3F6 - Software Engineering and Design

Handout 3

Classes and C++ (II)

With Markup

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Copies of these notes plus additional materials relating to this course can be found at:
`http://mi.eng.cam.ac.uk/~er258/teaching.html`.

A Drawing Editor Example

Imagine a very simple drawing editor where drawings consist only of rectangles represented by `class Rectangle`.

```
Rectangle * my_rectangles[N];

Ellipse * my_ellipses[N];

// display the drawing
for(int i=0; i<num_rectangles; i++){
  my_rectangles[i]->draw();
}

for(int i=0; i<num_ellipses; i++){
  my_ellipses[i]->draw();
}
```

If we now want to extend our drawing editor to allow ellipses as well, we could create `class Ellipse` and add a list of ellipses to the list of rectangles.

Because `Ellipse` has the same interface as `Rectangle`, we can easily extend the program by cutting and pasting.

But this quickly becomes unmanageable. (eg think of all the shapes in Powerpoint).

```
class Rectangle {
public:
  void draw();
  void move(int dx, int dy);
  void fill(int colour);

private:
  int left;
  int right;
  int top;
  int bottom;
};


class Ellipse {
public:
  void draw();
  void move(int dx, int dy);
  void fill(int colour);

private:
  int x_centre;
  int y_centre;
  int width;
  int height;
};
```

Polymorphism

When we created `class Ellipse` to look like `class Rectangle`, we were using a weak kind of **is-a** relationship. Both `Rectangle` and `Ellipse` provide the same interface for drawing, moving and filling shapes.

We can formalise this by using *class derivation* as in the `VideoFrame` example. However, here we go further.

First, we define an abstract data type to represent the abstract concept `Shape`.

```
class Shape {
public:
  virtual void draw()=0;
  virtual void move(int dx, int dy)=0;
  virtual void fill(int colour)=0;
};
```

This is called the *base* class and its functions are *pure virtual functions*. They have no implementation bodies, instead they are placeholders for the concrete functions that will be defined in each class derived from `Shape`.

We then derive `Rectangle`, `Ellipse` and any other shape that we want from this base class. Note "virtual" means that the function can be redefined in a derived class. "=0" means that no implementation body will be provided.

```
class Rectangle : public Shape {
public:
  virtual void draw();
  virtual void move(int dx, int dy);
  virtual void fill(int colour);
private:
  // as before
};
class Ellipse : public Shape {
public:
  virtual void draw();
  virtual void move(int dx, int dy);
  virtual void fill(int colour);
private:
  // as before
};
```

These are called *subclasses*, *derived types* or *derived classes*.

We can now declare pointers of type `Shape` and use them to point to these derived classes.

```
Shape *p;
Rectangle *r = new Rectangle();
Ellipse   *e = new Ellipse();

// assign either r or e to p

p->draw();   // draw whatever p points to
```

This is called *polymorphism*.

Using Virtual Functions

We can now simplify the code for drawing the rectangles and ellipses into a single loop:

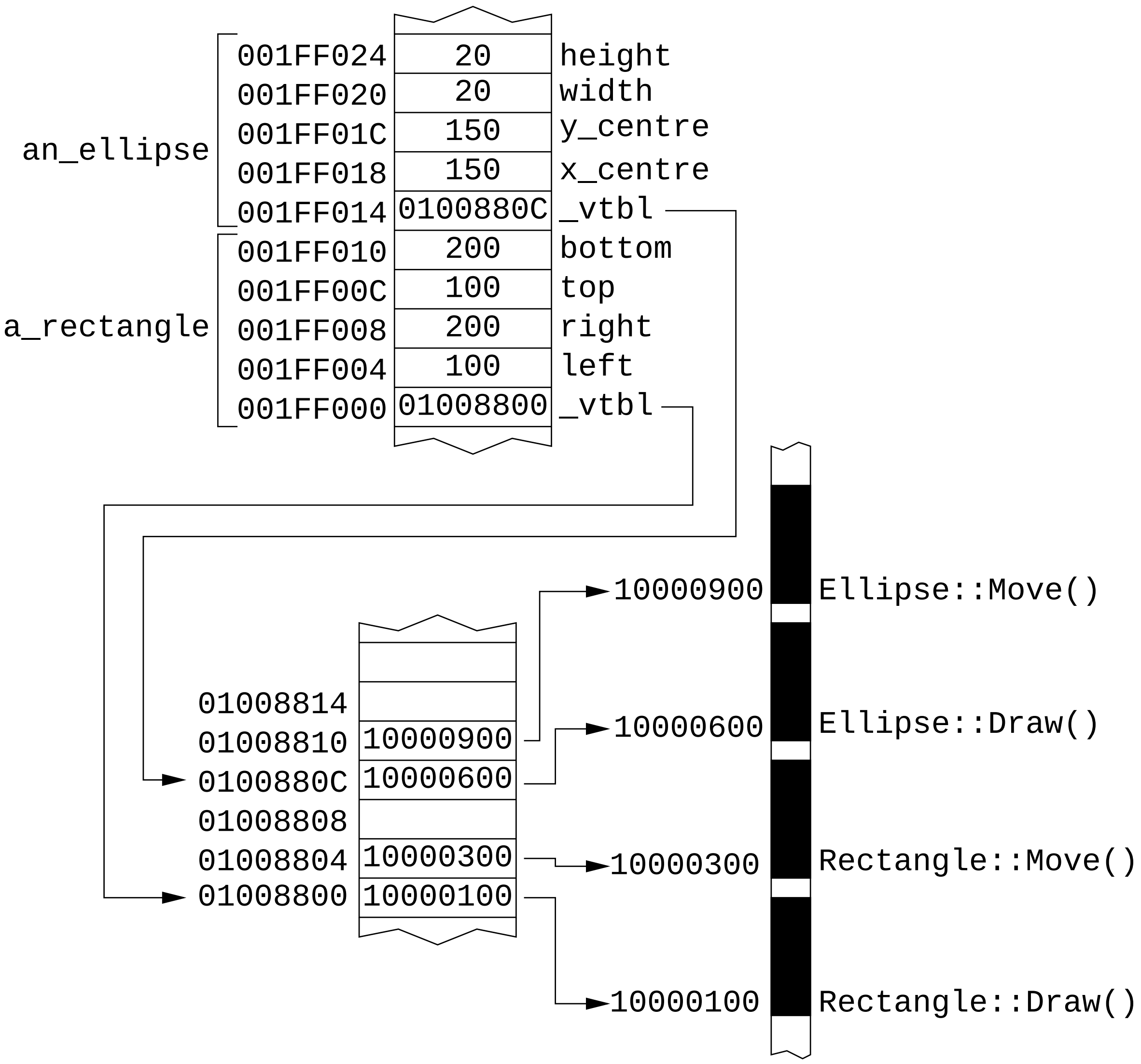
```
Shape* my_shapes[MAX_NUM_SHAPES];
int num_shapes = 0;

void AddShape(Shape *s) {
  my_shapes[num_shapes++] = s;
}

void DrawShapes() {
  for(int i=0; i<num_shapes; i++){
    my_shapes[i]->draw();
  }
}
```

A further advantage of this approach is that this code doesn't change when we introduce further shapes into our drawing editor with their own virtual functions. The line of code

```
my_shapes[i]->draw();
```

will automatically detect new subclasses of `Shape` and call the draw function that has been supplied by the programmer of the subclass.

How Virtual Functions are Implemented



Note that we use a double indirection to avoid duplicating a large set of pointers for every instance of the object.

Reporting Errors

Errors in the operation of a program are inevitable and robust software must be able to detect and handle them appropriately.

Consider the following:

```
int main() {
   ...
   int traderr = MyTrader();
   if(traderr != OKAY) {
      // Sort out the error
   }
   ...
}
//-------------------------------------------------
int MyTrader() {
   ...
   float price;
   int ret = TE_GetPrice(day, price);
   if(ret != OKAY)  return ret; // Pass the error back
   ...
   return OKAY; // Signal success
}
//-------------------------------------------------
int TE_GetPrice(int day, float& price) {
   ...
   if (!Valid(day)) return BAD_DAY;
   ...
   return OKAY;
}
```

Here return codes are used to signal errors.

Exceptions

Errors such as the above represent *exceptions* to the normal program flow.

Handling exceptions via return codes has a number of disadvantages:

- Extra code needs to be inserted in each function to pass the errors back.
- If one function fails to check for errors and pass them back, the errors will not get handled.
- The extra error checking obscures the main function of the code, making it difficult to understand.
- Error recovery code becomes intertwined with the normal operation code.
- Functions cannot use return values for normal purposes.

Fortunately, there is a better way.

Exception handling

In a structured approach to exception handling, exceptions are represented by class objects. The fields of the class can be used to record all relevant error information.

For example,

```
class TradingErr {
   TradingErr(ErrType ee, Time tt) {e=ee; t=tt;}
   ErrType e;
   Time t;
};
```

Exception handling now consists of two stages:

a) Raising the Error

```
throw TradingErr(BAD_DAY,TimeNow());
```

The effect of a **`throw`** is to exit the current procedure. If the calling procedure has a handler, it is invoked. Otherwise, the process repeats.

Note that the class object is constructed before it is thrown.

b) Handling the Error

At an appropriate point in the procedure call hiearchy, a `catch` statement is inserted to catch and handle a specific exception.

```
void SomeFunction () {
try {
   // regular code
}
// exception handler
catch (TradingErr x) {
    if (x.e == ... ) ....
}
```

Note

- using exception handlers, the code is much cleaner because the error handling parts are clearly separated from the regular code.
- a handler can throw the exception again allowing some errors to be trapped and repaired and others to be propagated.

The Trading example again:

```
int main() {

  try {
     ...
     MyTrader();
     ...
  }
  catch (TradingError x) {
     ReportError(x.e, x.t);
  }

}
//--------------------------------------------------
void MyTrader() {
   ....
   float price = TE_GetPrice(day);
   ....
}
//--------------------------------------------------
float TE_GetPrice(int day) {


   ...
   if (!Valid(day))
      throw TradingErr(BAD_DAY,TimeNow());
   ...


}
```

Templates

The `Image` class we defined earlier can only store greyscale images because

- The `pixels` data member is of type `char *`.
- The `get_pixel()` function returns a `char`.
- The `set_pixel()` function takes a `char` as its third argument.

If we want to handle colour images (where every pixel is of type `Colour`) or images where every pixel is an `int`, we have to either

(a) create new classes for each specific pixel type or

(b) define a polymorphic class for pixels.

but (a) is tedious and (b) is very inefficient.

What is needed is a specific mechanism to parameterise types.

In C++ this is achieved using *Templates*

- Templates allows a type to vary without virtual functions
- Templates provide *compile-time* polymorphism
- You can also template with numeric constants e.g. fixed sized matrices.
- Templates are Turing complete!

```
template <class T>     // T is a generic type
class Image {
public:
  Image(int w, int h);
  ~Image();

  int get_width();
  int get_height();

  T get_pixel(int x, int y);
  void set_pixel(int x, int y, T val);

  void load(char *filename);
  void save(char *filename);

private:
  int width;
  int height;
  T *pixels;          // array of T's
};
```

We can use template classes in the following way:

```
// create a greyscale image where T = char
Image<char> grey_im(200,200);}

// create a colour image  where T = Colour
Image<Colour> colour_im(200,200);}

...
grey_im.set_pixel(100,100,255);

Colour col = colour_im.get_pixel(100,100);
...
etc
```

The C++ Standard Template Library

The most common use for template programming is to create container classes. The standard template library (STL) contains many of these. For example

```
template<class T>
class vector {...};
```

allows the user to create arrays that work in a similar way to C style arrays but with many extra features such as dynamic sizing, array bound checking, etc.

```
vector<int> primes(100);
primes[0]=2;
primes[1]=3;
```

This code creates an array of 100 integers and stores the integer values 2 and 3 into the first two slots.

`vector` supports other functions as well, for example:

```
primes.push_back(547);
```

increases the size of the array by one and sets the last entry to 547.

Lists and Iterators

An alternative to the `vector` container is the `list`:

```
template<class T>
class list {...};
```

which allows the user to create linked lists:

```
list<int> lprimes;
lprimes.push_back(2);
lprimes.push_back(3);
```

This creates an initially empty linked list of integers and then pushes the integers 2 and 3 onto the list.

It is possible to iterate through the elements of a linked list by declaring an *iterator* type.

An iterator is a generalised form of index:

```
list<int>::iterator it;
for(it=lprimes.begin(); it!=lprimes.end(); it++){
    cout << (*it) << endl;
}
```

Note that similar code could be used to scan the elements of a vector

```
// scan vector using iterators
vector<int>::iterator it;
for(it = primes.begin(); it!=primes.end(); it++){
    cout << (*it) << endl;
```

However, in the case of vectors only, conventional indexing is supported

```
// scan vector using an integer index
int i;
for(i=0; i < primes.size(); i++){
    cout << primes[i] << endl;
}
```

where `primes.size()` returns the number of elements in the container (vector in this case).

One day, the syntax will get better. The new C++ standard is due to be finalised in March.

The STL Containers

The STL provides a variety of container types which allow complex program structures to be built with very little effort.

1. lists - linked list
2. vectors - array
3. strings - character array
4. sets - set of values
5. map - associative map, values are accessed using a key
6. mmap - a map which supports duplicate keys

plus a large set of built-in algorithms for manipulating these containers such as find, insert, replace, sort, reverse, ... , etc.

A further advantage of using STL and similar libraries is that they are robust and they have built-in memory management which helps to avoid memory leaks.

OO Programming

The object-oriented programming mechanisms described in the previous two lectures change the way we go about designing software. The process is something like:

1. What kinds of objects are present in the problem domain?

   - list of potential classes

2. Are there any classes with similar functionality and common purpose?

   - introduce abstract base classes
   - find the is-a relationships
   - define class hierarchies

3. What are the relationships between classes?

   - find the has-a relationships.
   - define class compositions

4. What services (functions) must each class provide?

   - define interfaces

5. How are these services going to be implemented?

   -implement interfaces

6. Iterate and refine 1–5.