Chapter 6

Loops

Iteration Statements

- C's iteration statements are used to set up loops.
- A ***loop*** is a statement whose job is to repeatedly execute some other statement (the ***loop body***).
- In C, every loop has a ***controlling expression***.
- Each time the loop body is executed (an ***iteration*** of the loop), the controlling expression is evaluated.
  - If the expression is true (has a value that's not zero) the loop continues to execute.

Iteration Statements

- C provides three iteration statements:
  - The `while` statement is used for loops whose controlling expression is tested *before* the loop body is executed.
  - The `do` statement is used if the expression is tested *after* the loop body is executed.
  - The `for` statement is convenient for loops that increment or decrement a counting variable.

The `while` Statement

- Using a `while` statement is the easiest way to set up a loop.
- The `while` statement has the form

  `while` (*expression*) *statement*
- *expression* is the controlling expression; *statement* is the loop body.

Program: Summing a Series of Numbers

- The `sum.c` program sums a series of integers entered by the user:

```
This program sums a series of integers.
Enter integers (0 to terminate): 8 23 71 5 0
The sum is: 107
```

- The program will need a loop that uses `scanf` to read a number and then adds the number to a running total.

sum.c

```
/* Sums a series of numbers */

#include <stdio.h>

int main(void)
{
  int n, sum = 0;

  printf("This program sums a series of integers.\n");
  printf("Enter integers (0 to terminate): ");

  scanf("%d", &n);
  while (n != 0) {
    sum += n;
    scanf("%d", &n);
  }
  printf("The sum is: %d\n", sum);

  return 0;
}
```

The do Statement

- General form of the do statement:

  do *statement* while (*expression*) ;
- When a do statement is executed, the loop body is executed first, then the controlling expression is evaluated.
- If the value of the expression is nonzero, the loop body is executed again and then the expression is evaluated once more.

Program: Calculating the Number of Digits in an Integer

- The numdigits.c program calculates the number of digits in an integer entered by the user:

```
Enter a nonnegative integer: 60
The number has 2 digit(s).
```

- The program will divide the user's input by 10 repeatedly until it becomes 0; the number of divisions performed is the number of digits.
- Writing this loop as a do statement is better than using a while statement, because every integer—even 0—has at least one digit.

numdigits.c

```
/* Calculates the number of digits in an integer */

#include <stdio.h>

int main(void)
{
  int digits = 0, n;

  printf("Enter a nonnegative integer: ");
  scanf("%d", &n);

  do {
    n /= 10;
    digits++;
  } while (n > 0);

  printf("The number has %d digit(s).\n", digits);

  return 0;
}
```


The for Statement

- The for statement is ideal for loops that have a "counting" variable, but it's versatile enough to be used for other kinds of loops as well.
- General form of the for statement:

  for (*expr1* ; *expr2* ; *expr3*) *statement*

  expr1, *expr2*, and *expr3* are expressions.
- Example:

```
for (i = 10; i > 0; i--)
  printf("T minus %d and counting\n", i);
```


The Comma Operator

- On occasion, a for statement may need to have two (or more) initialization expressions or one that increments several variables each time through the loop.
- This effect can be accomplished by using a ***comma expression*** as the first or third expression in the for statement.
- A comma expression has the form

  expr1 , *expr2*

  where *expr1* and *expr2* are any two expressions.

The Comma Operator

- The comma operator makes it possible to "glue" two expressions together to form a single expression.
- Certain macro definitions can benefit from the comma operator.
- The for statement is the only other place where the comma operator is likely to be found.
- Example:

```
for (sum = 0, i = 1; i <= N; i++)
  sum += i;
```

- With additional commas, the for statement could initialize more than two variables.

The `break` Statement

- The `break` statement can transfer control out of a switch statement, but it can also be used to jump out of a `while`, `do`, or `for` loop.
- A loop that checks whether a number `n` is prime can use a `break` statement to terminate the loop as soon as a divisor is found:

```
for (d = 2; d < n; d++)
  if (n % d == 0)
    break;
```


The `break` Statement

- After the loop has terminated, an `if` statement can be used to determine whether termination was premature (hence `n` isn't prime) or normal (`n` is prime):

```
if (d < n)
  printf("%d is divisible by %d\n", n, d);
else
  printf("%d is prime\n", n);
```


The `continue` Statement

- The `continue` statement is similar to `break`:
  - `break` transfers control just past the end of a loop.
  - `continue` transfers control to a point just before the end of the loop body.
- With `break`, control leaves the loop; with `continue`, control remains inside the loop.
- There's another difference between `break` and `continue`: `break` can be used in `switch` statements and loops (`while`, `do`, and `for`), whereas `continue` is limited to loops.

The `continue` Statement

- A loop that uses the `continue` statement to sum 10 non-zero numbers:

```
n = 0;
sum = 0;
while (n < 10) {
  scanf("%d", &i);
  if (i == 0)
    continue;
  sum += i;
  n++;
  /* continue jumps to here */
}
```


The `continue` Statement

- The same loop written without using `continue`:

```
n = 0;
sum = 0;
while (n < 10) {
  scanf("%d", &i);
  if (i != 0) {
    sum += i;
    n++;
  }
}
```


The Null Statement

- A statement can be ***null***—free from symbols except for the semicolon at the end.
- The null statement is primarily good for one thing: writing loops whose bodies are empty.

The Null Statement

- Consider the following prime-finding loop:

```
for (d = 2; d < n; d++)
  if (n % d == 0)
    break;
```

- If the `n % d == 0` condition is moved into the loop's controlling expression, the body of the loop becomes empty:

```
for (d = 2; d < n && n % d != 0; d++)
  ;           /* empty loop body */
```


Chapter 7

Basic Types

Basic Types

- C's ***basic*** (built-in) ***types:***
  - Integer types, including long integers, short integers, and unsigned integers
  - Floating types (`float`, `double`, and `long double`)
  - `char`
  - `_Bool` (C99)

Signed and Unsigned Integers

- By default, integer variables are signed in C—the leftmost bit is reserved for the sign.
- To tell the compiler that a variable has no sign bit, declare it to be `unsigned`.
- Unsigned numbers are primarily useful for systems programming and low-level, machine-dependent applications.

Integer Types in C99

- The `short int`, `int`, `long int`, and `long long int` types (along with the `signed char` type) are called ***standard signed integer types*** in C99.
- The `unsigned short int`, `unsigned int`, `unsigned long int`, and `unsigned long long int` types (along with the `unsigned char` type and the `_Bool` type) are called ***standard unsigned integer types.***

Floating Types

- C provides three ***floating types,*** corresponding to different floating-point formats:
  - `float` Single-precision floating-point
  - `double` Double-precision floating-point
  - `long double` Extended-precision floating-point
- `float` is suitable when the amount of precision isn't critical.
- `double` provides enough precision for most programs.
- `long double` is rarely used.

Reading and Writing Floating-Point Numbers

- The conversion specifications `%e`, `%f`, and `%g` are used for reading and writing single-precision floating-point numbers.
- When reading a value of type `double`, put the letter `l` in front of `e`, `f`, or `g`:

```
double d;

scanf("%lf", &d);
```

- *Note:* Use `l` only in a `scanf` format string, not a `printf` string.
- In a `printf` format string, the `e`, `f`, and `g` conversions can be used to write either `float` or `double` values.
- When reading or writing a value of type `long double`, put the letter `L` in front of `e`, `f`, or `g`.

Character Types

- A variable of type `char` can be assigned any single character:

```
char ch;

ch = 'a';   /* lower-case a */
ch = 'A';   /* upper-case A */
ch = '0';   /* zero         */
ch = ' ';   /* space        */
```

- Notice that character constants are enclosed in single quotes, not double quotes.

Operations on Characters

- Working with characters in C is simple, because of one fact: *C treats characters as small integers.*
- The character `'a'` has the value 97, `'A'` has the value 65, `'0'` has the value 48, and `' '` has the value 32.
- Character constants actually have `int` type rather than `char` type.

Operations on Characters

- When a character appears in a computation, C uses its integer value.
- Consider the following examples, which assume the ASCII character set:

```
char ch;
int i;

i = 'a';        /* i is now 97   */
ch = 65;        /* ch is now 'A' */
ch = ch + 1;    /* ch is now 'B' */
ch++;           /* ch is now 'C' */
```


Escape Sequences

- A complete list of character escapes:

Name	*Escape Sequence*
Alert (bell)	`\a`
Backspace	`\b`
Form feed	`\f`
New line	`\n`
Carriage return	`\r`
Horizontal tab	`\t`
Vertical tab	`\v`
Backslash	`\\`
Question mark	`\?`
Single quote	`\'`
Double quote	`\"`

Character-Handling Functions

- Calling C's `toupper` library function is a fast and portable way to convert case:

```
ch = toupper(ch);
```

- `toupper` returns the upper-case version of its argument.
- Programs that call `toupper` need to have `#include <ctype.h>` directive at the top.

Reading and Writing Characters Using `scanf` and `printf`

- The `%c` conversion specification allows `scanf` and `printf` to read and write single characters:

```
char ch;

scanf("%c", &ch);  /* reads one character */
printf("%c", ch);  /* writes one character */
```

- `scanf` doesn't skip white-space characters.
- To force `scanf` to skip white space before reading a character, put a space in its format string just before `%c`:

```
scanf(" %c", &ch);
```


Reading and Writing Characters Using `getchar` and `putchar`

- For single-character input and output, `getchar` and `putchar` are an alternative to `scanf` and `printf`.
- `putchar` writes a character:

```
putchar(ch);
```

- Each time `getchar` is called, it reads one character, which it returns:

```
ch = getchar();
```

- `getchar` returns an `int` value rather than a `char` value, so `ch` will often have type `int`.
- Like `scanf`, `getchar` doesn't skip white-space characters as it reads.

Reading and Writing Characters Using `getchar` and `putchar`

- `getchar` is useful in loops that skip characters as well as loops that search for characters.
- A statement that uses `getchar` to skip an indefinite number of blank characters:

```
while ((ch = getchar()) == ' ')
  ;
```

- When the loop terminates, `ch` will contain the first nonblank character that `getchar` encountered.

Program: Determining the Length of a Message

- The `length.c` program displays the length of a message entered by the user:

```
Enter a message: Brevity is the soul of wit.
Your message was 27 character(s) long.
```

- The length includes spaces and punctuation, but not the new-line character at the end of the message.
- We could use either `scanf` or `getchar` to read characters; most C programmers would choose `getchar`.
- `length2.c` is a shorter program that eliminates the variable used to store the character read by `getchar`.

`length.c`

```
/* Determines the length of a message */

#include <stdio.h>

int main(void)
{
  char ch;
  int len = 0;

  printf("Enter a message: ");
  ch = getchar();
  while (ch != '\n') {
    len++;
    ch = getchar();
  }
  printf("Your message was %d character(s) long.\n", len);

  return 0;
}
```


`length2.c`

```
/* Determines the length of a message */

#include <stdio.h>

int main(void)
{
  int len = 0;

  printf("Enter a message: ");
  while (getchar() != '\n')
    len++;
  printf("Your message was %d character(s) long.\n", len);

  return 0;
}
```

The `sizeof` Operator

- The value of the expression

  `sizeof ( type-name )`

  is an unsigned integer representing the number of bytes required to store a value belonging to *type-name*.
- `sizeof(char)` is always 1, but the sizes of other types may vary.
- On a 32-bit machine, `sizeof(int)` is normally 4.

Chapter 8

Arrays

Scalar Variables versus Aggregate Variables

- So far, the only variables we've seen are ***scalar:*** capable of holding a single data item.
- C also supports ***aggregate*** variables, which can store collections of values.
- There are two kinds of aggregates in C: arrays and structures.

One-Dimensional Arrays

- An ***array*** is a data structure containing a number of data values, all of which have the same type.
- These values, known as ***elements,*** can be individually selected by their position within the array.
- The simplest kind of array has just one dimension.
- The elements of a one-dimensional array `a` are conceptually arranged one after another in a single row (or column):

One-Dimensional Arrays

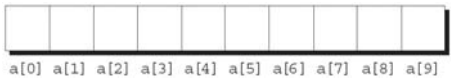
- To declare an array, we must specify the *type* of the array's elements and the *number* of elements:

  ```
  int a[10];
  ```
- The elements may be of any type; the length of the array can be any (integer) `constant` expression.
- Using a macro to define the length of an array is an excellent practice:

  ```
  #define N 10
  …
  int a[N];
  ```


Array Subscripting

- To access an array element, write the array name followed by an integer value in square brackets.
- This is referred to as ***subscripting*** or ***indexing*** the array.
- The elements of an array of length *n* are indexed from 0 to *n* – 1.
- If `a` is an array of length 10, its elements are designated by `a[0]`, `a[1]`, …, `a[9]`:



Array Subscripting

- Many programs contain `for` loops whose job is to perform some operation on every element in an array.
- Examples of typical operations on an array `a` of length `N`:

```
for (i = 0; i < N; i++)
  a[i] = 0;             /* clears a */

for (i = 0; i < N; i++)
  scanf("%d", &a[i]);   /* reads data into a */

for (i = 0; i < N; i++)
  sum += a[i];          /* sums the elements of a */
```


Array Subscripting

- An array subscript may be any integer expression:

```
a[i+j*10] = 0;
```

- The expression can even have side effects:

```
i = 0;
while (i < N)
  a[i++] = 0;
```


Program: Reversing a Series of Numbers

- The `reverse.c` program prompts the user to enter a series of numbers, then writes the numbers in reverse order:

```
Enter 10 numbers: 34 82 49 102 7 94 23 11 50 31
In reverse order: 31 50 11 23 94 7 102 49 82 34
```

- The program stores the numbers in an array as they're read, then goes through the array backwards, printing the elements one by one.

reverse.c

```
/* Reverses a series of numbers */

#include <stdio.h>

#define N 10

int main(void)
{
  int a[N], i;

  printf("Enter %d numbers: ", N);
  for (i = 0; i < N; i++)
    scanf("%d", &a[i]);

  printf("In reverse order:");
  for (i = N - 1; i >= 0; i--)
    printf(" %d", a[i]);
  printf("\n");

  return 0;
}
```


Array Initialization

- An array, like any other variable, can be given an initial value at the time it's declared.
- The most common form of ***array initializer*** is a list of constant expressions enclosed in braces and separated by commas:

```
int a[10] = {1, 2, 3, 4, 5, 6, 7, 8, 9, 10};
```


Array Initialization

- If the initializer is shorter than the array, the remaining elements of the array are given the value 0:

```
int a[10] = {1, 2, 3, 4, 5, 6};
/* initial value of a is {1, 2, 3, 4, 5, 6, 0, 0, 0, 0} */
```

- Using this feature, we can easily initialize an array to all zeros:

```
int a[10] = {0};
/* initial value of a is {0, 0, 0, 0, 0, 0, 0, 0, 0, 0} */
```

  There's a single 0 inside the braces because it's illegal for an initializer to be completely empty.
- It's also illegal for an initializer to be longer than the array it initializes.

Array Initialization

- If an initializer is present, the length of the array may be omitted:

```
int a[] = {1, 2, 3, 4, 5, 6, 7, 8, 9, 10};
```

- The compiler uses the length of the initializer to determine how long the array is.

Designated Initializers (C99)

- It's often the case that relatively few elements of an array need to be initialized explicitly; the other elements can be given default values.
- An example:

```
int a[15] =
  {0, 0, 29, 0, 0, 0, 0, 0, 0, 7, 0, 0, 0, 0, 48};
```

- For a large array, writing an initializer in this fashion is tedious and error-prone.

Designated Initializers (C99)

- C99's ***designated initializers*** can be used to solve this problem.
- Here's how we could redo the previous example using a designated initializer:

```
int a[15] = {[2] = 29, [9] = 7, [14] = 48};
```

- Each number in brackets is said to be a ***designator.***
- Also, the order in which the elements are listed no longer matters.

Using the `sizeof` Operator with Arrays

- The `sizeof` operator can determine the size of an array (in bytes).
- If `a` is an array of 10 integers, then `sizeof(a)` is typically 40 (assuming that each integer requires four bytes).
- We can also use `sizeof` to measure the size of an array element, such as `a[0]`.
- Dividing the array size by the element size gives the length of the array:

```
sizeof(a) / sizeof(a[0])
```


Using the `sizeof` Operator with Arrays

- To avoid a warning, we can add a cast that converts `sizeof(a) / sizeof(a[0])` to a signed integer:

```
for (i = 0; i < (int) (sizeof(a) / sizeof(a[0])); i++)
  a[i] = 0;
```

- Defining a macro for the size calculation is often helpful:

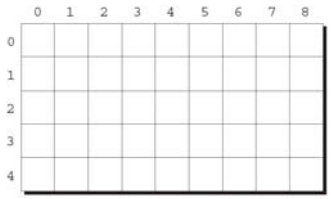
```
#define SIZE ((int) (sizeof(a) / sizeof(a[0])))

for (i = 0; i < SIZE; i++)
  a[i] = 0;
```


Multidimensional Arrays

- An array may have any number of dimensions.
- The following declaration creates a two-dimensional array (a *matrix*, in mathematical terminology):

```
int m[5][9];
```

- `m` has 5 rows and 9 columns. Both rows and columns are indexed from 0:

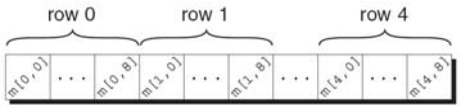


Multidimensional Arrays

- To access the element of `m` in row `i`, column `j`, we must write `m[i][j]`.
- The expression `m[i]` designates row `i` of `m`, and `m[i][j]` then selects element `j` in this row.
- Resist the temptation to write `m[i,j]` instead of `m[i][j]`.

Multidimensional Arrays

- Although we visualize two-dimensional arrays as tables, that's not the way they're actually stored in computer memory.
- C stores arrays in ***row-major order,*** with row 0 first, then row 1, and so forth.
- How the `m` array is stored:



Multidimensional Arrays

- Nested `for` loops are ideal for processing multidimensional arrays.
- Consider the problem of initializing an array for use as an identity matrix. A pair of nested `for` loops is perfect:

```
#define N 10

double ident[N][N];
int row, col;

for (row = 0; row < N; row++)
  for (col = 0; col < N; col++)
    if (row == col)
      ident[row][col] = 1.0;
    else
      ident[row][col] = 0.0;
```


Initializing a Multidimensional Array

- We can create an initializer for a two-dimensional array by nesting one-dimensional initializers:

```
int m[5][9] = {{1, 1, 1, 1, 1, 0, 1, 1, 1},
               {0, 1, 0, 1, 0, 1, 0, 1, 0},
               {0, 1, 0, 1, 1, 0, 0, 1, 0},
               {1, 1, 0, 1, 0, 0, 0, 1, 0},
               {1, 1, 0, 1, 0, 0, 1, 1, 1}};
```

- Initializers for higher-dimensional arrays are constructed in a similar fashion.
- C provides a variety of ways to abbreviate initializers for multidimensional arrays

Initializing a Multidimensional Array

- If an initializer isn't large enough to fill a multidimensional array, the remaining elements are given the value 0.
- The following initializer fills only the first three rows of `m`; the last two rows will contain zeros:

```
int m[5][9] = {{1, 1, 1, 1, 1, 0, 1, 1, 1},
               {0, 1, 0, 1, 0, 1, 0, 1, 0},
               {0, 1, 0, 1, 1, 0, 0, 1, 0}};
```


Initializing a Multidimensional Array

- If an inner list isn't long enough to fill a row, the remaining elements in the row are initialized to 0:

```
int m[5][9] = {{1, 1, 1, 1, 1, 0, 1, 1, 1},
               {0, 1, 0, 1, 0, 1, 0, 1},
               {0, 1, 0, 1, 1, 0, 0, 1},
               {1, 1, 0, 1, 0, 0, 0, 1},
               {1, 1, 0, 1, 0, 0, 1, 1, 1}};
```

Initializing a Multidimensional Array

- We can even omit the inner braces:

```
int m[5][9] = {1, 1, 1, 1, 1, 0, 1, 1, 1,
               0, 1, 0, 1, 0, 1, 0, 1, 0,
               0, 1, 0, 1, 1, 0, 0, 1, 0,
               1, 1, 0, 1, 0, 0, 0, 1, 0,
               1, 1, 0, 1, 0, 0, 1, 1, 1};
```

  Once the compiler has seen enough values to fill one row, it begins filling the next.
- Omitting the inner braces can be risky, since an extra element (or even worse, a missing element) will affect the rest of the initializer.

Constant Arrays

- An array can be made "constant" by starting its declaration with the word `const`:

```
const char hex_chars[] =
  {'0', '1', '2', '3', '4', '5', '6', '7', '8', '9',
   'A', 'B', 'C', 'D', 'E', 'F'};
```

- An array that's been declared `const` should not be modified by the program.

Constant Arrays

- Advantages of declaring an array to be `const`:
  - Documents that the program won't change the array.
  - Helps the compiler catch errors.
- `const` isn't limited to arrays, but it's particularly useful in array declarations.

Program: Dealing a Hand of Cards

- The `deal.c` program illustrates both two-dimensional arrays and constant arrays.
- The program deals a random hand from a standard deck of playing cards.
- Each card in a standard deck has a *suit* (clubs, diamonds, hearts, or spades) and a *rank* (two, three, four, five, six, seven, eight, nine, ten, jack, queen, king, or ace).

Program: Dealing a Hand of Cards

- The user will specify how many cards should be in the hand:

```
Enter number of cards in hand: 5
Your hand: 7c 2s 5d as 2h
```

- Problems to be solved:
  - How do we pick cards randomly from the deck?
  - How do we avoid picking the same card twice?

Program: Dealing a Hand of Cards

- To pick cards randomly, we'll use several C library functions:
  - `time` (from `<time.h>`) – returns the current time, encoded in a single number.
  - `srand` (from `<stdlib.h>`) – initializes C's random number generator.
  - `rand` (from `<stdlib.h>`) – produces an apparently random number each time it's called.
- By using the `%` operator, we can scale the return value from `rand` so that it falls between 0 and 3 (for suits) or between 0 and 12 (for ranks).

Program: Dealing a Hand of Cards

- The `in_hand` array is used to keep track of which cards have already been chosen.
- The array has 4 rows and 13 columns; each element corresponds to one of the 52 cards in the deck.
- All elements of the array will be false to start with.
- Each time we pick a card at random, we'll check whether the element of `in_hand` corresponding to that card is true or false.
  - If it's true, we'll have to pick another card.
  - If it's false, we'll store `true` in that element to remind us later that this card has already been picked.

Program: Dealing a Hand of Cards

- Once we've verified that a card is "new," we'll need to translate its numerical rank and suit into characters and then display the card.
- To translate the rank and suit to character form, we'll set up two arrays of characters—one for the rank and one for the suit—and then use the numbers to subscript the arrays.
- These arrays won't change during program execution, so they are declared to be `const`.

deal.c

```
/* Deals a random hand of cards */

#include <stdbool.h>   /* C99 only */
#include <stdio.h>
#include <stdlib.h>
#include <time.h>

#define NUM_SUITS 4
#define NUM_RANKS 13

int main(void)
{
  bool in_hand[NUM_SUITS][NUM_RANKS] = {false};
  int num_cards, rank, suit;
  const char rank_code[] = {'2','3','4','5','6','7','8',
                            '9','t','j','q','k','a'};
  const char suit_code[] = {'c','d','h','s'};
```



```
  srand((unsigned) time(NULL));

  printf("Enter number of cards in hand: ");
  scanf("%d", &num_cards);

  printf("Your hand:");
  while (num_cards > 0) {
    suit = rand() % NUM_SUITS;     /* picks a random suit */
    rank = rand() % NUM_RANKS;     /* picks a random rank */
    if (!in_hand[suit][rank]) {
      in_hand[suit][rank] = true;
      num_cards--;
      printf(" %c%c", rank_code[rank], suit_code[suit]);
    }
  }
  printf("\n");

  return 0;
}
```


Variable-Length Arrays (C99)

- In C89, the length of an array variable must be specified by a constant expression.
- In C99, however, it's sometimes possible to use an expression that's *not* constant.
- The `reverse2.c` program—a modification of `reverse.c`—illustrates this ability.

reverse2.c

```
/* Reverses a series of numbers using a variable-length
   array - C99 only */

#include <stdio.h>

int main(void)
{
  int i, n;

  printf("How many numbers do you want to reverse? ");
  scanf("%d", &n);

  int a[n];   /* C99 only - length of array depends on n */

  printf("Enter %d numbers: ", n);
  for (i = 0; i < n; i++)
    scanf("%d", &a[i]);
```

```
  printf("In reverse order:");
  for (i = n - 1; i >= 0; i--)
    printf(" %d", a[i]);
  printf("\n");

  return 0;
}
```


Variable-Length Arrays (C99)

- The array `a` in the `reverse2.c` program is an example of a ***variable-length array*** (or ***VLA***).
- The length of a VLA is computed when the program is executed.
- The chief advantage of a VLA is that a program can calculate exactly how many elements are needed.
- If the programmer makes the choice, it's likely that the array will be too long (wasting memory) or too short (causing the program to fail).