C/C++ Programming Language

CS205 Spring

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- Storage Duration, Scope, and Linkage
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  - 1. Automatic Storage Duration
  - 2. Static Duration Variables: External, Internal and No Linkage
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  - Functions Linkage
  - 3. Storage Schemes and Dynamic Allocation
- Summary

Brief Review

Content of Last Class

- Adventures in functions
  - Inline function
  - Reference variables
  - Default arguments
  - Function overloading
  - Function template

Separate Compilation

Separate Compilation

- C++ allows to locate the component functions of a program in separate files
  - Modify one file and then recompile just that one file
  - Make it easier to manage large programs
  - Most IDEs provide additional facilities to help with the management (The make programs in Unix and Linux systems)
- Divide the original program into three parts
  - A header file that contains the structure (type) declarations and prototypes for functions that use those structures (types)
  - A source code file that contains the code that define the structure (type) - related functions
  - A source code file that contains the code that calls the structure (type) - related functions

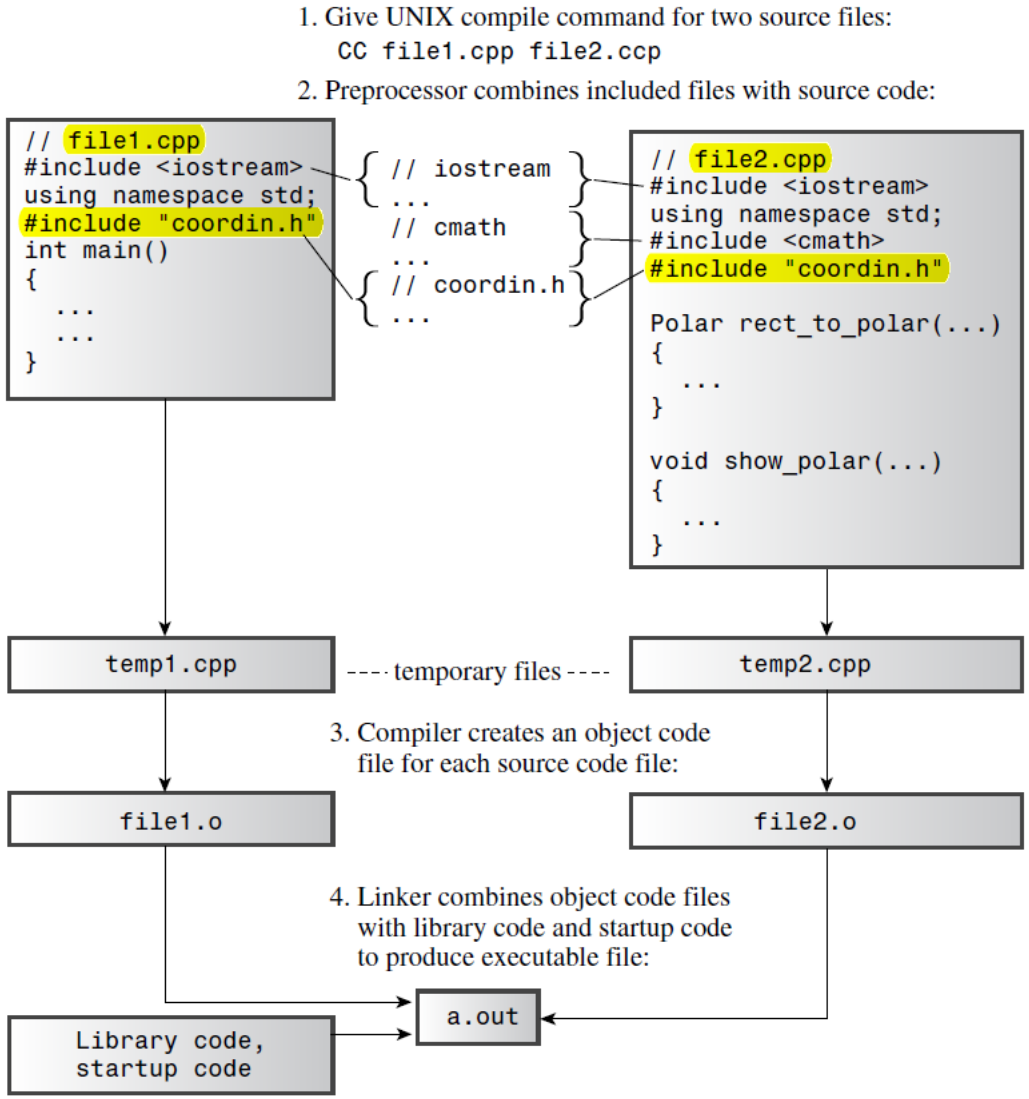
A Header File

- Shouldn't put function definitions or variable declarations into a header file
- Commonly found in header files
  - Function prototypes
  - Symbolic constants defined using #define or const (special linkage)
  - Structure declarations (not variable)
  - Class declarations
  - Template declarations (not code to be compiled)
  - Inline functions (special linkage)
- Don't add header files to the project list in IDEs
- Don't use #include to include source code files in other source code files

Header File Management

- You should include a header file just once in a file
- Most of the standard C and C++ header files use this guarding scheme

```
#ifndef COORDIN_H_
#define COORDIN_H_
// place include file contents here
#endif
```



Storage Duration, Scope, and Linkage

Storage

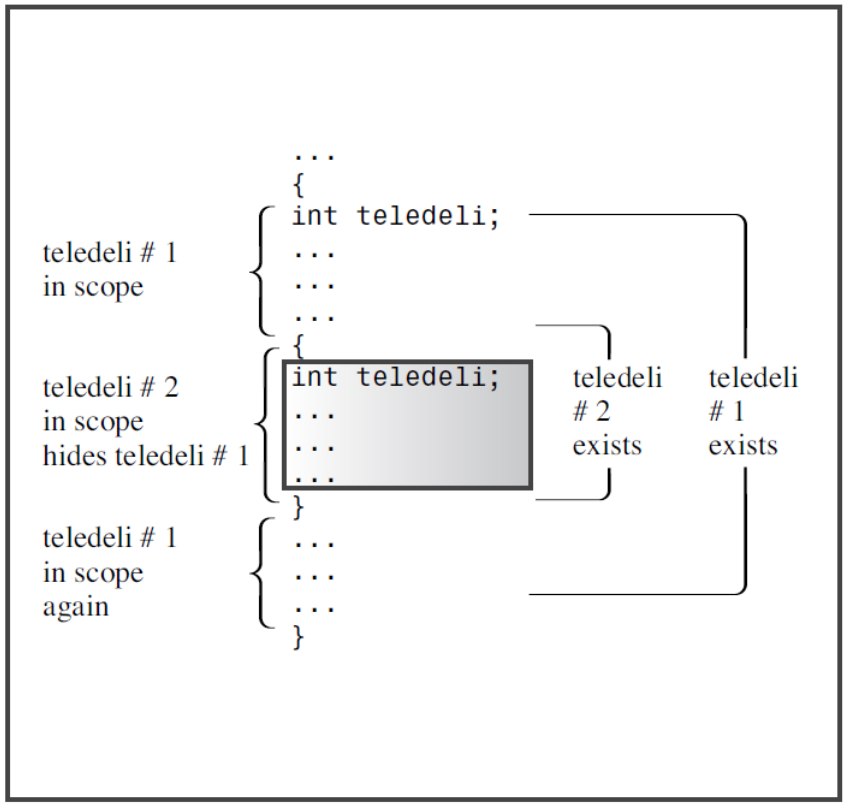
- Three plus one separate schemes for storing data
  - Automatic storage duration
    - ✓ Variables declared inside a function definition
    - ✓ They are created when program execution enters the function or block
    - ✓ The memory used for them is freed when execution leaves the function or block
  - Static storage duration
    - ✓ Using the keyword static to have static storage duration
    - ✓ Persist for the entire time a program is running
  - Dynamic storage duration
    - ✓ Memory allocated by the new operator persists until it is freed with the delete operator or until the program ends
  - Thread storage duration (C++11)
    - ✓ Allow a program to split computations into separate threads
    - ✓ Variables declared with the thread_local keyword have storage that persists for as long as the containing thread lasts

Scope and Linkage

- Scope: describe how widely visible a name is in a file
  - Local scope: within the block
  - Global (file) scope: throughout the file after the point
  - A function prototype scope: within the parentheses
  - Class scope
  - Namespace scope
- Linkage: describe how a name can be shared in different units
  - A name with external linkage can be shared across files
  - A name with internal linkage can be shared within a single file
  - Names of automatic variables have no linkage

1. Automatic Storage Duration

- Function parameters and variables declared inside a function have, by default, automatic storage duration
- Have local scope and no linkage



1. Two Variables: Automatic and Register

- Initialization of automatic variables
  - You can initialize an automatic variable with any expression whose value will be known when the declaration is reached
- Automatic variables and the stack (first-in-last-out)
  - Set aside a section of memory and treat it as a stack for managing the flow and ebb of variables
  - New data is figuratively stacked atop old data
  - Remove from the stack when a program is finished with it
- Register Variables
  - C originally introduced the register keyword to suggest that the compiler use a CPU register to store an automatic variable

2. Static Duration Variables

- C++, like C, provides static storage duration variables with three kinds of linkage
  - External linkage (accessible across files)
  - Internal linkage (accessible to functions within a single file)
  - No linkage (accessible to just one function or to one block)
- Properties of static variables
  - The number of static variables doesn't change
  - Doesn't need a special device such as a stack to manage them
  - Allocate a fixed block of memory to hold all the static variables
  - Stay present as long as the program executes

2. Declaring and Initializing Static Variables

- Examples of declaration
- Initialization
  - Zero-initialized,
  - Constant expression initialization
  - Dynamic initialization

```
...
int global = 1000;           // static duration, external linkage
static int one_file = 50;    // static duration, internal linkage
int main()
{
...
}
void funct1(int n)
{
    static int count = 0;  // static duration, no linkage
    int llama = 0;
...
}
void funct2(int q)
{
...
}
```

```
#include <cmath>
int x;                              // zero-initialization
int y = 5;                          // constant-expression initialization
long z = 13 * 13;                   // constant-expression initialization
const double pi = 4.0 * atan(1.0);  // dynamic initialization
```

- What determines which form of initialization takes place?
  - All static variables are zero-initialized
  - Do simple calculations if needed

2.1 Static Duration, External Linkage

- Static variables with external linkage
  - Have static storage duration and file scope
  - Be defined outside any function
- The one definition rule
  - Have to be declared in **each** file
  - Two kinds of variable declarations
    - ✓ Defining declaration
    - ✓ Referencing declaration
  - A referencing declaration uses the keyword extern
- See program example 1

```
// file1.cpp
#include <iostream>
using namespace std;

// function prototypes
#include "mystuff.h"

// defining an external variable
int process_status = 0;

void promise ();
int main()
{
   ...
}

void promise ()
{
   ...
}
```

This file defines the variable process_status, causing the compiler to allocate space for it.

```
// file2.cpp
#include <iostream>
using namespace std;

// function prototypes
#include "mystuff.h"

// referencing an external variable
extern int process_status;

int manipulate(int n)
{
   ...
}

char * remark(char * str)
{
   ...
}
```

This file uses extern to instruct the program to use the variable process_status that was defined in another file.

2.2 Static Duration, Internal Linkage

- Static variables with internal linkage
  - Applying the static modifier to a file-scope variable gives it internal linkage
  - A variable with internal linkage is local to the file that contains it
  - What if you want to use the same name to denote different variables in different files?
    - ✓ Add codes (int a_int = 1;) in program example 1

- See program example 2

2.3 Static Storage Duration, No Linkage

- Static variables with no linkage
  - Applying the static modifier to a variable defined inside a block
  - Exist even while the block is inactive
  - Preserve values between function calls
  - Subsequent calls to the function don't reinitialize the variable
- See program example 3

Specifiers and Qualifiers

- Specifiers:
  - auto (eliminated as a specifier in C++11)
  - register
  - static
  - extern
  - thread_local (added by C++11)
  - mutable: a particular member of a structure (or class) can be altered even if a particular structure (or class) variable is a const
- CV-Qualifiers (*cv* stands for const and volatile):
  - const
  - volatile: the value in a memory location can be altered even though nothing in the program code modifies the contents (A pointer to a hardware location. Or two programs may interact, sharing data)

The Five Kinds of Variable Storage

- Comparison: summarize the storage class features as used in the pre-namespace era

Storage Description	Duration	Scope	Linkage	How Declared
Automatic	Automatic	Block	None	In a block
Register	Automatic	Block	None	In a block with the keyword `register`
Static with no linkage	Static	Block	None	In a block with the keyword `static`
Static with external linkage	Static	File	External	Outside all functions
Static with internal linkage	Static	File	Internal	Outside all functions with the keyword `static`

More Linkage

- Functions
  - C/C++ does not allow you to define one function inside another
  - External linkage: all functions automatically have static storage duration
- Function linkage
  - Use the keyword extern in a function prototype (optional)
    - ✓Check the program example 1 without use of extern
  - Use the keyword static to give a function internal linkage, confining its use to a single file

3. Storage Schemes and Dynamic Allocation

- Dynamic memory
  - Controlled by the new and delete operators
  - Not by scope and linkage rules
  - Can be allocated from one function and freed from another function
- Initialization with the new operator
  - Built-in types:
    - ✓ Using ()

```
int *pi = new int (6);   // *pi set to 6
double * pd = new double (99.99);  // *pd set to 99.99
```

  - Structure or an array
    - ✓ Using {}

```
struct where {double x; double y; double z;};
where * one = new where {2.5, 5.3, 7.2};  // C++11
int * ar = new int [4] {2,4,6,7};         // C++11
```

  - Remember [] ?

3. new: Operators, Functions, and Replacement Functions

- The new and new[] operators call upon two allocation functions

```
void * operator new(std::size_t);      // used by new
void * operator new[](std::size_t);    // used by new[]
```

- The placement new operator
  - Allow to specify the location to be used
  - Deal with hardware that is accessed via a particular address or to construct objects in a particular memory location
- See program example 4
  - Include the new header file
  - Use new with an argument that provides the intended address

Summary

- A header file
- Header File Management (guarding scheme)
- Scope and Linkage
- 1. Automatic Storage Duration
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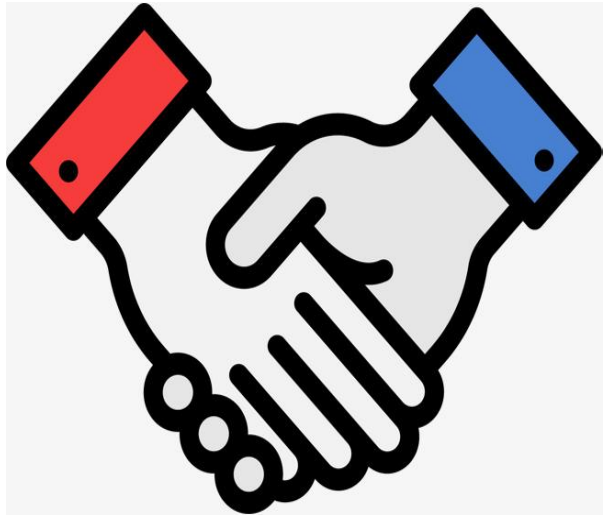

Thanks

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