deep se
dependable evolvable pervasive software engineering group

Classes

08/10/2024

Danilo Ardagna

Politecnico di Milano

danilo.ardagna@polimi.it

POLITECNICO DI MILANO

Content

- Classes and Structs
- `this`
- Operators

Classes

- User-defined type, specifies a blueprint for objects
- Consists of a set of members
  - data members
  - member functions (methods)
- Member functions can define the meaning of creation (constructor), initialization, assignment, copy, and cleanup (destruction)

Classes – C++ general syntax

```
class X {// this class' name is X
public:// public members -- that's the interface to users
        //  (accessible by all)
        // functions
        // types
        // data (often best kept private!)

private:// private members -- that's the implementation details
        // (accessible by members of this class only)
        // functions
        // types
        // data
};
```

Classes

- Members are accessed using **.** (dot) for objects and **->** (arrow) for pointers
- Operators, such as **+**, **!**, and **[]**, can be defined
- The **public** members provide the class interface and the **private** members provide implementation details

Classes

Class members are private by default:

```
class X {
        int mf();
        // …
};
```

is equivalent to

```
class X {
private:
        int mf();
        // …
};
```

So

```
X x;                    // variable x of type X
X *px = &x;             // pointer to type X

int y = x.mf();// error: mf is private (i.e., inaccessible)
int w = (*px).mf();// error: mf is private (i.e., inaccessible)
int z = px->mf();// error: mf is private (i.e., inaccessible)
```

The syntax is correct, but the method is private

Structs vs. Classes

A struct in C++ is a class where members are public by default:

```
struct X {
        int m;
        // …
};
```

is equivalent to 

```
class X {
public:
        int m;
        // …
};
```

Question to answer today

- Which are the benefits of public/private?
- When shall we use a Class and when a Struct?
- Running example: let's implement a *Date* data structure

Public/private benefits

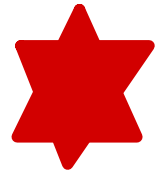
- Why bother with the public/private distinction?
- Why not make everything public?
  - To provide a clean interface
    - Data and messy functions can be made private
  - **To allow a change of representation**
    - You need only to change a fixed set of functions
    - You don't really know who is using a public member

you change internally the code (i.e private)

If internal representation is hidden (**information hiding** principle)
- It is easier to support code evolution
- We can change the internals without changing the remaining code

cont'd

Public/private benefits



- Why bother with the public/private distinction?
- Why not make everything public?
  - To provide a clean interface
    - Data and messy functions can be made private
  - **To allow a change of representation**
    - You need only to change a fixed set of functions
    - You don't really know who is using a public member
  - To ease debugging
    - (known as the "round up the usual suspects" technique)
  - **To maintain an invariant**

Invariants → A rule allowing to tell if an object is valid or not.

- Example of Date:
  - The notion of a “valid Date” is an important special case of the idea of a valid value

- We try to design our types so that values are guaranteed to be valid
  - or we have to check for validity all the time

- A rule for what constitutes a valid value is called an “**invariant**”
  - The invariant for Date (“a Date must represent a date in the past, present, or future”) is unusually hard to state precisely
  - Remember February 28, leap years, etc.

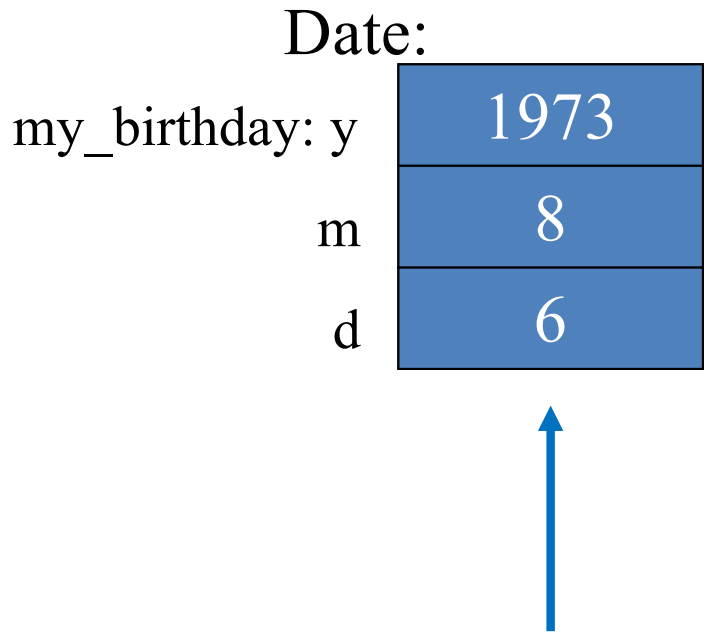
Invariants

As a principle, the teacher never uses struct.

- If we **can't think of a good invariant**, we are probably dealing with **plain data**
  - if so, use a `struct`

- Try hard to **think of good invariants** and use classes
  - that saves you from poor buggy code

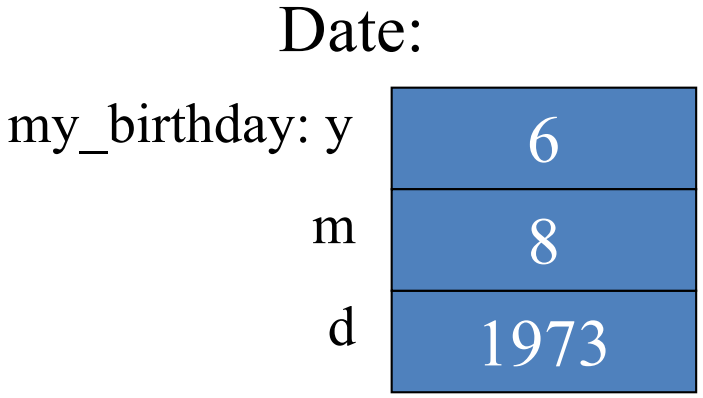
Structs



// simplest Date (just data)

```
struct Date {
  int y,m,d; // year, month, day
};

Date my_birthday; // a Date variable (object)

my_birthday.y = 1973;
my_birthday.m = 6;
my_birthday.d = 8;
```

Structs




```
// simplest Date (just data)
struct Date {
  int y,m,d; // year, month, day
};

Date my_birthday; // a Date variable (object)

my_birthday.y = 6;
my_birthday.m = 8;
my_birthday.d = 1973;
```

```
// oops! (no day 1973 in month 8)
// later in the program, we'll have a
// problem
```

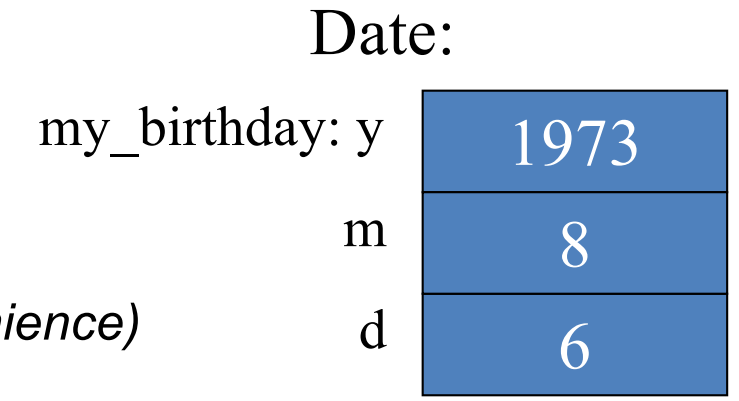
Here we are clearly breaking the invariant ...

we can create a method to check the validity of dates.

Structs – C version

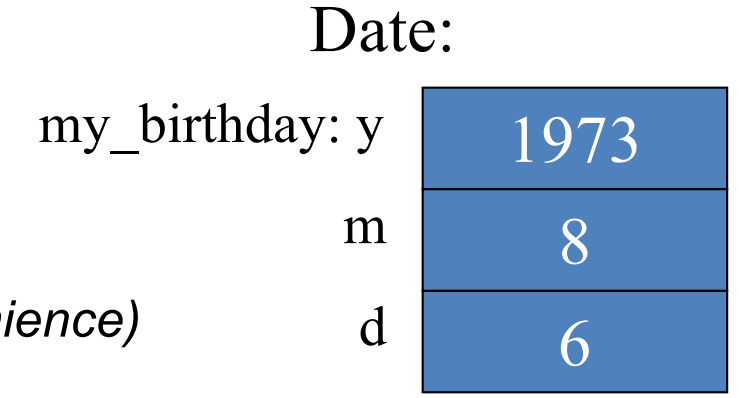
```
// simple Date (with a few helper functions for convenience)
struct Date {
  int y,m,d;   // year, month, day
};

Date my_birthday;  // a Date variable (object)

// helper functions:

void init_day(Date& dd, int y, int m, int d);
        // check for valid date and  Initialize
        // Note: this y, m, and d are local

void add_day(Date& dd, int n);
        // increase the Date by n days

init_day(my_birthday, 6, 8, 1973);// run time error: no day 1973 in month 8
```

Structs – C version




```
// simple Date (with a few helper functions for convenience)
struct Date {
  int y,m,d;   // year, month, day
};

Date my_birthday;  // a Date variable (object)

// helper functions:

void init_day(Date& dd, int y, int m, int d);
        // check for valid date and  Initialize
        // Note: this y, m, and d are local

void add_day(Date& dd, int n);
        // increase the Date by n days

init_day(my_birthday, 1973, 6, 8);
```

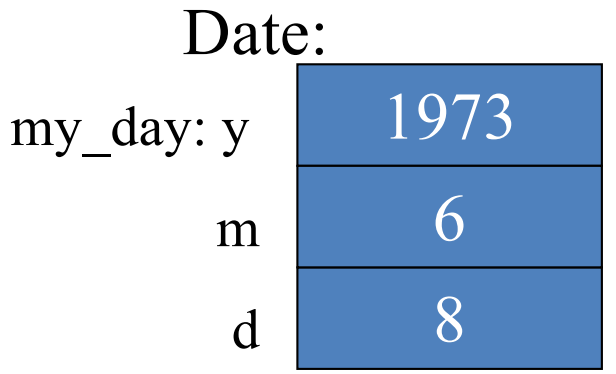
Structs – C version




```
// simple Date (with a few helper functions for convenience)
struct Date {
  int y,m,d;   // year, month, day
};

Date my_birthday;  // a Date variable (object)

// helper functions:

void init_day(Date& dd, int y, int m, int d);
        // check for valid date and  Initialize
        // Note: this y, m, and d are local

void add_day(Date& dd, int n);
        // increase the Date by n days

init_day(my_birthday, 1973, 6, 8);
```

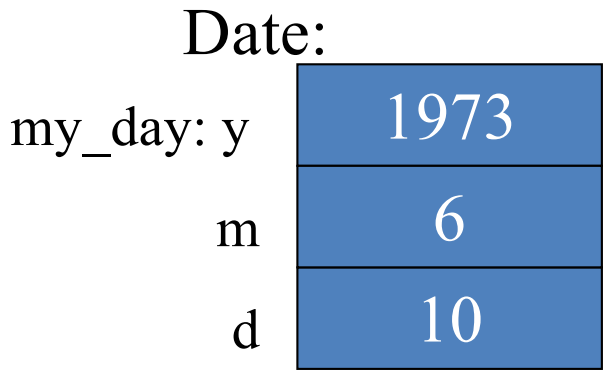
{ check validity

Structs – C++ v. 0.1



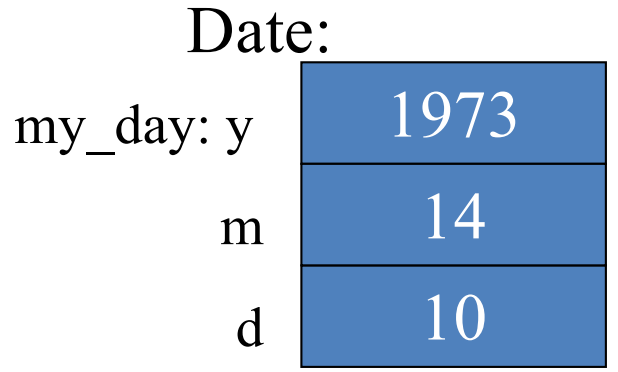

```
// simple Date
//        guarantee initialization with constructor
//        provide some notational convenience
struct Date {
  int y,m,d;   // year, month, day
  Date(int y, int m, int d);     // constructor: check for valid
                                 // date and initialize
  void add_day(int n); // increase the Date by n days
};

// ...
Date my_birthday(8, 6, 1973); // oops! Runtime error
Date my_day(1973, 6, 8);      // ok
```

Structs – C++ v. 0.1




```
// simple Date
//        guarantee initialization with constructor
//        provide some notational convenience
struct Date {
  int y,m,d;   // year, month, day
  Date(int y, int m, int d);     // constructor: check for valid
                                 // date and initialize
  void add_day(int n); // increase the Date by n days
};

// ...
Date my_birthday(8, 6, 1973); // oops! Runtime error
Date my_day(1973, 6, 8);      // ok
my_day.add_day(2);            // June 10, 1973
```

Structs – C++ v. 0.1



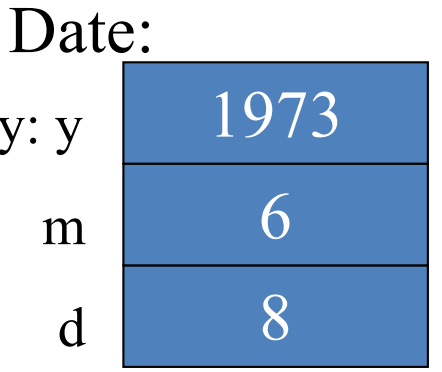

```
// simple Date
//        guarantee initialization with constructor
//        provide some notational convenience
struct Date {
  int y,m,d;   // year, month, day
  Date(int y, int m, int d);     // constructor: check for valid
                                 // date and initialize
  void add_day(int n); // increase the Date by n days
};

// ...
Date my_birthday(8, 6, 1973); // oops! Runtime error
Date my_day(1973, 6, 8);      // ok
my_day.add_day(2);            // June 10, 1973
my_day.m = 14;                // ouch! (now my_day is a
                              // bad date)
```

Let's use classes instead

Why structs are bad

We can write this since we have only public methods!!

Classes – C++ v. 0.2




```
// simple Date (control access)
class Date {
  int y,m,d;              // year, month, day
public:
  Date(int y, int m, int d); // constructor: check for valid date
                             // and initialize
  void add_day(int n);       // increase the Date by n days
  int month() const { return m; } //  access functions:
  int day() const { return d; }
  int year() const { return y; }
};

// …
Date my_birthday(1973, 6, 8);   // ok
cout << my_birthday.month() << endl; // we can read
my_birthday.m = 14;  ——————→ // error: Date::m is private
```

Classes

```
// simple Date (some people prefer implementation details last)
class Date {
public:
    Date(int yy, int mm, int dd); // constructor: check
                                  // for valid date and initialize
    void add_day(int n);          // increase the Date by n days
    int month() const;
    // …
private:
    int y,m,d;      // year, month, day
};
```

```
Date::Date(int yy, int mm, int dd)  // definition; note :: member of"
  :y(yy), m(mm), d(dd) {/* … */};// note: member initializers
void Date::add_day(int n) { /* … */};    // definition
```

Classes

Date.h (or Date.hh or Date.hpp)

```
// simple Date (some people prefer implementation details last)
class Date {
public:
    Date(int yy, int mm, int dd); // constructor: check
                                  // for valid date and initialize
    void add_day(int n);          // increase the Date by n days
    int month() const;
    // …
private:
    int y,m,d;      // year, month, day
};
```

```
Date::Date(int yy, int mm, int dd)  // definition; note :: member of"
  :y(yy), m(mm), d(dd) {/* … */};// note: member initializers
void Date::add_day(int n) { /* … */};    // definition
```

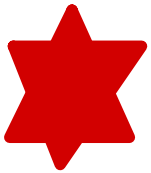
Classes

```
// simple Date (some people prefer implementation details last)
class Date {
public:
    Date(int yy, int mm, int dd); // constructor: check
                                  // for valid date and initialize
    void add_day(int n);          // increase the Date by n days
    int month() const;
    // …
private:
    int y,m,d;      // year, month, day
};
```

```
Date::Date(int yy, int mm, int dd)  // definition; note :: member of"
  :y(yy), m(mm), d(dd) {/* … */};// note: member initializers
void Date::add_day(int n) { /* … */};    // definition
```

Date.cpp

Classes



```
// simple Date (some people prefer implementation details last)
class Date {
public:
    Date(int yy, int mm, int dd); // constructor: check
                                  // for valid date and initialize
    void add_day(int n);          // increase the Date by n days
    int month() const;
    // …
private:
    int y,m,d;      // year, month, day
};
```

```
int month() { return m; }   // error: forgot Date::
// this month() will be seen as a global function not the member function, so can't access
// members
int Date::season(){/*…*/}// error: no member season
```

See the exercise notes for the full implementation of Date class.

season is not declared within class.

Date.cpp

this

`this`

Date my_birthday (1973, 6, 8);

int m1 = my_birthday.month();

- Here we use the dot operator to run month() on the object named my_birthday
- With the exception of `static` members, **when we call a member function we do so on behalf of an object**
- When month() refers to members of Date (e.g., m), it is referring implicitly to the members of the object on which the function was called. In this call, when **month()** returns m, it is implicitly returning **my_birthday.m**

this

- Member functions access the object on which they were called through an extra, implicit parameter named **this**
- When we call a member function, **this is initialized with the address of the object on which the function was invoked**. For example, when we call

```
my_birthday.month();
```

- the compiler passes the address of `my_birthday` to the implicit **this** parameter. It is as if the compiler rewrites this call as

```
// pseudo-code illustration of how a call to a member function is translated
int Date::month(Date * this)
```

That's what happens implicitly.

```
Date::month(&my_birthday)
```

- which calls the `month` member of `Date` passing the address of `my_birthday`

this

- Inside a member function, we can refer directly to the members of the object on which the function was called

- Any direct use of a member of the class is assumed to be an implicit reference through `this`. That is, **when `month()` uses `m`**, it is implicitly using the member to which this points. It is as if we had **written `this->m`**

`this`

- The `this` parameter **is defined for us implicitly**:
  - It is illegal for us to define a parameter or variable named *this*
  - Inside the body of a member function, we can use `this`
    - It would be legal, although unnecessary, to define month() as

```
int month() { return this->m; }
```

because this is intended to always refer to “this” object

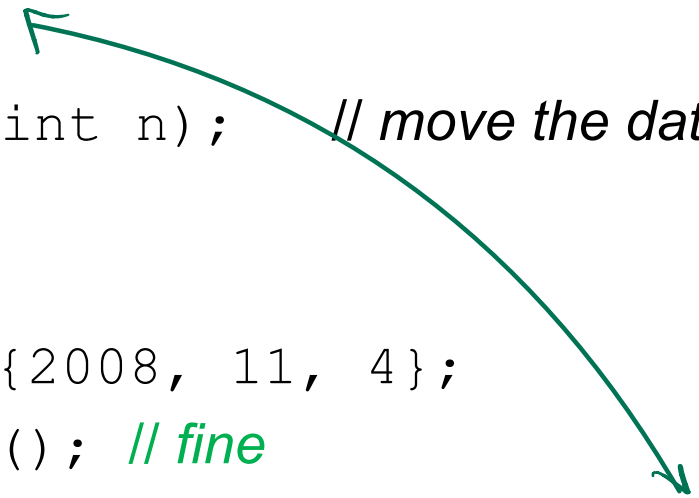
- `this` is a **const pointer**, we cannot change the address that `this` holds

DEMO

More on `const`

Const member functions

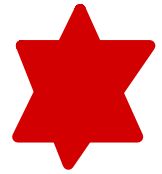
```
// Distinguish between functions that can modify (mutate) objects
// and those that cannot ("const member functions")
class Date {
public:
  // …
  int day() const; // get (a copy of) the day
  // …
  void add_day(int n);     // move the date n days forward
  // …
};
const Date dx {2008, 11, 4};
int d = dx.day(); // fine
dx.add_day(4);      // error: can't modify constant (immutable) date
```



Const member functions

```
Date d (2004, 1, 7);              // a variable
const Date d2 (2004, 2, 28);      // a constant
d2 = d;                           // error: d2 is const
d2.add(1);                        // error: d2 is const
d = d2;                           // fine
d.add(1);                         // fine
```

Classes: What makes a good interface?



- Minimal
  - As small as possible
- Complete
  - And no smaller
- Invariant preserving
  - Invariants hold from object creation (i.e., constructors!) and for every operation performed (non-const methods!)
- `const` correct

Interfaces and “helper functions”

- Keep a class interface (the set of public functions) minimal
  - Simplifies understanding
  - Simplifies debugging
  - Simplifies maintenance

- When we keep the class interface simple and minimal, we need extra “helper functions” outside the class (non-member functions)
  - `next_weekday()`, `next_Sunday()`
  - `==` (equality) , `!=` (inequality)

Helper functions

```
Date next_Sunday(const Date& d)
{
  // access d using d.day(), d.month(), and d.year()
  // make new Date to return
}

Date next_weekday(const Date& d) { /* … */ }

bool operator==(const Date& a, const Date& b)
{
  return a.year()== b.year()
      && a.month()== b.month()
      && a.day()== b.day();
}

bool operator!=(const Date& a, const Date& b) {
  return !(a==b); }
```

y is private so we need .year().

"operator overloading": we redefine operator "==" for Date datatype.

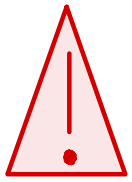
Helper functions

```
Date next_Sunday(const Date& d)
{
  // access d using d.day(), d.month(), and d.year()
  // make new Date to return
}

Date next_weekday(const Date& d) { /* … */ }

b
{
        && a.day()== b.day();
}

bool operator!=(const Date& a, const Date& b) {
  return !(a==b); }
```

- Declare helper functions in the Class header
- Define helper function in the Class source (.cpp) file

Operators

Operator overloading



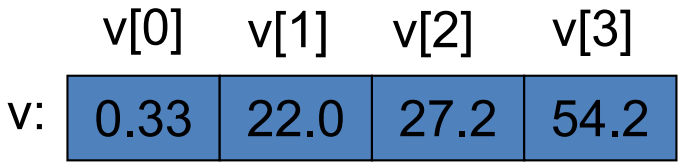
- You can define only existing operators
  - E.g., `+ - = += * / % [] () ^ ! & < <= > >=`
- You can define operators only with their conventional number of operands
  - E.g., no unary <= (less than or equal) and no binary `!` (not)
- An overloaded operator must have at least one user-defined type as operand
  - `int operator+(int,int);` // error: you can't overload built-in +
  - `Vector operator+(const Vector&, const Vector &);` // ok

Advices

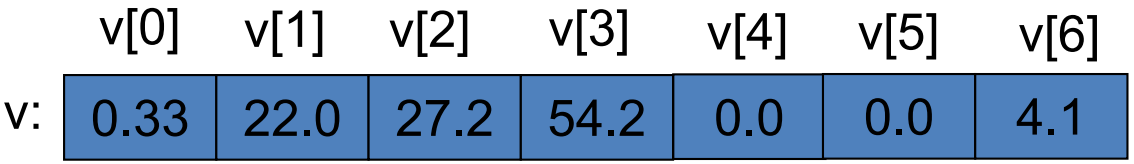
- Overload operators only with their conventional meaning
  - + should be addition, * be multiplication, [] be access, () be call, etc.
- Don’t overload unless you really have to
- Don’t overload , * && || !
  - Operand-evaluation are not preserved
  - Short circuit does not work anymore

Class example: `MatlabVector`

- We want to implement Matlab like vectors in C++
  - Implement row vectors of double type
  - Elements indexing follows the C++ convention, i.e., the first element has index 0! **(-2 points at exams otherwise!)**
  - Vectors can grow as in Matlab
    - Simplified version: a read of an element which does not exist do not return error



v[6] = 4.1



Class example: `MatlabVector`

- Goals:
  - Provide `operator+`
  - Implement the product with a scalar: `operator*`
  - Provide `operator[]` to access individual elements
  - Neglect, in the beginning, errors (e.g., vectors size do not match)

MatlabVector

```
class MatlabVector {

    vector<double> elem;

public:
    double get(size_t n); // access: read
    void set(size_t n, double v); // access: write
    size_t size() const; // return number of elements


    MatlabVector operator*(double scalar) const;
};

MatlabVector operator+(MatlabVector& v1, MatlabVector& v2);
```

DEMO

MatlabVector

```
size_t MatlabVector::size() const{

    return elem.size();

}

double MatlabVector::get(size_t n){

    while (elem.size() < n+1)
       elem.push_back(0.);

    return elem[n];
}
```

MatlabVector

```
void MatlabVector::set(size_t n, double v){

    while (elem.size() < n+1)
       elem.push_back(0.);

    elem[n] = v;
}

MatlabVector MatlabVector::operator*(double scalar) const{
    MatlabVector result;

    for (size_t i=0; i<elem.size(); ++i)
        result.set(i, scalar * elem[i]);
         // alternatively result.elem[i]=scalar * elem[i];

    return result;
}
```

MatlabVector

```
MatlabVector operator+(MatlabVector& v1, MatlabVector& v2)
{
    MatlabVector result;
    for (size_t i=0; i<v1.size(); ++i)
        result.set(i,v1.get(i) + v2.get(i));

    return result;
}
```

MatlabVector (primitive access)

```
MatlabVector v;
for (size_t i=0; i<10; ++i) {// pretty ugly:
        v.set(i,i);
        cout << v.get(i);
}

for (size_t i=0; i<10; ++i) {// we're used to this:
        v[i]=i;
        cout << v[i];
}
```

MatlabVector

(we use references for access)

```
class MatlabVector {
    vector<double> elem;
public:
    double & operator[](size_t n); // access: return reference
    size_t size() const; // return number of elements

    MatlabVector operator*(double scalar) const;
};
MatlabVector operator+(MatlabVector& v1, MatlabVector& v2);

MatlabVector v;
for (size_t i=0; i<10; ++i) {// works and looks right!
        v[i] = i;                    // v[i] returns a reference to the ith element
        cout << v[i];
}
```

MatlabVector

```
double & MatlabVector::operator[](size_t int n) {

    while (elem.size() < n+1)
        elem.push_back(0.);

    return elem[n];

}
```

08/10/2024

Operators member functions

- First operand (left hand) is bounded to this
  - They have one less explicit operator

```
class MatlabVector {

    vector<double> elem;

public:
    double & operator[](size_t n); // access: return reference
    size_t size() const; // return number of elements


    MatlabVector operator*(double scalar) const;
    MatlabVector operator+(const MatlabVector& rhs) const;
};
```

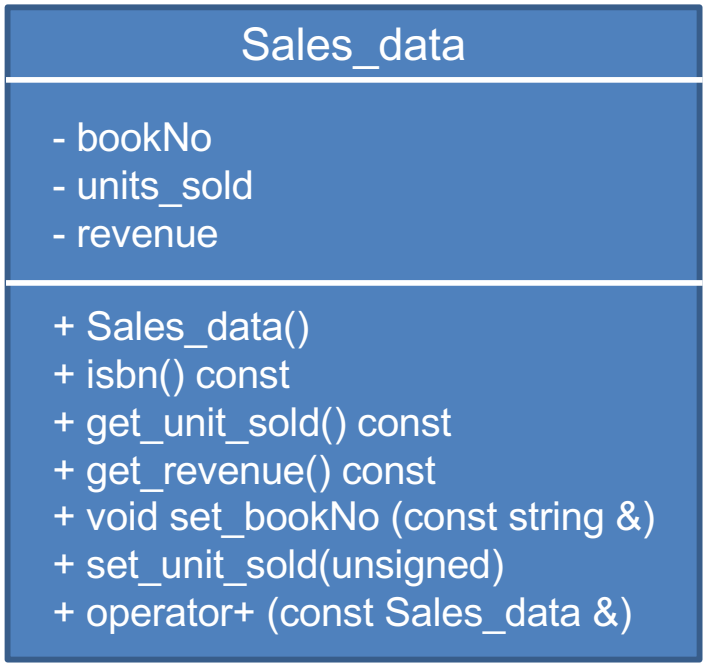
Operators member functions

- First operand (left hand) is bounded to this
  - They have one less explicit operator

```
MatlabVector operator+(const MatlabVector& rhs) const
{
    MatlabVector result;
    for (size_t i=0; i< elem.size(); ++i)
        result[i] = elem[i] + rhs.elem[i];

    return result;
}
```

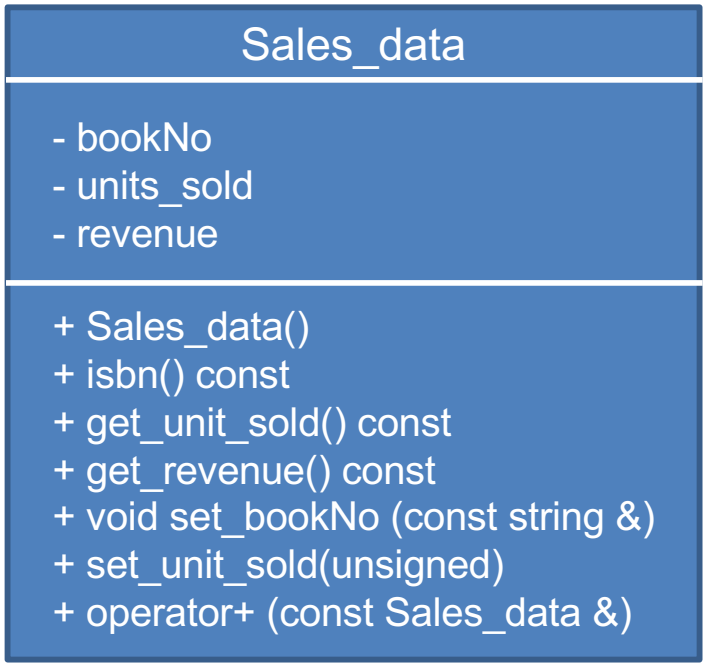
Class example: Sales_data

```
class Sales_data {
private:
    string bookNo;
    unsigned units_sold;
    double revenue;
public:
Sales_data() :
        bookNo(""),
        units_sold(0),
        revenue(0.0)
    {}
```



Class example: Sales_data

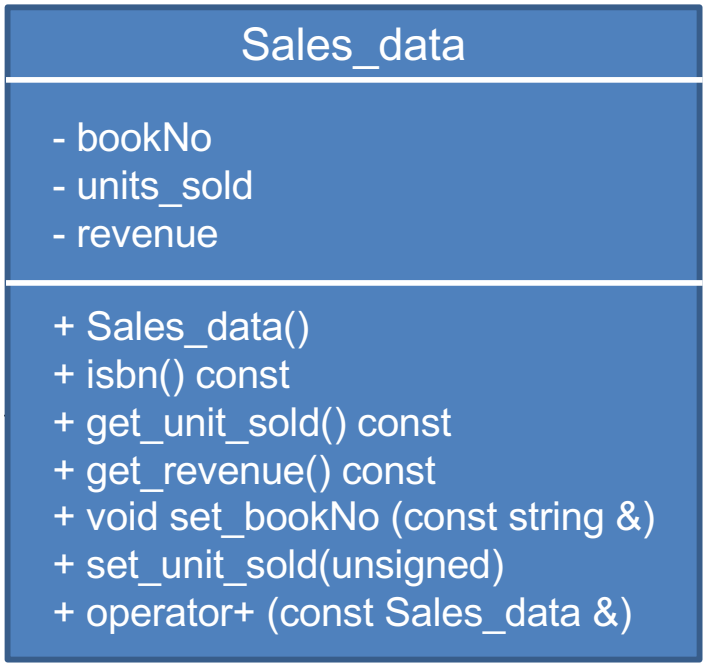
```
        /* Getters and Setters */
        string isbn() const;
        unsigned get_unit_sold() const;
        double get_revenue () const;
        void set_bookNo (const string & bn);
        void set_unit_sold(unsigned u);
        void set_revenue (double r);

};
```



Operators member functions

- First operand (left hand) is bounded to this
  - They have one less explicit operator

```
class Sales_data {
    //Other code
public:
    Sales_data operator+(const Sales_data &rhs) const;
}

Sales_data Sales_data::operator+(con
const {
    Sales_data ret;
    ret.bookNo = bookNo;
    ret.units_sold = units_sold + rhs
    ret.revenue = revenue + rhs.reven
    return ret;
}
```



Operators member functions

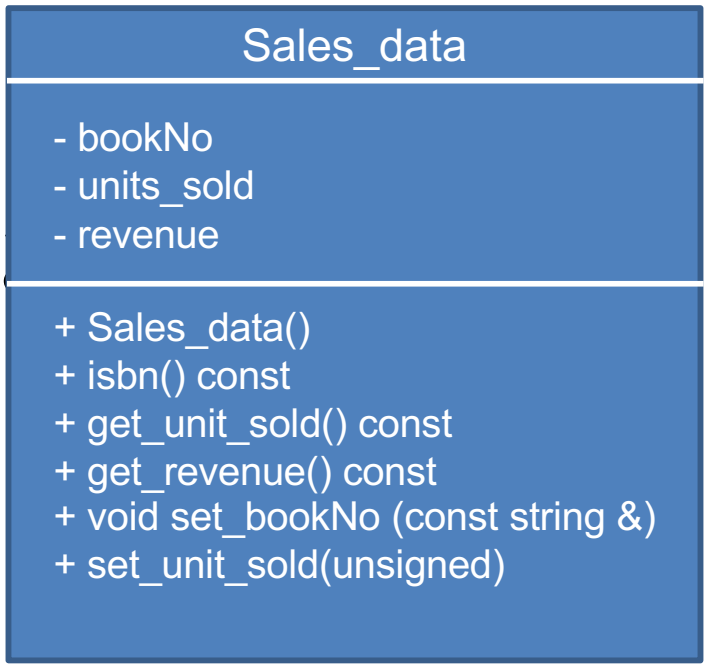
- First operand (left hand) is bounded to this
  - They have one less explicit operator

```
class Sales_data {
    //Other code
public:
    Sales_data operator+(const Sales_data &rhs) const;
}

Sales_data Sales_data::operator+(const & Sales_data rhs)
const {
    Sales_data ret;
    ret.bookNo = bookNo;
    ret.units_sold = units_sold + rhs.units_sold;
    ret.revenue = revenue + rhs.revenue;
    return ret;
}
```

Operators non-member functions

- Same number of parameters as the operator
- They need to access to all data members of type
  - Typically declared as friend, we will see how in the next class

```
Sales_data operator+(const Sales_data & lhs,
                     const Sales_data &rhs)
{
    Sales_data ret;
    ret.set_bookNo(lhs.isbn());
    ret.set_units_sold(lhs.get_units_so
                       rhs.get_units_s
    ret.set_revenue(lhs_get_revenue() +
                    rhs.get_revenue())
    return ret;
}
```



Operators non-member functions

- Same number of parameters as the operator
- They need to access to all data members of type
  - Typically declared as friend, we will see how in the next class

```
Sales_data operator+(const Sales_data & lhs,
                     const Sales_data &rhs)
{
   Sales_data ret;
   ret.set_bookNo(lhs.isbn());
   ret.set_units_sold(lhs.get_units_sold() +
                      rhs.get_units_sold());
   ret.set_revenue(lhs_get_revenue() +
                   rhs.get_revenue());
   return ret;
}
```

Operators non-member functions

- Same number of parameters as the operator
- They need to access to all data members of type
  - Typically declared as friend, we will see how in the next class

```
Sales_data operator+(const Sales_data & lhs,
                     const Sales_data &rhs)
{
   Sales_data ret;
   ret.set_bookNo(lhs.isbn());
   ret.set_units_sold(lhs.get_units_sold() +
                      rhs.get_units_sold());
   ret.set_revenue(lhs_get_revenue() +
                   rhs.get_revenue());
   return ret;
}
```

Member or non-member?

- Must be member

  `= [] () ->`

- Should be member
  - Compound assignments `+= -= /= %= %= ^= &= |= *= <<= >>=`
  - Modify operators `++ -- *`

- Better non-member
  - Arithmetic operators `+ - * %`
  - Bitwise operators `^ & |`
  - Equality operators `< > <= => != ==`
  - Relational operators `! && ||`

Member or non-member?

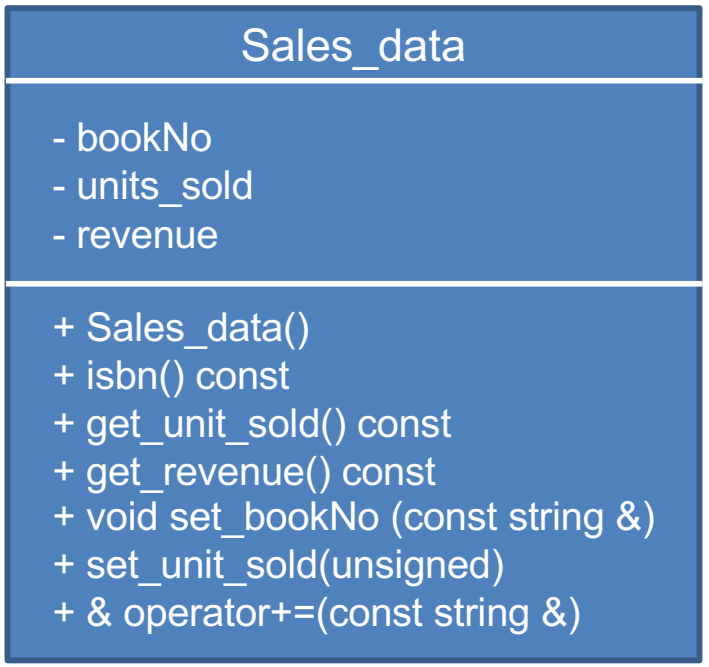
- Better not overloaded

  * && || !
- Cannot be overloaded

  `:: .* . ?:`

Defining a Function to Return "this" Object

```
class Sales_data {
public:
    std::string isbn() const { return bookNo; }
    Sales_data& operator+=(const Sales_data&);
    double get_revenue() const;
private:
    std::string bookNo;
    unsigned units_sold;
    double revenue;
};
```



Why return a reference

- `+= =` etc. must return a reference
  - mimic built-in operators
- `a = b = c`
  - works also even with copies
- `(a = b) = c`
  - Return copy: `a` takes value of `b`
  - Return reference: `a` takes value of `c`

DEMO

Defining a Function to Return “this” Object

```
Sales_data trans;
/* modify trans */
Sales_data total;
/* modify total */
total += trans; // total.combine(trans);
```

in the Lipman’s book

Defining a Function to Return “this” Object

- The object on which this operator is called represents the left-hand operand of the assignment. The right-hand operand is passed as an explicit argument

```
Sales_data& Sales_data::operator+=(const Sales_data &rhs)
{
    units_sold += rhs.units_sold; // add the members of rhs
    revenue += rhs.revenue;       // into the members of "this‘’
                                  // object
    return *this; // return the object on which the function was
                  // called
}
```

Defining a Function to Return "this" Object

```
total += (trans); // update the running total
```

- the address of total is bound to the implicit `this` parameter and rhs is bound to trans
- Thus, when += executes:

```
units_sold += rhs.units_sold;
```

- the effect is to add `total.units_sold` and `trans.units_sold`, storing the result back into `total.units_sold`
- the same happens for `revenues`

Defining a Function to Return “this” Object

- The interesting part about this operator is its return type and the return statement

- When we define an operator, it should mimic the behavior of the built-in operator
  - The built-in assignment operators return their left-hand operand as an lvalue
  - To return an lvalue, our operator **must** return a reference, because the left-hand operand is a `Sales_data` object, the return type is `Sales_data&`

Defining a Function to Return “this” Object

- As we have seen, we do not need to use the implicit `this` pointer to access the members of the object on which a member function is executing. However, we do need to use `this` to access the object as a whole:

```
return *this;  // return the object on which the function
               // was called
```

- Here the return statement dereferences `this` to obtain the object on which the operator is executing

References

- Lippman Chapters 1, 7, 14

Credits

- Bjarne Stroustrup. www.stroustrup.com/Programming