Chapter 9

Functions

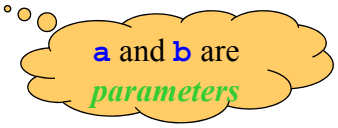
Introduction

- A *function* is a series of *statements* that have been grouped together and given a name
- Each *function* is essentially a *small program*, with its own
  - Declarations
  - Statements
- Advantages of functions:
  - A program can be divided into small pieces that are *easier to understand and modify*
  - We can *avoid duplicating* code that is used more than once
  - A function that was originally part of one program can be *reused in other programs*

Program: Computing Averages

- A function named `average` that computes the average of two `double` values:

```
double average(double a, double b)
{
  return (a + b) / 2;
}
```



- The word `double` at the beginning is the ***return type*** of `average`
- The identifiers `a` and `b` (the function's ***parameters***) represent the numbers that will be supplied when `average` is called

Program: Computing Averages

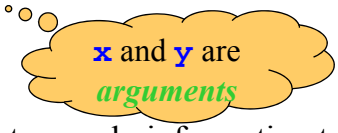
- Every function has an executable part, called the ***body***, which is enclosed in braces
- In this example, the body of the function `average` consists of a single `return` statement

```
double average(double a, double b)
{
  return (a + b) / 2;
}
```

- Executing this statement causes the function to:
  - "return" to the place from which it was called
  - the value of `(a + b) / 2` will be the value returned by the function

Program: Computing Averages

- A *function call* consists of a ***function name*** followed by a list of ***arguments***
  - `average(x, y)` is a call of the `average` function



- Arguments are used to supply information to a function
  - The call `average(x, y)` causes the values of `x` and `y` to be ***copied*** into the parameters `a` and `b`
- An argument does not have to be a variable; any expression of a compatible type will do
  - `average(5.1, 8.9)` and `average(x/2, y/3)` are legal

Program: Computing Averages

- We'll put the call of `average` in the place where we need to use the return value
- A statement that prints the average of `x` and `y`:

```
printf("Average: %g\n", average(x, y));
```

  The return value of `average` is not saved; the program prints it and then discards it
- If we had needed the return value later in the program, we could have captured it in a variable:

```
avg = average(x, y);
```

Program: Computing Averages

- The `average.c` program reads three numbers and uses the `average` function to compute their averages, one pair at a time:

```
Enter three numbers: 3.5 9.6 10.2
Average of 3.5 and 9.6: 6.55
Average of 9.6 and 10.2: 9.9
Average of 3.5 and 10.2: 6.85
```


average.c

```
/* Computes pairwise averages of three numbers */

#include <stdio.h>

double average(double a, double b)
{
  return (a + b) / 2;
}

int main(void)
{
  double x, y, z;

  printf("Enter three numbers: ");
  scanf("%lf%lf%lf", &x, &y, &z);
  printf("Average of %g and %g: %g\n", x, y, average(x, y));
  printf("Average of %g and %g: %g\n", y, z, average(y, z));
  printf("Average of %g and %g: %g\n", x, z, average(x, z));

  return 0;
}
```

Program: Printing a Countdown

- To indicate that a *function has no return value*, we specify that its return type is `void`:

```
void print_count(int n)
{
  printf("Counting down %d\n", n);
}
```

- `void` is a type with no values
- A call of `print_count` must appear in a statement by itself:

```
print_count(i);
```

- The `countdown.c` program calls `print_count` 10 times inside a loop

countdown.c

```
/* Prints a countdown */

#include <stdio.h>

void print_count(int n)
{
  printf("Counting down %d\n", n);
}

int main(void)
{
  int i;

  for (i = 10; i > 0; --i)
    print_count(i);

  return 0;
}
```

Program: Printing a Pun (Revisited)

- When a *function has no parameters*, the word `void` is placed in parentheses after the function's name:

```
void print_pun(void)
{
  printf("To C, or not to C: that is the question.\n");
}
```

- To call a function with no arguments, we write the function's name, followed by parentheses:

```
print_pun();
```

  The parentheses *must* be present
- The `pun2.c` program tests the `print_pun` function

pun2.c

```
/* Prints a bad pun */

#include <stdio.h>

void print_pun(void)
{
  printf("To C, or not to C: that is the question.\n");
}

int main(void)
{
  print_pun();
  return 0;
}
```

Function Definitions

- General form of a ***function definition:***

return-type function-name (parameters)
{
  declarations
  statements
}

Function Definitions

- The *return-type* of a function is the type of value that the function returns
- Specifying that the return-type is `void` indicates that the function does not return a value
- Functions *may not* return *arrays*
- If the return-type is omitted in C89, the function is presumed to return a value of type `int`
- In C99, omitting the return type is *illegal*

Function Definitions

- After the function name, a list of parameters comes
- Each parameter is preceded by a specification of its type
- Parameters are separated by commas
- If the function has no parameters, the word `void` should appear between the parentheses

Function Definitions

- The body of a function may include both declarations and statements
- An alternative version of the `average` function:

```
double average(double a, double b)
{
  double sum;        /* declaration */

  sum = a + b;       /* statement */
  return sum / 2;    /* statement */
}
```

Function Definitions

- Variables declared in the body of a function *can not* be examined or modified by other functions

- In C89, variable declarations must come first, before all statements in the body of a function
- In C99, variable declarations and statements can be mixed, as long as each variable is declared prior to the first statement that uses the variable

Function Calls

- A function call consists of a function name followed by a list of arguments, enclosed in parentheses:

```
average(x, y)
print_count(i)
print_pun()
```

- If the parentheses are missing, the function *will not* be called:

```
print_pun;    /*** WRONG ***/
```

Function Calls

- A call of a `void` function is always followed by a semicolon to turn it into a statement:

```
print_count(i);
print_pun();
```

- A call of a `non-void` function produces a value that can be stored in a variable, tested, printed, or used in some other way:
  - `avg = average(x, y);`
  -
```
if(average(x, y) > 0)
   printf("Average is positive\n");
```
  - `printf("The average is %g\n", average(x, y));`

Function Calls

- The value returned by a `non-void` function can always be discarded if it is not needed:

```
average(x, y);  /* discards return value */
```

- Ignoring the return value of `average` is an odd thing to do, but for some functions it makes sense
- `printf` returns the number of characters that it prints
- After the following call, `num_chars` will have the value 9:

```
num_chars = printf("Hi, Mom!\n");
```

- We will normally discard `printf`'s return value:

```
printf("Hi, Mom!\n"); /* discards return value */
```

Function Calls

- To make it clear that we are deliberately discarding the return value of a function, `C` allows us to put `(void)` before the call:

```
(void) printf("Hi, Mom!\n");
```

- Using `(void)` makes it clear to others that you deliberately discarded the return value, not just forgot that there was one

Program: Testing Whether a Number Is Prime

- The `prime.c` program tests whether a number is prime:

```
Enter a number: 34
Not prime
```

- The program uses a function named `is_prime` that returns
  - `true` if its parameter is a prime number and
  - `false` if it is not
- `is_prime` divides its parameter `n` by each of the numbers between `2` and the *square root* of `n`;
  - if the remainder is ever `0`, `n` is not prime

prime.c

```
/* Tests whether a number is prime */

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

bool is_prime(int n)
{
  int divisor;

  if (n <= 1)
    return false;
  for (divisor = 2; divisor * divisor <= n; divisor++)
    if (n % divisor == 0)
      return false;
  return true;
}
```



```
int main(void)
{
  int n;

  printf("Enter a number: ");
  scanf("%d", &n);
  if (is_prime(n))
    printf("Prime\n");
  else
    printf("Not prime\n");
  return 0;
}
```

Function Declarations

- C *does not* require that the definition of a function precedes its calls
- Suppose that we rearrange the `average.c` program by putting the definition of `average` *after* the definition of `main`

Function Declarations

```
#include <stdio.h>

int main(void)
{
  double x, y, z;

  printf("Enter three numbers: ");
  scanf("%lf%lf%lf", &x, &y, &z);
  printf("Average of %g and %g: %g\n", x, y, average(x, y));
  printf("Average of %g and %g: %g\n", y, z, average(y, z));
  printf("Average of %g and %g: %g\n", x, z, average(x, z));

  return 0;
}

double average(double a, double b)
{
  return (a + b) / 2;
}
```

Function Declarations

- When the compiler encounters the first call of `average` in `main`, it has no information about the function
- Instead of producing an error message, the compiler assumes that `average` returns an `int` value
- We say that the compiler has created an ***implicit declaration*** of the function

Function Declarations

- The compiler is *unable to check* that we are passing `average` *the right number of arguments and that the arguments have the proper type*
- Instead, it performs the *default argument promotions* and hopes for the best
- When it encounters the definition of `average` later in the program, the compiler notices that the function's return type is actually `double`, not `int`, and so we get an error message

Function Declarations

- One way to avoid the problem of *call-before-definition* is to arrange the program so that the definition of each function precedes all its calls
- Unfortunately, such an arrangement does not always exist
- Even when it does, it may make the program harder to understand by putting its function definitions in an unnatural order

Function Declarations

- Fortunately, `C` offers a better solution:
  - declare each function before calling it
- A ***function declaration*** provides the compiler with a brief look at a function whose full definition will appear later
- General form of a function declaration:

  return-type function-name (*parameters*) **;**

  Do not forget this ;
- The declaration of a function must be consistent with the function's definition
- Here is the `average.c` program with a declaration of `average` added

Function Declarations

```
#include <stdio.h>

double average(double a, double b);   /* DECLARATION */

int main(void)
{
  double x, y, z;

  printf("Enter three numbers: ");
  scanf("%lf%lf%lf", &x, &y, &z);
  printf("Average of %g and %g: %g\n", x, y, average(x, y));
  printf("Average of %g and %g: %g\n", y, z, average(y, z));
  printf("Average of %g and %g: %g\n", x, z, average(x, z));

  return 0;
}

double average(double a, double b)    /* DEFINITION */
{
  return (a + b) / 2;
}
```


Function Declarations

- Function declarations of the kind we are discussing are known as ***function prototypes***
- A function prototype does not have to specify the names of the function's parameters, as long as their types are present:

  ```
  double average(double, double);
  ```

- It is usually best *not to* omit parameter names

Arguments

- In C, arguments are ***passed by value***
  - when a function is called, each argument is evaluated and its value assigned to the corresponding parameter
- Since the parameter contains *a copy* of the argument's value, any changes made to the parameter during the execution of the function does not affect the argument

Arguments

- The fact that arguments are passed by value has both advantages and disadvantages
  - ✓ Cons:
    - ✓ a parameter can be modified without affecting the corresponding argument
    - ✓ we can use parameters as variables within the function, reducing the number of genuine variables needed

Arguments

- Consider the following function, which raises a number `x` to a power `n`:

```
int power(int x, unsigned int n)
{
  int result = 1, i;

  for (i = 1; i <= n; i++)
    result = result * x;

  return result;
}
```


Arguments

- Consider the following function, which raises a number `x` to a power `n`:

```
int power(int x, unsigned int n)
{
  int result = 1;

  for (     ;  n > 0; n--)
    result = result * x;

  return result;
}
```

Arguments

- Since `n` is a *copy* of the original exponent, the function can safely modify it, removing the need for `i`:

```
int power(int x, unsigned int n)
{
  int result = 1;

  while (n-- > 0)
    result = result * x;

  return result;
}
```


Arguments

- Pros: C's requirement that arguments be passed by value makes it difficult to write certain kinds of functions
- Suppose that we need a function that will decompose a `double` value into *an integer part* and *a fractional part*
- Since a function can not *return* two numbers, we might try passing a pair of variables to the function and having it modify them:

```
void decompose(double x,
               long   int_part,
               double frac_part)
{ /* THE FUNCTION WILL NOT RETURN
     THE REQUIRED DECOMPOSETION */
  int_part = (long) x;
  frac_part = x - int_part;
}
```

Arguments

- Consider the following call to the function:

```
decompose(3.14159, i, d);
```

- The arguments are passed to the function in a form of:

```
int_part = i;
frac_part = d;
```

- Unfortunately, `i` and `d` will not be affected by the assignments to `int_part` and `frac_part`
- *Chapter 11* shows how to make `decompose` works correctly

Argument Conversions

- C *allows* function calls in which the *types of the arguments do not match the types of the parameters*
- The rules governing how the arguments are converted depend on whether or not the compiler has seen a prototype for the function (or the function's full definition) prior to the call

Argument Conversions

- ***The compiler has encountered a prototype prior to the call***
  - The value of each argument is implicitly converted to the type of the corresponding parameter as if by assignment

- Example:

  If an `int` argument is passed to a function that was expecting a `double`, the argument is automatically converted to `double`

Argument Conversions

- ***The compiler has not encountered a prototype prior to the call***
  - The compiler performs the ***default argument promotions*****:**
  - `float` arguments to be converted to `double`
  - `char` and `short` arguments to be converted to `int`

- *Relying on the default argument promotions is dangerous*

Argument Conversions

- Example:
- At the time `square` is called, the compiler does not know that it expects an argument of type `int`

Argument Conversions

- Instead, the compiler performs the default argument promotions on `x`, with no effect
- Since it is expecting an argument of type `int` but has been given a `double` value instead, the effect of calling `square` is *undefined*
- The problem can be fixed by casting `square`'s argument to the proper type:

```
printf("Square: %d\n", square((int) x));
```

- A much better solution is to provide a prototype for `square` before calling it
- In C99, calling `square` without first providing a declaration or definition of the function is an error

Array Arguments

- When a function parameter is *a one-dimensional array*, the length of the array is left unspecified:

```
int f(int a[])  /* no length specified */
{
  …
}
```

- C does not provide any easy way for a function to determine the length of an array passed to it
- Instead, we'll have to supply the length—if the function needs it—as an additional argument

Array Arguments

- Example:

```
int sum_array(int a[], int n)
{
  int i, sum = 0;

  for (i = 0; i < n; i++)
    sum += a[i];

  return sum;
}
```

- Since `sum_array` needs to know the length of `a`, we must supply it as a second argument

Array Arguments

- The prototype for `sum_array` has the following appearance:

```
int sum_array(int a[], int n);
```

- As usual, in prototypes, we *can omit the parameter names* if we wish:

```
int sum_array(int [], int);
```


Array Arguments

- When `sum_array` is called, the first argument will be the name of an array, and the second will be its length:

```
#define LEN 100

int main(void)
{
  int b[LEN], total;
  …
  total = sum_array(b, LEN);
  …
}
```

- Notice that we *do not put brackets after an array name when passing it to a function*:

```
total = sum_array(b[], LEN);    /*** WRONG ***/
```

Array Arguments

- A function has no way to check that we've passed it the correct array length
- We can exploit this fact by telling the function that the array is smaller than it really is
- Suppose that we've only stored 50 numbers in the `b` array, even though it can hold 100
- We can sum just the first 50 elements by writing

```
total = sum_array(b, 50);
```


Array Arguments

- *Be careful* not to tell a function that an array argument is *larger* than it really is:

```
total = sum_array(b, 150);    /*** WRONG ***/
```

`sum_array` will go past the end of the array, causing undefined behavior

Array Arguments

- A function is allowed to change the elements of an array parameter, and the change is reflected in the corresponding argument
- A function that modifies an array by storing zero into each of its elements:

```
void store_zeros(int a[], int n)
{
  int i;

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


Array Arguments

- A call of `store_zeros`:

```
store_zeros(b, 100);
```

- The ability to modify the elements of an array argument may seem to contradict the fact that C passes arguments by value
- Chapter 12 explains why there is actually no contradiction

Array Arguments

- If a parameter is *a multidimensional array*, only the length of the *first* dimension *can be* left unspecified
- If we revise `sum_array` so that `a` is a two-dimensional array, we *must specify the number of columns* in `a` (*needed to calculate the address of each element in the array*)

```
#define LEN 10

int sum_two_dimensional_array(int a[][LEN], int row)
{
  int i, j, sum = 0;

  for (i = 0; i < row; i++)
    for (j = 0; j < LEN; j++)
      sum += a[i][j];

  return sum;
}
```


Array Arguments

- Not being able to pass multidimensional arrays with an arbitrary number of columns can be an annoyance
- We can often work around this difficulty by using *arrays of pointers (Chapter 13)*

The `return` Statement

- A `non-void` function must use the `return` statement to specify what value it will return
- The `return` statement has the form

  `return` *expression*`;`
- The expression is often just a constant or variable:

```
return 0;
return status;
```

- More complex expressions are possible:

```
return n >= 0 ? n : 0;
```


The `return` Statement

- If the type of the expression in a `return` statement does not match the function's return type, the expression will be *implicitly converted* to the return type
  - If a function returns an `int`, but the `return` statement contains a `double` expression, the value of the expression is converted to `int`

The `return` Statement

- `return` statements may appear in functions whose return type is `void`, provided that no expression is given:

```
return;  /* return in a void function */
```

- Example:

```
void print_positive_int(int i)
{
  if (i <= 0)
    return;
  printf("%d", i);
}
```


The `return` Statement

- A `return` statement may appear at the end of a `void` function:

```
void print_pun(void)
{
  printf("To C, or not to C: that is the question.\n");
  return;   /* OK, but not needed */
}
```

Using `return` here is unnecessary

Program Termination

- Normally, the return type of `main` is `int`:

```
int main(void)
{
  …
}
```

- Older `C` programs often omit `main`'s return type, taking advantage of the fact that it traditionally defaults to `int`
- Omitting the return type of a function is *illegal* in C99, so it is best to avoid this practice
- Omitting the word `void` in `main`'s parameter list remains legal, but—as a matter of style—it is best to include it

Program Termination

- The value returned by `main` is a status code that can be tested when the program terminates
- `main` should return `0` if the program terminates normally
- To indicate abnormal termination, `main` should return a value other than `0`
- It is good practice to make sure that every `C` program returns a status code

The `exit` Function

- To terminate a program, you may:
  - Execute a `return` *statement* in `main`, or
  - Call the `exit` *function* from anywhere in the program
    - `exit` belongs to `<stdlib.h>`.
- The statement

  `return` *expression*`;`

  in `main` is equivalent to

  `exit(`*expression*`);`
- The difference between `return` and `exit` is that:
  - `exit` causes *program termination* regardless of which function calls it
  - The `return` statement causes program termination only when it appears in the `main` function

Recursion

- A function is considered ***recursive*** if it calls itself
- The following function computes *n!* recursively, using the formula *n! = n × (n – 1)!*, where *1! = 1*

```
int fact(unsigned int n)
{
  if (n <= 1)
    return 1;
  else
    return n * fact(n - 1);
}
```

Recursion

- To see how recursion works, let us trace the execution of the statement

```
i = fact(3);
```

`fact(3)` finds that 3 is not less than or equal to 1, so it calls
`fact(2)`, which finds that 2 is not less than or equal to 1, so it calls
`fact(1)`, which finds that 1 is less than or equal to 1, so it returns 1, causing
`fact(2)` to return 2 × 1 = 2, causing
`fact(3)` to return 3 × 2 = 6.

Recursion

- The following recursive function computes x^n, using the formula $x^n = x \times x^{n-1}$, where $x^0 = 1$

```
int power(int x, unsigned int n)
{
  if (n == 0)
    return 1;
  else
    return x * power(x, n - 1);
}
```

Recursion

- We can condense the `power` function by putting a conditional expression in the `return` statement:

```
int power(int x, unsigned int n)
{
  return n == 0 ? 1 : x * power(x, n - 1);
}
```

- All recursive functions need some kind of *termination condition* in order to prevent infinite recursion

The Quicksort Algorithm

- Recursion might be helpful for sophisticated algorithms that require a function to call itself two or more times

- Recursion often arises as a result of an algorithm design technique known as ***divide-and-conquer***, in which a large problem is divided into smaller pieces that are then tackled by the same algorithm

The Quicksort Algorithm

- A classic example of divide-and-conquer can be found in the popular ***Quicksort*** algorithm
- Assume that the array to be sorted is indexed from 1 to *n*

Quicksort algorithm

1. Choose an array element *e* (the "partitioning element")
2. Rearrange the array so that
   - elements 1, …, *i* – 1 are less than or equal to *e*,
   - element *i* contains e, and
   - elements *i* + 1, …, *n* are greater than or equal to *e*.
3. Sort elements 1, …, *i* – 1 by using Quicksort recursively.
4. Sort elements *i* + 1, …, *n* by using Quicksort recursively.

The Quicksort Algorithm

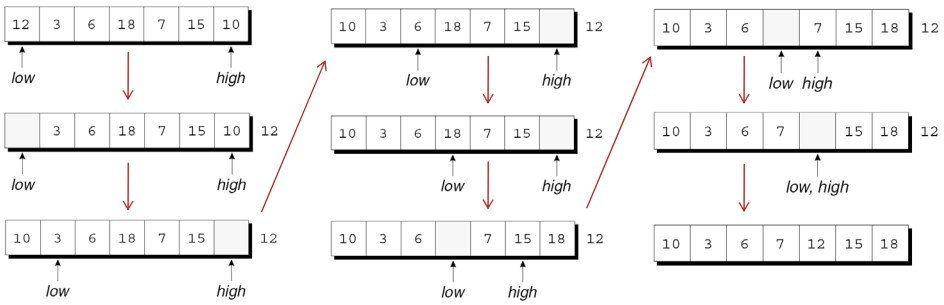
- Steps 1 & 2 of the Quicksort algorithm is obviously critical
- There are various methods to partition an array
- We'll use a technique that is *easy to understand* but *not particularly efficient*
- The algorithm relies on two "markers" named *low* and *high*, which keep track of positions within the array

The Quicksort Algorithm

- Initially, *low* points to the first element; *high* points to the last
- We copy the first element (the partitioning element) into a temporary location, leaving a "hole" in the array (pointed to by *low*)
- Next, we move *high* across the array from right to left until it points to an element that is smaller than the partitioning element
- We then copy the element into the hole that *low* points to, which creates a new hole (pointed to by *high*)
- We now move *low* from left to right, looking for an element that is larger than the partitioning element
- When we find one, we copy it into the hole that *high* points to
- The process repeats until *low* and *high* meet at a hole
- Finally, we copy the partitioning element into this hole

The Quicksort Algorithm

- Example of partitioning an array:



The Quicksort Algorithm

- By the final figure, all elements to the left of the partitioning element are less than or equal to 12, and all elements to the right are greater than or equal to 12
- Now that the array has been partitioned, we can use Quicksort recursively to sort the first four elements of the array (10, 3, 6, and 7) and the last two (15 and 18)

Program: Quicksort

- Let us develop a recursive function named `quicksort` that uses the Quicksort algorithm to sort an array of integers
- The `qsort.c` program reads 10 numbers into an array, calls `quicksort` to sort the array, then prints the elements in the array:

```
Enter 10 numbers to be sorted: 9 16 47 82 4 66 12 3 25 51
In sorted order: 3 4 9 12 16 25 47 51 66 82
```

- The code for partitioning the array is in a separate function named `split`

qsort.c

```
/* Sorts an array of integers using Quicksort algorithm */
#include <stdio.h>

#define N 10

void quicksort(int a[], int low, int high);
int split(int a[], int low, int high);

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

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

  quicksort(a, 0, N - 1);

  printf("In sorted order: ");
  for (i = 0; i < N; i++)
    printf("%d ", a[i]);
  printf("\n");

  return 0;
}
```



```
void quicksort(int a[], int low, int high)
{
  int middle;

  if (low >= high)
     return;

  middle = split(a, low, high);

  quicksort(a, low, middle - 1);
  quicksort(a, middle + 1, high);
}
```

```
int split(int a[], int low, int high)
{
  int part_element = a[low];

  for (;;)
  { while (low < high && part_element <= a[high])
      high--;

    if (low == high)
      break;

    a[low++] = a[high];

    while (low < high && a[low] <= part_element)
      low++;

    if (low == high)
       break;

    a[high--] = a[low];
  }

  a[high] = part_element;
  return high;
}
```


Program: Quicksort

- Ways to improve the program's performance:
  - Improve the partitioning algorithm
  - Use a different method to sort small arrays
  - Make Quicksort *nonrecursive*