Programming with C++

COMP2011: Separate Compilation

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Part I

Separate Compilation

Motivation Example: Mutual Recursion

```
#include <iostream>      /* File: odd-even.cpp */
using namespace std;

bool even(int);

bool odd(int x) { return (x == 0) ? false : even(x-1); }

bool even(int x) { return (x == 0) ? true : odd(x-1); }

int main()
{
    int x;
    cin >> x;            // Assume x > 0

    cout << boolalpha << odd(x) << endl;
    cout << boolalpha << even(x) << endl;

    return 0;
}
```

Divided We Win

- The odd-even example consists of 3 functions:
  - bool odd(int);
  - bool even(int);
  - int main();
- Now instead of putting them all in one .cpp file, we would like to put each function in a separate .cpp file of its own.
- There are good reasons for doing that:
  - We can then easily reuse a function in another program.
  - In a big project, programmers work in a team. After the program framework is designed in terms of a set of function prototypes, each programmer writes only some functions.
  - If a function needs to be changed, only one file needs to be modified.
- But how to compile the separate files into one single executable program?

Solution #1: Separate Compilation

- In order that each file can be separately compiled on its own, each file must know the existence of every variable, constant, function that it uses.
- All global constants, variables, functions that are *used* in a file "A" but are defined in another file "B" must be declared in file "A" before they are used in the file.
  - global constants: repeat their definitions
  - external variables: add the keyword extern
  - external functions: add their function prototypes. The keyword extern is optional since all C++ functions are global anyway.
- The keyword extern in front of a variable/function means that the variable/function is global and is defined in another file.
- Usually put all external declarations at the top of a file. Why?

Solution #1: Separate Compilation — main( )

```
#include <iostream>     /* File: main.cpp */
using namespace std;

/* Constant definitions */
const int MAX_CALLS = 100;

/* Global variable definition */
int num_calls;

/* Function declarations */
extern bool odd(int);   // "extern" is optional for functions

int main()
{
    int x;
    while (cin >> x)    // Assume x > 0
    {
        num_calls = 0; cout << boolalpha << odd(x) << endl;
    }

    return 0;
}
```

Solution #1: Separate Compilation — even( )

```
#include <iostream> /* File: even.cpp */
#include <cstdlib>
using namespace std;

/* Constant definitions */
const int MAX_CALLS = 100;

/* Global variable declarations */
extern int num_calls;   // "extern" is a must for global variables

/* External function declarations */
extern bool odd(int);   // "extern" is optional for functions

bool even(int x)
{
    if (++num_calls > MAX_CALLS)
    {
        cout << "max #calls exceeded\n"; exit(-1);
    }

    return (x == 0) ? true : odd(x-1);
}
```

Solution #1: Separate Compilation — odd( )

```
#include <iostream>     /* File: odd.cpp */
#include <cstdlib>
using namespace std;

/* Constants definitions */
const int MAX_CALLS = 200;

/* Global variable declarations */
extern int num_calls;   // "extern" is a must for global variables

/* Function declarations */
extern bool even(int);  // "extern" is optional for functions

bool odd(int x)
{
    if (++num_calls > MAX_CALLS)
    {
        cout << "max #calls exceeded\n"; exit(-1);
    }

    return (x == 0) ? false : even(x-1);
}
```

Solution #1: Separate Compilation Procedure 1

- Compile all the source .cpp files with the following command:

```
g++ -o odd-even main.cpp even.cpp odd.cpp
```

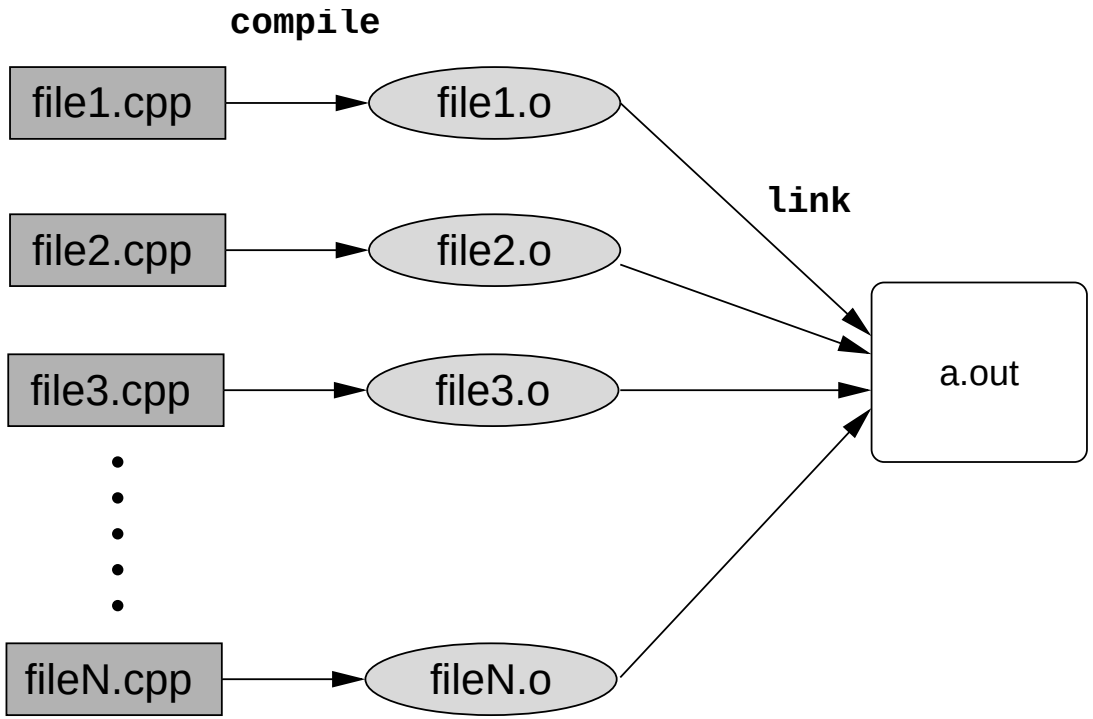
But this will again compile all files even if you may only change one of the file.

- Better to compile them separately:

```
g++ -c main.cpp
g++ -c even.cpp
g++ -c odd.cpp
g++ -o odd-even main.o even.o odd.o
```

- The command `g++ -c a.cpp` will produce an object file "a.o" for the source file "a.cpp".
- Then the final line `g++ -o odd-even main.o even.o odd.o` invokes the linker to link or merge the separate object files into one single executable program "odd-even".

Solution #1: Separate Compilation Procedure 2



- Now, if you later modify only "main.cpp", then you just need to re-compile "main.cpp" and re-link all object .o files.

```
g++ -c main.cpp
g++ -o odd-even main.o even.o odd.o
```

- In general, just re-compile those source files that are modified, and re-link all object files of the project.

Part II

Definition vs. Declaration and Header Files

Variable and Function Definition

A definition introduces the name and type of an identifier such as a variable or a function.

- A variable definition requires the compiler to reserve an amount of memory for the variable as required by its type.
- A variable may also be initialized in its definition. For instance, `int x = 5;` .
- A function definition generates machine codes for the function as specified by its (function) body.
- In both cases, definition causes memory to be allocated to store the variable or function.
- A variable and function identifier must be defined exactly once in the whole program even if the program is written in separate files.

Variable and Function Declaration

The declaration of a variable or function announces that the variable or function exists and is defined somewhere — in the same file, or in a separate file.

- A variable's declaration consists of the its name and type preceded by the keyword extern. No initialization is allowed.
- A function's declaration consists of the its prototype, and may be optionally preceded by the keyword extern.
- A declaration does not generate codes for a function, and does not reserve memory for a variable.

Variable and Function Declaration ..

- There can be many declarations for a variable or function in the whole program.
- An identifier must be defined or declared before it can be used.
- During separate compilation, the compiler generates necessary information so that when the linker combines the separate object files, it can tell that the variable/function declared in a file is the same as the global variable/function defined in another file, and they should share the same memory or codes.

Header Files

- In Solution#1, you see that many global variable or function declarations are repeated in "odd.cpp" and "even.cpp". That is undesirable because:
  - We are lazy, and we do not want to repeat writing the same declarations in multiple files.
  - Should a declaration require updating, one has to go through all files that have the declaration and make the change.
  - More importantly, maintaining duplicate information in multiple files is error-prone.
- The solution is to use .h header files which contains
  - definitions of global variables and constants
  - declarations of global variables and functions
- Header files are inserted to a file by the preprocessor directive #include.

```
#include <iostream> // standard library header files
#include "my_include.h" // user-defined header files
```

Solution #2: Separate Compilation — Header Files

```
/* File: my_include.h */
/* Include system or user-defined header files */
#include <iostream>
#include <cstdlib>
using namespace std;

/* Constant definitions */
const int MAX_CALLS = 100;

/* External function declarations */
extern bool odd(int); // "extern" is optional for functions
extern bool even(int);
```

```
/* File: global.h */
/* Global variable definitions */
int num_calls;
```

```
/* File: extern.h */
/* External global variable declarations */
extern int num_calls;
```

Solution #2: Separate Compilation — main( )

```
#include "my_include.h" /* File: main.cpp */
#include "global.h"

int main()
{
    int x;
    while (cin >> x) // assume x > 0
    {
        num_calls = 0;
        cout << boolalpha << odd(x) << endl;
    }

    return 0;
}
```

Solution #2: Separate Compilation — even( )

```
#include "my_include.h" /* File: even.cpp */
#include "extern.h"

bool even(int x)
{
    if (++num_calls > MAX_CALLS)
    {
        cout << "max #calls exceeded\n";
        exit(-1);
    }

    return (x == 0) ? true : odd(x-1);
}
```

Solution #2: Separate Compilation — odd( )

```
#include "my_include.h" /* File: odd.cpp */
#include "extern.h"

bool odd(int x)
{
    if (++num_calls > MAX_CALLS)
    {
        cout << "max #calls exceeded\n";
        exit(-1);
    }

    return (x == 0) ? false : even(x-1);
}
```

Header Files of the Standard C++ Libraries

- iostream: input/output functions
- iomanip: input/output manipulation functions
- cctype: character functions
  e.g. int isdigit(char); int isspace(char); int isupper(char);
- cstring C string functions:
  e.g. int strlen(const char []);
  int strcmp(const char [], const char []);
- cmath: math functions
  e.g. double sqrt(double); double cos(double);
- cstdlib: commonly used functions
  e.g. int system(const char []); int atoi(const char []);
  void exit(int); int rand( ); void srand(unsigned int);