

Chapter 10

Program Organization

Local Variables

- A variable declared in the body of a function is said to be *local* to the function:

```
int sum_digits(int n)
{
    int sum = 0;    /* local variable */

    while (n > 0) {
        sum += n % 10;
        n /= 10;
    }

    return sum;
}
```


Local Variables

- Default properties of local variables:
 - **Automatic storage duration.** Storage is “automatically” allocated when the enclosing function is called and deallocated when the function returns.
 - **Block scope.** A local variable is visible from its point of declaration to the end of the enclosing function body.

Local Variables

- Since C99 doesn't require variable declarations to come at the beginning of a function, it's possible for a local variable to have a very small scope:

```
void f(void)
{
    ...
    int i;
    ...
}
```



scope of i

Static Local Variables

- Including `static` in the declaration of a local variable causes it to have *static storage duration*.
- A variable with static storage duration has a permanent storage location, so it retains its value throughout the execution of the program.

- Example:

```
void f(void)
{
    static int i;    /* static local variable */
    ...
}
```

- A static local variable still has block scope, so it's not visible to other functions.

Parameters

- Parameters have the same properties—automatic storage duration and block scope—as local variables.
- Each parameter is initialized automatically when a function is called (by being assigned the value of the corresponding argument).

External Variables

- Passing arguments is one way to transmit information to a function.
- Functions can also communicate through *external variables*—variables that are declared outside the body of any function. *(global variable)*
- External variables are sometimes known as *global variables*.

External Variables

- Properties of external variables:
 - Static storage duration
 - File scope
- Having *file scope* means that an external variable is visible from its point of declaration to the end of the enclosing file.

Example: Using External Variables to Implement a Stack

- To illustrate how external variables might be used, let's look at a data structure known as a *stack*.
- A stack, like an array, can store multiple data items of the same type.
- The operations on a stack are limited:
 - *Push* an item (add it to one end—the “stack top”)
 - *Pop* an item (remove it from the same end)
- Examining or modifying an item that's not at the top of the stack is forbidden.

Example: Using External Variables to Implement a Stack

- One way to implement a stack in C is to store its items in an array, which we'll call `contents`.
- A separate integer variable named `top` marks the position of the stack top.
 - When the stack is empty, `top` has the value 0.
- To *push* an item: Store it in `contents` at the position indicated by `top`, then increment `top`.
- To *pop* an item: Decrement `top`, then use it as an index into `contents` to fetch the item that's being popped.

Example: Using External Variables to Implement a Stack

- The following program fragment declares the `contents` and `top` variables for a stack.
- It also provides a set of functions that represent stack operations.
- All five functions need access to the `top` variable, and two functions need access to `contents`, so `contents` and `top` will be external.

Example: Using External Variables to Implement a Stack

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

#define STACK_SIZE 100

/* external variables */
int contents[STACK_SIZE];
int top = 0;

void make_empty(void)
{
    top = 0;
}

bool is_empty(void)
{
    return top == 0;
}
```

Example: Using External Variables to Implement a Stack

```
bool is_full(void)
{
    return top == STACK_SIZE;
}

void push(int i)
{
    if (is_full())
        stack_overflow();
    else
        contents[top++] = i;
}

int pop(void)
{
    if (is_empty())
        stack_underflow();
    else
        return contents[--top];
}
```

Pros and Cons of External Variables

- External variables are convenient when many functions must share a variable or when a few functions share a large number of variables.
- In most cases, it's better for functions to communicate through parameters rather than by sharing variables:
 - If we change an external variable during program maintenance (by altering its type, say), we'll need to check every function in the same file to see how the change affects it.
 - If an external variable is assigned an incorrect value, it may be difficult to identify the guilty function.
 - Functions that rely on external variables are hard to reuse in other programs.

Pros and Cons of External Variables

- Don't use the same external variable for different purposes in different functions.
- Suppose that several functions need a variable named `i` to control a `for` statement.
- Instead of declaring `i` in each function that uses it, some programmers declare it just once at the top of the program.
- This practice is misleading; someone reading the program later may think that the uses of `i` are related, when in fact they're not.

Pros and Cons of External Variables

- Make sure that external variables have meaningful names.
- Local variables don't always need meaningful names: it's often hard to think of a better name than `i` for the control variable in a `for` loop.

Pros and Cons of External Variables

- Making variables external when they should be local can lead to some rather frustrating bugs.
- Code that is supposed to display a 10 × 10 arrangement of asterisks:

```
int i;

void print_one_row(void)
{
    for (i = 1; i <= 10; i++)
        printf("*");
}

void print_all_rows(void)
{
    for (i = 1; i <= 10; i++) {
        print_one_row();
        printf("\n");
    }
}
```

- Instead of printing 10 rows, `print_all_rows` prints only one.

Program: Guessing a Number

- The `guess.c` program generates a random number between 1 and 100, which the user attempts to guess in as few tries as possible:

Guess the secret number between 1 and 100.

A new number has been chosen.

Enter guess: 55

Too low; try again.

Enter guess: 65

Too high; try again.

Enter guess: 60

Too high; try again.

Enter guess: 58

You won in 4 guesses!

Program: Guessing a Number

Play again? (Y/N) y

A new number has been chosen.

Enter guess: 78

Too high; try again.

Enter guess: 34

You won in 2 guesses!

Play again? (Y/N) n

- Tasks to be carried out by the program:
 - Initialize the random number generator
 - Choose a secret number
 - Interact with the user until the correct number is picked
- Each task can be handled by a separate function.

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guess.c

```
/* Asks user to guess a hidden number */

#include <stdio.h>
#include <stdlib.h>
#include <time.h>

#define MAX_NUMBER 100

/* external variable */
int secret_number;

/* prototypes */
void initialize_number_generator(void);
void choose_new_secret_number(void);
void read_guesses(void);
```

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```
int main(void)
{
    char command;
    printf("Guess the secret number between 1 and %d.\n\n",
          MAX_NUMBER);
    initialize_number_generator();
    do {
        choose_new_secret_number();
        printf("A new number has been chosen.\n");
        read_guesses();
        printf("Play again? (Y/N) ");
        scanf(" %c", &command);
        printf("\n");
    } while (command == 'y' || command == 'Y');

    return 0;
}
```

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```

/*****
 * initialize_number_generator: Initializes the random
 *                             number generator using
 *                             the time of day.
 *****/
void initialize_number_generator(void)
{
    srand((unsigned) time(NULL));
}

/*****
 * choose_new_secret_number: Randomly selects a number
 *                           between 1 and MAX_NUMBER and
 *                           stores it in secret_number.
 *****/
void choose_new_secret_number(void)
{
    secret_number = rand() % MAX_NUMBER + 1;
}

```

Chapter 10: Program Organization

```
/******  
 * read_guesses: Repeatedly reads user guesses and tells  *  
 *               the user whether each guess is too low,  *  
 *               too high, or correct. When the guess is  *  
 *               correct, prints the total number of      *  
 *               guesses and returns.                     *  
******/  
void read_guesses(void)  
{  
    int guess, num_guesses = 0;  
  
    for (;;) {  
        num_guesses++;  
        printf("Enter guess: ");  
        scanf("%d", &guess);  
        if (guess == secret_number) {  
            printf("You won in %d guesses!\n\n", num_guesses);  
            return;  
        } else if (guess < secret_number)  
            printf("Too low; try again.\n");  
        else  
            printf("Too high; try again.\n");  
    }  
}
```

Program: Guessing a Number

- Although `guess.c` works fine, it relies on the external variable `secret_number`.
- By altering `choose_new_secret_number` and `read_guesses` slightly, we can move `secret_number` into the `main` function.
- The new version of `guess.c` follows, with changes in **bold**.

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guess2.c

```
/* Asks user to guess a hidden number */

#include <stdio.h>
#include <stdlib.h>
#include <time.h>

#define MAX_NUMBER 100

/* prototypes */
void initialize_number_generator(void);
int new_secret_number(void);
void read_guesses(int secret_number);
```

Chapter 10: Program Organization

```
int main(void)
{
    char command;
    int secret_number;

    printf("Guess the secret number between 1 and %d.\n\n",
           MAX_NUMBER);
    initialize_number_generator();
    do {
        secret_number = new_secret_number();
        printf("A new number has been chosen.\n");
        read_guesses(secret_number);
        printf("Play again? (Y/N) ");
        scanf(" %c", &command);
        printf("\n");
    } while (command == 'y' || command == 'Y');

    return 0;
}
```

Chapter 10: Program Organization

```

/*****
 * initialize_number_generator: Initializes the random
 *                             number generator using
 *                             the time of day.
 *****/
void initialize_number_generator(void)
{
    srand((unsigned) time(NULL));
}

/*****
 * new_secret_number: Returns a randomly chosen number
 *                   between 1 and MAX_NUMBER.
 *****/
int new_secret_number(void)
{
    return rand() % MAX_NUMBER + 1;
}

```

Chapter 10: Program Organization

```
/******  
 * read_guesses: Repeatedly reads user guesses and tells  *  
 *               the user whether each guess is too low,  *  
 *               too high, or correct. When the guess is  *  
 *               correct, prints the total number of      *  
 *               guesses and returns.                     *  
******/  
void read_guesses(int secret_number)  
{  
    int guess, num_guesses = 0;  
  
    for (;;) {  
        num_guesses++;  
        printf("Enter guess: ");  
        scanf("%d", &guess);  
        if (guess == secret_number) {  
            printf("You won in %d guesses!\n\n", num_guesses);  
            return;  
        } else if (guess < secret_number)  
            printf("Too low; try again.\n");  
        else  
            printf("Too high; try again.\n");  
    }  
}
```

Blocks

- In Section 5.2, we encountered compound statements of the form
 $\{ \textit{statements} \}$
- C allows compound statements to contain declarations as well as statements:
 $\{ \textit{declarations} \textit{ statements} \}$
- This kind of compound statement is called a *block*.

Blocks

- Example of a block:

```
if (i > j) {  
    /* swap values of i and j */  
    int temp = i;  
    i = j;  
    j = temp;  
}
```

Blocks

- By default, the storage duration of a variable declared in a block is automatic: storage for the variable is allocated when the block is entered and deallocated when the block is exited.
- The variable has block scope; it can't be referenced outside the block.
- A variable that belongs to a block can be declared `static` to give it static storage duration.

Blocks

- The body of a function is a block.
- Blocks are also useful inside a function body when we need variables for temporary use.
- Advantages of declaring temporary variables in blocks:
 - Avoids cluttering declarations at the beginning of the function body with variables that are used only briefly.
 - Reduces name conflicts.
- C99 allows variables to be declared anywhere within a block.

Scope

- In a C program, the same identifier may have several different meanings.
- C's scope rules enable the programmer (and the compiler) to determine which meaning is relevant at a given point in the program.
- The most important scope rule: When a declaration inside a block names an identifier that's already visible, the new declaration temporarily “hides” the old one, and the identifier takes on a new meaning.
- At the end of the block, the identifier regains its old meaning.

Scope

- In the example on the next slide, the identifier `i` has four different meanings:
 - In Declaration 1, `i` is a variable with static storage duration and file scope.
 - In Declaration 2, `i` is a parameter with block scope.
 - In Declaration 3, `i` is an automatic variable with block scope.
 - In Declaration 4, `i` is also automatic and has block scope.
- C's scope rules allow us to determine the meaning of `i` each time it's used (indicated by arrows).

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```
int i ;           /* Declaration 1 */

void f(int i)     /* Declaration 2 */
{
    i = 1;
}

void g(void)
{
    int i = 2;     /* Declaration 3 */
    if (i > 0) {
        int i;     /* Declaration 4 */
        i = 3;
    }
    i = 4;
}

void h(void)
{
    i = 5;
}
```

The diagram illustrates the scope resolution of the variable 'i' across different functions. Arrows point from each occurrence of 'i' to its corresponding declaration:

- The 'i' in the first line points to '/* Declaration 1 */'.
- The 'i' in the function parameter of 'f' points to '/* Declaration 2 */'.
- The 'i' in the assignment 'i = 2;' inside 'g' points to '/* Declaration 3 */'.
- The 'i' in the 'if' condition and the 'i' in the assignment 'i = 3;' inside the 'if' block of 'g' both point to '/* Declaration 4 */'.
- The 'i' in the assignment 'i = 4;' inside 'g' points back to '/* Declaration 1 */'.
- The 'i' in the assignment 'i = 5;' inside 'h' points back to '/* Declaration 1 */'.

Organizing a C Program

- Major elements of a C program:
 - Preprocessing directives such as `#include` and `#define`
 - Type definitions
 - Declarations of external variables
 - Function prototypes
 - Function definitions

Organizing a C Program

- C imposes only a few rules on the order of these items:
 - A preprocessing directive doesn't take effect until the line on which it appears.
 - A type name can't be used until it's been defined.
 - A variable can't be used until it's declared.
- It's a good idea to define or declare every function prior to its first call.
 - C99 makes this a requirement.

Organizing a C Program

- There are several ways to organize a program so that these rules are obeyed.
- One possible ordering:
 - `#include` directives
 - `#define` directives
 - Type definitions
 - Declarations of external variables
 - Prototypes for functions other than `main`
 - Definition of `main`
 - Definitions of other functions

Organizing a C Program

- It's a good idea to have a boxed comment preceding each function definition.
- Information to include in the comment:
 - Name of the function
 - Purpose of the function
 - Meaning of each parameter
 - Description of return value (if any)
 - Description of side effects (such as modifying external variables)

Program: Classifying a Poker Hand

- The `poker.c` program will classify a poker hand.
- Each card in the hand has a *suit* and a *rank*.
 - Suits: clubs, diamonds, hearts, spades
 - Ranks: two, three, four, five, six, seven, eight, nine, ten, jack, queen, king, ace
- Jokers are not allowed, and aces are high.
- After reading a hand of five cards, the program will classify the hand using the categories on the next slide.
- If a hand falls into two or more categories, the program will choose the best one.

Program: Classifying a Poker Hand

- Categories (listed from best to worst):
 - straight flush (both a straight and a flush)
 - four-of-a-kind (four cards of the same rank)
 - full house (a three-of-a-kind and a pair)
 - flush (five cards of the same suit)
 - straight (five cards with consecutive ranks)
 - three-of-a-kind (three cards of the same rank)
 - two pairs
 - pair (two cards of the same rank)
 - high card (any other hand)

Program: Classifying a Poker Hand

- For input purposes, ranks and suits will be single letters (upper- or lower-case):
Ranks: 2 3 4 5 6 7 8 9 t j q k a
Suits: c d h s
- Actions to be taken if the user enters an illegal card or tries to enter the same card twice:
 - Ignore the card
 - Issue an error message
 - Request another card
- Entering the number 0 instead of a card will cause the program to terminate.

Program: Classifying a Poker Hand

- A sample session with the program:

Enter a card: 2s

Enter a card: 5s

Enter a card: 4s

Enter a card: 3s

Enter a card: 6s

Straight flush

Program: Classifying a Poker Hand

```
Enter a card: 8c
Enter a card: as
Enter a card: 8c
Duplicate card; ignored.
Enter a card: 7c
Enter a card: ad
Enter a card: 3h
Pair
```

Program: Classifying a Poker Hand

```
Enter a card: 6s  
Enter a card: d2  
Bad card; ignored.  
Enter a card: 2d  
Enter a card: 9c  
Enter a card: 4h  
Enter a card: ts  
High card
```

```
Enter a card: 0
```

Program: Classifying a Poker Hand

- The program has three tasks:
 - Read a hand of five cards
 - Analyze the hand for pairs, straights, and so forth
 - Print the classification of the hand
- The functions `read_cards`, `analyze_hand`, and `print_result` will perform these tasks.
- `main` does nothing but call these functions inside an endless loop.

Program: Classifying a Poker Hand

- The functions will need to share a fairly large amount of information, so we'll have them communicate through external variables.
- `read_cards` will store information about the hand into several external variables.
- `analyze_hand` will then examine these variables, storing its findings into other external variables for the benefit of `print_result`.

Program: Classifying a Poker Hand

- Program outline:

```
/* #include directives go here */

/* #define directives go here */

/* declarations of external variables go here */

/* prototypes */
void read_cards(void);
void analyze_hand(void);
void print_result(void);
```


Program: Classifying a Poker Hand

```
/******  
 * main: Calls read_cards, analyze_hand, and print_result *  
 *         repeatedly. *  
******/  
int main(void)  
{  
    for (;;) {  
        read_cards();  
        analyze_hand();  
        print_result();  
    }  
}  
  
/******  
 * read_cards: Reads the cards into external variables; *  
 *             checks for bad cards and duplicate cards. *  
******/  
void read_cards(void)  
{  
    ...  
}
```

Program: Classifying a Poker Hand

```
/******  
 * analyze_hand: Determines whether the hand contains a      *  
 *                straight, a flush, four-of-a-kind,         *  
 *                and/or three-of-a-kind; determines the     *  
 *                number of pairs; stores the results into    *  
 *                external variables.                         *  
******/  
void analyze_hand(void)  
{  
    ...  
}  
  
/******  
 * print_result: Notifies the user of the result, using      *  
 *                the external variables set by              *  
 *                analyze_hand.                               *  
******/  
void print_result(void)  
{  
    ...  
}
```

Program: Classifying a Poker Hand

- How should we represent the hand of cards?
- `analyze_hand` will need to know how many cards are in each rank and each suit.
- This suggests that we use two arrays, `num_in_rank` and `num_in_suit`.
 - `num_in_rank[r]` will be the number of cards with rank `r`.
 - `num_in_suit[s]` will be the number of cards with suit `s`.
- We'll encode ranks as numbers between 0 and 12.
- Suits will be numbers between 0 and 3.

Program: Classifying a Poker Hand

- We'll also need a third array, `card_exists`, so that `read_cards` can detect duplicate cards.
- Each time `read_cards` reads a card with rank `r` and suit `s`, it checks whether the value of `card_exists[r][s]` is true.
 - If so, the card was previously entered.
 - If not, `read_cards` assigns `true` to `card_exists[r][s]`.

Program: Classifying a Poker Hand

- Both the `read_cards` function and the `analyze_hand` function will need access to the `num_in_rank` and `num_in_suit` arrays, so they will be external variables.
- The `card_exists` array is used only by `read_cards`, so it can be local to that function.
- As a rule, variables should be made external only if necessary.

Chapter 10: Program Organization

poker.c

```
/* Classifies a poker hand */

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

#define NUM_RANKS 13
#define NUM_SUITS 4
#define NUM_CARDS 5

/* external variables */
int num_in_rank[NUM_RANKS];
int num_in_suit[NUM_SUITS];
bool straight, flush, four, three;
int pairs;    /* can be 0, 1, or 2 */
```

Chapter 10: Program Organization

```
/* prototypes */
void read_cards(void);
void analyze_hand(void);
void print_result(void);

/*****
 * main: Calls read_cards, analyze_hand, and print_result *
 *         repeatedly.                                     *
 *****/
int main(void)
{
    for (;;) {
        read_cards();
        analyze_hand();
        print_result();
    }
}
```

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```

/*****
 * read_cards: Reads the cards into the external
 *              variables num_in_rank and num_in_suit;
 *              checks for bad cards and duplicate cards.
 *****/
void read_cards(void)
{
    bool card_exists[NUM_RANKS][NUM_SUITS];
    char ch, rank_ch, suit_ch;
    int rank, suit;
    bool bad_card;
    int cards_read = 0;

    for (rank = 0; rank < NUM_RANKS; rank++) {
        num_in_rank[rank] = 0;
        for (suit = 0; suit < NUM_SUITS; suit++)
            card_exists[rank][suit] = false;
    }

    for (suit = 0; suit < NUM_SUITS; suit++)
        num_in_suit[suit] = 0;

```


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```
while (cards_read < NUM_CARDS) {
    bad_card = false;
    printf("Enter a card: ");
    rank_ch = getchar();
    switch (rank_ch) {
        case '0':                exit(EXIT_SUCCESS);
        case '2':                rank = 0; break;
        case '3':                rank = 1; break;
        case '4':                rank = 2; break;
        case '5':                rank = 3; break;
        case '6':                rank = 4; break;
        case '7':                rank = 5; break;
        case '8':                rank = 6; break;
        case '9':                rank = 7; break;
        case 't': case 'T':      rank = 8; break;
        case 'j': case 'J':      rank = 9; break;
        case 'q': case 'Q':      rank = 10; break;
        case 'k': case 'K':      rank = 11; break;
        case 'a': case 'A':      rank = 12; break;
        default:                 bad_card = true;
    }
}
```

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```
suit_ch = getchar();
switch (suit_ch) {
    case 'c': case 'C': suit = 0; break;
    case 'd': case 'D': suit = 1; break;
    case 'h': case 'H': suit = 2; break;
    case 's': case 'S': suit = 3; break;
    default:          bad_card = true;
}

while ((ch = getchar()) != '\n')
    if (ch != ' ') bad_card = true;

if (bad_card)
    printf("Bad card; ignored.\n");
else if (card_exists[rank][suit])
    printf("Duplicate card; ignored.\n");
else {
    num_in_rank[rank]++;
    num_in_suit[suit]++;
    card_exists[rank][suit] = true;
    cards_read++;
}
}
```

Chapter 10: Program Organization

```
/* ****  
 * analyze_hand: Determines whether the hand contains a      *  
 *                straight, a flush, four-of-a-kind,        *  
 *                and/or three-of-a-kind; determines the     *  
 *                number of pairs; stores the results into    *  
 *                the external variables straight, flush,     *  
 *                four, three, and pairs.                     *  
 **** */  
void analyze_hand(void)  
{  
    int num_consec = 0;  
    int rank, suit;  
    straight = false;  
    flush = false;  
    four = false;  
    three = false;  
    pairs = 0;
```

Chapter 10: Program Organization

```
/* check for flush */
for (suit = 0; suit < NUM_SUITS; suit++)
    if (num_in_suit[suit] == NUM_CARDS)
        flush = true;

/* check for straight */
rank = 0;
while (num_in_rank[rank] == 0) rank++;
for (; rank < NUM_RANKS && num_in_rank[rank] > 0; rank++)
    num_consec++;
if (num_consec == NUM_CARDS) {
    straight = true;
    return;
}

/* check for 4-of-a-kind, 3-of-a-kind, and pairs */
for (rank = 0; rank < NUM_RANKS; rank++) {
    if (num_in_rank[rank] == 4) four = true;
    if (num_in_rank[rank] == 3) three = true;
    if (num_in_rank[rank] == 2) pairs++;
}
}
```

Chapter 10: Program Organization

```
/* ****  
 * print_result: Prints the classification of the hand, *  
 * based on the values of the external *  
 * variables straight, flush, four, three, *  
 * and pairs. *  
 **** */  
void print_result(void)  
{  
    if (straight && flush) printf("Straight flush");  
    else if (four)         printf("Four of a kind");  
    else if (three &&  
             pairs == 1)   printf("Full house");  
    else if (flush)        printf("Flush");  
    else if (straight)     printf("Straight");  
    else if (three)        printf("Three of a kind");  
    else if (pairs == 2)   printf("Two pairs");  
    else if (pairs == 1)   printf("Pair");  
    else                   printf("High card");  
  
    printf("\n\n");  
}
```