DM560

Introduction to Programming in C++

Object Oriented Programming: Classes

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[*Based on slides by Bjarne Stroustrup*]

Outline

1. Classes
2. Enumerations
3. `const`
4. Operator Overloading

Outline

- Classes
  - Interface and implementation
  - Constructors
  - Member functions
- Enumerations
- Operator overloading

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Classes

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  - Examples: vector, matrix, input stream, string, FFT, valve controller, robot arm, device driver, picture on screen, dialog box, graph, window, temperature reading, clock

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  - Examples: vector, matrix, input stream, string, FFT, valve controller, robot arm, device driver, picture on screen, dialog box, graph, window, temperature reading, clock
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- 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

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)
};
```

Members and Member Access

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```
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 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
};
```

Struct and Class

- In a 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:

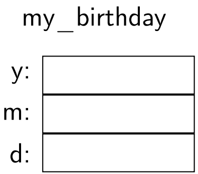
```
struct X {
  int m;
  // ...
};
```

means

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

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

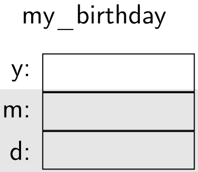
Structs




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

```
Date my_birthday;          // a Date variable (object)

my_birthday.y = 12;
my_birthday.m = 30;
my_birthday.d = 1950;      // oops! (no day 1950 in month 30)
                           // later in the program, we'll have a problem
```

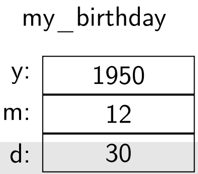
Structs




```
// 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 validity and initialize
                                              // Note: these y, m, and d are local

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

init_day(my_birthday, 12, 30, 1950); // run time error: no day 1950 in month 30
```

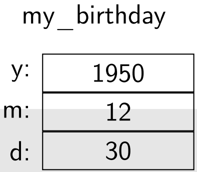
Structs




```
// 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 validity and initialize
  void add_day(int n);          // increase the Date by n days
};
```

```
// ...
Date my_birthday;                    // error: my_birthday not initialized
Date my_birthday {12, 30, 1950};            // oops! Runtime error
Date my_day {1950, 12, 30};          // ok
my_day.add_day(2);                   // January 1, 1951
my_day.m = 14;                       // ouch! (now my_day is a bad date)
```

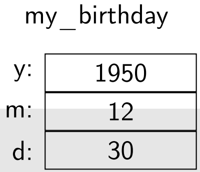
Classes




```
// 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 my_birthday {1950, 12, 30};                    // ok
cout << my_birthday.month() << endl;     // we can read
my_birthday.m = 14;
```

Classes




```
// 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 my_birthday {1950, 12, 30};                    // ok
cout << my_birthday.month() << endl;     // we can read
my_birthday.m = 14;                      // error: Date::m is private
```

Classes

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- 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.

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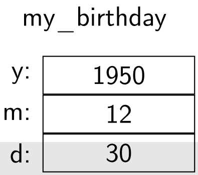
  The invariant for Date ("a Date must represent a date in the past, present, or future") is unusually hard to state precisely – Remember February 28, leap years, etc.
- If we can't think of a good invariant, we are probably dealing with plain data
  - If so, use a struct
  - Try hard to think of good invariants for your classes (that saves you from poor buggy code)

Classes

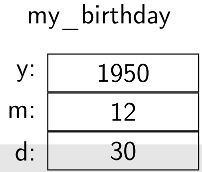



```
// simple Date
class Date {
public:
  Date(int yy, int mm, int dd);  // constructor: check for validity and initialize
  void add_day(int n);           // increase the Date by n days
  int month();
  // ...
private:                         // some people prefer implementation details last
  int y,m,d;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

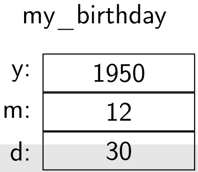



```
// simple Date (some people prefer implementation details last)
class Date {
public:
  Date(int yy, int mm, int dd);  // constructor: check for validity and initialize
  void add_day(int n);     // increase the Date by n days
  int month();
  // ...
private:
  int y,m,d;     // year, month, day
};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

```
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

int Date::season() { /* ... */ }
```

Classes

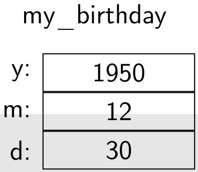



```
// simple Date (some people prefer implementation details last)
class Date {
public:
  Date(int yy, int mm, int dd);  // constructor: check for validity and initialize
  void add_day(int n);      // increase the Date by n days
  int month();
  // ...
private:
  int y,m,d;    // year, month, day
};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

```
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

int Date::season() { /* ... */ }                  // error: no member called season
```

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)) throw Invalid();         // check for validity
}
```

Classes

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- Why not make everything public?
  - To provide a clean interface
    Data and messy functions can be made private

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      Data and messy functions can be made private
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    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)

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- 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

Outline

1. Classes
2. Enumerations
3. `const`
4. Operator Overloading

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
};
```

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For example:

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

```
Month m = Month::feb;
m = 7;          // error: can't assign int to Month
int n = m;              // error: we can't get the numeric value of a Month
Month mm = Month(7);    // convert int to Month (unchecked)
```

“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
```

Class Enumeration

- 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
```

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)

enum class Month { jan, feb, mar, /* ... */ };

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
```

Outline

const

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

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() << endl; // ok
d.add_day(1);    // ok
cd.add_day(1);   // error: cd is a const
```

const

```
class Date {
public:
  // ...
  int day() const { return d; }        // const member: can't modify
  void add_day(int n);               // non-const member: can modify
};
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const Date cd {2001, Month::feb, 21};

cout << d.day() << `` - `` << cd.day() << endl; // ok
d.add_day(1);    // ok
cd.add_day(1);   // error: cd is a 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_day(1);   // error d2 is const
d = d2;          // fine
d.add_day(1);    // fine
```

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() << endl; // ok
d.add_day(1);   // ok
cd.add_day(1);  // error: cd is a 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_day(1);  // error d2 is const
d = d2;         // fine
d.add_day(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 members)
- Copy assignment (defaults to: copy the members)
- Destructor (defaults to: nothing)

For example:

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

Outline

Interfaces and "Helper 'Functions"

- A class interface is the set of public functions
- Keep a class interface 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). Examples:
  - `==` (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

Summary

1. Classes
2. Enumerations
3. `const`
4. Operator Overloading