Chapter 13

Strings

Introduction

- This chapter covers both string *constants* (or *literals*, as they're called in the C standard) and string *variables*.
- Strings are arrays of characters in which a special character—the null character—marks the end.
- The C library provides a collection of functions for working with strings.

String Literals

- A ***string literal*** is a sequence of characters enclosed within double quotes:

```
"When you come to a fork in the road, take it."
```

- String literals may contain escape sequences.
- Character escapes often appear in `printf` and `scanf` format strings.
- For example, each `\n` character in the string

```
"Candy\nIs dandy\nBut liquor\nIs quicker.\n  --Ogden Nash\n"
```

causes the cursor to advance to the next line:

```
Candy
Is dandy
But liquor
Is quicker.
  --Ogden Nash
```

Continuing a String Literal

- The backslash character (`\`) can be used to continue a string literal from one line to the next:

```
printf("When you come to a fork in the road, take it.  \
--Yogi Berra");
```

- In general, the `\` character can be used to join two or more lines of a program into a single line.

Continuing a String Literal

- There's a better way to deal with long string literals.
- When two or more string literals are adjacent, the compiler will join them into a single string.
- This rule allows us to split a string literal over two or more lines:

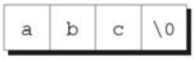
```
printf("When you come to a fork in the road, take it.  "
        "--Yogi Berra");
```

How String Literals Are Stored

- When a C compiler encounters a string literal of length *n* in a program, it sets aside *n* + 1 bytes of memory for the string.
- This memory will contain the characters in the string, plus one extra character—the ***null character***—to mark the end of the string.
- The null character is a byte whose bits are all zero, so it's represented by the `\0` escape sequence.

How String Literals Are Stored

- The string literal `"abc"` is stored as an array of four characters:



- The string `""` is stored as a single null character:

Operations on String Literals

- We can use a string literal wherever C allows a `char *` pointer:

```
char *p;

p = "abc";
```

- This assignment makes `p` point to the first character of the string.

Operations on String Literals

- String literals can be subscripted:

```
char ch;

ch = "abc"[1];
```

The new value of `ch` will be the letter `b`.

- A function that converts a number between 0 and 15 into the equivalent hex digit:

```
char digit_to_hex_char(int digit)
{
  return "0123456789ABCDEF"[digit];
}
```

Operations on String Literals

- Attempting to modify a string literal causes undefined behavior:

```
char *p = "abc";

*p = 'd';   /*** WRONG ***/
```

- A program that tries to change a string literal may crash or behave erratically.

String Literals versus Character Constants

- A string literal containing a single character isn't the same as a character constant.
  - `"a"` is represented by a *pointer*.
  - `'a'` is represented by an *integer*.
- A legal call of `printf`:

```
printf("\n");
```

- An illegal call:

```
printf('\n');   /*** WRONG ***/
```

String Variables

- Any one-dimensional array of characters can be used to store a string.
- A string must be terminated by a null character.
- If a string variable needs to hold 80 characters, it must be declared to have length 81:

```
#define STR_LEN 80
…
char str[STR_LEN+1];
```

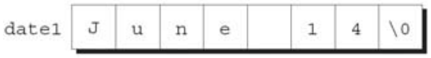
- Adding 1 to the desired length allows room for the null character at the end of the string.

Initializing a String Variable

- A string variable can be initialized at the same time it’s declared:

```
char date1[8] = "June 14";
```

- The compiler will automatically add a null character so that `date1` can be used as a string:



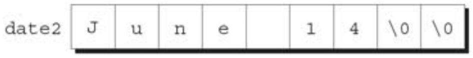
- `"June 14"` is not a string literal in this context.

Initializing a String Variable

- If the initializer is too short to fill the string variable, the compiler adds extra null characters:

```
char date2[9] = "June 14";
```

Appearance of `date2`:

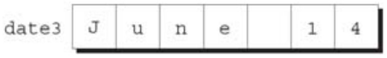


Initializing a String Variable

- An initializer for a string variable can’t be longer than the variable, but it can be the same length:

```
char date3[7] = "June 14";
```

- There’s no room for the null character, so the compiler makes no attempt to store one:



Initializing a String Variable

- The declaration of a string variable may omit its length, in which case the compiler computes it:

```
char date4[] = "June 14";
```

- The compiler sets aside eight characters for `date4`, enough to store the characters in `"June 14"` plus a null character.
- Omitting the length of a string variable is especially useful if the initializer is long, since computing the length by hand is error-prone.

Character Arrays versus Character Pointers

- The declaration

```
char date[] = "June 14";
```

declares `date` to be an *array*,

- The similar-looking

```
char *date = "June 14";
```

declares `date` to be a *pointer*.

- Thanks to the close relationship between arrays and pointers, either version can be used as a string.

Character Arrays versus Character Pointers

- However, there are significant differences between the two versions of `date`.
  - In the array version, the characters stored in `date` can be modified. In the pointer version, `date` points to a string literal that shouldn’t be modified.

Reading and Writing Strings

- Writing a string is easy using either `printf` or `puts`.
- Reading a string is a bit harder, because the input may be longer than the string variable into which it's being stored.
- To read a string in a single step, we can use either `scanf` or `gets`.
- As an alternative, we can read strings one character at a time.

Writing Strings Using `printf` and `puts`

- The `%s` conversion specification allows `printf` to write a string:

```
char str[] = "Are we having fun yet?";

printf("%s\n", str);
```

  The output will be

```
Are we having fun yet?
```

- `printf` writes the characters in a string one by one until it encounters a null character.
- The C library also provides `puts`: `puts(str);`
- After writing a string, `puts` always writes an additional new-line character.

Writing Strings Using `printf` and `puts`

- To print part of a string, use the conversion specification `%.`*`p`*`s`.
- *p* is the number of characters to be displayed.
- The statement

```
printf("%.6s\n", str);
```

  will print

```
Are we
```

Writing Strings Using `printf` and `puts`

- The `%`*`m`*`s` conversion will display a string in a field of size *m*.
- If the string has fewer than *m* characters, it will be right-justified within the field.
- To force left justification instead, we can put a minus sign in front of *m*.
- The *m* and *p* values can be used in combination.
- A conversion specification of the form `%`*`m`*`.`*`p`*`s` causes the first *p* characters of a string to be displayed in a field of size *m*.

Reading Strings Using `scanf` and `gets`

- The `%s` conversion specification allows `scanf` to read a string into a character array:

```
scanf("%s", str);
```

- `str` is treated as a pointer, so there's no need to put the `&` operator in front of `str`.
- When `scanf` is called, it skips white space, then reads characters and stores them in `str` until it encounters a white-space character.
- `scanf` always stores a null character at the end of the string.

Reading Strings Using `scanf` and `gets`

- `scanf` won't usually read a full line of input.
- A new-line character will cause `scanf` to stop reading, and so will a space or tab character.
- To read an entire line of input, we can use `gets`.
- Properties of `gets`:
  - Doesn't skip white space before starting to read input.
  - Reads until it finds a new-line character.
  - Discards the new-line character instead of storing it; the null character takes its place.

Reading Strings Using **scanf** and **gets**

- Consider the following program fragment:

```
char sentence[SENT_LEN+1];

printf("Enter a sentence:\n");
scanf("%s", sentence);
```

- Suppose that after the prompt

```
Enter a sentence:
```

the user enters the line

```
  To C, or not to C: that is the question.
```

- `scanf` will store the string `"To"` in `sentence`.

Reading Strings Using **scanf** and **gets**

- Suppose that we replace `scanf` by `gets`:

```
gets(sentence);
```

- When the user enters the same input as before, `gets` will store the string

```
"  To C, or not to C: that is the question."
```

in `sentence`.

Reading Strings Using **scanf** and **gets**

- As they read characters into an array, `scanf` and `gets` have no way to detect when it's full.
- Consequently, they may store characters past the end of the array, causing undefined behavior.
- `scanf` can be made safer by using the conversion specification `%`*n*`s` instead of `%s`.
- *n* is an integer indicating the maximum number of characters to be stored.
- `gets` is inherently unsafe; `fgets` is a much better alternative.

Accessing the Characters in a String

- A function that counts the number of spaces in a string:

```
int count_spaces(const char s[])
{
  int count = 0, i;

  for (i = 0; s[i] != '\0'; i++)
    if (s[i] == ' ')
      count++;
  return count;
}
```

Accessing the Characters in a String

- A version that uses pointer arithmetic instead of array subscripting :

```
int count_spaces(const char *s)
{
  int count = 0;

  for (; *s != '\0'; s++)
    if (*s == ' ')
      count++;
  return count;
}
```

Accessing the Characters in a String

- Questions raised by the `count_spaces` example:
  - *Is it better to use array operations or pointer operations to access the characters in a string?* We can use either or both. Traditionally, C programmers lean toward using pointer operations.
  - *Should a string parameter be declared as an array or as a pointer?* There's no difference between the two.
  - *Does the form of the parameter (*`s[]` *or* `*s`*) affect what can be supplied as an argument?* No.

Using the C String Library

- Some programming languages provide operators that can copy strings, compare strings, concatenate strings, select substrings, and the like.
- C's operators, in contrast, are essentially useless for working with strings.
- Strings are treated as arrays in C, so they're restricted in the same ways as arrays.
- In particular, they can't be copied or compared using operators.

Using the C String Library

- Direct attempts to copy or compare strings will fail.
- Copying a string into a character array using the = operator is not possible:

```
char str1[10], str2[10];
…
str1 = "abc";   /*** WRONG ***/
str2 = str1;    /*** WRONG ***/
```

  Using an array name as the left operand of = is illegal.
- *Initializing* a character array using = is legal, though:

```
char str1[10] = "abc";
```

Using the C String Library

- Attempting to compare strings using a relational or equality operator is legal but won't produce the desired result:

```
if (str1 == str2) …    /*** WRONG ***/
```

- This statement compares `str1` and `str2` as *pointers*.
- Since `str1` and `str2` have different addresses, the expression `str1` == `str2` must have the value 0.

Using the C String Library

- The C library provides a rich set of functions for performing operations on strings.
- Programs that need string operations should contain the following line:

```
#include <string.h>
```

- In subsequent examples, assume that `str1` and `str2` are character arrays used as strings.

The **`strcpy`** (String Copy) Function

- Prototype for the `strcpy` function:

```
char *strcpy(char *s1, const char *s2);
```

- `strcpy` copies the string `s2` into the string `s1`.
- `strcpy` returns `s1` (a pointer to the destination string).

The **`strcpy`** (String Copy) Function

- In the call `strcpy(str1, str2)`, `strcpy` has no way to check that the `str2` string will fit in the array pointed to by `str1`.
- If it doesn't, undefined behavior occurs.

The **strcpy** (String Copy) Function

- Calling the `strncpy` function is a safer, albeit slower, way to copy a string.
- `strncpy` has a third argument that limits the number of characters that will be copied.
- A call of `strncpy` that copies `str2` into `str1`:

```
strncpy(str1, str2, sizeof(str1));
```

The **strcpy** (String Copy) Function

- `strncpy` will leave `str1` without a terminating null character if the length of `str2` is greater than or equal to the size of the `str1` array.
- A safer way to use `strncpy`:

```
strncpy(str1, str2, sizeof(str1) - 1);
str1[sizeof(str1)-1] = '\0';
```

- The second statement guarantees that `str1` is always null-terminated.

The **strlen** (String Length) Function

- Prototype for the `strlen` function:

```
size_t strlen(const char *s);
```

- `size_t` is a `typedef` name that represents one of C's unsigned integer types.

The **strlen** (String Length) Function

- `strlen` returns the length of a string `s`, not including the null character.
- Examples:

```
int len;

len = strlen("abc");   /* len is now 3 */
len = strlen("");      /* len is now 0 */
strcpy(str1, "abc");
len = strlen(str1);    /* len is now 3 */
```

The **strcat** (String Concatenation) Function

- Prototype for the `strcat` function:

```
char *strcat(char *s1, const char *s2);
```

- `strcat` appends the contents of the string `s2` to the end of the string `s1`.
- It returns `s1` (a pointer to the resulting string).
- `strcat` examples:

```
strcpy(str1, "abc");
strcat(str1, "def");
  /* str1 now contains "abcdef" */
strcpy(str1, "abc");
strcpy(str2, "def");
strcat(str1, str2);
  /* str1 now contains "abcdef" */
```

The **strcat** (String Concatenation) Function

- As with `strcpy`, the value returned by `strcat` is normally discarded.
- The following example shows how the return value might be used:

```
strcpy(str1, "abc");
strcpy(str2, "def");
strcat(str1, strcat(str2, "ghi"));
  /* str1 now contains "abcdefghi";
     str2 contains "defghi" */
```

The `strcat` (String Concatenation) Function

- `strcat(str1, str2)` causes undefined behavior if the `str1` array isn't long enough to accommodate the characters from `str2`.
- Example:

```
char str1[6] = "abc";

strcat(str1, "def");    /*** WRONG ***/
```

- `str1` is limited to six characters, causing `strcat` to write past the end of the array.

The `strcat` (String Concatenation) Function

- The `strncat` function is a safer but slower version of `strcat`.
- Like `strncpy`, it has a third argument that limits the number of characters it will copy.
- A call of `strncat`:

```
strncat(str1, str2, sizeof(str1) - strlen(str1) - 1);
```

- `strncat` will terminate `str1` with a null character.

The `strcmp` (String Comparison) Function

- Prototype for the `strcmp` function:

```
int strcmp(const char *s1, const char *s2);
```

- `strcmp` compares the strings `s1` and `s2`, returning a value less than, equal to, or greater than 0, depending on whether `s1` is less than, equal to, or greater than `s2`.

The `strcmp` (String Comparison) Function

- Testing whether `str1` is less than `str2`:

```
if (strcmp(str1, str2) < 0)    /* is str1 < str2? */
  …
```

- Testing whether `str1` is less than or equal to `str2`:

```
if (strcmp(str1, str2) <= 0) /* is str1 <= str2? */
  …
```

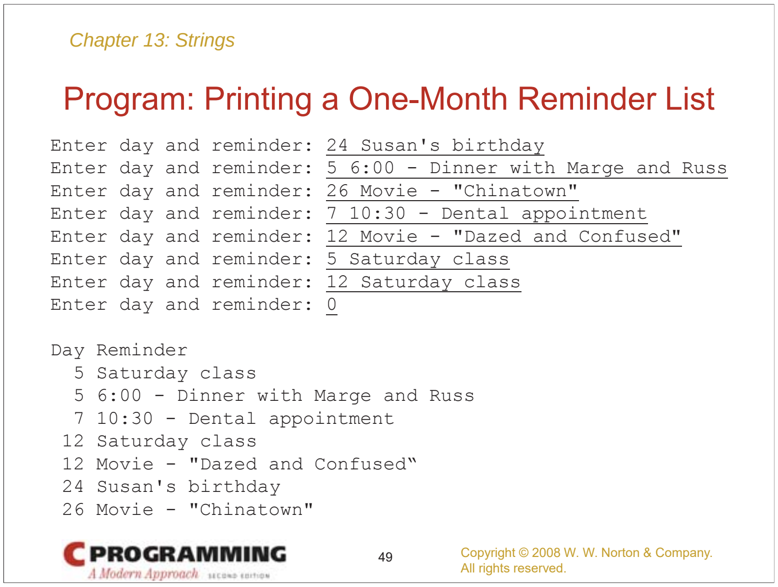
- By choosing the proper operator (<, <=, >, >=, ==, !=), we can test any possible relationship between `str1` and `str2`.

The `strcmp` (String Comparison) Function

- As it compares two strings, `strcmp` looks at the numerical codes for the characters in the strings.
- Some knowledge of the underlying character set is helpful to predict what `strcmp` will do.
- Important properties of ASCII:
  - A–Z, a–z, and 0–9 have consecutive codes.
  - All upper-case letters are less than all lower-case letters.
  - Digits are less than letters.
  - Spaces are less than all printing characters.

Program: Printing a One-Month Reminder List

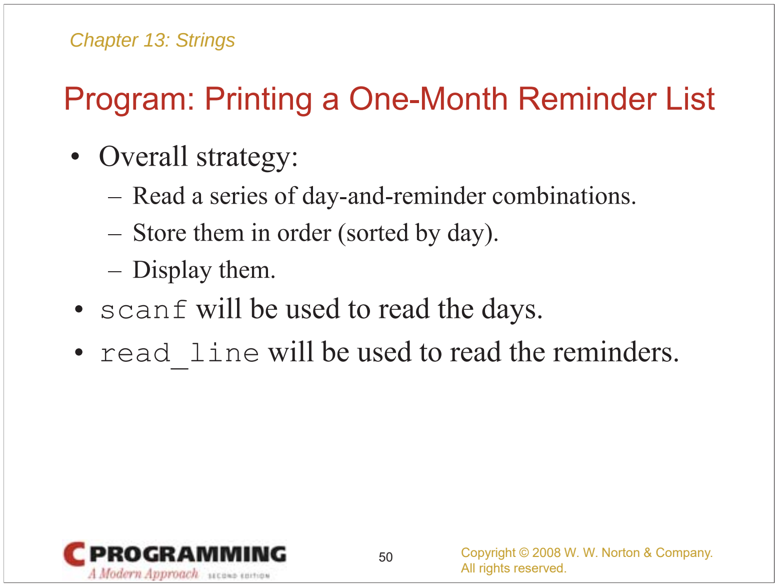
- The `remind.c` program prints a one-month list of daily reminders.
- The user will enter a series of reminders, with each prefixed by a day of the month.
- When the user enters 0 instead of a valid day, the program will print a list of all reminders entered, sorted by day.
- The next slide shows a session with the program.



Program: Printing a One-Month Reminder List

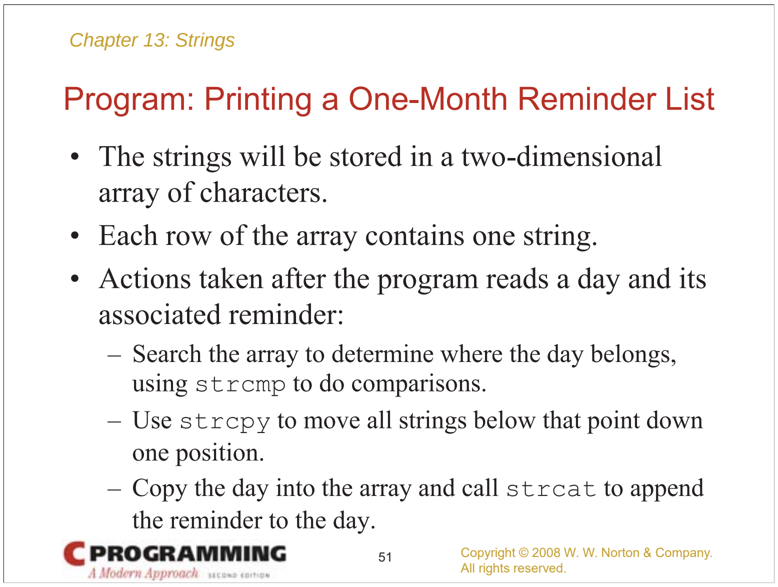
```
Enter day and reminder: 24 Susan's birthday
Enter day and reminder: 5 6:00 - Dinner with Marge and Russ
Enter day and reminder: 26 Movie - "Chinatown"
Enter day and reminder: 7 10:30 - Dental appointment
Enter day and reminder: 12 Movie - "Dazed and Confused"
Enter day and reminder: 5 Saturday class
Enter day and reminder: 12 Saturday class
Enter day and reminder: 0

Day Reminder
  5 Saturday class
  5 6:00 - Dinner with Marge and Russ
  7 10:30 - Dental appointment
 12 Saturday class
 12 Movie - "Dazed and Confused‟
 24 Susan's birthday
 26 Movie - "Chinatown"
```



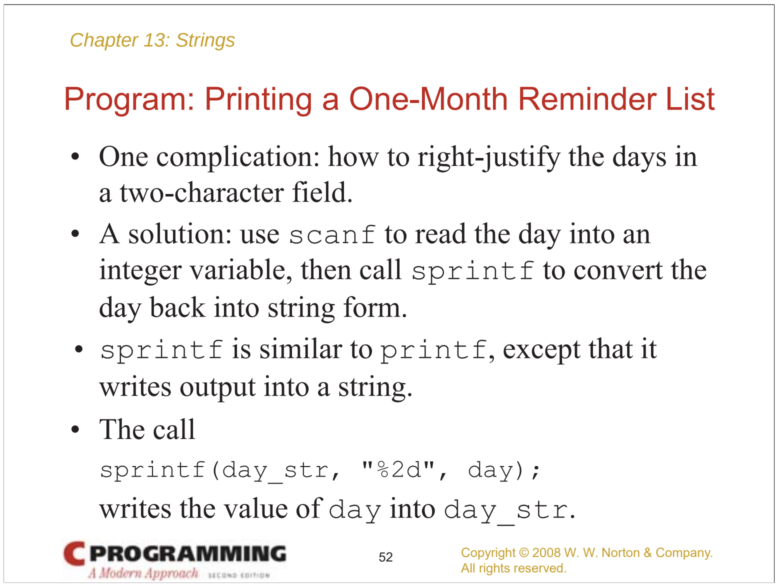
Program: Printing a One-Month Reminder List

- Overall strategy:
  - Read a series of day-and-reminder combinations.
  - Store them in order (sorted by day).
  - Display them.
- `scanf` will be used to read the days.
- `read_line` will be used to read the reminders.



Program: Printing a One-Month Reminder List

- The strings will be stored in a two-dimensional array of characters.
- Each row of the array contains one string.
- Actions taken after the program reads a day and its associated reminder:
  - Search the array to determine where the day belongs, using `strcmp` to do comparisons.
  - Use `strcpy` to move all strings below that point down one position.
  - Copy the day into the array and call `strcat` to append the reminder to the day.

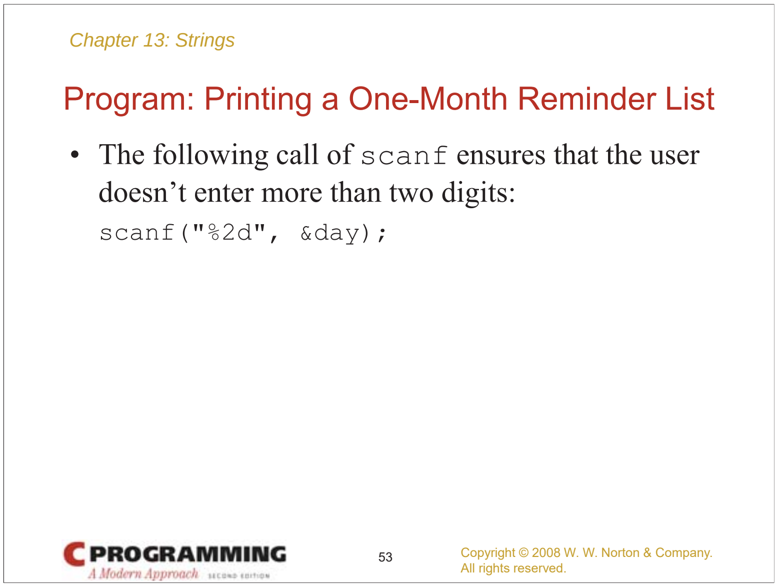


Program: Printing a One-Month Reminder List

- One complication: how to right-justify the days in a two-character field.
- A solution: use `scanf` to read the day into an integer variable, then call `sprintf` to convert the day back into string form.
- `sprintf` is similar to `printf`, except that it writes output into a string.
- The call

  ```
  sprintf(day_str, "%2d", day);
  ```

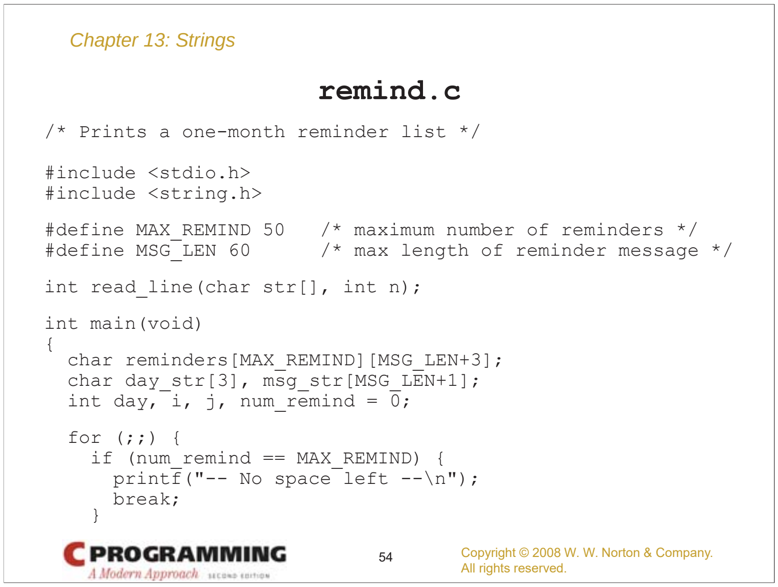
  writes the value of `day` into `day_str`.



Program: Printing a One-Month Reminder List

- The following call of `scanf` ensures that the user doesn’t enter more than two digits:

  ```
  scanf("%2d", &day);
  ```



remind.c

```
/* Prints a one-month reminder list */

#include <stdio.h>
#include <string.h>

#define MAX_REMIND 50   /* maximum number of reminders */
#define MSG_LEN 60      /* max length of reminder message */

int read_line(char str[], int n);

int main(void)
{
  char reminders[MAX_REMIND][MSG_LEN+3];
  char day_str[3], msg_str[MSG_LEN+1];
  int day, i, j, num_remind = 0;

  for (;;) {
    if (num_remind == MAX_REMIND) {
      printf("-- No space left --\n");
      break;
    }
```

```
    printf("Enter day and reminder: ");
    scanf("%2d", &day);
    if (day == 0)
      break;
    sprintf(day_str, "%2d", day);
    read_line(msg_str, MSG_LEN);

    for (i = 0; i < num_remind; i++)
      if (strcmp(day_str, reminders[i]) < 0)
        break;
    for (j = num_remind; j > i; j--)
      strcpy(reminders[j], reminders[j-1]);

    strcpy(reminders[i], day_str);
    strcat(reminders[i], msg_str);

    num_remind++;
  }

  printf("\nDay Reminder\n");
  for (i = 0; i < num_remind; i++)
    printf(" %s\n", reminders[i]);

  return 0;
}
```

```
int read_line(char str[], int n)
{
  int ch, i = 0;

  while ((ch = getchar()) != '\n')
    if (i < n)
      str[i++] = ch;
  str[i] = '\0';
  return i;
}
```