Splitting C Programs into Multiple Files

- All our programs so far are written in a single file
- But programs can be very big!
  - E.g., Linux-2.6.0 contains 5,929,913 lines of C code
- Let’s split our programs into multiple source files
  - Easier to write and update
  - Especially with multiple programmers
    - Each programmer writes into his/her own file
  - It is easier to recompile
    - If you change a small part of the program, you can recompile just the part that has changed
Modular C Programming

- A C program usually contains:
  - Multiple .c files: contain the functions and global variables
  - Multiple .h files: contain declarations of functions, types and variables
- Unlike in Java, you can put as many functions/variables/types per file as you want
  - It is up to you to organize everything
  - But there are general rules that will help you...
  - Most important: keep related things in a single file

Definition vs Declaration

- A definition actually creates a function/variable and gives it a value
  - “From now on, variable foo of type int will be created”
  - “From now on, function baz() will have the following prototype and realize the following operations”

```c
int foo;

double baz(double x, double y) {
    return x*x + y*y;
}
```

- A declaration simply informs the compiler that something does exist
  - “Trust me, it will be defined somewhere else”

```c
extern int foo;

double baz(double, double); // no function code here! */
Calling an External Function

- If you want to call a function in a piece of code, you must first declare the prototype of the function.
  - You do not need to write the full code of the function.
  - A prototype (i.e., interface) is enough.
  - Of course, the code of the function must be present in another file of the program.

```c
int this_func_is_defined somewherewhere_else(char *);

int foo() {
  return this_func_is_defined somewherewhere_else("foo");
}
```

- A function must be **defined** only once in a program.
  - Otherwise the compiler wouldn’t know which one to use.
- But it can be **declared** any number of times.
  - Provided all declaration are the same...

Using an External Variable

- To use a (global) variable defined in another file you must first declare it.
  - Attention: you must define the variable only once.

```c
/* file1.c */
extern int my_variable; /* the variable is declared but not defined */
int foo() {
  return my_variable++;
}

/* file2.c */
int my_variable; /* the variable is declared and defined here */
```
Using Header Files

- Some information must be present in multiple files
  - Better to write them only once in a "header" file
  - And include the header file wherever it is needed
- Header files (*.h) should contain:
  - Function prototypes
  - Type declaration
  - Global variable declarations (but not definitions!)
- C files (*.c) should contain:
  - #include <standard_files.h>
    * Includes files from /usr/include, /usr/local/include etc.
  - #include "header_files.h"
    * Includes files from the working directory
  - Function code (definitions)
  - Global variable (definitions)
- Each C file usually has its corresponding header file...

Example

- A program that exchanges messages across a network
Example

A program that exchanges messages across a network

```c
#include <stdio.h>

struct message {
    char buf[1024];
    int length;
};

struct message *create_message(char *message);
```

message.h

- `message.h` contains:
  - The declaration of `struct message`
  - The declaration of function `create_message()`

```c
#define MESSAGE_H_
#define _MESSAGE_H_

#include <stdio.h>

struct message {
    char buf[1024];
    int length;
};

struct message *create_message(char *message);
```

```c
#define /* _MESSAGE_H_ */
```
message.c

- message.c:
  - Includes standard header files string.h and stdlib.h (they contain the prototypes of strcpy and malloc)
  - Includes header file message.h (it contains the declaration of struct message)
  - Defines function create_message

```c
#include <string.h>
#include <stdlib.h>
#include "message.h"

struct message *create_message(char *message) {
    struct message *m = (struct message *) malloc(sizeof(struct message));
    strcpy(m->buf, message);
    return m;
}
```

network.h

```c
#ifndef NETWORK_H_
#define NETWORK_H_

#include "message.h" /* why is this required? */

struct address {
    char ip[16];
    int port;
};

struct address *create_address(char *ip);
int send_message(struct message *m, struct address *dest);
int recv_message(struct message *m, struct address *from);
#endif /* NETWORK_H_ */
```
network.c

#include "network.h"
#include "main.h"

struct address *create_address(char *ip) {
    struct address *a = (struct address*) malloc(sizeof(struct address));
    strcpy(a->ip, ip);
    a->port = port_ab;
    return a;
}

int send_message(struct message *m, struct address *dest) {
    /* ... */
}

int recv_message(struct message *m, struct address *from) {
    /* ... */
}

- Can you guess what main.h contains?
- Why don’t we include message.h?
- What would happen if we included it?

main.h

#ifdef __MAIN_H__
#define __MAIN_H__

extern int port_ab; /* Declare the global variable */
/* Do we need to declare the prototype of function main() here? */
#endif /* __MAIN_H__ */
main.c

```c
#include "main.h"
#include "network.h"

int port_nb; /* instantiate the global variable */

int main()
{
    struct message *m = create_message("Hello, world!");
    struct address  *a = create_address("190.37.103.66");
    send_message(m, a);
    recv_message(m, a);
    printf("Received: %s\n", m->buf);
}
```

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Compiling it All Together

- Compile each C file separately into an **object** file

  ```bash
  $ gcc -c -Wall message.c  
  $ gcc -c -Wall network.c  
  $ gcc -c -Wall main.c  
  $  
  ```

  **This creates files message.o, network.o and main.o.**

- Link all object files into an executable

  ```bash
  $ gcc message.o network.o main.o  
  $  
  ```

  **This creates file a.out**
Compiling it All Together

- One object file must define a `main()` function:

```bash
$ gcc message.o network.o main.o
/usr/lib/gcc/i386-unknown-linux/3.4.2/.../.../lib64/crt1.o(.text+0x21): In function `start':
  undefined reference to `main'
collect2: ld returned 1 exit status
```

- All functions and variables must be defined:

```bash
$ gcc message.o network.o main.o
main.o(.text+0xa): In function `main':
  undefined reference to `create_message'
collect2: ld returned 1 exit status
```

- They must be defined only once:

```bash
$ gcc message.o network.o main.o
network.o(.text+0x0): In function `create_message':
  multiple definition of `create_message'
message.o(.text+0x0): first defined here
collect2: ld returned 1 exit status
```

Building Complex Programs

- Imagine that you write a program split into 100 C files and 100 header files
  - To compile your program, you must call gcc 101 times (perhaps with long option lines)
- What happens when you update one of these files?
  - You can recompile everything from scratch
    * But it takes a lot of time
  - You can decide to recompile only the parts which have changed
    * Much faster!
  - What happens if the updated file is a header file?
    * You must recompile all C files which include it
    * This is getting quite complex...
- **make** is a standard tool which will do the job for you
Using make

- To use make, you must write a file called Makefile
  - It defines dependencies between files...
  - ...and the command to generate each file from its dependencies

```bash
# This is a comment
main: message.o network.o main.o
    gcc -o main main.o message.o network.o

message.o: message.c message.h
    gcc -c -Wall message.c

network.o: network.c network.h message.h
    gcc -c -Wall network.c

main.o: main.c main.h network.h message.h
    gcc -c -Wall main.c
```

- `\t` means “tab”: you cannot use spaces there!

Using make

- If you type `make main`, make will do all that is necessary to generate file main:
  - To generate main, I first need to have files message.o, network.o and main.o.
  - These files do not exist, let's try to create them
  * To generate message.o I first need to have files message.c and message.h.
  * OK, I already have them.
  * Let's generate message.o by calling gcc -c message.c
  * To generate network.o I first need to have files network.c, network.h and message.h
  * etc...
  - Let's generate file main by calling gcc -o main main.o message.o network.o
Using make to re-compile a program

- If you update a few files, you want to recompile just what is necessary
  - make will check the dates of your files:

<table>
<thead>
<tr>
<th>target: dependency1 dependency2 dependency3</th>
</tr>
</thead>
<tbody>
<tr>
<td>command</td>
</tr>
</tbody>
</table>

- If you updated dependency1 after target was generated, then you must re-generate target
- If the target is more recent than all its dependencies, then no re-generation is necessary

- You must not forget dependencies!
  - Otherwise, make will not recompile all that is necessary

Generating Dependencies

- makedepend will generate dependencies automatically
  - Just create one more rule:

  depend:

  \[ \rightarrow \text{makedepend } \text{message.c network.c main.c} \]

  - It will read files message.c, network.c and main.c and generate dependencies automatically
  - Dependencies will be added at the end of your Makefile:

  * DO NOT DELETE

  ```
  main.o: /usr/include/stdio.h /usr/include/features.h /usr/include/sys/consts.h
  main.o: /usr/include/gnu/stubs.h
  main.o: /usr/lib/gcc/x86_64-redhat-linux/3.4.2/include/stubdef.h
  main.o: /usr/include/bits/types.h /usr/include/bits/wordsize.h
  main.o: message.h /usr/include/string.h network.h
  network.o: network.h message.h /usr/include/string.h /usr/include/features.h
  network.o: /usr/include/sys/consts.h /usr/include/gnu/stubs.h
  network.o: /usr/lib/gcc/x86_64-redhat-linux/3.4.2/include/stddef.h
  # etc...
  ```
Implicit Rules

- Very often, the command to compile a given type of files is the same:
  - `gcc -c FOO.c`
  - All *o files depend on the corresponding *.c file and are generated using the command `gcc -c XXX.c`

<table>
<thead>
<tr>
<th><code>%o</code></th>
<th><code>%c</code></th>
</tr>
</thead>
</table>
| gcc `-c ` | `&lt;` | `-o` | `$0`

- `$<` means "the name of the dependency file" (here: `FOO.c`)
- `&$0` means "the name of the target" (here: `FOO.o`)

Using Variables in Makefiles

- You can create variables in your Makefiles
  - The list of all your *.c files, etc.

```makefile
CC     = gcc
CFLAGS = -g -Wall
SRC    = main.c network.c message.c
OBJ    = main.o network.o message.o

main: $(OBJ)  
  $(CC) -o $@ $(OBJ)

%.o: %.c  
  $(CC) $(CFLAGS) -c $<

depend:  
  rm -f depend $(SRC)

clean:  
  # We can write rules which do not create any file
  rm main *.o
```
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