Chapter 15

Writing Large Programs

Source Files

- A `C` program may be divided among any number of ***source files***
- By convention, source files have the extension `.c`
- Each source file contains part of the program, primarily definitions of functions and variables
- One source file must contain a function named `main`, which serves as the starting point for the program

Source Files

- Consider the problem of writing a simple `calculator` program
- The program will evaluate integer expressions entered in ***Reverse Polish notation*** (***RPN***), in which *operators follow operands*
  - RPN was introduced in 1954 to reduce computer memory access
  - RPN was widely used in the 1970s and 1980s in handheld calculators
- If the user enters an expression such as

  ```
  30 5 - 7 *
  ```

  the program should print its value (175, in this case)

Source Files

- The program will read ***operands*** and ***operators***, one by one, using a *stack* to keep track of intermediate results
  - If the program reads a number, it will *push* the number onto the stack
  - If the program reads a binary operator, it will *pop* two numbers from the stack, perform the operation, and then push the result back onto the stack
- When the program finishes evaluating the user's input, the value of the expression will be on the top of the stack

Source Files

- How the expression `30 5 - 7 *`: will be evaluated:
  1. *Push* 30 onto the stack
  2. *Push* 5 onto the stack
  3. *Pop* the top two numbers from the stack, subtract 5 from 30, giving 25, and then *push* the result back onto the stack
  4. *Push* 7 onto the stack
  5. *Pop* the top two numbers from the stack, multiply them, and then *push* the result back onto the stack
- The stack will now contain 175, the value of the expression

Source Files

- The program's `main` function will contain a loop that performs the following actions:
  - Read a *token* (*a number* or *an operator*)
  - If the *token is a number*
    - *push* it onto the stack
  - If the *token is an operator*
    - *pop* its operands from the stack,
    - *perform* the operation, and
    - *push* the result back onto the stack
- When dividing such a program into files, it makes sense to put related functions and variables into the same file

Source Files

- The function that reads tokens could go into one source file (**`token.c`**, say), together with any functions that have to do with tokens
- Stack-related functions such as `push`, `pop`, `make_empty`, `is_empty`, and `is_full` could go into a different file, **`stack.c`**
- The variables that represent the stack would also go into **`stack.c`**
- The `main` function would go into yet another file, **`calc.c`**

Source Files

- Splitting a program into multiple source files has significant advantages:
  - Grouping related functions and variables into a single file helps clarify the structure of the program
  - Each source file can be compiled separately, which saves time
  - Functions are more easily reused in other programs when grouped in separate source files

Header Files

- Problems that arise when a program is divided into several source files:
  - How can a function in one file *call a function* that is *defined in another file*?
  - How can a function access an *external variable* in another file?
  - How can two files *share* the same *macro definition* or *type definition*?
- ***The answer*** lies with the `#include` directive, which makes it possible *to share information* among any number of source files

Header Files

- The `#include` directive tells the preprocessor to insert the contents of a specified file
- Information to be shared among several source files can be put into such a file
- `#include` can then be used to bring the file's contents into each of the source files
- Files that are included in this fashion are called ***header files*** (or sometimes ***include files***)
- By convention, header files have the extension `.h`

The `#include` Directive

- The `#include` directive has two primary forms
  - The first is used for header files that belong to **C**'s own library:
    `#include <`*filename*`>`
  - The second is used for all other header files:
    `#include "`*filename*`"`
- The ***difference*** between the two has to do with *how* the compiler *locates* the header file

The `#include` Directive

- Typical rules for locating header files:
  - `#include <`*filename*`>`:
    - Search the directory (or directories) in which system header files reside
  - `#include "`*filename*`"`:
    - Search the *current directory*, ***then***
    - Search the directory (or directories) in which system header files reside
- The ***places*** to be searched for header files ***can be altered*** by a *command-line option* such as `-I`*path*

The `#include` Directive

- Do not use brackets when including header files that you have written:

```
#include <myheader.h>    /*** WRONG ***/
```

- The preprocessor will look for `myheader.h` where the system header files are kept

The `#include` Directive

- The file name in an `#include` directive may include information that helps locate the file, such as a directory path or drive specifier:

```
#include "c:\cprogs\utils.h"
  /* Windows path */

#include "/cprogs/utils.h"
  /* UNIX path */
```

- Although the quotations in the `#include` directive make ***file names look like string literals***, ***the preprocessor does not treat them that way***

The `#include` Directive

- It is usually best ***not*** to include full path or drive information in `#include` directives
- ***Bad examples*** of Windows `#include` directives:

```
#include "d:utils.h"
#include "\cprogs\include\utils.h"
#include "d:\cprogs\include\utils.h"
```

- ***Better versions***:

```
#include "utils.h"
#include "..\include\utils.h"
```


The `#include` Directive

- The `#include` directive has a third form:

  `#include` *tokens*

  tokens is any sequence of *preprocessing tokens*
- The preprocessor will scan the tokens and replace any macros that it finds
- After macro replacement, the resulting directive must match one of the other forms of `#include`
- The advantage of the third kind of `#include` is that the file name can be ***defined by a macro*** rather than being ***hard-coded*** into the directive itself

The `#include` Directive

- Example:

```
#if defined(IA32) //Intel Architecture, 32 bit
  #define CPU_FILE "ia32.h"
#elif defined(IA64)//Intel Architecture, 64 bit
  #define CPU_FILE "ia64.h"
#elif defined(AMD64)
  #define CPU_FILE "amd64.h"
#endif

#include CPU_FILE
```


Sharing Macro Definitions and Type Definitions

- Most large programs contain macro definitions and type definitions that need to be shared by several source files
- These definitions should go into header files

Sharing Macro Definitions and Type Definitions

- Suppose that a program uses macros named `BOOL`, `TRUE`, and `FALSE`
- Their definitions can be put in a header file with a name like `boolean.h`:

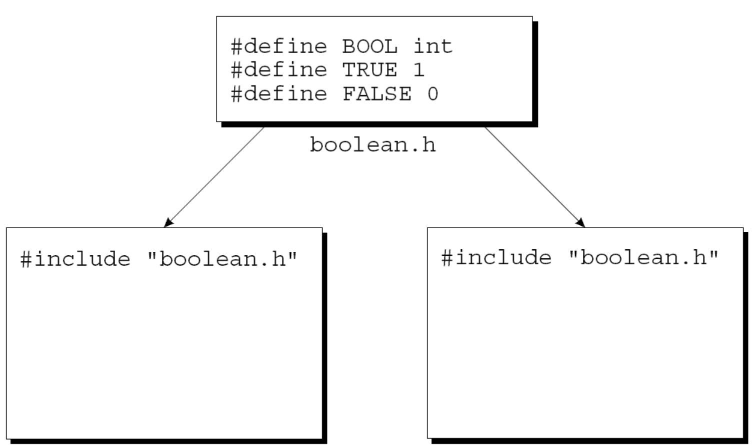
```
#define BOOL int
#define TRUE 1
#define FALSE 0
```

- Any source file that requires these macros will simply contain the line

```
#include "boolean.h"
```


Sharing Macro Definitions and Type Definitions

- A program in which two files include `boolean.h`:



Sharing Macro Definitions and Type Definitions

- Type definitions are also common in header files
- For example, instead of defining a `BOOL` macro, we might use `typedef` to create a `Bool` type
- If we do, the `boolean.h` file will have the following appearance:

```
#define TRUE 1
#define FALSE 0
typedef int Bool;
```


Sharing Macro Definitions and Type Definitions

- Advantages of putting definitions of macros and types in header files:
  - Saves time
    - We do not have to copy the definitions into the source files where they are needed
  - Makes the program easier to modify
    - Changing the definition of a macro or type requires editing a single header file
  - Avoids inconsistencies
    - Source files containing different definitions of the same macro or type may cause inconsistency

Sharing Function Prototypes

- Suppose that a source file contains a call of a function `f` that is defined in another file, `foo.c`
- Calling `f` without declaring it first is risky
  - The compiler assumes that `f`'s return type is `int`
  - It also assumes that the number of parameters matches the number of arguments in the call of `f`
  - The arguments themselves are converted automatically by the default argument promotions

Sharing Function Prototypes

- Declaring `f` in the file where it is called solves the problem but can create a maintenance nightmare
- A *better solution* is to put `f`'s prototype in a header file (`foo.h`), then include the header file in all the places where `f` is called
- We will also need to include `foo.h` in `foo.c`, enabling the compiler to check that `f`'s prototype in `foo.h` matches its definition in `foo.c`

Sharing Function Prototypes

- If `foo.c` contains other functions, most of them should be declared in `foo.h`
- Functions that are intended for use only within `foo.c` should not be declared in a header file, otherwise; it would be misleading

Sharing Function Prototypes

- The *RPN* calculator example can be used to illustrate the use of function prototypes in header files
- The `stack.c` file will contain definitions of the `make_empty`, `is_empty`, `is_full`, `push`, and `pop` functions
- Prototypes for these functions should go in the `stack.h` header file:

```
void make_empty(void);
int is_empty(void);
int is_full(void);
void push(int i);
int pop(void);
```

Sharing Function Prototypes

- We will include `stack.h` in `calc.c` to allow the compiler to check any calls of stack functions that appear in the latter file
- We will also include `stack.h` in `stack.c` so the compiler can verify that the prototypes in `stack.h` match the definitions in `stack.c`

Sharing Function Prototypes

```
void make_empty(void);
int is_empty(void);
int is_full(void);
void push(int i);
int pop(void);
```

stack.h

```
#include "stack.h"

int main(void)
{
  make_empty();
  …
}
```

calc.c

```
#include "stack.h"

int contents[100];
int top = 0;

void make_empty(void)
{ … }

int is_empty(void)
{ … }

int is_full(void)
{ … }

void push(int i)
{ … }

int pop(void)
{ … }
```

stack.c

Sharing Variable Declarations

- *To share a function* among files,
  - we put its *definition* in one source file, then
  - we put its *declaration* (i.e., its *prototype*) in other files that need to call the function
- ***Sharing*** an ***external variable*** is done in much the same way

Sharing Variable Declarations

- An example that both *declares* and *defines* `i` (causing the compiler to set aside space):

```
int i;
```

- The keyword `extern` is used to *declare* a variable *without defining* it:

```
extern int i;
```

- `extern` informs the compiler that `i` is *defined elsewhere* in the program, so there is no need to allocate space for it

Sharing Variable Declarations

- When we use `extern` in the declaration of an array, we can omit the length of the array:

```
extern int a[];
```

- Since the compiler does not allocate space for `a` at this time, there is no need for it to know `a`'s length

Sharing Variable Declarations

- To share a variable `i` among several source files, we first put a *definition* of `i` in ***one*** file:

```
int i;
```

- If `i` needs to be initialized, the initializer would go here
- The other files will contain *declarations* of `i`:

```
extern int i;
```

- By declaring `i` in each file, it becomes possible to access and/or modify `i` within those files

Sharing Variable Declarations

- When declarations of the same variable appear in different files, *the compiler can not check that the declarations match the variable's definition*
- For example, one file may contain the definition

  ```
  int i;
  ```

  while another file contains the declaration

  ```
  extern long i;
  ```

- An error of this kind *will be caught during the linking phase*

Sharing Variable Declarations

- To avoid inconsistency, ***declarations*** of shared variables are usually put in *header files*
- A source file that *needs access* to a particular variable can then *include the appropriate header file*
- In addition, each *header file that contains a variable* ***declaration*** is included in the *source file that contains the variable's* ***definition***, enabling the ***compiler*** to check that the two match

Nested Includes

- A header file itself may contain another `#include` directives
- For example, `stack.h` contains the following prototypes:

```
int is_empty(void);
int is_full(void);
```

- Since these functions return only `0` or `1`, it is a good idea to declare their return type to be `Bool`:

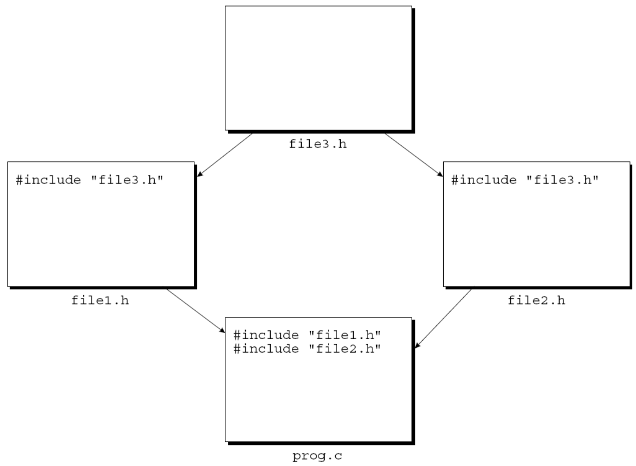
```
Bool is_empty(void);
Bool is_full(void);
```

- We will need to include the `boolean.h` file in `stack.h` so that the definition of `Bool` is available when `stack.h` is compiled

Protecting Header Files

- If a source file includes the same header file twice, compilation errors ***may*** result
- This problem is common when header files include other header files
- Example, see next page

Protecting Header Files



- When `prog.c` is compiled, `file3.h` will be compiled twice

Protecting Header Files

- Including the same header file twice *does not always cause a compilation error*
- If the file contains only *macro definitions*, *function prototypes*, and/or *variable declarations*, there will not be any difficulty
- If the file contains a ***type definition***, however, we will get a compilation error

- Just to be safe, it is probably a good idea to ***protect*** all header files against multiple inclusion

Protecting Header Files

- To protect a header file, we will enclose the contents of the file in an `#ifndef` – `#endif` pair
- Example: To protect the `boolean.h` file:

```
#ifndef BOOLEAN_H
#define BOOLEAN_H

#define TRUE 1
#define FALSE 0
typedef int Bool;

#endif
```


Protecting Header Files

- Making the name of the macro resemble the name of the header file is a good way to avoid conflicts with other macros
- Since we can not name the macro `BOOLEAN.H` (***why?***), a name such as `BOOLEAN_H` is a good alternative

Dividing a Program into Files

- Designing a program involves
  - determining the functions needed and
  - arranging these functions into logically related groups
- Once a program has been designed, there is a simple technique for dividing it into files

Dividing a Program into Files

- Each set of functions will go into a separate source file (`foo.c`)
- Each source file will have a matching header file (`foo.h`)
  - `foo.h` will contain prototypes for the functions defined in `foo.c`
  - Functions to be used only within `foo.c` should not be declared in `foo.h`
- `foo.h` will be included in each source file that needs to call a function defined in `foo.c`
- `foo.h` will also be included in `foo.c` so the compiler can check that the prototypes in `foo.h` match the definitions in `foo.c`

Dividing a Program into Files

- The `main` function will go in a file whose name matches the name of the program
- It is possible that there are other functions in the same file as `main`, as long as they are not called from other files in the program

Program: Text Formatting

- Let us apply this technique to a small *text-formatting* program named `justify`
- Assume that a file named `quote` contains the following sample input:

```
   C     is quirky,  flawed,    and  an
enormous   success.      Although accidents of   history
 surely  helped,   it evidently    satisfied   a   need

   for  a   system  implementation    language    efficient
 enough   to  displace         assembly   language,
   yet sufficiently   abstract   and fluent    to describe
  algorithms    and     interactions    in a    wide    variety
of   environments.
                     --      Dennis     M.        Ritchie
```

Program: Text Formatting

- To run the program from a Unix or Windows prompt, we would enter the command

```
justify < quote
```

- The `<` symbol informs the operating system that `justify` will read from the file `quote` instead of accepting input from the keyboard
- This feature, supported by Unix, Windows, and other operating systems, is called ***input redirection***

Program: Text Formatting

- Output of `justify`:

```
C is quirky,  flawed,  and  an  enormous  success.  Although
accidents of history surely helped, it evidently satisfied a
need for a system implementation language  efficient  enough
to displace assembly language, yet sufficiently abstract and
fluent to describe algorithms and  interactions  in  a  wide
variety of environments. -- Dennis M. Ritchie
```

- The output of `justify` will normally appear on the screen, but we can save it in a file by using ***output redirection:***

```
justify < quote > newquote
```

Program: Text Formatting

- `justify` will delete extra spaces and blank lines as well as *filling* and *justifying* lines
  - *Filling* a line means adding words until one more word would cause the line to overflow
  - *Justifying* a line means adding extra spaces between words so that each line has exactly the same length (60 characters)
- Justification must be done so that the *space between words in a line is equal* (*or nearly equal*)
- *The last line* of the output *will not be justified*

Program: Text Formatting

- We assume that no word is longer than 20 characters, including any adjacent punctuation
- If the program encounters a longer word, it must ignore all characters after the first 20, replacing them with a single asterisk
- For example, the word

  `antidisestablishmentarianism`

  would be printed as

  `antidisestablishment*`

Program: Text Formatting

- The program can not write words one by one as they are read
- Instead, it will have to store them in a *line buffer* until there are enough to fill a line

Program: Text Formatting

- The heart of the program will be a loop:

```
for (;;) {
  read word;
  if (can not read word) {
     write contents of line buffer without justification;
     terminate program;
  }
  if (word does not fit in line buffer) {
    write contents of line buffer with justification;
    clear line buffer;
  }
  add word to line buffer;
}
```

Program: Text Formatting

- The program will be split into *three source files*:
  - `word.c`: functions related to words
  - `line.c`: functions related to the line buffer
  - `justify.c`: contains the `main` function
- We will also need *two header files*:
  - `word.h`: prototypes for the functions in `word.c`
  - `line.h`: prototypes for the functions in `line.c`

Program: Text Formatting

- `word.h` will contain the prototype for a function that reads a word

word.h

```
#ifndef WORD_H
#define WORD_H

/**********************************************************
 * read_word: Reads the next word from the input and      *
 *            stores it in word.                          *
 *                                                        *
 *            Makes word empty if no word could be read   *
 *            because of end-of-file.                     *
 *                                                        *
 *            Truncates the word if its length exceeds    *
 *            len.                                        *
 **********************************************************/
void read_word(char *word, int len);

#endif
```


Program: Text Formatting

- The outline of the main loop reveals the need for functions that perform the following operations:
  - Write contents of line buffer without justification
  - Determine how many characters are left in line buffer
  - Write contents of line buffer with justification
  - Clear line buffer
  - Add word to line buffer
- We will call these functions `flush_line`, `space_remaining`, `write_line`, `clear_line`, and `add_word`

line.h

```
#ifndef LINE_H
#define LINE_H

/**********************************************************
 * clear_line: Clears the current line.                   *
 **********************************************************/
void clear_line(void);

/**********************************************************
 * add_word: Adds word to the end of the current line.    *
 *           If this is not the first word on the line,   *
 *           puts one space before word.                  *
 **********************************************************/
void add_word(const char *word);
```



```
/**********************************************************
 * space_remaining: Returns the number of characters left *
 *                  in the current line.                  *
 **********************************************************/
int space_remaining(void);

/**********************************************************
 * write_line: Writes the current line with               *
 *             justification.                             *
 **********************************************************/
void write_line(void);

/**********************************************************
 * flush_line: Writes the current line without            *
 *             justification.                             *
 *             If the line is empty, do nothing.          *
 **********************************************************/
void flush_line(void);

#endif
```

Program: Text Formatting

- Before we write the `word.c` and `line.c` files, we can use the functions declared in `word.h` and `line.h` to write `justify.c`, the main program
- Writing this file is mostly a matter of translating the original loop design into **C**

justify.c

```
/* Formats a file of text */

#include <string.h>
#include "line.h"
#include "word.h"

#define MAX_WORD_LEN 20

int main(void)
{
  char word[MAX_WORD_LEN+2];
  int word_len;
```

```
  clear_line();

  for (;;) {
    read_word(word, MAX_WORD_LEN+1);
    word_len = strlen(word);

    if (word_len == 0) {
      flush_line();
      return 0;
    }

    if (word_len > MAX_WORD_LEN)
      word[MAX_WORD_LEN] = '*';

    if (1 + word_len > space_remaining()) {
      write_line();
      clear_line();
    }

    add_word(word);
  }
}
```


Program: Text Formatting

- `main` uses a ***trick*** to handle words that exceed 20 characters
- When it calls `read_word`, `main` tells it to truncate any word that ***exceeds 21*** characters
- After `read_word` returns, `main` checks whether `word` contains a string that is longer than 20 characters
- If so, the word must have been at least 21 characters long (before truncation), so `main` replaces its 21st character by an asterisk

Program: Text Formatting

- The `word.h` header file has a prototype for only one function, `read_word`
- `read_word` is easier to write if we add a small *helper* function, `read_char`
- `read_char`'s job is to read a single character and, if it is a new-line character or tab, convert it to a space
- Having `read_word` call `read_char` instead of `getchar` solves the problem of treating new-line characters and tabs as spaces

`word.c`

```
#include <stdio.h>
#include "word.h"

int read_char(void)
{
  int ch = getchar();

  if (ch == '\n' || ch == '\t')
    return ' ';
  return ch;
}
```

```
void read_word(char *word, int len)
{
  int ch, pos = 0;

  while ((ch = read_char()) == ' ')
    ;

  while (ch != ' ' && ch != EOF) {
    if (pos < len)
      word[pos++] = ch;
    ch = read_char();
  }
  word[pos] = '\0';
}
```


Program: Text Formatting

- `line.c` supplies definitions of the functions declared in `line.h`
- `line.c` will also need variables to keep track of the state of the line buffer:
  - `line[]`: to store the characters in the current line
  - `line_len`: to track the number of characters in the current line
  - `num_words`: to track the number of words in the current line

line.c

```
#include <stdio.h>
#include <string.h>
#include "line.h"
#define MAX_LINE_LEN 60

char line[MAX_LINE_LEN+1];
int line_len = 0;
int num_words = 0;

void clear_line(void)
{
  line[0] = '\0';
  line_len = 0;
  num_words = 0;
}
```



```
void add_word(const char *word)
{
  if (num_words > 0) {
    line[line_len++] = ' ';
    line[line_len] = '\0';
}
  strcat(line, word);
  line_len += strlen(word);
  num_words++;
}

int space_remaining(void)
{
  return MAX_LINE_LEN - line_len;
}
```

```
void flush_line(void)
{
  if (line_len > 0)
    puts(line);
}

void write_line(void)
{
  int extra_spaces, spaces_to_insert, i, j;

  extra_spaces = space_remaining();
  for (i = 0; i < line_len; i++) {
    if (line[i] != ' ')
      putchar(line[i]);
    else {
      spaces_to_insert = extra_spaces / (num_words - 1);
      for (j = 1; j <= spaces_to_insert + 1; j++)
        putchar(' ');
      extra_spaces -= spaces_to_insert;
      num_words--;
    }
  }
  putchar('\n');
}
```


Building a Multiple-File Program

- Building a large program requires the same basic steps as building a small one:
  - *Compiling*
  - *Linking*

Building a Multiple-File Program

- Each source file in the program must be compiled separately
- Header files do not need to be compiled
- The contents of a header file are automatically compiled whenever a source file that includes it is compiled
- For each source file, the compiler generates a file containing object code
- These files—known as ***object files***—have the extension `.o` in Unix and `.obj` in Windows

Building a Multiple-File Program

- The linker combines the object files created in the previous step—along with code for library functions—to produce an executable file
- Among other duties, the linker is responsible for
  - resolving external references left behind by the compiler

    (An external reference occurs when a function in one file calls a function defined in another file or accesses a variable defined in another file)

Building a Multiple-File Program

- Most compilers allow us to build a program in a single step
- A `gcc` command that builds `justify`:

```
gcc -o justify justify.c line.c word.c
```

- The three source files are first compiled into object code
- The object files are then automatically passed to the linker, which combines them into a single file
- The `-o` option specifies that we want the executable file to be named `justify`

Makefiles

- To make it easier to build large programs, Unix originated the concept of the ***makefile***
  - Alternatives to makefiles include the ***project files*** supported by some integrated development environments
- A makefile not only lists the files that are part of the program, but also describes ***dependencies*** among the files
- Suppose that the file `foo.c` includes the file `bar.h`
  - We say that `foo.c` *depends* on `bar.h`, because a change to `bar.h` will require us to recompile `foo.c`

Makefiles

- A Unix makefile for the `justify` program:

```
justify: justify.o word.o line.o
        gcc -o justify justify.o word.o line.o

justify.o: justify.c word.h line.h
        gcc -c justify.c

word.o: word.c word.h
        gcc -c word.c

line.o: line.c line.h
        gcc -c line.c
```

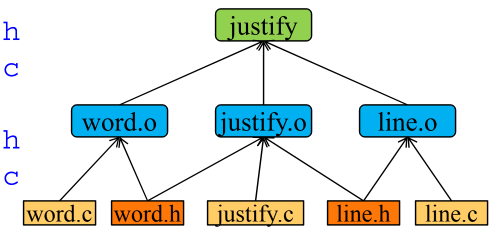
A tab, not spaces

A tab, not spaces

`-c` means compile only

A tab, not spaces

A tab, not spaces



Makefiles

- There are four *groups of lines*
  - each group is known as a ***rule***
- In each rule,
  - The *first line* gives a ***target*** file, followed by the files on which it ***depends***
  - The *second line* is a ***command*** to be executed if the target should need to be rebuilt because of a change to one of its dependent files

Makefiles

- In the first rule, `justify` (the executable file) is the target:

```
justify: justify.o word.o line.o
        gcc -o justify justify.o word.o line.o
```

- The first line states that `justify` depends on the files `justify.o`, `word.o`, and `line.o`
- If any of these files have changed since the program was last built, `justify` needs to be rebuilt
- The command on the following line shows how the rebuilding is to be done

Makefiles

- In the second rule, `justify.o` is the target:

```
justify.o: justify.c word.h line.h
        gcc -c justify.c
```

- The first line indicates that `justify.o` needs to be rebuilt if there is been a change to `justify.c`, `word.h`, or `line.h`
- The next line shows how to update `justify.o` (by recompiling `justify.c`)
- The `-c` option tells the compiler to compile `justify.c` but not to attempt to link it

Makefiles

- Once we have created a makefile for a program, we can use the `make` utility to build (or rebuild) the program
- By *checking the time and date* associated with each file in the program, `make` can determine which files are out of date
- It then invokes the commands necessary to rebuild the program

Makefiles

- Each command in a makefile (*the second line of a rule*) must be preceded by ***a tab character, not a series of spaces***
- A makefile is normally stored in a file named `Makefile` (or `makefile`)
- When the `make` utility is used, it automatically checks the current directory for a file with one of these names

Makefiles

- To invoke `make`, use the command

  `make` *target*

  where *target* is one of the targets listed in the makefile
- If *no target is specified* when `make` is invoked, it will ***build the target of the first rule***
- Except for this special property of the first rule, the order of rules in a makefile is arbitrary

Errors During Linking

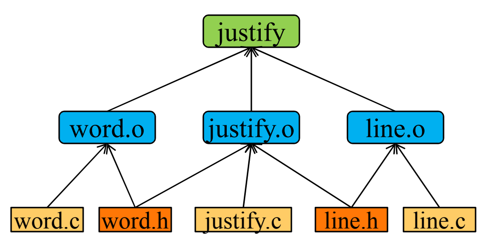
- Some errors that can not be detected during compilation will be found during linking
- If the definition of a function or variable is missing from a program, the linker will be unable to resolve external references to it
- The result is a message such as ***undefined symbol*** or ***undefined reference***

Errors During Linking

- Common causes of errors during linking:
  - ***Misspellings***
    If the name of a variable or function is misspelled, the linker will report it as missing
  - ***Missing files***
    If the linker can not find the file `foo.c`, it may not know about the functions that are in the file
  - ***Missing libraries***
    The linker may not be able to find all library functions used in the program
- In Unix, the `-lm` option may need to be specified when a program that uses `<math.h>` is linked

Rebuilding a Program

- During the development of a program, it is rare that we will need to compile all its files
- To save time, the rebuilding process should recompile only those files that might be affected by the latest change
- Assume that a program has been designed with a header file for each source file
- To see how many files will need to be recompiled after a change, we need to consider two possibilities



Rebuilding a Program

- If the change affects a single source file, only that file must be recompiled
- Suppose that we decide to condense the `read_char` function in `word.c`:

```
int read_char(void)
{
  int ch = getchar();

  return (ch == '\n' || ch == '\t') ? ' ' : ch;
}
```

- This modification does not affect `word.h`, so we need only recompile `word.c` and relink the program

Rebuilding a Program

- The second possibility is that the change affects a header file
- In that case, we should recompile all files that include the header file, since they could potentially be affected by the change

Rebuilding a Program

- Suppose that we modify `read_word` so that it returns the length of the word that it reads
- First, we change the prototype of `read_word` in `word.h`:

```
/**********************************************************
 * read_word: Reads the next word from the input and      *
 *            stores it in word. Makes word empty if no   *
 *            word could be read because of end-of-file.  *
 *            Truncates the word if its length exceeds    *
 *            len. Returns the number of characters       *
 *            stored.                                     *
 **********************************************************/
int read_word(char *word, int len);
```


Rebuilding a Program

- Next, we change the definition of `read_word`:

```
int read_word(char *word, int len)
{
  int ch, pos = 0;

  while ((ch = read_char()) == ' ')
    ;
  while (ch != ' ' && ch != EOF) {
    if (pos < len)
      word[pos++] = ch;
    ch = read_char();
  }
  word[pos] = '\0';
  return pos;
}
```

Rebuilding a Program

- Finally, we modify `justify.c` by removing the include of `<string.h>` and changing `main`:

```
int main(void)
{
  char word[MAX_WORD_LEN+2];
  int word_len;

  clear_line();
  for (;;) {
    word_len = read_word(word, MAX_WORD_LEN+1);
    …
  }
}
```


Rebuilding a Program

- Once we have made these changes, we will rebuild **`justify`** by recompiling `word.c` and `justify.c` and then relinking
- A **`gcc`** command that rebuilds the program:

```
gcc -o justify justify.c word.c line.o
```

Rebuilding a Program

- One of the advantages of using ***makefiles*** is that rebuilding is handled automatically
- By examining the date of each file, `make` can determine which files have changed since the program was last built
- It then recompiles these files, together with all files that depend on them, either directly or indirectly

Rebuilding a Program

- Suppose that we make the indicated changes to `word.h`, `word.c`, and `justify.c`
- When the **`justify`** program is rebuilt, `make` will perform the following actions:
  1. Build `justify.o` by compiling `justify.c` (because `justify.c` and `word.h` were changed)
  2. Build `word.o` by compiling `word.c` (because `word.c` and `word.h` were changed)
  3. Build **`justify`** by linking `justify.o`, `word.o`, and `line.o` (because `justify.o` and `word.o` were changed)