Programming Design

Inheritance

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Outline

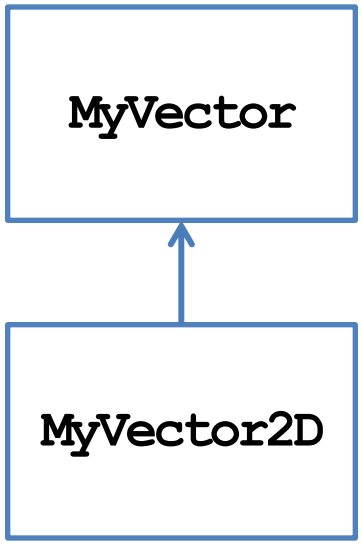
- **Basic ideas and the first example**
- Defining new members and overriding old members
- Cascade inheritance and inheritance visibility
- One last discussion

Inheritance

- The three main characteristic/functionalities of OOP:
  - Encapsulation: packaging + data hiding.
  - **Inheritance**: today's topic.
  - Polymorphism: next lecture's topic.
- Through inheritance, we may **create new classes from existing classes**.
  - A **derived** (**child**) class inherits a **base** (**parent**) class.
  - A child class has (some) members defined in the parent class.
- This is particularly useful when "**XXX is a OOO**".
  - An apple is a fruit.
  - A circle is a shape.
  - A truck is a vehicle.

The first example

- Recall that we have defined **`MyVector`**.
- A two-dimensional (2D) vector is a vector!
- Let's create a class for 2D vector by inheritance.




```
class MyVector
{
protected: // to be explained
  int n;
  double* m;
public:
  MyVector();
  MyVector(int n, double m[]);
  MyVector(const MyVector& v);
  ~MyVector()
  void print() const;
  // ==, !=, <, [], =, +=
};
```

Child class MyVector2D

```
class MyVector2D : public MyVector
{
public:
  MyVector2D();
  MyVector2D(double m[]);
};
MyVector2D::MyVector2D()
{
  this->n = 2;
}
MyVector2D::MyVector2D(double m[]) : MyVector(2, m)
{
}
```

```
int main()
{
  double i[2] = {1, 2};
  MyVector2D v(i);
  v.print();
  cout << v[1] << endl;

  return 0;
}
```

- That is all for **MyVector2D**!
  - The modifier **public** will be discussed later.

Inheriting parent class' members

- Members in the parent class are **automatically** defined in the child class.
  - **Except** private members, constructors, and the destructor.
  - A **protected** member can only be accessed by itself and its successors.
- What are the members of **MyVector2D**?

```
class MyVector2D : public MyVector
{
public:
  MyVector2D();
  MyVector2D(double m[]);
};
```

```
class MyVector
{
protected:
  int n;
  double* m;
public:
  MyVector();
  MyVector(int n, double m[]);
  MyVector(const MyVector& v);
  ~MyVector()
  void print() const;
  // ==, !=, <, [], =, +=
};
```

Invoking parent class' constructors

- The parent class' constructor will not be inherited.
- One of them will be invoked **before** the child class' constructor is invoked.
  - Create the parent before creating the child!
- If not specified, the parent's **default** constructor will be invoked.

```
MyVector::MyVector(): n(0), m(NULL)
{
}

MyVector2D::MyVector2D()
{
  this->n = 2;
  // this->m = NULL is redundant
}
```

```
int main()
{
  MyVector2D v;

  return 0;
}
```

Invoking parent class' constructors

- To **specify** a parent's constructor to call, use the syntax for member initializer:
  - **Pass appropriate arguments** to control the behavior.

```
MyVector::MyVector(int n, double m[])
{
  this->n = n;
  this->m = new double[n];
  for(int i = 0; i < n; i++)
    this->m[i] = m[i];
}
MyVector2D::MyVector2D(double m[]) : MyVector(2, m)
{
  // not MyVector(2, m) here!
}
```

```
int main()
{
  double i[2] = {1, 2};
  MyVector2D v(i);
  v.print();
  cout << v[1] << endl;

  return 0;
}
```

Invoking copy constructors

- How about the copy constructor?
- If we do not define one for the child, the system provides a **default** one.
- **Before** the child's default copy constructor is invoked, the parent's copy constructor will be **automatically** invoked.

```
MyVector::MyVector(const MyVector& v)
{
  this->n = v.n;
  this->m = new double[n];
  for(int i = 0; i < n; i++)
    this->m[i] = v.m[i];
}
class MyVector2D : public MyVector
{
public:
  MyVector2D();
  MyVector2D(double m[]);
  // no copy constructor
};
```

Invoking copy constructors

- If we define a copy constructor for the child, we must **specify** the constructor we want to invoke!
  - Otherwise the parent's **default** constructor will be invoked.

```
class MyVector2D : public MyVector
{
public:
  MyVector2D();
  MyVector2D(double m[]);
  MyVector2D(const MyVector2D& v) {}
};
```

```
int main()
{
  double i[2] = {1, 2};
  MyVector2D v(i);
  MyVector2D w(v);
  w.print(); // error
  cout << w[1] << endl;

  return 0;
}
```

Using parent's member functions

- Once member variables are set properly, typically all the member functions of the parent can be used with no error.

```
void MyVector::print() const
{
  cout << "(";
  for(int i = 0; i < n - 1; i++)
    cout << m[i] << ", ";
  cout << m[n-1] << ")\n";
}
double& MyVector::operator[](int i)
{
  if(i < 0 || i >= n)
    exit(1);
  return m[i];
}
```

```
int main()
{
  double i[2] = {1, 2};
  MyVector2D v(i);
  v.print();
  cout << v[1] << endl;

  return 0;
}
```

Invoking parent class' destructor

- When an object of the child class is to be destroyed:
  - First the child's destructor is invoked.
  - **Then** the parent's destructor is invoked **automatically**, even if we do not define a destructor for the child.
- Do not **delete a pointer twice**!
  - This may result in a run time error.

```
MyVector::~MyVector()
{
  delete [] m;
}
class MyVector2D : public MyVector
{
public:
  MyVector2D();
  MyVector2D(double m[]);
  // no destructor
};
```

Summary

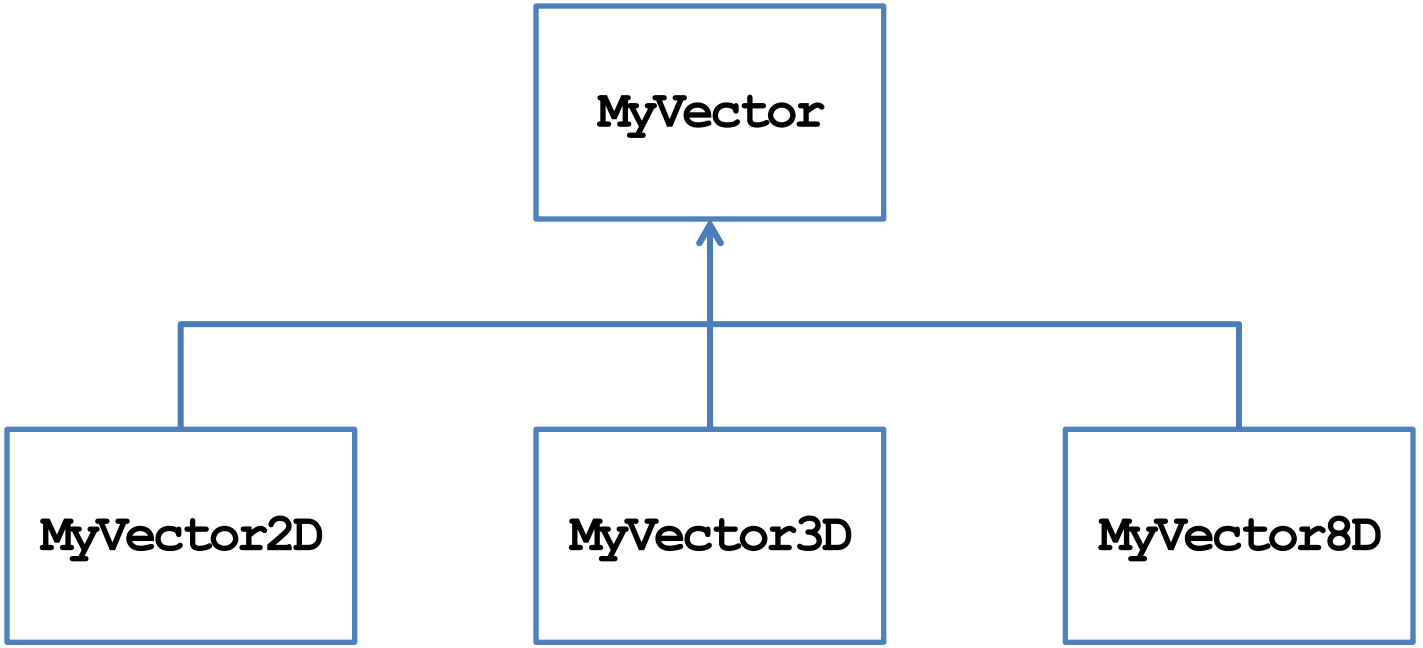
- Using inheritance to create new classes is so simple!

```
class MyVector2D : public MyVector
{
public:
  MyVector2D() { this-> n = 2; }
  MyVector2D(double m[]) : MyVector(2, m) {}
};
```

  - We save time and enhance **consistency**.
  - Pay attention to default constructors, copy constructors, and destructors.
  - If one thing should not be inherited, set it to private.

Brothers and sisters

- One parent class can be inherited by multiple child classes.



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- Cascade inheritance and inheritance visibility
- One last discussion

Defining new members for the child

- A child may have **its own members**.
  - The parent has no way to access a child's member.
- Let's define a **`setValue()`** function without using arrays:
  - Note that this should never be a member of **`MyVector`**.
- We may also define new member variables and static members.

```
class MyVector2D : public MyVector
{
public:
  MyVector2D() { this-> n = 2; }
  MyVector2D(double m[]) : MyVector(2, m) {}
  void setValue(double i1, double i2);
};
void MyVector2D::setValue(double i1, double i2)
{
  if(this->m == NULL)
    this->m = new double[2];
  this->m[0] = i1;
  this->m[1] = i2;
}
```

Function overriding

- We may also redefine existing member inherited from a parent.
  - This typically happens to member functions.
  - We say that we **override** the member function.
- As an example, let's override **`print()`**:

```
class MyVector2D : public MyVector
{
public:
  MyVector2D() { this-> n = 2; }
  MyVector2D(double m[]) : MyVector(2, m) {}
  void setValue(double i1, double i2);
  void print() const;
};
void MyVector2D::print() const
{
  cout << "2D: (";
  for(int i = 0; i < n - 1; i++)
    cout << m[i] << ", ";
  cout << m[n-1] << ")\n";
}
```

Function overriding

- To override a parent's member function, define a child's member function with exactly the same **function signature**.
  - A child object will invoke the child's implementation.
  - The parent's implementation becomes hidden to a child object.
- Inside the child class, we may invoke a parent's member function by using `::`.

```
void MyVector2D::print() const
{
  cout << "2D: ";
  MyVector::print();
}
```

  - Use it if consistency can be enhanced.

Overriding a constant function

- What will happen to the following program?

```
int main()
{
  double i[2] = {1, 2};
  const MyVector2D v(i);
  v.print(); // ?

  MyVector2D u;
  u.setValue(3, 4);
  u.print(); // ?

  return 0;
}
```

```
class MyVector
{
  // ...
  void print() const;
};
class MyVector2D : public MyVector
{
  // ...
  void print() { MyVector::print(); }
  void print() const
  {
    cout << "2D: ";
    MyVector::print();
  }
};
```

Overriding a constant function

- How about this?

```
int main()
{
  double i[2] = {1, 2};
  const MyVector2D v(i);
  v.print(); // error!

  MyVector2D u;
  u.setValue(3, 4);
  u.print(); // ?

  return 0;
}
```

```
class MyVector
{
  // ...
  void print() const;
};
class MyVector2D : public MyVector
{
  // ...
  void print() { MyVector::print(); }
};
```

Overriding a member variable?

- Technically, we may override a member variable.
- For example, it seems to be a good idea to override **n** by a **static constant**:

```
class MyVector2D : public MyVector
{
private:
  static const int n;
public:
  MyVector2D() { // no this->n = 2; }
  MyVector2D(double m[]) : MyVector(2, m) {}
  // not overriding print();
  void setValue(double i1, double i2);
};

const int MyVector2D::n = 2;
```

```
int main()
{
  double i[2] = {1, 2};
  const MyVector2D v(i);
  v.print(); // good :)

  MyVector2D u;
  u.setValue(3, 4);
  u.print(); // bad :(

  return 0;
}
```

Overriding a member variable?

- As **`print()`** is not overridden, **`v`** and **`u`** invoke the parent's implementation.
- The parent's implementation uses **`MyVector::n`**.
  - With the constructor with an array as a parameter, **`MyVector::n`** is set to 2.
  - With the default constructor, **`MyVector::n`** is set to 0!
- Even though **`MyVector2D::n`** is set to 2, it is not used in **`MyVector::print()`**.
- What if we also override **`print()`**?

```
void MyVector2D::print() const
{
  cout << "2D: (";
  for(int i = 0; i < n - 1; i++)
    cout << m[i] << ", ";
  cout << m[n-1] << ")\n"; // good :)
}
```

```
void MyVector2D::print() const
{
  cout << "2D: ";
  MyVector::print(); // bad :(
}
```

Overriding parent's member

- In general, overriding a parent's member variable is not suggested.
  - Unless you really know what you are doing.
  - After all, we will inheritance because we believe XXX is a OOO. A parent's member variable should be a part of a child!
- Overriding a parent's member function is useful.
- What is the difference between function overloading and function overriding?
- Sometimes we override a member function for efficiency.

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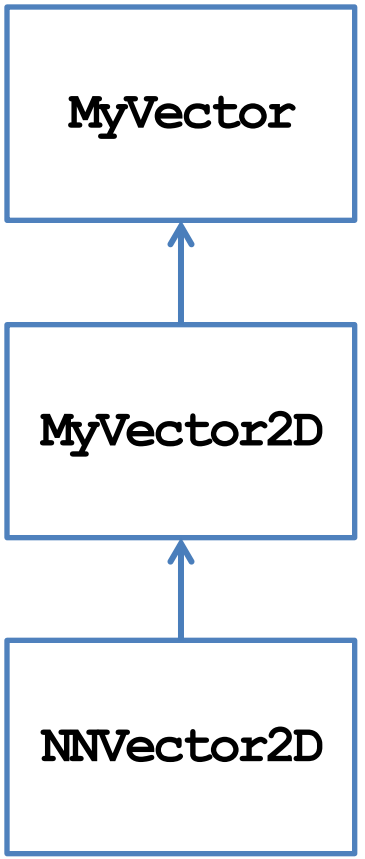
Cascade inheritance

- While a child inherits its parent, it may have a grandchild inheriting itself.
- How may we create a class for two-dimensional nonnegative vectors?
  - $\{(x, y) \mid x \geqq 0, y \geqq 0\}$.
- A 2D nonnegative vector **is a** 2D vector!
- Let's use inheritance again.



Child class NNVector2D

- Defining **NNVector2D** is simple:

```
class NNVector2D : public MyVector2D
{
public:
  NNVector2D(); // do we need it?
  NNVector2D(double m[]);
  void setValue(double i1, double i2);
};
NNVector2D::NNVector2D()
{
}
```

```
NNVector2D::NNVector2D(double m[])
{
  this->m = new double[2];
  this->m[0] = m[0] >= 0 ? m[0] : 0;
  this->m[1] = m[1] >= 0 ? m[1] : 0;
}
void NNVector2D::setValue
  (double i1, double i2)
{
  if(this->m == NULL)
    this->m = new double[2];
  this->m[0] = i1 >= 0 ? i1 : 0;
  this->m[1] = i2 >= 0 ? i2 : 0;
}
```

  - Why not specifying a parent's constructor?
  - What happens when an **NNVector2D** object is created?

Child class NNVector2D

- How about

```
NNVector2D::NNVector2D(double m[]) : MyVector2D(2, m)
{
  if(m[0] < 0)
    this->m[0] = 0;
  if(m[1] < 0)
    this->m[1] = 0;
}
```

or

```
NNVector2D::NNVector2D(double m[])
{
  setValue(m[0], m[1]);
}
```

Cascade inheritance

- In general, a class has all the protected and public members (excluding constructors and destructors) of its predecessors.
- When an object is created:
  - Constructors are invoked from the oldest class to the youngest class.
  - Each constructor can specify a **one-level-above** constructor to invoke.
  - Only one level!
- When an object is destroyed:
  - Destructors are invoked from the youngest to the oldest.

Inheritance visibility

- Recall that we added the modifier **`public`** when **`MyVector2D`** inherits **`MyVector`** and when **`NNVector2D`** inherits **`MyVector2D`**.
  - This modifier specifies the **inheritance visibility**.
  - It shows how this child modify the member visibility set by its predecessors.
- When one inherits something from its parent, it may **narrow** the **visibility** of these members.
  - E.g., if my parent set its to protected, I may set it to private.
  - E.g., if my parent set its to private, I cannot set it to public.
- Why only narrowing?

Inheritance visibility

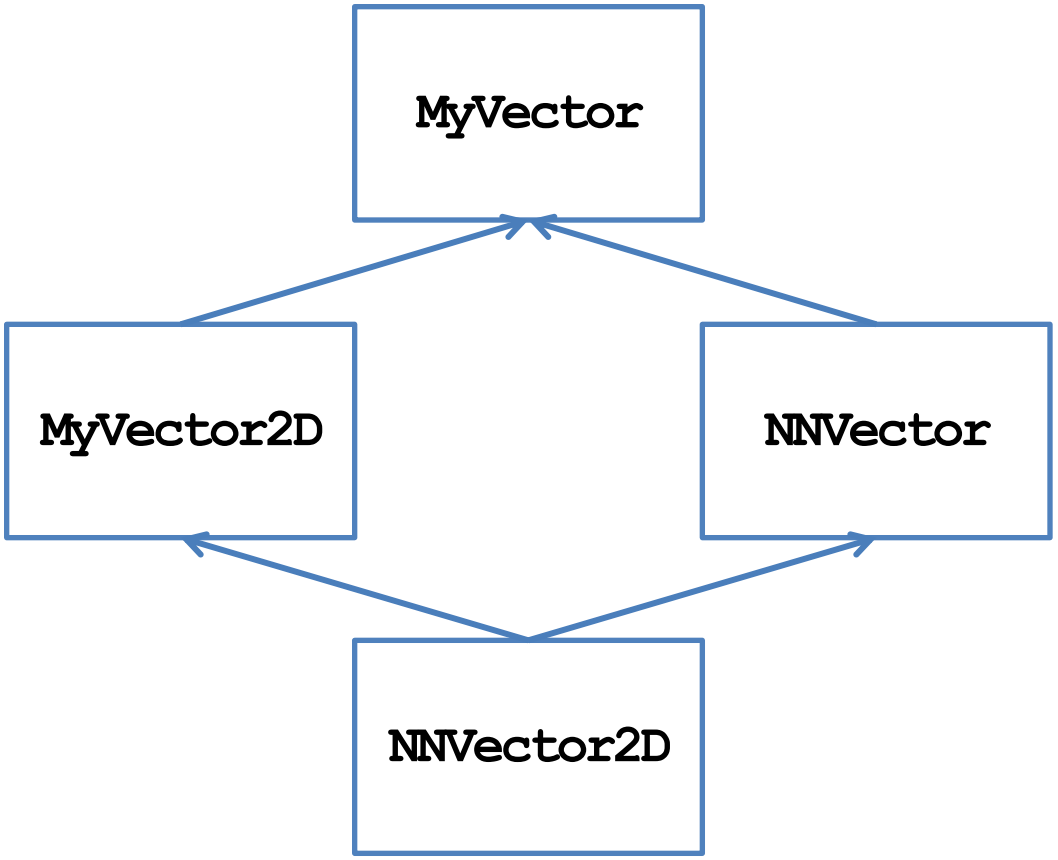
- In general, the visibility of a member in a child class depends on:
  - The member visibility by the parent.
  - The inheritance modifier.

Member visibility by the parent	Inheritance modifier		
	`public`	**`protected`**	**`private`**
`public`	**`public`**	**`protected`**	**`private`**
`protected`	**`protected`**	**`protected`**	**`private`**
`private`	**`private`**	**`private`**	**`private`**

- If you have no idea, just use public inheritance.

Multiple inheritance

- Suppose your friend argues:
  - A two-dimensional vector is a vector.
  - A nonnegative vector is a vector.
  - A two-dimensional nonnegative vector should be the child of them!
- Does that make sense?



Multiple inheritance

- In C++, **multiple inheritance** is allowed.
- However, it is not recommended!
  - In some other object-oriented programming languages (e.g., Java), multiple inheritance is forbidden.
- If there are multiple parents:
  - Whose constructor/destructor goes first?
  - Whose variables are stored in the front?
  - May I inherit from my sister? May I inherit from my grandaunt?
- We also suggest you not to do multiple inheritance (even though it has been used in C++ standard library).

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A problem regarding the overridden =

- In fact, the definition of **`MyVector2D`** contains a flaw.
  - It is possible to have an object with **`n = 2`** but **`m = NULL`**.
- This is inconsistent.
- How to fix it?

```
int main()
{
  double i[2] = {1, 2};
  MyVector2D v(i);

  MyVector2D u;
  u = v; // error!
  u.print();
  return 0;
}
```

```
const MyVector& MyVector::operator=
  (const MyVector& v)
{
  if(this != &v)
  {
    if(this->n != v.n)
    {
      delete [] this->m;
      this->n = v.n;
      this->m = new double[this->n];
    }
    for(int i = 0; i < n; i++)
      this->m[i] = v.m[i]; // error!
  }
  return *this;
}
```

A question regarding the overridden =

- Beside the previous issue, is there anything weird with the overridden **=**?

```
const MyVector& operator=(const MyVector& v);
```

- The type of the parameter is **MyVector**, not **MyVector2D**!
  - Has **MyVector2D** been casted to **MyVector**?
  - May we cast **MyVector** to **MyVector2D**?
  - Is casting between classes allowed if they are not parent and child?
  - What if they are brothers are sisters (like **MyVector2D** and **NNVector**)?
  - How may we utilize casting between classes?
- We will discuss these questions when we introduce **polymorphism**.