Computer Science & Engineering 155E
Computer Science I: Systems Engineering Focus

Lecture 02 - Introduction To C

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- C Language Elements
- Variable Declarations and Data Types
- Executable Statements
- General Form of a C Program
- Arithmetic Expressions
- Formatting Numbers in Program Output
- Interactive Mode, Batch Mode, and Data Files
- Common Programming Errors

Overview of C Programming I

History

- Developed by Dennis Ritchie, AT&T Bell Laboratories, 1972
- Closely related to Unix
- Various updates and specifications: ANSI C, C89, C99, C11
- C++, Object-oriented extension of C by Bjarne Stroustrup, 1983

Overview of C Programming II

Features

- Imperative language (series of statements change a program's state)
- Useful in systems development (OS, embedded)
- Ubiquitious (C compilers exist for most systems)
- Offers low-level system access (memory-level, direct communication with the OS, system calls)
- Compiled, efficient, optimizable
- Influenced many other programming languages

C Language Elements

- Preprocessor Directives
- Syntax Displays for Preprocessor Directives
- "int main()" Function
- Reserved Words
- Standard Identifiers
- User-Defined Identifiers
- Uppercase and Lowercase Letters
- Program Style

Preprocessor Directives

- The *C preprocessor* modifies the text of the C program before it is passed to the compiler.
- Preprocessor directives are C program lines beginning with a `#` that provide instructions to the C preprocessor.
- Preprocessor directives begins with a `#`, either `#include` or `#define`.
- Predefined libraries are useful functions and symbols that are predefined by the C language (standard libraries).

#include and #define

- `#include<libraryName>` gives the program access to a library
- Example: `#include<studio.h>` (standard input and output) has definitions for input and output, such as `printf` and `scanf`.
- `#define NAME value` associates a constant *macro*
- Example:

```
1  #define KMS_PER_MILE 1.609
2  #define PI 3.14159
```

Comments

Comments provide supplementary information making it easier for us to understand the program, but comments are ignored by the C preprocessor and compiler.

- `/* */` - anything between them with be considered a comment, even if they span multiple lines.
- `//` - anything after this and before the end of the line is considered a comment.

Function main

- The point at which a C program begins execution is the `main` function:

```
1  int main(void)
```

- **Every** C program must have a main function.
- The main function (and every other function) body has two parts:
  - Declarations - tell the compiler what memory cells are needed in the function
  - Executable statements - (derived from the algorithm) are translated into machine language and later executed

Function main

- The main function contains *punctuation* and *special symbols*
  - Punctuation - Commas separate items in a list, semicolons appear at the end of each statement
  - Special Symbols: `*`, `=`, `{`, `}`, etc.
  - Brackets mark the beginning and end of the body of function main.

Reserved Words

- A word that has special meaning in C
  - `int` - Indicates the main function returns an integer value,
  - `double` - Indicates the memory cells used to store these values will store real numbers.
- Always lower case,
- Can not be used for other purposes,
- Appendix E has a full listing of reserved words (ex: `double`, `int`, `if`, `else`, `void`, `return` etc.)

Standard Identifiers

- Standard identifiers have a special meaning in C (assigned by standard libraries).
- Standard identifiers can be redefined and used by the programmer for other purposes
  - Not recommended If you redefine a standard identifier, C will no longer be able to use it for its original purpose.
- Examples: input/output functions `printf`, `scanf`

User-Defined Identifiers

We choose our own identifiers to name memory cells that will hold data and program results and to name operations (*functions*) that we define (more on this in Chapter 3).

- An identifier must consist only of letters `[a-zA-Z]`, digits `[0-9]`, and underscores.
- An identifier cannot begin with a digit (and *shouldn't* begin with an underscore).
- A C reserved word cannot be used as an identifier.
- An identifier defined in a C standard library should not be redefined.

User-Defined Identifiers

- Examples: `letter_1`, `Inches`, `KMS_PER_MILE`
- Some compilers will only see the first 31 characters
- Uppercase and lowercase are different (`Variable`, `variable`, `VARIABLE` are all *different*)
- Choosing identifer names:
  - Choose names that mean something,
  - Should be easy to read and understand,
  - Shorten only if possible
- Don't use `Big`, `big`, and `BIG` as they are easy to confuse
- Identifiers using all-caps are usually used for preprocessor-defined identifiers (`#define`)

Program Style

A program that "looks good" is easier to read and understand than one that is sloppy (i.e. good spacing, well-named identifiers).

In industry, programmers spend considerably more time on program maintenance than they do on its original design or coding.

Style Tips

Rigorous Comments

- The number of comments in your program doesn't affect its speed or size.
- Always best to include as much documentation as possible in the form of comments.
- Begin each program or function with a full explanation of its inputs, outputs, and how it works.
- Include comments as necessary throughout the program

Style Tips

Naming Conventions

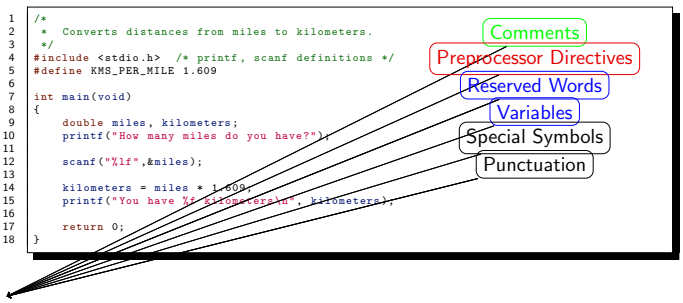
- Give your variables *meaningful* names (identifiers)
- `x`, `y` may be good if you're dealing with coordinates, but bad in general.
- `myVariable`, `aVariable`, `anInteger`, etc are *bad*: they do not describe the purpose of the variable.
- `tempInt`, `PI`, `numberOfStudents` are good because they do.

Style Tips

CamelCaseNotation

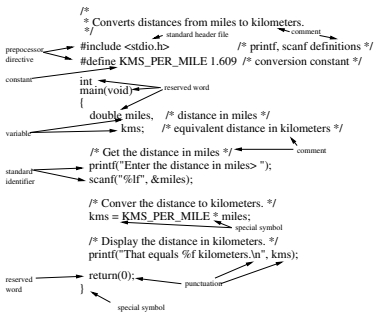
- Old School C convention: separate compound words with underscores
- `number_of_students`, `interest_rate`, `max_value`, etc.
- Underscore (shift-hyphen) is inconvenient
- Solution: camelCaseNotation - connect compound words with upper-case letters.
- Example: `numberOfStudents`, `interestRate`, `maxValue`, etc.
- Much easier to shift-capitalize
- Much more readable
- Ubiquitous outside of programming: MasterCard, PetsMart, etc.

Anatomy of a Program




```
1  /*
2   *  Converts distances from miles to kilometers.
3   */
4  #include <stdio.h>  /* printf, scanf definitions */
5  #define KMS_PER_MILE 1.609
6
7  int main(void)
8  {
9      double miles, kilometers;
10     printf("How many miles do you have?");
11
12     scanf("%lf",&miles);
13
14     kilometers = miles * 1.609;
15     printf("You have %f kilometers\n", kilometers);
16
17     return 0;
18 }
```

Anatomy of a Program



Variable Declarations and Data Types

- Variable Declaration
- Data Types

Variables Declarations

- Variables - a name associated with memory cells (`miles`, `kilometers`) that store a programs input data. The value of this memory cell can be changed.
- Variable declarations - statements that communicate to the compiler that names of variables in the program and the kind of information stored in each variable.
  - Example: `double miles, kms;`
  - Each declaration begins with a *unique* identifier to indicate the type of data
  - Every variable used must be declared before it can be used

Data Types

- Data Types: a set of values and a set of operations that can be used on those values.
- In other words, it is a classification of a particular type of information.
  - Integers `int`
  - Doubles `double`
  - Characters `char`
- The idea is to give semantic meaning to 0's and 1's.

Data Types

Integers

- Integers are whole numbers, negative and positive
- Declaration: `int`
- The ANSI C standard requires integers be *at least* 16 bits: in the range -32767 to 32767
- One bit for the *sign* and 15 for the number
- Modern standard that `int` types are 32 bits. Range: $-2^{31} = -2,147,483,648$ to $2,147,483,648 = 2^{31}$
- Newer systems are 64-bit. What range does this give?

Data Types
Doubles

- Doubles are decimal numbers, negative and positive
- Example: `0.5, 3.14159265, 5, 8.33`
- Declaration: `double`
- On most systems, doubles are 8 bytes = 64 bits
- Precision is *finite*: cannot *fully* represent π, $\frac{1}{3}$, etc.
- An approximation only, but: 15–16 digits of precision

Data Types
Characters

- `char`: an individual character values with single quotes around it.
- Example: a letter, a digit, or a special symbol
- Example: `a, B, *, !`
- You can treat each character as a number: see Appendix A
- The ASCII standard assigns number (0 thru 255) to each character: `A` is 65, many are non-printable control characters

Data Types
Characters: ASCII Table

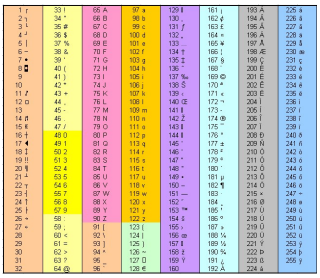


Figure: ASCII Table

Executable Statements

- Assignment Statements
- Input/Output Operations and Functions
- `printf` Function
- `scanf` Function
- `return` Statement

Assignment Statements

- Assignment statements - stores a value or a computational result in a variable,
- Used to perform most arithmetic operations in a program.
- Form: `variable = expression;`
  - `kms = KMS_PER_MILE * miles;`

The assignment statement above assigns a value to the variable kms. The value assigned is the result of the multiplication of the constant macro `KMS_PER_MILE` (1.609) by the variable miles.

Memory of Program

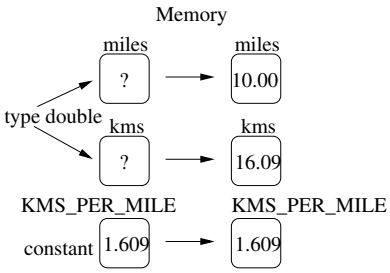


Figure: Memory

Assignments Continued

- In C, the symbol = is the assignment operator.
- Read as "becomes", "gets", or "takes the value of" rather than "equals"
- In C, == tests equality.
- Examples:

```
1 int a, b, c;
2 b = 10;
3 a = 15;
4 c = a + b;
```

Assignments

Misconception

- In C you can write:
  `sum = sum + item;` or
  `a = a + 1;`
- These are *not* algebraic expressions
- This does not imply that `0 = 1`
- Meaning: `a` is to be given the value that `a` had before plus one
- Common programming practice
- Instructs the computer to add the current value of `sum` to the value of `item` then store the result into the variable `sum`.

Input/Output Operations and Functions

- Input operation - data transfer from the outside world into memory.
- Output operation - An instruction that displays program results to the program user.
- input/output functions - special program units that do all input/output operations. Common I/O functions found in the *Standard Input/Output Library*: `stdio.h`
- Function call - in C, a function call is used to call or activate a function.
- Analogous to ordering food from a restaurant. You (the calling routine) do not know all of the ingredients and procedures for the food, but the called routine (the restaurant) provides all of this for you.

Output Function: printf Function

Included in the `stdio.h` library.

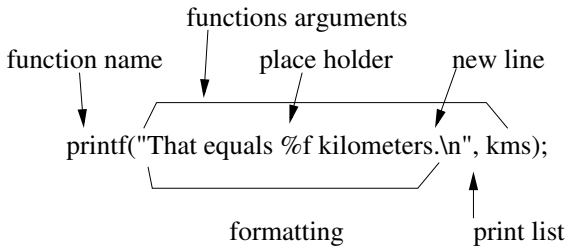


Figure: Parts of the printf function

Place Holder

A placeholder always begins with the symbol %. Also the newline escape sequence `\n`. Format strings can have multiple placeholders.

Placeholder	Variable Type	Function Use
%c	char	printf, scanf
%d	int	printf, scanf
%f	double	printf only
%lf	double	scanf only

Displaying Prompts

When input data is needed in an interactive program, you should use the `printf` function to display a **prompting message**, or **prompt**, that tells the program user what data to enter.

```
printf("Do you have any questions? ");
```

or

```
printf("Enter the number of items> ");
```

Input Function: scanf

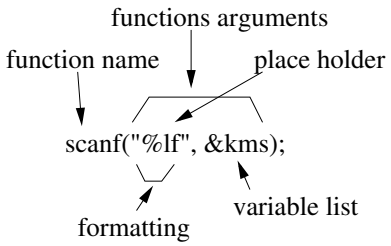


Figure: Parts of the scanf function

- In general, do not put extra characters in the format string
- Be sure to use the *ampersand*, & with `scanf`!!!

Return Statement

```
return 0;
```

This statement returns a 0 to the Operating System to signify that the program ended in a correct position. It does not mean the program did what it was suppose to do. It only means there was no syntax errors. There still may have been logical errors.

Program Example

```
1  #include <stdio.h>
2
3  int main(void) {
4      char first, last;
5
6      printf("Enter you first and last initials");
7      scanf("%c %c", &first, &last);
8
9      printf("Hello %c. %c.  How are you?\n", first, last);
10
11     return 0;
12 }
```

General Form of a C Program

- Programs begin with preprocessor directives that provide information about functions from standard libraries and definitions of necessary program constants.
  - `#include` and `#define`
- Next is the main function.
  - Inside the main function is the declarations and executable statements.

General Form of a C Program

```
1  proprocessor directives
2
3  main function heading {
4
5      declarations
6
7      executable statements
8  }
```

Program Style - Spaces in Programs

The compiler ignores extra blanks between words and symbols, but you may insert space to improve the readability and style of a program.

- You should always leave a blank space after a comma and before and after operators such as $*$, $-$, and $=$.
- Indent the body of the main function, as well as between any other curly brackets.

```
1  int main(void) {
2      {
3          {
4              { }
5          }  // End Level 2
6      }  /* End Level 1 */
7      return 0;
8  } // end main
```

Comments in Programs

Use comments to do **Program Documentation**, so it help others read and understand the program.

- The start of the program should consist of a comment that includes programmer's name, date of current version, and brief description of what the program does.
- Include comments for each variable and each major step in the program.
- For any function, make comments to briefly describe the input to the function, the output of the function, and the use of the function.

Comments in Programs

Style:

```
1 /*
2  * Multiple line comments are good
3  * for describing functions.
4  */
5
6 /* This /* is NOT */ ok.  */
7
8 /* // ok. */
```

Arithmetic Expressions

- Operators / and % (Read *mod* or *remainder*)
- Data Type of Expression
- Mixed-Type Assignment Statement
- Type Conversion through Cast
- Expressions with Multiple Operators
- Writing Mathematical Formulas in C

Arithmetic Expressions

- To solve most programming problems, you will need to write arithmetic expressions that manipulate type `int` and `double` data.
- Each operator manipulates two operands, which may be constants, variables, or other arithmetic expressions.
- `+, -, *, /` can be used with integers or doubles
- `%` can be used only with integers to find the remainder.

Arithmetic Expressions

Operator	Meaning	Examples
+	addition	5 + 2 is 7
		5.0 + 2.0 is 7.0
-	subtraction	5 - 2 is 3
		5.0 - 2.0 is 3.0
*	multiplication	5 * 2 is 10
		5.0 * 2.0 is 10.0
/	division	5 / 2 is 2
		5.0 / 2.0 is 2.5
%	remainder	5 % 2 is 1

Division

- When applied to two positive integers
  - The division operator (/) computes the integer part of the result of dividing its first operand by its second.
  - Example: the result of `7 / 2` is 3
  - C only allows the answer to have the same accuracy as the operands.
  - If both operands are integers, the result will be an integer.
- If one or both operands are double, the answer will be a double.
- According to the book different C implementations differ on dividing by a negative number.
- `/` is undefined when the second operand is `0.4 / 0 = ?`

Remainder Operator

The remainder operator (%) returns the integer remainder of the result of dividing its first operand by its second.

- Similar to integer division, except instead of outputting integral portion, outputs remainder.
- The operand % can give different answers when the second operand is negative.
- As with division, % is undefined when the second operand is 0.

Remainder Operator

Exercise

Problem

What are the results of the following operations?

1. `51 % 2`
2. `100 % 4`
3. `101 % 31`

1. `51 % 2` $\rightarrow$ 1
2. `100 % 4` $\rightarrow$ 0
3. `101 % 31` $\rightarrow$ 8

Data Type of an Expression

The data type of each variable must be specified in its declaration, but how does C determine the data type of an expression?

- The data type of an expression depends on the type(s) of its operand(s). If both are of type `int`, then result is of type `int`. If either one or both is of type `double`, then result is of type `double`.
- An expression that has operands of both `int` and `double` is a mixed-type expression, and will be typed as `double`.

For a mixed-type assignment, be aware that the expression is evaluated first, and then the *result* is converted to the correct type.

Type Conversion through Type Casting

C is flexible enough to allow the programmer to convert the type of an expression by placing the desired type in parentheses before the expression, an operation called a *type cast*.

Example: `(double)5 / 2` results in 2.5, not 2 as seen previously.

Expressions with Multiple Operators

- In expressions, we often have multiple operators
  - Equations may not evaluate as we wish them to:
  - Is $x/y*z$ the same as $(x/y)*z$ or $x/(y*z)$?
- **Unary operators** take only one operand: `-5, +3, -3.1415`, etc.
- **Binary operators** take two operands: `3 + 4, 7 / 5, 2 * 6, 4 % 3`, etc.

Rules for Evaluating Expressions

1. *Parenthese rule*: All expressions in parentheses must be evaluated separately. Nested parenthesized expressions must be evaluated from the inside out, with the innermost expression evaluated first.
2. *Operator precedence rule*: Operators in the same expression are evaluated in a fixed order (see Table 1 in your book)

Unary Operators	`+,-`
Binary Operators	`*,/,%`
Binary Arithmetic	`+,-`

3. *Associativity rule*:
   - Unary operators in the same subexpression and at the same precedence level are evaluated right to left.
   - Binary operators in the same subexpression and at the same precedence level are evaluated left to right.

Exercise

Problem

What are the results of the following expressions:

1. `x = -15 * 4 / 2 * 3;`
2. `y = 5 + 2 * 4;`
3. `z = 4 - 5 * 2 - 4 + -10;`

1. `x` = -90 (why not -10?)
2. `y` = 13
3. `z` = -20

Make Expressions Unambiguous

```
x = (-15 * 4) / (2 * 3);
```

Writing Mathematical Formulas in C

Pitfalls

Common misconception: Mathematical Formulas in algebra and in C are *not* the same.

- Algebra: multiplication is implied: xy
- C: Operations must be explicit: `x * y`
- Algebra: division is written $\frac{a+b}{c+d}$
- C: Cannot use such conveniences, must write `(a + b)/(c + d)`

Formatting Numbers in Program Output

- Formatting Values of Type `int`
- Formatting Values of Type `double`
- Program Style

C displays all numbers in its default notation unless you instruct it to do otherwise.

Formatting Integer Types

- Recall the placeholder in `printf/scanf` for integers: `%d`
- By default, the complete integer value is output with no leading space
- You can insert a number to specify the *minimum* number of columns to be printed: `%`n`d`
- If n is less than the number of digits, no effect
- Otherwise, leading blank spaces are inserted before the number so that n columns are printed

Formatting Integer Types

Example

```
1 int  x = 2345;
2 printf("%6d\n",x);
3 printf("%2d\n",x);
```

Result:

```
1   2345
2 2345
```

Formatting Values of Type double

- Recall the placeholder for doubles: `%f`
- Must specify both the total number of columns as well as the *precision* (number of decimal digits)
- Format: `%`n`.`m`f`
  - n is the field width (minimum number of columns to be printed *including* the decimal)
  - m is the number of digits after the decimal to be printed (may end up being padded with zeros
- May or may not define both n, m.

Formatting Values of Type double

Example

```
1 double pi = 3.141592;
2 printf("%.2f\n",pi);
3 printf("%6.2f\n",pi);
4 printf("%15.10f\n",pi);
```

Result:

```
1 3.14
2   3.14
3     3.1415920000
```

Programming Tip

Man pages

- The command `man` (short for manual) can be used to read documentation on standard library functions.
- Example: `:prompt>man printf` gives a detailed description on `printf`
- Contains additional information: how to print leading zeros instead of blanks, etc.

Interactive Mode, Batch Mode, and Data Files

- Input Redirection
- Program Style
- Output Redirection
- Program-Controlled Input and Output Files

Definitions

- Active mode - the program user interacts with the program and types in data while the program is running.
- Batch mode - the program scans its data from a data file prepared beforehand instead of interacting with its user.

Input Redirection

- Recall miles-to-kilometers conversion program: active mode prompted user for input
- If expected formatting of input/output is known, you can put it in a plain text file and use *input/output redirection* on the command line
- Example:

```
prompt:> conversion < mydata
```

where `mydata` is a plain text file containing a single double-formatted number.

Recall the mile-to-kilometer program.

```c
#include <stdio.h>
int main(void)
{
    double miles, kilometers;
    printf("How many miles do you have?");

    scanf("%lf",&miles);

    kilometers = miles * 1.609;
    printf("You have %f kilometers\n",kilometers);

    return 0;
}
```

Echo Prints vs. Prompts

- `scanf` gets a value for *miles* from the first (and only) line of the data file
- If we will only run the program in batch mode, there is no need for the prompting message
- We do need to output the answer though:
  `printf("The distance in miles is %.2f.\n",miles);`
- However, we can also redirect the output to a file:
  `prompt:> conversion < mydata > result.txt`
- Its enough to echo only the number: `printf("%.2f.\n",miles);`

Program-Controlled Input and Output Files

As an alternative to input/output redirection, C allows a program to explicitly name a file from which the program will take input and a file to which the program will send output. The steps needed to do this are:

1. Include `stdio.h`
2. Declare a variable of type `FILE *`.
3. Open the file for reading, writing or both.
4. Read/write to/from the file.
5. Close the file.

Program Example

File Input/Output

```c
#include <stdio.h>
#define KMS_PER_MILE 1.609

int main(void) {
 double kms, miles;
 FILE *inp, *outp;

 inp = fopen("distance.dat","r");
 outp = fopen("distance.out","w");
 fscanf(inp, "%lf", &miles);
 fprintf(outp, "The distance in miles is %.2f.\n", miles);

 kms = KMS_PER_MILES * miles;
 fprintf(outp, "That equals %.2f kilometers.\n", miles);
 fclose(inp);
 fclose(outp);
 return 0;
}
```

Common Programming Errors

- Syntax Errors
- Run-Time Errors
- Undetected Errors
- Logic Errors

Errors

- Bugs - Errors in a programs code.
- Debugging - Finding and removing errors in the program.
- When the compiler detects an error, it will output an error message.
  - Difficult to interpret
  - Often misleading
- Three types of errors
  - Syntax error
  - Run-time error
  - Undetected error
  - Logic error

Syntax Errors

A syntax error occurs when your code violates one or more grammar rules of C and is detected by the compiler at it attempts to translate your program. If a statement has a syntax error, it cannot be translated and your program will not be executed.

Common syntax errors:

- Missing semicolon
- Undeclared variable
- Last comment is not closed
- A grouping character not closed ('(', '{', '[')

Run-Time Errors

- Detected and displayed by the computer during the *execution* of a program
- Occurs when the program directs the computer to perform an illegal operation. Example: dividing a number by zero or opening a file that does not exist
- When a run-time errors occurs, the computer will stop executing your program
- May display a useful (or not) error message
- Core dump, bus error, etc

Undetected Errors

- Code was correct and logical, executed fine, *but* lead to incorrect results.
- Essential that you test your program on known correct input/outputs.
- Common formatting errors with `scanf`/`printf`: keep in mind the correct placeholders and syntax.

Logic Errors

- Logic errors occur when a program follows a faulty algorithm.
- Usually do not cause run-time errors and do not display error messages—difficult to detect
- Must rigorously test your program with various inputs/outputs
- Pre-planning your algorithm with pseudocode or flow-charts will also help you avoid logic errors

Questions

Questions?

Exercise

Debug the following program:

```
1  /*
2   * Calculate and display the difference of two input values
3   */
4  #include <stdio.h>
5
6  int main(void)
7  {
8    int a, b;  /* inputs
9    integer sum;   /* sum of inputs */
10   printf("Input the first number: %d", &A);
11   printf("Input the second number: ");
12   scanf("%d", b);
13   a + b = sum;
14   printf("%d + %d = %d\n", a; b, sum);
15   return 0;
```

Exercise: Answer

```c
/*
 * Calculate and display the difference of two input values
 */
#include <stdio.h>

int main(void)
{
  int a, b;  /* inputs */
  int sum;   /* sum of inputs */
  printf("Input the first number: ");
  scanf("%d", &a);
  printf("Input the second number: ");
  scanf("%d", &b);
  sum = a + b;
  printf("%d + %d = %d\n", a, b, sum);
  return 0;
}
```