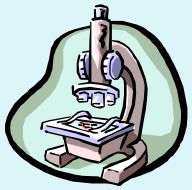
Storage Classes, Scope and Linkage

- ***Overview***

  - Focus is on the structure of a C++ program with
    - Multiple implementation files
    - Variables that must be shared among the files

  - How to
    - Compile separate files
    - Link them to create an executable

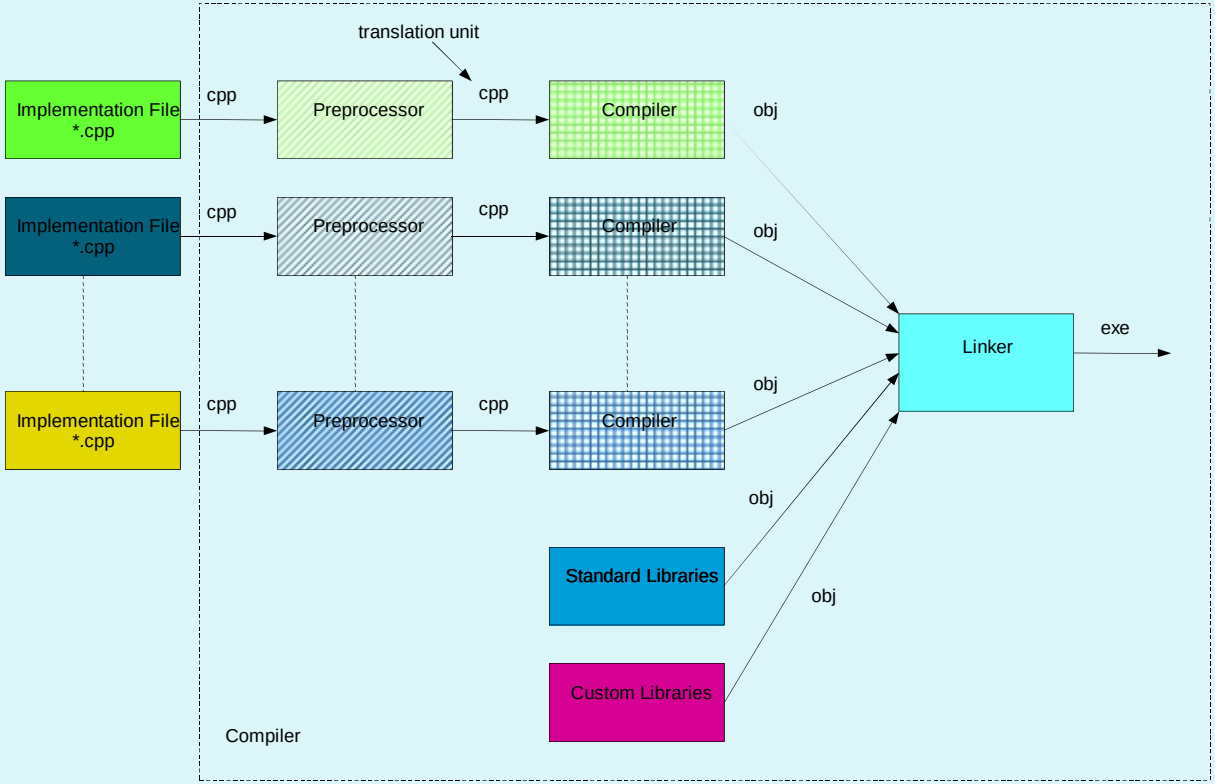


Storage Classes, Scope and Linkage

- ***Separate Compilation***
  - In today's large software systems many people are involved in developing
  - same program
  - Each individual works on only a piece of the program
    - ✓ A program comprised of all the implementation files.
    - ✓ The linker combines or links compiled files into the executable program
    - ✓ The entire process is called a *build*

Storage Classes, Scope and Linkage

- ***Separate Compilation***



Storage Classes, Scope and Linkage

- ***Separate Compilation***
  - Preprocessor locates each header file and places a copy of it in the
  - translation unit
    - Replacing the *#include* of that header file

    - Processes any other preprocessor directives
      - *#ifndef, #define*, etc

Storage Classes, Scope and Linkage

- ***Separate Compilation***
  - After the compiler compiles the translation unit to create the object file
    - The translation unit is deleted
    - Each tr
      - It car
      - trans

Calling *functionA()* when the code for *functionA()* is outside the translation unit produces an error...

Same is true for variables declared outside the translation unit

When this happens…the translation unit has an ***unresolved external reference***

Storage Classes, Scope and Linkage

- ***Linking***
  - Each implementation file is separately compiled to yield an object file
  - by a program called the *linker*
    - The linker
      - Reads each object file
      - Copies it to the executable program
  - ...At this time unresolved external references are resolved

Storage Classes, Scope and Linkage

- ***Linking***
  - When the linker fails to resolve an external reference
    - It generates an *unresolved external reference* error
    - Does not create the executable program

Storage Classes, Scope and Linkage

- ***Make Files***
  - The build process requires a place to contain the instructions for
    - Which files to compile
    - Lists of standard and custom libraries
    - The name of the executable program
    - Perhaps whether or not debugging information should be
    - included in the executable
  - Such a place called a *makefile*

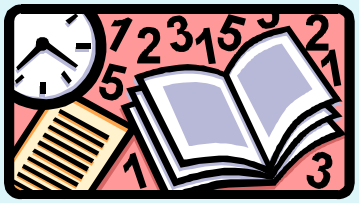
Storage Classes, Scope and Linkage

- ***Make Files***
  - The utility that ...
    - Reads the makefile
    - Calls up the preprocessor, compiler, and linker

is called the *make* utility

Storage Classes, Scope and Linkage

- ***Standard and Custom Libraries***
  - Compiler vendors provide libraries of compiled code to implement the
  - C++ programming language
    - These are called *standard libraries*
  - We may write our own library to contain our favorite functions
    - These are called *custom libraries*
  - As part of the make file...
    - ...we must specify the list of standard and custom libraries



Storage Classes, Scope and Linkage

- ***Standard and Custom Libraries***
  - Libraries are distributed with both a ...
    - Header file
    - Binary file containing the compiled code
  - We include
    - Header file in implementation file
    - Name of the library in the make file
  - Then we may make function calls into library functions.so are used

Storage Classes, Scope and Linkage

- ***Debug and Release Builds***
  - A build can include or exclude information that permits a debugger to
  - operate
    - If the debugger information is excluded, the executable is much smaller, however without debugger information, we can't debug
    - If the debugger information is included, the executable is much larger and slower, however debugger will operate

Storage Classes, Scope and Linkage

- ***Debug and Release Builds***
  - Usually a compiler switch toggles between release and debug builds
  - We must use caution when toggling between builds….
    - When we perform a debug build, we must be certain to use
    - debug libraries in build
    - Conversely with a release build we must be certain to use
    - release libraries
    - Reason
      - Memory allocators may be different between debug and
      - release builds

Storage Classes, Scope and Linkage

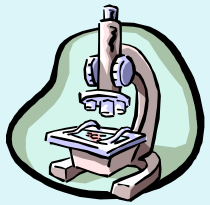
- ***Linkage, Scope, Storage Classes, and Specifiers***
  - The terms ...
    - Linkage,
    - Scope,
    - Storage classes,
    - Storage class specifiers
  - Often used interchangeably yet really have distinct meanings.

Storage Classes, Scope and Linkage

- ***Linkage***
  - There are two types of linkage *internal* and *external*
  - When a variable or a function has
    - Internal linkage
      - It can be used only in the implementation file in which it has
      - been defined...
      - ...it cannot be shared by code in another implementation file
    - External linkage
      - Means that the variable or function can be shared with
      - another implementation file.

Storage Classes, Scope and Linkage

- ***Scope***
  - Scope defines visibility….
    - Variables declared inside a function are only visible in that function their scope is the block of code of the function
    - Variables declared outside a function - an *external variable* visible to any function in the implementation file
      - *These external variables are commonly called global*
      - *variables*



Storage Classes, Scope and Linkage

- ***Storage Class***
  - Storage class describes where variables are stored
    - C++ has three storage classes...
      - ⇒ *automatic*
      - ⇒ *static*
      - ⇒ *freestore*

Storage Classes, Scope and Linkage

- ***Storage Class***
  - *Automatic Storage Class*
    - Variables with the *automatic* storage class are declared inside
    - functions
    - They have internal linkage and block scope
    - These variables only useable in the implementation file where
    - they are declared...
      - ...and further only within the block of code in which they are
      - declared

Storage Classes, Scope and Linkage

- ***Storage Class***
  - *Static Storage Class*
    - Variables with the *static* storage class are declared outside of any
    - function
    - These are *external* variables...
      - External variables are created before any use of the variable
      - External variables always have external linkage
      - External variables have the scope of the implementation file

Storage Classes, Scope and Linkage

- ***Storage Class***
  - *Freestore Storage Class*
    - Variables with the *freestore* storage class are those the
    - programmer creates
      - These variables have the linkage and scope of the pointer containing the address of the variable in freestore.
      - These variables exist until specifically deleted

Storage Classes, Scope and Linkage

- ***Storage Class***
  - *Storage Class Specifier*
    - Used to provide instructions to the compiler for modifying

      the

      - Storage class, linkage, or scope of a specific variable or
      - function
    - Storage class specifiers apply only to the automatic and static
    - storage classes

Storage Classes, Scope and Linkage

- ***Storage Class***
  - *Storage Class Specifier*
    - Stora iers are....

- auto
- register
- static
- extern

```
auto  int  data;
register  int  data;
static  int  data;
extern  int  data;
```

Storage Classes, Scope and Linkage

- ***Storage Class***
  - *Auto Storage Class Specifier*
    - The *auto* storage class specifier
      - Used only with variables to specify the *automatic* storage class
      - *auto* storage class defines
        - The variable will be stored on the *stack*
        - The variable will be local to the function using it
        - The compiler will destroy it automatically when it is no longer needed

Storage Classes, Scope and Linkage

- ***Storage Class***
  - *Auto Storage Class Specifier*

```
auto  int  aValue;              // Error. No auto variables outside a function

void FunctionA()
{
    auto  int  a;               // Ok. auto variables go on the stack
          int  b;               // Ok. auto is assumed
}
```

Storage Classes, Scope and Linkage

- ***Storage Class***
  - *Register Storage Class Specifier*
    - Instructs the compiler to keep a variable in a register within the processor if possible
    - With the variable in a processor register not in memory
      - Cannot take the address of a register variable
      - Cannot have a pointer to register variable
    - Register storage class is a *recommendation* to the compiler
    - Processing may be faster

Storage Classes, Scope and Linkage

- ***Storage Class***
  - *Register Storage Class Specifier*
    - Time to use this storage class is when a variable is going to be
    - accessed frequently in a very short period
    - Unless you are very aware of what you are doing, typically will
    - never use register storage class
    - ….Register variables are in a processor register
      - Cannot exist for the life of the program
      - Cannot declare a register variable outside a function
    - *To do so requires the static storage class which would require the*
    - *compiler to permanently reserve a processor register for the*
    - *variable…since this is not possible, a register declaration outside a*
    - *function is an error*

Storage Classes, Scope and Linkage

- ***Storage Class***
  - *Static Storage Class Specifier*
    - The *static* storage class specifier can be used with
      - Automatic or static variables
      - Functions
    - Confusion arises because...
      - Name of a storage class is *static* and
      - Name of the storage class specifier is also *static*

Storage Classes, Scope and Linkage

- ***Storage Class***
  - *Using the Static Storage Class Specifier*
    - Using the static storage class specifier on a variable that normally
    - would be automatic makes the variable static
    - Can use the static storage class specifier with variables declared
    - inside functions
    - When the function is called the first time....
      - Variable is created and initialized to zero
      - Remains in existence for the remainder of the program
      - Scope of the variable remains unchanged
      - Can be used only in the block that declared it

Storage Classes, Scope and Linkage

- **Storage Class**
  - Stat

```
void CountIt()
{
        int  count = 0;   // auto variable created on each CountIt call
        ++count;
}
```

```
void CountIt()
{
        static int  count = 0;          // variable created on first CountIt call
        ++count;
}
```

Storage Classes, Scope and Linkage

- ***Storage Class***
  - *Static Storage Class Specifier*
    - Static storage class specifier changes the linkage of static
    - variables to internal linkage
    - Such change can *only* occur with variables declared outside
    - functions
    - The scope of the variable remains unchanged
    - The variable can be used by any function in the implementation
    - file
    - Internal linkage prevents functions in other implementation files
    - from accessing the variable

Storage Classes, Scope and Linkage

- ***Storage Class***
  - *Static Storage Class Specifier*

Note: This use of the static storage class specifier is in C++ for backwards compatibility with C programs.

In C++, we would use a namespace to restrict access to a variable to the implementation file.

Namespaces are not covered in this course.

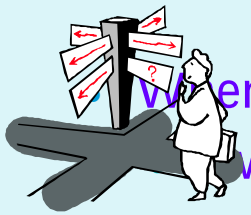
Storage Classes, Scope and Linkage

- ***Storage Class***
  - *Static Storage Class Specifier*
    - Using the static storage class specifier with a function limits the
    - scope of the function to the implementation file containing the
    - function
      - Only other functions in the same implementation file can call it
      - It is not possible to call a static function from outside the implementation file

```
static void functionA()
{
        // some processing
}
```

Storage Classes, Scope and Linkage

- ***Storage Class***
  - *Extern Storage Class*
    - The *extern* storage class specifier informs the compiler that the
    - variable is not defined in the current implementation file
    - The compiler will not check to see if it is actually declared



    - When this implementation file is compiled
      - will have an unresolved external reference
      - Reference will be left to the linker to resolve
      - The location where the variable is defined is not specified

Storage Classes, Scope and Linkage

- ***Storage Class***
  - *Extern Storage Class*
    - Using the *extern* storage class specifier prevents the compiler
    - from st
    - referen

```
void countIt()
{
        extern  int  count;          // count is declared outside this file
        ++count;
}
```

Storage Classes, Scope and Linkage

- ***Storage Class***
  - *Extern Storage Class*
    - The extern storage class specifier with a function works the same
    - as with a variable
    - Specifi
    - implem

```
extern void countIt();          // function not defined in this file
```

Storage Classes, Scope and Linkage

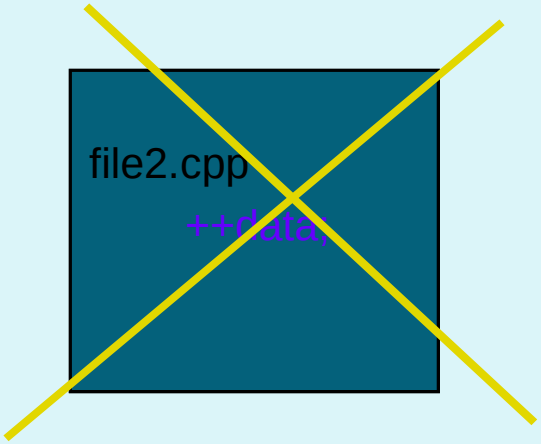
- ***Storage Class***
  - *Extern Storage Class*

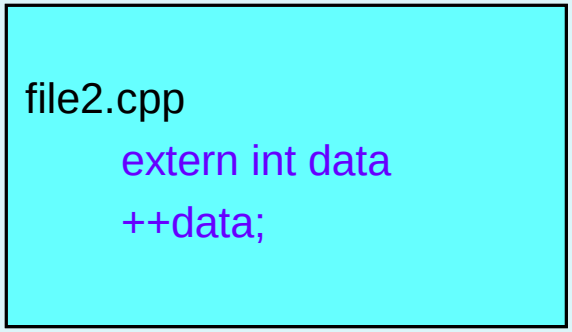
Note: Do not confuse the *extern* storage class specifier with *external* variables.

External variables are variables declared outside any function.

Storage Classes, Scope and Linkage

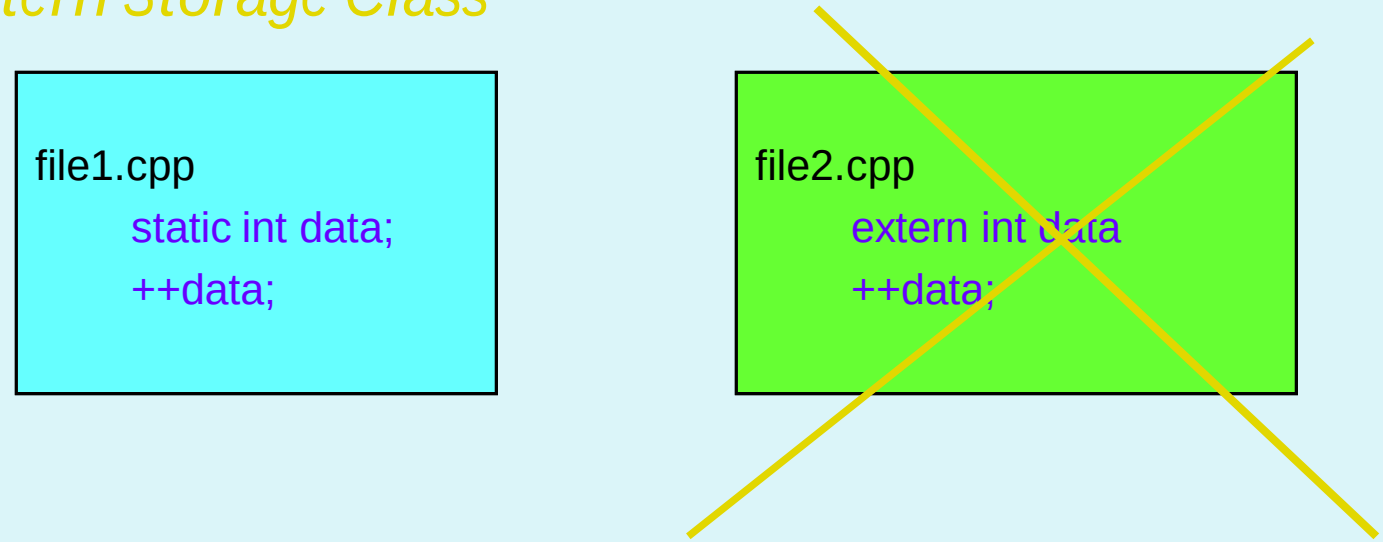
- **Storage Class**
  - *Exte ass*





Storage Classes, Scope and Linkage

- **Storage Class**
  - *Extern Storage Class*



Storage Classes, Scope and Linkage

- **Storage Class - Summary**

Specifier	Storage Class	Linkage	Scope
auto	automatic	internal	declaring block
register	automatic	internal	declaring block
--------	automatic	internal	declaring block
--------	static	external	global
static	static	internal	file or declaring block
extern	static	external	global or declaring block

Storage Classes, Scope and Linkage

- ***Const Revisited***
  - A global variable may be *const*:
    - const double PI = 3.14159;
  - Because a *const* variable must be initialized when it is created….
  - …. PI is initialized to 3.14159 when created
  - If we want to share this *const* variable from another implementation
  - file we would write
    - extern const int PI;
  - When the compiler compiles this file what value is assigned to PI?

Storage Classes, Scope and Linkage

- ***Const Revisited***
  - Answer is unknown ..... because PI is *extern*,
  - The declaration violates the *const* rule of initializing a variable with the
  - constant value when it is created....
  - ...as a result, the above line of code will generate an error
  - To use
    - const double PI = 3.14159;
  - In each implementation file we must declare it in each implementation
  - file
  - ....that is *const* global variables have *internal*, or local, linkage
- They behave as static variables

Storage Classes, Scope and Linkage

- ***Functions Revisited***
  - **Where C++ Finds Functions???**
    - When we make a function call, C++ locates the function
    - according to this decision logic

      - If the function is static
        - Will use the function in the implementation file
      - If the function is not static
        - Will use the function from another object file
      - If the function can't be found in the object file
        - Library definition will be used

Storage Classes, Scope and Linkage

- ***Functions Revisited***

  - When user specified function prototype matches the

    function

  - prototype of a library function

  - ...The user function will be selected over the library function

Storage Classes, Scope and Linkage

- ***Summary***

  - In this lesson we've studied

    - how to use multiple implementation files
    - how to construct a header file
    - how to use storage classes correctly
    - how share variables among implementation files