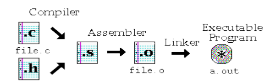
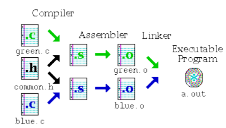
The Compilation Process

- Compiler:
  - All **.c** files are converted/assembled into Assembly Language, i.e. making **.s** files.
- Assembler:
  - The assembly language files from the previous step are converted into object code (machine code), i.e. **.o** files.
- Linker:
  - The object code is then linked to libraries and other files for cross-reference.

Lec13

Compilation





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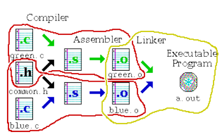
Compiler/Assembler and Linker

- Compile green.o: `cc –c green.c`
- Compile blue.o: `cc –c blue.c`
- Link together: `cc green.o blue.o`



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Multiple Source Files

- The decision to divide your program into multiple source files is not only a matter of size.
- One and only one **.c** file must contain a **main**.
- Functions that handle some common aspects of a program should be grouped into the same file.
  - main, data structure implementation (i.e. linked list), I/O, utilities, display/GUI, etc

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Header Files

- To share information between files.
  - types
  - macros
  - functions
  - externals
- Each `.c` should have its own `.h`.
- Information share btw. several or all files should go into one `.h` (usually `main.h`).

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Types and Macros

- Types:
  - **typedef**
  - **enum**
- Macros
  - **#include**
  - **#define**
  - **#ifdef**
  - **#error**

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Sharing Functions

- If a function is to be called in more than one file, put its prototype into a `.h`.
- Always include the `.h` with `f`' s prototype in the `.c` that contains `f`' s definition.
  - For any `.c`, always include your own `.h`.
- A header file should never contain function definitions.

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Sharing Variables

- Variables shared between files are defined in one file, and declared in all files that need to access it.
  - Definition of a variable causes the compiler to set memory aside
- `extern`
  - `extern int i, a[];`
  - extern informs the compiler that the variables `i` and `a` are defined elsewhere.

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`extern` variables

- `extern` declarations often go in to a header file.
- The variable must have one (and only one) definition among all files.
  - `int x;`
- Any file that wishes to access a variable that is defined in another file must declare such a variable as `extern`
  - `extern int x;`

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Chapter 9
Technicalities: Classes, etc.

Bjarne Stroustrup

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Abstract

- This lecture presents language technicalities, mostly related to user defined types; that is, classes and enumerations.

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Overview

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

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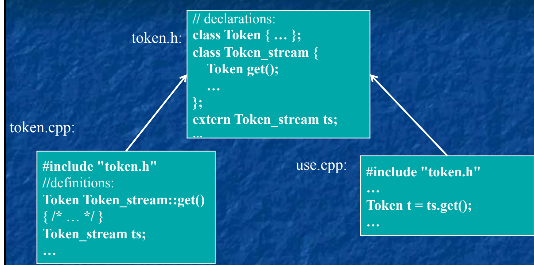
Source files



- A header file (here, **token.h**) defines an interface between user code and implementation code (usually in a library)
- The same **#include** declarations in both **.cpp** files (definitions and uses) ease consistency checking

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 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

- 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

Structs

Date:
my_birthday: y
m
d

```
// 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

Date:
my_birthday: y
m
d

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


Structs

Date:
my_birthday: y 1950
m 12
d 30

```
// 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;                    // 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

Date:
my_birthday: y 1950
m 12
d 30

```
// 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

- 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.
- 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

Date:
my_birthday: y 1950
m 12
d 30

```
// 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

Date:
my_birthday: y 1950
m 12
d 30

```
// 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
};

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
```

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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
}
```

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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

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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 m = 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)
```

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"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
```

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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
```

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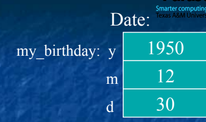
Enumerations – Values

- 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
```


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

```
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)
  - 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)
```

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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()**

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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); }
```

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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
```

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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

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