Week 2

NWEN 241 Systems Programming

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Content

- Admin stuff
- Derived and user-defined types
- C++ classes

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Programming Assignment #1

- Will be released today
- E-mail will be sent out once available in course wiki

Derived & User-Defined Types

Background

- Basic C/C++ data types
  - ✓ char : character
  - ✓ short, int, long, long long : integer
  - ✓ float, double, long double : floating point number
- Basic C++ only data types
  - ✓ wchar_t : wide character
  - ✓ bool : boolean
- Derived data types
  - ✓ Arrays
  - ✓ C strings
  - – Structures, unions, and C++ classes
- User defined data types
  - – New "types" including *enumeration* types

Enumeration

- Enumeration is a user-defined data type that is used to assign identifiers to integral constants
- It is defined using the keyword `enum` and the syntax is:

```
enum enum_tag {
      identifier_0, identifier_1, ..., identifier_n
} variable_list;
```

  - ***enum_tag*** specifies the name of the enumeration type
  - ***enum_tag*** and ***variable_list*** are optional
  - If ***enum_tag*** is not specified, ***variable_list*** should be specified; otherwise, there is no way to declare variables using the unnamed enumeration type

Enumeration

- Enumeration is a user-defined data type that is used to assign identifiers to integral constants
- It is defined using the keyword `enum` and the syntax is:

```
enum enum_tag {
      identifier_0, identifier_1, ..., identifier_n
} variable_list;
```

  - The identifiers in the braces are symbolic constants that take on integer values from `0` through n
    - → `identifier_0` has value `0`,
    - → `identifier_1` has value `1`, and so on

Enumeration

- As an example, the statement:

```
enum colors { red, yellow, green };
```

creates three constants. `red` is assigned the value 0, `yellow` is assigned 1 and `green` is assigned 2

- It is possible to override the integer assignment, e.g.

```
enum colors { red = 3, yellow = 2, green = 1};
```

Enumeration

- If an identifier is assigned a value and subsequent identifiers are not assigned, the subsequent identifiers continue the progression from the assigned value

```
enum colors { red, yellow = 3, green, blue };
```

- `red` is assigned the value 0, `yellow` is assigned 3, `green` is assigned 4, and `blue` is assigned 5.

Enum Example 1 (Pure C)

```c
#include <stdio.h>

/* Declaration defines integer constants */
enum colors { red, yellow = 3, green, blue };

int main(void)
{
    /* Declaration defines variables of type enum colors */
    /* Can take values of red, yellow, green or blue */
    enum colors fgcolor = blue, bgcolor = yellow;

    printf ("%d %d\n", fgcolor, bgcolor);
    /* Will print 5 3 */

    return 0;
}
```

Enum Example 1 (C++)

```
#include <iostream>

/* Declaration defines integer constants */
enum colors { red, yellow = 3, green, blue };

int main(void)
{
    /* Declaration defines variables of type enum colors */
    /* Can take values of red, yellow, green or blue */
    enum colors fgcolor = blue, bgcolor = yellow;

    std::cout << fgcolor << " " << bgcolor << "\n";
    /* Will print 5 3 */

    return 0;
}
```

Enum Example (2)

```
/* This program uses enumerated data types
   to access the elements of an array */
#include <stdio.h>
int main(void)
{
    int August[5][7] = {{0,0,1,2,3,4,5},
                        {6,7,8,9,10,11,12},
                        {13,14,15,16,17,18,19},
                        {20,21,22,23,24,25,26},
                        {27,28,29,30,31,0,0}};
    enum days {Sun, Mon, Tue, Wed, Thu, Fri, Sat};
    enum week {week_one, week_two, week_three, week_four,
                   week_five};

    printf ("Monday the third week of August "
            "is August %d\n", August[week_three][Mon]);
}
```

C Structures

- A `C struct` is a derived data type composed of members that are each fundamental or derived data types.

- A single `C struct` would store the data for one object. An array of `C struct`s would store the data for several objects.

- A `C struct` can be defined in several ways as illustrated in the following examples.

Declaring a C Structure

- Syntax of the structure type declaration:

```
struct structure_tag {
        type1 member1;
        type2 member2;
        ...
} variable_list;
```

  - *`structure_tag`* specifies the name of the structure
  - *`structure_tag`* and *`variable_list`* are optional
  - If *`structure_tag`* is not specified, *`variable_list`* should be specified; otherwise, there is no way to declare variables using the unnamed structure type

Declaring a C Structure

- Syntax of the structure type declaration:

```
struct structure_tag {
        type1 member1;
        type2 member2;
        ...
} variable_list;
```

- Structure members can be
  - Basic data types
  - Derived and user-defined types
  - Pointers to basic, derived and user-defined data types

Examples

- struct declaration that only defines a type:

```
struct student_info { // named struct
      char name [20];
      int student_id;
      int age;
}; // does not reserve any space
```

- struct declaration that defines a type and reserves storage for variables:

```
struct student_info { // named struct
      char name [20];
      int student_id;
      int age;
} s, t; // reserves space for s and t
```

Examples

- Declaring a variable `current_student`

```
struct student_info current_student;
```

Above statement reserves space for:

- 20 character array,
- integer to store student ID, and
- integer to store age

- Declaring array of structures to store information of enrolled students in a class

```
struct student_info nwen241class[250];
```

Reserves space for 250 element array of records (structs) for students enrolled in NWEN241.

typedef

- The keyword `typedef` provides a mechanism for creating synonyms (or aliases) for previously defined data types

```
typedef existing_type_name new_type_name;
```

- Examples:

```
typedef unsigned long ulong;
typedef unsigned char uchar;

ulong i;  /* unsigned long i; */
uchar c;  /* unsigned char c; */
```

Creating New User-Defined Types

- Instead of typing `struct student_info` every time we declare a variable, we can define it as a new data type, e.g.

```
typedef struct { // unamed struct
      char name [20];
      int student_id;
      int age;
} StudentInfo;
```

- This makes `StudentInfo` a new user-defined type, and you can declare a variable as follows:

```
StudentInfo current_student;
```

New struct and data type

- If `struct student_info` has been previously defined, then we can create a new data type using `typedef` :

```
typedef struct student_info StudentInfo;
```

Accessing and Manipulating Structs

- We can reference a component of a structure by the **direct component selection operator**, which is a **period**, e.g.

```
strcpy(student1.name, "John Smith");
student1.age = 18;
printf("%s is in age %d\n", student1.name,
student1.age);
```

- The **direct component selection operator** has level 1 priority in the operator precedence
- The copy of an entire structure can be easily done by the assignment operator

```
student1 = student2;
```

Example

```
#include <stdio.h>
#include <string.h>

int main() {
   typedef struct student_info {
       char name[20];
       int student_id;
       int age;
   } StudentInfo;

   StudentInfo current_student;     // declare new variable using
                                    // new type StudentInfo
   struct student_info new_student; // declare using struct format

   // do stuff – see next slide
}
```

Example (continuation)

```
#include <stdio.h>
#include <string.h>
int main() {
   // declarations in previous slide
   …
   // create new student record
   strcpy(new_student.name , "John Smith");
   new_student.student_id = 300300300;
   new_student.age = 22;

   current_student = new_student;

   printf("Student name : %s\n", current_student.name);
   printf("Student ID   : %.9d\n", current_student.student_id);
   printf("Student Age  : %d\n", current_student.age);

}
```

Struct as Function Input Parameter

- Suppose a structure defined as follows

```
typedef struct {
   char name[20];
   double diameter;
   int moons;
   double orbit_time, rotation_time;
} planet_t;
```

Struct as Function Input Parameter

- When a structure variable is passed as an input argument to a function, all its component values are copied into the local structure variable

```c
/*
 * Displays with labels all components of a planet_t structure
 */
void
print_planet(planet_t pl) /* input - one planet structure */
{
      printf("%s\n", pl.name);
      printf("  Equatorial diameter: %.0f km\n", pl.diameter);
      printf("  Number of moons: %d\n", pl.moons);
      printf("  Time to complete one orbit of the sun: %.2f years\n",
             pl.orbit_time);
      printf("  Time to complete one rotation on axis: %.4f hours\n",
             pl.rotation_time);
}
```

- Not efficient when struct is a large object

Array of Structures

- An array of structures can be defined as follows:

```
typedef struct {
   int student_id;
   double gpa;
} student_t;

student_t student_list[50];

student_list[3].student_id = 300922023;
student_list[3].gpa = 8.0;
```

Array of Structures

- Can be simply manipulated as arrays of simple data types

	.student_id	.gpa
student_list[0]	300981683	6.5
student_list[1]	300961592	5.1
student_list[2]	300182652	7.3
student_list[3]	300922023	8.0
…	…	…
student_list[49]	300139414	9.0

student_list[0].gpa

student_list[3].student_id

Unions

- A union is like a struct, but the different fields take up the **same** space within memory

```
union union_tag {
      type1 member1;
      type2 member2;
      ...
} variable_list;
```

  - *union_tag* specifies the name of the structure
  - *union_tag* and *variable_list* are optional
  - If *union_tag* is not specified, *variable_list* should be specified; otherwise, there is no way to declare variables using the unnamed structure type

Unions

- A union is like a struct, but the different fields take up the **same** space within memory

```
union union_tag {
      type1 member1;
      type2 member2;
      ...
} variable_list;
```

  - At any given time, only one of the members can contain a value
  - The size of a union is determined by the largest member

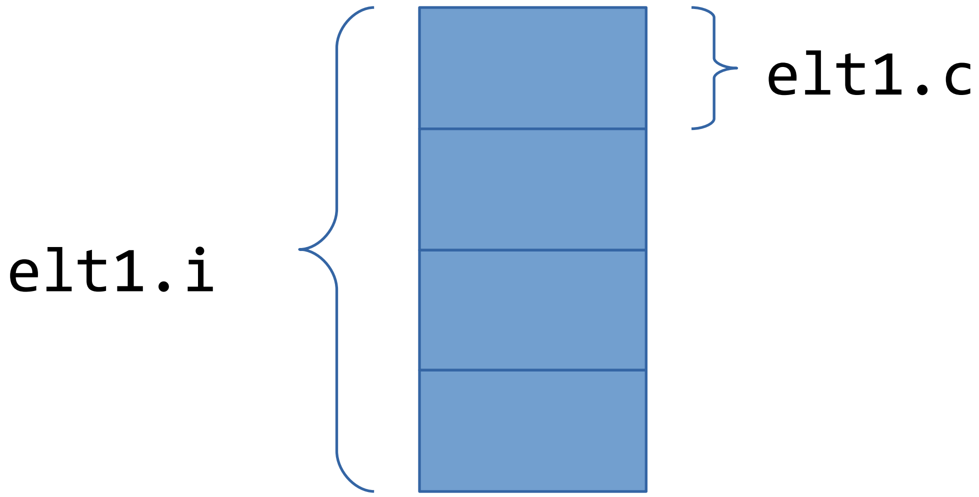
```
sizeof(union space) =
max(sizeof(member1),sizeof(member2),...)
```

Example

```
union elt {
    int   i;
    char  c;
} elt1;

elt1.c = 'A';
elt1.i = 300;
```

Assuming an int takes up
32 bits (4 bytes):

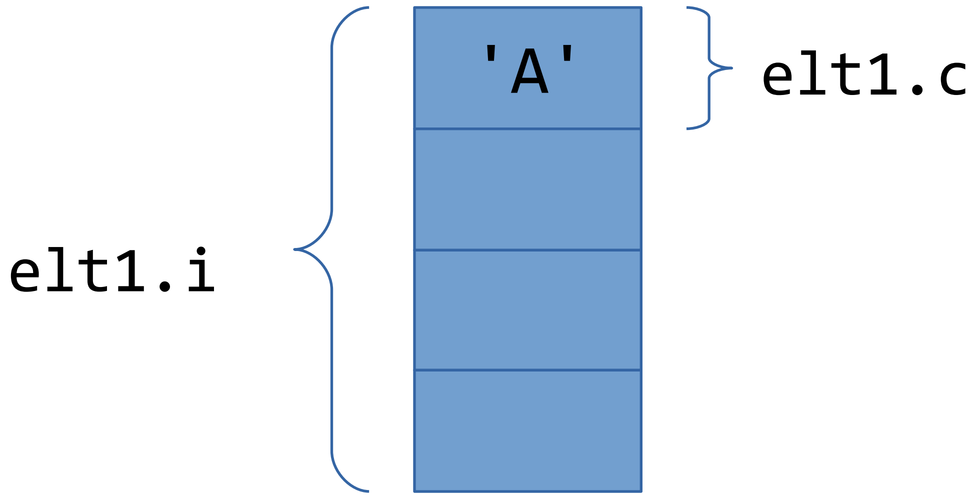


Example

```
union elt {
    int   i;
    char  c;
} elt1;

elt1.c = 'A';
elt1.i = 300;
```

Assuming an int takes up 32 bits (4 bytes):

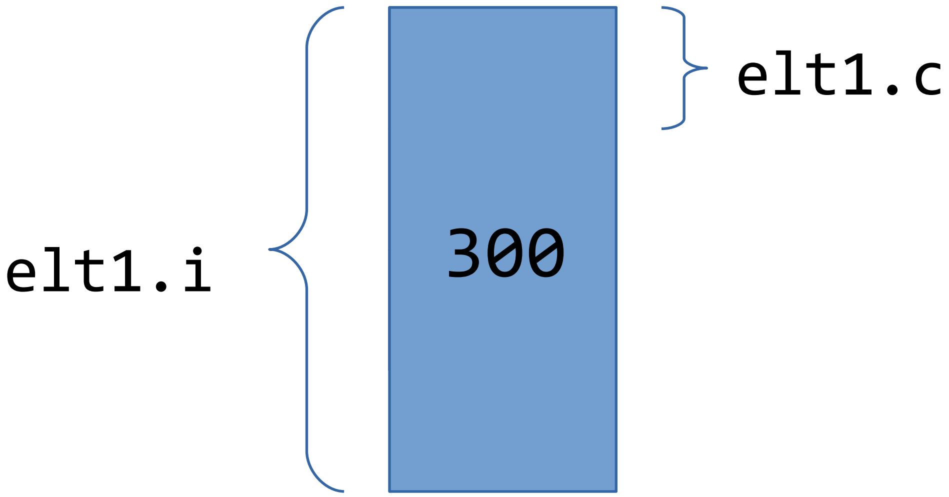


Example

```
union elt {
    int   i;
    char  c;
} elt1;

elt1.c = 'A';
elt1.i = 300;
```

Assuming an int takes up 32 bits (4 bytes):



Union Doesn’t Know What It Contains

- How should your program keep track whether `elt1` holds an `int` or a `char`?

- Basic answer:
  Use another variable to hold that info

```
union elt {
   int   i;
   char  c;
} elt1;

elt1.c = 'A';
elt1.i = 300;

if (elt1 currently has a char)
  …
```

Tagged Unions

- *Tag* every value with its case
- Pair the type info together with the union – implicit in other programming languages like Java

```
enum u_tag { INT, CHAR };
struct tagged_union {
   enum u_tag  tag;
   union {
      int   i;
      char  c;
   } data;
};
```

`enum` must be external to **`struct`**, so constants are globally visible.

`struct` field must be named.

C++ Classes

From Structure to Class

C++ Structures

- C++ structures are similar to C structures
- Same declaration syntax
- **But C++ structures can have functions as members and can be extended (supports inheritance)**

- Key disadvantage of C++ structures: **member variables and functions are all public**

Classes

C++ classes generalizes structures in an object-oriented sense:

- Classes are types representing groups of similar instances
- Each instance has certain fields that define it (instance variables)
- Instances also have functions that can be applied to them– also known as *methods* in OOP parlance
- Access to parts of the class can be limited

Classes allow the combination of data and operations in a single unit

Defining a Class

- A class is a collection of fixed number of components called **members** of the class

- General syntax for defining a class:

```
class class_identifier {
      class_member_list
};
```

  - `class_member_list` consists of variable declarations and/or functions

Example

```
class Time {
public:
      void set(int, int, int);
      void print() const;
      Time();
      Time(int, int, int);

private:
      int hour;
      int minute;
      int second;
};
```

Member access specifiers

Possible specifiers:

- `private`
- `protected`
- `public`

Example

```
class Time {
public:
      void set(int, int, int);
      void print() const;
      Time();
      Time(int, int, int);

private:
      int hour;
      int minute;
      int second;
};
```

Constructors

- Named after class name
- Similar to Java

When class performs dynamic memory allocation, **destructor** is also needed

Example

```
class Time {
public:
      void set(int, int, int);
      void print() const;
      Time();
      Time(int, int, int);

private:
      int hour;
      int minute;
      int second;
};
```

Member functions

const at end of function specifies that member function cannot modify member variables

Example

```
class Time {
public:
      void set(int, int, int);
      void print() const;
      Time();
      Time(int, int, int);

private:
      int hour;
      int minute;
      int second;
};
```

Member variables

Constant member variables can be initialized during declaration

Member Access Specifier

- C++ does not impose order on declaring `private`, `protected` and `public` members
- When member access specifier is not indicated, default access is `private`

- **Private members** – can only by accessed by member functions (and friends) and not accessible by descendant classes
- **Protected members** – can only be accessed by member functions (and friends) and inherited by descendant classes
- **Public members** – can be accessed by anyone and inherited by descendant classes

Constructors

- Default constructor: constructor without input parameters
  - When no default constructor is defined, the compiler will automatically generate one with empty body
- Properties of constructors:
  - Constructor name is the name of the class itself
  - No type: neither a value-returning function nor a void function
  - Class can have more than 1 constructor
  - If more than 1 constructor, constructors must have different formal parameter lists
  - Constructors are executed automatically when a class object is declared
    - Which constructor is executed depends on the actual parameters passed in the declaration

Example

```
class Time {
public:
      void set(int, int, int);
      void print() const;
      Time();
      Time(int, int, int);

private:
      int hour;
      int minute;
      int second;
};
```

```
Time myTime;
```

```
Time myTime(9, 0, 0);
```

How about these?

```
Time myTime();
```

```
Time myTime(9, 0);
```

Example

```
Time myTime;
```

```
Time myTime(9, 0, 0);
```

- These declarations creates instances of class `Time`
- Space automatically allocated for the objects in stack*
- Not possible in Java
  - Classes are instantiated using `new` statement

* We will talk more about stack (and heap) in dynamic memory allocation

Member Functions

- Member functions can be declared in 2 ways:
  - By specifying the function prototype
  - By specifying the function implementation

- How about in Java?

```
class Time {
public:
        void print() const;
        void set(int h, int m, int s) {
                hour = h;
                minute = m;
                second = s;
        }
        Time();
        Time(int, int, int);

private:
        int hour;
        int minute;
        int second;
};
```

Inline Functions

- Including the implementation of a function is an implicit *request* (to the compiler) to make a function **inline**
- When a function is inline, the compiler does not make a function call
  - The code of the function is used in place of the function call (and appropriate argument substitutions made)
  - Compiled code may be slightly larger, but will execute faster because function call overhead is avoided
- Can explicitly request to make member functions inline
  - Add `inline` keyword before return type in function declaration and definition

Inline Functions

- Not all inline requests are granted by the compiler
- Reasons for not granting inline requests:
  - Function contains a loop (for, while, do-while)
  - Function contains static variables
  - Function is recursive
  - Function return type is other than void, and the return statement doesn’t exist in function body
  - Function contains switch or goto statement

Implementing Functions Separately

- For member functions that are not implemented in the class declaration, they must be implemented separately

```
class Time {
public:
  void print() const;
  void set(int h, int m, int s) {
    hour = h;
    minute = m;
    second = s;
  }
  …
};
```

```
#include <cstdio>

void Time::print() const
{
  printf("%2d:%2d:%2d", hour,
    minute, second);
}
```

Explicit Inline Request

- Add `inline` keyword before return type in function declaration and definition

```
class Time {
public:
  inline void print() const;
  void set(int h, int m, int s) {
    hour = h;
    minute = m;
    second = s;
  }
  …
};
```

```
#include <cstdio>

inline void Time::print() const
{
  printf("%2d:%2d:%2d", hour,
    minute, second);
}
```

Implementing Constructors

- Implementation of constructs follow the same rules as member functions
- They can be implemented within the class declaration (implicit inline)

```
class Time {
public:
  …
  Time() {
    hour = 0;
    minute = 0;
    second = 0;
  }
  Time(int h, int m, int s) {
    hour = h;
    minute = m;
    second = s;
  }
  …
};
```

Implementing Constructors

- Implementation of constructs follow the same rules as member functions
- They can be implemented within the class declaration (implicit inline)
- Or separately

```
Time::Time() {
    hour = 0;
    minute = 0;
    second = 0;
}

Time::Time(int h, int m, int s) {
    hour = h;
    minute = m;
    second = s;
}
```

Another Syntax For Initializing Member Variables

```
class Time {
public:
  …
  Time() {
    hour = 0;
    minute = 0;
    second = 0;
  }
  Time(int h, int m, int s) {
    hour = h;
    minute = m;
    second = s;
  }
  …
};
```

```
class Time {
public:
  …
  Time() : hour(0), minute(0),
    second(0) {}

  Time(int h, int m, int s) :
    hour(h), minute(m),
    second(s) {}
  …
};
```

Order is important: must be the same as order of declaration in class

Another Syntax For Initializing Member Variables

```
Time::Time() {
    hour = 0;
    minute = 0;
    second = 0;
}

Time::Time(int h, int m, int s) {
    hour = h;
    minute = m;
    second = s;
}
```

```
Time::Time() : hour(0), minute(0),
    second(0) {
}

Time::Time(int h, int m, int s) :
    hour(h), minute(m),
    second(s) {
}
```

Example: Accessing Members

```
class Time {
public:
      void set(int, int, int);
      void print() const;
      Time();
      Time(int, int, int);

private:
      int hour;
      int minute;
      int second;
};
```

```
// Creates instance using
// default constructor
Time myTime;

// Invokes member function
myTime.set(10, 30, 0);

// Is this allowed?
myTime.hour = 12;
```

Member access operator

Where to Declare and Implement Classes and Member Functions

- You may declare classes and implement the member functions in the same C++ source file

- Disadvantage: other sources will not be able to use the class

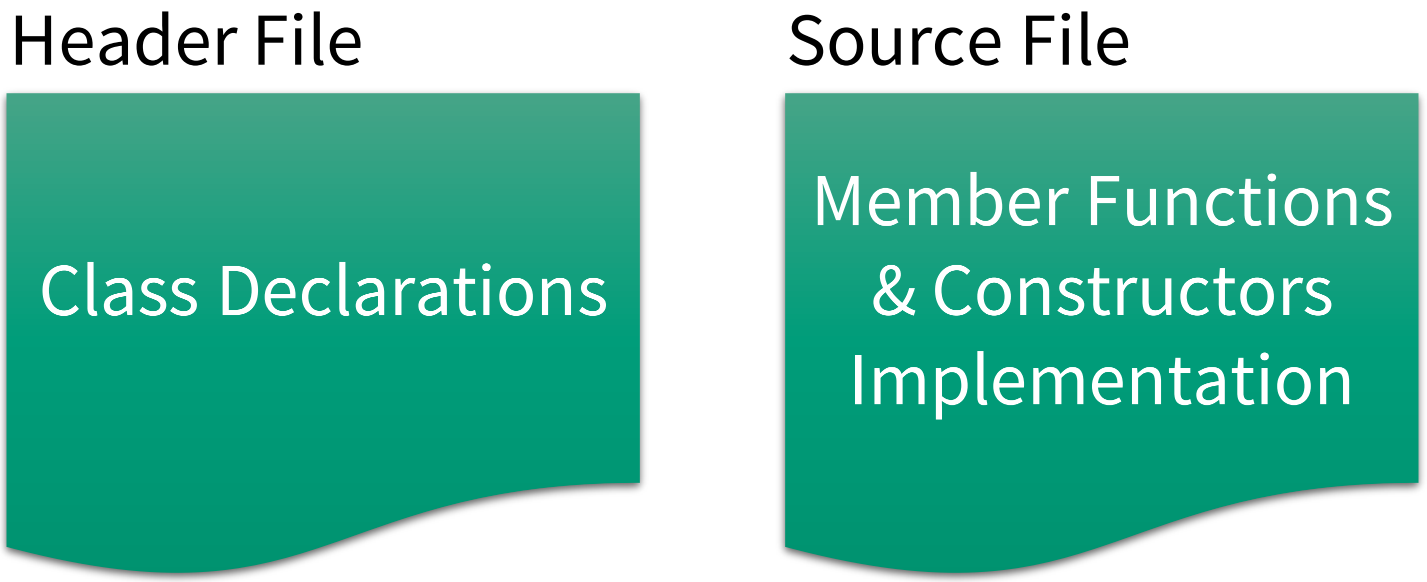
```
class Time {
public:
  void set(int, int, int);
  void print() const;
  …
};

void Time::set(int h, int m, int s)
{
  hour = h;
  minute = m;
  second = s;
}

void Time::print() const
{
  printf("%2d:%2d:%2d", hour, minute, second);
}
```

Where to Declare and Implement Classes and Member Functions

- Good programming practice is to declare the class in a header file
- Separate the implementation of the member functions (and possibly constructors) in another source file



Example

time.h

```
class Time {
public:
  void set(int, int, int);
  void print() const;
  Time();
  Time(int, int, int);

private:
  int hour;
  int minute;
  int second;
};
```

time.cc

```
…
#include "time.h"

Time::Time() : hour(0), minute(0), second(0) {
}

Time::Time(int h, int m, int s) :
 hour(h), minute(m), second(s) {
}

void Time::set(int h, int m, int s) {
  hour = h; minute = m; second = s;
}

void Time::print() const {
  printf("%2d:%2d:%2d", hour, minute, second);
}
```

Static Members

- C++ classes can contain static members
- A static member variable is a variable that is shared by all instances of a class
- Often used to declare class constants
- A static member function is function that can be invoked outside class instance

- Member functions and variables can be made static by using the `static` qualifier

Example

```
class Time {
public:
  void set(int, int, int);
  void print() const;
  static int getCounter();
  Time();
  Time(int, int, int);

private:
  int hour;
  int minute;
  int second;
  static int counter;
};
```

```
…
#include "time.h"

Time::Time() : hour(0), minute(0), second(0) {
  counter++;
}

Time::Time(int h, int m, int s) :
 hour(h), minute(m), second(s) {
  counter++;
}
…
// Initialize static member variable
int Time::counter = 0;

// Define static member function
int Time::getCounter()
{
  return counter;
}
```

Example (continued)

```
#include <iostream>
#include "time.h"

using namespace std;

…

int main(void)
{
    cout << Time::getCounter() << "\n";
    Time t1;
    cout << Time::getCounter() << "\n";
    Time t2(10,0,0);
    cout << Time::getCounter() << "\n";

    return 0;
}
```

Output:

```
0
1
2
```

Extending Classes

- Just like Java, C++ supports class **inheritance**

- **Sub Class or Derived class** – a class that inherits member fields from another class

- **Super Class or Base Class** – a class whose fields are inherited by sub class

- **The sub class is said to extend the base class**

Extending Classes

- Syntax of extending a single base class:

```
class subclass_name : access_mode baseclass_name {
      class_member_list
};
```

  - *subclass_name* is the identifier given to the sub class being declared
  - *access_mode* controls the access of inherited fields
  - *baseclass_name* is the identifier of the super class being extended

Example

Base Class:

```
class Animal {
public:
  const char *getName() const;
  void sleep();
  void eat(int food);
  Animal();
  Animal(const char *);

protected:
  int age;

private:
  char name[100];
};
```

Sub Class:

```
class Dog : public Animal {
public:
  int bark(int loudness);
  int bite(int strength);
  void run(int speed);
  void eat(int food);
  Dog(const char *n) : Animal(n) {}

private:
  int skills;
};
```

Example

```
class Dog : public Animal {
public:
  int bark(int loudness);
  int bite(int strength);
  void run(int speed);
  void eat(int food);
  Dog(const char *n) : Animal(n) {}

private:
  int skills;
};
```

Access mode – controls access to inherited fields

Base class member access specifier	Access mode		
	public	protected	private
public	public	protected	private
protected	protected	protected	private
private	(Not accessible)		

Example

```
class Dog : public Animal {
public:
  int bark(int loudness);
  int bite(int strength);
  void run(int speed);
  void eat(int food);
  Dog(const char *n) : Animal(n) {}

private:
  int skills;
};
```

Member functions specific to sub class Dog

Member function present in base class - will be **overridden** by sub class

Member variable specific to sub class Dog

Example

```
class Dog : public Animal {
public:
  int bark(int loudness);
  int bite(int strength);
  void run(int speed);
  void eat(int food);
  Dog(const char *n) : Animal(n) {}

private:
  int skills;
};
```

Constructor of Dog invokes appropriate super class constructor

- Unlike Java, C++ does not have super keyword for invoking super class constructor

Overriding Member Functions

- Declare the member function to be overridden in the class declaration
  - Prototype must be exactly the same as member function to override
- Provide overriding implementation

How to invoke base class function:

```
class Dog : public Animal {
public:
  …
  // Overridden function
  void eat(int food);
  …
};
```

```
Animal::eat(10);
```

Within member function

```
Dog d;
d.Animal::eat(10);
```

From an instance

Abstract Classes

- A class that contains at least one **pure virtual function** member
- Abstract classes cannot be instantiated
  - Similar to Java interfaces
- Pure virtual functions must be implemented by a sub class that need to be instantiated (**concrete)**

```
class Shape {
public:
  // Pure virtual function
  virtual float draw() = 0;

  // Virtual function
  virtual int getSides() {
    return 1;
  }
};
```

Multiple Inheritance

- C++ supports multiple inheritance

- Syntax for extending multiple classes:

```
class subclass_name : access_mode1 baseclass_name1, … ,
  access_modeN baseclass_nameN {
      class_member_list
};
```

Example

- Suppose that Human and Dog are existing classes

```
class Werewolf : public Human, public Dog {
public:
  void transform();
  …
  Werewolf(const char *n) : Human(n), Dog(n) {}

private:
  int transformCount;
  …
};
```

Member Function Clash

- What happens if base classes of a derived class have a common member function?

```
class A : {
public:
  void foo();
  …
};

class B : {
public:
  void foo();
  …
};
```

```
class C : public A, public B {
  …
};
```

Class C must override foo(), example:

```
class C : public A, public B {
public:
  void foo() {
    A::foo(); // Use A's implementation of foo!
  }
};
```

Other Aspects of C++ Classes (For Self-Study)

- Operator overloading
- Friend functions and classes

Next Lectures

- Strings

- Pointers