CSE 303
Lecture 22

Advanced Classes and Objects in C++

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Arrays of objects

- array of objects

```
Point spointarray[5];                 // stack
Point* hpointarray = new Point[5];    // heap

cout << spointarray[0].getX();        // 0
```

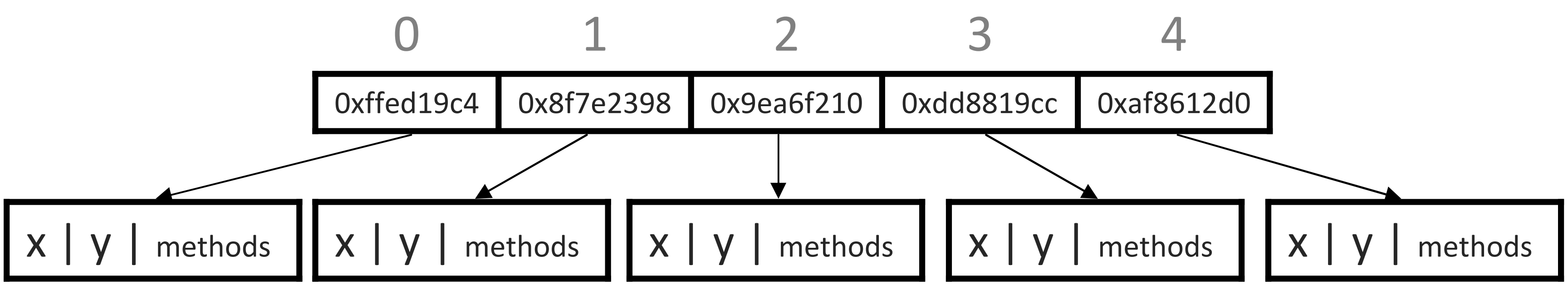
0	1	2	3	4
x | y | methods	x | y | methods	x | y | methods	x | y | methods	x | y | methods

- immediately constructs each object with ( ) constructor
  - if no () constructor exists, a compiler error
- aoeu

Arrays of pointers

- array of pointers to objects (more common)

```
Point* spointarray[5];                    // stack
Point** hpointarray = new Point*[5];      // heap

for (int i = 0; i < 4; i++) {
    spointarray[i] = new Point(i, 2 * i);
    cout << spointarray[i]->getX();       // i
}
```



  - each element object must be created/freed manually

Operator overloading

- **operator overloading**: Redefining the meaning of a C++ operator in particular contexts.
  - example: the `string` class overloads + to do concatenation
  - example: the stream classes overload << and >> to do I/O

- it is legal to redefine almost all C++ operators
  - `() [] ^ % ! | & << >> = == != < >` and many others
  - intended to be used when that operator "makes sense" for your type
    - example: a `Matrix` class's * operator would do matrix multiplication
    - allows your classes to be "first class citizens" like primitives
  - cannot redefine operators between built-in types (`int + int`)

- a useful, but very easy to abuse, feature of C++ (not in C or Java)

Overloading syntax

```
public:    // declare in .h
    returntype operator op(parameters);


returntype classname::operator op(parameters) {
    statements;                           // define in .cpp
}
```

- most overloaded operators are placed inside a class
  - example: overriding `Point + Point`
- some overloaded operators don't go inside your class
  - example: overriding `int + Point`

Overloaded comparison ops

- Override == to make objects comparable like Java's `equals`
  - comparison operators like == return type `bool`
  - by default == does not work on objects (what about `Point*`?)
  - **if you override == , you must also override !=**

```
// Point.h
bool Point::operator==(const Point& p);

// Point.cpp
bool Point::operator==(const Point& p) {
    return x == p.getX() && y == p.getY();
}
```

- Override <, >, etc. to make comparable like Java's `compareTo`
  - even if you override < and ==, you must still manually override <=

Overriding <<

- Override << to make your objects printable like Java's `toString`
  - note that the operator << goes *outside* your class (not a member)
  - << accepts a reference to the stream and to your object
  - returns a reference to the same stream passed in (why?)

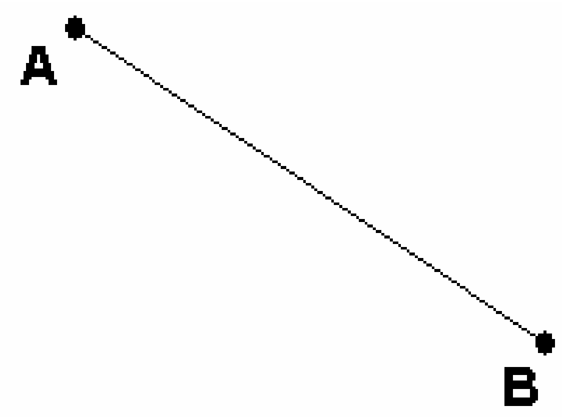
```
// Point.h (outside class)
std::ostream& operator<<(std::ostream& out, const Point& p);

// Point.cpp
std::ostream& operator<<(std::ostream& out, const Point& p) {
    out << "(" << p.getX() << ", " << p.getY() << ")";
    return out;
}
```

  - similarly, you can override >> on an istream to read in an object

Designing a class

- Suppose we want to design a class `LineSegment`, where each object represents a 2D line segment between two points.

  We should be able to:
  - create a segment between two pairs of coordinates,
  - ask a segment for its endpoint coordinates,
  - ask a segment for its length,
  - ask a segment for its slope, and
  - translate (shift) a line segment's position.



- How should we design this class?

LineSegment.h

```
#ifndef _LINESEGMENT_H
#define _LINESEGMENT_H

#include "Point.h"

class LineSegment {
    private:
        Point* p1;    // endpoints of line
        Point* p2;

    public:
        LineSegment(int x1, int y1, int x2, int y2);
        double getX1() const;
        double getY1() const;
        double getX2() const;
        double getY2() const;
        double length() const;
        double slope() const;
        void translate(int dx, int dy);
};

#endif
```

LineSegment.cpp

```
#include "LineSegment.h"

LineSegment::LineSegment(int x1, int y1, int x2, int y2) {
    p1 = new Point(x1, y1);
    p2 = new Point(x2, y2);
}

double LineSegment::length() const {
    return p1->distance(*p2);
}

double LineSegment::slope() const {
    int dy = p2->getY() - p1->getY();
    int dx = p2->getX() - p1->getX();
    return (double) dy / dx;
}

void LineSegment::translate(int dx, int dy) {
    p1->setLocation(p1->getX() + dx, p1->getY() + dy);
    p2->setLocation(p2->getX() + dx, p2->getY() + dy);
}
...
```

Problem: memory leaks

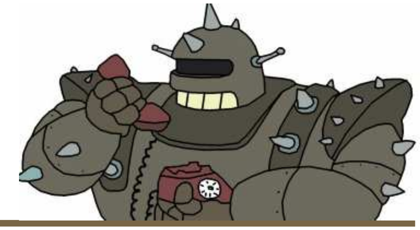
- if we create `LineSegment` objects, we'll leak memory:

```
LineSegment* line = new LineSegment(1, 2, 5, 4);
...
delete line;
```

  - what memory is leaked, and why?

- the two `Point` objects p1 and p2 inside `line` are not freed
  - the delete operator is a "shallow" delete operation
  - it doesn't recursively delete/free pointers nested inside the object
    - why not?

Destructors



```
public:
    ~classname();                   // declare in .h


classname::~classname() {       // define in .cpp
    statements;
}
```

- **destructor**: Code that manages the deallocation of an object.
  - usually not needed if the object has no pointer fields
  - called by `delete` and when a stack object goes out of scope
  - the default destructor frees the object's memory, but no pointers
    - Java has a very similar feature to destructors, called a *finalizer*

Destructor example

```
// LineSegment.h
class LineSegment {
    private:
        Point* p1;
        Point* p2;

    public:
        LineSegment(int x1, int y1, int x2, int y2);
        double getX1() const;
        ...
        ~LineSegment();
};

// LineSegment.cpp
LineSegment::~LineSegment() {
    delete p1;
    delete p2;
}
```

Shallow copy bug

- A subtle problem occurs when we copy `LineSegment` objects:

```
LineSegment line1(0, 0, 10, 20);
LineSegment line2 = line1;
line2.translate(5, 3);
cout << line1.getX2() << endl;    // 15 !!!
```

- When you declare one object using another, its state is copied
  - it is a *shallow copy*; any pointers in the second object will store the same address as in the first object (both point to same place)
  - if you change what's pointed to by one, it affects the other
- even worse: the same p1, p2 above are freed twice!

Copy constructors

- **copy constructor**: Copies one object's state to another.
  - called when you assign one object to another at declaration

    ```
    LineSegment line2 = line1;
    ```

  - can be called explicitly (same behavior as above)

    ```
    LineSegment line2(line1);
    ```

  - called when an object is passed as a parameter

    ```
    foo(line1);       // void foo(LineSegment l)...
    ```

- if your class doesn't have a copy constructor,
  - the default one just copies all members of the object
  - if any members are objects, it calls their copy constructors
    - (but not pointers)

Copy constructor syntax

```
public:
    classname(const classname& rhs);   // declare in .h


classname::classname(const classname& rhs) {
    statements;                        // define in .cpp
}
```

- in the copy constructor's body, do anything you need to do to properly copy the object's state

Copy constructor example

```
// LineSegment.h
class LineSegment {
    private:
        Point* p1;
        Point* p2;

    public:
        LineSegment(int x1, int y1, int x2, int y2);
        LineSegment(const LineSegment& line);
        ...


// LineSegment.cpp
LineSegment::LineSegment(const LineSegment& line) {
    p1 = new Point(line.getX1(), line.getY1());   // deep-copy
    p2 = new Point(line.getX2(), line.getY2());   // both points
}
```

Assignment bug

- Another problem occurs when we assign `LineSegment` objects:

```
LineSegment line1(0, 0, 10, 20);
LineSegment line2(9, 9, 50, 80);
...
line2 = line1;
line2.translate(5, 3);
cout << line1.getX2() << endl;    // 15 again !!!
```

- When you assign one object to another, its state is copied
  - it is a *shallow copy*; if you change one, it affects the other
  - assignment with = does NOT call the copy constructor (why not?)
- we wish the = operator behaved differently...

Overloading =

```
// LineSegment.h
class LineSegment {
    private:
        Point* p1;
        Point* p2;
        void init(int x1, int y1, int x2, int y2);

    public:
        LineSegment(int x1, int y1, int x2, int y2);
        LineSegment(const LineSegment& line);
        ...
        const LineSegment& operator=(const LineSegment& rhs);
...
```

Overloading = , cont'd.

```
// LineSegment.cpp
void LineSegment::init(int x1, int y1, int x2, int y2) {
    p1 = new Point(x1, y1);   // common helper init function
    p2 = new Point(x2, y2);
}
LineSegment::LineSegment(int x1, int y1, int x2, int y2) {
    init(x1, y1, x2, y2);
}

LineSegment::LineSegment(const LineSegment& line) {
    init(line.getX1(), line.getY1(), line.getX2(), line.getY2());
}

const LineSegment& LineSegment::operator=(const LineSegment& rhs) {
    init(rhs.getX1(), rhs.getY1(), rhs.getX2(), rhs.getY2());
    return *this;   // always return *this from =
}
```

An extremely subtle bug

- if your object was storing pointers to two Points p1, p2 but is then assigned to have new state using =, the old pointers will leak!

- the correction:

```
const LineSegment& LineSegment::operator=(const LineSegment& rhs) {
    delete p1;
    delete p2;
    init(rhs.getX1(), rhs.getY1(), rhs.getX2(), rhs.getY2());
    return *this;   // always return *this from =
}
```

Another subtle bug

- if an object is assigned to itself, our = operator will crash!

```
LineSegment line1(10, 20, 30, 40);
...
line1 = line1;
```

- the correction:

```
const LineSegment& LineSegment::operator=(const LineSegment& rhs) {
    if (this != &rhs) {
        delete p1;
        delete p2;
        init(rhs.getX1(), rhs.getY1(), rhs.getX2(), rhs.getY2());
    }
    return *this;   // always return *this from =
}
```

Recap

`Point p1;`	calls 0-argument constructor
`Point p2(17, 5);`	calls 2-argument constructor
`Point p3 = p2;`	calls copy constructor
`Point p4(p3);`	calls copy constructor
`foo(p4);`	calls copy constructor
`p4 = p1;`	calls operator =

- When writing a class with pointers as fields, you must define:
  - a destructor
  - a copy constructor
  - an overloaded operator =

conclusion: C++ blows.