C Programming Language: Chapter Notes

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1 Chapter 1: Overview of Some Basic Concepts

1.1 Operator v Statement

An operator is a symbol that acts of data in some way. For example +, -, % etc.

A statement is a complete instruction that tells a program to do something e.g. an if statement, a while statement etc.

1.2 Strongly Typed v Weakly Typed Language

A strongly typed language is one whereby the type of every value is strictly enforced, and does not allow one to mix types without an explicit conversion. Ada is a strongly typed language. C is not.

```
#include <stdio.h>

x = float
y = string

z = x + y \\ Error in STL

z = x + float(y) \\Acceptable in most STL
```
Listing 1: Example of Strongly Typed Language

1.3 Static v Dynamic Typed

Static means that when a variable is assigned a type, it keeps that type and its type is checked at compile time. Example languages are C, Rust, Go and Ada

```
int x = 5;
x = "hello";    // compile-time error
```
Listing 2: Example of Static Typed Language

So, strongly typed −> cannot mix variable types and operations
Statically typed −> Once a variable is assigned a type it maintains that type and this is checked at compile time.

Dynamically typed means a varibale can be assigned one type somewhere, and re-assigned another type later on. Example languages are Python, JavaScript, Ruby.

```
int x = 5;
x = "hello";    // NO compile-time error
```
Listing 3: Example of Static Typed Language

1.4 Procedural v Functional Language

Procedural languages are based around writing functions that operate on data. Examples are C, Python, Ada. Use looping structures, and can be viewed as carrying out programs step-by-step.
Functional languages are based on mathematical functions and expressions. Do not have, e.g., for loops, instead using recursion. Example languages are Haskell, OCaml. They are less step-by-step and more based around writing and calling functions which are the mian building blocks.

1.5 Imperative v Declarative Programming

Imperative programming focuses on how to do something by providing step-by-step instructions. Example languages are C, Python, Ada.

Declarative programming focuses on what the desired outcome is without specifying the exact steps e.g. Coq (Gallina), SQL, Haskell.

Difference between i-- and --i:

```
1  int i = 5;
2
3  int a = i--;    // a = 5, i becomes 4 (post-decrement)
4  int b = --i;    // i becomes 3, b = 3 (pre-decrement)
```

Listing 4: Pre- vs Post-Decrement

2 Chapter 2 Notes: Input and Output Functions

C provides powerful yet simple functions for performing input and output operations. Two of the most commonly used are `printf()` and `scanf()`, both defined in the `<stdio.h>` header file.

2.1 The `printf()` Function

The `printf()` function is used to send formatted output to the standard output stream (usually the screen). Its general form is:

```
1   printf("control string", expressions);
```

Listing 5: General form of printf()

The control string contains ordinary characters, which are printed as they appear, and conversion specifications, each beginning with a `%` character, which tell `printf()` how to format and display the corresponding expressions.

Specifier	Meaning
%d	prints an integer value
%f	prints a floating-point value
%c	prints a single character
%s	prints a string of characters
%02d	prints an integer padded with zeros (e.g. 05)
%.2f	prints a floating-point number to 2 decimal places
%.3f	prints a floating-point number to 3 decimal places
%6.2f	prints a floating-point number in a field width of 6, with 2 digits after the decimal point
%5d	prints an integer in a field width of 5 characters (right-aligned by default)

The general form of a format specification is:

$$\%[\textit{flags}][\textit{width}][.\textit{precision}][\textit{length}]\textit{specifier}$$

where:

- **width** specifies the minimum number of characters to print.

- **precision** controls the number of digits after the decimal point for floating-point numbers, or the maximum number of characters printed for strings.

- **0** flag pads numbers with zeros instead of spaces.

- The output is right-justified by default; use the `-` flag for left-justification.

For example:

```
1  #include <stdio.h>
2
3  int main(void) {
4      int hour = 9, minute = 5;
5      float temperature = 18.437;
6
7      printf("The time is %d:%02d\n", hour, minute);
8      printf("Temperature: %.2f\\textdegree C\n", temperature);
9      printf("Temperature (3dp): %.3f\\textdegree C\n", temperature);
10     printf("Right-aligned field (width 6): %6.2f\\n", temperature);
11     printf("Left-aligned field: %-6.2f\\n", temperature);
12
13     return 0;
14 }
```

Listing 6: Example of printf() usage

This will print:

```
The time is 9:05
Temperature: 18.44°C
Temperature (3dp): 18.437°C
Right-aligned field (width 6):  18.44
Left-aligned field: 18.44
```

Here:

- %.2f rounds to 2 decimal places.

- %.3f rounds to 3 decimal places.

- %6.2f ensures the total printed field occupies at least 6 characters.

- %-6.2f left-aligns the number within that 6-character field.

- %02d pads with leading zeros if the integer has fewer than 2 digits.

2.2 The scanf() Function

The scanf() function reads formatted input from the standard input stream (usually the keyboard). Its general form is:

```
1    scanf("control string", address list);
```

Listing 7: General form of scanf()

The control string works similarly to that of **printf()**, using format specifiers to determine the type of data being read. Each variable to be read must be preceded by an **&** (address-of operator), because scanf() needs to know where to store the input value.

Specifier	Meaning
%d	reads an integer value
%f	reads a floating-point value
%c	reads a single character
%s	reads a string of characters (stops at whitespace)
%lf	reads a double-precision floating-point number
%3d	reads at most 3 digits of an integer (useful for limiting input length)
%5s	reads at most 5 characters into a string (prevents overflow)

The general form of a scanf() conversion specification is:

$$\%[width][length]\,specifier$$

where:

- **width** limits the number of characters read for that input item.

- **length** is used for type modifiers such as l (for long) or lf (for double).

For example:

```c
#include <stdio.h>

int main(void) {
    int hour, minute;
    float temperature;

    printf("Enter a 24-hour time (hh:mm): ");
    scanf("%d:%d", &hour, &minute);

    printf("Enter current temperature: ");
    scanf("%f", &temperature);

    printf("You entered %02d:%02d and %.3f\\textdegree C\n", hour, minute, temperature);

    return 0;
}
```

Listing 8: Example of scanf() usage

If the user inputs:

```
09:30
18.437
```

the program will output:

```
You entered 09:30 and 18.437°C
```

The precision specifier in `scanf()` (such as `%3d` or `%5s`) does not control rounding or decimal places — instead, it limits the number of characters `scanf()` reads from the input buffer. This prevents reading too many characters into a variable or string.

2.3   Important Notes and Common Pitfalls

- **Always match format specifiers to variable types.** Using the wrong one (for example, reading a float with `%d`) can lead to undefined behaviour.

- **Use & in `scanf()`.** Forgetting it causes the program to overwrite memory at an undefined location, often leading to crashes. `scanf("%d", n);` is incorrect — it should be `scanf("%d", &n);`.

- **Width and precision serve different purposes.** In `printf()`, width controls field size and precision controls decimal places. In `scanf()`, width controls the *maximum number of characters read*.

- **Whitespace handling:** `scanf()` skips leading whitespace (spaces, newlines, tabs) for most format specifiers except `%c`, which reads the next character literally — even if it's a newline.

- **`%s` stops at whitespace.** It reads characters until the first space, tab, or newline. To read full lines of text including spaces, use `fgets()` instead.

- **Input validation:** If the user types a non-numeric value when `%d` or `%f` is expected, `scanf()` fails and leaves variables unchanged. Always check its return value (the number of items successfully read).

- **Clearing the input buffer:** After using `scanf()`, unwanted newline characters can remain in the input buffer and affect the next input. To safely handle mixed input (e.g. reading both numbers and characters), use:

```c
    while (getchar() != '\n'); // clear leftover characters

```

- **Printing special characters:** To print a percent sign, use `%%`. For example:

```c
    printf("Progress: 100%% complete\n");

```

4

2.4 Summary

- `printf()` is used for formatted output; `scanf()` for formatted input.

- Both functions use format specifiers beginning with `%` to handle different data types.

- Field width and precision control output spacing and rounding for `printf()`, but input limits for `scanf()`.

- Each variable in `scanf()` must be preceded by `&`.

- `scanf()` skips whitespace for most specifiers but not for `%c`.

- `printf()` allows control of output precision, padding, and alignment.

- Always ensure the types of variables match their format specifiers.

3 Chapter 5 Notes: Selection Statements

3.1 Relational Operators

Symbol	Meaning
$<$	less than
$>$	greater than
$<=$	less than or equal to
$>=$	greater than or equal to

The relational operators produce 0 when false and 1 when true e.g. $1 < 2$ produces 1 (true). $1 > 2$ produces 0 (false).

The expression $i < j < k$ doesn't have the meaning one may expect, as $<$ is left associative. It is equivalent to $(i<j)<k$ i.e. it tests whether i is less than j, and then the 1 or 0 is compared with the value of k.

To test if j lies within i and k, the correct expression is $i<j$ `&&` $j<k$.

3.2 Equality Operators

Symbol	Meaning
$==$	equal to
$!=$	not equal to

Like the relational operators, the equality operators are left associative and produce 0 or 1. However, they have *lower precedence* than the relational operators, meaning the expression $i<j$ `==` $j<k$ is equivalent to $(i<j)$ `==` $(j<k)$.

3.3 Logical Operators

Symbol	Meaning
!	logical negation
&&	logical *and*
||	logical *or*

The logical operators often produce 0 or 1 as there result. They behave as follows:

- `!expr` has the value 1 if *expr* has the value 0.

- `expr1 && expr2` has the value 1 if both expressions are non-zero.

- `expr1 || expr2` has the value 1 if either `expr1` or `expr2` (or both) has a non-zero value.

3.4   if statement

An if statement takes the form

```
if (expression) statement
```

Listing 9: if statement

If you want numeroues statements, one can use the curly braces:

```
if (line_num == max_lines){

    line_num = 0;
    page_num++;
}
```

Curly braces can be add to if and if else statements even when not strictly required to aid in readability:

```c
#include <stdio.h>

int main(void) {
    int score = 85;

    // Even though braces aren't strictly required for single statements,
    // adding them improves clarity and helps prevent future errors.
    if (score >= 90) {
        printf("Grade: A\n");
    } else if (score >= 80) {
        printf("Grade: B\n");
    } else {
        printf("Grade: C or below\n");
    }

    return 0;
}
```

Listing 10: Using curly braces for readability in if-else statements

3.4.1   Dangling else Problem

An else statement belongs to the nearest if statement that hasn´t already been paired with an else. Using curly braces aids in recognising which else statement belongs to which if statement.

3.5   Conditional Expressions

C provides an operator that allows an expression to produce one of two values depending on the value of a condition. This operator cosists of two symbols (? and :) which have to be used in the following way.

```
expr1 ? expr2 : expr3
```

Listing 11: Using curly braces for readability in if-else statements

The expressions can be of any type. This operator is unique in C in that it requires 3 operands instead of the usual one or two and is therefore called the ternary operator. It is read as *"if expr1 thhen expr2 else expr3"*.
expr1 is evaluated, if it is not 0, then expr2 is evaluated and it´s value is the value of the expression. If expr1 is 0, then the value of expr3 is the value of the expression as a whole. For example:

```c
i = 1;
j = 2;
k = i>j ? i : j; // if i is greater than j, k is value of i (1), else it is value of
    j (2).
                 // so here, k is 2
k = (i>=0 ? i : 0) + j; // k is now 3 (i is greater than 0, so expr2 is evaluated, and
    has +j added to it)
```

3.6 Boolean Types

None in C89. Need to define a macro ifelsebraces

```
1   #define BOOL int
2   .
3   .
4   .
5   BOOL flag
```

In C99 there are boolean types declared basicstyle

```
1   _Bool flag
```

where _Bool is an unsigned integer type that can only be assigned 0 or 1. Giving value greater than 1 usually causes it to be assigned 1. The header file $< stdbool.h >$ can also be used which makes it easier to work with boolean values. It provides a macro, bool, that stands for _Bool.

3.7 Switch Statement

Similar to a case statement in VHDL/Ada. Its syntax is:

```
1   switch (expression) {
2     case constant-expression : statements
3     ...
4     case constant-exprsion : statements
5     default : statements
6   }
```

For example:

```
1
2   int grade = 2;
3
4   switch (grade) {
5     case 1:
6         printf("Grade: A\n");
7         break;
8     case 2:
9         printf("Grade: B\n");
10        break;
11    case 3:
12        printf("Grade: C\n");
13        break;
14    default:
15        printf("Grade: F (fail)\n");
16        break;
17  }
```

Here, the value of the variable grade is tested against different values. As int grade = 2, when case 2 is executed, the statement inside this case will execute. Each case ends with a break; to prevent "fall-through". Without the break;, the next case is evaluated even if the condition doesn´t match.

4   Chapter 6 Notes: Loops

Chapter 5 covered C´s selection statements, if and switch. This chapter introduces C´s iteration statements, which allows one to set up loops.
A loop is a statement whose job is to repeatedly execute some other statement termed the loop body. In C every loop has a controlling statement, and each time the loop body is executed (termed an iteration of the loop), the controlling statement is evaluated. If the expression is true, that is, has a value that is not 0, the loop continues to execute.
C provides 3 interation staements: while, do and for. The While statement is used for loops whose controlling expression is tested before the loop body is tested. The Do staement is used if the controlling expression is tested after the loop body is executed. The For statemnt is used if one wants to increment or decrement a counting variable.
C also has break, continue and goto staements, which are typically used in conjuction with loops.

4.1 While Statement

This is the most simple and most fundamental statement in C. It has the form *while (controlling expression) statement.* For example:

```
while(i<n) /* controlling expression*/
 i=i*2    /* loop body */
```
Listing 12: While Statement

When a While statement is executed, its controlling expression is evaluated first. If its value is non-zero (true), the loop body is evaluated, and the controlling expression tested again. To have more than one statement inside the loop body, one can use curly braces:

```
while(i>0) {
    printf("T minus %d and counting\n", i);
    i--;
}
```
Listing 13: While Statement Multiple Statements

A while loop can be used to create an infinite loop via while(1), which executes forever unless there is a statement that transfers control out of the loop (e.g. break, goto, return) or calls a function that causes the program to terminate.

4.2 Do Statement

Do statement is essentially a While statement whose controlling expression is tested after each execution of the loop body.

```
do (statement) while (expression) ;
```
Listing 14: Do Statement

for example:

```
i = 10;

do {

    printf("T minus %d and counting\n", i);
    i--
}   while (i > 0)
```
Listing 15: Do Statement Example

This has the same output as the while statement given in the While statment section i.e. the Do statement and While statement are indistinguishable. The main difference is that the body of a Do statement is always executed at least once, whereas the While statement body may be skipped entirely depending on the controlling expression.

4.3 For Loop

The for loop has the form for (expr1 ; expr2 ; expr3) statement. For example

```
for(i=10 ; i>0 ; i--)
    printf("T minus %d and counting\n", i);
```
Listing 16: For Loop

When this is executed, i is initialised to 10, the loop executes whilst i is greater than 0 and i is decremented by 1 each time the loop executes. The body is executed 10 times in all, with i varying from 10 down to 1. Thus, expr1 is an intialisation step that is performed only once, expr2 controls loop termination (the loop continues to execute as long as the value of expr2 is non-zero i.e. true) and expr3 is an operation to be performed at the end of each loop. For loops can omit expr´s however the semi-colon must always be present e.g.

```
1
2 i=10;
3 for(; i>0 ; i--)
4     printf("T minus %d and counting\n", i);
```
Listing 17: For Loop

is valid, as i has been initialised previously. One may want to have two or more intialisation expressions or one that increments several expressions each time through the loop. This can be achieved via a comma expression as the first or third expression in the for loop. Forexample

```
1
2 i=10;
3 for(i=1, j=2, k=i+j; k>0 ; k--)
4     printf("T minus %d and counting\n", i);
```
Listing 18: For Loop

where the comma expression is left associative so i is ¨read¨ first.

4.4   Break Statement

The break statement allows one to exit a loop. Further, it can only exit one level of nesting, so a break in an inner nested loop will break out to the next level loop.

4.5   Continue Statement

Continue statements do not exit a loop or statement, transferring control to a point just before the end of a loop. This is in contrast to the break statement which transfers control to a point past the end of a loop. Thus, with a continue statement, control remains inside the loop. Also, unlike break statments which can be used in switch statements and loops (while, do, for), the continue statement can only be used in the latter. An example usage of the continue statement is:

```
1
2 n = 0;
3 sum = 0;
4 while (n < 10){
5     scanf(%d,&i);
6     if (i==0)
7         continue;
8     sum += i;
9     n++;
10    /* continue jumps to here */
11 }
```
Listing 19: Continue Statement

Without continue, the above would have to be written such as:

```
1
2 n = 0;
3 sum = 0;
4 while (n < 10){
5     scanf(%d,&i);
6     if (i!=0){
7         continue;
8     sum += i;
9     n++;
10    }
11 }
```
Listing 20: Continue Statement 2

i.e. the if statement would have to contain the body of the loop, so that the statements for updating the sum and incrementing n are executed only when the condition is satisfied.

4.6   goto Statement

Both the break and and continue statements are jump statements that transfer control from one point in the program to another. Both are restricted; break retruns one to a point just after the end of the

closing loop, whereas continue to a point just before the end of the loop. In contrast, the goto statement is capable of jumping to any statement in a function, provided that the statement has a label.

A label is an identifier placed at the beginning of a statement - identifier : statement. A statement may have more than one label. The goto statement itself has the form - goto identifier ; . As an example:

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

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

Listing 21: goto statement example

5 Basic Types

5.1 Numeric Types

5.1.1 Signed, unsigned, long, short and long long int

C supports two fundamentally different numeric types: integer types and floating types. Integer types are whole numbers whereas values of a floating type can have fractional parts as well. Integer types in turn are divided into two categories; signed and unsigned. With signed, the MSB is in fact a sign bit, 0 being positive and 1 being negative. By default, integer variables in C are signed by default, and one must use the reserved word unsigned to tell the compiler that there is no sign bit.

An integer is typically 32 bits (though this is machine dependent, bieng 16 bits on old CPUs). C also provides long integers, which have more than 32 bits. Short integers are also available if one wants to store an integer in less space than normal. The different types can be combined, however, only only the following six combinations actually produce different types:

- short int

- unsigned short int

- int

- unsigned int

- long int

- unsigned long int

Other combinations are synonyms for one of these six types. (For example, long signed int is the same as long int, since integers are always signed unless otherwise specified.) Incidentally, the order of the specifiers doesn't matter; unsigned short int is the same as short unsigned int. C allows us to abbreviate the names of integer types by dropping the word int. For example, unsigned short int may be abbreviated to unsigned short, and long int may be abbreviated to just 1ong. Typical value ranges for the vrious it types are given in figure 1.

The above ranges vary between compilers. To check the ranges for the various numeric types, one can check the limits.h header file. C99 added long long int and unsigned long long int. Both long long types are required to be at least 64 bits wide.

5.1.2 Constants

Constants can be written in decimal (base 10), octal (base 8) or hexadecimal (base 16). Integers can start with any number except 0. Octal uses any digit between 0 and 7 and must begin with 0. Hexadecimal can contain any digit between 0 and 9, and the letters A to F, and begin with 0x. The different forms can be mixed together when, e.g., adding or subtracting numbers. To force the compiler to treat a constant as a long integer, just follow it with the letter L (or 1): 15L 0377L 0x7fffL To indicate that a constant is unsigned, put the letter U (or u) after it: 15U 0377U 0x7fffU L and U may be used in combination to

Table 7.2 Integer Types on a 32-bit Machine	Type	Smallest Value	Largest Value
	short int	−32,768	32,767
	unsigned short int	0	65,535
	int	−2,147,483,648	2,147,483,647
	unsigned int	0	4,294,967,295
	long int	−2,147,483,648	2,147,483,647
	unsigned long int	0	4,294,967,295

In recent years, 64-bit CPUs have become more common. Table 7.3 shows typical ranges for the integer types on a 64-bit machine (especially under UNIX).

Table 7.3 Integer Types on a 64-bit Machine	Type	Smallest Value	Largest Value
	short int	−32,768	32,767
	unsigned short int	0	65,535
	int	−2,147,483,648	2,147,483,647
	unsigned int	0	4,294,967,295
	long int	−9,223,372,036,854,775,808	9,223,372,036,854,775,807
	unsigned long int	0	18,446,744,073,709,551,615

Figure 1: Typical integer ranges for 16 and 32 bit machines. Taken from *C: A Modern Approach*.

show that a constant is both long and unsigned: 0xffffffffUL. (The order of the L and U doesn't matter, nor does their case.) Integer Constants in C99 In C99, integer constants that end with either LL or 11 (the case of the two letters must match) have type long long int. Adding the letter U (or u) before or after the LL or 11 denotes a constant of type unsigned long long int.

5.2 Floating Types

Integer types are not suitable for all applications. In many cases, we need to represent numbers with fractional parts or values that are extremely large or small. Such numbers are stored using floating-point representation, so called because the position of the decimal point can "float." C provides three floating-point types:

- float

- double

- long double

These correspond to single-precision, double-precision, and extended-precision floating-point formats, respectively. The `float` type is appropriate when limited precision is acceptable, while `double` offers greater precision and is sufficient for most programs. The `long double` type provides the highest precision, but is used less frequently.

The C standard does not specify the exact precision or range of floating types, as these are machine dependent. Most modern systems follow the IEEE Standard 754 for floating-point arithmetic. Under this standard, floating-point numbers are stored in a form of scientific notation consisting of three components: a sign, an exponent, and a fraction (mantissa). The size of the exponent determines the range of representable values, while the size of the fraction determines precision.

In IEEE 754 single-precision format (32 bits), the exponent is 8 bits and the fraction is 23 bits, giving a maximum value of approximately 3.4×10^{38} and about 6 decimal digits of precision. Double-precision format (64 bits) provides roughly 15 decimal digits of precision and a much larger range. The size of `long double` varies by implementation, commonly being 80 or 128 bits.

The characteristics of floating types on a given system can be obtained from the `<float.h>` header file. On systems that do not follow IEEE 754, the ranges and precision may differ.

5.2.1 Floating Constants

Floating constants may be written using a decimal point, an exponent, or both. For example, the following are all valid floating constants:

```
57.0    57.    57.0e0    57E0    5.7e1    570.e-1
```

By default, floating constants are treated as type `double`. To force a constant to be stored as a `float`, append the letter F or f (e.g., `57.0F`). To store a constant as a `long double`, append L or l (e.g., `57.0L`). C99 also allows hexadecimal floating constants, although they are rarely used.

5.2.2 Reading and Writing Floating-Point Values

When reading floating-point values using `scanf`, different conversion specifiers are required depending on the type. For values of type `double`, the letter l must precede the conversion specifier:

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

For values of type `long double`, the letter L must be used:

```
long double ld;
scanf("%Lf", &ld);
printf("%Lf", ld);
```

In calls to `printf`, the e, f, and g conversion specifiers may be used for both `float` and `double` values.

6 Character Types

The only remaining basic type is char, the character type. The values of char differ from one machine to the next as different machines may have different underlying character sets. The most popular is the ASCII set. C treats characters as small integers.