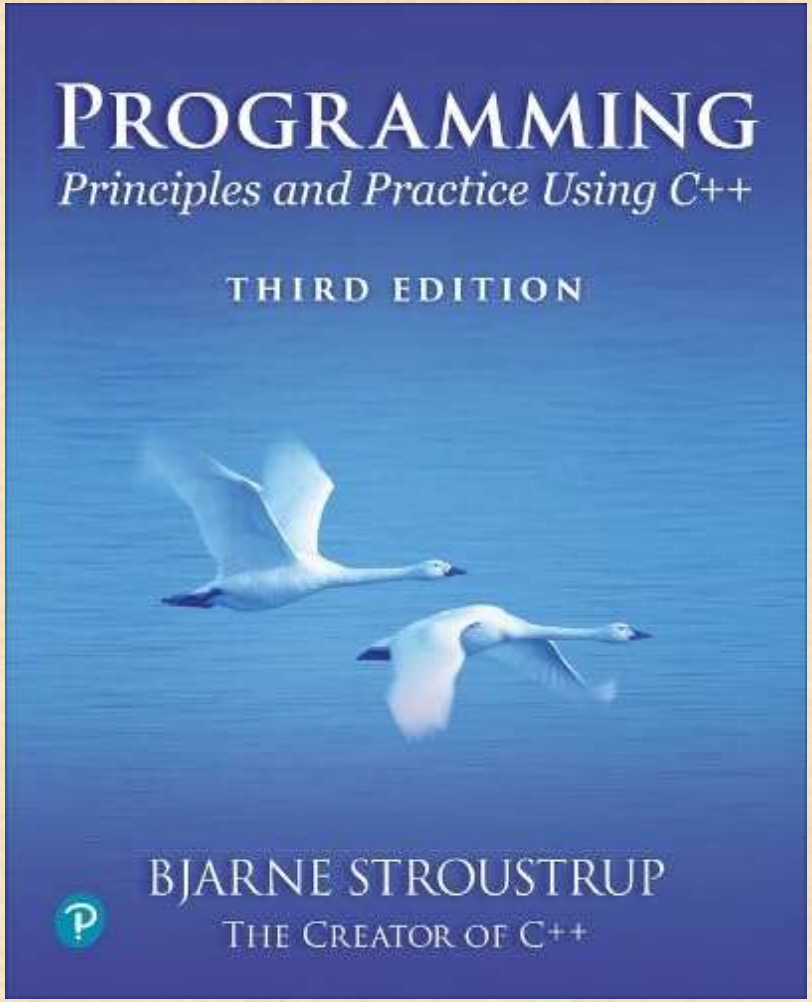
Chapter 8 – Technicalities: Classes, etc.



Remember, things take time.
– Piet Hein

Overview

- Classes
  - Implementation and interface
  - Constructors
  - Member functions
- Enumerations
- Operator overloading

Classes

- The idea:
  - A class directly represents a concept in a program
    - If you can think of “it” as a separate entity, it is plausible that it could be a class or an object of a class
    - Examples: vector, matrix, input stream, string, FFT, valve controller, robot arm, device driver, picture on screen, dialog box, graph, window, temperature reading, clock
  - A class is a (user-defined) type that specifies how objects of its type can be created and used
  - In C++ (as in most modern languages), a class is the key building block for large programs
    - And very useful for small ones also
  - The concept was originally introduced in Simula67

Members and member access

- One way of looking at a class;

```
class X {       // this class' name is X
        // data members (they store information)
        // function members (they do things, using the information)
};
```

- Example

```
class X {
public:
        int m;                                          // data member
        int mf(int v) { int old = m; m=v; return old; }         // function member
};

    X var;                      // var is a variable of type X
    var.m = 7;                  // access var's data member m
    int x = var.mf(9);          // call var's member function mf()
```

Classes

- A class is a user-defined type

```
class X {       // this clas's name is X
public:
        // the interface to users (accessible by all)
        //      functions
        //      types
        //      data (often best kept private)
private:
        // the implementation details (accessible by members of this class only)
        //      functions
        //      types
        //      data
};
```

Struct and class

- Class members are private by default:

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

- Means

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

- So

```
X x;                // variable x of type X
int y = x.mf();     // error: mf is private (i.e., inaccessible)
```

Struct and class

- A struct is a class where members are public by default:

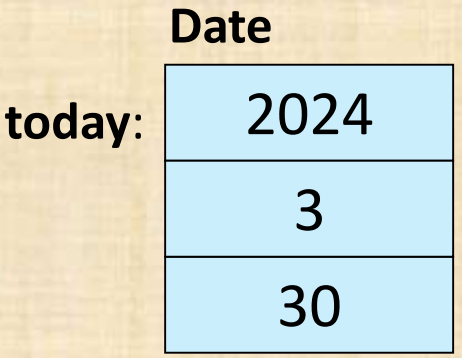
```
struct X {
        int m;
        // …
};
```

- Means

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

- **struct**s are primarily used for data structures where the members can take any value

Struct #1




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

Date today;                 // a Date variable (object)
today.y = 2024;             // assignment notation
today.m = 3;
today.d = 30;

Date someday = {12,30,1950};  // initializer notation
                              // oops! (no day 1950 in month 30); later , we'll have a problem
```

Struct #2

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

Date someday;     // a Date variable (object)

// helper functions:
void init_day(Date& dd, int y, int m, int d);   // check for valid
 date and initialize
void add_day(Date& dd, int n);                  // increase the Date
 by n days
// …
init_day(someday, 12, 30, 1950);          // run time error: no day
 1950 in month 30
```

Struct #3

```
// Simple date with 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 someday;                       // error: someday not initialized
Date someday2 {12, 30, 1950};       // oops! Runtime error
Date someday3 {1950, 12, 30};       // ok
Date mozart = {1756, 1, 27};        // ok (slightly verbose)
Date beethoven = Date{1770,12,16}; // ok (verbose style)
someday.2.add_day(2);               // January 1, 1951
// but we don't have to use those convenience functions:
mozart.m = 14;                      // Ouch! (now mozart is a bad date)
```

Class #1

```
// 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

        // access functions:
        void add_day(int n);          // increase the Date by n
 days
        int month() { return m; }
        int day() { return d; }
        int year() { return y; }
};

// …
Date mozart {1756, 1, 27};          // ok
cout << mozart.month() << '\n';              // we can read through
 month()
```

Classes

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

Class #2

```
// 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();
        // …
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

```
// member functions and helper functions
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();
        // …
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
```

Classes

```
// simple Date (what can we do in case of an invalid date?)
class Date {
public:
        class Invalid { };                      // to be used as exception
        Date(int y, int m, int d);              // check for valid date and initialize
        // …
private:
        int y,m,d;                      // year, month, day
        bool is_valid(int y, int m, int d); // is (y,m,d) a valid date?
};

Date:: Date(int yy, int mm, int dd)
        : y{yy}, m{mm}, d{dd}           // initialize data members
{
        if (!is_valid (y,m,d))
```

Classes

- 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 maintain an invariant
    - Only a fixed set of functions can access the data
  - To ease debugging
    - Only a fixed set of functions can access the data
    - (known as the "round up the usual suspects" technique)
  - 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

Enumerations

- An **enum** (enumeration) is a simple user-defined type, specifying its set of values (its enumerators)
- For example:

```
enum class Month {
    jan=1, feb, mar, apr, may, jun, jul, aug, sep, oct, nov, dec
};

Month m1 = Month::feb;      // OK
Month m 2= feb;             // error: no feb in scope
m = 7;                      // error: can't assign int to Month
int n = m;                  // error: we can't implicitly get the
  numeric value of a Month
Month m3 = Month(7);  // OK explicit conversion of  int to Month
  (unchecked)
Month m4  {7};              // OK: explicit initialization (unchecked)
```

Class Enumerations

- Type with a list of typed named constants

```
enum class Color { red, green, blue, /* … */  };
enum class Month { jan, feb, mar, /* … */ };
enum class Traffic_light { green, yellow, red };    // OK:
  scoped enumerators

Month m1 = jan;         // error: jan not in scope
Month m1 = Month::jan;      // OK
Month m2 = Month::red;      // error: red isn't a Month
Month m3 = 7;           // error: 7 isn't a Month
Color c1 = Color::red;      // OK
Color c2 = Traffic_light::red;    // error
int i = m1;                 // error: an enumerator is not
  converted to int
```

"Plain" Enumerations

- Simple list of constants:

```
enum { red, green };          // a "plain" enum { } doesn't define a scope
int a = red;                  // red is available here
enum { red, blue, purple }; // error: red defined twice
```

- Type with a list of named constants

```
enum Color { red, green, blue, /* … */  };
enum Month { jan, feb, mar, /* … */ };

Month m1 = jan;
Month m2 = red; // error: red isn't a Month
Month m3 = 7;   // error: 7 isn't a Month
int i = m1;             // ok: an enumerator is converted to its value, i==0

bool cmp(Color c, Month m) { return c==m; }          // we really don't this to work
                                                     // so use class enums
```

Enumerations – Values

- By default

```
// the first enumerator  has the value  0,
// the next enumerator has the value "one plus the value of the enumerator before it"
enum { horse, pig, chicken };                    // horse==0, pig==1, chicken==2
```

- You can control numbering

```
enum { jan=1, feb, march /* … */ };              // feb==2, march==3
enum stream_state { good=1, fail=2, bad=4, eof=8 };
int flags = fail+eof;                            // flags==10
stream_state s = flags;                          // error: can't assign an int to a stream_state
stream_state s2 = stream_state(flags);           // explicit conversion (be careful!)
```

Classes

```
// simple Date (use enum class Month)
class Date {
public:
        Date(int y, Month m, int d);  // check for valid date and
 initialize
        // …
private:
        int y;              // year
        Month m;
        int d;      // day
};

Date my_birthday(1950, 30, Month::dec);      // error: 2nd argument
 not a Month
Date my_birthday(1950, Month::dec, 30);      // OK
```

Classes and const

```
class Date {
public:
        // …
        int day() const { return d; } // const member: can't modify
        void add_day(int n);          // non-const member: can modify
        // …
};

Date d {2000, Month::jan, 20};
const Date cd {2001, Month::feb, 21};

cout << d.day() << " - " << cd.day() << '\n';   // ok
d.add_day(1);                                   // ok
cd.add_day(1);                                  // error: cd is a const
```

Const

```
Date d {2004, Month::jan, 7};        // a variable
const Date d2 {2004, Month::feb, 28};     // a constant

d2 = d;              // error: d2 is const
d2.add(1);  // error d2 is const
d = d2;              // fine
d.add(1);   // fine

d2.f();      // should work if and only if f() doesn't modify d2
      // how do we achieve that? (say that's what we want, of course)
```

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, Month::nov, 4};
int d = dx.day();         // fine
dx.add_day(4);            // error: can't modify constant
  (immutable) date
```

Classes

- What makes a good interface?
  - Minimal
    - As small as possible
  - Complete
    - And no smaller
  - Type safe
    - Beware of confusing argument orders
    - Beware of over-general types (e.g., int to represent a month)
  - Const correct

Classes

- Essential operations
  - Default constructor (defaults to: nothing)
    - No default if any other constructor is declared
  - Copy constructor (defaults to: copy the member)
  - Copy assignment (defaults to: copy the members)
  - Move constructor (defaults to: copy the member)
  - Move assignment (defaults to: copy the members)
  - Destructor (defaults to: nothing)
- For example

```
Date d;   // error: no default constructor
Date d2 = d;    // ok: copy initialized (copy the elements)
d = d2;   // ok copy assignment (copy the elements)
```

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)
  - E.g. == (equality) , != (inequality)
  - **next_weekday(), next_Sunday()**

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); }
```

Operator overloading

- You can define almost all C++ operators for a class or enumeration operands
  - That's often called "operator overloading"

```
enum class Month {
 jan=1, feb, mar, apr, may, jun, jul, aug, sep, oct,
 nov, dec
};

Month operator++(Month& m)      // prefix increment operator
{
 // "wrap around":
 m = (m==Month::dec) ? Month::jan : Month(m+1);
 return m;
}

Month m = Month::nov;
++m;    // m becomes dec
++m;    // m becomes jan
```

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
- Advice (not language rule):
  - Overload operators only with their conventional meaning
  - **+** should be addition, ***** be multiplication, **[]** be access, **()** be call, etc.
- Advice (not language rule):
  - Don't overload unless you really have to

Dates

- For real use, don't use the PPP Date
  - Use the ISO C++ chrono facilities
  - For example:
    - **auto birthday = December/16/1700;** **//** *year_month_day{year{1770}, December, day{16}}*
- The standard is
  - Better thought out
  - Useful in more places
  - Better known
  - Better tested
  - Better maintained
- than our specialized, hand-crafter classes

Next class

- I/O streams
  - Text oriented input and output