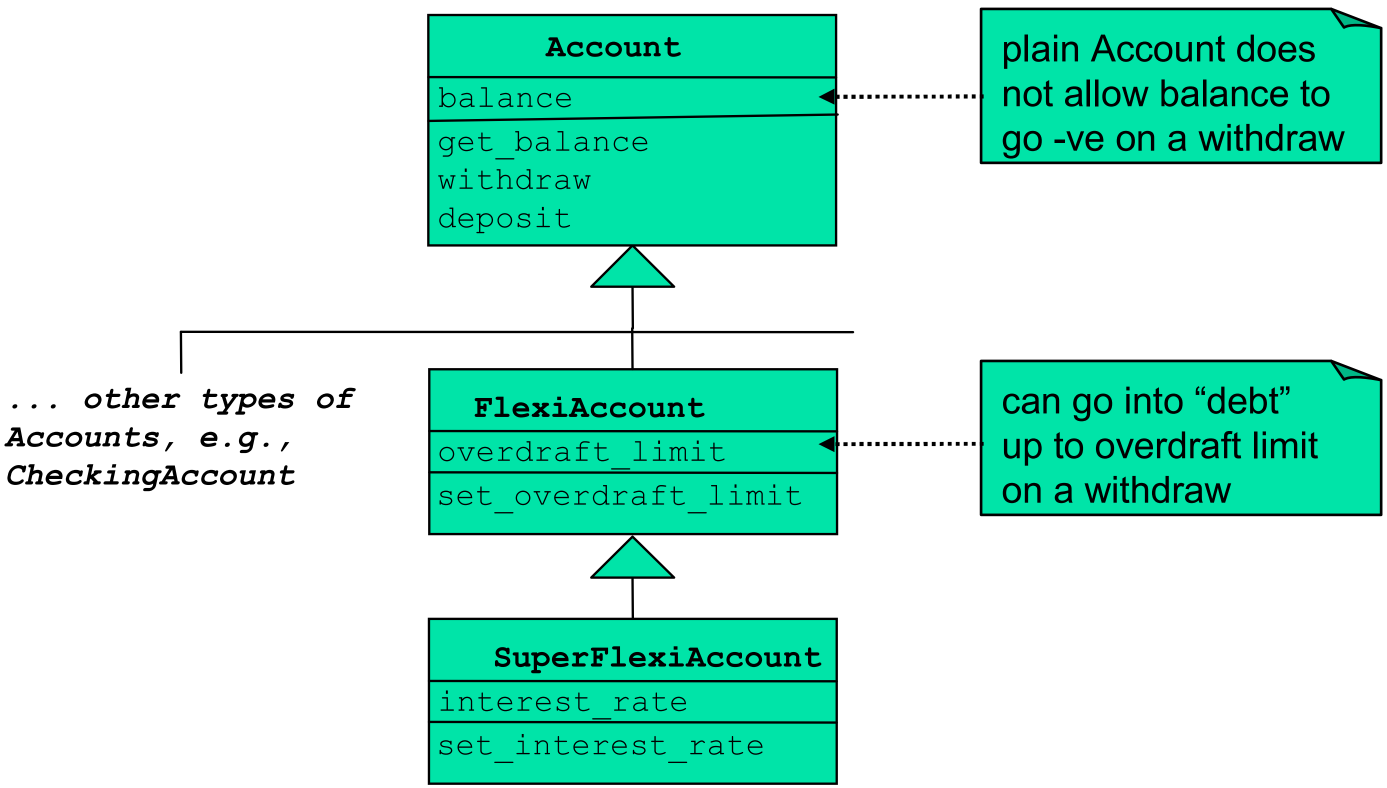
Inheritance Hierarchies

- Suppose that we were building a banking application, with various types of accounts and transactions
- In our business analysis, for a particular bank, we will assume we have identified 3 types of account:
  - a plain savings `Account`
    - Supports deposit and withdraw, but no overdrafts or interest
  - `Flexi Account`
    - Supports deposit, withdraw, and overdrafts to a set limit (you can borrow money from the bank), but no interest
  - `SuperFlexi Account`
    - Supports deposit, withdraw, overdrafts, and credits interest for large balances
  - We will restrict our example to just these simple classes and properties

? How might these be related by inheritance?
  - The “is a kind of” test can be used to determine if inheritance is appropriate

Inheritance Hierarchies (cont.)

- We might implement a skeleton of the hierarchy as follows



Inheritance Hierarchies (cont.)

```cpp
// File "account1.h"
class Account
{
  int balance;
public:
  Account() : balance(0) {
  int get_balance()
    { return balance; }
  bool withdraw(int amount);
  bool deposit(int amount);
};
```

withdraw() and deposit() not overridden yet by FlexiAccount

```cpp
// File "flexiaccount1.h"
#include "account1.h"
class FlexiAccount : public Account
{
  int overdraft_limit;
public:
  FlexiAccount()
    : overdraft_limit(0) {}
  bool set_overdraft_limit(int limit);
};
```

```cpp
#include "flexiaccount1.h"
#include <iostream>
using namespace std;
int main()
{
  Account a;
  cout << a.get_balance();

  FlexiAccount fa;
  fa.deposit(10);
  fa.withdraw(5);
  cout << fa.get_balance();

  fa.set_overdraft_limit(20);
  fa.withdraw(10);
  cout << fa.get_balance();
  ...
};
```

main() output will be:
0 5 5 !!

Inheritance Hierarchies (cont.)

```
#include "account1.h"
bool Account::withdraw(int amount)
{
  if (amount <= 0 || amount > balance)
return false;
  balance -= amount;
  return true;
}
bool Account::deposit(int amount)
{
  if (amount <= 0)
    return false;
  balance += amount;
  return true;
}
```

File account1.cpp: implementation of `withdraw` and `deposit`. `withdraw` does not allow -ve balance. Both `withdraw` and `deposit` return **`false`** if the operation failed

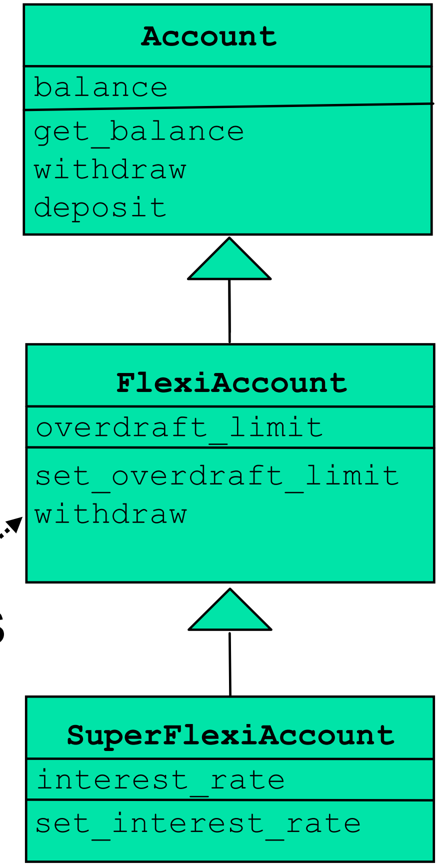
```
#include "flexiaccount1.h"
bool FlexiAccount::set_overdraft_limit(int limit)
{
  if (limit < 0) return false;
  overdraft_limit = limit;
  return true;
}
```

File flexiaccount1.cpp : implemention of `FlexiAccount` `set_overdraft_limit` method

Inheritance Hierarchies (cont.)

- At present, the earlier **`main()`** program does not work properly, because **`FlexiAccount`** inherits **`Account::withdraw()`**
  - `Account::withdraw()` does not permit a negative `balance`
  - `FlexiAccount` wants to allow overdrafts up to `overdraft_limit`
- A simple solution is to define **`withdraw`** in **`FlexiAccount`** to allow negative balances
  - A class member function i[illegible] preference to a base-class member function

withdraw now defined in FlexiAccount



Inheritance Hierarchies (cont.)

```
// File "flexiaccount2.h"
#include "account1.h"
class FlexiAccount : public Account
{
  int overdraft_limit;
public:
  FlexiAccount() : overdraft_limit(0) { }
  bool set_overdraft_limit(int limit);
  bool withdraw(int amount);

};
```

```
#include "flexiaccount2.h"
bool FlexiAccount::withdraw(int amount)
{
  if (amount <= 0 || amount > balance + overdraft_limit)
    return false;
  balance -= amount;
  return true;
}
```

Override base member function
Allow withdraw of amount up to a balance of
- overdraft_limit

? What access errors occur in the member function? How can we fix this?
Consider the access permissions of ***`Account::balance`***

Inheritance Hierarchies (cont.)

- **`balance`** is private so **`FlexiAccount::withdraw`** cannot use it
- A quick fix is to make **`balance`** `public`, but this violates encapsulation
  - A better approach is public `get` and `set` methods

```
// File "account2.h"
class Account
{
  int balance;
public:
  Account() : balance(0) { }
  int get_balance() { return balance; }
  void set_balance(int new_balance) { balance = new_balance; }
  bool withdraw(int amount);
  bool deposit(int amount);
};
```

balance private

two new member functions

```
#include "flexiaccount2.h"
bool FlexiAccount::withdraw(int amount)
{
  if (amount <= 0 || amount > get_balance() + overdraft_limit)
    return false;
  set_balance(get_balance() - amount);
  return true;
}
```

now use get and set methods

Inheritance Hierarchies (cont.)

- At first glance, it might seem that **`get`** and **`set`** methods are no different to a public data member
  - Any read or write can be implemented using `get` and `set`
- The key difference is that **`get`** and **`set`** encapsulate all updates and access
  - For example, if we needed to check for overflow of an account balance or check for high balances, the only change needed is to the `set` member

```
// File "account2.h"
class Account
{
  int balance;
public:
  Account() : balance(0) { }
  int get_balance() { return balance; }
  void set_balance(int new_balance) { balance = new_balance; }
  bool withdraw(int amount);
  bool deposit(int amount);
};
```

put balance checks here

deposit and withdraw should call set_balance

Inheritance Hierarchies (cont.)

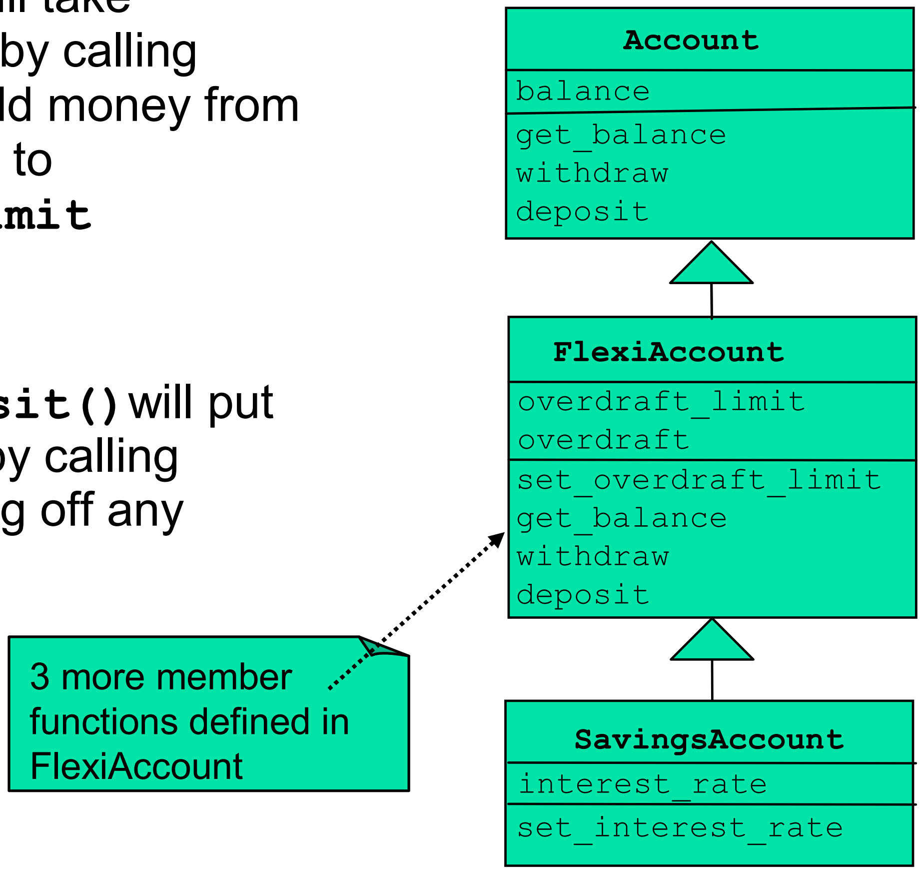
- This approach still is unsatisfactory from a design and maintenance viewpoint
  - Anyone can change `Account::balance` via a `set_balance` call

  The base class did not explicitly say that it was willing to let derived classes override the `withdraw` method
- A better approach is to maintain a separate **`overdraft`** balance in **`FlexiAccount`**
  - A `FlexiAccount` balance is the base `Account::balance` minus any `overdraft` amount
  - `Account::set_balance` is no longer needed
  - `FlexiAccount` now needs to redefine `deposit`, `withdraw`, and `get_balance`

Inheritance Hierarchies (cont.)

- **`FlexiAccount::withdraw()`** will take money from **`Account::balance`** by calling **`Account::withdraw()`** and/or add money from **`FlexiAccount::overdraft`**, up to **`FlexiAccount::overdraft_limit`**

- Similarly, **`FlexiAccount::deposit()`** will put money into **`Account::balance`** by calling **`Account::deposit()`** after paying off any **`FlexiAccount::overdraft`**



Inheritance Hierarchies (cont.)

```
// File "flexiaccount3.h"
#include "account1.h"
class FlexiAccount : public Account
{
  int overdraft_limit;
  int overdraft;
public:
  FlexiAccount() : overdraft_limit(0), overdraft(0) { }
  bool set_overdraft_limit(int limit);
  bool withdraw(int amount);
  bool deposit(int amount);
  int get_balance();
};
```

new data member

override 3 base member functions

Inheritance Hierarchies (cont.)

```
#include "flexiaccount3.h"
int FlexiAccount::get_balance()
{
  return Account::get_balance() - overdraft;
}
bool FlexiAccount::withdraw(int amount)
{
  if (amount < 0 || amount > (get_balance() + overdraft_limit))
    return false;
  int from_account = min(Account::get_balance(), amount);
  Account::withdraw(from_account);
  overdraft += amount - from_account;
  return true;
}
bool FlexiAccount::deposit(int amount)
{
  if (amount < 0)return false;
  int to_overdraft = min(amount, overdraft);
  Account::deposit(amount - to_overdraft);
  overdraft -= to_overdraft;
  return true;
}
```

call base member function using its qualified name

Withdraw `amount` from either the base `Account` `balance` or `overdraft` or both

`Deposit` adds to `overdraft`, `balance` or both

Derived Class Constructors

- A derived class instance "is a" base class instance
  - So a base class default constructor is called automatically

```
// File "account3.h"
class Account
{
  int balance;
public:
  Account()
    : balance(0) { }
  int get_balance()
    { return balance; }
  bool withdraw(int amount);
  bool deposit(int amount);
};
```

```
// File "flexiaccount3.h"
#include "account3.h"
class FlexiAccount : public
Account
{
  int overdraft_limit;
public:
  FlexiAccount()
    :
    overdraft_limit(0) { }
  ...
};
```

Implicit call
to base constructor
here.
We can have an
explicit call
for readability

Derived Class Constructors (cont.)

? What if the base class has no default constructor?

Is this constructor definition legal?

```
// File ”flexiaccount4.h”
#include "account4.h"
class FlexiAccount : public Account
{
  int overdraft_limit;
public:
  FlexiAccount()
    : overdraft_limit(0) {}
  ...
};
```

```
// File "account4.h"
class Account
{
  int balance;
public:
  Account(int init_balance)
    : balance(init_balance) {}
  int get_balance()
    { return balance; }
  bool withdraw(int amount);
  bool deposit(int amount);
};
```

Derived Class Constructors (cont.)

- If the base class has no default constructor
  - Then the derived class must call the constructor in the member initializer list
  - Anything else is a syntax error

```
// File "account4.h"
class Account
{
  int balance;
public:
  Account(int init_balance)
    : balance(init_balance) { }
  int get_balance()
    { return balance; }
  bool withdraw(int amount);
  bool deposit(int amount);
};
```

Base class constructor explicitly called here, member initializations must be comma separated

```
// File "flexiaccount5.h"
#include "account4.h"
class FlexiAccount : public Account
{
  int overdraft_limit;
public:
  FlexiAccount(int init_balance)
    : Account(init_balance),
      overdraft_limit(0) { }
  ...
};
```

Derived Class Constructors (cont.)

- C++ has a strict rule of initialization in "declaration order"
  - Base classes are initialized before any data members
    - And so base-base clases before base, recursively
  - Then data members, in the order they are declared in the class
    - NOT the member initializer order

```
// File "foo.h"
class Foo
{
  int x;
public:
  Foo(int init_x)
    : x(init_x) { }
  ...
};
```

```
// File "bar.h"
#include "account4.h"
class Bar : public Foo
{
  int y;
  int z;
public:
  Bar(int init_x)
    : z(10),
      y(z),
      Foo(init_x)
  {}
  ...
};
```

Foo initialized first, then y, then z!
So y is undefined!
Never initialize members with other members in a member initialization list

Base-class member-access specifier	Type of inheritance		
	public inheritance	protected inheritance	private inheritance
public	public in derived class. Can be accessed directly by member functions, friend functions and nonmember functions.	protected in derived class. Can be accessed directly by member functions and friend functions.	private in derived class. Can be accessed directly by member functions and friend functions.
protected	protected in derived class. Can be accessed directly by member functions and friend functions.	protected in derived class. Can be accessed directly by member functions and friend functions.	private in derived class. Can be accessed directly by member functions and friend functions.
private	Hidden in derived class. Can be accessed by member functions and friend functions through public or protected member functions of the base class.	Hidden in derived class. Can be accessed by member functions and friend functions through public or protected member functions of the base class.	Hidden in derived class. Can be accessed by member functions and friend functions through public or protected member functions of the base class.

Fig. 12.16 | Summary of base-class member accessibility in a derived class.

Polymorphism

Type Compatibility

- A derived-class "is a kind of" base-class, but not conversely
  - So a derived-class instance can be assigned to a base-class instance, but not conversely
  - Also, base-class pointer can point to a derived-class instance, but not conversely

```
#include "superflexiaccount1.h"
int main()
{
  Account a;
  FlexiAccount fa;
  SuperFlexiAccount sa;
  a = fa;
  Account* aptr;
  aptr = &sa;

  fa = a;
  SuperFlexiAccount* sptr;
  sptr = &a;
  return 0;
}
```

This include also includes flexiaccount.h and account.h

"member-wise copy": *balance=oa.balance*

Now `aptr` points to `sa`

Two compile errors

Type Compatibility (cont.)

- Base-class pointers are very useful, because they potentially allow us to access instances of any derived class
  - At runtime, we can choose which derived class to access

```
#include "superflexiaccount3.h"
#include <iostream>
using namespace std;
int main()
{
  Account* aptr;
  FlexiAccount fa;
  SuperFlexiAccount sa;
  ...
  aptr = &fa;
  ...
  aptr->deposit(50);
  cout << aptr->get_balance();
  return 0;
};
```

This include also includes flexiaccount.h and account.h

Or `aptr = &sa`, we still get calls of base class members

Call `Account::deposit()`, then `Account::get_balance()`, output: 50

Dynamic Binding

- In C++, binding is static by default, for run time efficiency
  - The type of the pointer (`aptr`) determines the function called
  - This is determined at compile time

```
...
  Account* aptr;
  FlexiAccount fa;
  SuperFlexiAccount sa;
  ...
  aptr = &fa;
  ...
  aptr->deposit(50);
...
```

- In Java, binding is dynamic
  - The type of the object pointed to (`aptr->`) determines the function called
  - This is determined at run time
- To get dynamic binding in C++, functions must be declared as `virtual`

Dynamic Binding (cont.)

base class declares 3 functions virtual for dynamic binding

```
// File "account5.h"
class Account
{
  int balance;
public:
  Account() : balance(0) { }
  virtual int get_balance()
    { return balance; }
  virtual bool withdraw(int amount);
  virtual bool deposit(int amount);
};
```

```
// File "flexiaccount5.h"
#include "account5.h"
class FlexiAccount : public Account
{
  int overdraft_limit;
  int overdraft;
public:
  FlexiAccount() : overdraft_limit(0), overdraft(0) {}
  bool set_overdraft_limit(int limit);
  bool withdraw(int amount);
  bool deposit(int amount);
  int get_balance();
}
```

not virtual

3 derived classes declarations inherit **virtual** for dynamic binding; **virtual** keyword optional on their declarations

Dynamic Binding (cont.)

Includes base FlexiAccount and bas-base Account

```
#include "superflexiaccount5.h"
#include <iostream>
using namespace std;
int main()
{
  Account* aptr;
  FlexiAccount fa(10);
  SuperFlexiAccount sfa(30);
    ...
  aptr = & fa;
  fa.set_overdraft_limit(10);
  aptr->withdraw(15);
  cout << aptr->get_balance();
    ...
  aptr = & sfa;
  sfa.set_overdraft_limit(20);
  aptr->withdraw(45);
  cout << aptr->get_balance();
  ...
};
```

Calls FlexiAccount::withdraw as Account::withdraw is virtual
Output will be: -5

Calls FlexiAccount::withdraw unless SuperFlexiAccount::withdraw is defined
Output will be: -15

Dynamic Binding (cont.)

- Derived classes inherit the virtual function definitions of their base class
- Thus, **`SuperFlexiAccount`** inherits **`FlexiAccount`**'s definition of **`withdraw()`**, but it can override this function if needed
  - A derived class always uses the "closest" **`virtual`** function definition in its parent hierarchy

	Overloaded functions	Virtual functions
Must have *same* name?	Yes	Yes
Different signatures?	Always	Never
Binding	Compile-time	Runtime
Scope	Same	Inherited

Dynamic Binding (cont.)

- Virtual functions are a powerful mechanism for writing adaptable applications

transfer works with “any” Account type and dynamically calls the right versions of deposit and withdraw

```
bool transfer(Account* from, Account* to, int amount)
{
  // call virtual functions withdraw and deposit
  if (!from->withdraw(amount)) return false;
  return to->deposit(amount);
}
```

- For example:

```
int main()
{
  Account a1(200);
  FlexiAccount fa(300);
  fa.set_overdraft_limit(500);
  transfer(&fa, &a1, 400);
  // call FlexiAccount::withdraw and Account::deposit
  return 0;
}
```

Interfaces

- Base classes are often defined with no intention of ever creating instances of them
  - **`class`** `Account`
    - Must specify what type of `Account`: `Checking`, `Savings`, ...
  - **`class`** `GraphicObject`
    - No object is “just” a GraphicObject, is it a `Square` or `Circle`, or …
- Such base classes are very useful abstractions of common operations, which are `virtual` functions declared in the base class and defined by derived classes
  - `print()`, ...
  - `draw()`, `rotate()`, `move()`, `remove()`
- Operations in such base classes often *<u>have no implementation</u>*
  - `GraphicObject::draw()` cannot be defined without the derived type

Interfaces (cont.)

- C++ provides a better approach, *pure virtual* member functions
  - Just like Java **`abstract`** functions

```
class Account
{
  // data common to all Accounts
public:
  virtual void print() = 0; // pure virtual
    // = 0 means "no definition necessary"
    // other methods
};
```

- If any of a class's virtual functions are *pure virtual*, the class is an *abstract class* and instances of it cannot be created

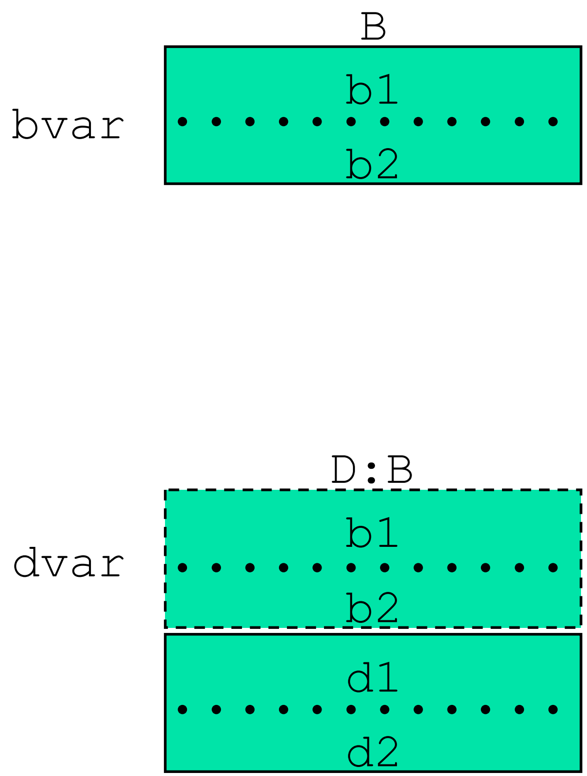
```
Account a;    // syntax error
Account* ap; // pointers to abstract classes are legal
```

- Derived classes must supply definitions of all pure virtual functions; otherwise, they are also abstract classes

Runtime Type Identification

- By default, classes are just like structs
  - Containers of data, with no run time type information

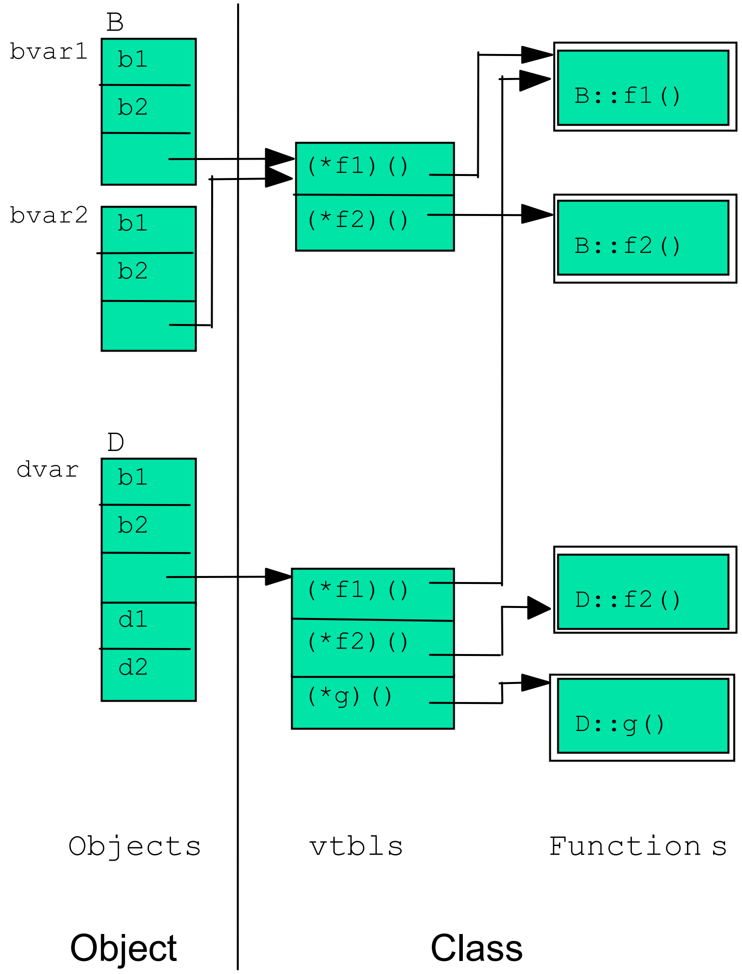
```
class B
{
   int b1, b2;
public:
   void f();
   B() {...}
};
class D: public B
{
   int d1, d2;
public:
   void g();
   D() {...}
};
B  bvar;
D  dvar;
```



Runtime Type Identification (cont.)

- But if they have virtual functions an object stores a pointer to them

```
class B
{
  int b1, b2;
public:
  virtual void f1();
  virtual void f2();
  B() {...}
};
class D : public B
{
  int d1, d2;
public:
  void f2();
  virtual void g();
  D() {...}
};
B  bvar1, bvar2;
D  dvar;
```



Runtime Type Identification (cont.)

- A base-class pointer can point to any derived-class object
  - If we know the actual class of the object, we can successfully *downcast* the pointer to that derived type

```
Account* aptr;
FlexiAccount fa;
 ...
aptr = &fa;
 ...
((FlexiAccount*)aptr)->set_overdraft_limit(10);
// how do we KNOW that ap is still pointing to
// a FlexiAccount? What happens if it is not?
```

- Standard C++ now supports “safe” *downcasts* for *polymorphic* classes (classes with virtual functions)

Runtime Type Identification (cont.)

- `dynamic_cast`**`<D*>(p)`** will succeed if **`p`** points to an object of class **`D`** or a class publicly derived from **`D`**
  - Otherwise, the result is a null pointer

```
Account* aptr;
FlexiAccount fa;
 ...
aptr = &fa;
 ...
FlexiAccount* fptr = dynamic_cast<OverdraftAccount*>(aptr);
if (fptr != 0)
  fptr->set_overdraft_limit(10);
else    // error
```

Runtime Type Identification (cont.)

- Unlike Java, C++ does not support "reflection"
  - Obtaining full run time information about a class or object
    - Such as its data members or base classes
  - There is no Object class that all objects derive from
- But the operator `typeid` returns information for objects with virtual functions

```
class type_info
{
public:
   // operators != and
   // == char* name();
private:
   ...
};
```

Typeid returns an instance of typeinfo, a standard library class with an operator ==

```
#include <typeinfo>
Account a;
FlexiAccount fa;
   ...
   if (typeid(a) == typeid(fa)) ...
   ...
   cout << "oa is of type\n"
     << typeid(fa).name() << '\n';
   ...
```

returns false

Output:
oa is of type
class FlexiAccount

Multiple Inheritance

Multiple Inheritance

- In C++, it is possible to inherit from a number of different base classes.
- This is termed **multiple inheritance**.
- Each base class can be inherited using a different type of inheritance if desired.

Multiple Inheritance

- From Java, we are used to only having single inheritance, and all inheritance being public.
- However, Java supports the idea of multiple implementations of interfaces by a class. This is the closest Java gets to having multiple inheritance.

Example

```
class Base1 {
   // ..
};

class Base 2 {
   // ..
};
```

Example

```
class Derived : public Base1, private Base2 {
   // ..
   public:
      Derived() : Base1(), Base2() { }
};
```

- Each base class has its inheritance type specified.
- Each base class constructor is placed in the initialiser list in the same order they are declared.

Explicit Scoping

- If a non-virtual base class is necessary (e.g. private inheritance for IS-IMPLEMENTED-IN-TERMS-OF), and access to a base class member is required, explicit scoping can be used.

Explicit scoping

```
void HighlyDerived::someFunction() const {
    // ..
    Derived1::baseClassFunction();

    // the following operates on different
    // base class, if Base is non-virtual
    Derived2::baseClassFunction();
}
```

Construction order

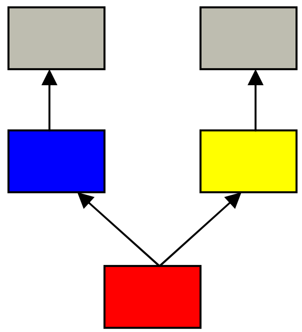
- Classes that inherit from multiple bases have their base classes constructed in the same order they are declared.
- An object is not considered created until *all* of its base class objects have also been created.

Destruction order

- First, the object’s destructor is called, then the base class destructors in reverse order.
- An object is no longer valid once the object’s destructor begins executing.

Common base classes

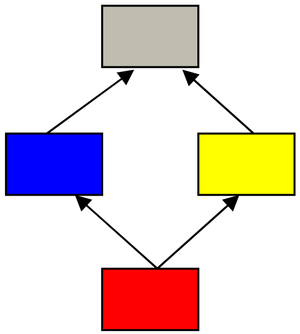
- Sometimes, you derive from two classes that both inherit from the same base class.



- This leads to two copies of data, and potential ambiguities. Which base class are you referring to?

Virtual base classes

- The usual method to get around this is to declare the base class as virtual. This leaves the following arrangement.



- A virtual base class must be initialised by the most-derived class in a hierarchy.

Virtual base class

```
class Derived1 : virtual public Base { };
class Derived2 : virtual public Base { };

class HighlyDerived : public Derived1,
      public Derived2 {
   // ..
};
```

Diamond Inheritence Example

```
// Fig. 24.13: fig24_13.cpp
// Attempting to polymorphically call a function t
// multiply inherited from two base classes.
#include <iostream>
using namespace std;

// class Base definition
class Base
{
public:
    virtual void print() const = 0; // pure vir
}; // end class Base

// class DerivedOne definition
class DerivedOne : public Base
{
public:
    // override print function
    void print() const
    {
        cout << "DerivedOne\n";
    } // end function print
}; // end class DerivedOne

// class DerivedTwo definition
class DerivedTwo : public Base
{
public:
    // override print function
    void print() const
    {
        cout << "DerivedTwo\n";
    } // end function print
}; // end class DerivedTwo

// class Multiple definition
class Multiple : public DerivedOne, public DerivedTwo
{
public:
    // qualify which version of function print
    void print() const
    {
        DerivedTwo::print();
    } // end function print
}; // end class Multiple

int main()
{
    Multiple both; // instantiate Multiple object
    DerivedOne one; // instantiate DerivedOne object
    DerivedTwo two; // instantiate DerivedTwo object
    Base *array[ 3 ]; // create array of base-class pointers

    array[ 0 ] = &both; // ERROR--ambiguous
    array[ 1 ] = &one;
    array[ 2 ] = &two;

    // polymorphically invoke print
    for ( int i = 0; i < 3; ++i )
        array[ i ] -> print();
} // end main
```

Diamond Inheritence Example .. Cont..

```cpp
// Fig. 24.14: fig24_14.cpp
// Using virtual base classes.
#include <iostream>
using namespace std;

// class Base definition
class Base
{
public:
    virtual void print() const = 0; // pure virtual
}; // end class Base

// class DerivedOne definition
class DerivedOne : virtual public Base
{
public:
    // override print function
    void print() const
    {
        cout << "DerivedOne\n";
    } // end function print
}; // end DerivedOne class

// class DerivedTwo definition
class DerivedTwo : virtual public Base
{
public:
    // override print function
    void print() const
    {
        cout << "DerivedTwo\n";
    } // end function print
}; // end DerivedTwo class

// class Multiple definition
class Multiple : public DerivedOne, public DerivedTwo
{
public:
    // qualify which version of function print
    void print() const
    {
        DerivedTwo::print();
    } // end function print
}; // end Multiple class

int main()
{
    Multiple both; // instantiate Multiple object
    DerivedOne one; // instantiate DerivedOne object
    DerivedTwo two; // instantiate DerivedTwo object

    // declare array of base-class pointers and initialize
    // each element to a derived-class type
    Base *array[ 3 ];
    array[ 0 ] = &both;
    array[ 1 ] = &one;
    array[ 2 ] = &two;

    // polymorphically invoke function print
    for ( int i = 0; i < 3; ++i )
        array[ i ]->print();
} // end main
```

When to use MI

- Multiple inheritance introduces a large number of problems, such as virtual base classes, construction order, explicit scoping and the like. When *would* you use it?
- Answer: Not often.

When to use MI

- Most systems can be modelled using single inheritance.
- MI should only be considered if base classes are protocol classes.
- Alternatively, if you are extending a library which you have not written, but the derived class needs to inherit from other classes as well, MI must be used.

- Use multiple inheritance when each inheritance would make sense in a single inheritance scenario.
- If these criteria are not met, perhaps reconsider your usage of multiple inheritance.

Operator Overloading

Operator Overloading

- We are used to using different operators on the built in types.

```
int c = a + b; // + operator
int d = ++c;   // prefix ++ operator
char e = d--;  // postfix -- operator
char f = -e;   // unary - operator
```

- It would often make sense to be able to perform these operations on classes that we have created.
- C++ allows this through **operator overloading**.

A compiler's view

- Let's assume we have a class of type `T`, that we are performing addition on:

```
T a, b, result;
result = a + b;
```

- When the compiler sees this, it will attempt to resolve the addition first (operator precedence rules).

A compiler's view

- The compiler now looks for a suitable function that will add two T objects. It first looks for a member function:

```
result = a.operator+(b);
```

- If it doesn't find a member function, it tries a free function:

```
result = operator+(a, b);
```

A compiler's view

- If it can't find any of those, it attempts to find a conversion constructor to convert either object to a form it knows.
- If that fails, the compiler will complain about a missing function declaration.

Operator Overloading

- This gives us a hint as to how to implement operator overloading.
  - As a member function. Not all operators can be made member functions.
  - As a free function. There are benefits and drawbacks to this approach.
- We will look at both approaches and when to use each. But first, some terminology.

Terminology

- **Binary operator** – an operator that works on two objects, such as addition or subtraction.
- **Unary operator** – an operator that works on one object, such as `!` (binary not), `~` (complement), or `++` and `--` (increment and decrement)
- **Ternary operator** – an operator that works on three objects. There is only one ternary operator, the conditional operator, `?:`

Terminology

- **Prefix** – Used to describe increment or decrementing. In prefix increment, the object is incremented, and the *new object* is returned.
- **Postfix** – In postfix increment, the object is incremented, and a copy of the *old object* is returned.

Member functions

- Let’s try implementing a less-than operator for a class:

```
class Game {
  private:
    int points;
  public:
    bool operator<(const Game& rhs) const;
};
```

Member functions

- Note that a comparison operator is logically const – it compares objects, not changes them. Likewise, the parameter is const.
- A comparison should return true or false – it's either less than, or not.

```
bool Game::operator<(const Game& rhs) const {
   return (points < rhs.points);
}
```

Free functions

- Now for the free function version. This time, the operator takes two parameters:

```
bool operator<(const Game& lhs, const Game& rhs) {
   return (lhs.getPoints() < rhs.getPoints());
}
```

Free functions

- Note that this is not a member function, so does not have the `Game::` scope resolution.
- As such, it needs to use accessor functions to do the comparison.
- Also, as this is no longer a member function, it is not immediately associated with the Game class – we have decreased cohesion.
- To limit the effect of this, declare the free function in the `game.h` file, and define it with `game.cpp`

Free functions

- Advantages:
  - Assume `Game` has a conversion constructor that takes an int.

```
Game g2 = g + 1; // works, 1 is converted
```

  - If the binary + operator is a member function, the following won't work, despite it being logically the same as above.

```
Game g2 = 1 + g; // ERROR!
```

Free functions

- Advantages (cont)
  - If the binary + operator was a free function, the 1 would be automatically converted to a Game class, and the compiler would be happy.
  - This reason is often enough to make binary operators free functions.
  - Other advantages include readability (it *makes sense* that binary + takes *two* parameters).

Friends

- To circumvent the use of accessors in the free function, we could have declared the overloaded operator to be a **friend** of the Game class.
- Being a friend enables the function to have direct access to private and protected data members of the Game class.

Friends

- We can declare a function, or a even whole class, to be a friend of another class.
- Friendship can only be granted to another class – another class can't claim to be a friend to get around visibility controls.
- Friendship has the highest coupling of any relationship between classes, including inheritance.

Friends

```
class B { };
class A {
   // . . .
   friend bool operator+(const A&, const A&);
   friend class B;
};

void B::someFunction(const A& a) {
   a.somePrivateDataMember = 2;
}
```

Overloadable Operators

- We can overload any operator, with the exception of the scope resolution operator (`::`), the pointer to member function operator, and the conditional operator.
- We cannot overload these operators as they are either too important to change their meaning (such as scope resolution), or impossible to represent (such as conditional operator)

New operators

- We cannot define new operators. Imagine defining a ^^ operator to represent exponentiation (eg, 2^3).
- What associativity does the new operator have?

```
a^^b^^c == (a^^b)^^c; // OR maybe
a^^b^^c == a^^(b^^c); // ?
```

New operators

- We cannot specify this easily. Secondly, what precedence does the operator have?

```
a^^b*c == (a^^b)*c; // OR maybe
a^^b*c == a^^(b*c); // ?
```

- As we cannot specify these consistently, C++ prevents us from creating new operators.

Canonical forms

- There are a few ‘standard’ ways of implementing overloaded operators. These are termed **canonical forms**.
- These could be described as a set of rules for implementing types of operators.

Canonical forms

- When defining a prefix or a postfix increment, always define *both* prefix and postfix.
- This ensures users can use both forms as necessary. This is supporting *expected behaviour.*
- Always define a postfix operator in terms of the prefix version.

Canonical pre- and postfix ++

```
class Game {
   private:
      int points;
   public:
      Game& operator++();
      Game operator++(int);
};
```

Canonical pre- and postfix ++

```
// prefix
Game& Game::operator++() {
   ++points;  // prefix too!
   return *this;
}

// postfix
Game Game::operator++(int) {
  Game tmp = *this; // save temp value
  ++(*this);  // define postfix in terms of prefix
  return tmp;  // return tmp, making a copy
}
```

Canonical form of operator=

- The assignment operator should always take a const reference, and return a reference to the current object. It should usually check for self-assignment.

```
Game& Game::operator=(const Game& rhs) {
   if (&rhs != this) { // check for self-
 assignment
      points = rhs.points;
   }
   return *this;
}
```

Conversion operators

- A conversion operator is similar to a conversion constructor.
- Let’s try to convert a Game class to an integer.

```
class Game {
 operator int() const;

};


Game::operator int() const {
 return points;

}
```

Conversion operators

- Note that the conversion operator does not have a return type (similar to a constructor).
- Keep the use of conversion operators to a minimum – this will prevent hard to trace ambiguities and errors.
- Use conversion operators when converting a class to a builtin type (which do not have conversion constructors)