Chapter 14

The Preprocessor

macro (short for macroinstruction)

A rule that specifies how a certain input sequence should be mapped to a replacement output sequence according to a defined procedure.

Introduction

- Directives such as `#define` and `#include`
  - are handled by the ***preprocessor,*** a piece of software that edits C programs just prior to compilation.
- Its reliance (依賴) on a preprocessor
  - makes C (along with C++) unique among major programming languages.
- The preprocessor
  - is a powerful tool,
  - but it also can be a source of hard-to-find bugs.

How the Preprocessor Works

- The preprocessor
  - looks for ***preprocessing directives,***
  - which begin with a # character.
- We've encountered the `#define` and `#include` directives before.
- `#define` defines a ***macro***
  - —a name that represents something else, such as a constant.
- The preprocessor responds to a `#define` directive by storing the name of the macro along with its definition.
- When the macro is used later, the preprocessor "expands" the macro, replacing it by its defined value.

How the Preprocessor Works

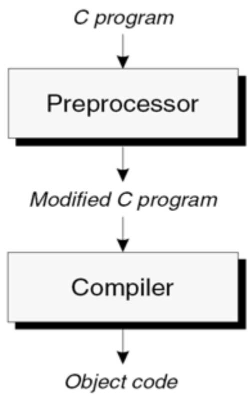
- `#include`
  - tells the preprocessor to open a particular file
  - and "include" its contents as part of the file being compiled.
- For example, the line

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

instructs the preprocessor to open the file named `stdio.h` and bring its contents into the program.

How the Preprocessor Works

- The preprocessor's role in the compilation process:



How the Preprocessor Works

- The input to the preprocessor
  – is a C program, possibly containing directives.

- The preprocessor
  – executes these directives,
  – removing them in the process.

- The preprocessor's output
  – goes directly into the compiler.

How the Preprocessor Works

- The `celsius.c` program of Chapter 2:

```
/* Converts a Fahrenheit temperature to Celsius */

#include <stdio.h>

#define FREEZING_PT 32.0f
#define SCALE_FACTOR (5.0f / 9.0f)

int main(void)
{
  float fahrenheit, celsius;

  printf("Enter Fahrenheit temperature: ");
  scanf("%f", &fahrenheit);

  celsius = (fahrenheit - FREEZING_PT) * SCALE_FACTOR;
  printf("Celsius equivalent is: %.1f\n", celsius);

  return 0;
}
```


How the Preprocessor Works

- The program after preprocessing:

```
/* Converts a Fahrenheit temperature
to Celsius */

#include <stdio.h>

#define FREEZING_PT 32.0f
#define SCALE_FACTOR (5.0f / 9.0f)

int main(void)
{ …
```

Blank line
Blank line
Lines brought in from stdio.h
Blank line
Blank line
Blank line
Blank line

```
int main(void)
{
  float fahrenheit, celsius;

  printf("Enter Fahrenheit temperature: ");
  scanf("%f", &fahrenheit);

  celsius = (fahrenheit - 32.0f) * (5.0f / 9.0f);

  printf("Celsius equivalent is: %.1f\n", celsius);

  return 0;
}
```

How the Preprocessor Works

- The preprocessor
  - does a bit more than just execute directives.
- In particular, it replaces each comment with a single space character.
- Some preprocessors go further and
  - remove unnecessary white-space characters,
  - including spaces and tabs at the beginning of indented lines.

How the Preprocessor Works

- In the early days of C, the preprocessor was a separate program.
- Nowadays, the preprocessor
  - is often part of the compiler,
  - and some of its output may not necessarily be C code.
- Still, it's useful to think of the preprocessor as separate from the compiler.

How the Preprocessor Works

- Most C compilers
  - provide a way to view the output of the preprocessor.
- Some compilers
  - generate preprocessor output
  - when a certain option is specified (GCC will do so when the `-E` option is used).
- Others come with a separate program
  - that behaves like the integrated preprocessor.

How the Preprocessor Works

- A word of caution:
  - The preprocessor has only a limited knowledge of C.
- As a result, it's quite capable of
  - creating illegal programs as it executes directives.
- In complicated programs,
  - examining the output of the preprocessor
  - may prove useful for locating this kind of error.

Preprocessing Directives

- Most preprocessing directives fall into one of three categories:
  - ***Macro definition.*** The `#define` directive defines a macro; the `#undef` directive removes a macro definition.
  - ***File inclusion.*** The `#include` directive causes the contents of a specified file to be included in a program.
  - ***Conditional compilation.*** The `#if`, `#ifdef`, `#ifndef`, `#elif`, `#else`, and `#endif` directives allow blocks of text to be either included in or excluded from a program.

Preprocessing Directives

- Several rules apply to all directives.
- ***Directives always begin with the # symbol.***
- The # symbol
  - need not be at the beginning of a line,
  - as long as only white space precedes it.
- ***Any number of spaces and horizontal tab characters***
  - ***may separate the tokens in a directive.*** Example:

```
#     define      N      100
```


Preprocessing Directives

- ***Directives always end at the first new-line character, unless explicitly continued.***
- To continue a directive to the next line, end the current line with a \ character:

```
#define DISK_CAPACITY (SIDES *              \
                       TRACKS_PER_SIDE *    \
                       SECTORS_PER_TRACK *  \
                       BYTES_PER_SECTOR)
```


Preprocessing Directives

- ***Directives can appear anywhere in a program.*** Although `#define` and `#include` directives usually appear at the beginning of a file, other directives are more likely to show up later.
- ***Comments may appear on the same line as a directive.*** It's good practice to put a comment at the end of a macro definition:

```
#define FREEZING_PT 32.0f /* freezing point of water */
```

Macro Definitions

- The macros that we've been using since Chapter 2
  - are known as *simple* macros,
  - because they have no parameters.
- The preprocessor also supports *parameterized* macros.

Simple Macros

- Definition of a ***simple macro*** (or ***object-like macro***):

  `#define` *identifier replacement-list*

  replacement-list is any sequence of ***preprocessing tokens.***
- The replacement list
  - may include identifiers, keywords, numeric constants, character constants, string literals, operators, and punctuation.
- Wherever *identifier* appears later in the file, the preprocessor substitutes *replacement-list*.

Simple Macros

- Any extra symbols in a macro definition will become part of the replacement list.
- Putting the = symbol in a macro definition is a common error:

```
#define N = 100   /*** WRONG ***/
…
int a[N];         /* becomes int a[= 100]; */
```


Simple Macros

- Ending a macro definition with a semicolon is another popular mistake:

```
#define N 100;  /*** WRONG ***/
…
int a[N];       /* becomes int a[100;]; */
```

- The compiler will detect most errors caused by extra symbols in a macro definition.
- Unfortunately, the compiler will flag each use of the macro as incorrect, rather than identifying the actual culprit (肇因): the macro's definition.

Simple Macros

- Simple macros are primarily used for defining "manifest (顯然的) constants"—names that represent numeric, character, and string values:

```
#define STR_LEN 80
#define TRUE    1
#define FALSE   0
#define PI      3.14159
#define CR      '\r'
#define EOS     '\0'
#define MEM_ERR "Error: not enough memory"
```


Simple Macros

- Advantages of using `#define` to create names for constants:
  - ***It makes programs easier to read.*** The name of the macro can help the reader understand the meaning of the constant.
  - ***It makes programs easier to modify.*** We can change the value of a constant throughout a program by modifying a single macro definition.
  - ***It helps avoid inconsistencies and typographical errors.*** If a numerical constant like 3.14159 appears many times in a program, chances are it will occasionally be written 3.1416 or 3.14195 by accident.

Simple Macros

- Simple macros have additional uses.
- ***Making minor changes to the syntax of C***

  Macros can serve as alternate names for C symbols:

```
#define BEGIN {
#define END   }
#define LOOP for (;;)
```

  Changing the syntax of C usually isn't a good idea, since it can make programs harder for others to understand.

Simple Macros

- ***Renaming types***

  An example from Chapter 5:

  `#define BOOL int`

  Type definitions are a better alternative.

- ***Controlling conditional compilation***

  Macros play an important role in controlling conditional compilation.

  A macro that might indicate "debugging mode":

  `#define DEBUG`

Simple Macros

- When macros are used as constants,
  - C programmers customarily capitalize all letters in their names.
- However, there's no consensus (一致) as to how to capitalize macros used for other purposes.
  - Some programmers like to draw attention to macros by using all upper-case letters in their names.
  - Others prefer lower-case names, following the style of K&R.

Parameterized Macros

- Definition of a ***parameterized macro*** (also known as a ***function-like macro***):

  `#define` *identifier*`(` x_1 `,` x_2 `,` … `,` x_n `)` *replacement-list*

  $x_1, x_2, \ldots, x_n$ are identifiers (the macro's ***parameters***).
- The parameters may appear as many times as desired in the replacement list.
- There must be *no space* between the macro name and the left parenthesis.
- If space is left (留下), the preprocessor will treat $(x_1, x_2, \ldots, x_n)$ as part of the replacement list.

Parameterized Macros

- When the preprocessor encounters the definition of a parameterized macro, it stores the definition away for later use.
- Wherever a macro ***invocation*** of the form *identifier* $(y_1, y_2, \ldots, y_n)$ appears later in the program, the preprocessor replaces it with *replacement-list*, substituting y_1 for x_1, y_2 for x_2, and so forth.
- Parameterized macros often serve as simple functions.

Parameterized Macros

- Examples of parameterized macros:

```
#define MAX(x,y)    ((x)>(y)?(x):(y))
#define IS_EVEN(n)  ((n)%2==0)
```

- Invocations of these macros:

```
i = MAX(j+k, m-n);
if (IS_EVEN(i)) i++;
```

- The same lines after macro replacement:

```
i = ((j+k)>(m-n)?(j+k):(m-n));
if (((i)%2==0)) i++;
```

Parameterized Macros

- A more complicated function-like macro:

```
#define TOUPPER(c) \
  ('a'<=(c)&&(c)<='z'?(c)-'a'+'A':(c))
```

- The `<ctype.h>` header provides a similar function named `toupper` that's more portable.
- A parameterized macro may have an empty parameter list:

```
#define getchar() getc(stdin)
```

- The empty parameter list isn't really needed, but it makes `getchar` resemble a function.

Parameterized Macros

- Using a parameterized macro instead of a true function has a couple of advantages:
  - ***The program may be slightly faster.*** A function call usually requires some overhead during program execution, but a macro invocation does not.
  - ***Macros are "generic."*** A macro can accept arguments of any type, provided that the resulting program is valid.

Parameterized Macros

- Parameterized macros also have disadvantages.
- ***The compiled code will often be larger.***
- Each macro invocation increases the size of the source program (and hence the compiled code).
- The problem is compounded (混合) when macro invocations are nested:

```
n = MAX(i, MAX(j, k));
```

- The statement after preprocessing:

```
n = ((i)>(((j)>(k)?(j):(k)))?(i):(((j)>(k)?(j):(k))));
```


Parameterized Macros

- ***Arguments aren't type-checked.***
  - When a function is called, the compiler checks each argument to see if it has the appropriate type.
  - Macro arguments aren't checked by the preprocessor, nor are they converted.
- ***It's not possible to have a pointer to a macro.***
  - C allows pointers to functions, a useful concept.
  - Macros are removed during preprocessing, so there's no corresponding notion of "pointer to a macro."

Parameterized Macros

- ***A macro may evaluate its arguments more than once.*** Unexpected behavior may occur if an argument has side effects:

```
n = MAX(i++, j);
```

The same line after preprocessing:

```
n = ((i++)>(j)?(i++):(j));
```

If `i` is larger than `j`, then `i` will be (incorrectly) incremented twice and `n` will be assigned an unexpected value.

Parameterized Macros

- Errors caused by evaluating a macro argument more than once
  - can be difficult to find,
  - because a macro invocation looks the same as a function call.
- To make matters worse,
  - a macro may work properly most of the time,
  - failing only for certain arguments that have side effects.
- For self-protection, it's a good idea to avoid side effects in arguments.

Parameterized Macros

- Parameterized macros can be used as patterns for segments of code that are often repeated.
- A macro that makes it easier to display integers:

```
#define PRINT_INT(n) printf("%d\n", n)
```

- The preprocessor will turn the line

```
PRINT_INT(i/j);
```

into

```
printf("%d\n", i/j);
```


The # Operator

- Macro definitions may contain two special operators, `#` and `##`.
- Neither operator is recognized by the compiler; instead, they're executed during preprocessing.
- The # operator
  - converts a macro argument into a string literal;
  - it can appear only in the replacement list of a parameterized macro.
- The operation performed by #
  - is known as "stringization."

The # Operator

- There are a number of uses for #; let's consider just one.
- Suppose that we decide to use the `PRINT_INT` macro
  - during debugging
  - as a convenient way to print the values of integer variables and expressions.
- The # operator
  - makes it possible for `PRINT_INT` to label each value that it prints.

The # Operator

- Our new version of `PRINT_INT`:

```
#define PRINT_INT(n) printf(#n " = %d\n", n)
```

- The invocation

```
PRINT_INT(i/j);
```

will become

```
printf("i/j" " = %d\n", i/j);
```

- The compiler
  - automatically joins adjacent string literals,
  - so this statement is equivalent to

```
printf("i/j = %d\n", i/j);
```


The ## Operator

- The ## operator
  - can "paste" two tokens together to form a single token.
- If one of the operands is a macro parameter, pasting occurs
  - after the parameter has been replaced by the corresponding argument.

The ## Operator

- A macro that uses the ## operator:

```
#define MK_ID(n) i##n
```

- A declaration that invokes `MK_ID` three times:

```
int MK_ID(1), MK_ID(2), MK_ID(3);
```

- The declaration after preprocessing:

```
int i1, i2, i3;
```

The ## Operator

- The ## operator has a variety of uses.
- Consider the problem of defining a max function that behaves like the MAX macro described earlier.
- A single max function usually isn't enough,
  - because it will only work for arguments of one type.
- Instead, we can write a macro
  - that expands into the definition of a max function.
- The macro's parameter will specify the type of the arguments and the return value.

The ## Operator

- There's just one snag (阻礙): if we use the macro to create more than one function named max, the program won't compile.
- To solve this problem, we'll use the ## operator to create a different name for each version of max:

```
#define GENERIC_MAX(type)         \
type type##_max(type x, type y) \
{                                 \
  return x > y ? x : y;           \
}
```

- An invocation of this macro:

```
GENERIC_MAX(float)
```

- The resulting function definition:

```
float float_max(float x, float y) { return x > y ? x : y; }
```


General Properties of Macros

- Several rules apply to both simple and parameterized macros.
- ***A macro's replacement list may contain invocations of other macros.***

  Example:

```
#define PI      3.14159
#define TWO_PI  (2*PI)
```

- When it encounters TWO_PI later in the program, the preprocessor replaces it by (2*PI).
- The preprocessor then ***rescans*** the replacement list to see if it contains invocations of other macros.

General Properties of Macros

- ***The preprocessor replaces only entire tokens.***

  Macro names embedded in identifiers, character constants, and string literals are ignored.

  Example:

```
#define SIZE 256

int BUFFER_SIZE;

if (BUFFER_SIZE > SIZE)
  puts("Error: SIZE exceeded");
```

  Appearance after preprocessing:

```
int BUFFER_SIZE;

if (BUFFER_SIZE > 256)
  puts("Error: SIZE exceeded");
```

General Properties of Macros

- ***A macro definition normally remains in effect until the end of the file in which it appears.***
  - Macros don't obey normal scope rules.
  - A macro defined inside the body of a function isn't local to that function; it remains defined until the end of the file.
- ***A macro may not be defined twice unless the new definition is identical to the old one.***
  - Differences in spacing are allowed, but the tokens in the macro's replacement list (and the parameters, if any) must be the same.

General Properties of Macros

- ***Macros may be "undefined" by the `#undef` directive.***

  The `#undef` directive has the form

  ```
  #undef identifier
  ```

  where *identifier* is a macro name.
- One use of `#undef`
  - is to remove the existing definition of a macro
  - so that it can be given a new definition.

Parentheses in Macro Definitions

- The replacement lists in macro definitions often require parentheses in order to avoid unexpected results.
- If the macro's replacement list contains an operator, always enclose the replacement list in parentheses:

  ```
  #define TWO_PI (2*3.14159)
  ```
- Also, put parentheses around each parameter every time it appears in the replacement list:

  ```
  #define SCALE(x) ((x)*10)
  ```
- Without the parentheses, we can't guarantee that the compiler will treat replacement lists and arguments as whole expressions.

Parentheses in Macro Definitions

- An example that illustrates the need to put parentheses around a macro's replacement list:

  ```
  #define TWO_PI 2*3.14159 /* 反例  */
  /* needs parentheses around replacement list */
  ```
- During preprocessing, the statement

  ```
  conversion_factor = 360/TWO_PI;
  ```

  becomes

  ```
  conversion_factor = 360/2*3.14159;
  ```

  The division will be performed before the multiplication.

Parentheses in Macro Definitions

- Each occurrence of a parameter in a macro's replacement list needs parentheses as well:

```
#define SCALE(x) (x*10) /* 反例  */
  /* needs parentheses around x */
```

- During preprocessing, the statement

```
j = SCALE(i+1);
```

becomes

```
j = (i+1*10);  /* should be j = ( (i+1) *10); */
```

This statement is equivalent to

```
j = i+10;
```


Creating Longer Macros

- The comma operator can be useful for creating more sophisticated macros by allowing us to make the replacement list a series of expressions.
- A macro that reads a string and then prints it:

```
#define ECHO(s) (gets(s), puts(s))
```

- Calls of `gets` and `puts` are expressions, so it's perfectly legal to combine them using the comma operator.
- We can invoke `ECHO` as though it were a function:

```
ECHO(str);  /* becomes (gets(str), puts(str)); */
```


Creating Longer Macros

- An alternative definition of `ECHO` that uses braces:

```
#define ECHO(s) { gets(s); puts(s); }
```

- Suppose that we use `ECHO` in an `if` statement:

```
if (echo_flag)
  ECHO(str);
else
  gets(str);
```

- Replacing `ECHO` gives the following result:

```
if (echo_flag)
  { gets(str); puts(str); };
else
  gets(str);
```


Creating Longer Macros

- The compiler treats the first two lines as a complete `if` statement:

```
if (echo_flag)
  { gets(str); puts(str); }
```

- It treats the semicolon that follows as a null statement and produces an error message for the `else` clause, since it doesn't belong to any `if`.
- We could solve the problem
  - by remembering not to put a semicolon after each invocation of `ECHO`,
  - but then the program would look odd.

Creating Longer Macros

- The comma operator solves this problem for `ECHO`, but not for all macros.
- If a macro needs to contain a series of *statements*, not just a series of *expressions*, the comma operator is of no help.
- The solution is to wrap the statements in a `do` loop whose condition is false:

```
do { … } while (0)
```

- Notice that the `do` statement needs a semicolon at the end.

Creating Longer Macros

- A modified version of the `ECHO` macro:

```
#define ECHO(s)        \
        do {           \
          gets(s);     \
          puts(s);     \
        } while (0)
```

- When `ECHO` is used, it must be followed by a semicolon, which completes the `do` statement:

```
ECHO(str);
/* becomes
   do { gets(str); puts(str); } while (0); */
```


Predefined Macros

- C has several predefined macros, each of which represents an integer constant or string literal.
- The `__DATE__` and `__TIME__` macros identify when a program was compiled.
- Example of using `__DATE__` and `__TIME__`:

```
printf("Wacky Windows (c) 2010 Wacky Software, Inc.\n");
printf("Compiled on %s at %s\n", __DATE__, __TIME__);
```

- Output produced by these statements:

```
Wacky Windows (c) 2010 Wacky Software, Inc.
Compiled on Dec 23 2010 at 22:18:48
```

- This information can be helpful for distinguishing among different versions of the same program.

Predefined Macros

- We can use the `__LINE__` and `__FILE__` macros to help locate errors.
- A macro that can help pinpoint the location of a division by zero:

```
#define CHECK_ZERO(divisor) \
  if (divisor == 0) \
    printf("*** Attempt to divide by zero on line %d " \
           "of file %s ***\n", __LINE__, __FILE__)
```

- The `CHECK_ZERO` macro would be invoked prior to a division:

```
CHECK_ZERO(j);
k = i / j;
```

Predefined Macros

- If `j` happens to be zero, a message of the following form will be printed:

```
*** Attempt to divide by zero on line 9 of file foo.c ***
```

- Error-detecting macros like this one are quite useful.
- In fact, the C library has a general-purpose error-detecting macro named `assert`.
- The remaining predefined macro is named `__STDC__`.
- This macro exists and has the value 1 if the compiler conforms to the C standard (either C89 or C99).

Additional Predefined Macros in C99

- C99 provides a few additional predefined macros.
- The `__STDC__HOSTED__` macro
  - represents the constant 1 if the compiler is a hosted implementation.
  - Otherwise, the macro has the value 0.
- An ***implementation*** of C consists of the compiler plus other software necessary to execute C programs.
- A ***hosted implementation*** must accept any program that conforms to the C99 standard.
- A ***freestanding implementation*** doesn't have to compile programs that use complex types or standard headers beyond a few of the most basic.

Additional Predefined Macros in C99

- The `__STDC__VERSION__` macro
  - provides a way to check which version of the C standard is recognized by the compiler.
  - If a compiler conforms to the C89 standard, including Amendment 1 (修訂一), the value is `199409L`.
  - If a compiler conforms to the C99 standard, the value is `199901L`.

Additional Predefined Macros in C99

- A C99 compiler will define up to three additional macros, but only if the compiler meets certain requirements:

  `__STDC_IEC_559__` is defined (and has the value 1) if the compiler performs floating-point arithmetic according to IEC 60559.

  `__STDC_IEC_559_COMPLEX__` is defined (and has the value 1) if the compiler performs complex arithmetic according to IEC 60559.

  `__STDC_ISO_10646__` is defined as *yyyymm*`L` if wide characters are represented by the codes in ISO/IEC 10646 (with revisions as of the specified year and month).

Empty Macro Arguments (C99)

- C99 allows any or all of the arguments in a macro call to be empty.
- Such a call will contain the same number of commas as a normal call.
- Wherever the corresponding parameter name appears in the replacement list, it's replaced by nothing.

Empty Macro Arguments (C99)

- Example:

```
#define ADD(x,y) (x+y)
```

- After preprocessing, the statement

```
i = ADD(j,k);
```

becomes

```
i = (j+k);
```

whereas the statement

```
i = ADD(,k);
```

becomes

```
i = (+k);
```


Empty Macro Arguments (C99)

- When an empty argument is an operand of the # or ## operators, special rules apply.
- If an empty argument is "stringized" by the # operator, the result is `""` (the empty string):

```
#define MK_STR(x) #x
…
char empty_string[] = MK_STR();
```

- The declaration after preprocessing:

```
char empty_string[] = "";
```


Empty Macro Arguments (C99)

- If one of the arguments of the ## operator
  - is empty,
  - it's replaced by an invisible "placemarker" token.
- Concatenating an ordinary token with a placemarker token
  - yields the original token (the placemarker disappears).
- If two placemarker tokens are concatenated,
  - the result is a single placemarker.
- Once macro expansion has been completed,
  - placemarker tokens disappear from the program.

Empty Macro Arguments (C99)

- Example:

```
#define JOIN(x,y,z) x##y##z
…
int JOIN(a,b,c), JOIN(a,b,), JOIN(a,,c), JOIN(,,c);
```

- The declaration after preprocessing:

```
int abc, ab, ac, c;
```

- The missing arguments
  - were replaced by placemarker tokens, which then disappeared when concatenated with any nonempty arguments.
- All three arguments to the `JOIN` macro
  - could even be missing, which would yield an empty result.

Macros with a Variable Number of Arguments (C99)

- C99 allows macros
  - that take an unlimited number of arguments.
- A macro of this kind can pass its arguments to a function that accepts a variable number of arguments.
- Example:

```
#define TEST(condition, ...) ((condition)? \
  printf("Passed test: %s\n", #condition): \
  printf(__VA_ARGS__))
```

- The `...` token (***ellipsis***)省略 goes at the end of the parameter list, preceded by ordinary parameters, if any.
- `__VA_ARGS__` is a special identifier
  - that represents all the arguments that correspond to the ellipsis.

Macros with a Variable Number of Arguments (C99)

- An example that uses the `TEST` macro:

```
TEST(voltage <= max_voltage,
     "Voltage %d exceeds %d\n", voltage, max_voltage);
```

- Preprocessor output (reformatted for readability):

```
((voltage <= max_voltage)?
  printf("Passed test: %s\n", "voltage <= max_voltage"):
  printf("Voltage %d exceeds %d\n", voltage, max_voltage));
```

- The program will display the message

```
Passed test: voltage <= max_voltage
```

if `voltage` is no more than `max_voltage`.

- Otherwise, it will display the values of `voltage` and `max_voltage`:

```
Voltage 125 exceeds 120
```


The `__func__` Identifier (C99)

- The `__func__` identifier
  - behaves like a string variable
  - that stores the name of the currently executing function.
- The effect is the same as if each function contains the following declaration at the beginning of its body:

`static const char __func__[] = "`*function-name*`";`

where *function-name* is the name of the function.

The `__func__` Identifier (C99)

- Debugging macros that rely on the `__func__` identifier:

```
#define FUNCTION_CALLED() printf("%s called\n", __func__);
#define FUNCTION_RETURNS() printf("%s returns\n", __func__);
```

- These macros can used to trace function calls:

```
void f(void)
{
  FUNCTION_CALLED();    /* displays "f called" */
  …
  FUNCTION_RETURNS();  /* displays "f returns" */
}
```

- Another use of `__func__`: it can be passed to a function to let it know the name of the function that called it.

Conditional Compilation

- The C preprocessor
  - recognizes a number of directives
  - that support ***conditional compilation.***
- This feature
  - permits the inclusion or exclusion of a section of program text
  - depending on the outcome of a test performed by the preprocessor.

The `#if` and `#endif` Directives

- Suppose we're in the process of debugging a program.
- We'd like the program to print the values of certain variables, so we put calls of `printf` in critical parts of the program.
- Once we've located the bugs, it's often a good idea to let the `printf` calls remain, just in case we need them later.
- Conditional compilation allows us to leave the calls in place, but have the compiler ignore them.

The `#if` and `#endif` Directives

- The first step is to define a macro and give it a nonzero value:

```
#define DEBUG 1
```

- Next, we'll surround each group of `printf` calls by an `#if`-`#endif` pair:

```
#if DEBUG
printf("Value of i: %d\n", i);
printf("Value of j: %d\n", j);
#endif
```

The `#if` and `#endif` Directives

- During preprocessing, the `#if` directive will test the value of `DEBUG`.
- Since its value isn't zero, the preprocessor will leave the two calls of `printf` in the program.
- If we change the value of `DEBUG` to zero and recompile the program, the preprocessor will remove all four lines from the program.
- The `#if`-`#endif` blocks can be left in the final program, allowing diagnostic information to be produced later if any problems turn up.

The `#if` and `#endif` Directives

- General form of the `#if` and `#endif` directives:

  `#if` *constant-expression*
  `#endif`

- When the preprocessor encounters the `#if` directive, it evaluates the constant expression.
  - If the value of the expression is zero, the lines between `#if` and `#endif` will be removed from the program during preprocessing.
  - Otherwise, the lines between `#if` and `#endif` will remain.

The `#if` and `#endif` Directives

- The `#if` directive treats undefined identifiers
  - as macros that have the value 0.
- If we neglect to define `DEBUG`, the test

  ```
  #if DEBUG
  ```

  will fail (but not generate an error message).

- The test

  ```
  #if !DEBUG
  ```

  will succeed.

The `defined` Operator

- The preprocessor supports three operators:
  - `#`, `##`, and `defined`.
- When applied to an identifier, `defined`
  - produces the value 1
    - if the identifier is a currently defined macro;
  - it produces 0 otherwise.
- The `defined` operator
  - is normally used in conjunction with the `#if` directive.

The `defined` Operator

- Example:

```
#if defined(DEBUG)
…
#endif
```

- The lines between `#if` and `#endif` will be included only if `DEBUG` is defined as a macro.
- The parentheses around `DEBUG` aren't required:

```
#if defined DEBUG
```

- It's not necessary to give `DEBUG` a value:

```
#define DEBUG
```


The `#ifdef` and `#ifndef` Directives

- The `#ifdef` directive tests whether an identifier is currently defined as a macro:

  `#ifdef` *identifier*
- The effect is the same as

  `#if defined(`*identifier*`)`
- The `#ifndef` directive tests whether an identifier is *not* currently defined as a macro:

  `#ifndef` *identifier*
- The effect is the same as

  `#if !defined(`*identifier*`)`

The `#elif` and `#else` Directives

- `#if`, `#ifdef`, and `#ifndef` blocks
  - can be nested just like ordinary `if` statements.
- When nesting occurs,
  - it's a good idea to use an increasing amount of indentation as the level of nesting grows.
- Some programmers put a comment on each closing `#endif` to indicate what condition the matching `#if` tests:

```
#if DEBUG
…
#endif /* DEBUG */
```


The `#elif` and `#else` Directives

- `#elif` and `#else` can be used in conjunction with `#if`, `#ifdef`, or `#ifndef` to test a series of conditions:

  `#if` *expr1*
  Lines to be included if expr1 is nonzero
  `#elif` *expr2*
  Lines to be included if expr1 is zero but expr2 is nonzero
  `#else`
  Lines to be included otherwise
  `#endif`
- Any number of `#elif` directives—but at most one `#else`—may appear between `#if` and `#endif`.

Uses of Conditional Compilation

- Conditional compilation
  - has other uses besides debugging.
- ***Writing programs that are portable to several machines or operating systems.***

  Example:

```
#if defined(WIN32)
…
#elif defined(MAC_OS)
…
#elif defined(LINUX)
…
#endif
```


Uses of Conditional Compilation

- ***Writing programs that can be compiled with different compilers.***

  An example that uses the `__STDC__` macro:

```
#if __STDC__
Function prototypes
#else
Old-style function declarations
#endif
```

If the compiler does not conform to the C standard, old-style function declarations are used instead of function prototypes.

Uses of Conditional Compilation

- ***Providing a default definition for a macro.***

  Conditional compilation makes it possible to check whether a macro is currently defined and, if not, give it a default definition:

```
#ifndef BUFFER_SIZE
#define BUFFER_SIZE 256
#endif
```


Uses of Conditional Compilation

- ***Temporarily disabling code that contains comments.***

  A `/*…*/` comment can't be used to "comment out" code that already contains `/*…*/` comments.

  An `#if` directive can be used instead:

```
#if 0
Lines containing comments
#endif
```

Uses of Conditional Compilation

- Chapter 15 discusses another common use of conditional compilation: protecting header files against multiple inclusion.

Miscellaneous Directives

- The `#error`, `#line`, and `#pragma` directives are more specialized than the ones we've already examined.

- These directives are used much less frequently.

The #error Directive

- Form of the `#error` directive:

  `#error` *message*

  message is any sequence of tokens.

- If the preprocessor encounters an `#error` directive, it prints an error message which must include *message*.

- If an `#error` directive is processed, some compilers immediately terminate compilation without attempting to find other errors.

The #error Directive

- `#error` directives are frequently used in conjunction with conditional compilation.

- Example that uses an `#error` directive to test the maximum value of the `int` type:

```
#if INT_MAX < 100000
#error int type is too small
#endif
```

The #error Directive

- The `#error` directive is often found in the `#else` part of an `#if`-`#elif`-`#else` series:

```
#if defined(WIN32)
…
#elif defined(MAC_OS)
…
#elif defined(LINUX)
…
#else
#error No operating system specified
#endif
```


The #line Directive

- The `#line` directive
  - is used to alter the way program lines are numbered.
- First form of the `#line` directive:

  `#line` *n*

  Subsequent lines in the program will be numbered *n*, *n* + 1, *n* + 2, and so forth.
- Second form of the `#line` directive:

  `#line` *n* "*file*"

  Subsequent lines are assumed to come from *file*, with line numbers starting at *n*.

The #line Directive

- The `#line` directive changes the value of the `__LINE__` macro (and possibly `__FILE__`).
- Most compilers will use the information from the `#line` directive when generating error messages.
- Suppose that the following directive appears at the beginning of `foo.c`:

  `#line 10 "bar.c"`

  If the compiler detects an error on line 5 of `foo.c`, the message will refer to line 13 of file `bar.c`.
- The `#line` directive is used primarily by programs that generate C code as output.

The #line Directive

- The most famous example is `yacc` (Yet Another Compiler-Compiler), a UNIX utility that automatically generates part of a compiler.
- The programmer prepares a file that contains information for `yacc` as well as fragments of C code.
- From this file, `yacc` generates a C program, `y.tab.c`, that incorporates the code supplied by the programmer.
- By inserting `#line` directives, `yacc` tricks the compiler into believing that the code comes from the original file.
- Error messages produced during the compilation of `y.tab.c` will refer to lines in the original file.

The `#pragma` Directive

- The `#pragma` directive
  - provides a way to request special behavior from the compiler.
- Form of a `#pragma` directive:

`#pragma` *tokens*

- `#pragma` directives can be very simple (a single token) or they can be much more elaborate (詳盡):

```
#pragma data(heap_size => 1000, stack_size => 2000)
```


The `#pragma` Directive

- The set of commands that can appear in `#pragma` directives is different for each compiler.
- The preprocessor
  - must ignore any `#pragma` directive that contains an unrecognized command;
  - it's not permitted to give an error message.
- In C89, there are no standard pragmas—they're all implementation-defined.
- C99 has three standard pragmas, all of which use `STDC` as the first token following `#pragma`.

The `_Pragma` Operator (C99)

- C99 introduces the `_Pragma` operator, which is used in conjunction with the `#pragma` directive.
- A `_Pragma` expression has the form

`_Pragma (` *string-literal* `)`

- When it encounters such an expression, the preprocessor "destringizes" the string literal:
  - Double quotes around the string are removed.
  - `\"` is replaced by `"`.
  - `\\` is replaced by `\`.

The `_Pragma` Operator (C99)

- The resulting tokens are then treated as though they appear in a `#pragma` directive.
- For example, writing

```
_Pragma("data(heap_size => 1000, stack_size => 2000)")
```

is the same as writing

```
#pragma data(heap_size => 1000, stack_size => 2000)
```

The _Pragma Operator (C99)

- The `_Pragma` operator
  - lets us work around the fact that a preprocessing directive can't generate another directive.
- `_Pragma`
  - , however, is an operator, not a directive,
  - and can therefore appear in a macro definition.
- This makes it possible for a macro expansion to leave behind a `#pragma` directive.

The _Pragma Operator (C99)

- A macro that uses the `_Pragma` operator:

```
#define DO_PRAGMA(x) _Pragma(#x)
```

- An invocation of the macro:

```
DO_PRAGMA(GCC dependency "parse.y")
```

- The result after expansion:

```
#pragma GCC dependency "parse.y"
```

- The tokens passed to `DO_PRAGMA` are stringized into `"GCC dependency \"parse.y\""`.
- The `_Pragma` operator destringizes this string, producing a `#pragma` directive.