Generalization versus Abstraction

Abstraction: simplify the description of something to those aspects that are relevant to the problem at hand.

Generalization: find and exploit the common properties in a set of abstractions.

- hierarchy
- polymorphism
- genericity
- patterns
Four-Fold Path to Generalization

Hierarchy
   Exploitation of an “is-a-kind-of” relationship among kinds of entities to allow related kinds to share properties and implementation.

Polymorphism
   Exploitation of logical or structural similarities of organization to allow related kinds to exhibit similar behaviors via similar interfaces.

Genericity
   Exploitation of logical or structural similarities of organization to produce generic objects.

Patterns
   Exploitation of common relationship scenarios among objects. (e.g., client/server system)
Hierarchy

Represented by generalize/specialize graph

Based on “is-a-kind-of” relationship
   E.g., a Manager is an Employee; a robin is a bird, and so is an ostrich.

Is a form of knowledge representation – a “taxonomy” structures knowledge about nearby entities.

Extendable without redefining everything
   E.g., knowing a robin is a bird tells me that a robin has certain properties and behaviors, assuming I know what a “bird” is.

Specialization can be added to proper subset of hierarchy
A generalization/specialization hierarchy based on “is-a-kind-of” relationships:

- **Person**
  - Name
  - Address

- **Student**
  - Name
  - Address
  - ID
  - Major
  - Level

- **Employee**
  - Name
  - Address
  - ID
  - Department

- More general, less details
- More specialized, more details
Inheritance

Terminology
- Base type or class (a.k.a. superclass, parent type)
- Derived type or class (a.k.a. subclass, subtype, child type)

Important Aspects
- **Programming**: implement efficiently a set of related classes (mechanical)
- **Design**: organize coherently the concepts in an application domain (conceptual)
- **Software Engineering**: design for flexibility and extensibility in software systems (logical)
class Student {
private:
    Name    Nom;
    Address Addr;
    string  Major;
    string  ID;
    int     Level;
public:
    Student(const Name& N, const Address& A, string M = "US",
             string I = "000-00-0000", int L = 10);
    Name    getName() const;
    Student& setName(const Name& N);
    //. . .
    string  getMajor() const;
    Student& setMajor(const string& D);
    string  getID() const;
    Student& setID(const string& I);
    int     getLevel() const;
    Student& setLevel(int L);
    ~Student();
};
Employee Class w/o Inheritance

```cpp
class Employee {
private:
    Name    Nom;
    Address Addr;
    string  Dept;
    string  ID;
public:
    Employee(const Name& N, const Address& A, string D = "", string I = "");
    Name  getName() const;
    Employee& setName(const Name& N);
    // . . .
    string  getDept() const;
    Employee& setDept(const string& D);
    string  getID() const;
    Employee& setID(const string& I);
    ~Employee();
};
```

Specify all the data members

Specify appropriate constructors

Specify accessors and mutators for all data members
What is Common?

Both classes contain the data members

```cpp
Name       Nom;
Address    Addr;
string     ID;
```

and the associated member functions

```cpp
Name       getName() const;
Address    getAddress() const;
string     getID() const;
void       setName(const Name& N);
void       setAddress (const Address& A);
void       setID(const string& I);
```

From a coding perspective, this is somewhat wasteful because we must duplicate the declarations and implementations in each class.

From a S/E perspective, this is undesirable since we must effectively maintain two copies of (logically) identical code.
What Do We Want?

Simply put, we want to exploit the fact that Student and Employee both are "people".

That is, each shares certain data and function members which logically belong to a more general (more basic) type which we will call a Person.

We would prefer to NOT duplicate implementation but rather to specify that each of the more specific types will automatically have certain features (data and functions) that are derived from (or inherited from) the general type.

Question: are there any attributes or operations in the overlap that we don't want to include in the base type Person?
By employing the C++ inheritance mechanism…

Inheritance in C++ is NOT simple, either syntactically or semantically. We will examine a simple case first (based on the previous discussion) and defer explicit coverage of many specifics until later.

Inheritance in C++ involves specifying in the declaration of one class that it is derived from (or inherits from) another class.

Inheritance may be public or private (or protected). At this time we will consider only public inheritance.

It is also possible for a class to be derived from more than one (unrelated) base class. Such multiple inheritance will be discussed later…
Having identified the common elements shared by both classes (Employee and Student), we specify a suitable base class:

```cpp
class Person {
private:
    Name    Nom;
    Address Addr;
public:
    Person(const Name& N = Name(),
            const Address& A = Address());
    Name    getName() const;
    Person& setName(const Name& N);
    Person& setAddress(const Address& A);
    Address getAddress() const;
    ~Person();
};
```

The base class should contain data members and function members that are general to all the types we will derive from the base class.
A Derived Class: **Employee**

```cpp
class Employee : public Person {
private:
    string Dept;
    string ID;

public:
    Employee();
    Employee(const Person& P, const string& D,
             const string& I);
    Employee(const Name& N, const Address& A,
             const string& D, const string& I);

    string getDept() const;
    Employee& setDept(const string& D);
    string getID() const;
    Employee& setID(const string& I);

    ~Employee();
};
```

Specify base class

Specify public inheritance

Specify additional data members not present in base class

Specify appropriate constructors

Specify accessors and mutators only for the added data members
Logical View of an Employee Object

Employee “layer”

Employee( . . .)

gDept()

Person “layer” (inherited from base type)

getAddress( )

Public interface

Private members

Dept

ID

Nom

Addr

public members of the base type are public in the derived type

private members of the base type are private in the derived type
Constructing a Derived Type Object

When an object of a derived type is declared, the default constructor for the base type will be invoked BEFORE the body of the constructor for the derived type is executed (unless an alternative action is specified...).

```cpp
Employee::Employee() : Person() {
    Dept = "None";
    ID   = "None";
}
```

It's not necessary to explicitly invoke the base constructor here, but it makes the behavior more obvious.

Alternatively, the derived type constructor may explicitly invoke a non-default base type constructor:

```cpp
Employee::Employee(const Person& P, const string& D,
                     const string& I) : Person(P) {
    Dept = D;
    ID   = I;
}
```

Here, the (default) copy constructor for the base class is used.
Derived Class Member Access Problem

Objects of a derived type inherit the data members and function members of the base type. However, the derived object may not directly access the private members of the base type:

Employee::Employee(const Person& P, const string& D, const string& I) {
    Nom  = P.getName();
    Addr = P.getAddress();
    Dept = D;
    ID   = I;
}

Error: cannot access private member declared in class Person.

For a derived-class constructor we directly invoke a base class constructor, as shown on the previous slide, or use the Person interface:

Employee::Employee(const Person& P, const string& D, const string& I) {
    setName(P.getName());
    setAddress(P.getAddress());
    // . . .
}
The restriction on a derived type's access seems to pose a dilemma:

- Having the base type use only public members is certainly unacceptable.
- Having the derived class use the public interface of the base class to access and/or modify private base class data members is clumsy.

C++ provides a middle-ground level of access control that allows derived types to access base members which are still restricted from access by unrelated types.

The keyword `protected` may be used to specify the access restrictions for a class member:

```cpp
class Person {
    protected:
        Name Nom;
        Address Addr;
    public:
        //...
};

Employee::Employee(/*...*/ ) {
    Nom   = N;       // OK now
    Addr  = A;
    Dept  = D;
    ID    = I;
}
```
A Sibling Class

```cpp
class Student : public Person {
private:
    string Major;
    string ID;
    int Level;

public:
    Student(const Person& P = Person(),
            const string& M = "None",
            const string& I = "000-00-0000", int L = 10);

    string getMajor() const;
    Student& setMajor(const string& D);
    string getID() const;
    Student& setID(const string& I);
    int getLevel() const;
    Student& setLevel(int L);

    ~Student();
};
```

Note that, so far as the language is concerned, Student and Employee enjoy no special relationship as a result of sharing the same base class.
Objects of a derived class may be declared and used in the usual way:

```cpp
// . . .
Person JBH(Name("Joe", "Bob", "Hokie"),
            Address("Oak Bridge Apts", "#13", "Blacksburg",
                    "Virginia", "24060"));

Employee JoeBob(JBH, "Sales", "jbhokie");

Call base member

cout << "Name:  " << JoeBob.getName().formattedName() << endl
    << "Dept:  " << JoeBob.getDept() << endl
    << "ID:    " << JoeBob.getID() << endl;

Call derived members

Person HHooIV(Name("Haskell", "Horatio", "Hoo"),
               Address("1 Rotunda Circle", "",
                       "Charlottesville", "VA", "21009"));
Student HaskellHoo(HHooIV, "Undecided", "101-01-0101", 40);

HaskellHoo.setAddress(Address("Deke House", "333 Coors Way",
                              "Charlottesville", "VA",
                              "21010"));

HaskellHoo.setMajor("Undeclared");
// . . .

...to the user there's no evidence here that the class is derived...
Extending the Hierarchy

Actually, Employee is not a terribly interesting class but it has two (or more) useful sub-types:

There's no restriction on how many levels of inheritance can be designed, nor is there any reason we can't mix inheritance with association and/or aggregation.
For the sake of an example, a staff member is paid an hourly wage, so the class Staff must provide the appropriate extensions...

```cpp
class Staff : public Employee {
private:
  double HourlyRate;
public:
  Staff(const Employee& E, double R = 0.0);
  double getRate() const;
  void setRate(double R);
  double grossPay(int Hours) const;
  ~Staff();
};
```

...whereas a professor is paid a fixed salary:

```cpp
class Professor : public Employee {
private:
  double Salary;
public:
  Professor(const Employee& E, double S = 0.0);
  double getSalary() const;
  void setSalary(double S);
  double grossPay(int Days) const;
  ~Professor();
};
```
The base member function `Employee::setID()` is simple:

```cpp
Employee& Employee::setID(const string& S) {
    ID = S;
    return (*this);
}
```

This implementation raises two issues we should consider:

- What if there's a specialized way to set the ID field for a derived type?
- Is the return type really acceptable for a derived type?

We’ll consider the first question now… suppose that the ID for a professor must begin with the first character of that person's department.

Then `Professor::setID()` must enforce that restriction.
Overriding a Base Class Member Function

In the derived class, provide an appropriate implementation, using the same interface. That will override the base class version when invoked on an object of the derived type:

```cpp
Professor& Professor::setID(const string& I) {
    if (I[0] == Dept[0])
        ID = I;
    else
        ID = Dept[0] + I;
    return (*this);
};
```

The appropriate member function implementation is chosen (at compile time), based upon the type of the invoking object and the inheritance hierarchy. Beginning with the derived class, the hierarchy is searched upward until a matching function definition is found:

```cpp
Employee   E( /* . . . */ );
Professor  F( /* . . . */ );
// . . .
E.setID("12334");  // Employee::setID()
F.setID("99012");  // Professor::setID()
```

Assuming that Dept has protected status.
Extending a Base Class Member Function

Suppose we added a display member function to the base type:

```cpp
void Person::Display(ostream& Out) {
   Out << "Name:    " << Name << endl
   << "Address: " << Address;
};
```

This is inadequate for a Professor object since it doesn't recognize the additional data members... we can fix that by overriding again (with a twist):

```cpp
void Professor::Display(ostream& Out) {
   Person::Display(Out);
   Out << "ID:   " << ID << endl
   << "Dept: " << Department;
};
```

Here, we use the base class display function, invoking it with the appropriate scope resolution, and then extend that implementation with the necessary additional code.
It is **legal** to assign a derived type object to a base type object:

```java
Employee eHomer(Name("Homer", "P", "Simpson"),
    Address("1 Chernenko Way", ",", "Blacksburg", 
    "VA", "24060"),
    "Physics", "P401" );
Professor Homer(eHomer, 45000.00);

Employee E;
Person P;

E = Homer; // legal assignments, but usually inadvisable
P = Homer;
```

When a derived object is assigned to a base target, only the data and function members appropriate to the target type are copied.

This is known as **slicing**.
void PrintEmployee(Employee toPrint, ostream& Out) {
    Out << toPrint.getID();
    Out << ' \t';
    Out << toPrint.getName();
    Out << ' \n';
}

PrintEmployee() sees only the Employee layer of the actual parameter that was passed to it by value.

That's actually OK in this case since that's all PrintEmployee() deals with anyway.

However, it's certainly a limitation you must be aware of... what if you wanted to write a generic print function that would accept any derived type, without slicing?
Assigning Base Type to Derived Type

By default, a base type object may not be assigned to a derived type object:

```cpp
// assume declarations from slide 24. . .
Homer = eHomer;    // illegal - compile time error
```

It's possible to legalize this with the right overloading (later), but…

... some sort of action must be taken with respect to the derived type data members that have no analogs in the base type.
Parameter Passing Issues

The rules are essentially the same in four situations:

- when passing a derived object by value as a parameter.
- when returning a derived object by value
- when initializing a base object with a derived object
- when assigning a derived object to a base object

A derived type may be copied when a base type is targeted — however, slicing will occur.

A base type may not be copied when a derived type is targeted — unless a suitable derived type constructor is provided to legalize the conversion.