Introduction to Computers and Programming

Lecture 7 –

String vs character array

Chap 13

Tien-Fu Chen

Dept. of Computer Science and Information Engineering

National Yang Ming Chiao Tung Univ.

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
```

How String Literals Are Stored

- A string literal of length *n* sets aside *n* + 1 bytes of memory for the string.
- This memory will contain the characters, plus one extra ***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.
- The string literal `"abc"` is stored as an array of four characters:

`a`	`b`	`c`	`\0`

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

`\0`

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 vs 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

- 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.
- Defining a macro that represents 80 and then adding 1 separately is a common practice.

String Variables

- Be sure to leave room for the null character when declaring a string variable.
- Failing to do so may cause unpredictable results when the program is executed.
- The actual length of a string depends on the position of the terminating null character.
- An array of `STR_LEN` + 1 characters can hold strings with lengths between 0 and `STR_LEN`.

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:

`date1`	`J`	`u`	`n`	`e`		`1`	`4`	`\0`

- `"June 14"` is not a string literal in this context.
- Instead, C views it as an abbreviation for an array initializer.

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`:

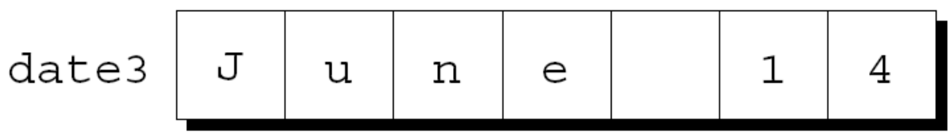
date2	J	u	n	e		1	4	\0	\0

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 vs 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 vs Character Pointers

- The declaration

  ```
  char *p;
  ```

  does not allocate space for a string.
- Before we can use `p` as a string, it must point to an array of characters.
- One possibility is to make `p` point to a string variable:

  ```
  char str[STR_LEN+1], *p;

  p = str;
  ```
- Another possibility is to make `p` point to a dynamically allocated string.

Character Arrays vs Character Pointers

- Using an uninitialized pointer variable as a string is a serious error.
- An attempt at building the string `"abc"`:

```
char *p;

p[0] = 'a';     /*** WRONG ***/
p[1] = 'b';     /*** WRONG ***/
p[2] = 'c';     /*** WRONG ***/
p[3] = '\0';    /*** WRONG ***/
```

- Since `p` hasn't been initialized, this causes undefined behavior.

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.

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*.

Writing Strings Using `printf` and `puts`

- `printf` isn't the only function that can write strings.
- The C library also provides `puts`:

```
puts(str);
```

- After writing a string, `puts` always writes an additional new-line character.

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, but 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 Character by Character

- Suppose we need a function that (1) doesn't skip white-space characters, (2) stops reading at the first new-line character (which isn't stored in the string), and (3) discards extra characters.
- A prototype for the function:

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

- If the input line contains more than `n` characters, `read_line` will discard the additional characters.
- `read_line` will return the number of characters it stores in `str`.

Reading Strings Character by Character

- `read_line` consists primarily of a loop that calls `getchar` to read a character and then stores the character in `str`, provided that there's room left:

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

  while ((ch = getchar()) != '\n')
    if (i < n)
      str[i++] = ch;
  str[i] = '\0';    /* terminates string */
  return i;         /* number of characters stored */
}
```

- `ch` has `int` type rather than `char` type because `getchar` returns an `int` value.

Access string

Accessing the Characters in a String

- To process every character in a string `s`, we can set up a loop that increments a counter `i` and access via the expression `s[i]`.
- 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;
}
```

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";
```

  In this context, = is not the assignment operator.

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`.
  - To be precise, we should say "`strcpy` copies the string pointed to by `s2` into the array pointed to by `s1`."
- `strcpy` returns `s1` (a pointer to the destination string).

The `strcpy` (String Copy) Function

- A call of `strcpy` that stores the string `"abcd"` in `str2`:

```
strcpy(str2, "abcd");
   /* str2 now contains "abcd" */
```

- A call that copies the contents of `str2` into `str1`:

```
strcpy(str1, str2);
   /* str1 now contains "abcd" */
```

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);
```

- `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

- 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" */
```

`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" */
```

`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.

`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, which isn't included in the third argument.

`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`.

`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`.

`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.

Search in string

Searching for the End of a String

- A version of `strlen` that searches for the end of a string, using a variable to keep track of the string’s length:

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

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

Searching for the End of a String

- The condition `*s != '\0'` is the same as `*s != 0`, which in turn is the same as `*s`.
- A version of `strlen` that uses these observations:

```
size_t strlen(const char *s)
{
  size_t n = 0;

  for (; *s; s++)
    n++;
  return n;
}
```

Searching for the End of a String

- The next version increments `s` and tests `*s` in the same expression:

```
size_t strlen(const char *s)
{
  size_t n = 0;

  for (; *s++;)
    n++;
  return n;
}
```

Searching for the End of a String

- Replacing the `for` statement with a `while` statement gives the following version of `strlen`:

```
size_t strlen(const char *s)
{
  size_t n = 0;

  while (*s++)
    n++;
  return n;
}
```

Searching for the End of a String

- Although we've condensed `strlen` quite a bit, it's likely that we haven't increased its speed.
- A version that *does* run faster, at least with some compilers:

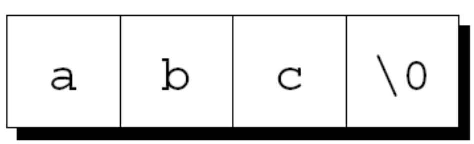
```
size_t strlen(const char *s)
{
  const char *p = s;

  while (*s)
    s++;
  return s - p;
}
```

Searching for the End of a String

- Idioms for "search for the null character at the end of a string":

```
while (*s)         while (*s++)
  s++;               ;
```

- The first version leaves `s` pointing to the null character.
- The second version is more concise, but leaves `s` pointing just past the null character.



Copying a String

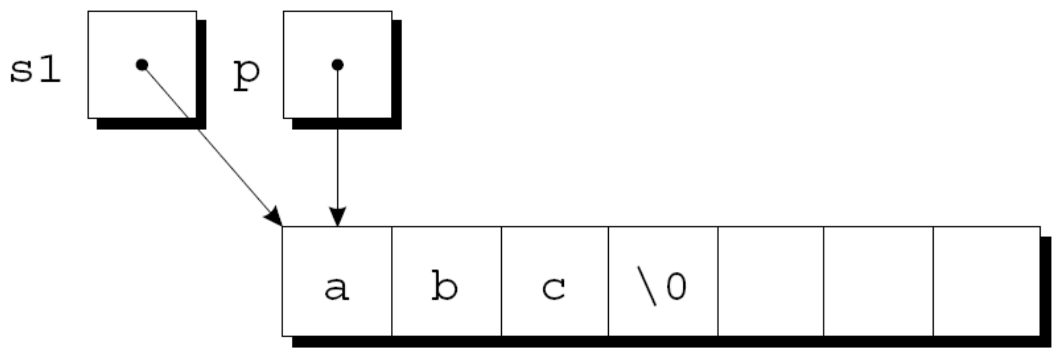
- Copying a string is another common operation.
- To introduce C's "string copy" idiom, we'll develop two versions of the `strcat` function.
- The first version of `strcat` (next slide) uses a two-step algorithm:
  - Locate the null character at the end of the string `s1` and make `p` point to it.
  - Copy characters one by one from `s2` to where `p` is pointing.

Copying a String

```
char *strcat(char *s1, const char *s2)
{
  char *p = s1;

  while (*p != '\0')
    p++;
  while (*s2 != '\0') {
    *p = *s2;
    p++;
    s2++;
  }
  *p = '\0';
  return s1;
}
```

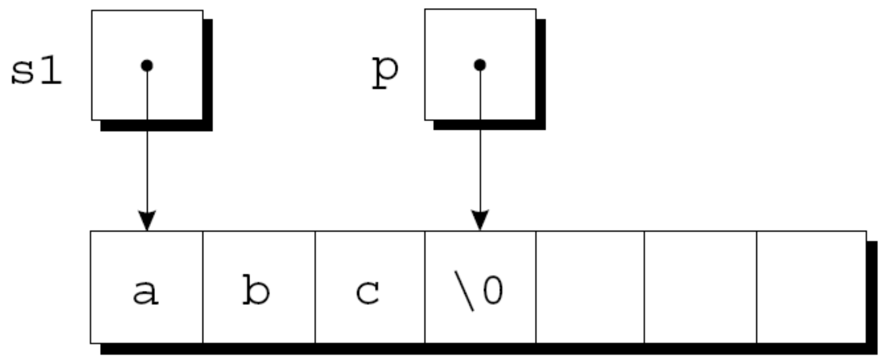
Copying a String

- `p` initially points to the first character in the `s1` string:



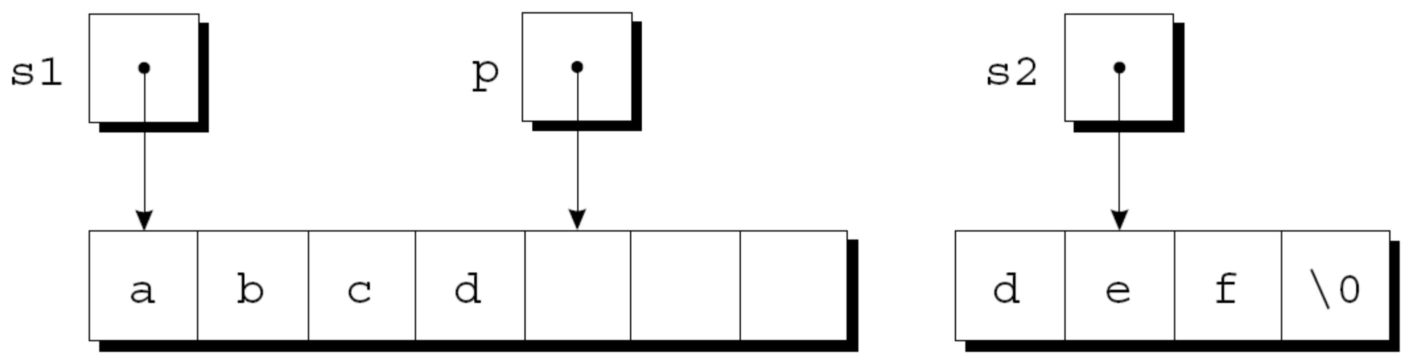
Copying a String

- The first `while` statement locates the null character at the end of `s1` and makes `p` point to it:



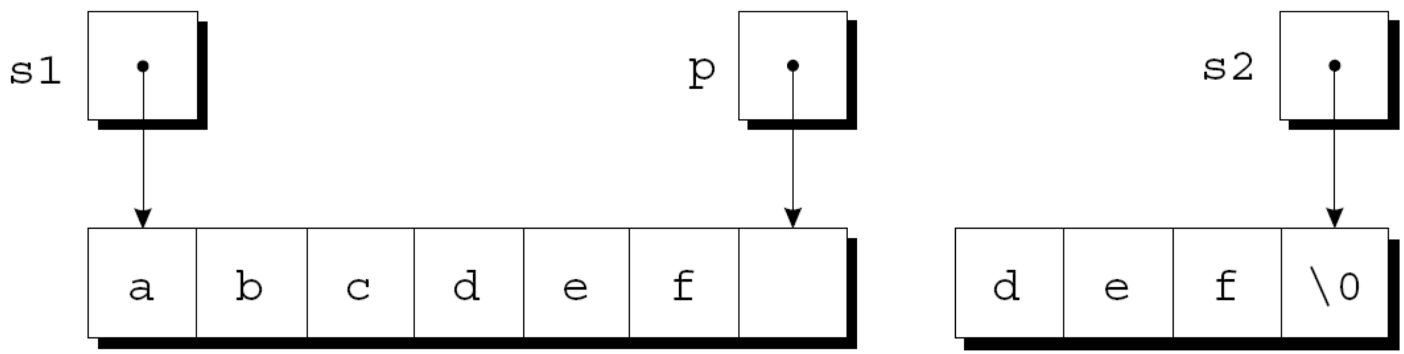
Copying a String

- The second `while` statement repeatedly copies one character from where `s2` points to where `p` points, then increments both `p` and `s2`.
- Assume that `s2` originally points to the string `"def"`.
- The strings after the first loop iteration:



Copying a String

- The loop terminates when `s2` points to the null character:



- After putting a null character where `p` is pointing, `strcat` returns.

Copying a String

- Condensed version of `strcat`:

```
char *strcat(char *s1, const char *s2)
{
  char *p = s1;

  while (*p)
    p++;
  while (*p++ = *s2++)
    ;
  return s1;
}
```

Copying a String

- The heart of the streamlined `strcat` function is the "string copy" idiom:

```
while (*p++ = *s2++)
  ;
```

- Ignoring the two `++` operators, the expression inside the parentheses is an assignment:

```
*p = *s2
```

- After the assignment, `p` and `s2` are incremented.
- Repeatedly evaluating this expression copies characters from where `s2` points to where `p` points.

Arrays of Strings

- There is more than one way to store an array of strings.
- One option is to use a two-dimensional array of characters, with one string per row:

```
char planets[][8] = {"Mercury", "Venus", "Earth",
                     "Mars", "Jupiter", "Saturn",
                     "Uranus", "Neptune", "Pluto"};
```

- The number of rows in the array can be omitted, but we must specify the number of columns.

Arrays of Strings

- Unfortunately, the `planets` array contains a fair bit of wasted space (extra null characters):

	0	1	2	3	4	5	6	7
0	M	e	r	c	u	r	y	\0
1	V	e	n	u	s	\0	\0	\0
2	E	a	r	t	h	\0	\0	\0
3	M	a	r	s	\0	\0	\0	\0
4	J	u	p	i	t	e	r	\0
5	S	a	t	u	r	n	\0	\0
6	U	r	a	n	u	s	\0	\0
7	N	e	p	t	u	n	e	\0
8	P	l	u	t	o	\0	\0	\0

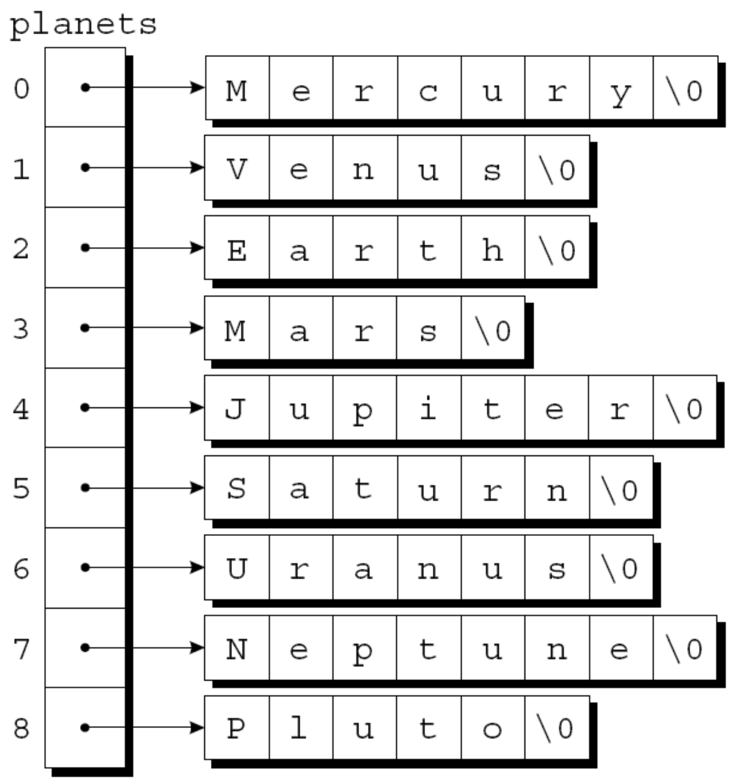
Arrays of Strings

- Most collections of strings will have a mixture of long strings and short strings.
- What we need is a ***ragged array,*** whose rows can have different lengths.
- We can simulate a ragged array in C by creating an array whose elements are *pointers* to strings:

```
char *planets[] = {"Mercury", "Venus", "Earth",
                   "Mars", "Jupiter", "Saturn",
                   "Uranus", "Neptune", "Pluto"};
```

Arrays of Strings

- This small change has a dramatic effect on how `planets` is stored:



Arrays of Strings

- To access one of the planet names, all we need do is subscript the `planets` array.
- Accessing a character in a planet name is done in the same way as accessing an element of a two-dimensional array.
- A loop that searches the `planets` array for strings beginning with the letter M:

```
for (i = 0; i < 9; i++)
  if (planets[i][0] == 'M')
    printf("%s begins with M\n", planets[i]);
```

Command-Line Arguments

- When we run a program, we'll often need to supply it with information.
- This may include a file name or a switch that modifies the program's behavior.
- Examples of the UNIX `ls` command:

```
ls
ls -l
ls -l remind.c
```

Command-Line Arguments

- Command-line information is available to all programs, not just operating system commands.
- To obtain access to ***command-line arguments***, `main` must have two parameters:

```
int main(int argc, char *argv[])
{
   …
}
```

- Command-line arguments are called ***program parameters*** in the C standard.

Command-Line Arguments

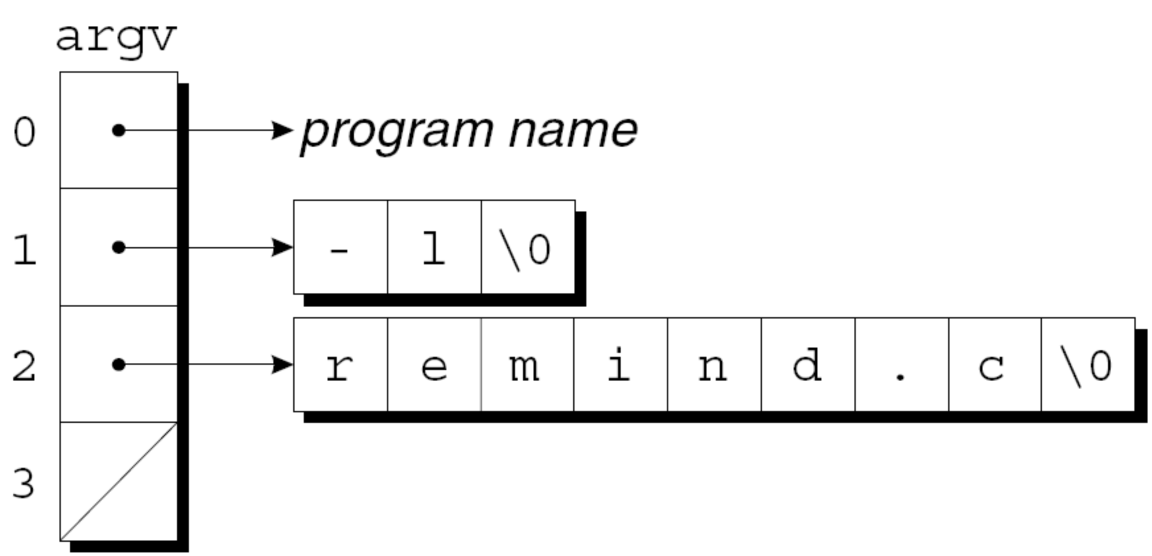
- `argc` ("argument count") is the number of command-line arguments.
- `argv` ("argument vector") is an array of pointers to the command-line arguments (stored as strings).
- `argv[0]` points to the name of the program, while `argv[1]` through `argv[argc-1]` point to the remaining command-line arguments.
- `argv[argc]` is always a ***null pointer***—a special pointer that points to nothing.
  - The macro `NULL` represents a null pointer.

Command-Line Arguments

- If the user enters the command line

  ```
  ls -l remind.c
  ```

  then `argc` will be 3, and `argv` will have the following appearance:



Command-Line Arguments

- Since `argv` is an array of pointers, accessing command-line arguments is easy.
- Typically, a program that expects command-line arguments will set up a loop that examines each argument in turn.
- One way to write such a loop is to use an integer variable as an index into the `argv` array:

```
int i;

for (i = 1; i < argc; i++)
  printf("%s\n", argv[i]);
```

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- Another technique is to set up a pointer to `argv[1]`, then increment the pointer repeatedly:

```
char **p;

for (p = &argv[1]; *p != NULL; p++)
  printf("%s\n", *p);
```