CS100 Recitation 7

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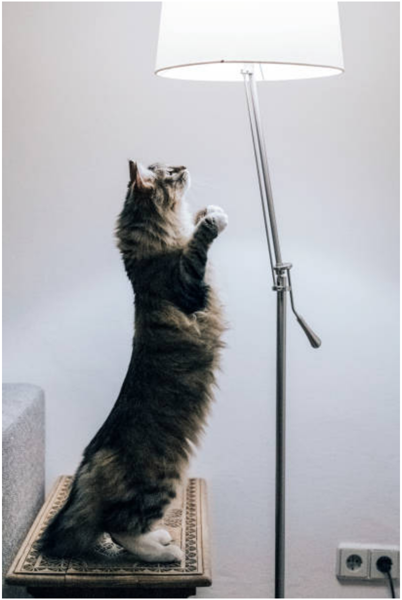
Content

Drawbacks of a Simple `struct`

Take the `Linked_list` as an example:

- Users can directly access and modify the structure of the list, **without letting the list know!**
- Even though methods of 'create' and 'destroy' are provided, memory management is still a problem because users may forget to call them (or fail to call them correctly).
- The name of every function starts with '`linked_list`', which is lengthy and inconvenient.



Separate Implementation Details and Interfaces

```
struct Point2d {
 private:
  // implementation details
  double x, y;
 public:
  // interfaces
  void set_x(double new_x)
    { x = new_x; }
  void set_y(double new_y)
    { y = new_y; }
  double get_x()
    { return x; }
  double get_y()
    { return y; }
};
```

Access modifiers:

- `private`: Only the code inside the class (or in a `friend`) can access.
- `public`: Everyone can access.
- `protected`: Only the code inside the class or in a subclass, or in a `friend` can access.

Separate Implementation Details and Interfaces

- Implementation details should be invisible to others.
- Interafces are defined for others to use.

```
// In C++, we can directly use the name Point2d without the
    struct keyword.
// The weird typedefs are not needed, either.
Point2d p;
p.x = 4.2;  // Error!
p.set_x(4.2);
p.set_y(3.5);
std::cout << "(" << p.get_x() << ", "
          << p.get_y() << ")" << std::endl;
```

Content

class or struct ?

In C++, **the only differences** between class and struct are

- Default access level for a class is private, while for a struct is public.

```
class Point {
  double x, y; // private here
  // Other members.
};
```

```
struct Point {
  double x, y; // public here
  // Other members.
};
```

- Default inheritance protection level for a class is private, while for a struct is public.

const Member Functions

```
void print_point(const Point2d &p) {
  std::cout << "(" << p.get_x() << ", "
            << p.get_y() << ")" << std::endl;
}
```

- The parameter should be declared as `const` reference, since it is not modified.
- However, the code above won't compile.
- We need to specify what we can do on `const` objects.

const Member functions

```
struct Point2d {
 private:
  double x, y;
 public:
  void set_x(double new_x)
    { x = new_x; }
  void set_y(double new_y)
    { y = new_y; }
  double get_x() const
    { return x; }
  double get_y() const
    { return y; }
};
```

- On a non-`const` object, both `const` members and non-`const` members can be called.
- On a `const` object, only the `const` members can be called.
- A `const` member function should not modify the data members.

Use `const` whenever possible!

The this Pointer

Inside a member function, when we refer to the name of a member, we are in fact referring to it through the this pointer.

```
class Point2d {
  double x, y;
 public:
  void set_x(double new_x) {
    this->x = new_x;    // equivalent to x = new_x;
  }
  // Other members.
};
```

- this is a pointer that points to the object itself. For example, in 'class Point2d', this is of type Point2d *.

Name Lookup in `class`

An exception to the name lookup rule:

- Inside a `class`, all the class members are visible, no matter they are before or after the usage.

```
class Point2d {
 public:
  void set_x(double new_x)
    { x = new_x; }      // OK: The member 'x' is visible here.
  void set_y(double new_y)
    { y = new_y; }
  double get_x() const
    { return x; }
  double get_y() const
    { return y; }
 private:
  double x, y;
};
```

Defining Member Functions outside the class

A member function can be defined outside the class definition, **but must be declared inside the class**.

```
class Point2d {
 public:
  void set_x(double new_x) {
    x = new_x;
  }
  void set_y(double new_y) {
    y = new_y;
  }
  double get_x() const;
  double get_y() const;
 private:
  double x, y;
};
```

- Use operator:: to refer to a name in the class scope.

```
double Point2d::get_x() const {
  return x;
}
double Point2d::get_y() const {
  return y;
}
```

- The const keyword, if needed, must appear at both declaration and definition. It is a part of the function type.

Reference to the Object itself

```cpp
class Point2d {
 public:
  Point2d &set_x(double new_x) {
    x = new_x;
    return *this;
  }
  Point2d &set_y(double new_y) {
    y = new_y;
    return *this;
  }
  // Other members.
};
```

- `set_x` and `set_y` returns a reference to the object itself (which is an lvalue) by `return *this;`
- Then we can do:

  `p.set_x(4.2).set_y(3.5);`

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Constructors

Constructors ('ctors' for short) define the ways of initializing an object.

```
class Point2d {
 public:
  Point2d(double a, double b)
    : x(a), y(b) {}
  Point2d() : x(0), y(0) {}
  // Other members.
};
```

```
// Initializing a Point2d object
     with x = 3.5, y = 4.2
Point2d p1(3.5, 4.2);
// Default-initialization calls
    the default ctor with no
    arguments.
Point2d p2;
// p2 is initialized with x = 0,
     y = 0.
```

Constructors

- The name of a ctor is name of the class.
- The return-type is omitted, because a construction expression always returns the constructed object. The following statement will output `4.2`.

```
std::cout << Point2d(4.2, 3.5).get_x() << std::endl;
```

- There is a **constructor initializer list** after the parameters, starting with '`:`', containing explicit initialization of several data members, separated with commas.
- The constructors are often overloaded, i.e. we may define several different ways of initialization.

The Ctor Initializer List

The most important part of a ctor is the **initializer list**.

- The ctor-init-list is the part where data members are initialized.
- **All the data members** will be initialized before the function body begins, **in the order in which they appear in the class definition**.
- If a data member does not appear in the ctor-init-list, it is **default-initialized**.
  - For built-in types, default-initialization makes the object hold an undefined value.
  - For class types, default-initialization is calling the **default-ctor** of that class.

Ctor-init-list: Examples

- The following ctor is **bad**: (It is default-initializing the members, and then assigning values to them.)

```
Point2d(double a, double b) {
  x = a;
  y = b;
}
```

- The following ctor is **misleading**:

```
Point2d(double a, double b) : y(b), x(a) {}
```

- The following ctor first default-initializes `x`, and then initializes `y` with given value.

```
Point2d(double b) : y(b) {}
```

Ctor-init-list: Examples

A typical bug I made (years ago):

```
class Snake_game {
  std::vector foods;
  size_t num_food;
  // Other members
 public:
  Snake_game(size_t n, /* other args */)
    : num_food(n), foods(num_food) {}
  // Other members
};
```

Importance of Using Ctor-init-list

It is strongly suggested to use ctor-init-lists **routinely**:

- Initialize the member directly, instead of first default-initialize it and then assign it with a value.
- Some members cannot be default-initialized or cannot be assigned.

```
class Foo {
  const int x;
  int y;
 public:
  Foo(int a, int b) {
    // Error: x cannot be assigned after initialization.
    x = a;
    y = b;
  }
};
```

Default Initialization

- The **default ctor** is the ctor with no arguments. It defines the behavior when the object is **default-initialized** or **value-initialized**.
- The following code outputs '`Liu Big God is so strong.`'.

```
class Point2d {
 public:
  Point2d() : x(0), y(0) {
    std::cout << "Liu Big God is so strong.\n"
  }
  // Other members.
};
// in main
Point2d p;
```

Default Initialization

```
class Line2d {
  Point2d p0, v;
 public:
  Line2d()
    { std::cout << "Liu Big God is so powerful.\n" }
  // Other members.
};
```

What's the output of the following code (inside the `main` function)?

```
Line2d line;
```

```
Liu Big God is so strong.
Liu Big God is so strong.
Liu Big God is so powerful.
```

Have a Try

Define a class `Vector`:

- Define the data members `m_size`, `m_capacity` and `m_data`, denoting the number of elements stored, the maximum possible size of the current storage, and a pointer to the storage.
  - The prefix `m_` means 'member'.
- Define a default-ctor that initializes the Vector to an empty Vector, i.e. `m_size = 0`, `m_capacity = 0`, `m_data = nullptr`.
- Define a ctor that receives an unsigned number `n`, which initializes the Vector to be holding `n` value-initialized `int`s.
- Define a ctor that receives two pointers `begin` and `end` pointing to the beginning and the pass-end of an array. The ctor copies the values from the range of the array.

Constructors

```
class Vector {
  size_t m_size, m_capacity;
  int *m_data;
 public:
  Vector() : m_size(0), m_capacity(0), m_data(nullptr) {}
  Vector(size_t n) : m_size(n), m_capacity(n),
    m_data(new int[n]()) {}
  Vector(int *begin, int *end)
    : m_size(end - begin), m_capacity(end - begin),
      m_data(new int[end - begin]()) {
    for (int *p = m_data; begin != end; ++begin, ++p)
      *p = *begin;
  }
};
```

nullptr

- In C, the null pointer `NULL` is defined to be of type `void *`, so that it can be converted to any pointer type.
- However, C++ does not allow implicit conversion from `void *` to other pointer types. It's possible that `NULL` is defined as `(long)0`.
  - C++ allows initialization of a pointer with integral literal `0`, but not other values.
- Since C++11, we use `nullptr` as a well-defined null pointer. It is of type `std::nullptr_t`, a type defined in `<cstddef>`. (`stddef.h` does not have this!)

`new` and `delete`

- Roughly speaking, `new` and `delete` are like the C++ version of `malloc` and `free`: They allocate memory on heap.
- `new` not only **allocates the memory**, but also **constructs the object**.
- `delete` first **destructs the object**, and then **deallocates (frees) the memory**.
- `new` and `delete` will call the ctor and dtor of the type, while `malloc` and `free` won't!
- When you have some object on heap in C++, **NEVER use** `malloc/calloc/realloc/free`. You should always use `new` and `delete` .

new and delete

```cpp
int *pi = new int;                  // default initialization
int *pi2 = new int();               // value initialization
int *pia = new int[10];             // default initialization
int *pia2 = new int[10]();          // value initialization
int *pia3 = new int[10]{1, 2, 3}; // First three values: 1, 2, 3
                                    // Others: value initialization
// call Point2d::Point2d(double, double)
Point2d *p = new Point2d(3, 4);
// call Point2d::Point2d()
Point2d *p2 = new Point2d;
// call Point2d::Point2d()
Point2d *p3 = new Point2d();
```

Initialization in `new`

- Whenever the explicit initializer is absent, default initialization is performed.
- Whenever an explicit initializer is provided but as an empty pair of parentheses, value initialization is performed.
- For a class type **with a user-defined default ctor**, both default initialization and value initialization call the default ctor.

The rules for initialization are **very complicated**. Now you only need to know these that are listed above.

new and delete

- To destroy the object created by `new` and free the memory, use `delete` .

```
int *pi = new int();
// after some operations
delete pi;
```

- For an array type, use `delete[]`.

```
int *pia = new int[10]();
// after some operations
delete[] pia;
```

- `delete` will call the destructor of a class type. (We will talk about destructors later.)

In-class Initializer

- An in-class initializer is used to define the default value for a member.
- When a member with an in-class initializer is default initialized or value initialized, it will be initialized with the in-class initializer.

```
class Point2d {
  double x = 0, y = 0;
  // Other members.
};

class Line2d {
  // Curly braces are allowed
     here since C++11.
  Point2d p0{0, 0}, v{1, 1};
  // Other members.
};
```

In-class Initializer

Due to the limitation of compilers (you will learn about it in CS131), parentheses are not allowed in in-class initializer: They will be viewed as function declarations!

```
class Line2d {
  // Error: They are seen as function declarations.
  Point2d p0(0, 0), v(1, 1);
  int foo(); // Exactly a member function declaration.
  // Other members.
};
```

Synthesized Default Ctor

The compiler will generate a default ctor if the following conditions are satisfied:

- Each member without a in-class initializer is default-initializable, and
- There is no user-defined ctors, or the default ctor is defined as `=default`.

Many kinds of members are not default-initializable, e.g. a reference, or a class type member whose class does not have accessible default ctor.

Synthesized Default Ctor

The synthesized default ctor will

- initialize a member with the in-class initializer, if it has an in-class initializer.
- Otherwise, it will default-initialize the member.

Delegating Ctor

Since C++11, a ctor can delegate part or all of its work to another ctor:

```
class Point2d {
  double x, y;
 public:
  Point2d() : Point2d(0, 0) {
    std::cout << "default ctor body\n";
  }
  Point2d(double a, double b) : x(a), y(b) {
    std::cout << "Point2d(double, double) body\n";
  }
};
// in main
Point2d p;
```

The above code outputs "`Point2d(double, double) body`" first, and then "`default ctor body`".

Example

```cpp
class Vector {
  size_t m_size = 0, m_capacity = 0;
  int *m_data = nullptr;
 public:
  // explicitly require a synthesized default ctor
  Vector() = default;
  Vector(size_t n) : m_size(n), m_capacity(n),
    m_data(new int[n]()) {}
  // delegate to Vector::Vector(size_t)
  Vector(int *begin, int *end) : Vector(end - begin) {
    for (int *p = m_data; begin != end; ++begin, ++p)
      *p = *begin;
  }
};
```

Content

Destructor

Definition (Destructor)

Destructor ('dtor' for short) is a member function which is called automatically when the object is destroyed.

Several typical cases:

- When control flow reaches the end of the scope of a local object.
- When the object (if it is `new`ed) is `delete`d.
- When an exception happens...

Define a Dtor

- A dtor does not return a value. The value-type is omitted.
- The name of a dtor is `~`*class-name*. E.g. `~Point2d`.
- The dtor is unique and cannot be overloaded. A dtor receives no arguments.
- The function body of the dtor does the work that needs to be done when an object is destroyed, e.g. frees the resources or output something.
- **After the function body is executed**, the members are destroyed by calling their own dtors, **in reverse order** from the order in which they are declared.

Define a Dtor

The dtor of the `Point2d` class doesn't need to do anything.

```
class Point2d {
 public:
  ~Point2d() {}
  // Other members.
};
```

The dtor of `Vector` should free the memory it holds.

```
class Vector {
 public:
  ~Vector() { delete[] m_data; }
  // Other members.
};
```

Access Level of Ctors and Dtors

- The access restrictions also apply to ctors and dtors. For example, a `private` ctor can only be accessed inside the class or in its `friend`s.
- At any part of the code, if the **dtor** of a class is invisible, then **constructing** an object of such type is not allowed. (If an object is not destructible, then it is not constructible.)

Synthesized Dtors

- If there is no user-defined dtor, the compiler will generate one by default.
- The synthesized dtor is
  - `public`,
  - with an empty function body,
  - non-virtual,
  - and implicitly `noexcept`.

Destructing Order

```
class Point2d {
 public:
  ~Point2d() {
    std::cout<< "Point dtor.\n";
  }
  // Other members.
};
class Line2d {
  Point2d p0{0, 0}, v;
 public:
  ~Line2d() {
    std::cout << "Line dtor.\n";
  }
  // Other members.
};
```

What's the output of the following code?

```
int main() {
  Point2d *p = new Point2d();
  delete p;
  Line2d l;
  return 0;
}
```

Content

Further Reading

- Effective C++ Item 18: Make interfaces easy to use correctly and hard to use incorrectly.
  - Read until the `class Month` example (about two pages). The rest part is not for you now.
- Effective C++ Item 22: Declare data members private.