C Programming
On the 28th of April 2012 the contents of the English as well as German Wikibooks and Wikipedia projects were licensed under Creative Commons Attribution-ShareAlike 3.0 Unported license. A URI to this license is given in the list of figures on page 277. If this document is a derived work from the contents of one of these projects and the content was still licensed by the project under this license at the time of derivation this document has to be licensed under the same, a similar or a compatible license, as stated in section 4b of the license. The list of contributors is included in chapter Contributors on page 257. The licenses GPL, LGPL and GFDL are included in chapter Licenses on page 281, since this book and/or parts of it may or may not be licensed under one or more of these licenses, and thus require inclusion of these licenses. The licenses of the figures are given in the list of figures on page 277. This PDF was generated by the LATEX typesetting software. The LATEX source code is included as an attachment (source.7z.txt) in this PDF file. To extract the source from the PDF file, you can use the pdfdetach tool including in the poppler suite, or the http://www.pdflabs.com/tools/pdftk-the-pdf-toolkit/ utility. Some PDF viewers may also let you save the attachment to a file. After extracting it from the PDF file you have to rename it to source.7z. To unpack the resulting archive we recommend the use of http://www.7-zip.org/. The LATEX source itself was generated by a program written by Dirk Hünniger, which is freely available under an open source license from http://de.wikibooks.org/wiki/Benutzer:Dirk_Huenniger/wb2pdf.
Contents

1 Why learn C? 3

2 History 7

3 What you need before you can learn 9
   3.1 Getting Started 9
   3.2 Footnotes 12

4 Using a Compiler 13

5 Beginning C 17

6 Intro exercise 19
   6.1 The "Hello, World!" Program 19
   6.2 References 21

7 Preliminaries 23
   7.1 Block Structure, Statements, Whitespace, and Scope 23
   7.2 Basics of Using Functions 25
   7.3 The Standard Library 26
   7.4 References 26

8 Compiling 27
   8.1 Preprocessor 27
   8.2 Syntax Checking 28
   8.3 Object Code 28
   8.4 Linking 28
   8.5 Automation 29
   8.6 References 30

9 Structure and style 31
   9.1 C Structure and Style 31
   9.2 Introduction 31
   9.3 Line Breaks and Indentation 32
   9.4 Comments 34
   9.5 References 37

10 Variables 39
   10.1 Declaring, Initializing, and Assigning Variables 39
   10.2 Literals 41
   10.3 The Four Basic Data Types 41
Contents

10.4 sizeof .................................................. 43
10.5 Data type modifiers ...................................... 44
10.6 const qualifier ............................................. 45
10.7 Magic numbers ............................................ 45
10.8 Scope ................................................... 46
10.9 Other Modifiers ........................................... 46
10.10 References ................................................ 50

11 Error handling ........................................... 51
11.1 Preventing divide by zero errors ...................... 52
11.2 Signals .................................................. 52
11.3 setjmp ................................................... 53

12 Simple Input and Output ................................. 55
12.1 Output using printf() ................................... 55
12.2 Other output methods .................................... 58
12.3 Input using scanf() ..................................... 58
12.4 References ............................................... 59

13 Simple math .............................................. 61
13.1 Arithmetic Operators ..................................... 61
13.2 Assignment Operators ................................... 62
13.3 Logical Operators ........................................ 62
13.4 Relational and Equality Operators .................... 63
13.5 Type Casting ............................................ 64
13.6 The Shift Operators (which may be used to rotate bits) ............................................ 64
13.7 Bitwise Operators ........................................ 66
13.8 Comma Operator ......................................... 66
13.9 References ............................................... 67

14 Further math .............................................. 69
14.1 Trigonometric functions ................................ 69
14.2 Hyperbolic functions .................................... 70
14.3 Exponential and logarithmic functions ............... 71
14.4 Power functions ......................................... 73
14.5 Nearest integer, absolute value, and remainder functions ............................................ 74
14.6 Error and gamma functions .............................. 76
14.7 References ............................................... 77

15 Control .................................................... 79
15.1 Conditionals ............................................. 79
15.2 Loops .................................................... 86
15.3 One last thing: goto ..................................... 90
15.4 Examples ................................................ 91
15.5 References ............................................... 92

16 Procedures and functions ............................... 93
16.1 More on functions ....................................... 94
16.2 Writing functions in C ................................... 94
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>16.3 Using C functions</td>
<td>96</td>
</tr>
<tr>
<td>16.4 Functions from the C Standard Library</td>
<td>97</td>
</tr>
<tr>
<td>16.5 Variable-length argument lists</td>
<td>99</td>
</tr>
<tr>
<td>16.6 References</td>
<td>101</td>
</tr>
<tr>
<td>17 Preprocessor</td>
<td>103</td>
</tr>
<tr>
<td>17.1 Directives</td>
<td>103</td>
</tr>
<tr>
<td>17.2 Useful Preprocessor Macros for Debugging</td>
<td>113</td>
</tr>
<tr>
<td>18 Libraries</td>
<td>119</td>
</tr>
<tr>
<td>18.1 What to put in header files</td>
<td>121</td>
</tr>
<tr>
<td>18.2 References</td>
<td>122</td>
</tr>
<tr>
<td>19 Standard libraries</td>
<td>123</td>
</tr>
<tr>
<td>19.1 History</td>
<td>123</td>
</tr>
<tr>
<td>19.2 Design</td>
<td>124</td>
</tr>
<tr>
<td>19.3 ANSI Standard</td>
<td>124</td>
</tr>
<tr>
<td>19.4 Common support libraries</td>
<td>126</td>
</tr>
<tr>
<td>19.5 Compiler built-in functions</td>
<td>126</td>
</tr>
<tr>
<td>19.6 POSIX standard library</td>
<td>126</td>
</tr>
<tr>
<td>19.7 References</td>
<td>127</td>
</tr>
<tr>
<td>20 File IO</td>
<td>129</td>
</tr>
<tr>
<td>20.1 Introduction</td>
<td>129</td>
</tr>
<tr>
<td>20.2 Streams</td>
<td>129</td>
</tr>
<tr>
<td>20.3 Standard Streams</td>
<td>130</td>
</tr>
<tr>
<td>20.4 FILE pointers</td>
<td>130</td>
</tr>
<tr>
<td>20.5 Opening and Closing Files</td>
<td>131</td>
</tr>
<tr>
<td>20.6 Other file access functions</td>
<td>132</td>
</tr>
<tr>
<td>20.7 Functions that Modify the File Position Indicator</td>
<td>133</td>
</tr>
<tr>
<td>20.8 Error Handling Functions</td>
<td>135</td>
</tr>
<tr>
<td>20.9 Other Operations on Files</td>
<td>136</td>
</tr>
<tr>
<td>20.10 Reading from Files</td>
<td>137</td>
</tr>
<tr>
<td>20.11 Writing to Files</td>
<td>145</td>
</tr>
<tr>
<td>20.12 References</td>
<td>153</td>
</tr>
<tr>
<td>21 Beginning exercises</td>
<td>155</td>
</tr>
<tr>
<td>21.1 Variables</td>
<td>155</td>
</tr>
<tr>
<td>21.2 Simple I/O</td>
<td>156</td>
</tr>
<tr>
<td>21.3 Program Flow</td>
<td>156</td>
</tr>
<tr>
<td>21.4 Functions</td>
<td>157</td>
</tr>
<tr>
<td>21.5 Math</td>
<td>157</td>
</tr>
<tr>
<td>21.6 Recursion</td>
<td>157</td>
</tr>
<tr>
<td>22 In-depth C ideas</td>
<td>161</td>
</tr>
<tr>
<td>23 Arrays</td>
<td>163</td>
</tr>
<tr>
<td>23.1 Arrays</td>
<td>163</td>
</tr>
<tr>
<td>23.2 Strings</td>
<td>165</td>
</tr>
<tr>
<td>Chapter</td>
<td>Section</td>
</tr>
<tr>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>23</td>
<td>3.3 References</td>
</tr>
<tr>
<td>24</td>
<td>Pointers and arrays</td>
</tr>
<tr>
<td>24.1</td>
<td>Declaring pointers</td>
</tr>
<tr>
<td>24.2</td>
<td>Assigning values to pointers</td>
</tr>
<tr>
<td>24.3</td>
<td>Pointer dereferencing</td>
</tr>
<tr>
<td>24.4</td>
<td>Pointers and Arrays</td>
</tr>
<tr>
<td>24.5</td>
<td>Pointers in Function Arguments</td>
</tr>
<tr>
<td>24.6</td>
<td>Pointers and Text Strings</td>
</tr>
<tr>
<td>24.7</td>
<td>Pointers to Functions</td>
</tr>
<tr>
<td>24.8</td>
<td>Practical use of function pointers in C</td>
</tr>
<tr>
<td>24.9</td>
<td>Examples of pointer constructs</td>
</tr>
<tr>
<td>24.10</td>
<td>sizeof</td>
</tr>
<tr>
<td>24.11</td>
<td>External Links</td>
</tr>
<tr>
<td>25</td>
<td>Memory management</td>
</tr>
<tr>
<td>25.1</td>
<td>The malloc function</td>
</tr>
<tr>
<td>25.2</td>
<td>The calloc function</td>
</tr>
<tr>
<td>25.3</td>
<td>The realloc function</td>
</tr>
<tr>
<td>25.4</td>
<td>The free function</td>
</tr>
<tr>
<td>25.5</td>
<td>References</td>
</tr>
<tr>
<td>26</td>
<td>Strings</td>
</tr>
<tr>
<td>26.1</td>
<td>Syntax</td>
</tr>
<tr>
<td>26.2</td>
<td>The &lt;string.h&gt; Standard Header</td>
</tr>
<tr>
<td>26.3</td>
<td>Examples</td>
</tr>
<tr>
<td>26.4</td>
<td>References</td>
</tr>
<tr>
<td>27</td>
<td>Complex types</td>
</tr>
<tr>
<td>27.1</td>
<td>Data structures</td>
</tr>
<tr>
<td>27.2</td>
<td>Enumerations</td>
</tr>
<tr>
<td>28</td>
<td>Networking in UNIX</td>
</tr>
<tr>
<td>28.1</td>
<td>A simple client</td>
</tr>
<tr>
<td>28.2</td>
<td>A simple server</td>
</tr>
<tr>
<td>28.3</td>
<td>Useful network functions</td>
</tr>
<tr>
<td>28.4</td>
<td>FAQs</td>
</tr>
<tr>
<td>29</td>
<td>Common practices</td>
</tr>
<tr>
<td>29.1</td>
<td>Dynamic multidimensional arrays</td>
</tr>
<tr>
<td>29.2</td>
<td>Constructors and destructors</td>
</tr>
<tr>
<td>29.3</td>
<td>Nulling freed pointers</td>
</tr>
<tr>
<td>29.4</td>
<td>Macro conventions</td>
</tr>
<tr>
<td>29.5</td>
<td>Further reading</td>
</tr>
<tr>
<td>30</td>
<td>C and beyond</td>
</tr>
<tr>
<td>31</td>
<td>Particularities of C</td>
</tr>
<tr>
<td>31.1</td>
<td>References</td>
</tr>
</tbody>
</table>
### 42 Licenses

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>42.1</td>
<td>GNU GENERAL PUBLIC LICENSE</td>
<td>281</td>
</tr>
<tr>
<td>42.2</td>
<td>GNU Free Documentation License</td>
<td>282</td>
</tr>
<tr>
<td>42.3</td>
<td>GNU Lesser General Public License</td>
<td>283</td>
</tr>
</tbody>
</table>
1 Why learn C?

w:C (programming language)\(^1\)

C\(^2\) is the most commonly used programming language for writing operating systems\(^3\). The first operating system written in C is Unix\(^4\). Later operating systems like GNU/Linux\(^5\) were all written in C. Not only is C the language of operating systems, it is the precursor and inspiration for almost all of the most popular high-level languages available today. In fact, Perl\(^6\), PHP\(^7\), Python\(^8\) and Ruby\(^9\) are all written in C.

By way of analogy, let's say that you were going to be learning Spanish, Italian, French, or Romanian. Do you think knowing Latin would be helpful? Just as Latin was the basis of all of those languages, knowing C will enable you to understand and appreciate an entire family of programming languages built upon the traditions of C. Knowledge of C enables freedom.

1.0.1 Why C, and not assembly language?

While assembly language\(^10\) can provide speed and maximum control of the program, C provides portability.

Different processors are programmed using different Assembly languages and having to choose and learn only one of them is too arbitrary. In fact, one of the main strengths of C is that it combines universality and portability across various computer architectures while retaining most of the control of the hardware provided by assembly language.

For example, C programs can be compiled and run on the HP 50g calculator (ARM\(^11\) processor), the TI-89 calculator (68000\(^12\) processor), Palm OS Cobalt smartphones (ARM processor), the original iMac (PowerPC\(^13\)), the Arduino (Atmel AVR\(^14\)), and the Intel iMac.

---

\(^1\) https://en.wikipedia.org/wiki/C%20%28programming%20language%29
\(^2\) https://en.wikipedia.org/wiki/C%20%28programming%20language%29
\(^3\) https://en.wikipedia.org/wiki/operating%20systems
\(^4\) https://en.wikipedia.org/wiki/Unix
\(^5\) https://en.wikipedia.org/wiki/Linux
\(^6\) https://en.wikipedia.org/wiki/Perl
\(^7\) https://en.wikipedia.org/wiki/PHP
\(^8\) https://en.wikipedia.org/wiki/Python%20%28programming%20language%29
\(^9\) https://en.wikipedia.org/wiki/Ruby%20%28programming%20language%29
\(^10\) https://en.wikipedia.org/wiki/Assembly%20language
\(^11\) https://en.wikipedia.org/wiki/ARM%20architecture
\(^12\) https://en.wikipedia.org/wiki/Motorola%2068000
\(^13\) https://en.wikipedia.org/wiki/PowerPC
\(^14\) https://en.wikipedia.org/wiki/Atmel%20AVR
Why learn C?

( Intel\textsuperscript{15} Core 2 Duo). Each of these devices has its own assembly language that is completely incompatible with the assembly language of any other.

Assembly, while extremely powerful, is simply too difficult to program large applications and hard to read or interpret in a logical way. C is a compiled language, which creates fast and efficient executable files. It is also a small “what you see is all you get” language: a C statement corresponds to at most a handful of assembly statements, everything else is provided by library functions.

So is it any wonder that C is such a popular language?

Like toppling dominoes, the next generation of programs follows the trend of its ancestors. Operating systems designed in C always have system libraries designed in C. Those system libraries are in turn used to create higher-level libraries (like OpenGL\textsuperscript{16}, or GTK\textsuperscript{17}), and the designers of those libraries often decide to use the language the system libraries used. Application developers use the higher-level libraries to design word processors, games, media players and the like. Many of them will choose to program in the language that the higher-level library uses. And the pattern continues on and on and on...

1.0.2 Why C, and not another language?

The primary design of C is to produce portable code while maintaining performance and minimizing footprint (CPU time\textsuperscript{18}, memory\textsuperscript{19} usage, disk I/O, etc.). This is useful for operating systems\textsuperscript{20}, embedded systems\textsuperscript{21} or other programs where performance matters a lot (“high-level” interface would affect performance). With C it’s relatively easy to keep a mental picture of what a given line really does, because most of the things are written explicitly in the code. C has a big codebase for low level applications. It is the “native” language of UNIX\textsuperscript{22}, which makes it flexible and portable. It is a stable and mature language which is unlikely to disappear for a long time and has been ported to most, if not all, platforms.

One powerful reason is memory allocation. Unlike most programming languages, C allows the programmer to write directly to memory. Key constructs in C such as structs, pointers and arrays are designed to structure and manipulate memory in an efficient, machine-independent fashion. In particular, C gives control over the memory layout of data structures. Moreover dynamic memory allocation is under the control of the programmer (which also means that memory deallocation has to be done by the programmer). Languages like Java\textsuperscript{23} and Perl shield the programmer from having to manage most details of memory allocation and pointers (except for memory leaks\textsuperscript{24} and some other forms of excess memory.

\begin{thebibliography}{9}
\bibitem{15} https://en.wikipedia.org/wiki/x86
\bibitem{16} https://en.wikipedia.org/wiki/OpenGL
\bibitem{17} https://en.wikipedia.org/wiki/GTK
\bibitem{18} https://en.wikipedia.org/wiki/CPU\%20time
\bibitem{19} https://en.wikipedia.org/wiki/Computer\%20memory
\bibitem{20} https://en.wikipedia.org/wiki/Operating\%20systems
\bibitem{21} https://en.wikipedia.org/wiki/Embedded\%20systems
\bibitem{22} https://en.wikipedia.org/wiki/Unix
\bibitem{23} https://en.wikipedia.org/wiki/Java\%20\%20programming\%20language\%20
\bibitem{24} https://en.wikipedia.org/wiki/Memory\%20leak
\end{thebibliography}
usage). This can be useful since dealing with memory allocation when building a high-level program is a highly error-prone process. However, when dealing with low-level code such as the part of the OS that controls a device, C provides a uniform, clean interface. These capabilities just do not exist in most other languages.

While Perl, PHP, Python and Ruby may be powerful and support many features not provided by default in C, they are not normally implemented in their own language. Rather, most such languages initially relied on being written in C (or another high-performance programming language), and would require their implementation be ported to a new platform before they can be used.

As with all programming languages, whether you want to choose C over another high-level language is a matter of opinion and both technical and business requirements could dictate which language is required.
2 History

The field of computing as we know it today started in 1947 with three scientists at Bell Telephone Laboratories—William Shockley\(^1\), Walter Brattain\(^2\), and John Bardeen\(^3\)—and their groundbreaking invention: the transistor\(^4\). In 1956, the first fully transistor-based computer, the TX-0\(^5\), was completed at MIT. The first integrated circuit\(^6\) was created in 1958 by Jack Kilby\(^7\) at Texas Instruments, but the first high-level programming language existed even before then.

"The Fortran\(^8\) project" was originally developed in 1954 by IBM. A shortening of "The IBM Mathematical Formula Translating System", the project had the purpose of creating and fostering development of a procedural, imperative programming language that was especially suited to numeric computation and scientific computing. It was a breakthrough in terms of productivity and programming ease (compared to assembly language) and speed (Fortran programs ran nearly as fast as, and in some cases, just as fast as, programs written in assembly). Furthermore, Fortran was written at a high-enough level (and thus was machine independent enough) to become the first widely adopted programming language. The Algorithmic Language (Algol 58\(^9\)) was derived from Fortran in 1958 and evolved into Algol 60\(^10\) in 1960. The Combined Programming Language (CPL)\(^11\) was then created out of Algol 60 in 1963. In 1967, it evolved into Basic CPL\(^12\), which was itself, the base for B\(^13\) in 1969. Finally, B, the root of C, was created in 1971.

C was the direct successor of B, a stripped down version of BCPL, created by Ken Thompson\(^14\) at Bell Labs, that was also a compiled language\(^15\) - User's Reference to B\(^16\), used in early internal versions of the UNIX operating system. As noted in Ritchie's C History\(^17\): 'The B compiler on the PDP-7 did not generate machine instructions, but instead 'threaded code', an interpretive scheme in which the compiler's output consists of a sequence of addresses of code fragments that perform the elementary operations. The operations typically

\(^1\) https://en.wikipedia.org/wiki/William%20Shockley
\(^2\) https://en.wikipedia.org/wiki/Walter%20Brattain
\(^3\) https://en.wikipedia.org/wiki/John%20Bardeen
\(^4\) https://en.wikipedia.org/wiki/transistor
\(^5\) https://en.wikipedia.org/wiki/TX-0
\(^6\) https://en.wikipedia.org/wiki/integrated%20circuit
\(^7\) https://en.wikipedia.org/wiki/Jack%20Kilby
\(^8\) https://en.wikipedia.org/wiki/Fortran
\(^9\) https://en.wikipedia.org/wiki/ALGOL%2058
\(^10\) https://en.wikipedia.org/wiki/ALGOL%2060
\(^12\) https://en.wikipedia.org/wiki/BCPL
\(^13\) https://en.wikipedia.org/wiki/B%20%28programming%20language%29
\(^14\) https://en.wikipedia.org/wiki/Ken%20Thompson
\(^15\) https://en.wikipedia.org/wiki/compiled%20language
\(^17\) https://www.bell-labs.com/usr/dmr/www/chist.html
— in particular for B — act on a simple stack machine”. Thompson and Dennis Ritchie\textsuperscript{18}, also working at Bell Labs, improved B and called the result NB. Further extensions to NB created its logical successor, C. Most of UNIX was rewritten in NB, and then C, which resulted in a more portable operating system.

The portability of UNIX was the main reason for the initial popularity of both UNIX and C. Rather than creating a new operating system for each new machine, system programmers could simply write the few system-dependent parts required for the machine, and then write a C compiler for the new system. Since most of the system utilities were thus written in C, it simply made sense to also write new utilities in C.

The American National Standards Institute began work on standardizing the C language in 1983, and completed the standard in 1989. The standard, ANSI X3.159-1989 "Programming Language C”, served as the basis for all implementations of C compilers. The standards were later updated in 1990 and 1999, allowing for features that were either in common use, or were appearing in C++.

\begin{itemize}
  \item de:C-Programmierung: Grundlagen\textsuperscript{19}
  \item es:Programación en C/Historia de C\textsuperscript{20}
  \item fr:Programmation C/Introduction\textsuperscript{21}
  \item it:C/Linguaggio/Panoramica\textsuperscript{22}
  \item pt:Programar em C/História da linguagem C\textsuperscript{23}
\end{itemize}

\textsuperscript{18} [https://en.wikipedia.org/wiki/Dennis%20Ritchie]
\textsuperscript{19} [https://de.wikibooks.org/wiki/C-Programmierung%20Grundlagen]
\textsuperscript{20} [https://es.wikibooks.org/wiki/Programaci\%C3\%B3n%20en%20C/Historia%20de%20C]
\textsuperscript{21} [https://fr.wikibooks.org/wiki/Programmation%20C/Introduction]
\textsuperscript{22} [https://it.wikibooks.org/wiki/C%2FLinguaggio%2FPanoramica]
\textsuperscript{23} [https://pt.wikibooks.org/wiki/Programar%20em%20C/ História da linguagem C]
3 What you need before you can learn

3.1 Getting Started

The goal of this book is to introduce you to and teach you the C programming language. Basic computer literacy is assumed, but no special knowledge is needed.

Before you can start programming in C, you will need a **C compiler**. A compiler is a program that converts C code into executable machine code.

**Popular C compilers/IDEs include:**

<table>
<thead>
<tr>
<th>Name</th>
<th>Website</th>
<th>Platform</th>
<th>License</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xcode</td>
<td>Xcode</td>
<td>macOS, OSX</td>
<td>Proprietary, free of charge</td>
<td>Default IDE on macOS</td>
</tr>
<tr>
<td>Tiny C Compiler (TCC)</td>
<td>tinycc</td>
<td>GNU/Linux, Windows</td>
<td>LGPL</td>
<td>Small, fast and simple compiler.</td>
</tr>
<tr>
<td>Clang</td>
<td>clang</td>
<td>GNU/Linux, Windows, Unix, OS X</td>
<td>University of Illinois/NCSA License</td>
<td>A free, permissively licensed front-end using a LLVM backend.</td>
</tr>
<tr>
<td>GNU C Compiler</td>
<td>gcc</td>
<td>GNU/Linux, MinGW, mingw-w64 (Windows), Unix, OS X</td>
<td>GPL</td>
<td>The De facto standard. Ships with most Unix systems.</td>
</tr>
</tbody>
</table>

---

3. Actually, GCC's (GNU C Compiler) `cc` (C Compiler) translates the input `.c` file to the target CPU’s assembly [https://en.wikipedia.org/wiki/Assembly%20language], output is written to an `.s` file. Then `as` (assembler) generates a machine code file from the `.s` file. Pre-processing is done by another sub-program `cpp` (C PreProcessor), which is not to be confused with `c++` (a compiler for another programming language).
5. [https://www.visualstudio.com/de/vs/visual-studio-express/](https://www.visualstudio.com/de/vs/visual-studio-express/)
8. [https://bellard.org/tcc/](https://bellard.org/tcc/)
11. [https://clang.llvm.org](https://clang.llvm.org)
12. [http://opensource.org/licenses/UoI-NCSA.php](http://opensource.org/licenses/UoI-NCSA.php)
15. [http://mingw.org](http://mingw.org)
16. [https://mingw-w64.org](https://mingw-w64.org)
What you need before you can learn

The minimum software requirements to program in C is a text editor\(^\text{18}\), as opposed to a word processor\(^\text{19}\). A plain text Notepad editor can be used but it does not offer any advanced capabilities such as syntax highlighting and code completion. There are many text editors (see List of Text Editors\(^\text{20}\)), among the most popular are Notepad++\(^\text{21}\) for Windows as well as Atom\(^\text{22}\), Sublime Text\(^\text{23}\), gedit\(^\text{24}\), Vim\(^\text{25}\) and Emacs\(^\text{26}\) which are also available on other operating systems (“cross-platform”). These text editors come with syntax highlighting\(^\text{27}\) and line numbers, which makes code easier to read at a glance, and to spot syntax errors.

Though not absolutely needed, many programmers prefer and recommend using an Integrated development environment\(^\text{28}\) (IDE) instead of a text editor. An IDE is a suite of programs that developers need, combined into one convenient package, usually with a graphical user interface. These programs include a text editor and file browser and are sometimes bundled with an easily accessible compiler. They also typically include a debugger, a tool that will enable you to do such things as step through the program you develop manually one source code line at a time, or alter data as an aid to finding and correcting programming errors.

Many IDEs do not offer their users a console-based interface to the compiler and for executing the developed program but offer only graphical buttons. For beginners it is recommended not to use such an IDE, since it hides most of what is going on. Using the command line builds up familiarity with the toolchain. Such an IDE may still be useful to somebody with programming experience who knows how the IDE works. So as a general guideline: Do not use an IDE unless you know what the IDE does!

Other popular compilers/IDEs include:

<table>
<thead>
<tr>
<th>Name</th>
<th>Website</th>
<th>Platform</th>
<th>License</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eclipse CDT(^\text{29})</td>
<td>Eclipse(^\text{30})</td>
<td>Windows, Mac OS X, GNU/Linux</td>
<td>Free/Libre and Open Source</td>
<td>Eclipse(^\text{31}) IDE for C/C++ development, a popular open source IDE.</td>
</tr>
<tr>
<td>Netbeans(^\text{22})</td>
<td>Netbeans(^\text{32})</td>
<td>Cross-platform GNU/Linux</td>
<td>CDDL(^\text{34}) and GPL(^\text{35}) 2.0</td>
<td>A Good comparable matured IDE to Eclipse. A feature-rich but simple IDE for the GNOME(^\text{39}) desktop environment.</td>
</tr>
<tr>
<td>GNOME Builder(^\text{36})</td>
<td>Builder(^\text{37})</td>
<td>GNU/Linux</td>
<td>GPL(^\text{36})</td>
<td></td>
</tr>
</tbody>
</table>

\(^\text{18}\) https://en.wikipedia.org/wiki/Text%20Editor
\(^\text{19}\) https://en.wikipedia.org/wiki/Word%20Processor
\(^\text{20}\) https://en.wikipedia.org/wiki/List%20of%20text%20editors
\(^\text{22}\) https://atom.io/
\(^\text{23}\) https://en.wikipedia.org/wiki/Sublime%20Text
\(^\text{24}\) https://en.wikipedia.org/wiki/gedit
\(^\text{25}\) https://en.wikipedia.org/wiki/Vim%20%28text%20editor%29
\(^\text{26}\) https://en.wikipedia.org/wiki/Emacs
\(^\text{27}\) https://en.wikipedia.org/wiki/syntax%20highlighting
\(^\text{28}\) https://en.wikipedia.org/wiki/Integrated%20development%20environment
\(^\text{29}\) https://en.wikipedia.org/wiki/Eclipse%20%28software%29
\(^\text{30}\) https://www.eclipse.org/downloads/packages/all
\(^\text{31}\) https://en.wikipedia.org/wiki/Eclipse%20%28software%29
\(^\text{32}\) https://en.wikipedia.org/wiki/Netbeans
\(^\text{33}\) http://netbeans.org
\(^\text{34}\) https://en.wikipedia.org/wiki/Common%20Development%20and%20Distribution%20License
\(^\text{35}\) https://en.wikipedia.org/wiki/GNU%20General%20Public%20License
\(^\text{36}\) https://en.wikipedia.org/wiki/GNOME%20Builder
\(^\text{37}\) https://wiki.gnome.org/Apps/Builder
\(^\text{38}\) https://en.wikipedia.org/wiki/GNU%20General%20Public%20License
\(^\text{39}\) https://en.wikipedia.org/wiki/GNOME
<table>
<thead>
<tr>
<th>Name</th>
<th>Website/Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anjuta</td>
<td><a href="https://en.wikipedia.org/wiki/Anjuta">Link</a></td>
</tr>
<tr>
<td>Geany</td>
<td><a href="http://anjuta.org">Link</a></td>
</tr>
<tr>
<td>KDevelop</td>
<td><a href="https://en.wikipedia.org/wiki/KDevelop">Link</a></td>
</tr>
<tr>
<td>Little C Compiler (LCC)</td>
<td><a href="https://en.wikipedia.org/wiki/LCC%20%28compiler%29">Link</a></td>
</tr>
<tr>
<td>Xcode</td>
<td><a href="https://en.wikipedia.org/wiki/Xcode">Link</a></td>
</tr>
<tr>
<td>Pelles C</td>
<td><a href="http://www.geany.org">Link</a></td>
</tr>
<tr>
<td>Dev-C++</td>
<td><a href="https://codelite.org/">Link</a></td>
</tr>
<tr>
<td>Microsoft Visual Studio Express</td>
<td><a href="https://en.wikipedia.org/wiki/Microsoft%20Visual%20Studio%20Express">Link</a></td>
</tr>
<tr>
<td>CodeLite</td>
<td><a href="https://en.wikipedia.org/wiki/CodeLite">Link</a></td>
</tr>
<tr>
<td>Code::Blocks</td>
<td><a href="http://orwelldevcpp.blogspot.com/">Link</a></td>
</tr>
</tbody>
</table>

On **GNU/Linux**, GCC is almost always included by default.

On **Microsoft Windows**, Dev-C++ is recommended for beginners because it is easy to use, free, and simple to install. Although the initial developer (Bloodshed) hasn’t updated it since 2005, a new version appeared in 2011, made by an independent programmer, and is being actively developed.\(^{69}\) An alternate option for those working only in the Windows environment is the proprietary Microsoft Visual Studio Express which is free of charge and has an excellent debugger.
On Mac OS X, the Xcode IDE provides the compilers needed to compile various source files. The newer versions do not include the command line tools. They need to be downloaded via Xcode->Preferences->Downloads.

### 3.2 Footnotes

pl:C/Czego potrzebujesz\(^70\)

\(^70\) https://pl.wikibooks.org/wiki/C%2FCzego%20potrzebujesz
4 Using a Compiler

4.0.1 Dev-C++

Dev C++\(^2\) is an Integrated Development Environment (IDE) for the C++ programming language, available from Bloodshed Software\(^3\). An updated version is available at Orwell Dev-C++\(^4\).

C++ is a programming language which contains within itself most of the C language, plus extensions. Most C++ compilers will compile C programs, sometimes with a few adjustments (like invoking them with a different name or command line switch). Therefore, you can use Dev C++ for C development.

However, Dev C++ is not the compiler. It is designed to use the MinGW\(^5\) or Cygwin\(^6\) versions of GCC\(^7\) - both of which can be obtained as part of the Dev C++ package, although they are completely different projects.

Dev C++ simply provides an editor, syntax highlighting, some facilities for the visualisation of code (like class and package browsing) and a graphical interface to the chosen compiler. Because Dev C++ analyses the error messages produced by the compiler and attempts to distinguish the line numbers from the errors themselves, the use of other compiler software is discouraged since the format of their error messages is likely to be different.

The latest version of Dev-C++ is a beta\(^8\) for version 5. However, it still has a significant number of bugs. All the features are there, and it is quite usable. It is considered one of the best free software C IDEs available for Windows.

A version of Dev C++ for Linux is in the pipeline. It is not quite usable yet, however. Linux users already have a wealth of IDEs available. (e.g. KDevelop\(^9\) and Anjuta\(^10\).) Most of the graphical text editors, and other common editors such as emacs and vim, support syntax highlighting\(^11\).

3 http://www.bloodshed.net/
4 http://orwelldevcpp.blogspot.com/
5 https://en.wikipedia.org/wiki/MinGW
6 https://en.wikipedia.org/wiki/Cygwin
7 https://en.wikipedia.org/wiki/GCC
8 https://en.wikipedia.org/wiki/beta%20version
9 https://en.wikipedia.org/wiki/KDevelop
10 https://en.wikipedia.org/wiki/Anjuta
4.0.2 GCC

The GNU Compiler Collection\textsuperscript{12} (GCC) is a free/libre\textsuperscript{13} set of compilers developed by the Free Software Foundation\textsuperscript{14}.

Steps for Obtaining the GCC Compiler if You're on GNU/Linux

On GNU/Linux, Installing the GNU C Compiler can vary in method from distribution\textsuperscript{15} to distribution. (Type in \texttt{cc -v} to see if it is installed already.)

- For Ubuntu\textsuperscript{16}, install the GCC compiler (along with other necessary tools) by using \texttt{sudo apt-get install build-essential}, or by using Synaptic. You do not need Universe enabled.
- For Debian\textsuperscript{18}, install the GCC compiler (as root) by using \texttt{apt-get install gcc}.
- For Fedora Core\textsuperscript{20}, install the GCC compiler (as root) by using \texttt{yum install gcc}.
- For Redhat\textsuperscript{22}, get a GCC RPM\textsuperscript{23}, e.g. using Rpmfind and then install (as root) using \texttt{rpm -ivh gcc-version-release.arch.rpm}
- For Mandrake\textsuperscript{24}, install the GCC compiler (as root) by using \texttt{urpmi gcc}
- For Slackware\textsuperscript{26}, the package is available on their website\textsuperscript{27} - simply download, and type \texttt{installpkg gcc-xxxxx.tgz}
- For Gentoo\textsuperscript{28}, you should already have GCC installed as it will have been used when you first installed. To update it run (as root) \texttt{emerge -uav gcc}.
- For Arch Linux\textsuperscript{29}, install the GCC compiler (as root) by using \texttt{pacman -S gcc}.
- If you cannot become root, get the GCC tarball from \texttt{ftp://ftp.gnu.org/} and follow the instructions in it to compile and install in your home directory. Be warned though, you need a C compiler to do that - yes, GCC itself is written in C.
- You can use some commercial C compiler/IDE.

Steps for Obtaining the GCC Compiler if You're on BSD Family Systems

\begin{itemize}
  \item \texttt{https://en.wikipedia.org/wiki/GNU%20Compiler%20Collection}
  \item \texttt{https://en.wikipedia.org/wiki/free%20software}
  \item \texttt{https://en.wikipedia.org/wiki/Free%20Software%20Foundation}
  \item \texttt{https://en.wikipedia.org/wiki/Linux%20distribution}
  \item \texttt{https://en.wikipedia.org/wiki/Ubuntu}
  \item \texttt{https://en.wikipedia.org/wiki/Advanced%20Packaging%20Tool}
  \item \texttt{https://en.wikipedia.org/wiki/Debian}
  \item \texttt{https://en.wikipedia.org/wiki/Advanced%20Packaging%20Tool}
  \item \texttt{https://en.wikipedia.org/wiki/Fedora%20Core}
  \item \texttt{https://en.wikipedia.org/wiki/yum}
  \item \texttt{https://en.wikipedia.org/wiki/Redhat}
  \item \texttt{https://en.wikipedia.org/wiki/RPM%20Package%20Manager}
  \item \texttt{https://en.wikipedia.org/wiki/Mandrake}
  \item \texttt{https://en.wikipedia.org/wiki/urpmi}
  \item \texttt{https://en.wikipedia.org/wiki/Slackware}
  \item \texttt{http://www.slackware.com/pb/}
  \item \texttt{https://en.wikipedia.org/wiki/Gentoo}
  \item \texttt{https://en.wikipedia.org/wiki/Arch%20Linux}
\end{itemize}
For Mac OS X\textsuperscript{30}, FreeBSD\textsuperscript{31}, NetBSD\textsuperscript{32}, OpenBSD\textsuperscript{33}, DragonFly BSD\textsuperscript{34}, Darwin\textsuperscript{35} the port of GNU gcc is available in the base system, or it could be obtained using the ports collection or pkgsrc\textsuperscript{36}.

**Steps for Obtaining the GCC Compiler if You're on Windows**

There are two ways to use GCC on Windows: Cygwin and MinGW. Applications compiled with Cygwin will not run on any computer without Cygwin, so MinGW is recommended. MinGW is simpler to install, and takes less disk space.

To get MinGW, do this:

1. Go to http://sourceforge.net/projects/mingw/ download and save this to your hard drive.
2. Once the download is finished, open it and follow the instructions. You can also choose to install additional compilers, or the tool Make, but these aren't necessary.
3. Now you need to set your PATH. Right-click on "My computer" and click "Properties". Go to the "Advanced" tab and click on "Environment variables". Go to the "System variables" section and scroll down until you see "Path". Click on it, then click "edit". Add ";C:\mingw\bin;" (without the quotes) to the end.
4. To test if GCC works, open a command prompt and type "gcc". You should get the message "gcc: fatal error: no input files compilation terminated.". If you get this message, GCC is installed correctly.

To get Cygwin, do this:

1. Go to http://www.cygwin.com and click on the "Install Cygwin Now" button in the upper right corner of the page.
2. Click "run" in the window that pops up, and click "next" several times, accepting all the default settings.
3. Choose any of the Download sites ("ftp.easynet.be", etc.) when that window comes up; press "next" and the Cygwin installer should start downloading.
4. When the "Select Packages" window appears, scroll down to the heading "Devel" and click on the "+" by it. In the list of packages that now displays, scroll down and find the "gcc-core" package; this is the compiler. Click once on the word "Skip", and it should change to some number like "3.4" etc. (the version number), and an "X" will appear next to "gcc-core" and several other related packages that will now be downloaded.
5. Click "next" and the compiler as well as the Cygwin tools should start downloading; this could take a while. While you're waiting for the installation to finish, download any text-editor designed for programming. While Cygwin does include some, you may prefer doing a web search to find other alternatives. While using a stock text editor is possible, it is not ideal.

\begin{footnotes}
\footnote{https://en.wikipedia.org/wiki/Mac\%20OS\%20X}
\footnote{https://en.wikipedia.org/wiki/FreeBSD}
\footnote{https://en.wikipedia.org/wiki/NetBSD}
\footnote{https://en.wikipedia.org/wiki/OpenBSD}
\footnote{https://en.wikipedia.org/wiki/DragonFly\%20BSD}
\footnote{https://en.wikipedia.org/wiki/Darwin}
\footnote{https://en.wikipedia.org/wiki/pkgsrc}
\end{footnotes}
6. Once the Cygwin downloads are finished and you have clicked "next", etc. to finish the installation, double-click the Cygwin icon on your desktop to begin the Cygwin "command prompt". Your home directory will automatically be set up in the Cygwin folder, which now should be at "C:\cygwin" (the Cygwin folder is in some ways like a small unix/linux computer on your Windows machine -- not technically of course, but it may be helpful to think of it that way).

7. Type "gcc" at the Cygwin prompt and press "enter"; if "gcc: no input files" or something like it appears you have succeeded and now have the gcc compiler on your computer (and congratulations -- you have also just received your first error message!).

The current stable (usable) version of GCC is 4.9.1 published on 2014-07-16, which supports several platforms. In fact, GCC is not only a C compiler, but a family of compilers for several languages, such as C++, Ada\(^{37}\), Java\(^{38}\), and Fortran\(^{39}\).

### 4.0.3 Embedded systems

- Most CPUs are microcontrollers in embedded systems, often programmed in C, but most of the compilers mentioned above (except GCC) do not support such CPUs. For specialized compilers that do support embedded systems, see Embedded Systems/C Programming\(^{40}\).

### 4.0.4 Other C compilers

We have a long list of C compilers\(^{41}\) in a much later section of this Wikibook. *Which of those compilers would be suitable for beginning C programmers, that we should say a few words about getting started with that particular compiler in this section of this Wikibook?*

pl:C/Używanie kompilatora\(^{42}\)

---

38 https://en.wikibooks.org/wiki/Java
39 https://en.wikibooks.org/wiki/Fortran
42 https://pl.wikibooks.org/wiki/C%2FU%C5%BCywanie%20kompilatora
5 Beginning C
6 Intro exercise

6.1 The "Hello, World!" Program

Tradition dictates that we begin with a very simple program, which simply displays the characters "Hello, World!" on the screen and immediately exits. Type the following source code in your preferred text editor/IDE and save this in a file named hello.c.

```
#include <stdio.h>

int main(void)
{
    printf("Hello, World!\n");
    return 0;
}
```

6.1.1 Source code analysis

Below are described the parts the program is composed of. The various details will be introduced and explained in later chapters.

```
#include <stdio.h>

int main(void)
{
    printf("Hello World!\n");
    return 0;
}
```

This is a preprocessor directive. Preprocessor directives instruct a part of the compiler - the preprocessor - to modify the code we've written before it is compiled. In this case, the `#include` directive is retrieving C code from the standard `stdio.h` file. Files used in this way are called header files and are saved with the `.h` extension. In this program, the only part we needed from stdio.h is the `printf` function.

```
int main(void)
{
    printf("Hello World!\n");
}
```

The function named `main` is the starting point of all C programs. In computer science, the term function tends to be used a bit more loosely than in mathematics, since functions often express imperative ideas (as in the case of C) - that is, how-to processes instead of declarations. For now, it suffices to say that functions let us define a complex process that we want to reference frequently.

```
printf("Hello World!\n");
```

This line is of particular interest, because it produces the actual output on the console (also known as the terminal in the context of Unix-like operating systems), a traditional text-based interface to system utilities and programs.

```
return 0;
```

Finally, we consider this line. When terminating our program, it is useful to be able to let the operating system know whether or not the program succeeded. We do this with an exit status, which we send to the operating system with a `return` statement in the
Intro exercise

main function. In this case, we provide an exit status of 0 to indicate that execution succeeded without error. As our programs grow in complexity, we can use other integers as codes to indicate various types of errors. This style of providing exit statuses is a long standing convention\(^1\).

6.1.2 Compiling

Unix-like

If you are using a Unix(-like) system, such as GNU/Linux\(^2\), Mac OS X\(^3\), or Solaris\(^4\), it will probably have GCC installed. Open the virtual console or a terminal emulator and enter the following:

```
gcc hello.c
```

Then run the program by typing:

```
./a.out
```

You should see Hello, World! printed after the last prompt.

To see the exit status of the last program you ran, type:

```
echo $?
```

This shows the value the main function has returned, which is 0 in the above example.

There are a lot of options you can use with the gcc compiler. For example, if you want the output to have a name other than a.out, you can use the -o option. The following shows a few examples:

-\(^{-}o\)

indicates that the next parameter is the name of the resulting program (or library). If this option is not specified, the compiled program will, for historic reasons, end up in a file called "a.out" or "a.exe" (for cygwin users).

-\(^{-}Wall\)

indicates that gcc should warn about many types of suspicious code that are likely to be incorrect.

You can use these options to create a program called "helloworld" instead of "a.out" by typing:

\(^1\) https://www.gnu.org/software/libc/manual/html_node/Exit-Status.html
\(^2\) https://en.wikipedia.org/wiki/GNU%2FLinux
\(^3\) https://en.wikipedia.org/wiki/Mac%20OS%20X
\(^4\) https://en.wikipedia.org/wiki/Solaris%20Operating%20Environment
gcc -o helloworld hello.c -Wall

Now you can run it by typing:

./helloworld

All the options are well documented in the manual\textsuperscript{5} for GCC.

**On IDEs**

If you are using an IDE you may have to select console project, and to compile you just select build from the menu or the toolbar. The executable will appear inside the project folder, but you should have a menu button so you can just run the executable from the IDE. The process is roughly the same on all IDEs.

### 6.2 References

\textsuperscript{5} [https://gcc.gnu.org/onlinedocs/](https://gcc.gnu.org/onlinedocs/)
7 Preliminaries

Before learning C syntax and programming constructs, it is important to learn the meaning of a few key terms that are central in understanding C.

7.1 Block Structure, Statements, Whitespace, and Scope

Note:
Sentences delimited with '/*' and '*/' are comments, and the compiler ignores them. They are described in Programming Structure and Style.

Now we are about to discuss the basic structure of a C program. If you're familiar with PASCAL¹, you may have heard it referred to as a block-structured language. C does not have complete block structure (and you'll find out why when you go over functions in detail) but it is still very important to understand what blocks are and how to use them.

So what is in a block? Generally, a block consists of executable statements.

Before blocks are explained, what is a statement? One way to put it is that statements are the text the compiler will attempt to turn into executable instructions, and the whitespace that surrounds them. An easier way to put it is that statements are bits of code that do things, like this:

```c
int i = 6;
```

This declares a variable of type integer, initializes it to the value 6, which can be later accessed with the identifier 'i'. The various data types are introduced in the chapter Variables².

You might have noticed the semicolon at the end of the statement. Statements in C always end with a semicolon (;) character. Leaving off the semicolon is a common mistake that a lot of people make, beginners and experts alike! So until it becomes second nature, be sure to double check your statements!

Since C is a "free-format" language, several statements can share a single line in the source file, like so:

```c
/* this declares the variables 'i', 'test', 'foo', and 'bar'
   note that ONLY 'bar' is set to six! */
int i, test, foo, bar = 6;
```

¹ https://en.wikipedia.org/wiki/Pascal%20%28programming%20language%29
² Chapter 10 on page 39
There are several kinds of statements, and you've seen some of them, such as the assignment (i = 6;). A substantial portion of this book deals with statement construction.

Now back to blocks. In C, blocks begin with an opening brace "{" and end with a closing brace "}". Blocks can contain other blocks which can contain their own blocks, and so on.

Let's show an example of blocks.

```c
int main(void)
{
    /* this is a 'block' */
    int i = 5;

    /* this is also a 'block', nested inside the outer block */
    int i = 6;
}
return 0;
}
```

You can use blocks with preceding statements, such as the main function declaration (and other statements to be taught), but you can also use blocks by themselves.

**Whitespace** refers to the tab, space and newline characters that separate the text characters that make up the source code. Like many things in life, it's hard to appreciate whitespace until it's gone. To a C compiler, the source code

```c
printf("Hello world"); return 0;
```

is the same as

```c
printf("Hello world");
return 0;
```

which is also the same as

```c
printf ( "Hello world" ) ;
return 0;
```

The compiler simply ignores most whitespace (except when it separates e.g. return from 0). However, it is common practice to use spaces (or tabs) to organize source code for human readability.

Most of the time we do not want other functions or other programmer's routines accessing data that we are currently manipulating. This is why it is important to understand the concept of scope.

**Scopes** describes the level at which a piece of data or a function is visible. There are two kinds of scopes in C, local and global. When we speak of something being global, we speak of something that can be seen or manipulated from anywhere in the program. When we speak of something being local, we speak of something that can be seen or manipulated only within the block it was declared.

Let’s show some examples, to give a better picture of the idea of scopes.

---

3 https://en.wikipedia.org/wiki/Subroutine
```c
int i = 5;  // this is a 'global' variable, it can be accessed from anywhere in
the program */

// this is a function, all variables inside of it
// are "local" to the function. */
int main(void)
{
    int i = 6;  // i' now equals 6 */
    printf("%d\n", i);  // prints a '6' to the screen, instead of the global
variable of 'i', which is 5 */

    return 0;
}
```

That shows a decent example of local and global, but what about different scopes inside of
functions? (you'll learn more about functions later, for now, just focus on the "main" part.)

```c
/* the main function */
int main(void)
{
    /* this is the beginning of a 'block', you read about those above */

    int i = 6;  // this is the first variable of this 'block', 'i' */

    {
        /* this is a new 'block', and because it's a different block, it has its
own scope */

        /* this is also a variable called 'i', but in a different 'block',
        because it's in a different 'block' than the old 'i', it doesn't
        affect the old one! */
        int i = 5;
        printf("%d\n", i);  // prints a '5' onto the screen */
    }  // now we're back into the old block */

    printf("%d\n", i);  // prints a '6' onto the screen */

    return 0;
}
```

### 7.2 Basics of Using Functions

**Functions** are a big part of programming. A function is a special kind of block that performs a well-defined task. If a function is well-designed, it can enable a programmer to perform a task without knowing anything about how the function works. The act of requesting a function to perform its task is called a **function call**. Many functions require a caller to hand it certain pieces of data needed to perform its task; these are called **arguments**. Many functions also return a value to the caller when they're finished; this is called a **return value** (the return value in the above program is 0).

The things you need to know before calling a function are:
- What the function does
- The data type (discussed later) of the arguments and what they mean
- The data type of the return value and what it means

Many functions use the return value to indicate whether they successfully completed their work. As you have
seen in the intro exercise, the **main** function uses the return value to provide an exit status to the operating system.

All code other than global data definitions and declarations needs to be a part of a function. Usually, you're free to call a function whatever you wish to. The only restriction is that every executable program needs to have one, and only one, **main** function, which is where the program begins executing.

We will discuss functions in more detail in a later chapter, C Programming/Procedures and functions\(^4\).

### 7.3 The Standard Library

In 1983, when C was in the process of becoming standardized, the American National Standards Institute\(^5\) (ANSI) formed a committee to establish a standard specification of C known as "ANSI C". That standard specification created a basic set of functions common to each implementation of C, which is referred to as the Standard Library\(^6\). The Standard Library provides functions for tasks such as input/output, string manipulation, mathematics, files, and memory allocation. The Standard Library does not provide functions that are dependent on specific hardware or operating systems, like graphics, sound, or networking. In the "Hello, World" program, a Standard Library function is used (**printf**) which outputs lines of text to the standard output\(^7\) stream.

### 7.4 References

pl:C/Podstawy\(^8\)

---

4 Chapter 16 on page 93
7 https://en.wikipedia.org/wiki/standard%20output
8 https://pl.wikibooks.org/wiki/C%2FPodstawy

26
8 Compiling

Having covered the basic concepts of C programming, we can now briefly discuss the process of compilation.

Like any programming language, C by itself is completely incomprehensible to a microprocessor\(^1\). Its purpose is to provide an intuitive way for humans to provide instructions that can be easily converted into machine code that is comprehensible to a microprocessor. The compiler is what takes this code, and translates it into the machine code.

To those new to programming, this seems fairly simple. A naive compiler might read in every source file, translate everything into machine code, and write out an executable. This could work, but has two serious problems. First, for a large project, the computer may not have enough memory to read all of the source code at once. Second, if you make a change to a single source file, you would rather not have to recompile the entire application.

To deal with these problems, compilers break their job down into steps; for each source file (each .c file), the compiler reads the file, reads the files it references with #include, and translates it to machine code. The result of this is an "object file" (.o). Once every object file is made, a "linker" collects all of the object files and writes the actual program. This way, if you change one source file, only that file needs to be recompiled and then the application needs to be re-linked.

Without going into the painful details, it can be beneficial to have a superficial understanding of the compilation process.

8.1 Preprocessor

The preprocessor provides the ability for the inclusion of header files, macro expansions, conditional compilation, and line control. Many times you will need to give special instructions to your compiler. This is done by inserting preprocessor directives\(^2\) into your code. When you begin compiling your code, a special program called the preprocessor scans the source code and performs simple substitution of tokenized strings for others according to predefined rules. The C preprocessor is not a part of the C language.

All preprocessor directives begin with the hash character (\#). You can see one preprocessor directive in the Hello world program\(^3\). Example:

```c
#include <stdio.h>
```

---

\(^1\) [https://en.wikipedia.org/wiki/microprocessor](https://en.wikipedia.org/wiki/microprocessor)

\(^2\) [https://en.wikipedia.org/wiki/Preprocessor%20directives](https://en.wikipedia.org/wiki/Preprocessor%20directives)

\(^3\) [https://en.wikibooks.org/wiki/Hello%20world%20program](https://en.wikibooks.org/wiki/Hello%20world%20program)
This directive causes the header to be included into your program. Other directives such as \texttt{#pragma} control compiler settings and macros. The result of the preprocessing stage is a text string. You can think of the preprocessor as a non-interactive text editor that prepares your code for the compilation step. The language of preprocessor directives is agnostic to the grammar of C, so the C preprocessor can also be used independently to process other kinds of text files.

### 8.2 Syntax Checking

This step ensures that the code is valid and will sequence into an executable program. Under most compilers, you may get messages or warnings indicating potential issues with your program (such as a conditional statement\(^4\) always being true or false, etc.)

When an error is detected in the program, the compiler will normally report the file name and line that is preventing compilation.

### 8.3 Object Code

The compiler produces a machine code equivalent of the source code that can then be linked into the final program. The code itself can't be executed yet, as it has to complete the linking stage.

It's important to note after discussing the basics that compilation is a "one way street". That is, compiling a C source file into machine code is easy, but "decompiling" (turning machine code into the C source that creates it) is not. Decompilers for C do exist, but the code they create is hard to understand and only useful for reverse engineering\(^5\).

### 8.4 Linking

Linking combines the separate object codes into one complete program by integrating libraries and the code and producing either an executable program\(^6\) or a library\(^7\). Linking is performed by a linker, which is often part of a compiler.

Common errors during this stage are either missing functions, or duplicate functions.

\(^7\) [https://en.wikipedia.org/wiki/Library%20%28computing%29](https://en.wikipedia.org/wiki/Library%20%28computing%29)
8.5 Automation

For large C projects, many programmers choose to automate compilation, both in order to reduce user interaction requirements and to speed up the process by only recompiling modified files.

Most integrated development environments have some kind of project management, which makes such automation very easy. However, the project management files are often only usable for users of the same integrated development environment, so all developers would need to use the same IDE.

On UNIX-like systems, make\(^8\) and Makefiles are often used to accomplish the same. make is traditional and flexible and is available as one of the standard developer tools on most Unix and GNU distributions.

Makefiles have been extended by the GNU Autotools\(^9\), composed of Automake\(^10\) and Autoconf\(^11\) for making software compilable, testable, translatable and configurable on many different kinds of machines. Automake and Autoconf are described in detail in their respective manuals.

The Autotools are often perceived to be complicated and various simpler build systems have been developed. Many components of the GNOME project\(^12\) now use the declarative Meson build system\(^13\) which is less flexible but instead focuses on providing the features most commonly needed from a build system in a simple way. Other popular build systems for programs written in the C language include CMake\(^14\) and Waf\(^15\).

Once gcc is installed, it can be called with a list of c source files that have been written but not yet compiled. eg. there is a main.c file that includes some functions described in myfun.h and implemented in myfun_a.c and myfun_b.c, then it is enough to write

```
gcc main.c myfun_a.c myfun_b.c
```

myfun.h is included in main.c, but if is in a separate header files directory, then that directory can be listed after a "-I" switch.

In larger programs, Makefiles and gnu make program can compile c files into intermediate files ending with suffix .o which can be linked by gcc.

How to compile each object file is usually described in the Makefile with the object file as a label ending with a colon followed by two spaces (tabs are often bad characters) followed by a list of other files that are dependencies, eg. .c files and .o files compiled in another section, and on the next line, the invocation of gcc that is required. typing `man make` or

---

8 https://en.wikibooks.org/wiki/make
9 https://en.wikipedia.org/wiki/GNU_Build_System
10 https://www.gnu.org/software/automake/
11 https://www.gnu.org/software/autoconf/
12 https://en.wikipedia.org/wiki/GNOME
13 http://mesonbuild.com/
14 https://cmake.org/
15 https://waf.io/
Compiling

info make often gives the information needed to jog the memory on how to use make, and the same goes for gcc, although gcc has a lot of option switches, the main ones being -g to generate debugging for gdb to allow it to show source code during stepping through of the machine code program. gdb has a 'h' command that shows what it can do, and is usually started with 'gdb a.out' if a.out is the anonymous executable machine code file that was compiled by gcc.


8.6 References

16 https://de.wikibooks.org/wiki/C-Programmierung%3A%20Kompilierung
17 https://es.wikibooks.org/wiki/Programaci%C3%B3n_en_C/Compilar_un_programa
18 https://et.wikibooks.org/wiki/Programmeerimiskeel%20C/Kompileerimine
19 https://fr.wikibooks.org/wiki/Programmation%20C-C%252B%252B/Modularit%C3%A9%20et%20compilation
20 https://it.wikibooks.org/wiki/C%2FCompilatore%20e%20precompilatore%2FCCompilatore
21 https://pt.wikibooks.org/wiki/Programar%20em%20C%2FUtilizando%20um%20compilador
9 Structure and style

9.1 C Structure and Style

This is a basic introduction to a good code style in the C Programming Language. It is designed to provide information on how to effectively use indentation, comments, and other elements that will make your C code more readable. It is not a tutorial on actually programming in C.

As a beginning programmer, the point of creating structure in the programs' code might not be clear, as the compiler doesn't care about the difference. However, as programs become complex, chances are that writing the program has become a joint effort. (Or others might want to see how it was accomplished. Or you may have to read it again years later.) Well-written code also helps you get an overview of what the code does. Therefore, the code is no longer designed purely for a compiler to read.

In the following sections, we will attempt to explain good programming practices that will in turn make your programs clearer.

9.2 Introduction

In C, programs are composed of statements. These statements are terminated with a semicolon, and are collected in sections known as functions. By convention, a statement should be kept on its own line, as shown in the example below:

```c
#include <stdio.h>

int main(void) {
    printf("Hello, World!\n");
    return 0;
}
```

The following block of code is essentially the same: while it contains exactly the same code, and will compile and execute with the same result, the removal of spacing causes an essential difference, making it harder to read:

```c
#include <stdio.h>
int main(void) { printf("Hello, World!\n"); return 0;}
```

The simple use of indents and line breaks can greatly improve the readability of the code; without making any impact whatsoever on how the code performs. By having readable code, it is much easier to see where functions and procedures end, and which lines are part of which loops and procedures.

This lesson is going to focus on improving the coding style of an example piece of code which applies a formula and prints the result. You will later see how to write code for such
tasks in more detail, but for now you should focus on how the code looks and not on what
it does.

9.3 Line Breaks and Indentation

The addition of white space inside your code is arguably the most important part of good
code structure. Effective use of white space can create a visual scale of how your code flows,
which can be very important when returning to your code when you want to maintain it.

9.3.1 Line Breaks

⚠️ **Warning**

Note that we have used line numbers here; they are not a part of the actual code.
They are only there for reference in this book.

With minimal line breaks, code is barely readable by humans, and may be hard to debug
or understand:

```c
1 #include <stdio.h>
2 int main(void) { int revenue = 80; int cost = 50; int roi; roi = (100 * (revenue
3 - cost)) / cost; if (roi >= 0) { printf ("%d\n", roi); } return 0; }
```

Rather than putting everything on one line, it is much more readable to break up long lines
so that each statement and declaration goes on its own line. After inserting line breaks, the
code will look like this:

```c
1 #include <stdio.h>
2 int main(void) {
3 int revenue = 80;
4 int cost = 50;
5 int roi;
6 roi = (100 * (revenue - cost)) / cost;
7 if (roi >= 0) {
8 printf ("%d\n", roi);
9 }
10 return 0;
11 }
```

9.3.2 Blank Lines

Blank lines should be used to offset the main components of your code. Always use them

- After precompiler declarations.
- After new variables are declared.
- Use your own judgment for finding other places where components should be separated.

Based on these two rules, there should now be at least two line breaks added.

- After line 1, because line 1 has a preprocessor directive.
- After line 5, because line 5 contains a variable declaration.
This will make the code much more readable than it was before:

The following lines of code have line breaks between functions, but without indentation.

```
#include <stdio.h>
int main(void) {
  int revenue = 80;
  int cost = 50;
  int roi;
  roi = (100 * (revenue - cost)) / cost;
  if (roi >= 0) {
    printf("%d\n", roi);
  }
  return 0;
}
```

But this still isn't as readable as it can be.

### 9.3.3 Indentation

**Note:**
Many text editors automatically indent appropriately when you hit the enter/return key.

Although adding simple line breaks between key blocks of code can make code easier to read, it provides no information about the block structure of the program. Using the tab key can be very helpful now: indentation visually separates paths of execution by moving their starting points to a new column in the line. This simple practice will make it much easier to read and understand code. Indentation follows a fairly simple rule:

- All code inside a new block should be indented by one tab

Based on the code from the previous section, there are two blocks requiring indentation:

- Lines 4 to 16
- Line 13

```
#include <stdio.h>
int main(void) {
  int revenue = 80;
  ...
}
```


Regardless of whether you prefer spaces or tabs, make sure you keep it consistent within projects you are working on, because mixing tabs and spaces can cause code to become unreadable.
int cost = 50;
int roi;
roi = (100 * (revenue - cost)) / cost;
if (roi >= 0) {
    printf("%d\n", roi);
}
return 0;

It is now fairly obvious as to which parts of the program fit inside which blocks. You can tell which parts of the program the coder has intended to be conditional, and which ones he or she has not. Although it might not be immediately noticeable, once many nested paths get added to the structure of the program, the use of indentation can be very important. This indentation makes the structure of your program clear.

It is claimed that research has shown that an indentation size between 2 to 4 characters is easier to read than 8 character indents. However, an indent of 8 characters may still be in use for some systems.

### 9.4 Comments

Comments in code can be useful for a variety of purposes. They provide the easiest way to set off specific parts of code (and their purpose); as well as providing a visual "split" between various parts of your code. Having good comments throughout your code will make it much easier to remember what specific parts of your code do.

Comments in modern flavors of C (and many other languages) can come in two forms:

```c
// Single Line Comments (added by C99 standard, famously known as c++ style of comments)

and

/* Multi-Line Comments (only form of comments supported by C89 standard) */
```

Note that Single line comments are a more recent addition to C, so some compilers may not support them. A recent version of GCC will have no problems supporting them.

This section is going to focus on the various uses of each form of commentary.

### 9.4.1 Single-line Comments

Single-line comments are most useful for simple 'side' notes that explain what certain parts of the code do. The best places to put these comments are next to variable declarations, and next to pieces of code that may need explanation. Comments should make clear the

---

3 http://www.oualline.com/vim/vim-cook.html#drawing Vim cookbook
5 https://en.wikipedia.org/wiki/GNU%20Compiler%20Collection
intention and ideas behind the corresponding code. What is immediately obvious from reading the code does not belong in a comment.

Based on our previous program, there are various good places to place comments

- Line 5 and/or 6, to explain what 'int revenue' and 'int cost' represent,
- Line 8, to explain what the variable 'roi' is going to be used for,
- Line 10, to explain the idea of the calculation,
- Line 12, to explain the purpose of the 'if'.

This will make our program look something like

```c
#include <stdio.h>

int main(void) {
    int revenue = 80; // as of 2016
    int cost = 50;
    int roi; // return on investment in percent
    roi = (100 * (revenue - cost)) / cost; // formula from accounting book
    if (roi >= 0) {
        printf("%d
", roi);
    }
    return 0;
}
```

### 9.4.2 Multi-line Comments

**Note:**

Single-line comments are a new feature, so many C programmers only use multi-line comments.

Multi-line comments are most useful for long explanations of code. They can be used as copyright/licensing notices, and they can also be used to explain the purpose of a block of code. This can be useful for two reasons: They make your functions easier to understand, and they make it easier to spot errors in code. If you know what a block is *supposed* to do, then it is much easier to find the piece of code that is responsible if an error occurs.

As an example, suppose we had a program that was designed to print "Hello, World! " a certain number of lines, a specified number of times. There would be many for loops in this program. For this example, we shall call the number of lines $i$, and the number of strings per line as $j$.

A good example of a multi-line comment that describes 'for' loop *is purpose would be:*

```c
/* For Loop (int i)
    Loops the following procedure $i$ times (for number of lines). Performs 'for'
    loop $j$ on each loop,
    and prints a new line at end of each loop.
*/
```

This provides a good explanation of what *is purpose is, whilst not going into detail of what $j$ does. By going into detail over what the specific path does (and not ones inside it), it will be easier to troubleshoot the path.*
Similarly, you should always include a multi-line comment before each function, to explain the role, preconditions and postconditions of each function. Always leave the technical details to the individual blocks inside your program - this makes it easier to troubleshoot.

A function descriptor should look something like:

```c
/* Function : int hworld (int i, int j)
   Input : int i (Number of lines), int j (Number of instances per line)
   Output : 0 (on success)
   Procedure: Prints "Hello, World!" j times, and a new line to standard output
             over i lines.
   */
```

This system allows for an at-a-glance explanation of what the function should do. You can then go into detail over how each aspect of the program is achieved later on in the program.

Finally, if you like to have aesthetically-pleasing source code, the multi-line comment system allows for the easy addition of comment boxes. These make the comments stand out much more than they would without otherwise. They look like this.

```c
/*****************************/
* This is a multi line comment
* That is nearly surrounded by a
* Cool, starry border!
******************************/
```

Applied to our original program, we can now include a much more descriptive and readable source code:

```c
#include <stdio.h>

int main(void)
{  
   /*********
   * Function: int main(void)
   * Input : none
   * Output : Returns 0 on success
   * Procedure: Prints 2016's return on investment in percent if it is not
               negative.
   *********
   
   int revenue = 80;     // as of 2016
   int cost = 50;

   int roi;              // return on investment in percent
   roi = (100 * (revenue - cost)) / cost;  // formula from accounting book
   if (roi >= 0) {        // we don't care about negative roi
      printf ("%d", roi);
   }
   return 0;
}
```

This will allow any outside users of the program an easy way to comprehend what the code functions are and how they operate. It also inhibits uncertainty with other like-named functions.

A few programmers add a column of stars on the right side of a block comment:

```c
/*****************************/
* This is a multi line comment
* that is completely surrounded by a *
******************************/
But most programmers don't put any stars on the right side of a block comment. They feel that aligning the right side is a waste of time.

Comments written in source files can be used for documenting source code automatically by using popular tools like Doxygen.6

9.5 References

• Aladdin's C coding guidelines8 - A more definitive C coding guideline.
• C/C++ Programming Styles9 GNU Coding styles & Linux Kernel Coding style
et:Programmeerimiskeel C/Stiil10

6 "Coding Conventions for C++ and Java" [http://www.macadamian.com/index.php?option=com_content&task=view&id=34&Itemid=37] "all the block comments illustrated in this document have no pretty stars on the right side of the block comment. This deliberate choice was made because aligning those pretty stars is a large waste of time and discourages the maintenance of in-line comments,"


8 http://www.cs.wisc.edu/~ghost/doc/AFPL/6.01/C-style.htm
9 http://www.mycplus.com/category/tutorials/programming-styles/
10 https://et.wikibooks.org/wiki/Programmeerimiskeel%20C%20Stiil
10 Variables

Like most programming languages, C is able to use and process named variables and their contents. Variables are simply names used to refer to some location in memory – a location that holds a value with which we are working.

It may help to think of variables as a placeholder for a value. You can think of a variable as being equivalent to its assigned value. So, if you have a variable \( i \) that is initialized (set equal) to 4, then it follows that \( i + 1 \) will equal 5.

Since C is a relatively low-level programming language, before a C program can utilize memory to store a variable it must claim the memory needed to store the values for a variable. This is done by declaring variables. Declaring variables is the way in which a C program shows the number of variables it needs, what they are going to be named, and how much memory they will need.

Within the C programming language, when managing and working with variables, it is important to know the type of variables and the size of these types. A type’s size is the amount of computer memory required to store one value of this type. Since C is a fairly low-level programming language, the size of types can be specific to the hardware and compiler used – that is, how the language is made to work on one type of machine can be different from how it is made to work on another.

All variables in C are typed. That is, every variable declared must be assigned as a certain type of variable.

10.1 Declaring, Initializing, and Assigning Variables

Here is an example of declaring an integer, which we've called `some_number`. (Note the semicolon at the end of the line; that is how your compiler separates one program statement from another.)

```c
int some_number;
```

This statement means we're declaring some space for a variable called `some_number`, which will be used to store integer data. Note that we must specify the type of data that a variable will store. There are specific keywords to do this – we'll look at them in the next section.

Multiple variables can be declared with one statement, like this:

```c
int anumber, anothernumber, yetanothernumber;
```

We can also declare and assign some content to a variable at the same time.

```c
int some_number = 3;
```
This is called initialization.

In early versions of C, variables had to be declared at the beginning of a block. In C99 it is allowed to mix declarations and statements arbitrarily – but doing so is not usual, because it is rarely necessary, some compilers still don’t support C99 (portability), and it may, because it is uncommon yet, irritate fellow programmers (maintainability).

After declaring variables, you can assign a value to a variable later on using a statement like this:

```c
some_number = 3;
```

You can also assign a variable the value of another variable, like so:

```c
anumber = anothernumber;
```

Or assign multiple variables the same value with one statement:

```c
anumber = anothernumber = yetanothernumber = 3;
```

This is because the assignment `x = y` returns the value of the assignment. `x = y = z` is really shorthand for `x = (y = z)`.

### 10.1.1 Naming Variables

Variable names in C are made up of letters (upper and lower case) and digits. The underscore character ("_") is also permitted. Names must not begin with a digit. Unlike some languages (such as Perl\(^1\) and some BASIC\(^2\) dialects), C does not use any special prefix characters on variable names.

Some examples of valid (but not very descriptive) C variable names:

- `foo`
- `Bar`
- `BAZ`
- `foo_bar`
- `_foo42`
- `_QuX`

Some examples of invalid C variable names:

- `2foo` (must not begin with a digit)
- `my foo` (spaces not allowed in names)
- `$foo` ($ not allowed -- only letters, and `_`)
- `while` (language keywords cannot be used as names)

As the last example suggests, certain words are reserved as keywords in the language, and these cannot be used as variable names.

It is not allowed to use the same name for multiple variables in the same scope\(^3\). When working with other developers, you should therefore take steps to avoid using the same name.

---

3. Chapter 7 on page 23
for global variables or function names. Some large projects adhere to naming guidelines\(^4\) to avoid duplicate names and for consistency.

In addition there are certain sets of names that, while not language keywords, are reserved for one reason or another. For example, a C compiler might use certain names "behind the scenes", and this might cause problems for a program that attempts to use them. Also, some names are reserved for possible future use in the C standard library. The rules for determining exactly what names are reserved (and in what contexts they are reserved) are too complicated to describe here, and as a beginner you don’t need to worry about them much anyway. For now, just avoid using names that begin with an underscore character.

The naming rules for C variables also apply to naming other language constructs such as function names, struct tags, and macros, all of which will be covered later.

### 10.2 Literals

Anytime within a program in which you specify a value explicitly instead of referring to a variable or some other form of data, that value is referred to as a literal. In the initialization example above, 3 is a literal. Literals can either take a form defined by their type (more on that soon), or one can use hexadecimal (hex) notation to directly insert data into a variable regardless of its type. Hex numbers are always preceded with \(0x\). For now, though, you probably shouldn't be too concerned with hex.

### 10.3 The Four Basic Data Types

In Standard C there are four basic data types. They are int, char, float, and double.

We will briefly describe them here, then go into more detail in C Programming/Types\(^5\).

#### 10.3.1 The int type

The int type stores integers in the form of "whole numbers". An integer is typically the size of one machine word, which on most modern home PCs is 32 bits (4 octets). Examples of literals are whole numbers (integers) such as 1,2,3, 10, 100... When int is 32 bits (4 octets), it can store any whole number (integer) between -2147483648 and 2147483647. A 32 bit word (number) has the possibility of representing any one number out of 4294967296 possibilities (2 to the power of 32).

If you want to declare a new int variable, use the int keyword. For example:

```c
int numberOfStudents, i, j=5;
```

---

4 Examples of naming guidelines are those of the GNOME Project \(\{https://developer.gnome.org/programming-guidelines/stable/namespacing.html\}\) or the parts of the Python interpreter \(\{https://www.python.org/dev/peps/pep-0007/\}\) that are written in C.

5 https://en.wikibooks.org/wiki/C%20Programming%2FTypes
In this declaration we declare 3 variables, numberOfStudents, i and j, j here is assigned the literal 5.

10.3.2 The char type

The char type is capable of holding any member of the execution character set. It stores the same kind of data as an int (i.e. integers), but typically has a size of one byte. The size of a byte is specified by the macro CHAR_BIT which specifies the number of bits in a char (byte). In standard C it never can be less than 8 bits. A variable of type char is most often used to store character data, hence its name. Most implementations use the ASCII character set as the execution character set, but it’s best not to know or care about that unless the actual values are important.

Examples of character literals are 'a', 'b', '1', etc., as well as some special characters such as '\0' (the null character) and '\n' (newline, recall "Hello, World"). Note that the char value must be enclosed within single quotations.

When we initialize a character variable, we can do it two ways. One is preferred, the other way is bad programming practice.

The first way is to write

```c
char letter1 = 'a';
```

This is good programming practice in that it allows a person reading your code to understand that letter1 is being initialized with the letter 'a' to start off with.

The second way, which should not be used when you are coding letter characters, is to write

```c
char letter2 = 97; /* in ASCII, 97 = 'a' */
```

This is considered by some to be extremely bad practice, if we are using it to store a character, not a small number, in that if someone reads your code, most readers are forced to look up what character corresponds with the number 97 in the encoding scheme. In the end, letter1 and letter2 store both the same thing – the letter 'a', but the first method is clearer, easier to debug, and much more straightforward.

One important thing to mention is that characters for numerals are represented differently from their corresponding number, i.e. '1' is not equal to 1. In short, any single entry that is enclosed within 'single quotes'!

There is one more kind of literal that needs to be explained in connection with chars: the string literal. A string is a series of characters, usually intended to be displayed. They are surrounded by double quotations (" ", not ' '). An example of a string literal is the "Hello, World!\n" in the "Hello, World" example.

The string literal is assigned to a character array, arrays are described later. Example:

```c
const char MY_CONSTANT_PEDANTIC_ITCH[] = "learn the usage context.\n";
```

---

6 https://en.wikipedia.org/wiki/Character_encoding%23Character_sets.2C_maps_and_code_pages
7 https://en.wikipedia.org/wiki/ASCII
10.3.3 The float type

float is short for floating point. It stores inexact representations of real numbers, both integer and non-integer values. It can be used with numbers that are much greater than the greatest possible int. float literals must be suffixed with F or f. Examples are: 3.1415926f, 4.0f, 6.022e+23f.

It is important to note that floating-point numbers are inexact. Some numbers like 0.1f cannot be represented exactly as floats but will have a small error. Very large and very small numbers will have less precision and arithmetic operations are sometimes not associative or distributive because of a lack of precision. Nonetheless, floating-point numbers are most commonly used for approximating real numbers and operations on them are efficient on modern microprocessors.\(^8\) Floating-point arithmetic\(^9\) is explained in more detail on Wikipedia.

float variables can be declared using the float keyword. A float is only one machine word in size. Therefore, it is used when less precision than a double provides is required.

10.3.4 The double type

The double and float types are very similar. The float type allows you to store single-precision floating point numbers, while the double keyword allows you to store double-precision floating point numbers – real numbers, in other words. Its size is typically two machine words, or 8 bytes on most machines. Examples of double literals are 3.1415926535897932, 4.0, 6.022e+23 (scientific notation\(^{10}\)). If you use 4 instead of 4.0, the 4 will be interpreted as an int.

The distinction between floats and doubles was made because of the differing sizes of the two types. When C was first used, space was at a minimum and so the judicious use of a float instead of a double saved some memory. Nowadays, with memory more freely available, you rarely need to conserve memory like this – it may be better to use doubles consistently. Indeed, some C implementations use doubles instead of floats when you declare a float variable.

If you want to use a double variable, use the double keyword.

10.4 sizeof

If you have any doubts as to the amount of memory actually used by any variable (and this goes for types we'll discuss later, also), you can use the sizeof operator to find out for

---

\(^8\) Representations of real numbers other than floating-point numbers exist but are not fundamental data types in C. Some C compilers support fixed-point arithmetic \(^{\text{https://en.wikipedia.org/wiki/Fixed-point_arithmetic}}\) data types, but these are not part of standard C. Libraries such as the GNU Multiple Precision Arithmetic Library \(^{\text{https://en.wikipedia.org/wiki/GNU%20Multiple%20Precision%20Arithmetic%20Library}}\) offer more data types for real numbers and very large numbers.

\(^9\) \text{https://en.wikipedia.org/wiki/Floating-point%20arithmetic}

\(^{10}\) \text{https://en.wikipedia.org/wiki/Scientific%20notation}
sure. (For completeness, it is important to mention that `sizeof` is a unary operator\(^\text{11}\), not a function.) Its syntax is:

```c
sizeof object
sizeof(type)
```

The two expressions above return the size of the object and type specified, in bytes. The return type is `size_t` (defined in the header `<stddef.h>`) which is an unsigned value. Here’s an example usage:

```c
size_t size;
int i;
size = sizeof(i);
```

`size` will be set to 4, assuming `CHAR_BIT` is defined as 8, and an integer is 32 bits wide. The value of `sizeof`’s result is the number of bytes.

Note that when `sizeof` is applied to a `char`, the result is 1; that is:

```c
sizeof(char)
```

always returns 1.

### 10.5 Data type modifiers

One can alter the data storage of any data type by preceding it with certain modifiers. `long` and `short` are modifiers that make it possible for a data type to use either more or less memory. The `int` keyword need not follow the `short` and `long` keywords. This is most commonly the case. A `short` can be used where the values fall within a lesser range than that of an `int`, typically -32768 to 32767. A `long` can be used to contain an extended range of values. It is not guaranteed that a `short` uses less memory than an `int`, nor is it guaranteed that a `long` takes up more memory than an `int`. It is only guaranteed that `sizeof(short) <= sizeof(int) <= sizeof(long)`. Typically a `short` is 2 bytes, an `int` is 4 bytes, and a `long` either 4 or 8 bytes. Modern C compilers also provide `long long` which is typically an 8 byte integer.

In all of the types described above, one bit is used to indicate the sign (positive or negative) of a value. If you decide that a variable will never hold a negative value, you may use the `unsigned` modifier to use that one bit for storing other data, effectively doubling the range of values while mandating that those values be positive. The `unsigned` specifier also may be used without a trailing `int`, in which case the size defaults to that of an `int`. There is also a `signed` modifier which is the opposite, but it is not necessary, except for certain uses of `char`, and seldom used since all types (except `char`) are signed by default.

To use a modifier, just declare a variable with the data type and relevant modifiers:

```c
unsigned short int usi; /* fully qualified -- unsigned short int */
short st; /* short int */
unsigned long uli; /* unsigned long int */
```

10.6 const qualifier

When the `const` qualifier is used, the declared variable must be initialized at declaration. It is then not allowed to be changed.

While the idea of a variable that never changes may not seem useful, there are good reasons to use `const`. For one thing, many compilers can perform some small optimizations on data when it knows that data will never change. For example, if you need the value of $\pi$ in your calculations, you can declare a const variable of `pi`, so a program or another function written by someone else cannot change the value of `pi`.

Note that a Standard conforming compiler must issue a warning if an attempt is made to change a `const` variable - but after doing so the compiler is free to ignore the `const` qualifier.

10.7 Magic numbers

When you write C programs, you may be tempted to write code that will depend on certain numbers. For example, you may be writing a program for a grocery store. This complex program has thousands upon thousands of lines of code. The programmer decides to represent the cost of a can of corn, currently 99 cents, as a literal throughout the code. Now, assume the cost of a can of corn changes to 89 cents. The programmer must now go in and manually change each entry of 99 cents to 89. While this is not that big of a problem, considering the "global find-replace" function of many text editors, consider another problem: the cost of a can of green beans is also initially 99 cents. To reliably change the price, you have to look at every occurrence of the number 99.

C possesses certain functionality to avoid this. This functionality is approximately equivalent, though one method can be useful in one circumstance, over another.

10.7.1 Using the `const` keyword

The `const` keyword helps eradicate magic numbers. By declaring a variable `const corn` at the beginning of a block, a programmer can simply change that const and not have to worry about setting the value elsewhere.

There is also another method for avoiding magic numbers. It is much more flexible than `const`, and also much more problematic in many ways. It also involves the preprocessor, as opposed to the compiler. Behold...

10.7.2 `#define`

When you write programs, you can create what is known as a macro, so when the computer is reading your code, it will replace all instances of a word with the specified expression.

Here's an example. If you write

```
#define PRICE_OF_CORN 0.99
```
when you want to, for example, print the price of corn, you use the word
PRICE_OF_CORN instead of the number 0.99 – the preprocessor will replace all instances
of PRICE_OF_CORN with 0.99, which the compiler will interpret as the literal double 0.99.
The preprocessor performs substitution, that is, PRICE_OF_CORN is replaced by 0.99 so this
means there is no need for a semicolon.

It is important to note that #define has basically the same functionality as the "find-and-
replace" function in a lot of text editors/word processors.

For some purposes, #define can be harmfully used, and it is usually preferable to use
const if #define is unnecessary. It is possible, for instance, to #define, say, a macro DOG as
the number 3, but if you try to print the macro, thinking that DOG represents a string that
you can show on the screen, the program will have an error. #define also has no regard for
type. It disregards the structure of your program, replacing the text everywhere (in effect,
disregarding scope), which could be advantageous in some circumstances, but can be the
source of problematic bugs.

You will see further instances of the #define directive later in the text. It is good convention
to write #defined words in all capitals, so a programmer will know that this is not a variable
that you have declared but a #defined macro. It is not necessary to end a preprocessor
directive such as #define with a semicolon; in fact, some compilers may warn you about
unnecessary tokens in your code if you do.

10.8 Scope

In the Basic Concepts section, the concept of scope was introduced. It is important to
revisit the distinction between local types and global types, and how to declare variables of
each. To declare a local variable, you place the declaration at the beginning (i.e. before any
non-declarative statements) of the block to which the variable is intended to be local. To
declare a global variable, declare the variable outside of any block. If a variable is global,
it can be read, and written, from anywhere in your program.

Global variables are not considered good programming practice, and should be avoided
whenever possible. They inhibit code readability, create naming conflicts, waste memory,
and can create difficult-to-trace bugs. Excessive usage of globals is usually a sign of laziness
or poor design. However, if there is a situation where local variables may create more obtuse
and unreadable code, there's no shame in using globals.

10.9 Other Modifiers

Included here, for completeness, are more of the modifiers that standard C provides. For
the beginning programmer, static and extern may be useful. volatile is more of interest to
advanced programmers. register and auto are largely deprecated and are generally not of
interest to either beginning or advanced programmers.
10.9.1 static

**static** is sometimes a useful keyword. It is a common misbelief that the only purpose is to make a variable stay in memory.

When you declare a function or global variable as **static**, you cannot access the function or variable through the **extern** (see below) keyword from other files in your project. This is called **static linkage**.

When you declare a local variable as **static**, it is created just like any other variable. However, when the variable goes out of scope (i.e. the block it was local to is finished) the variable stays in memory, retaining its value. The variable stays in memory until the program ends. While this behaviour resembles that of global variables, static variables still obey scope rules and therefore cannot be accessed outside of their scope. This is called **static storage duration**.

Variables declared static are initialized to zero (or for pointers, **NULL**\(^{12}\)) by default. They can be initialized explicitly on declaration to any **constant** value. The initialization is made just once, at compile time.

You can use static in (at least) two different ways. Consider this code, and imagine it is in a file called jfile.c:

```c
#include <stdio.h>

static int j = 0;

void up(void)
{
    /* k is set to 0 when the program starts. The line is then "ignored"
     * for the rest of the program (i.e. k is not set to 0 every time up() is called)
     */
    static int k = 0;
    j++;
    k++;
    printf("up() called. k= %2d, j= %2d\n", k, j);
}

void down(void)
{
    static int k = 0;
    j--;
    k--;
    printf("down() called. k= %2d, j= %2d\n", k, j);
}

int main(void)
{
    int i;

    /* call the up function 3 times, then the down function 2 times */
    for (i = 0; i < 3; i++)
        up();
    for (i = 0; i < 2; i++)
        down();
}
```

\(^{12}\) [http://c-faq.com/null/macros.html](http://c-faq.com/null/macros.html) - What is **NULL** and how is it defined?
return 0;
}

The j variable is accessible by both up and down and retains its value. The k variables also retain their value, but they are two different variables, one in each of their scopes. Static variables are a good way to implement encapsulation, a term from the object-oriented way of thinking that effectively means not allowing changes to be made to a variable except through function calls.

Running the program above will produce the following output:

up() called. k= 1, j= 1
up() called. k= 2, j= 2
up() called. k= 3, j= 3
down() called. k= -1, j= 2
down() called. k= -2, j= 1

Features of static variables:

<table>
<thead>
<tr>
<th>Feature</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Keyword usage</td>
<td>static</td>
</tr>
<tr>
<td>Storage</td>
<td>Memory</td>
</tr>
<tr>
<td>Default value</td>
<td>Zero</td>
</tr>
<tr>
<td>Scope</td>
<td>Local to the block in which it is declared</td>
</tr>
<tr>
<td>Lifetime</td>
<td>Value persists between different function calls</td>
</tr>
<tr>
<td>Keyword optionality</td>
<td>Mandatory to use the keyword</td>
</tr>
</tbody>
</table>

10.9.2 extern

extern is used when a file needs to access a variable in another file that it may not have included directly. Therefore, extern does not actually carve out space for a new variable, it just provides the compiler with sufficient information to access the remote variable.

Features of extern variable:

<table>
<thead>
<tr>
<th>Feature</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Keyword usage</td>
<td>extern</td>
</tr>
<tr>
<td>Storage</td>
<td>Memory</td>
</tr>
<tr>
<td>Default value</td>
<td>Zero</td>
</tr>
<tr>
<td>Scope</td>
<td>Global (all over the program)</td>
</tr>
<tr>
<td>Lifetime</td>
<td>Value persists till the program's execution comes to an end</td>
</tr>
<tr>
<td>Keyword optionality</td>
<td>Optional if declared outside all the functions</td>
</tr>
</tbody>
</table>

10.9.3 volatile

volatile is a special type of modifier which informs the compiler that the value of the variable may be changed by external entities other than the program itself. This is necessary for certain programs compiled with optimizations – if a variable were not defined volatile then the compiler may assume that certain operations involving the variable are safe to optimize away when in fact they aren't. volatile is particularly relevant when working with embedded systems (where a program may not have complete control of a variable) and multi-threaded applications.
10.9.4 auto

auto is a modifier which specifies an "automatic" variable that is automatically created when in scope and destroyed when out of scope. If you think this sounds like pretty much what you’ve been doing all along when you declare a variable, you're right: all declared items within a block are implicitly "automatic". For this reason, the auto keyword is more like the answer to a trivia question than a useful modifier, and there are lots of very competent programmers that are unaware of its existence.

Features of automatic variables:

1. Keyword used - auto
2. Storage - Memory
3. Default value - Garbage value (random value)
4. Scope - Local to the block in which it is defined
5. Lifetime - Value persists while the control remains within the block
6. Keyword optionality - Optional

10.9.5 register

register is a hint to the compiler to attempt to optimize the storage of the given variable by storing it in a register of the computer's CPU when the program is run. Most optimizing compilers do this anyway, so use of this keyword is often unnecessary. In fact, ANSI C states that a compiler can ignore this keyword if it so desires – and many do. Microsoft Visual C++ is an example of an implementation that completely ignores the register keyword.

Features of register variables:

1. Keyword used - register
2. Storage - CPU registers (values can be retrieved faster than from memory)
3. Default value - Garbage value
4. Scope - Local to the block in which it is defined
5. Lifetime - Value persists while the control remains within the block
6. Keyword optionality - Mandatory to use the keyword

10.9.6 Concepts

- Variables
- Types
- Data Structures
- Arrays

---

10.9.7 In this section

- C variables
- C types
- C arrays

10.10 References

de:C-Programmierung: Variablen und Konstanten
et:Programmeerimiskeel C/Muutujad
fi:C/Muuttujat
fr:Programmation C/Bases du langage
it:C/Variabili, operatori e costanti/Variabili
ja:C言語 変数
pl:C/Zmienne
pt:Programar em C/Variáveis

17 Chapter 10 on page 39
19 https://de.wikibooks.org/wiki/C-Programmierung%20Variablen%20und%20Konstanten
20 https://et.wikibooks.org/wiki/Programmeerimiskeel%20C%20Muutujad
21 https://fi.wikibooks.org/wiki/C%20Muuttujat
22 https://fr.wikibooks.org/wiki/Programmation%20C/Bases%20du%20Langage
23 https://it.wikibooks.org/wiki/C%20Variabili%2C%20Operatori%20e%20Costanti%20VARIABILI
24 https://ja.wikibooks.org/wiki/C%uE8%A8%80%E8%AA%9E%uE5%A4%89%E6%95%B0
26 https://pt.wikibooks.org/wiki/Programar%20em%20C/Vari%20VARIABLES

50
11 Error handling

C does not provide direct support for error handling (also known as exception handling). By convention, the programmer is expected to prevent errors from occurring in the first place, and test return values from functions. For example, -1 and NULL are used in several functions such as socket() (Unix socket programming) or malloc() respectively to indicate problems that the programmer should be aware about. In a worst case scenario where there is an unavoidable error and no way to recover from it, a C programmer usually tries to log the error and "gracefully" terminate the program.

There is an external variable called "errno", accessible by the programs after including <errno.h> - that file comes from the definition of the possible errors that can occur in some Operating Systems (e.g. Linux - in this case, the definition is in include/asm-generic/errno.h) when programs ask for resources. Such variable indexes error descriptions accessible by the function 'strerror( errno )'.

The following code tests the return value from the library function malloc to see if dynamic memory allocation completed properly:

```c
#include <stdio.h> /* perror */
#include <errno.h> /* errno */
#include <stdlib.h> /* malloc, free, exit */

int main(void)
{
    /* Pointer to char, requesting dynamic allocation of 2,000,000,000
     * storage elements (declared as an integer constant of type
     * unsigned long int). (If your system has less than 2 GB of memory
     * available, then this call to malloc will fail.)
     */
    char *ptr = malloc(2000000000UL);
    if (ptr == NULL) {
        perror("malloc failed");
        /* here you might want to exit the program or compensate
           for that you don’t have 3GB available */
    } else {
        /* The rest of the code hereafter can assume that 2,000,000,000
           * chars were successfully allocated...
           */
        free(ptr);
    }

    exit(EXIT_SUCCESS); /* exiting program */
}
```

The code snippet above shows the use of the return value of the library function malloc to check for errors. Many library functions have return values that flag errors, and thus should be checked by the astute programmer. In the snippet above, a NULL pointer returned from malloc signals an error in allocation, so the program exits. In more complicated
implementations, the program might try to handle the error and try to recover from the failed memory allocation.

11.1 Preventing divide by zero errors

A common pitfall made by C programmers is not checking if a divisor is zero before a division command. The following code will produce a runtime error and in most cases, exit.

```c
int dividend = 50;
int divisor = 0;
int quotient;
quotient = (dividend/divisor); /* This will produce a runtime error! */
```

For reasons beyond the scope of this document, you must check or make sure that a divisor is never zero. Alternatively, for *nix processes, you can stop the OS from terminating your process by blocking the SIGFPE signal.

The code below fixes this by checking if the divisor is zero before dividing.

```c
#include <stdio.h> /* for fprintf and stderr */
#include <stdlib.h> /* for exit */
int main( void )
{
   int dividend = 50;
   int divisor = 0;
   int quotient;
   if (divisor == 0) {
      /* Example handling of this error. Writing a message to stderr, and exiting with failure. */
      fprintf(stderr, "Division by zero! Aborting...
");
      exit(EXIT_FAILURE); /* indicate failure. */
   }
   quotient = dividend / divisor;
   exit(EXIT_SUCCESS); /* indicate success. */
}
```

11.2 Signals

In some cases, the environment may respond to a programming error in C by raising a signal. Signals are events raised by the host environment or operating system to indicate that a specific error or critical event has occurred (e.g. a division by zero, interrupt, and so on.) However, these signals are not meant to be used as a means of error catching; they usually indicate a critical event that will interfere with normal program flow.

To handle signals, a program needs to use the signal.h header file. A signal handler will need to be defined, and the signal() function is then called to allow the given signal to be handled. Some signals that are raised to an exception within your code (e.g. a division by zero) are unlikely to allow your program to recover. These signal handlers will be required to instead ensure that some resources are properly cleaned up before the program terminates.

This example creates a signal handler and raises the signal:
#include <signal.h>
#include <stdio.h>
#include <stdlib.h>

static void catch_function(int signal) {
    puts("Interactive attention signal caught.");
}

int main(void) {
    if (signal(SIGINT, catch_function) == SIG_ERR) {
        fputs("An error occurred while setting a signal handler.\n", stderr);
        return EXIT_FAILURE;
    }
    puts("Raising the interactive attention signal.");
    if (raise(SIGINT) != 0) {
        fputs("Error raising the signal.\n", stderr);
        return EXIT_FAILURE;
    }
    puts("Exiting.");
    return 0;
}

11.3 setjmp

The setjmp function can be used to emulate the exception handling feature of other programming languages. The first call to setjmp provides a reference point to returning to a given function, and is valid as long as the function containing setjmp() doesn't return or exit. A call to longjmp causes the execution to return to the point of the associated setjmp call.

#include <stdio.h>
#include <setjmp.h>

jmp_buf test1;

void tryjump()
{
    longjmp(test1, 3);
}

int main (void)
{
    if (setjmp(test1)==0) {
        printf("setjmp() returned 0.");
        tryjump();
    } else {
        printf("setjmp returned from a longjmp function call.");
    }
}

The values of non-volatile variables may be corrupted when setjmp returns from a longjmp call.

While setjmp() and longjmp() may be used for error handling, it is generally preferred to use the return value of a function to indicate an error, if possible.
12 Simple Input and Output

When you take time to consider it, a computer would be pretty useless without some way to talk to the people who use it. Just like we need information in order to accomplish tasks, so do computers. And just as we supply information to others so that they can do tasks, so do computers.

These supplies and returns of information to a computer are called input and output. 'Input' is information supplied to a computer or program. 'Output' is information provided by a computer or program. Frequently, computer programmers will lump the discussion in the more general term input/output or simply, I/O.

In C, there are many different ways for a program to communicate with the user. Amazingly, the most simple methods usually taught to beginning programmers may also be the most powerful. In the Hello, World!

1 example at the beginning of this text, we were introduced to a Standard Library file stdio.h, and one of its functions, printf(). Here we discuss more of the functions that stdio.h gives us.

12.1 Output using printf()

Recall from the beginning of this text the demonstration program duplicated below:

```c
#include <stdio.h>

int main(void)
{
    printf("Hello, World!");
    return 0;
}
```

If you compile and run this program, you will see the sentence below show up on your screen:

```
Hello, world!
```

This amazing accomplishment was achieved by using the function printf(). A function is like a "black box" that does something for you without exposing the internals inside. We can write functions ourselves in C, but we will cover that later.

You have seen that to use printf() one puts text, surrounded by quotes, in between the parentheses. We call the text surrounded by quotes a literal string (or just a string), and we call that string an argument to printf.

---

1 Chapter 6 on page 19
As a note of explanation, it is sometimes convenient to include the open and closing parentheses after a function name to remind us that it is, indeed, a function. However usually when the name of the function we are talking about is understood, it is not necessary.

As you can see in the example above, using `printf()` can be as simple as typing in some text, surrounded by double quotes (note that these are double quotes and not two single quotes). So, for example, you can print any string by placing it as an argument to the `printf()` function:

```c
printf("This sentence will print out exactly as you see it...");
```

And once it is contained in a proper `main()` function, it will show:

```
This sentence will print out exactly as you see it...
```

### 12.1.1 Printing numbers and escape sequences

#### Placeholder codes

The `printf()` function is a powerful function, and is probably the most-used function in C programs.

For example, let us look at a problem. Say we don’t know what 19 + 31 is. Let’s use C to get the answer.

We start writing

```c
#include "stdio.h" // this is important, since printf
             // can’t be used without this header

int main(void)
{
    printf("19+31 is");
}
```

But here we are stuck! `printf()` only prints strings! Thankfully, `printf` has methods for printing numbers. What we do is put a *placeholder format code* in the string. We write:

```c
printf("19+31 is '''%d'''", 19+31);
```

The placeholder `%d` literally “holds the place” for the actual number that is the result of adding 19 to 31.

These placeholders are called *format specifiers*. Many other format specifiers work with `printf()`. If we have a floating-point number, we can use `%f` to print out a floating-point number, decimal point and all. Other format specifiers are:

- `%d` - int (same as `%i`)
- `%ld` - long int (same as `%li`)
- `%f` - float
- `%lf` - double

---

2 Actually `%f` prints doubles as well, but the use of `%f` for input is different. For more details, see the Wikipedia article on C data types [here](https://en.wikipedia.org/wiki/C%20data%20types).

---

56
Output using `printf()`

- `%c` - char
- `%s` - string
- `%x` - hexadecimal

A complete listing of all the format specifiers for `printf()` is on Wikipedia³.

Tabs and newlines

What if, we want to achieve some output that will look like:

```
1905
312 +
-----
```

`printf()` will not put line breaks in at the end of each statement: we must do this ourselves. But how?

What we can do is use the newline *escape character*. An escape character is a special character that we can write but will do something special onscreen, such as make a beep, write a tab, and so on. To write a newline we write `\n`. All escape characters start with a backslash.

So to achieve the output above, we write

```c
printf("\n1905\n312 +\n-----\n");
```

or to be a bit more clear, we can break this long `printf` statement over several lines. So our program will be

```c
#include <stdio.h>

int main(void)
{
    printf("1905\n");
    printf("312 +\n");
    printf("-----\n");
    printf("%d", 1905+312);
    return 0;
}
```

There are other escape characters⁴ we can use. Another common one is to use `\t` to write a tab. You can use `\a` to ring the computer's bell, but you should not use this very much in your programs, as excessive use of sound is not very friendly to the user.

³ https://en.wikipedia.org/wiki/printf%20format%20string

⁴ Chapter 26.1.1 on page 187
12.2 Other output methods

12.2.1 puts()

The puts() function is a very simple way to send a string to the screen when you have no placeholders to be concerned about. It works very much like the printf() function we saw in the "Hello, World!" example:

```c
puts("Print this string.");
```

will print to the screen:

```
Print this string.
```

followed by the newline character (as discussed above). (The puts function appends a newline character to its output.)

12.3 Input using scanf()

The scanf() function is the input method equivalent to the printf() output function - simple yet powerful. In its simplest invocation, the scanf format string holds a single placeholder representing the type of value that will be entered by the user. These placeholders are mostly the same as the printf() function - %d for ints, %f for floats, and %lf for doubles.

There is, however, one variation to scanf() as compared to printf(). The scanf() function requires the memory address of the variable to which you want to save the input value. While pointers (variables storing memory addresses) can be used here, this is a concept that won’t be approached until later in the text. Instead, the simple technique is to use the address-of operator, &. For now it may be best to consider this “magic” before we discuss pointers.

A typical application might be like this:

```c
#include "stdio.h"

int main(void)
{
    int a;
    printf("Please input an integer value: ");
    scanf("%d", &a);
    printf("You entered: \%d\n", a);
    return 0;
}
```

If you were to describe the effect of the scanf() function call above, it might read as: "Read in an integer from the user and store it at the address of variable a”.

If you are trying to input a string using scanf, you should not include the & operator. The code below will produce a runtime error and the program will likely crash.
scanf("%s", &a);

The correct usage would be:
scanf("%s", a);

This is because, whenever you use a format specifier for a string (%s), the variable that you use to store the value will be an array and, the array names (in this case - a) themselves point out to their base address and hence, the address of operator is not required.

(Although, this is vulnerable to Buffer overflow\(^5\). \texttt{fgets()} is preferred to \texttt{scanf()}).

\textbf{Note on inputs}: When data is typed at a keyboard, the information does not go straight to the program that is running. It is first stored in what is known as a \textit{buffer} - a small amount of memory reserved for the input source. Sometimes there will be data left in the buffer when the program wants to read from the input source, and the \texttt{scanf()} function will read this data instead of waiting for the user to type something. Some may suggest you use the function \texttt{fflush(stdin)}, which may work as desired on some computers, but isn’t considered good practice, as you will see later. Doing this has the downfall that if you take your code to a different computer with a different compiler, your code may not work properly.

\section*{12.4 References}

et:Programmeerimiskeel C/IO\(^6\) pl:C/Podstawowe procedury wejścia i wyjścia\(^7\)
pt:Programar em C/Entrada e saída simples\(^8\)

\begin{itemize}
\item[5] \url{https://en.wikipedia.org/wiki/Buffer%20overflow}
\item[6] \url{https://et.wikibooks.org/wiki/Programmeerimiskeel%20C%2FIO}
\item[7] \url{https://pl.wikibooks.org/wiki/C%2FPodstawowe%20procedury%20wejcia%20i%20wyjcia}
\item[8] \url{https://pt.wikibooks.org/wiki/Programar%20em%20C/Entrada%20e%20saída%20simples}
\end{itemize}
13 Simple math

13.1 Arithmetic Operators

In C, simple math is very easy to handle. The following operators exist: + (addition), - (subtraction), * (multiplication), / (division), and % (modulus); You likely know all of them from your math classes - except, perhaps, modulus. It returns the remainder of a division (e.g. 5 % 2 = 1). (Modulus is not defined for floating-point numbers, but the math.h library has an fmod function.)

Care must be taken with the modulus, because it's not the equivalent of the mathematical modulus: (-5) % 2 is not 1, but -1. Division of integers will return an integer, and the division of a negative integer by a positive integer will round towards zero instead of rounding down (e.g. (-5) / 3 = -1 instead of -2). However, it is always true that for all integer a and nonzero integer b, ((a / b) * b) + (a % b) == a.

There is no inline operator to do exponentiation (e.g. 5 ^ 2 is not 25 [it is 7; ^ is the exclusive-or operator], and 5 ** 2 is an error), but there is a power function.

The mathematical order of operations does apply. For example (2 + 3) * 2 = 10 while 2 + 3 * 2 = 8. Multiplicative operators have precedence over additive operators.

```c
#include <stdio.h>

int main(void)
{
    int i = 0, j = 0;

    /* while i is less than 5 AND j is less than 5, loop */
    while((i < 5) && (j < 5))
    {
        /* postfix increment, i++ */
        /* the value of i is read and then incremented */
        printf("i: \t", i++);

        /* prefix increment, ++j */
        /* the value of j is incremented and then read */
        printf("j: \n", ++j);
    }

    printf("At the end they have both equal values:\ni: \tj: \n", i, j);

    getchar(); /* pause */
    return 0;
}
```

1 Chapter 14.4 on page 73
will display the following:

```
i: 0  j: 1
i: 1  j: 2
i: 2  j: 3
i: 3  j: 4
i: 4  j: 5
```

At the end they have both equal values:

```
i: 5  j: 5
```

### 13.2 Assignment Operators

The assignment operators are =, *=, /=, %=, +=, -=, <<=, >>=, &=, ^=, and |=. The = operator stores the value of the right operand into the location determined by the left operand, which must be an lvalue\(^2\) (a value that has an address, and therefore can be assigned to).

For the others, \(x \text{ op} = y\) is shorthand for \(x = x \text{ op} (y)\). Hence, the following expressions are the same:

<table>
<thead>
<tr>
<th>Expression</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. (x += y)</td>
<td>(x = x + y)</td>
</tr>
<tr>
<td>2. (x -= y)</td>
<td>(x = x - y)</td>
</tr>
<tr>
<td>3. (x *= y)</td>
<td>(x = x \times y)</td>
</tr>
<tr>
<td>4. (x /= y)</td>
<td>(x = x / y)</td>
</tr>
<tr>
<td>5. (x %= y)</td>
<td>(x = x % y)</td>
</tr>
</tbody>
</table>

The value of the assignment expression is the value of the left operand after the assignment. Thus, assignments can be chained; e.g. the expression \(a = b = c = 0;\) would assign the value zero to all three variables.

### 13.3 Logical Operators

The logical operators are \&\& (and), and || (or). Both of these operators produce 1 if the relationship is true and 0 for false. Both of these operators short-circuit; if the result of the expression can be determined from the first operand, the second is ignored. The \&\& operator has higher precedence than the || operator.

\&\& is used to evaluate expressions left to right, and returns a 1 if both statements are true.

```c
int x = 7;
int y = 5;
if(x == 7 && y == 5) {
    ...
}
```

Here, the \&\& operator checks the left-most expression, then the expression to its right. If there were more than two expressions chained (e.g. \(x \&\& y \&\& z\), the operator would

\(^2\) https://en.wikibooks.org/wiki/lvalue
check x first, then y, then continue rightwards to z if neither x or y is zero. Since both statements return true, the && operator returns true, and the code block is executed.

```cpp
if(x == 5 && y == 5) {
    ...
}
```

The && operator checks in the same way as before, and finds that the first expression is false. The && operator stops evaluating as soon as it finds a statement to be false, and returns a false.

|| is used to evaluate expressions left to right, and returns a 1 if either of the expressions are true.

```cpp
/* Use the same variables as before. */
if(x == 2 || y == 5) { // the || statement checks both expressions, finds that the latter is true, and returns true
    ...
}
```

The || operator here checks the left-most expression, finds it false, but continues to evaluate the next expression. It finds that the next expression returns true, stops, and returns a 1. Much how the && operator ceases when it finds an expression that returns false, the || operator ceases when it finds an expression that returns true.

It is worth noting that C does not have Boolean values (true and false) commonly found in other languages. It instead interprets a 0 as false, and any nonzero value as true.

### 13.3.1 The conditional operator

The ternary ?: operator is the conditional operator. The expression (x ? y : z) has the value of y if x is nonzero, z otherwise.

Example:

```cpp
int x = 0;
int y;
y = (x ? 10 : 6); /* The parentheses are technically not necessary as assignment has a lower precedence than the conditional operator, but it's there for clarity. */
```

The expression x evaluates to 0. The ternary operator then looks for the “if-false” value, which in this case, is 6. It returns that, so y is equal to six. Had x been a non-zero, then the expression would have returned a 10.

### 13.4 Relational and Equality Operators

The relational binary operators < (less than), > (greater than), <= (less than or equal), and >= (greater than or equal) operators return a value of 1 if the result of the operation is true, 0 if false.
Simple math

The equality binary operators == (equals) and != (not equals) operators are similar to the relational operators except that their precedence is lower.

13.5 Type Casting

A parenthesized type name followed by a cast expression is a cast expression. The parenthesized type name has the effect of forcing the cast expression into the type specified by the type name in parentheses. For arithmetic types, this either does not change the value of the expression, or truncates the value of the expression if the expression is an integer and the new type is smaller than the previous type.

An example of casting a float as an int:

```c
float pi = 3.141592;
int truncated_pi = (int)pi; // truncated_pi == 3
```

An example of casting a char as an int:

```c
char my_char = 'A';
int my_int = (int)my_char; // my_int == 65, which is the ASCII value of 'A'
```

13.6 The Shift Operators (which may be used to rotate bits)

Shift functions are often used in low-level I/O hardware interfacing. Shift and rotate functions are heavily used in cryptography and software floating point emulation. Other than that, shifts can be used in place of division or multiplication by a power of two. Many processors have dedicated function blocks to make these operations fast -- see Microprocessor Design/Shift and Rotate Blocks3. On processors which have such blocks, most C compilers compile shift and rotate operators to a single assembly-language instruction -- see X86 Assembly/Shift and Rotate4.

13.6.1 shift left

The << operator shifts the binary representation to the left, dropping the most significant bits and appending it with zero bits. The result is equivalent to multiplying the integer by a power of two.

13.6.2 unsigned shift right

The unsigned shift right operator, also sometimes called the logical right shift operator. It shifts the binary representation to the right, dropping the least significant bits and prepending it with zeros. The >> operator is equivalent to division by a power of two for unsigned integers.

---

3 https://en.wikibooks.org/wiki/Microprocessor%20Design%2FShift%20and%20Rotate%20Blocks
4 https://en.wikibooks.org/wiki/X86%20Assembly%2FShift%20and%20Rotate
13.6.3 signed shift right

The signed shift right operator, also sometimes called the arithmetic right shift operator. It shifts the binary representation to the right, dropping the least significant bit, but prepending it with copies of the original sign bit. The >> operator is not equivalent to division for signed integers.

In C, the behavior of the >> operator depends on the data type it acts on. Therefore, a signed and an unsigned right shift looks exactly the same, but produces a different result in some cases.

13.6.4 rotate right

Contrary to popular belief, it is possible to write C code that compiles down to the "rotate" assembly language instruction (on CPUs that have such an instruction).

Most compilers recognize this idiom:

```c
unsigned int x;
unsigned int y;
/* ... */
y = (x >> shift) | (x << (32 - shift));
```

and compile it to a single 32 bit rotate instruction.  

On some systems, this may be "#define"ed as a macro or defined as an inline function called something like "rightrotate32" or "rotr32" or "ror32" in a standard header file like "bitops.h".

13.6.5 rotate left

Most compilers recognize this idiom:

```c
unsigned int x;
unsigned int y;
/* ... */
y = (x << shift) | (x >> (32 - shift));
```

and compile it to a single 32 bit rotate instruction.

On some systems, this may be "#define"ed as a macro or defined as an inline function called something like "leftrotate32" or "rotl32" in a header file like "bitops.h".

---


6 "Cleanups in ROTL/ROTR DAG combiner code" *(http://www.mail-archive.com/llvm-commits@cs.uiuc.edu/msg17216.html)* mentions that this code supports the "rotate" instruction in the CellSPU

13.6.6 Relational and equality operators

The relational binary operators $<$ (less than), $>$ (greater than), $\leq$ (less than or equal), and $\geq$ (greater than or equal) operators return a value of 1 if the result of the operation is true, 0 if false.

The equality binary operators $==$ (equals) and $!=$ (not equals) operators are similar to the relational operators except that their precedence is lower.

13.7 Bitwise Operators

The bitwise operators are $\&$ (and), $\wedge$ (exclusive or) and $|$ (inclusive or). The $\&$ operator has higher precedence than $\wedge$, which has higher precedence than $|$. The values being operated upon must be integral; the result is integral.

One use for the bitwise operators is to emulate bit flags. These flags can be set with OR, tested with AND, flipped with XOR, and cleared with AND NOT. For example:

```c
/* This code is a sample for bitwise operations. */
#define BITFLAG1 (1)
#define BITFLAG2 (2)
#define BITFLAG3 (4) /* They are powers of 2 */

unsigned bitbucket = 0U; /* Clear all */
bitbucket |= BITFLAG1; /* Set bit flag 1 */
bitbucket &= BITFLAG2; /* Clear bit flag 2 */
bitbucket ^= BITFLAG3; /* Flip the state of bit flag 3 from off to on or vice versa */

if (bitbucket & BITFLAG3) {
    /* bit flag 3 is set */
} else {
    /* bit flag 3 is not set */
}
```

13.8 Comma Operator

The operator with the least precedence is the comma operator. The value of the expression $x, y$ will evaluate both $x$ and $y$, but provides the value of $y$.

This operator is useful for including multiple actions in one statement (e.g. within a for loop conditional).

Here are some small examples of the comma operator:

```c
int i, x;  /* Declares two ints, i and x, in one declaration. 
            Technically, this is not the comma operator. */

/* this loop initializes x and i to 0, then runs the loop */
for (x = 0, i = 0; i <= 6; i++) {
    printf("x = %d, and i = %d\n", x, i);
}
```
13.9 References

fr:Programmation C/Opérateurs\(^8\) pl:C/Operatory\(^9\)

---

8 https://fr.wikibooks.org/wiki/Programmation%C2%A0%C3%A9rateurs
9 https://pl.wikibooks.org/wiki/C%2FOperatory
14 Further math

The `<math.h>` header contains prototypes for several functions that deal with mathematics. In the 1990 version of the ISO standard, only the `double` versions of the functions were specified; the 1999 version added the `float` and `long double` versions. To use these math functions, you must link your program with the math library. For some compilers (including GCC), you must specify the additional parameter `-lm`.

The math functions may produce one of two kinds of errors. Domain errors occur when the parameters to the functions are invalid, such as a negative number as a parameter to `sqrt` (the square root function). Range errors occur when the result of the function cannot be expressed in that particular floating-point type, such as `pow(1000.0, 1000.0)` if the maximum value of a double is around $10^{308}$.

The functions can be grouped into the following categories:

### 14.1 Trigonometric functions

#### 14.1.1 The `acos` and `asin` functions

The `acos` functions return the arccosine of their arguments in radians, and the `asin` functions return the arcsine of their arguments in radians. All functions expect the argument in the range $[-1,+1]$. The arccosine returns a value in the range $[0,π]$; the arcsine returns a value in the range $[-π/2,+π/2]$.

```c
#include <math.h>
float asinf(float x); /* C99 */
float acosf(float x); /* C99 */
double asin(double x);
double acos(double x);
long double asinl(long double x); /* C99 */
long double acosl(long double x); /* C99 */
```

#### 14.1.2 The `atan` and `atan2` functions

The `atan` functions return the arctangent of their arguments in radians, and the `atan2` function return the arctangent of $y/x$ in radians. The `atan` functions return a value...
Further math

in the range \([-\pi/2, +\pi/2]\) (the reason why \(\pm\pi/2\) are included in the range is because the floating-point value may represent infinity, and \(\text{atan}(\pm\infty) = \pm\pi/2\); the \text{atan2} functions return a value in the range \([-\pi, +\pi]\). For \text{atan2}, a domain error may occur if both arguments are zero.

```c
#include <math.h>
float atanf(float x); /* C99 */
float atan2f(float y, float x); /* C99 */
double atan(double x);
double atan2(double y, double x);
long double atanl(long double x); /* C99 */
long double atan2l(long double y, long double x); /* C99 */
```

### 14.1.3 The cos, sin, and tan functions

The \text{cos}, \text{sin}, and \text{tan} functions return the cosine, sine, and tangent of the argument, expressed in radians.

```c
#include <math.h>
float cosf(float x); /* C99 */
float sinf(float x); /* C99 */
float tanf(float x); /* C99 */
double cos(double x);
double sin(double x);
double tan(double x);
long double cosl(long double x); /* C99 */
long double sinl(long double x); /* C99 */
long double tanl(long double x); /* C99 */
```

### 14.2 Hyperbolic functions

The \text{cosh}, \text{sinh} and \text{tanh} functions compute the hyperbolic cosine, the hyperbolic sine, and the hyperbolic tangent of the argument respectively. For the hyperbolic sine and cosine functions, a range error occurs if the magnitude of the argument is too large.

The \text{acosh} functions compute the inverse hyperbolic cosine of the argument. A domain error occurs for arguments less than 1.

The \text{asinh} functions compute the inverse hyperbolic sine of the argument.

The \text{atanh} functions compute the inverse hyperbolic tangent of the argument. A domain error occurs if the argument is not in the interval \([-1, +1]\). A range error may occur if the argument equals -1 or +1.

```c
#include <math.h>
float coshf(float x); /* C99 */
float sinhf(float x); /* C99 */
float tanhf(float x); /* C99 */
double cosh(double x);
double sinh(double x);
double tanh(double x);
long double coshl(long double x); /* C99 */
long double sinhl(long double x); /* C99 */
long double tanhl(long double x); /* C99 */
float acoshf(float x); /* C99 */
float asinhf(float x); /* C99 */
float atanhf(float x); /* C99 */
double acosh(double x); /* C99 */
```
14.3 Exponential and logarithmic functions

14.3.1 The exp, exp2, and expm1 functions

The exp functions compute the base-e exponential function of x \( (e^x) \). A range error occurs if the magnitude of x is too large.

The exp2 functions compute the base-2 exponential function of x \( (2^x) \). A range error occurs if the magnitude of x is too large.

The expm1 functions compute the base-e exponential function of the argument, minus 1. A range error occurs if the magnitude of x is too large.

```c
#include <math.h>
float expf(float x); /* C99 */
double exp(double x);
long double expl(long double x); /* C99 */
float exp2f(float x); /* C99 */
double exp2(double x); /* C99 */
long double exp2l(long double x); /* C99 */
float expm1f(float x); /* C99 */
double expm1(double x); /* C99 */
long double expm1l(long double x); /* C99 */
```

14.3.2 The frexp, ldexp, modf, scalbn, and scalbln functions

These functions are heavily used in software floating-point emulators, but are otherwise rarely directly called.

Inside the computer, each floating point number is represented by two parts:

- The significand is either in the range \([1/2, 1)\), or it equals zero.
- The exponent is an integer.

The value of a floating point number \( v \) is \( v = \text{significand} \times 2^{\text{exponent}} \).

The frexp functions break the argument floating point number value into those two parts, the exponent and significand. After breaking it apart, it stores the exponent in the int object pointed to by ex, and returns the significand. In other words, the value returned is a copy of the given floating point number but with an exponent replaced by 0. If value is zero, both parts of the result are zero.

The ldexp functions multiply a floating-point number by an integral power of 2 and return the result. In other words, it returns copy of the given floating point number with the exponent increased by ex. A range error may occur.

The modf functions break the argument value into integer and fraction parts, each of which has the same sign as the argument. They store the integer part in the object pointed to
Further math

by *iptr and return the fraction part. The *iptr is a floating-point type, rather than an "int" type, because it might be used to store an integer like 1 000 000 000 000 000 000 000 which is too big to fit in an int.

The scalbn and scalbln compute $x \times \text{FLT\_RADIX}^n$. FLT\_RADIX is the base of the floating-point system; if it is 2, the functions are equivalent to ldexp.

#include <math.h>

float frexpf(float value, int *ex); /* C99 */
double frexpl(long double value, int *ex); /* C99 */
float ldexpf(float x, int ex); /* C99 */
double ldexp(double x, int ex);
long double ldexpl(long double x, int ex); /* C99 */
float modff(float value, float *iptr); /* C99 */
double modfp(double value, double *iptr);
long double modfl(long double value, long double *iptr);
float scalbnf(float x, int ex); /* C99 */
double scalbnd(double x, int ex); /* C99 */
long double scalbnl(long double x, int ex); /* C99 */
float scalblnf(float x, long int ex); /* C99 */
double scalblnd(double x, long int ex); /* C99 */
long double scalblnl(long double x, long int ex); /* C99 */

Most C floating point libraries also implement the IEEE754-recommended nextafter(), nextUp( ), and nextDown( ) functions. http://www.opengroup.org/onlinepubs/009695399/functions/nextafter.html

14.3.3 The log, log2, log1p, and log10 functions

The log functions compute the base-e natural (not common) logarithm of the argument and return the result. A domain error occurs if the argument is negative. A range error may occur if the argument is zero.

The log1p functions compute the base-e natural (not common) logarithm of one plus the argument and return the result. A domain error occurs if the argument is less than -1. A range error may occur if the argument is -1.

The log10 functions compute the common (base-10) logarithm of the argument and return the result. A domain error occurs if the argument is negative. A range error may occur if the argument is zero.

The log2 functions compute the base-2 logarithm of the argument and return the result. A domain error occurs if the argument is negative. A range error may occur if the argument is zero.

#include <math.h>

float logf(float x); /* C99 */
double log(double x);
long double logl(long double x); /* C99 */
float log1pf(float x); /* C99 */
double log1p(double x); /* C99 */
long double log1pl(long double x); /* C99 */
float log10f(float x); /* C99 */
double log10(double x); /* C99 */
long double log10l(long double x); /* C99 */
float log2f(float x); /* C99 */
double log2(double x); /* C99 */
long double log2l(long double x); /* C99 */
14.3.4 The ilogb and logb functions

The ilogb functions extract the exponent of x as a signed int value. If x is zero, they return the value FP_ILOGBO; if x is infinite, they return the value INT_MAX; if x is not-a-number they return the value FP_ILOGBNAN; otherwise, they are equivalent to calling the corresponding logb function and casting the returned value to type int. A range error may occur if x is zero. FP_ILOGBO and FP_ILOGBNAN are macros defined in math.h; INT_MAX is a macro defined in limits.h.

The logb functions extract the exponent of x as a signed integer value in floating-point format. If x is subnormal, it is treated as if it were normalized; thus, for positive finite x, 1 ≤ x × FLT_RADIX−logb(x) < FLT_RADIX. FLT_RADIX is the radix for floating-point numbers, defined in the float.h header.

```c
#include <math.h>
int ilogbf(float x); /* C99 */
int ilogb(double x); /* C99 */
int ilogbl(long double x); /* C99 */
float logbf(float x); /* C99 */
double logb(double x); /* C99 */
long double logbl(long double x); /* C99 */
```

14.4 Power functions

14.4.1 The pow functions

The pow functions compute x raised to the power y and return the result. A domain error occurs if x is negative and y is not an integral value. A domain error occurs if the result cannot be represented when x is zero and y is less than or equal to zero. A range error may occur.

```c
#include <math.h>
float powf(float x, float y); /* C99 */
double pow(double x, double y);
long double powl(long double x, long double y); /* C99 */
```

14.4.2 The sqrt functions

The sqrt functions compute the positive square root of x and return the result. A domain error occurs if the argument is negative.

```c
#include <math.h>
float sqrtf(float x); /* C99 */
double sqrt(double x);
long double sqrtl(long double x); /* C99 */
```

14.4.3 The cbrt functions

The cbrt functions compute the cube root of x and return the result.

```c
#include <math.h>
float cbrtf(float x); /* C99 */
```
Furthermath

double cbrt(double x); /* C99 */
long double cbrtl(long double x); /* C99 */

14.4.4 The hypot functions

The hypot functions compute the square root of the sums of the squares of x and y, without overflow or underflow, and return the result.

```c
#include <math.h>
float hypotf(float x, float y); /* C99 */
double hypot(double x, double y); /* C99 */
long double hypotl(long double x, long double y); /* C99 */
```

14.5 Nearest integer, absolute value, and remainder functions

14.5.1 The ceil and floor functions

The ceil functions compute the smallest integral value not less than x and return the result; the floor functions compute the largest integral value not greater than x and return the result.

```c
#include <math.h>
float ceilf(float x); /* C99 */
double ceil(double x);
long double ceill(long double x); /* C99 */
float floorf(float x); /* C99 */
double floor(double x);
long double floorl(long double x); /* C99 */
```

14.5.2 The fabs functions

The fabs functions compute the absolute value of a floating-point number x and return the result.

```c
#include <math.h>
float fabsf(float x); /* C99 */
double fabsl(double x);
long double fabsl(long double x); /* C99 */
```

14.5.3 The fmod functions

The fmod functions compute the floating-point remainder of x/y and return the value x - i * y, for some integer i such that, if y is nonzero, the result has the same sign as x and magnitude less than the magnitude of y. If y is zero, whether a domain error occurs or the fmod functions return zero is implementation-defined.

```c
#include <math.h>
float fmodf(float x, float y); /* C99 */
double fmod(double x, double y);
long double fmodl(long double x, long double y); /* C99 */
```
14.5.4 The \texttt{nearbyint}, \texttt{rint}, \texttt{lrint}, and \texttt{llrint} functions

The \texttt{nearbyint} functions round their argument to an integer value in floating-point format, using the current rounding direction and without raising the "inexact" floating-point exception.

The \texttt{rint} functions are similar to the \texttt{nearbyint} functions except that they can raise the "inexact" floating-point exception if the result differs in value from the argument.

The \texttt{lrint} and \texttt{llrint} functions round their arguments to the nearest integer value according to the current rounding direction. If the result is outside the range of values of the return type, the numeric result is undefined and a range error may occur if the magnitude of the argument is too large.

```c
#include <math.h>
float nearbyintf(float x); /* C99 */
double nearbyint(double x); /* C99 */
long double nearbyintl(long double x); /* C99 */
float rintf(float x); /* C99 */
double rint(double x); /* C99 */
long double rintl(long double x); /* C99 */
long int lrintf(float x); /* C99 */
long int lrint(double x); /* C99 */
long int lrintl(long double x); /* C99 */
long int lllrintf(float x); /* C99 */
long int lllrint(double x); /* C99 */
long int lllrintl(long double x); /* C99 */
```

14.5.5 The \texttt{round}, \texttt{lround}, and \texttt{llround} functions

The \texttt{round} functions round the argument to the nearest integer value in floating-point format, rounding halfway cases away from zero, regardless of the current rounding direction.

The \texttt{lround} and \texttt{llround} functions round the argument to the nearest integer value, rounding halfway cases away from zero, regardless of the current rounding direction. If the result is outside the range of values of the return type, the numeric result is undefined and a range error may occur if the magnitude of the argument is too large.

```c
#include <math.h>
float roundf(float x); /* C99 */
double round(double x); /* C99 */
long double roundl(long double x); /* C99 */
long int lroundf(float x); /* C99 */
long int lround(double x); /* C99 */
long int lroundl(long double x); /* C99 */
long int llroundf(float x); /* C99 */
long int llround(double x); /* C99 */
long int llroundl(long double x); /* C99 */
```

14.5.6 The \texttt{trunc} functions

The \texttt{trunc} functions round their argument to the integer value in floating-point format that is nearest but no larger in magnitude than the argument.

```c
#include <math.h>
float truncf(float x); /* C99 */
```
double trunc(double x); /* C99 */
long double truncl(long double x); /* C99 */

14.5.7 The remainder functions

The remainder functions compute the remainder \( x \) \( \text{REM} \) \( y \) as defined by IEC 60559. The definition reads, "When \( y \neq 0 \), the remainder \( r = x \) \( \text{REM} \) \( y \) is defined regardless of the rounding mode by the mathematical reduction \( r = x - ny \), where \( n \) is the integer nearest the exact value of \( x/y \); whenever \( |n - x/y| = \frac{1}{2} \), then \( n \) is even. Thus, the remainder is always exact. If \( r = 0 \), its sign shall be that of \( x \)." This definition is applicable for all implementations.

#include <math.h>
float remainderf(float x, float y); /* C99 */
double remainder(double x, double y); /* C99 */
long double remanerlld(long double x, long double y); /* C99 */

14.5.8 The remquo functions

The remquo functions return the same remainder as the remainder functions. In the object pointed to by quo, they store a value whose sign is the sign of \( x/y \) and whose magnitude is congruent modulo \( 2^n \) to the magnitude of the integral quotient of \( x/y \), where \( n \) is an implementation-defined integer greater than or equal to 3.

#include <math.h>
float remquof(float x, float y, int *quo); /* C99 */
double remquo(double x, double y, int *quo); /* C99 */
long double remquol(long double x, long double y, int *quo); /* C99 */

14.6 Error and gamma functions

The erf functions compute the error function of the argument \( \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} \text{d}t \); the erfc functions compute the complimentary error function of the argument (that is, \( 1 - \text{erf} x \)). For the erfc functions, a range error may occur if the argument is too large.

The lgamma functions compute the natural logarithm of the absolute value of the gamma of the argument (that is, \( \log_e |\Gamma(x)| \)). A range error may occur if the argument is a negative integer or zero.

The tgamma functions compute the gamma of the argument (that is, \( \Gamma(x) \)). A domain error occurs if the argument is a negative integer or if the result cannot be represented when the argument is zero. A range error may occur.

#include <math.h>
float erff(float x); /* C99 */
double erff(double x); /* C99 */
long double erfll(long double x); /* C99 */
float erfcf(float x); /* C99 */
double erfcf(double x); /* C99 */
long double erfcfl(long double x); /* C99 */
float lgammaf(float x); /* C99 */
double lgamma(double x); /* C99 */
long double lgammal(long double x); /* C99 */
float tgammaf(float x); /* C99 */
double tgamma(double x); /* C99 */
long double tgammal(long double x); /* C99 */

14.7 References

w:circular shift

fr:Programmation C/Mathématiques
pl:C/Zaawansowane operacje matematyczne

5 https://fr.wikibooks.org/wiki/Programmation%20C%20Mathématiques
6 https://pl.wikibooks.org/wiki/C%20Zaawansowane%20operacje%20matematyczne
15 Control

Very few programs follow exactly one control path and have each instruction stated explicitly. In order to program effectively, it is necessary to understand how one can alter the steps taken by a program due to user input or other conditions, how some steps can be executed many times with few lines of code, and how programs can appear to demonstrate a rudimentary grasp of logic. C constructs known as conditionals and loops grant this power.

From this point forward, it is necessary to understand what is usually meant by the word *block*. A block is a group of code statements that are associated and intended to be executed as a unit. In C, the beginning of a block of code is denoted with { (left curly), and the end of a block is denoted with }. It is not necessary to place a semicolon after the end of a block. Blocks can be empty, as in {}. Blocks can also be nested; i.e. there can be blocks of code within larger blocks.

15.1 Conditionals

There is likely no meaningful program written in which a computer does not demonstrate basic decision-making skills. It can actually be argued that there is no meaningful human activity in which some sort of decision-making, instinctual or otherwise, does not take place. For example, when driving a car and approaching a traffic light, one does not think, “I will continue driving through the intersection.” Rather, one thinks, “I will stop if the light is red, go if the light is green, and if yellow go only if I am traveling at a certain speed a certain distance from the intersection.” These kinds of processes can be simulated in C using conditionals.

A conditional is a statement that instructs the computer to execute a certain block of code or alter certain data only if a specific condition has been met. The most common conditional is the If-Else statement, with conditional expressions and Switch-Case statements typically used as more shorthanded methods.

Before one can understand conditional statements, it is first necessary to understand how C expresses logical relations. C treats logic as being arithmetic. The value 0 (zero) represents false, and all other values represent true. If you chose some particular value to represent true and then compare values against it, sooner or later your code will fail when your assumed value (often 1) turns out to be incorrect. Code written by people uncomfortable with the C language can often be identified by the usage of #define to make a "TRUE" value. ¹

¹ C FAQ ^{http://www.c-faq.com/bool/bool2.html}
Because logic is arithmetic in C, arithmetic operators and logical operators are one and the same. Nevertheless, there are a number of operators that are typically associated with logic:

15.1.1 Relational and Equivalence Expressions:

\[ a < b \]
1 if \( a \) is less than \( b \), 0 otherwise.

\[ a > b \]
1 if \( a \) is greater than \( b \), 0 otherwise.

\[ a <= b \]
1 if \( a \) is less than or equal to \( b \), 0 otherwise.

\[ a >= b \]
1 if \( a \) is greater than or equal to \( b \), 0 otherwise.

\[ a == b \]
1 if \( a \) is equal to \( b \), 0 otherwise.

\[ a != b \]
1 if \( a \) is not equal to \( b \), 0 otherwise.

New programmers should take special note of the fact that the “equal to” operator is ==, not =. This is the cause of numerous coding mistakes and is often a difficult-to-find bug, as the expression \( a = b \) sets \( a \) equal to \( b \) and subsequently evaluates to \( b \); but the expression \( a == b \), which is usually intended, checks if \( a \) is equal to \( b \). It needs to be pointed out that, if you confuse = with ==, your mistake will often not be brought to your attention by the compiler. A statement such as \( \text{if } (c = 20) \ { \} \) is considered perfectly valid by the language, but will always assign 20 to \( c \) and evaluate as true. A simple technique to avoid this kind of bug (in many, not all cases) is to put the constant first. This will cause the compiler to issue an error, if == got misspelled with =.

Note that C does not have a dedicated boolean type as many other languages do. 0 means false and anything else true. So the following are equivalent:

\[
\text{if } (\text{foo}()) \ { \}
\text{// do something}
\]

and

\[
\text{if } (\text{foo}() \neq 0) \ { \}
\text{// do something}
\]

Often \#define TRUE 1 and \#define FALSE 0 are used to work around the lack of a boolean type. This is bad practice, since it makes assumptions that do not hold. It is a better idea to indicate what you are actually expecting as a result from a function call, as there are many different ways of indicating error conditions, depending on the situation.
if (strstr("foo", bar) >= 0) {
    // bar contains "foo"
}

Here, strstr returns the index where the substring foo is found and -1 if it was not found. Note that this would fail with the TRUE definition mentioned in the previous paragraph. It would also not produce the expected results if we omitted the >= 0.

One other thing to note is that the relational expressions do not evaluate as they would in mathematical texts. That is, an expression myMin < value < myMax does not evaluate as you probably think it might. Mathematically, this would test whether or not value is between myMin and myMax. But in C, what happens is that value is first compared with myMin. This produces either a 0 or a 1. It is this value that is compared against myMax. Example:

```c
int value = 20;
/* ... */
if (0 < value < 10) { // don’t do this! it always evaluates to "true"!
    /* do some stuff */
}
```

Because value is greater than 0, the first comparison produces a value of 1. Now 1 is compared to be less than 10, which is true, so the statements in the if are executed. This probably is not what the programmer expected. The appropriate code would be

```c
int value = 20;
/* ... */
if (0 < value && value < 10) { // the && means "and"
    /* do some stuff */
}
```

15.1.2 Logical Expressions

a || b

when EITHER a or b is true (or both), the result is 1, otherwise the result is 0.

a && b

when BOTH a and b are true, the result is 1, otherwise the result is 0.

!a

when a is true, the result is 0, when a is 0, the result is 1.

Here’s an example of a larger logical expression. In the statement:

```
e = ((a && b) || (c > d));
```

e is set equal to 1 if a and b are non-zero, or if c is greater than d. In all other cases, e is set to 0.

C uses short circuit evaluation of logical expressions. That is to say, once it is able to determine the truth of a logical expression, it does no further evaluation. This is often useful as in the following:
In the snippet of code, the comparison of i with 12 is done first. If it evaluates to 0 (false), i would be out of bounds as an index to `myArray`. In this case, the program never attempts to access `myArray[i]` since the truth of the expression is known to be false. Hence we need not worry here about trying to access an out-of-bounds array element if it is already known that i is greater than or equal to zero. A similar thing happens with expressions involving the or `||` operator.

doThat() is never called if doThis() returns a non-zero (true) value.

### 15.1.3 Bitwise Boolean Expressions

The bitwise operators work bit by bit on the operands. The operands must be of integral type (one of the types used for integers). The six bitwise operators are `&` (AND), `|` (OR), `^` (exclusive OR, commonly called XOR), `~` (NOT, which changes 1 to 0 and 0 to 1), `<<` (shift left), and `>>` (shift right). The negation operator is a unary operator which precedes the operand. The others are binary operators which lie between the two operands. The precedence of these operators is lower than that of the relational and equivalence operators; it is often required to parenthesize expressions involving bitwise operators.

For this section, recall that a number starting with `0x` is hexadecimal, or hex for short. Unlike the normal decimal system using powers of 10 and digits 0123456789, hex uses powers of 16 and digits 0123456789abcdef. Hexadecimal is commonly used in C programs because a programmer can quickly convert it to or from binary (powers of 2 and digits 01). C does not directly support binary notation, which would be really verbose anyway.

#### a & b

bitwise boolean and of a and b

0xc & 0xa produces the value 0x8 (in binary, 1100 & 1010 produces 1000)

#### a | b

bitwise boolean or of a and b

0xc | 0xa produces the value 0xe (in binary, 1100 | 1010 produces 1110)

#### a ^ b

bitwise xor of a and b

0xc ^ 0xa produces the value 0x6 (in binary, 1100 ^ 1010 produces 0110)

### ~a

82
bitwise complement of \texttt{a}.

\texttt{~0xc} produces the value -1-0xc (in binary, \texttt{~1100} produces ...11110011 where”...” may be many more 1 bits)

\texttt{a} \texttt{<<} \texttt{b}

shift \texttt{a} left by \texttt{b} (multiply \texttt{a} by \texttt{2}^\texttt{b})

\texttt{0xc} \texttt{<<} \texttt{1} produces the value \texttt{0x18} (in binary, \texttt{1100} \texttt{<<} \texttt{1} produces the value \texttt{11000})

\texttt{a} \texttt{>>} \texttt{b}

shift \texttt{a} right by \texttt{b} (divide \texttt{a} by \texttt{2}^\texttt{b})

\texttt{0xc} \texttt{>>} \texttt{1} produces the value \texttt{0x6} (in binary, \texttt{1100} \texttt{>>} \texttt{1} produces the value \texttt{110})

15.1.4 The If-Else statement

If-Else provides a way to instruct the computer to execute a block of code only if certain conditions have been met. The syntax of an If-Else construct is:

\begin{verbatim}
if (/* condition goes here */) {
   /* if the condition is non-zero (true), this code will execute */
} else {
   /* if the condition is 0 (false), this code will execute */
}
\end{verbatim}

The first block of code executes if the condition in parentheses directly after the \texttt{if} evaluates to non-zero (true); otherwise, the second block executes.

The \texttt{else} and following block of code are completely optional. If there is no need to execute code if a condition is not true, leave it out.

Also, keep in mind that an \texttt{if} can directly follow an \texttt{else} statement. While this can occasionally be useful, chaining more than two or three if-elses in this fashion is considered bad programming practice. We can get around this with the Switch-Case construct described later.

Two other general syntax notes need to be made that you will also see in other control constructs: First, note that there is no semicolon after \texttt{if} or \texttt{else}. There could be, but the block (code enclosed in \{ and \}) takes the place of that. Second, if you only intend to execute one statement as a result of an \texttt{if} or \texttt{else}, curly braces are not needed. However, many programmers believe that inserting curly braces anyway in this case is good coding practice.

The following code sets a variable \texttt{c} equal to the greater of two variables \texttt{a} and \texttt{b}, or \texttt{0} if \texttt{a} and \texttt{b} are equal.

\begin{verbatim}
if (a > b) {
   c = a;
} else if (b > a) {
   c = b;
} else {
   c = 0;
}
\end{verbatim}

Consider this question: why can't you just forget about \texttt{else} and write the code like:
if (a > b) {
    c = a;
}
if (a < b) {
    c = b;
}
if (a == b) {
    c = 0;
}

There are several answers to this. Most importantly, if your conditionals are not mutually exclusive, two cases could execute instead of only one. If the code was different and the value of a or b changes somehow (e.g.: you reset the lesser of a and b to 0 after the comparison) during one of the blocks? You could end up with multiple if statements being invoked, which is not your intent. Also, evaluating if conditionals takes processor time. If you use else to handle these situations, in the case above assuming (a > b) is non-zero (true), the program is spared the expense of evaluating additional if statements. The bottom line is that it is usually best to insert an else clause for all cases in which a conditional will not evaluate to non-zero (true).

The conditional expression

A conditional expression is a way to set values conditionally in a more shorthand fashion than If-Else. The syntax is:

```c
(/* logical expression goes here */) ? (/* if non-zero (true) */) : (/* if 0 (false) */) 
```

The logical expression is evaluated. If it is non-zero (true), the overall conditional expression evaluates to the expression placed between the ? and :, otherwise, it evaluates to the expression after the :. Therefore, the above example (changing its function slightly such that c is set to b when a and b are equal) becomes:

```c
    c = (a > b) ? a : b;
```

Conditional expressions can sometimes clarify the intent of the code. Nesting the conditional operator should usually be avoided. It’s best to use conditional expressions only when the expressions for a and b are simple. Also, contrary to a common beginner belief, conditional expressions do not make for faster code. As tempting as it is to assume that fewer lines of code result in faster execution times, there is no such correlation.

15.1.5 The Switch-Case statement

Say you write a program where the user inputs a number 1-5 (corresponding to student grades, A(represented as 1)-D(4) and F(5)), stores it in a variable grade and the program responds by printing to the screen the associated letter grade. If you implemented this using If-Else, your code would look something like this:
if (grade == 1) {
    printf("A\n");
} else if (grade == 2) {
    printf("B\n");
} else if /* etc. etc. */

Having a long chain of if-else-if-else-if-else can be a pain, both for the programmer and anyone reading the code. Fortunately, there's a solution: the Switch-Case construct, of which the basic syntax is:

```c
switch (/* integer or enum goes here */) {
    case /* potential value of the aforementioned int or enum */:
        /* code */
    case /* a different potential value */:
        /* different code */
    /* insert additional cases as needed */
    default:
        /* more code */
}
```

The Switch-Case construct takes a variable, usually an int or an enum, placed after `switch`, and compares it to the value following the `case` keyword. If the variable is equal to the value specified after `case`, the construct "activates", or begins executing the code after the `case` statement. Once the construct has "activated", there will be no further evaluation of cases.

Switch-Case is syntactically "weird" in that no braces are required for code associated with a `case`.

**Very important**: Typically, the last statement for each case is a `break` statement. This causes program execution to jump to the statement following the closing bracket of the switch statement, which is what one would normally want to happen. However if the break statement is omitted, program execution continues with the first line of the next case, if any. This is called a fall-through. When a programmer desires this action, a comment should be placed at the end of the block of statements indicating the desire to fall through. Otherwise another programmer maintaining the code could consider the omission of the 'break' to be an error, and inadvertently 'correct' the problem. Here's an example:

```c
switch (someVariable) {
    case 1:
        printf("This code handles case 1\n");
        break;
    case 2:
        printf("This prints when someVariable is 2, along with...
");  /* FALL THROUGH */
    case 3:
        printf("This prints when someVariable is either 2 or 3.\n");
        break;
}
```

If a `default` case is specified, the associated statements are executed if none of the other cases match. A `default` case is optional. Here's a switch statement that corresponds to the sequence of if - else if statements above.

Back to our example above. Here's what it would look like as Switch-Case:

```c
switch (grade) {
    case 1:
        printf("A\n");
        break;
    case 2:
```
A set of statements to execute can be grouped with more than one value of the variable as in the following example. (the fall-through comment is not necessary here because the intended behavior is obvious)

```c
switch (something) {
    case 2:
    case 3:
    case 4:
        /* some statements to execute for 2, 3 or 4 */
        break;
    case 1:
    default:
        /* some statements to execute for 1 or other than 2,3,and 4 */
        break;
}
```

Switch-Case constructs are particularly useful when used in conjunction with user defined `enum` data types. Some compilers are capable of warning about an unhandled enum value, which may be helpful for avoiding bugs.

### 15.2 Loops

Often in computer programming, it is necessary to perform a certain action a certain number of times or until a certain condition is met. It is impractical and tedious to simply type a certain statement or group of statements a large number of times, not to mention that this approach is too inflexible and unintuitive to be counted on to stop when a certain event has happened. As a real-world analogy, someone asks a dishwasher at a restaurant what he did all night. He will respond, "I washed dishes all night long." He is not likely to respond, "I washed a dish, then washed a dish, then washed a dish, then...". The constructs that enable computers to perform certain repetitive tasks are called loops.

#### 15.2.1 While loops

A while loop is the most basic type of loop. It will run as long as the condition is non-zero (true). For example, if you try the following, the program will appear to lock up and you will have to manually close the program down. A situation where the conditions for exiting the loop will never become true is called an infinite loop.

```c
int a = 1;
while (42) {
    a = a * 2;
}
```
Here is another example of a while loop. It prints out all the powers of two less than 100.

```c
int a = 1;
while (a < 100) {
    printf("a is %d \n", a);
    a = a * 2;
}
```

The flow of all loops can also be controlled by `break` and `continue` statements. A break statement will immediately exit the enclosing loop. A continue statement will skip the remainder of the block and start at the controlling conditional statement again. For example:

```c
int a = 1;
while (42) { // loops until the break statement in the loop is executed
    printf("a is %d ", a);
    a = a * 2;
    if (a > 100) {
        break;
    } else if (a == 64) {
        continue; // Immediately restarts at while, skips next step
    }
    printf("a is not 64\n");
}
```

In this example, the computer prints the value of `a` as usual, and prints a notice that `a` is not 64 (unless it was skipped by the continue statement).

Similar to If above, braces for the block of code associated with a While loop can be omitted if the code consists of only one statement, for example:

```c
int a = 1;
while (a < 100)
    a = a * 2;
```

This will merely increase `a` until `a` is not less than 100.

When the computer reaches the end of the while loop, it always goes back to the while statement at the top of the loop, where it re-evaluates the controlling condition. If that condition is "true" at that instant -- even if it was temporarily 0 for a few statements inside the loop -- then the computer begins executing the statements inside the loop again; otherwise the computer exits the loop. The computer does not "continuously check" the controlling condition of a while loop during the execution of that loop. It only "peeks" at the controlling condition each time it reaches the `while` at the top of the loop.

It is very important to note, once the controlling condition of a While loop becomes 0 (false), the loop will not terminate until the block of code is finished and it is time to reevaluate the conditional. If you need to terminate a While loop immediately upon reaching a certain condition, consider using `break`.

A common idiom is to write:

```c
int i = 5;
while (--i) {
    printf("java and c# can't do this\n");
}
```

This executes the code in the while loop 5 times, with `i` having values that range from 4 down to 0 (inside the loop). Conveniently, these are the values needed to access every item of an array containing 5 elements.
15.2.2 For loops

For loops generally look something like this:

```c
for (initialization; test; increment) {
    /* code */
}
```

The *initialization* statement is executed exactly once - before the first evaluation of the *test* condition. Typically, it is used to assign an initial value to some variable, although this is not strictly necessary. The *initialization* statement can also be used to declare and initialize variables used in the loop.

The *test* expression is evaluated each time before the code in the *for* loop executes. If this expression evaluates as 0 (false) when it is checked (i.e. if the expression is not true), the loop is not (re)entered and execution continues normally at the code immediately following the FOR-loop. If the expression is non-zero (true), the code within the braces of the loop is executed.

After each iteration of the loop, the *increment* statement is executed. This often is used to increment the loop index for the loop, the variable initialized in the initialization expression and tested in the test expression. Following this statement execution, control returns to the top of the loop, where the *test* action occurs. If a *continue* statement is executed within the *for* loop, the increment statement would be the next one executed.

Each of these parts of the *for* statement is optional and may be omitted. Because of the free-form nature of the *for* statement, some fairly fancy things can be done with it. Often a *for* loop is used to loop through items in an array, processing each item at a time.

```c
int myArray[12];
int ix;
for (ix = 0; ix < 12; ix++) {
    myArray[ix] = 5 * ix + 3;
}
```

The above for loop initializes each of the 12 elements of *myArray*. The loop index can start from any value. In the following case it starts from 1.

```c
for (ix = 1; ix <= 10; ix++) {
    printf("%d ", ix);
}
```

which will print

```
1 2 3 4 5 6 7 8 9 10
```

You will most often use loop indexes that start from 0, since arrays are indexed at zero, but you will sometimes use other values to initialize a loop index as well.

The *increment* action can do other things, such as *decrement*. So this kind of loop is common:

```c
for (i = 5; i > 0; i--) {
    printf("%d ", i);
}
```
Loops

which yields

5 4 3 2 1

Here's an example where the test condition is simply a variable. If the variable has a value of 0 or NULL, the loop exits, otherwise the statements in the body of the loop are executed.

```c
for (t = list_head; t; t = NextItem(t)) {
    /* body of loop */
}
```

A WHILE loop can be used to do the same thing as a FOR loop, however a FOR loop is a more condensed way to perform a set number of repetitions since all of the necessary information is in a one-line statement.

A FOR loop can also be given no conditions, for example:

```c
for (;;) {
    /* block of statements */
}
```

This is called an infinite loop since it will loop forever unless there is a break statement within the statements of the for loop. The empty test condition effectively evaluates as true.

It is also common to use the comma operator in for loops to execute multiple statements.

```c
int i, j, n = 10;
for (i = 0, j = 0; i < n; i++, j += 2) {
    printf("i = %d , j = %d \n", i, j);
}
```

Special care should be taken when designing or refactoring the conditional part, especially whether using < or <=, whether start and stop should be corrected by 1, and in case of prefix- and postfix-notations. (On a 100 yards promenade with a tree every 10 yards there are 11 trees.)

```c
int i, n = 10;
for (i = 0; i <= n; i++)
    printf("%d ", i); // processed n times => 0 1 2 3 ... (n-1)
printf("\n");
for (i = 0; i <= n; i++)
    printf("%d ", i); // processed (n+1) times => 0 1 2 3 ... n
printf("\n");
for (i = n; i--;)
    printf("%d ", i); // processed n times => (n-1) ...3 2 1 0
printf("\n");
for (i = n; --i;)
    printf("%d ", i); // processed (n-1) times => (n-1) ...4 3 2 1
printf("\n");
```

### 15.2.3 Do-While loops

A DO-WHILE loop is a post-check while loop, which means that it checks the condition after each run. As a result, even if the condition is zero (false), it will run at least once. It follows the form of:
do {
    /* do stuff */
} while (condition);

Note the terminating semicolon. This is required for correct syntax. Since this is also a type of while loop, break and continue statements within the loop function accordingly. A continue statement causes a jump to the test of the condition and a break statement exits the loop.

It is worth noting that Do-While and While are functionally almost identical, with one important difference: Do-While loops are always guaranteed to execute at least once, but While loops will not execute at all if their condition is 0 (false) on the first evaluation.

15.3 One last thing: goto

goto is a very simple and traditional control mechanism. It is a statement used to immediately and unconditionally jump to another line of code. To use goto, you must place a label at a point in your program. A label consists of a name followed by a colon (:) on a line by itself. Then, you can type "goto label;" at the desired point in your program. The code will then continue executing beginning with label. This looks like:

MyLabel:
    /* some code */
    goto MyLabel;

The ability to transfer the flow of control enabled by gotos is so powerful that, in addition to the simple if, all other control constructs can be written using gotos instead. Here, we can let "S" and "T" be any arbitrary statements:

    if ('cond') {
        S;
    } else {
        T;
    }
    /* ... */

The same statement could be accomplished using two gotos and two labels:

    if ('cond') goto Label1;
    T;
    goto Label2;
Label1:
    S;
Label2:
    /* ... */

Here, the first goto is conditional on the value of "cond". The second goto is unconditional. We can perform the same translation on a loop:

    while ('cond1') {
        S;
        if ('cond2')
            break;
        T;
    }
    /* ... */

Which can be written as:
As these cases demonstrate, often the structure of what your program is doing can usually be expressed without using gotos. Undisciplined use of gotos can create unreadable, unmaintainable code when more idiomatic alternatives (such as if-elses, or for loops) can better express your structure. Theoretically, the goto construct does not ever have to be used, but there are cases when it can increase readability, avoid code duplication, or make control variables unnecessary. You should consider first mastering the idiomatic solutions, and use goto only when necessary. Keep in mind that many, if not most, C style guidelines strictly forbid use of *goto*, with the only common exceptions being the following examples.

One use of goto is to break out of a deeply nested loop. Since `break` will not work (it can only escape one loop), `goto` can be used to jump completely outside the loop. Breaking outside of deeply nested loops without the use of the goto is always possible, but often involves the creation and testing of extra variables that may make the resulting code far less readable than it would be with `goto`. The use of `goto` makes it easy to undo actions in an orderly fashion, typically to avoid failing to free memory that had been allocated.

Another accepted use is the creation of a state machine. This is a fairly advanced topic though, and not commonly needed.

### 15.4 Examples

```c
#include <errno.h>
#include <stdio.h>
#include <stdlib.h>

int main(void)
{
    int years;
    printf("Enter your age in years : ");
    fflush(stdout);
    errno = 0;
    if (scanf("%d", &years) != 1 || errno)
        return EXIT_FAILURE;
    printf("Your age in days is %d\n", years * 365);
    return 0;
}
```
15.5 References

de:C-Programmierung: Kontrollstrukturen\textsuperscript{2} et:Programmeerimiskeel C/Keelestruktuurid\textsuperscript{3} fr:Programmation C/Tests\textsuperscript{4} pl:C/Instrukcje sterujące\textsuperscript{5} pt:Programar em C/Controle de fluxo\textsuperscript{6} fi:C/Ohjausrakenteet\textsuperscript{7}

\textsuperscript{2} https://de.wikibooks.org/wiki/C-Programmierung%20Kontrollstrukturen
\textsuperscript{3} https://et.wikibooks.org/wiki/Programmeerimiskeel%20Keelestruktuurid
\textsuperscript{4} https://fr.wikibooks.org/wiki/Programmation%20C%20Tests
\textsuperscript{5} https://pl.wikibooks.org/wiki/C%20Instrukcje%20Steruj\%C4%85ce
\textsuperscript{6} https://pt.wikibooks.org/wiki/Programar%20em%20C%20Controle%20de%20fluxo
\textsuperscript{7} https://fi.wikibooks.org/wiki/C%20Ohjausrakenteet
16 Procedures and functions

In C programming, all executable code resides within a function. A function is a named block of code that performs a task and then returns control to a caller. Note that other programming languages may distinguish between a "function", "subroutine", "subprogram", "procedure", or "method" -- in C, these are all functions.

A function is often executed (called) several times, from several different places, during a single execution of the program. After finishing a subroutine, the program will branch back (return) to the point after the call.

Functions are a powerful programming tool.

As a basic example, suppose you are writing code to print out the first 5 squares of numbers, do some intermediate processing, then print the first 5 squares again. We could write it like this:

```c
#include <stdio.h>

int main(void)
{
    int i;
    for(i=1; i <= 5; i++)
    {
        printf("%d ", i*i);  
    }
    for(i=1; i <= 5; i++)
    {
        printf("%d ", i*i);  
    }
    return 0;
}
```

We have to write the same loop twice. We may want to somehow put this code in a separate place and simply jump to this code when we want to use it. This would look like:

```c
#include <stdio.h>

void Print_Squares(void)
{
    int i;
    for(i=1; i <= 5; i++)
    {
        printf("%d ", i*i);
    }
}

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

This is precisely what functions are for.
16.1 More on functions

A function is like a black box. It takes in input, does something with it, then spits out an answer.

Note that a function may not take any inputs at all, or it may not return anything at all. In the above example, if we were to make a function of that loop, we may not need any inputs, and we aren't returning anything at all (Text output doesn't count - when we speak of returning we mean to say meaningful data that the program can use).

We have some terminology to refer to functions:

- A function, call it $f$, that uses another function $g$, is said to call $g$. For example, $f$ calls $g$ to print the squares of ten numbers.
- A function's inputs are known as its arguments
- A function $g$ that gives some kind of answer back to $f$ is said to return that answer. For example, $g$ returns the sum of its arguments.

16.2 Writing functions in C

It's always good to learn by example. Let's write a function that will return the square of a number.

```c
int square(int x)
{
    int square_of_x;
    square_of_x = x * x;
    return square_of_x;
}
```

To understand how to write such a function like this, it may help to look at what this function does as a whole. It takes in an `int`, $x$, and squares it, storing it in the variable `square_of_x`. Now this value is returned.

The first `int` at the beginning of the function declaration is the type of data that the function returns. In this case when we square an integer we get an integer, and we are returning this integer, and so we write `int` as the return type.

Next is the name of the function. It is good practice to use meaningful and descriptive names for functions you may write. It may help to name the function after what it is written to do. In this case we name the function "square", because that's what it does - it squares a number.

Next is the function's first and only argument, an `int`, which will be referred to in the function as $x$. This is the function's input.

In between the braces is the actual guts of the function. It declares an integer variable called `square_of_x` that will be used to hold the value of the square of $x$. Note that the variable `square_of_x` can only be used within this function, and not outside. We'll learn more about this sort of thing later, and we will see that this property is very useful.

We then assign $x$ multiplied by $x$, or $x$ squared, to the variable `square_of_x`, which is what this function is all about. Following this is a return statement. We want to return
the value of the square of x, so we must say that this function returns the contents of the variable square_of_x.

Our brace to close, and we have finished the declaration.

Written in a more concise manner, this code performs exactly the same function as the above:

```c
def square(int x):
    return x * x;
```

Note this should look familiar - you have been writing functions already, in fact - main is a function that is always written.

16.2.1 In general

In general, if we want to declare a function, we write

```c
type name(type1 arg1, type2 arg2, ...)
{
    /* code */
}
```

We've previously said that a function can take no arguments, or can return nothing, or both. What do we write if we want the function to return nothing? We use C's `void` keyword. `void` basically means "nothing" - so if we want to write a function that returns nothing, for example, we write

```c
void sayhello(int number_of_times)
{
    int i;
    for(i=1; i <= number_of_times; i++) {
        printf("Hello!\n");
    }
}
```

Notice that there is no `return` statement in the function above. Since there's none, we write `void` as the return type. (Actually, one can use the `return` keyword in a procedure to return to the caller before the end of the procedure, but one cannot return a value as if it were a function.)

What about a function that takes no arguments? If we want to do this, we can write for example

```c
float calculate_number(void)
{
    float to_return=1;
    int i;
    for(i=0; i < 100; i++) {
        to_return *= 1;
        to_return = 1/to_return;
    }
    return to_return;
}
```
Procedures and functions

Notice this function doesn't take any inputs, but merely returns a number calculated by this function.

Naturally, you can combine both void return and void in arguments together to get a valid function, also.

### 16.2.2 Recursion

Here's a simple function that does an infinite loop. It prints a line and calls itself, which again prints a line and calls itself again, and this continues until the stack overflows and the program crashes. A function calling itself is called recursion, and normally you will have a conditional that would stop the recursion after a small, finite number of steps.

```c
// don't run this!
void infinite_recursion()
{
    printf("Infinite loop!\n");
    infinite_recursion();
}
```

A simple check can be done like this. Note that `++depth` is used so the increment will take place before the value is passed into the function. Alternatively you can increment on a separate line before the recursion call. If you say `print_me(3,0);` the function will print the line Recursion 3 times.

```c
void print_me(int j, int depth)
{
    if(depth < j) {
        printf("Recursion! depth = %d j = %d\n",depth,j); // j keeps its value
        print_me(j, ++depth);
    }
}
```

Recursion is most often used for jobs such as directory tree scans, seeking for the end of a linked list, parsing a tree structure in a database and factorising numbers (and finding primes) among other things.

### 16.2.3 Static functions

If a function is to be called only from within the file in which it is declared, it is appropriate to declare it as a static function. When a function is declared static, the compiler will now compile to an object file in a way that prevents the function from being called from code in other files. Example:

```c
static int compare( int a, int b )
{
    return (a+4 < b)? a : b;
}
```

### 16.3 Using C functions

We can now write functions, but how do we use them? When we write main, we place the function outside the braces that encompass main.
When we want to use that function, say, using our `calculate_number` function above, we can write something like

```c
float f;
f = calculate_number();
```

If a function takes in arguments, we can write something like

```c
int square_of_10;
square_of_10 = square(10);
```

If a function doesn't return anything, we can just say

```c
say_hello();
```

since we don't need a variable to catch its return value.

### 16.4 Functions from the C Standard Library

While the C language doesn't itself contain functions, it is usually linked with the C Standard Library. To use this library, you need to add an `#include` directive at the top of the C file, which may be one of the following:

- `<assert.h>`
- `<ctype.h>`
- `<cerrno.h>`
- `<float.h>`
- `<limits.h>`
- `<locale.h>`
- `<math.h>`
- `<setjmp.h>`
- `<signal.h>`
- `<stdarg.h>`
- `<stddef.h>`
- `<stdio.h>`
- `<stdlib.h>`
- `<string.h>`
- `<time.h>`
- `<complex.h>`

The functions available are:

<table>
<thead>
<tr>
<th><code>&lt;assert.h&gt;</code></th>
<th><code>&lt;limits.h&gt;</code></th>
<th><code>&lt;signal.h&gt;</code></th>
<th><code>&lt;stdlib.h&gt;</code></th>
</tr>
</thead>
</table>

1. [https://en.wikipedia.org/wiki/Assert.h](https://en.wikipedia.org/wiki/Assert.h)
5. [https://en.wikipedia.org/wiki/Limits.h](https://en.wikipedia.org/wiki/Limits.h)
6. [https://en.wikipedia.org/wiki/Locale.h](https://en.wikipedia.org/wiki/Locale.h)
## Procedures and functions

<table>
<thead>
<tr>
<th><code>&lt;assert.h&gt;</code></th>
<th><code>&lt;limits.h&gt;</code></th>
<th><code>&lt;signal.h&gt;</code></th>
<th><code>&lt;stdlib.h&gt;</code></th>
</tr>
</thead>
<tbody>
<tr>
<td>• assert(int)</td>
<td>• (constants only)</td>
<td>• int raise(int sig). This</td>
<td>• atof(char*), atoi(char*), atol(char*)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• void* signal(int sig, void (*func)(int))</td>
<td>• strtof(char * str, char ** endptr), strtol(char *str, char **endptr), strtoul(char *str, char **endptr)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• rand(), srand()</td>
<td>• rand()</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• malloc(size_t), calcloc(size_t elements, size_t elementSize), realloc(void*, int)</td>
<td>• malloc(size_t), calcloc(size_t elements, size_t elementSize), realloc(void*, int)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• exit(int), abort()</td>
<td>• exit(int), abort()</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• atexit(void (*func)())</td>
<td>• atexit(void (*func)())</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• getenv</td>
<td>• getenv</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• system</td>
<td>• system</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• qsort(void <em>, size_t number, size_t size, int (<em>sortfunc)(void</em>, void</em>))</td>
<td>• qsort(void <em>, size_t number, size_t size, int (<em>sortfunc)(void</em>, void</em>))</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• abs, labs</td>
<td>• abs, labs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• div, ldiv</td>
<td>• div, ldiv</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><code>&lt;ctype.h&gt;</code></th>
<th><code>&lt;locale.h&gt;</code></th>
<th><code>&lt;stdarg.h&gt;</code></th>
<th><code>&lt;string.h&gt;</code></th>
</tr>
</thead>
<tbody>
<tr>
<td>• isalnum, isalpha, isblank</td>
<td></td>
<td>• va_start(va_list, ap)</td>
<td>• memcasecmp, memmove</td>
</tr>
<tr>
<td>• iscntrl, isdigit, isgraph</td>
<td>• struct lconv* localeconv(void);</td>
<td>• va_arg(ap, (type))</td>
<td>• memchr, memcmpeq, memmove</td>
</tr>
<tr>
<td>• islower, isprint, ispunct</td>
<td>• char* setlocale(int, const char*);</td>
<td>• va_end(ap)</td>
<td>• strcat, strncat, strchr, strcch</td>
</tr>
<tr>
<td>• isspace, isupper, isxdigit</td>
<td>• va_copy(va_list, va_list)</td>
<td>• va_copy(va_list, va_list)</td>
<td>• strlen</td>
</tr>
<tr>
<td>• tolower, toupper</td>
<td></td>
<td></td>
<td>• strerror</td>
</tr>
</tbody>
</table>

| `errno.h` | `math.h` | `stdio.h` | `time.h` |
Variable-length argument lists

Functionswith variable-length argument lists are functions that can take a varying number of arguments. An example in the C standard library is the `printf` function, which can take any number of arguments depending on how the programmer wants to use it.

C programmers rarely find the need to write new functions with variable-length arguments. If they want to pass a bunch of things to a function, they typically define a structure to

---

16.5 Variable-length argument lists

Functions with variable-length argument lists are functions that can take a varying number of arguments. An example in the C standard library is the `printf` function, which can take any number of arguments depending on how the programmer wants to use it.

C programmers rarely find the need to write new functions with variable-length arguments. If they want to pass a bunch of things to a function, they typically define a structure to

---

17 https://en.wikibooks.org/wiki/%2Fprintf%2F
18 http://www.utas.edu.au/infosys/info/documentation/C/CStdLib.html#ctype.h
Procedures and functions

hold all those things -- perhaps a linked list, or an array -- and call that function with the data in the arguments.

However, you may occasionally find the need to write a new function that supports a variable-length argument list. To create a function that can accept a variable-length argument list, you must first include the standard library header `stdarg.h`. Next, declare the function as you would normally. Next, add as the last argument an ellipsis ("..."). This indicates to the compiler that a variable list of arguments is to follow. For example, the following function declaration is for a function that returns the average of a list of numbers:

```c
float average (int n_args, ...);
```

Note that because of the way variable-length arguments work, we must somehow, in the arguments, specify the number of elements in the variable-length part of the arguments. In the `average` function here, it's done through an argument called `n_args`. In the `printf` function, it's done with the format codes that you specify in that first string in the arguments you provide.

Now that the function has been declared as using variable-length arguments, we must next write the code that does the actual work in the function. To access the numbers stored in the variable-length argument list for our `average` function, we must first declare a variable for the list itself:

```c
va_list myList;
```

The `va_list` type is a type declared in the `stdarg.h` header that basically allows you to keep track of your list. To start actually using `myList`, however, we must first assign it a value. After all, simply declaring it by itself wouldn't do anything. To do this, we must call `va_start`, which is actually a macro defined in `stdarg.h`. In the arguments to `va_start`, you must provide the `va_list` variable you plan on using, as well as the name of the last variable appearing before the ellipsis in your function declaration:

```c
#include <stdarg.h>
float average (int n_args, ...)
{
    va_list myList;
    va_start (myList, n_args);
    va_end (myList);
}
```

Now that `myList` has been prepped for usage, we can finally start accessing the variables stored in it. To do so, use the `va_arg` macro, which pops off the next argument on the list. In the arguments to `va_arg`, provide the `va_list` variable you're using, as well as the primitive data type (e.g. `int`, `char`) that the variable you're accessing should be:

```c
#include <stdarg.h>
float average (int n_args, ...)
{
    va_list myList;
    va_start (myList, n_args);

    int myNumber = va_arg (myList, int);
    va_end (myList);
}
```

By popping `n_args` integers off of the variable-length argument list, we can manage to find the average of the numbers:
```c
#include <stdarg.h>
float average (int n_args, ...) {
    va_list myList;
    va_start (myList, n_args);
    int numbersAdded = 0;
    int sum = 0;
    while (numbersAdded < n_args) {
        int number = va_arg (myList, int); // Get next number from list
        sum += number;
        numbersAdded += 1;
    }
    va_end (myList);

    float avg = (float)(sum) / (float)(numbersAdded); // Find the average
    return avg;
}
```

By calling `average (2, 10, 20)`, we get the average of 10 and 20, which is 15.

### 16.6 References

fr:Programmation C/Fonctions et procédures
it:C/Blocchi e funzioni/Funzioni
pl:C/Funkcje

19 [https://fr.wikibooks.org/wiki/Programmation%C3%A0C%2FFonctions%20et%20proc%C3%A9dures](https://fr.wikibooks.org/wiki/Programmation%C3%A0C%2FFonctions%20et%20proc%C3%A9dures)
20 [https://it.wikibooks.org/wiki/C%2FBlocchi%20e%20funzioni%2FFunzioni](https://it.wikibooks.org/wiki/C%2FBlocchi%20e%20funzioni%2FFunzioni)
21 [https://pl.wikibooks.org/wiki/C%2FFunkcje](https://pl.wikibooks.org/wiki/C%2FFunkcje)
17 Preprocessor

Preprocessors are a way of making text processing with your C program before they are actually compiled. Before the actual compilation of every C program it is passed through a Preprocessor. The Preprocessor looks through the program trying to find out specific instructions called Preprocessor directives that it can understand. All Preprocessor directives begin with the # (hash) symbol. C++ compilers use the same C preprocessor.1

The preprocessor2 is a part of the compiler which performs preliminary operations (conditionally compiling code, including files etc...) to your code before the compiler sees it. These transformations are lexical, meaning that the output of the preprocessor is still text.

NOTE: Technically the output of the preprocessing phase for C consists of a sequence of tokens, rather than source text, but it is simple to output source text which is equivalent to the given token sequence, and that is commonly supported by compilers via a -E or /E option -- although command line options to C compilers aren’t completely standard, many follow similar rules.

17.1 Directives

Directives are special instructions directed to the preprocessor (preprocessor directive) or to the compiler3 (compiler directive) on how it should process part or all of your source code or set some flags on the final object and are used to make writing source code easier (more portable for instance) and to make the source code more understandable. Directives are handled by the preprocessor, which is either a separate program invoked by the compiler or part of the compiler itself.

17.1.1 #include

C has some features as part of the language and some others as part of a standard library, which is a repository of code that is available alongside every standard-conformant C compiler. When the C compiler compiles your program it usually also links it with the standard C library. For example, on encountering a #include <stdio.h> directive, it replaces the directive with the contents of the stdio.h header file.


2 https://en.wikipedia.org/wiki/Preprocessor

3 https://en.wikipedia.org/wiki/compiler
When you use features from the library, C requires you to declare what you would be using. The first line in the program is a preprocessor directive which should look like this:

```c
#include <stdio.h>
```

The above line causes the C declarations which are in the `stdio.h` header\(^4\) to be included for use in your program. Usually this is implemented by just inserting into your program the contents of a header file called `stdio.h`, located in a system-dependent location. The location of such files may be described in your compiler's documentation. A list of standard C header files is listed below in the Headers table.

The `stdio.h` header contains various declarations for input/output (I/O) using an abstraction of I/O mechanisms called streams. For example there is an output stream object called `stdout` which is used to output text to the standard output, which usually displays the text on the computer screen.

If using angle brackets like the example above, the preprocessor is instructed to search for the include file along the development environment path for the standard includes.

```c
#include "other.h"
```

If you use quotation marks (" "), the preprocessor is expected to search in some additional, usually user-defined, locations for the header file, and to fall back to the standard include paths only if it is not found in those additional locations. It is common for this form to include searching in the same directory as the file containing the `#include` directive.

NOTE: You should check the documentation of the development environment you are using for any vendor specific implementations of the `#include` directive.

**Headers**

**The C90 standard headers list:**

17.1.2 #pragma

The **pragma** (pragmatic information) directive is part of the standard, but the meaning of any pragma depends on the software implementation of the standard that is used. The #pragma directive provides a way to request special behavior from the compiler. This directive is most useful for programs that are unusually large or that need to take advantage of the capabilities of a particular compiler.

Pragmas are used within the source program.

```
#pragma token(s)
```

1. pragma is usually followed by a single token, which represents a command for the compiler to obey. You should check the software implementation of the C standard you intend on using for a list of the supported tokens. Not surprisingly, the set of commands that can appear in #pragma directives is different for each compiler; you'll have to consult the documentation for your compiler to see which commands it allows and what those commands do.

---

5  https://en.wikipedia.org/wiki/Assert.h  
6  https://en.wikipedia.org/wiki/Ctype.h  
7  https://en.wikipedia.org/wiki/Errno.h  
8  https://en.wikipedia.org/wiki/Float.h  
9  https://en.wikipedia.org/wiki/Limits.h  
10  https://en.wikipedia.org/wiki/Locale.h  
11  https://en.wikipedia.org/wiki/Math.h  
12  https://en.wikipedia.org/wiki/Setjmp.h  
14  https://en.wikipedia.org/wiki/Stdarg.h  
15  https://en.wikipedia.org/wiki/Stddef.h  
16  https://en.wikipedia.org/wiki/Stdio.h  
17  https://en.wikipedia.org/wiki/Stdlib.h  
18  https://en.wikipedia.org/wiki/String.h  
19  https://en.wikipedia.org/wiki/Time.h  
20  https://en.wikipedia.org/wiki/Complex.h  
21  https://en.wikipedia.org/wiki/Fenv.h  
22  https://en.wikipedia.org/wiki/Inttypes.h  
23  https://en.wikipedia.org/wiki/Isot646.h  
24  https://en.wikipedia.org/wiki/Stdbool.h  
26  https://en.wikipedia.org/wiki/Tgmath.h  
27  https://en.wikipedia.org/wiki/Wchar.h  
28  https://en.wikipedia.org/wiki/Wctype.h  

---
For instance one of the most implemented preprocessor directives, `#pragma once` when placed at the beginning of a header file, indicates that the file where it resides will be skipped if included several times by the preprocessor.

NOTE: Other methods exist to do this action that is commonly referred as using include guards.

### 17.1.3 `#define`

WARNING: Preprocessor macros, although tempting, can produce quite unexpected results if not done right. Always keep in mind that macros are textual substitutions done to your source code before anything is compiled. The compiler does not know anything about the macros and never gets to see them. This can produce obscure errors, amongst other negative effects. Prefer to use language features, if there are equivalent (In example use `const int` or `enum` instead of `#define` constants). That said, there are cases, where macros are very useful (see the `debug` macro below for an example).

The `#define` directive is used to define values or macros that are used by the preprocessor to manipulate the program source code before it is compiled. Because preprocessor definitions are substituted before the compiler acts on the source code, any errors that are introduced by `#define` are difficult to trace.

By convention, values defined using `#define` are named in uppercase. Although doing so is not a requirement, it is considered very bad practice to do otherwise. This allows the values to be easily identified when reading the source code.

Today, `#define` is primarily used to handle compiler and platform differences. E.g., a define might hold a constant which is the appropriate error code for a system call. The use of `#define` should thus be limited unless absolutely necessary; `typedef` statements and constant variables can often perform the same functions more safely.

Another feature of the `#define` command is that it can take arguments, making it rather useful as a pseudo-function creator. Consider the following code:

```c
#define ABSOLUTE_VALUE( x ) ( ((x) < 0) ? -(x) : (x) )
...
int x = -1;
while( ABSOLUTE_VALUE( x ) ) {
    ...
}
```

It's generally a good idea to use extra parentheses when using complex macros. Notice that in the above example, the variable "x" is always within its own set of parentheses. This way, it will be evaluated in whole, before being compared to 0 or multiplied by -1. Also, the entire macro is surrounded by parentheses, to prevent it from being contaminated by other code. If you're not careful, you run the risk of having the compiler misinterpret your code.
Because of side-effects it is considered a very bad idea to use macro functions as described above.

```c
int x = -10;
int y = ABSOLUTE_VALUE(x++);
```

If ABSOLUTE_VALUE() were a real function 'x' would now have the value of '-9', but because it was an argument in a macro it was expanded twice and thus has a value of -8.
Example: To illustrate the dangers of macros, consider this naive macro 
#define MAX(a, b) a>b?a:band the code 
i = MAX(2,3) + 5; 
j = MAX(3,2) + 5; 
Take a look at this and consider what the value after execution might be. The statements are turned into 
int i = 2 > 3?2:3 + 5; int j = 3 > 2?3:2 + 5; 
Thus, after execution i = 8 and j = 3 instead of the expected result of i = j = 8! This is why you were cautioned to use an extra set of parenthesis above, but even with these, the road is fraught with dangers. The alert reader might quickly realize that if \texttt{a} or \texttt{b} contains expressions, the definition must parenthesize every use of \texttt{a,b} in the macro definition, like this: 
#define MAX(a, b) ((a)>(b)?(a):(b)) 
This works, provided \texttt{a,b} have no side effects. Indeed, 
i = 2; j = 3; \texttt{k = MAX(i++, j++);} would result in \texttt{k = 4, i = 3 and j = 5}. This would be highly surprising to anyone expecting \texttt{MAX()} to behave like a function. So what is the correct solution? The solution is not to use macro at all. A global, inline function, like this inline int max(int a, int b) { return a>b?a:b } has none of the pitfalls above, but will not work with all types. 

NOTE: The explicit \texttt{inline} declaration is not really necessary unless the definition is in a header file, since your compiler can inline functions for you (with gcc this can be done with \texttt{-finline-functions} or \texttt{-O3}). The compiler is often better than the programmer at predicting which functions are worth inlining. Also, function calls are not really expensive (they used to be). The compiler is actually free to ignore the \texttt{inline} keyword. It is only a hint (except that \texttt{inline} is necessary in order to allow a function to be defined in a header file without generating an error message due to the function being defined in more than one translation unit).
Directives

The # and ## operators are used with the \texttt{\#define} macro. Using \# causes the first argument after the # to be returned as a string in quotes. For example, the command

\begin{verbatim}
#define as_string( s ) # s
\end{verbatim}

will make the compiler turn this command

\begin{verbatim}
puts( as_string( Hello World! ) );
\end{verbatim}

into

\begin{verbatim}
puts( "Hello World!" );
\end{verbatim}

Using ## concatenates what's before the ## with what's after it. For example, the command

\begin{verbatim}
#define concatenate( x, y ) x ## y
... int xy = 10;
...
\end{verbatim}

will make the compiler turn

\begin{verbatim}
printf( "%d", concatenate( x, y ));
\end{verbatim}

into

\begin{verbatim}
printf( "%d", xy);
\end{verbatim}

which will, of course, display 10 to standard output.

It is possible to concatenate a macro argument with a constant prefix or suffix to obtain a valid identifier as in

\begin{verbatim}
#define make_function( name ) int my_ ## name (int foo) {}
make_function( bar )
\end{verbatim}

which will define a function called \texttt{my\_bar()}. But it isn't possible to integrate a macro argument into a constant string using the concatenation operator. In order to obtain such an effect, one can use the ANSI C property that two or more consecutive string constants are considered equivalent to a single string constant when encountered. Using this property, one can write
#define eat( what ) puts( "I'm eating " #what " today." )
eat( fruit )

which the macro-processor will turn into

puts( "I'm eating " "fruit" " today." )

which in turn will be interpreted by the C parser as a single string constant.

The following trick can be used to turn a numeric constants into string literals

```
#define num2str(x) str(x)
#define str(x) #x
#define CONST 23
puts(num2str(CONST));
```

This is a bit tricky, since it is expanded in 2 steps. First num2str(CONST) is replaced with str(23), which in turn is replaced with "23". This can be useful in the following example:

```
#include <stdio.h>
#define SLICES 8
#define ADD(x) ( (x) / SLICES )

int main(void)
{
    int a = 0, b = 10, c = 6;

    a = ADD(b + c);

    // Example of using num2str
    puts(num2str(a));
}
```

This will give you a nice debug message including the file and the line where the message was issued. If DEBUG is not defined however the debugging message will completely vanish from your code. Be careful not to use this sort of construct with anything that has side effects, since this can lead to bugs, that appear and disappear depending on the compilation parameters.

### 17.1.4 macros

Macros aren’t type-checked and so they do not evaluate arguments. Also, they do not obey scope properly, but simply take the string passed to them and replace each occurrence of the macro argument in the text of the macro with the actual string for that parameter (the code is literally copied into the location it was called from).

An example on how to use a macro:

```
#include <stdio.h>
#define SLICES 8
#define ADD(x) ( (x) / SLICES )

int main(void)
{
    int a = 0, b = 10, c = 6;

    a = ADD(b + c);
    puts("A");
}
```
```c
printf("%d\n", a);
return 0;
}
```

-- the result of "a" should be "2" (b + c = 16 -> passed to ADD -> 16 / SLICES -> result is "2")

**NOTE:**
It is usually bad practice to define macros in headers. A macro should be defined only when it is not possible to achieve the same result with a function or some other mechanism. Some compilers are able to optimize code to where calls to small functions are replaced with inline code, negating any possible speed advantage. Using typedefs, enums, and `inline` (in C99) is often a better option.

One of the few situations where inline functions won't work -- so you are pretty much forced to use function-like macros instead -- is to initialize compile time constants (static initialization of structs). This happens when the arguments to the macro are literals that the compiler can optimize to another literal. 29

### 17.1.5 `#error`

The `#error` directive halts compilation. When one is encountered the standard specifies that the compiler should emit a diagnostic containing the remaining tokens in the directive. This is mostly used for debugging purposes.

Programmers use "#error" inside a conditional block, to immediately halt the compiler when the "#if" or "#ifdef" -- at the beginning of the block -- detects a compile-time problem. Normally the compiler skips the block (and the "#error" directive inside it) and the compilation proceeds.

* `#error` message

### 17.1.6 `#warning`

Many compilers support a `#warning` directive. When one is encountered, the compiler emits a diagnostic containing the remaining tokens in the directive.

* `#warning` message

### 17.1.7 `#undef`

The `#undef` directive undefines a macro. The identifier need not have been previously defined.

---

17.1.8 #if, #else, #elif, #endif (conditionals)

The #if command checks whether a controlling conditional expression evaluates to zero or nonzero, and excludes or includes a block of code respectively. For example:

```
#if 1
    /* This block will be included */
#endif
#if 0
    /* This block will not be included */
#endif
```

The conditional expression could contain any C operator except for the assignment operators, the increment and decrement operators, the address-of operator, and the sizeof operator.

One unique operator used in preprocessing and nowhere else is the defined operator. It returns 1 if the macro name, optionally enclosed in parentheses, is currently defined; 0 if not.

The #endif command ends a block started by #if, #ifdef, or #ifndef.

The #elif command is similar to #if, except that it is used to extract one from a series of blocks of code. E.g.:

```
#if /* some expression */
    :
    :
#elif /* another expression */
    /* imagine many more #elsifs here ... */
    :
#else
    /* The optional #else block is selected if none of the previous #if or #elif blocks are selected */
    :
#endif /* The end of the #if block */
```

17.1.9 #ifdef, #ifndef

The #ifdef command is similar to #if, except that the code block following it is selected if a macro name is defined. In this respect,

```
#define NAME
```

is equivalent to

```
#if defined NAME
```

The #ifndef command is similar to #ifdef, except that the test is reversed:
Useful Preprocessor Macros for Debugging

```c
#ifdef NAME
#else
#endif
```

is equivalent to

```c
#if !defined NAME
#else
#endif
```

### 17.2 Useful Preprocessor Macros for Debugging

ANSI C defines some useful preprocessor macros and variables,\(^{30}\)\(^{31}\) also called ”magic constants”, include:

<table>
<thead>
<tr>
<th>Macro</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>__FILE__</code></td>
<td>The name of the current file, as a string literal</td>
</tr>
<tr>
<td><code>__LINE__</code></td>
<td>Current line of the source file, as a numeric literal</td>
</tr>
<tr>
<td><code>__DATE__</code></td>
<td>Current system date, as a string</td>
</tr>
<tr>
<td><code>__TIME__</code></td>
<td>Current system time, as a string</td>
</tr>
<tr>
<td><code>__TIMESTAMP__</code></td>
<td>Date and time (non-standard)</td>
</tr>
<tr>
<td><code>__cplusplus</code></td>
<td>undefined when your C code is being compiled by a C compiler; 199711L when your C code is being compiled by a C++ compiler compliant with 1998 C++ standard.</td>
</tr>
<tr>
<td><code>__func__</code></td>
<td>Current function name of the source file, as a string (part of C99)</td>
</tr>
<tr>
<td><code>__PRETTY_FUNCTION__</code></td>
<td>”decorated” Current function name of the source file, as a string (in GCC; non-standard)</td>
</tr>
</tbody>
</table>

#### Compile-time assertions

Compile-time assertions can help you debug faster than using only run-time assert() statements, because the compile-time assertions are all tested at compile time, while it is possible that a test run of a program may fail to exercise some run-time assert() statements.

\(^{30}\) HP C Compiler Reference Manual \(^{http://docs.hp.com/en/B3901-90003/ch07s04.html}\)

\(^{31}\) C++ reference: Predefined preprocessor variables \(^{http://www.cppreference.com/wiki/preprocessor/preprocessor_vars}\)
Prior to the C11 standard, some people\textsuperscript{32,33,34} defined a preprocessor macro to allow compile-time assertions, something like:

\begin{verbatim}
#define COMPILETIME_ASSERT(pred) switch(0){case 0:case pred:;}

COMPILETIME_ASSERT( BOOLEAN CONDITION );
\end{verbatim}

The \texttt{static\_assert.hpp} Boost library\textsuperscript{35} defines a similar macro.\textsuperscript{36}

Since C11, such macros are obsolete, as \texttt{\_Static\_assert} and its macro equivalent \texttt{static\_assert} are standardized and built-in to the language.

\section*{X-Macros}

UNKNOWN TEMPLATE merge to

\section*{C Programming/Serialization/\#X-Macros}

One little-known usage pattern of the C preprocessor is known as "X-Macros"\textsuperscript{37,38,39,40} An X-Macro is a header file\textsuperscript{41} or macro. Commonly these use the extension ".def" instead of the traditional ".h". This file contains a list of similar macro calls, which can be referred to as "component macros". The include file is then referenced repeatedly in the following pattern. Here, the include file is "xmacro.def" and it contains a list of component macros of the style "foo(x, y, z)".

\begin{verbatim}
#define foo(x, y, z) doSomethingWith(x, y, z);
#include "xmacro.def"
#undef foo
#define foo(x, y, z) doSomethingElseWith(x, y, z);
#include "xmacro.def"
#undef foo
(etc...)
\end{verbatim}

\footnotesize
\textsuperscript{32} "Compile Time Assertions in C" \texttt{http://www.jaggersoft.com/pubs/CVu11_3.html} by Jon Jagger 1999
\textsuperscript{33} Pádraig Brady. "static assertion" \texttt{http://www.pixelbeat.org/programming/gcc/static\_assert.html}.
\textsuperscript{34} "ternary operator with a constant (true) value?" \texttt{http://stackoverflow.com/questions/27586311/ternary-operator-with-a-constant-true-value}.
\textsuperscript{36} Wikipedia: C++0x#Static assertions \texttt{https://en.wikipedia.org/wiki/%20C%2B%2B%20%23Static%20assertions}
\textsuperscript{39} Stephan Beal. Supermacros Supermacros \texttt{wanderinghorse.net/computing/papers/#supermacros}. August 2004 \texttt{http://wanderinghorse.net/computing/papers/#supermacros}
Useful Preprocessor Macros for Debugging

The most common usage of X-Macros is to establish a list of C objects and then automatically generate code for each of them. Some implementations also perform any #undefs they need inside the X-Macro, as opposed to expecting the caller to undefine them.

Common sets of objects are a set of global configuration settings, a set of members of a struct, a list of possible XML tags for converting an XML file to a quickly-traversable tree, or the body of an enum declaration; other lists are possible.

Once the X-Macro has been processed to create the list of objects, the component macros can be redefined to generate, for instance, accessor and/or mutator functions. Structure serializing and deserializing are also commonly done.

Here is an example of an X-Macro that establishes a struct and automatically creates serialize/deserialize functions. For simplicity, this example doesn’t account for endianness or buffer overflows.

File star.def:

```c
#define EXPAND_EXPAND_STAR_MEMBER(x, int) 
#define EXPAND_EXPAND_STAR_MEMBER(y, int) 
#define EXPAND_EXPAND_STAR_MEMBER(z, int) 
#define EXPAND_EXPAND_STAR_MEMBER(radius, double) 
#undef EXPAND_EXPAND_STAR_MEMBER
```

File star_table.c:

```c
typedef struct {
    int x;
    int y;
    int z;
    double radius;
} starStruct;

void serialize_star(const starStruct *const star, unsigned char *buffer) {
    memcpy(buffer, &(star->x), sizeof(star->x)); 
    buffer += sizeof(star->x);
    memcpy(buffer, &(star->y), sizeof(star->y)); 
    buffer += sizeof(star->y);
    memcpy(buffer, &(star->z), sizeof(star->z)); 
    buffer += sizeof(star->z);
    memcpy(buffer, &(star->radius), sizeof(star->radius)); 
    buffer += sizeof(star->radius);
}

void deserialize_star(starStruct *const star, const unsigned char *buffer) {
    memcpy(&(star->x), buffer, sizeof(star->x)); 
    buffer += sizeof(star->x);
    memcpy(&(star->y), buffer, sizeof(star->y)); 
    buffer += sizeof(star->y);
    memcpy(&(star->z), buffer, sizeof(star->z)); 
    buffer += sizeof(star->z);
    memcpy(&(star->radius), buffer, sizeof(star->radius)); 
    buffer += sizeof(star->radius);
}
```

Handlers for individual data types may be created and accessed using token concatenation (“##”) and quoting (“#”) operators. For example, the following might be added to the above code:

```c
#define EXPAND_EXPAND_STAR_MEMBER(member, type) 
#define print_int(val) printf("%d", val) 
#define print_double(val) printf("%g", val)

void print_star(const starStruct *const star) {
    printf("%s: ", #member);
}
```

References:
Note that in this example you can also avoid the creation of separate handler functions for each datatype in this example by defining the print format for each supported type, with the additional benefit of reducing the expansion code produced by this header file:

```c
#define FORMAT_(type) FORMAT_##type
#define FORMAT_int "%d"
#define FORMAT_double "%g"

void print_star(const starStruct *const star) {
    /* FORMAT_(type) will be replaced with FORMAT_int or FORMAT_double */
    #define EXPAND_EXPAND_STAR_MEMBER(member, type) \
        printf("%s: " FORMAT_(type) "\n", #member, star->member);
    #include "star.def"
}
```

The creation of a separate header file can be avoided by creating a single macro containing what would be the contents of the file. For instance, the above file "star.def" could be replaced with this macro at the beginning of:

```c
#define EXPAND_STAR \
    EXPAND_STAR_MEMBER(x, int) \n    EXPAND_STAR_MEMBER(y, int) \n    EXPAND_STAR_MEMBER(z, int) \n    EXPAND_STAR_MEMBER(radius, double)
```

and then all calls to `#include "star.def"` could be replaced with a simple `EXPAND_STAR` statement. The rest of the above file would become:

```c
typedef struct {
    #define EXPAND_STAR_MEMBER(member, type) type member;
    EXPAND_STAR
    } starStruct;
}
```

```c
void serialize_star(const starStruct *const star, unsigned char *buffer) {
    #define EXPAND_STAR_MEMBER(member, type) \
        memcpy(buffer, &(star->member), sizeof(star->member)); \
        buffer += sizeof(star->member);
    EXPAND_STAR
    #undef EXPAND_STAR_MEMBER
}
```

```c
void deserialize_star(starStruct *const star, const unsigned char *buffer) {
    #define EXPAND_STAR_MEMBER(member, type) \
        memcpy(&(%(star->member)), buffer, sizeof(star->member)); \
        buffer += sizeof(star->member);
    EXPAND_STAR
    #undef EXPAND_STAR_MEMBER
}
```

and the print handler could be added as well as:

```c
#define print_int(val) printf("%d", val)
#define print_double(val) printf("%g", val)
```

```c
void print_star(const starStruct *const star) {
    /* print_##type will be replaced with print_int or print_double */
    #define EXPAND_STAR_MEMBER(member, type) \
        printf("%s: ", #member);
    #include "star.def"
}
```
Useful Preprocessor Macros for Debugging

```c
print_##type(star->member); \nprintf("\n");
EXPAND_STAR
#undef EXPAND_STAR_MEMBER
}

or as:
#define FORMAT_(type) FORMAT_##type
#define FORMAT_int "%d"
#define FORMAT_double "%g"

void print_star(const starStruct *const star) {
    /* FORMAT_(type) will be replaced with FORMAT_int or FORMAT_double */
    #define EXPAND_STAR_MEMBER(member, type) \
    printf("%s: " FORMAT_(type) "\n", #member, star->member);
    EXPAND_STAR
    #undef EXPAND_STAR_MEMBER
}

A variant which avoids needing to know the members of any expanded sub-macros is to accept the operators as an argument to the list macro:

File `star_table.c`:
/*
 * Generic
 */
#define STRUCT_MEMBER(member, type, dummy) type member;
#define SERIALIZE_MEMBER(member, type, obj, buffer) \
    memcpy(buffer, &(obj->member), sizeof(obj->member)); \
    buffer += sizeof(obj->member);
#define DESERIALIZE_MEMBER(member, type, obj, buffer) \
    memcpy(&(obj->member), buffer, sizeof(obj->member)); \
    buffer += sizeof(obj->member);
#define FORMAT_(type) FORMAT_##type
#define FORMAT_int "%d"
#define FORMAT_double "%g"
/* FORMAT_(type) will be replaced with FORMAT_int or FORMAT_double */
#define PRINT_MEMBER(member, type, obj) \
    printf("%s: " FORMAT_(type) "\n", #member, obj->member);

/*
 * starStruct
 */
#define EXPAND_STAR(_, ...) \
    _x, int, _VA_ARGS_\n    _y, int, _VA_ARGS_\n    _z, int, _VA_ARGS_\n    _radius, double, _VA_ARGS_

typedef struct {
    EXPAND_STAR(STRUCT_MEMBER, )
} starStruct;

void serialize_star(const starStruct *const star, unsigned char *buffer) {
    EXPAND_STAR(SERIALIZE_MEMBER, star, buffer)
}

void deserialize_star(starStruct *const star, const unsigned char *buffer) {
    EXPAND_STAR(DESERIALIZE_MEMBER, star, buffer)
}
```

117
void print_star(const starStruct *const star) {
    EXPAND_STAR(PRINT_MEMBER, star)
}

This approach can be dangerous in that the entire macro set is always interpreted as if it
was on a single source line, which could encounter compiler limits with complex component
macros and/or long member lists.

This technique was reported by Lars Wirzenius\(^\text{47}\) in a web page dated January 17, 2000, in
which he gives credit to Kenneth Oksanen for "refining and developing" the technique prior
to 1997. The other references describe it as a method from at least a decade before the turn
of the century.

We discuss X-Macros more in a later section, Serialization and X-Macros\(^\text{48}\).

w:C preprocessor\(^\text{49}\)

de:C-Programmierung: Prüprozessor\(^\text{50}\)
fr:Programmation C/Préprocesseur\(^\text{51}\)
it:C/Compilatore e precompilatore/Direttive\(^\text{52}\)
pl:C/Preprocesor\(^\text{53}\)


\(^{49}\) https://en.wikipedia.org/wiki/C%20preprocessor

\(^{50}\) https://de.wikibooks.org/wiki/C-Programmierung%3A%20Pr%C3%A4prozessor

\(^{51}\) https://fr.wikibooks.org/wiki/Programmation%20C%20Pr%C3%A9processeur

\(^{52}\) https://it.wikibooks.org/wiki/C%20Compilatore%20e%20Precompilatore%20Direttive

\(^{53}\) https://pl.wikibooks.org/wiki/C%20Preprocesor
18 Libraries

A library in C is a group of functions and declarations, exposed for use by other programs. The library therefore consists of an interface expressed in a .h file (named the "header") and an implementation expressed in a .c file. This .c file might be precompiled or otherwise inaccessible, or it might be available to the programmer. (Note: Libraries may call functions in other libraries such as the Standard C or math libraries to do various tasks.)

The format of a library varies with the operating system and compiler one is using. For example, in the Unix and Linux operating systems, a library consists of one or more object files, which consist of object code that is usually the output of a compiler (if the source language is C or something similar) or an assembler (if the source language is assembly language). These object files are then turned into a library in the form of an archive by the ar archiver (a program that takes files and stores them in a bigger file without regard to compression). The filename for the library usually starts with "lib" and ends with ".a"; e.g. the libc.a file contains the Standard C library and the "libm.a" the mathematics routines, which the linker would then link in. Other operating systems such as Microsoft Windows use a ".lib" extension for libraries and an ".obj" extension for object files. Some programs in the Unix environment such as lex and yacc generate C code that can be linked with the libl and liby libraries to create an executable.

We’re going to use as an example a library that contains one function: a function to parse\(^1\) arguments from the command line. Arguments on the command line could be by themselves:

```
-i
```

have an optional argument that is concatenated\(^2\) to the letter:

```
-i optarg
```

or have the argument in a separate argv-element:

```
-i optarg
```

The library also has four declarations that it exports in addition to the function: three integers and a pointer to the optional argument. If the argument does not have an optional argument, the pointer to the optional argument will be null.

In order to parse all these types of arguments, we have written the following "getopt.c" file:

---

\(^1\) [https://en.wikipedia.org/wiki/Parsing](https://en.wikipedia.org/wiki/Parsing)

Libraries
#include <stdio.h>
#include <string.h>
#include "getopt.h"

/* for fprintf() and EOF */
/* for strchr() */
/* consistency check */

/* variables */
int opterr = 1;
int optind = 1;
int optopt;
char *optarg;

/*
/*
/*
/*

getopt prints errors if this is on */
token pointer */
option character passed back to user */
flag argument (or value) */

/* function */
/* return option character, EOF if no more or ? if problem.
The arguments to the function:
argc, argv - the arguments to the main() function. An argument of "--"
stops the processing.
opts - a string containing the valid option characters.
an option character followed by a colon (:) indicates that
the option has a required argument.
*/
int
getopt (int argc, char **argv, char *opts)
{
static int sp = 1;
/* character index into current token */
register char *cp;
/* pointer into current token */
if (sp == 1)
{
/* check for more flag-like tokens */
if (optind >= argc || argv[optind][0] != '-' || argv[optind][1] == '\0')
return EOF;
else if (strcmp (argv[optind], "--") == 0)
{
optind++;
return EOF;
}
}
optopt = argv[optind][sp];
if (optopt == ':' || (cp = strchr (opts, optopt)) == NULL)
{
if (opterr)
fprintf (stderr, "%s: invalid option -- '%c'\n", argv[0], optopt);
/* if no characters left in this token, move to next token */
if (argv[optind][++sp] == '\0')
{
optind++;
sp = 1;
}
return '?';
}
if (*++cp == ':')
{
/* if a value is expected, get it */
if (argv[optind][sp + 1] != '\0')
/* flag value is rest of current token */
optarg = argv[optind++] + (sp + 1);
else if (++optind >= argc)
{
if (opterr)
fprintf (stderr, "%s: option requires an argument -- '%c'\n",
argv[0], optopt);
sp = 1;
return '?';
}

120


else
   /* flag value is next token */
optarg = argv[optind++];
sp = 1;
}
else
{
   /* set up to look at next char in token, next time */
   if (argv[optind][++sp] == '\0')
   {
      /* no more in current token, so setup next token */
      sp = 1;
      optind++;
   }
optarg = 0;
}
return optopt;
*/ END OF FILE */

The interface would be the following "getopt.h" file:

```
#ifndef GETOPT_H
#define GETOPT_H
/* exported variables */
extern int opterr, optind, optopt;
extern char *optarg;
/* exported function */
int getopt(int, char **, char *);
#endif
/* END OF FILE */
```

At a minimum, a programmer has the interface file to figure out how to use a library, although, in general, the library programmer also wrote documentation on how to use the library. In the above case, the documentation should say that the provided arguments **argv and *opts both shouldn't be null pointers (or why would you be using the getopt function anyway?). Specifically, it typically states what each parameter is for and what return values can be expected in which conditions. Programmers that use a library, are normally not interested in the implementation of the library -- unless the implementation has a bug, in which case he would want to complain somehow.

Both the implementation of the getopts library, and programs that use the library should state #include "getopt.h", in order to refer to the corresponding interface. Now the library is "linked" to the program -- the one that contains the main() function. The program may refer to dozens of interfaces.

In some cases, just placing #include "getopt.h" may appear correct but will still fail to link properly. This indicates that the library is not installed correctly, or there may be some additional configuration required. You will have to check either the compiler's documentation or library's documentation on how to resolve this issue.

## 18.1 What to put in header files

As a general rule, headers should contain any declarations and macro definitions (preprocessor #defines) to be "seen" by the other modules in a program.
Possible declarations:

- struct, union, and enum declarations
- typedef declarations
- external function declarations
- global variable declarations

In the above `getopt.h` example file, one function (`getopt`) is declared and four global variables (`optind`, `optopt`, `optarg`, and `opterr`) are also declared. The variables are declared with the storage class specifier `extern` in the header file because that keyword specifies that the "real" variables are stored elsewhere (i.e. the `getopt.c` file) and not within the header file.

The `#ifndef GETOPT_H/#define GETOPT_H` trick is colloquially called include guards. This is used so that if the `getopt.h` file were included more than once in a translation unit, the unit would only see the contents once.

18.2 References

- C FAQ: "I'm wondering what to put in .c files and what to put in .h files. (What does ".h" mean, anyway?)"³
- PIClist thread: "Global variables in projects with many C files."⁴
- "How do I use extern to share variables between source files in C?"⁵

fr:Programmation C/Bibliothèque standard⁶ pl:C/Biblioteki⁷

---

³ http://c-faq.com/cpp/hfiles.html
19 Standard libraries

The C standard library is a standardized collection of header files and library routines used to implement common operations, such as input/output and character string handling. Unlike other languages (such as COBOL, Fortran, and PL/I) C does not include built-in keywords for these tasks, so nearly all C programs rely on the standard library to operate.

19.1 History

The C programming language previously did not provide any elementary functions, such as I/O operations. Over time, user communities of C shared ideas and implementations to provide those functions. These ideas became common, and were eventually incorporated into the definition of the standardized C programming language. These are now called the C standard libraries.

Both Unix and C were created at AT&T's Bell Laboratories in the late 1960s and early 1970s. During the 1970s the C programming language became increasingly popular, with many universities and organizations beginning to create their own variations of the language for their own projects. By the start of the 1980s compatibility problems between the various C implementations became apparent. In 1983 the American National Standards Institute (ANSI) formed a committee to establish a standard specification of C known as "ANSI C". This work culminated in the creation of the so-called C89 standard in 1989. Part of the resulting standard was a set of software libraries called the ANSI C standard library.

Later revisions of the C standard have added several new required header files to the library. Support for these new extensions varies between implementations.

The headers `<iso646.h>`, `<wchar.h>`, and `<wctype.h>` were added with Normative Addendum 1 (hereafter abbreviated as NA1), an addition to the C Standard ratified in 1995.

The headers `<complex.h>`, `<fenv.h>`, `<inttypes.h>`, `<stdbool.h>`, `<stdint.h>`, and `<tgmath.h>` were added with C99, a revision to the C Standard published in 1999.

Note:
The C++ programming language includes the functions of the ANSI C 89 standard library, but has made several modifications, such as placing all identifiers into the std namespace and changing the names of the header files from `<xxx.h>` to `<cxxx>` (however, the C-style names are still available, although deprecated).

\[a \] https://en.wikibooks.org/wiki/C%2B%2B

123
19.2 Design

The declaration of each function is kept in a header file, while the actual implementation of functions are separated into a library file. The naming and scope of headers have become common but the organization of libraries still remains diverse. The standard library is usually shipped along with a compiler. Since C compilers often provide extra functions that are not specified in ANSI C, a standard library with a particular compiler is mostly incompatible with standard libraries of other compilers.

Much of the C standard library has been shown to have been well-designed. A few parts, with the benefit of hindsight, are regarded as mistakes. The string input functions `gets()` (and the use of `scanf()` to read string input) are the source of many buffer overflows, and most programming guides recommend avoiding this usage. Another oddity is `strtok()`, a function that is designed as a primitive lexical analyser¹ but is highly "fragile" and difficult to use.

19.3 ANSI Standard

The ANSI C standard library consists of 24 C header files which can be included into a programmer's project with a single directive. Each header file contains one or more function declarations, data type definitions and macros. The contents of these header files follows.

In comparison to some other languages (for example Java) the standard library is minuscule. The library provides a basic set of mathematical functions, string manipulation, type conversions, and file and console-based I/O. It does not include a standard set of "container types" like the C++ Standard Template Library, let alone the complete graphical user interface (GUI) toolkits, networking tools, and profusion of other functions that Java provides as standard. The main advantage of the small standard library is that providing a working ANSI C environment is much easier than it is with other languages, and consequently porting C to a new platform is relatively easy.

Many other libraries have been developed to supply equivalent functions to that provided by other languages in their standard library. For instance, the GNOME desktop environment project has developed the GTK+ graphics toolkit and GLib, a library of container data structures, and there are many other well-known examples. The variety of libraries available has meant that some superior toolkits have proven themselves through history. The considerable downside is that they often do not work particularly well together, programmers are often familiar with different sets of libraries, and a different set of them may be available on any particular platform.

19.3.1 ANSI C library header files

<table>
<thead>
<tr>
<th>Header File</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>&lt;assert.h&gt;</code></td>
<td>Contains the assert macro, used to assist with detecting logical errors and other types of bug in debugging versions of a program.</td>
</tr>
</tbody>
</table>

¹ https://en.wikipedia.org/wiki/lexical_analysis
² https://en.wikipedia.org/wiki/Assert.h
<table>
<thead>
<tr>
<th>Header File</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;complex.h&gt;</td>
<td>A set of functions for manipulating complex numbers. (New with C99)</td>
</tr>
<tr>
<td>&lt;ctype.h&gt;</td>
<td>This header file contains functions used to classify characters by their types or to convert between upper and lower case in a way that is independent of the used character set (typically ASCII or one of its extensions, although implementations utilizing EBCDIC are also known).</td>
</tr>
<tr>
<td>&lt;errno.h&gt;</td>
<td>For testing error codes reported by library functions.</td>
</tr>
<tr>
<td>&lt;float.h&gt;</td>
<td>Contains defined constants specifying the implementation-specific properties of the floating-point library, such as the minimum difference between two different floating-point numbers (_EPSILON), the maximum number of digits of accuracy (_DIG), and the range of numbers which can be represented (_MIN, _MAX).</td>
</tr>
<tr>
<td>&lt;inttypes.h&gt;</td>
<td>For precise conversion between integer types. (New with C99)</td>
</tr>
<tr>
<td>&lt;iso646.h&gt;</td>
<td>For programming in ISO 646 variant character sets. (New with NA1)</td>
</tr>
<tr>
<td>&lt;limits.h&gt;</td>
<td>Contains defined constants specifying the implementation-specific properties of the integer types, such as the range of numbers which can be represented (_MIN, _MAX).</td>
</tr>
<tr>
<td>&lt;locale.h&gt;</td>
<td>For setlocale() and related constants. This is used to choose an appropriate locale.</td>
</tr>
<tr>
<td>&lt;math.h&gt;</td>
<td>For computing common mathematical functions—see ../Furthermath/C++Programming/Code/Standard C Library/Math for details.</td>
</tr>
<tr>
<td>&lt;setjmp.h&gt;</td>
<td>For manipulating control structures.</td>
</tr>
<tr>
<td>&lt;signal.h&gt;</td>
<td>For controlling various exceptional conditions.</td>
</tr>
<tr>
<td>&lt;stdarg.h&gt;</td>
<td>For accessing a varying number of arguments passed to functions.</td>
</tr>
<tr>
<td>&lt;stdlib.h&gt;</td>
<td>For performing a variety of operations, including conversion, pseudorandom numbers, memory allocation, process control, environment, signalling, searching, and sorting.</td>
</tr>
<tr>
<td>&lt;stdio.h&gt;</td>
<td>Provides the core input and output capabilities of the C language. This file includes the venerable printf function.</td>
</tr>
<tr>
<td>&lt;stdio.h&gt;</td>
<td>For performing a variety of operations, including conversion, pseudorandom numbers, memory allocation, process control, environment, signalling, searching, and sorting.</td>
</tr>
<tr>
<td>&lt;stdlib.h&gt;</td>
<td>For manipulating several kinds of strings.</td>
</tr>
<tr>
<td>&lt;tgmath.h&gt;</td>
<td>For type-generic mathematical functions. (New with C99)</td>
</tr>
<tr>
<td>&lt;time.h&gt;</td>
<td>For converting between various time and date formats.</td>
</tr>
<tr>
<td>&lt;wchar.h&gt;</td>
<td>For manipulating wide strings and several kinds of strings using wide characters—key to supporting a range of languages. (New with NA1)</td>
</tr>
<tr>
<td>&lt;wctype.h&gt;</td>
<td>For classifying wide characters. (New with NA1)</td>
</tr>
</tbody>
</table>

3 https://en.wikipedia.org/wiki/Complex.h
4 https://en.wikipedia.org/wiki/Ctype.h
5 https://en.wikipedia.org/wiki/Errno.h
6 https://en.wikipedia.org/wiki/Fenv.h
7 https://en.wikipedia.org/wiki/Float.h
8 https://en.wikipedia.org/wiki/Inttypes.h
9 https://en.wikipedia.org/wiki/Iso646.h
10 https://en.wikipedia.org/wiki/Limits.h
11 https://en.wikipedia.org/wiki/Locale.h
12 https://en.wikipedia.org/wiki/Math.h
13 Chapter 14 on page 69
15 2FMath
16 https://en.wikipedia.org/wiki/Setjmp.h
17 https://en.wikipedia.org/wiki/Signal.h
18 https://en.wikipedia.org/wiki/Stdarg.h
19 https://en.wikipedia.org/wiki/Stdint.h
20 https://en.wikipedia.org/wiki/Stddef.h
21 https://en.wikipedia.org/wiki/Stdio.h
22 https://en.wikipedia.org/wiki/Stdlib.h
23 https://en.wikipedia.org/wiki/String.h
24 https://en.wikipedia.org/wiki/Tgmath.h
26 https://en.wikipedia.org/wiki/Wchar.h
27 https://en.wikipedia.org/wiki/Wctype.h
19.4 Common support libraries

While not standardized, C programs may depend on a runtime library of routines which contain code the compiler uses at runtime. The code that initializes the process for the operating system, for example, before calling `main()`, is implemented in the C Run-Time Library for a given vendor's compiler. The Run-Time Library code might help with other language feature implementations, like handling uncaught exceptions or implementing floating point code.

The C standard library only documents that the specific routines mentioned in this article are available, and how they behave. Because the compiler implementation might depend on these additional implementation-level functions to be available, it is likely the vendor-specific routines are packaged with the C Standard Library in the same module, because they're both likely to be needed by any program built with their toolset.

Though often confused with the C Standard Library because of this packaging, the C Runtime Library is not a standardized part of the language and is vendor-specific.

19.5 Compiler built-in functions

Some compilers (for example, GCC\(^\text{28}\)) provide built-in versions of many of the functions in the C standard library; that is, the implementations of the functions are written into the compiled object file, and the program calls the built-in versions instead of the functions in the C library shared object file. This reduces function call overhead, especially if function calls are replaced with inline variants, and allows other forms of optimization (as the compiler knows the control-flow characteristics of the built-in variants), but may cause confusion when debugging (for example, the built-in versions cannot be replaced with instrumented variants).

19.6 POSIX standard library

POSIX, (along with the Single Unix Specification), specifies a number of routines that should be available over and above those in the C standard library proper; these are often implemented alongside the C standard library functions, with varying degrees of closeness. For example, glibc implements functions such as fork within libc.so, but before NPTL was merged into glibc it constituted a separate library with its own linker flag. Often, this POSIX-specified function will be regarded as part of the library; the C library proper may be identified as the ANSI or ISO C library.

The following libraries are recognized by POSIX:

\(^{28}\) https://en.wikipedia.org/wiki/GCC
This option shall make available all interfaces referenced in the System Interfaces volume of POSIX.1-2008, with the possible exception of those interfaces listed as residing in `<aio.h>`, `<arpa/inet.h>`, `<complex.h>`, `<fenv.h>`, `<math.h>`, `<mqueue.h>`, `<netdb.h>`, `<netinet/in.h>`, `<sched.h>`, `<semaphore.h>`, `<spawn.h>`, `<sys/socket.h>`, `pthread_kill()`, and `pthread_sigmask()` in `<signal.h>`, `<trace.h>`, interfaces marked as optional in `<sys/mman.h>`, interfaces marked as ADV (Advisory Information) in `<fcntl.h>`, and interfaces beginning with the prefix `clock_` or `time_` in `<time.h>`. This option shall not be required to be present to cause a search of this library.

This option shall make available all interfaces required by the C-language output of lex that are not made available through the `-lc` option. (The flex program, a clone of lex, uses `fl` instead of `l`.)

This option shall make available all interfaces referenced in `<pthread.h>` and `pthread_kill()` and `pthread_sigmask()` referenced in `<signal.h>`. An implementation may search this library in the absence of this option.

This option shall make available all interfaces referenced in `<math.h>`, `<complex.h>`, and `<fenv.h>`. An implementation may search this library in the absence of this option.

This option shall make available all interfaces referenced in `<aio.h>`, `<mqueue.h>`, `<sched.h>`, `<semaphore.h>`, and `<spawn.h>`, interfaces marked as optional in `<sys/mman.h>`, interfaces marked as ADV (Advisory Information) in `<fcntl.h>`, and interfaces beginning with the prefix `clock_` and `time_` in `<time.h>`. An implementation may search this library in the absence of this option.

This option shall make available all interfaces referenced in `<trace.h>`. An implementation may search this library in the absence of this option.

This option shall make available all interfaces referenced in `<arpa/inet.h>`, `<netinet/in.h>`, and `<sys/socket.h>`. An implementation may search this library in the absence of this option.

This option shall make available all interfaces required by the C-language output of yacc that are not made available through the `-ly` option. (Some clones of yacc, including bison and byacc, include the entire library in the generated file, so it is not necessary to use `-ly`.)

### 19.7 References

pl:C/Biblioteka standardowa[^29]

[^29]: https://pl.wikibooks.org/wiki/C%2FBiblioteka%20standardowa
20 File IO

20.1 Introduction

The `stdio.h` header declares a broad assortment of functions that perform input and output to files and devices such as the console. It was one of the earliest headers to appear in the C library. It declares more functions than any other standard header and also requires more explanation because of the complex machinery that underlies the functions.

The device-independent model of input and output has seen dramatic improvement over the years and has received little recognition for its success. FORTRAN II was touted as a machine-independent language in the 1960s, yet it was essentially impossible to move a FORTRAN program between architectures without some change. In FORTRAN II, you named the device you were talking to right in the FORTRAN statement in the middle of your FORTRAN code. So, you said `READ INPUT TAPE 5` on a tape-oriented IBM 7090 but `READ CARD` to read a card image on other machines. FORTRAN IV had more generic `READ` and `WRITE` statements, specifying a `logical unit number` (LUN) instead of the device name. The era of device-independent I/O had dawned.

Peripheral devices such as printers still had fairly strong notions about what they were asked to do. And then, peripheral interchange utilities were invented to handle bizarre devices. When cathode-ray tubes came onto the scene, each manufacturer of consoles solved problems such as console cursor movement in an independent manner, causing further headaches.

It was into this atmosphere that Unix was born. Ken Thompson and Dennis Ritchie, the developers of Unix, deserve credit for packing any number of bright ideas into the operating system. Their approach to device independence was one of the brightest.

The ANSI C `<stdio.h>` library is based on the original Unix file I/O primitives but casts a wider net to accommodate the least-common denominator across varied systems.

20.2 Streams

Input and output, whether to or from physical devices such as terminals and tape drives, or whether to or from files supported on structured storage devices, are mapped into logical data streams, whose properties are more uniform than their various inputs and outputs. Two forms of mapping are supported: text streams and binary streams.

A text stream consists of one or more lines. A line in a text stream consists of zero or more characters plus a terminating new-line character. (The only exception is that in some implementations the last line of a file does not require a terminating new-line character.) Unix adopted a standard internal format for all text streams. Each line of text is terminated
by a new-line character. That's what any program expects when it reads text, and that's what any program produces when it writes text. (This is the most basic convention, and if it doesn't meet the needs of a text-oriented peripheral attached to a Unix machine, then the fix-up occurs out at the edges of the system. Nothing in between needs to change.) The string of characters that go into, or come out of a text stream may have to be modified to conform to specific conventions. This results in a possible difference between the data that go into a text stream and the data that come out. For instance, in some implementations when a space-character precedes a new-line character in the input, the space character gets removed out of the output. In general, when the data only consists of printable characters and control characters like horizontal tab and new-line, the input and output of a text stream are equal.

Compared to a text stream, a binary stream is pretty straight forward. A binary stream is an ordered sequence of characters that can transparently record internal data. Data written to a binary stream shall always equal the data that gets read out under the same implementation. Binary streams, however, may have an implementation-defined number of null characters appended to the end of the stream. There are no further conventions which need to be considered.

Nothing in Unix prevents the program from writing arbitrary 8-bit binary codes to any open file, or reading them back unchanged from an adequate repository. Thus, Unix obliterated the long-standing distinction between text streams and binary streams.

20.3 Standard Streams

When a C program starts its execution the program automatically opens three standard streams named stdin, stdout, and stderr. These are attached for every C program.

The first standard stream is used for input buffering and the other two are used for output. These streams are sequences of bytes.

Consider the following program:

```c
/* An example program. */
int main()
{
    int var;
    scanf ("%d", &var); /* use stdin for scanning an integer from keyboard. */
    printf ("%d", var); /* use stdout for printing a character. */
    return 0;
} /* end program. */
```

By default stdin points to the keyboard and stdout and stderr point to the screen. It is possible under Unix and may be possible under other operating systems to redirect input from or output to a file or both.

20.4 FILE pointers

The <stdio.h> header contains a definition for a type FILE (usually via a typedef) which is capable of processing all the information needed to exercise control over a stream, including
its file position indicator, a pointer to the associated buffer (if any), an error indicator that records whether a read/write error has occurred, and an end-of-file indicator that records whether the end of the file has been reached.

It is considered bad manners to access the contents of FILE directly unless the programmer is writing an implementation of <stdio.h> and its contents. Better access to the contents of FILE is provided via the functions in <stdio.h>. It can be said that the FILE type is an early example of object-oriented programming.

### 20.5 Opening and Closing Files

To open and close files, the <stdio.h> library has three functions: fopen, freopen, and fclose.

#### 20.5.1 Opening Files

```c
#include <stdio.h>
FILE *fopen(const char *filename, const char *mode);
FILE *freopen(const char *filename, const char *mode, FILE *stream);
```

fopen and freopen opens the file whose name is in the string pointed to by filename and associates a stream with it. Both return a pointer to the object controlling the stream, or, if the open operation fails, a null pointer. The error and end-of-file indicators are cleared, and if the open operation fails error is set. freopen differs from fopen in that the file pointed to by stream is closed first when already open and any close errors are ignored.

**mode** for both functions points to a string consisting of one of the following sequences:

```
<table>
<thead>
<tr>
<th>Sequence</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>r</td>
<td>open a text file for reading</td>
</tr>
<tr>
<td>w</td>
<td>truncate to zero length or create a text file for writing</td>
</tr>
<tr>
<td>a</td>
<td>append; open or create text file for writing at end-of-file</td>
</tr>
<tr>
<td>rb</td>
<td>open binary file for reading</td>
</tr>
<tr>
<td>wb</td>
<td>truncate to zero length or create a binary file for writing</td>
</tr>
<tr>
<td>ab</td>
<td>append; open or create binary file for writing at end-of-file</td>
</tr>
<tr>
<td>r+</td>
<td>open text file for update (reading and writing)</td>
</tr>
<tr>
<td>w+</td>
<td>truncate to zero length or create a text file for update</td>
</tr>
<tr>
<td>a+</td>
<td>append; open or create text file for update</td>
</tr>
<tr>
<td>r+b or rb+</td>
<td>open binary file for update (reading and writing)</td>
</tr>
<tr>
<td>w+b or wb+</td>
<td>truncate to zero length or create a binary file for update</td>
</tr>
<tr>
<td>a+b or ab+</td>
<td>append; open or create binary file for update</td>
</tr>
</tbody>
</table>
```

Opening a file with read mode (‘r’ as the first character in the **mode** argument) fails if the file does not exist or cannot be read.

Opening a file with append mode (‘a’ as the first character in the **mode** argument) causes all subsequent writes to the file to be forced to the then-current end-of-file, regardless of intervening calls to the fseek function. In some implementations, opening a binary file with append mode (‘b’ as the second or third character in the above list of **mode** arguments) may

---

initially position the file position indicator for the stream beyond the last data written, because of null character padding.

When a file is opened with update mode ('+' as the second or third character in the above list of mode argument values), both input and output may be performed on the associated stream. However, output may not be directly followed by input without an intervening call to the fflush function or to a file positioning function (fseek, fsetpos, or rewind), and input may not be directly followed by output without an intervening call to a file positioning function, unless the input operation encounters end-of-file. Opening (or creating) a text file with update mode may instead open (or create) a binary stream in some implementations.

When opened, a stream is fully buffered if and only if it can be determined not to refer to an interactive device.

20.5.2 Closing Files

```c
#include <stdio.h>
int fclose(FILE *stream);
```

The `fclose` function causes the stream pointed to by `stream` to be flushed and the associated file to be closed. Any unwritten buffered data for the stream are delivered to the host environment to be written to the file; any unread buffered data are discarded. The stream is disassociated from the file. If the associated buffer was automatically allocated, it is deallocated. The function returns zero if the stream was successfully closed or `EOF` if any errors were detected.

20.6 Other file access functions

20.6.1 The `fflush` function

```c
#include <stdio.h>
int fflush(FILE *stream);
```

If `stream` points to an output stream or an update stream in which the most recent operation was not input, the `fflush` function causes any unwritten data for that stream to be deferred to the host environment to be written to the file. The behavior of `fflush` is undefined for input stream.

If `stream` is a null pointer, the `fflush` function performs this flushing action on all streams for which the behavior is defined above.

The `fflush` functions returns `EOF` if a write error occurs, otherwise zero.

The reason for having a `fflush` function is because streams in C can have buffered input/output; that is, functions that write to a file actually write to a buffer inside the `FILE` structure. If the buffer is filled to capacity, the write functions will call `fflush` to actually "write" the data that is in the buffer to the file. Because `fflush` is only called every once in a while, calls to the operating system to do a raw write are minimized.
The `setbuf` function

```c
#include <stdio.h>

void setbuf(FILE *stream, char *buf);
```

Except that it returns no value, the `setbuf` function is equivalent to the `setvbuf` function invoked with the values `_IOFBF` for `mode` and `BUFSIZ` for `size`, or (if `buf` is a null pointer) with the value `_IONBF` for `mode`.

The `setvbuf` function

```c
#include <stdio.h>

int setvbuf(FILE *stream, char *buf, int mode, size_t size);
```

The `setvbuf` function may be used only after the stream pointed to by `stream` has been associated with an open file and before any other operation is performed on the stream. The argument `mode` determines how the stream will be buffered, as follows: `_IOFBF` causes input/output to be fully buffered; `_IOLBF` causes input/output to be line buffered; `_IONBF` causes input/output to be unbuffered. If `buf` is not a null pointer, the array it points to may be used instead of a buffer associated by the `setvbuf` function. (The buffer must have a lifetime at least as great as the open stream, so the stream should be closed before a buffer that has automatic storage duration is deallocated upon block exit.) The argument `size` specifies the size of the array. The contents of the array at any time are indeterminate.

The `setvbuf` function returns zero on success, or nonzero if an invalid value is given for `mode` or if the request cannot be honored.

20.7 Functions that Modify the File Position Indicator

The `stdio.h` library has five functions that affect the file position indicator besides those that do reading or writing: `fgetpos`, `fseek`, `fsetpos`, `ftell`, and `rewind`.

The `fseek` and `ftell` functions are older than `fgetpos` and `fsetpos`.

The `fgetpos` and `fsetpos` functions

```c
#include <stdio.h>

int fgetpos(FILE *stream, fpos_t *pos);
int fsetpos(FILE *stream, const fpos_t *pos);
```

The `fgetpos` function stores the current value of the file position indicator for the stream pointed to by `stream` in the object pointed to by `pos`. The value stored contains unspecified information usable by the `fsetpos` function for repositioning the stream to its position at the time of the call to the `fgetpos` function.

If successful, the `fgetpos` function returns zero; on failure, the `fgetpos` function returns nonzero and stores an implementation-defined positive value in `errno`.

133
The `fsetpos` function sets the file position indicator for the stream pointed to by `stream` according to the value of the object pointed to by `pos`, which shall be a value obtained from an earlier call to the `fgetpos` function on the same stream.

A successful call to the `fsetpos` function clears the end-of-file indicator for the stream and undoes any effects of the `ungetc` function on the same stream. After an `fsetpos` call, the next operation on an update stream may be either input or output.

If successful, the `fsetpos` function returns zero; on failure, the `fsetpos` function returns nonzero and stores an implementation-defined positive value in `errno`.

### 20.7.2 The `fseek` and `ftell` functions

```c
#include <stdio.h>
int fseek(FILE *stream, long int offset, int whence);
long int ftell(FILE *stream);
```

The `fseek` function sets the file position indicator for the stream pointed to by `stream`.

For a binary stream, the new position, measured in characters from the beginning of the file, is obtained by adding `offset` to the position specified by `whence`. Three macros in `stdio.h` called SEEK_SET, SEEK_CUR, and SEEK_END expand to unique values. If the position specified by `whence` is SEEK_SET, the specified position is the beginning of the file; if `whence` is SEEK_END, the specified position is the end of the file; and if `whence` is SEEK_CUR, the specified position is the current file position. A binary stream need not meaningfully support `fseek` calls with a `whence` value of SEEK_END.

For a text stream, either `offset` shall be zero, or `offset` shall be a value returned by an earlier call to the `ftell` function on the same stream and `whence` shall be SEEK_SET.

The `fseek` function returns nonzero only for a request that cannot be satisfied.

The `ftell` function obtains the current value of the file position indicator for the stream pointed to by `stream`. For a binary stream, the value is the number of characters from the beginning of the file; for a text stream, its file position indicator contains unspecified information, usable by the `fseek` function for returning the file position indicator for the stream to its position at the time of the `ftell` call; the difference between two such return values is not necessarily a meaningful measure of the number of characters written or read.

If successful, the `ftell` function returns the current value of the file position indicator for the stream. On failure, the `ftell` function returns `-1L` and stores an implementation-defined positive value in `errno`.

### 20.7.3 The `rewind` function

```c
#include <stdio.h>
void rewind(FILE *stream);
```

The `rewind` function sets the file position indicator for the stream pointed to by `stream` to the beginning of the file. It is equivalent to
except that the error indicator for the stream is also cleared.

20.8 Error Handling Functions

20.8.1 The clearerr function

```c
#include <stdio.h>
void clearerr(FILE *stream);
```

The `clearerr` function clears the end-of-file and error indicators for the stream pointed to by `stream`.

20.8.2 The feof function

```c
#include <stdio.h>
int feof(FILE *stream);
```

The `feof` function tests the end-of-file indicator for the stream pointed to by `stream` and returns nonzero if and only if the end-of-file indicator is set for `stream`, otherwise it returns zero.

20.8.3 The ferror function

```c
#include <stdio.h>
int ferror(FILE *stream);
```

The `ferror` function tests the error indicator for the stream pointed to by `stream` and returns nonzero if and only if the error indicator is set for `stream`, otherwise it returns zero.

20.8.4 The perror function

```c
#include <stdio.h>
void perror(const char *s);
```

The `perror` function maps the error number in the integer expression `errno` to an error message. It writes a sequence of characters to the standard error stream thus: first, if `s` is not a null pointer and the character pointed to by `s` is not the null character, the string pointed to by `s` followed by a colon (:) and a space; then an appropriate error message string followed by a new-line character. The contents of the error message are the same as those returned by the `strerror` function with the argument `errno`, which are implementation-defined.
20.9 Other Operations on Files

The stdio.h library has a variety of functions that do some operation on files besides reading and writing.

20.9.1 The remove function

```c
#include <stdio.h>
int remove(const char *filename);
```

The remove function causes the file whose name is the string pointed to by filename to be no longer accessible by that name. A subsequent attempt to open that file using that name will fail, unless it is created anew. If the file is open, the behavior of the remove function is implementation-defined.

The remove function returns zero if the operation succeeds, nonzero if it fails.

20.9.2 The rename function

```c
#include <stdio.h>
int rename(const char *old_filename, const char *new_filename);
```

The rename function causes the file whose name is the string pointed to by old_filename to be henceforth known by the name given by the string pointed to by new_filename. The file named old_filename is no longer accessible by that name. If a file named by the string pointed to by new_filename exists prior to the call to the rename function, the behavior is implementation-defined.

The rename function returns zero if the operation succeeds, nonzero if it fails, in which case if the file existed previously it is still known by its original name.

20.9.3 The tmpfile function

```c
#include <stdio.h>
FILE *tmpfile(void);
```

The tmpfile function creates a temporary binary file that will automatically be removed when it is closed or at program termination. If the program terminates abnormally, whether an open temporary file is removed is implementation-defined. The file is opened for update with "wb+" mode.

The tmpfile function returns a pointer to the stream of the file that it created. If the file cannot be created, the tmpfile function returns a null pointer.

20.9.4 The tmpnam function

```c
#include <stdio.h>
char *tmpnam(char *s);
```
The `tmpnam` function generates a string that is a valid file name and that is not the name of an existing file.

The `tmpnam` function generates a different string each time it is called, up to `TMP_MAX` times. (`TMP_MAX` is a macro defined in `stdio.h`.) If it is called more than `TMP_MAX` times, the behavior is implementation-defined.

The implementation shall behave as if no library function calls the `tmpnam` function.

If the argument is a null pointer, the `tmpnam` function leaves its result in an internal static object and returns a pointer to that object. Subsequent calls to the `tmpnam` function may modify the same object. If the argument is not a null pointer, it is assumed to point to an array of at least `L_tmpnam` characters (`L_tmpnam` is another macro in `stdio.h`); the `tmpnam` function writes its result in that array and returns the argument as its value.

The value of the macro `TMP_MAX` must be at least 25.

## 20.10 Reading from Files

### 20.10.1 Character Input Functions

The `fgetc` function

```c
#include <stdio.h>
int fgetc(FILE *stream);
```

The `fgetc` function obtains the next character (if present) as an unsigned char converted to an int, from the input stream pointed to by `stream`, and advances the associated file position indicator for the stream (if defined).

The `fgetc` function returns the next character from the input stream pointed to by `stream`. If the stream is at end-of-file, the end-of-file indicator for the stream is set and `fgetc` returns `EOF` (`EOF` is a negative value defined in `<stdio.h>`, usually `-1`). If a read error occurs, the error indicator for the stream is set and `fgetc` returns `EOF`.

The `fgets` function

```c
#include <stdio.h>
char *fgets(char *s, int n, FILE *stream);
```

The `fgets` function reads at most one less than the number of characters specified by `n` from the stream pointed to by `stream` into the array pointed to by `s`. No additional characters are read after a new-line character (which is retained) or after end-of-file. A null character is written immediately after the last character read into the array.

The `fgets` function returns `s` if successful. If end-of-file is encountered and no characters have been read into the array, the contents of the array remain unchanged and a null pointer is returned. If a read error occurs during the operation, the array contents are indeterminate and a null pointer is returned.
Warning: Different operating systems may use different character sequences to represent the end-of-line sequence. For example, some filesystems use the terminator \\n in text files; fgets may read those lines, removing the \n but keeping the \r as the last character of s. This expuruous character should be removed in the string s before the string is used for anything (unless the programmer doesn’t care about it). Unixes typically use \n as its end-of-line sequence, MS-DOS and Windows uses \r\n, and Mac OSes used \r before OS X.

/* A example program that reads from stdin and writes to stdout */
#include <stdio.h>
#define BUFFER_SIZE 100

int main(void)
{
    char buffer[BUFFER_SIZE]; /* a read buffer */
    while( fgets (buffer, BUFFER_SIZE, stdin) != NULL)
    {
        printf("%s",buffer);
    }
    return 0;
} /* end program. */

The getc function

#include <stdio.h>
int getc(FILE *stream);

The getc function is equivalent to fgetc, except that it may be implemented as a macro. If it is implemented as a macro, the stream argument may be evaluated more than once, so the argument should never be an expression with side effects (i.e. have an assignment, increment, or decrement operators, or be a function call).

The getc function returns the next character from the input stream pointed to by stream. If the stream is at end-of-file, the end-of-file indicator for the stream is set and getc returns EOF (EOF is a negative value defined in <stdio.h>, usually (-1)). If a read error occurs, the error indicator for the stream is set and getc returns EOF.

The getchar function

#include <stdio.h>
int getchar(void);

The getchar function is equivalent to getc with the argument stdin.

The getchar function returns the next character from the input stream pointed to by stdin. If stdin is at end-of-file, the end-of-file indicator for stdin is set and getchar returns EOF (EOF is a negative value defined in <stdio.h>, usually (-1)). If a read error occurs, the error indicator for stdin is set and getchar returns EOF.
The **gets** function

```c
#include <stdio.h>
char *gets(char *s);
```

The `gets` function reads characters from the input stream pointed to by `stdin` into the array pointed to by `s` until an end-of-file is encountered or a new-line character is read. Any new-line character is discarded, and a null character is written immediately after the last character read into the array.

The `gets` function returns `s` if successful. If the end-of-file is encountered and no characters have been read into the array, the contents of the array remain unchanged and a null pointer is returned. If a read error occurs during the operation, the array contents are indeterminate and a null pointer is returned.

This function and description is only included here for completeness. Most C programmers nowadays shy away from using `gets`, as there is no way for the function to know how big the buffer is that the programmer wants to read into. Commandment #5 of Henry Spencer²'s *The Ten Commandments for C Programmers (Annotated Edition)* reads, "Thou shalt check the array bounds of all strings (indeed, all arrays), for surely where thou typest foo someone someday shall type *supercalifragilisticexpialidocious*." It mentions `gets` in the annotation: "As demonstrated by the deeds of the Great Worm, a consequence of this commandment is that robust production software should never make use of `gets()`, for it is truly a tool of the Devil. Thy interfaces should always inform thy servants of the bounds of thy arrays, and servants who spurn such advice or quietly fail to follow it should be dispatched forthwith to the Land Of Rm, where they can do no further harm to thee."

The **ungetc** function

```c
#include <stdio.h>
int ungetc(int c, FILE *stream);
```

The `ungetc` function pushes the character specified by `c` (converted to an `unsigned char`) back onto the input stream pointed to by `stream`. The pushed-back characters will be returned by subsequent reads on that stream in the reverse order of their pushing. A successful intervening call (with the stream pointed to by `stream`) to a file-positioning function (`fseek`, `fsetpos`, or `rewind`) discards any pushed-back characters for the stream. The external storage corresponding to the stream is unchanged.

One character of pushback is guaranteed. If the `ungetc` function is called too many times on the same stream without an intervening read or file positioning operation on that stream, the operation may fail.

If the value of `c` equals that of the macro `EOF`, the operation fails and the input stream is unchanged.

A successful call to the `ungetc` function clears the end-of-file indicator for the stream. The value of the file position indicator for the stream after reading or discarding all pushed-back

---

characters shall be the same as it was before the characters were pushed back. For a text stream, the value of its file-position indicator after a successful call to the `ungetc` function is unspecified until all pushed-back characters are read or discarded. For a binary stream, its file position indicator is decremented by each successful call to the `ungetc` function; if its value was zero before a call, it is indeterminate after the call.

The `ungetc` function returns the character pushed back after conversion, or `EOF` if the operation fails.

### 20.10.2 EOF pitfall

A mistake when using `fgetc`, `getc`, or `getchar` is to assign the result to a variable of type `char` before comparing it to `EOF`. The following code fragments exhibit this mistake, and then show the correct approach (using type `int`):

<table>
<thead>
<tr>
<th>Mistake</th>
<th>Correction</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>char c;</code>&lt;br&gt;<code>while ((c = getchar()) != EOF)</code>&lt;br&gt;<code>putchar(c);</code></td>
<td><code>int c;</code>&lt;br&gt;<code>while ((c = getchar()) != EOF)</code>&lt;br&gt;<code>putchar(c);</code></td>
</tr>
</tbody>
</table>

Consider a system in which the type `char` is 8 bits wide, representing 256 different values. `getchar` may return any of the 256 possible characters, and it also may return `EOF` to indicate end-of-file, for a total of 257 different possible return values.

When `getchar`'s result is assigned to a `char`, which can represent only 256 different values, there is necessarily some loss of information—when packing 257 items into 256 slots, there must be a collision. The `EOF` value, when converted to `char`, becomes indistinguishable from whichever one of the 256 characters shares its numerical value. If that character is found in the file, the above example may mistake it for an end-of-file indicator; or, just as bad, if type `char` is unsigned, then because `EOF` is negative, it can never be equal to any unsigned `char`, so the above example will not terminate at end-of-file. It will loop forever, repeatedly printing the character which results from converting `EOF` to `char`.

However, this looping failure mode does not occur if the char definition is signed (C makes the signedness of the default char type implementation-dependent),\(^5\) assuming the commonly used `EOF` value of -1\(^6\). However, the fundamental issue remains that if the `EOF` value is defined outside of the range of the `char` type, when assigned to a `char` that value is sliced and will no longer match the full `EOF` value necessary to exit the loop. On the other hand, if `EOF` is within range of `char`, this guarantees a collision between `EOF` and a char value. Thus, regardless of how system types are defined, never use `char` types when testing against `EOF`.

---

\(^3\) [https://en.wikibooks.org/wiki/end-of-file](https://en.wikibooks.org/wiki/end-of-file)  
\(^5\) [C99 §6.2.5/15](https://en.wikibooks.org/wiki/End-of-file)  
On systems where int and char are the same size (i.e., systems incompatible with minimally the POSIX and C99 standards), even the "good" example will suffer from the indistinguishability of EOF and some character's value. The proper way to handle this situation is to check feof\(^7\) and ferror\(^8\) after getchar returns EOF. If feof indicates that end-of-file has not been reached, and ferror indicates that no errors have occurred, then the EOF returned by getchar can be assumed to represent an actual character. These extra checks are rarely done, because most programmers assume that their code will never need to run on one of these "big char" systems. Another way is to use a compile-time assertion to make sure that UINT_MAX > UCHAR_MAX, which at least prevents a program with such an assumption from compiling in such a system.

### 20.10.3 Direct input function: the fread function

```c
#include <stdio.h>
size_t fread(void *ptr, size_t size, size_t nmemb, FILE *stream);
```

The fread function reads, into the array pointed to by ptr, up to nmemb elements whose size is specified by size, from the stream pointed to by stream. The file position indicator for the stream (if defined) is advanced by the number of characters successfully read. If an error occurs, the resulting value of the file position indicator for the stream is indeterminate. If a partial element is read, its value is indeterminate.

The fread function returns the number of elements successfully read, which may be less than nmemb if a read error or end-of-file is encountered. If size or nmemb is zero, fread returns zero and the contents of the array and the state of the stream remain unchanged.

### 20.10.4 Formatted input functions: the scanf family of functions

```c
#include <stdio.h>
int fscanf(FILE *stream, const char *format, ...);
int scanf(const char *format, ...);
int sscanf(const char *s, const char *format, ...);
```

The fscanf function reads input from the stream pointed to by stream, under control of the string pointed to by format that specifies the admissible sequences and how they are to be converted for assignment, using subsequent arguments as pointers to the objects to receive converted input. If there are insufficient arguments for the format, the behavior is undefined. If the format is exhausted while arguments remain, the excess arguments are evaluated (as always) but are otherwise ignored.

The format shall be a multibyte character sequence, beginning and ending in its initial shift state. The format is composed of zero or more directives: one or more white-space characters; an ordinary multibyte character (neither % or a white-space character); or a

\(^7\) https://en.wikibooks.org/wiki/feof
\(^8\) https://en.wikibooks.org/wiki/ferror
conversion specification. Each conversion specification is introduced by the character \%. After the \%, the following appear in sequence:

- An optional assignment-suppressing character \*.
- An optional nonzero decimal integer that specifies the maximum field width.
- An optional h, l (ell) or L indicating the size of the receiving object. The conversion specifiers d, i, and n shall be preceded by h if the corresponding argument is a pointer to short int rather than a pointer to int, or by l if it is a pointer to long int. Similarly, the conversion specifiers o, u, and x shall be preceded by h if the corresponding argument is a pointer to unsigned short int rather than unsigned int, or by l if it is a pointer to unsigned long int. Finally, the conversion specifiers e, f, and g shall be preceded by l if the corresponding argument is a pointer to double rather than a pointer to float, or by L if it is a pointer to long double. If an h, l, or L appears with any other format specifier, the behavior is undefined.
- A character that specifies the type of conversion to be applied. The valid conversion specifiers are described below.

The fscanf function executes each directive of the format in turn. If a directive fails, as detailed below, the fscanf function returns. Failures are described as input failures (due to the unavailability of input characters) or matching failures (due to inappropriate input).

A directive composed of white-space character(s) is executed by reading input up to the first non-white-space character (which remains unread) or until no more characters remain unread.

A directive that is an ordinary multibyte character is executed by reading the next characters of the stream. If one of the characters differs from one comprising the directive, the directive fails, and the differing and subsequent characters remain unread.

A directive that is a conversion specification defines a set of matching input sequences, as described below for each specifier. A conversion specification is executed in the following steps:

Input white-space characters (as specified by the isspace function) are skipped, unless the specification includes a [l, c, or n specifier. (The white-space characters are not counted against the specified field width.)

An input item is read from the stream, unless the specification includes an n specifier. An input item is defined as the longest matching sequences of input characters, unless that exceeds a specified field width, in which case it is the initial subsequence of that length in the sequence. The first character, if any, after the input item remains unread. If the length of the input item is zero, the execution of the directive fails; this condition is a matching failure, unless an error prevented input from the stream, in which case it is an input failure.

Except in the case of a % specifier, the input item (or, in the case of a %n directive, the count of input characters) is converted to a type appropriate to the conversion specifier. If the input item is not a matching sequence, the execution of the directive fails; this condition is a matching failure. Unless assignment suppression was indicated by a \*, the result of the conversion is placed in the object pointed to by the first argument following the format argument that has not already received a conversion result. If this object does not have an appropriate type, or if the result of the conversion cannot be represented in the space provided, the behavior is undefined.
The following conversion specifiers are valid:

d
Matches an optionally signed decimal integer, whose format is the same as expected for the subject sequence of the `strtol` function with the value 10 for the `base` argument. The corresponding argument shall be a pointer to integer.

i
Matches an optionally signed integer, whose format is the same as expected for the subject sequence of the `strtol` function with the value 0 for the `base` argument. The corresponding argument shall be a pointer to integer.

o
Matches an optionally signed octal integer, whose format is the same as expected for the subject sequence of the `strtol` function with the value 8 for the `base` argument. The corresponding argument shall be a pointer to unsigned integer.

u
Matches an optionally signed decimal integer, whose format is the same as expected for the subject sequence of the `strtol` function with the value 10 for the `base` argument. The corresponding argument shall be a pointer to unsigned integer.

x
Matches an optionally signed hexadecimal integer, whose format is the same as expected for the subject sequence of the `strtol` function with the value 16 for the `base` argument. The corresponding argument shall be a pointer to unsigned integer.

e, f, g
Matches an optionally signed floating-point number, whose format is the same as expected for the subject string of the `strtod` function. The corresponding argument will be a pointer to floating.

s
Matches a sequence of non-white-space characters. (No special provisions are made for multibyte characters.) The corresponding argument shall be a pointer to the initial character of an array large enough to accept the sequence and a terminating null character, which will be added automatically.

[
Matches a nonempty sequence of characters (no special provisions are made for multibyte characters) from a set of expected characters (the scanset). The corresponding argument shall be a pointer to the initial character of an array large enough to accept the sequence and a terminating null character, which will be added automatically. The conversion specifier includes all subsequent characters in the format string, up to and including the matching right bracket (`]`). The characters between the brackets (the scanlist) comprise the scanset, unless the character after the left bracket is a circumflex (`^`), in which case the scanset contains all the characters that do not appear in the scanlist between the circumflex and the right bracket. If the conversion specifier begins with `[]` or `[^]`, the right-bracket
character is in the scanlist and the next right bracket character is the matching right bracket
that ends the specification; otherwise, the first right bracket character is the one that ends
the specification. If a - character is in the scanlist and is not the first, nor the second where
the first character is a ^, nor the last character, the behavior is implementation-defined.

c
Matches a sequence of characters (no special provisions are made for multibyte characters)
of the number specified by the field width (1 if no field width is present in the directive).
The corresponding argument shall be a pointer to the initial character of an array large
enough to accept the sequence. No null character is added.

p
Matches an implementation-defined set of sequences, which should be the same as the set
of sequences that may be produced by the %p conversion of the fprintf function. The
corresponding argument shall be a pointer to void. The interpretation of the input then
is implementation-defined. If the input item is a value converted earlier during the same
program execution, the pointer that results shall compare equal to that value; otherwise
the behavior of the %p conversion is undefined.

n
No input is consumed. The corresponding argument shall be a pointer to integer into
which is to be written the number of characters read from the input stream so far by this
call to the fscanf function. Execution of a %n directive does not increment the assignment
count returned at the completion of execution of the fscanf function.

%
Matches a single %; no conversion or assignment occurs. The complete conversion specifi-
cation shall be %%.

If a conversion specification is invalid, the behavior is undefined.
The conversion specifiers E, G, and X are also valid and behave the same as, respectively, e,
g, and x.

If end-of-file is encountered during input, conversion is terminated. If end-of-file occurs
before any characters matching the current directive have been read (other than leading
white space, where permitted), execution of the current directive terminates with an input
failure; otherwise, unless execution of the current directive is terminated with a matching
failure, execution of the following directive (if any) is terminated with an input failure.

If conversion terminates on a conflicting input character, the offending input character is
left unread in the input stream. Trailing white space (including new-line characters) is
left unread unless matched by a directive. The success of literal matches and suppressed
assignments is not directly determinable other than via the %n directive.

The fscanf function returns the value of the macro EOF if an input failure occurs before
any conversion. Otherwise, the fscanf function returns the number of input items assigned,
which can be fewer than provided for, or even zero, in the event of an early matching failure.

The scanf function is equivalent to fscanf with the argument stdin interposed before the
arguments to scanf. Its return value is similar to that of fscanf.
The `sscanf` function is equivalent to `fscanf`, except that the argument `s` specifies a string from which the input is to be obtained, rather than from a stream. Reaching the end of the string is equivalent to encountering the end-of-file for the `fscanf` function. If copying takes place between objects that overlap, the behavior is undefined.

20.11 Writing to Files

20.11.1 Character Output Functions

The `fputc` function

```c
#include <stdio.h>
int fputc(int c, FILE *stream);
```

The `fputc` function writes the character specified by `c` (converted to an `unsigned char`) to the stream pointed to by `stream` at the position indicated by the associated file position indicator (if defined), and advances the indicator appropriately. If the file cannot support positioning requests, or if the stream is opened with append mode, the character is appended to the output stream. The function returns the character written, unless a write error occurs, in which case the error indicator for the stream is set and `fputc` returns `EOF`.

The `fputs` function

```c
#include <stdio.h>
int fputs(const char *s, FILE *stream);
```

The `fputs` function writes the string pointed to by `s` to the stream pointed to by `stream`. The terminating null character is not written. The function returns `EOF` if a write error occurs, otherwise it returns a nonnegative value.

The `putc` function

```c
#include <stdio.h>
int putc(int c, FILE *stream);
```

The `putc` function is equivalent to `fputc`, except that if it is implemented as a macro, it may evaluate `stream` more than once, so the argument should never be an expression with side effects. The function returns the character written, unless a write error occurs, in which case the error indicator for the stream is set and the function returns `EOF`.

The `putchar` function

```c
#include <stdio.h>
int putchar(int c);
```
The `putchar` function is equivalent to `putc` with the second argument `stdout`. It returns the character written, unless a write error occurs, in which case the error indicator for `stdout` is set and the function returns `EOF`.

**The `puts` function**

```c
#include <stdio.h>
int puts(const char *s);
```

The `puts` function writes the string pointed to by `s` to the stream pointed to by `stdout`, and appends a new-line character to the output. The terminating null character is not written. The function returns `EOF` if a write error occurs; otherwise, it returns a nonnegative value.

**20.11.2 Direct output function: the `fwrite` function**

```c
#include <stdio.h>
size_t fwrite(const void *ptr, size_t size, size_t nmemb, FILE *stream);
```

The `fwrite` function writes, from the array pointed to by `ptr`, up to `nmemb` elements whose size is specified by `size` to the stream pointed to by `stream`. The file position indicator for the stream (if defined) is advanced by the number of characters successfully written. If an error occurs, the resulting value of the file position indicator for the stream is indeterminate. The function returns the number of elements successfully written, which will be less than `nmemb` only if a write error is encountered.

**20.11.3 Formatted output functions: the `printf` family of functions**

```c
#include <stdarg.h>
#include <stdio.h>
int fprintf(FILE *stream, const char *format, ...);
int printf(const char *format, ...);
int sprintf(char *s, const char *format, ...);
int vfprintf(FILE *stream, const char *format, va_list arg);
int vprintf(const char *format, va_list arg);
int vsprintf(char *s, const char *format, va_list arg);
```

*Note: Some length specifiers and format specifiers are new in C99. These may not be available in older compilers and versions of the stdio library, which adhere to the C89/C90 standard. Wherever possible, the new ones will be marked with (C99).*

The `fprintf` function writes output to the stream pointed to by `stream` under control of the string pointed to by `format` that specifies how subsequent arguments are converted for output. If there are insufficient arguments for the format, the behavior is undefined. If the format is exhausted while arguments remain, the excess arguments are evaluated (as always) but are otherwise ignored. The `fprintf` function returns when the end of the format string is encountered.

The format shall be a multibyte character sequence, beginning and ending in its initial shift state. The format is composed of zero or more directives: ordinary multibyte characters
Writing to Files

(not %), which are copied unchanged to the output stream; and conversion specifications, each of which results in fetching zero or more subsequent arguments, converting them, if applicable, according to the corresponding conversion specifier, and then writing the result to the output stream.

Each conversion specification is introduced by the character %. After the %, the following appear in sequence:

- Zero or more flags (in any order) that modify the meaning of the conversion specification.
- An optional minimum field width. If the converted value has fewer characters than the field width, it is padded with spaces (by default) on the left (or right, if the left adjustment flag, described later, has been given) to the field width. The field width takes the form of an asterisk * (described later) or a decimal integer. (Note that 0 is taken as a flag, not as the beginning of a field width.)
- An optional precision that gives the minimum number of digits to appear for the d, i, o, u, x, and X conversions, the number of digits to appear after the decimal-point character for a, A, e, E, f, and F conversions, the maximum number of significant digits for the g and G conversions, or the maximum number of characters to be written from a string in s conversions. The precision takes the form of a period (.) followed either by an asterisk * (described later) or by an optional decimal integer; if only the period is specified, the precision is taken as zero. If a precision appears with any other conversion specifier, the behavior is undefined. Floating-point numbers are rounded to fit the precision; i.e. printf("%1.1f\n", 1.19); produces 1.2.
- An optional length modifier that specifies the size of the argument.
- A conversion specifier character that specifies the type of conversion to be applied.

As noted above, a field width, or precision, or both, may be indicated by an asterisk. In this case, an int argument supplies the field width or precision. The arguments specifying field width, or precision, or both, shall appear (in that order) before the argument (if any) to be converted. A negative field width argument is taken as a - flag followed by a positive field width. A negative precision argument is taken as if the precision were omitted.

The flag characters and their meanings are:

- The result of the conversion is left-justified within the field. (It is right-justified if this flag is not specified.)
+ The result of a signed conversion always begins with a plus or minus sign. (It begins with a sign only when a negative value is converted if this flag is not specified. The results of all floating conversions of a negative zero, and of negative values that round to zero, include a minus sign.)

space

If the first character of a signed conversion is not a sign, or if a signed conversion results in no characters, a space is prefixed to the result. If the space and + flags both appear, the space flag is ignored.

#
The result is converted to an "alternative form". For o conversion, it increases the precision, if and only if necessary, to force the first digit of the result to be a zero (if the value and precision are both 0, a single 0 is printed). For x (or X) conversion, a nonzero result has Ox (or 0X) prefixed to it. For a, A, e, E, f, F, g, and G conversions, the result always contains a decimal-point character, even if no digits follow it. (Normally, a decimal-point character appears in the result of these conversions only if a digit follows it.) For g and G conversions, trailing zeros are not removed from the result. For other conversions, the behavior is undefined.

For d, i, o, u, x, X, a, A, e, E, f, F, g, and G conversions, leading zeros (following any indication of sign or base) are used to pad to the field width; no space padding is performed. If the 0 and - flags both appear, the 0 flag is ignored. For d, i, o, u, x, and X conversions, if a precision is specified, the 0 flag is ignored. For other conversions, the behavior is undefined.

The length modifiers and their meanings are:

**hh**

(C99) Specifies that a following d, i, o, u, x, or X conversion specifier applies to a signed char or unsigned char argument (the argument will have been promoted according to the integer promotions, but its value shall be converted to signed char or unsigned char before printing); or that a following n conversion specifier applies to a pointer to a signed char argument.

**h**

Specifies that a following d, i, o, u, x, or X conversion specifier applies to a short int or unsigned short int argument (the argument will have been promoted according to the integer promotions, but its value shall be converted to short int or unsigned short int before printing); or that a following n conversion specifier applies to a pointer to a short int argument.

**l (ell)**

Specifies that a following d, i, o, u, x, or X conversion specifier applies to a long int or unsigned long int argument; that a following n conversion specifier applies to a pointer to a long int argument; (C99) that a following c conversion specifier applies to a wint_t argument; (C99) that a following a conversion specifier applies to a pointer to a wchar_t argument; or has no effect on a following a, A, e, E, f, F, g, or G conversion specifier.

**ll (ell-ell)**

(C99) Specifies that a following d, i, o, u, x, or X conversion specifier applies to a long long int or unsigned long long int argument; or that a following n conversion specifier applies to a pointer to a long long int argument.

**j**
(C99) Specifies that a following d, i, o, u, x, or X conversion specifier applies to an intmax_t or uintmax_t argument; or that a following n conversion specifier applies to a pointer to an intmax_t argument.

z

(C99) Specifies that a following d, i, o, u, x, or X conversion specifier applies to a size_t or the corresponding signed integer type argument; or that a following n conversion specifier applies to a pointer to a signed integer type corresponding to size_t argument.

t

(C99) Specifies that a following d, i, o, u, x, or X conversion specifier applies to a ptrdiff_t or the corresponding unsigned integer type argument; or that a following n conversion specifier applies to a pointer to a ptrdiff_t argument.

L

Specifies that a following a, A, e, E, f, F, g, or G conversion specifier applies to a long double argument.

If a length modifier appears with any conversion specifier other than as specified above, the behavior is undefined.

The conversion specifiers and their meanings are:

d, i

The int argument is converted to signed decimal in the style [-]dddd. The precision specifies the minimum number of digits to appear; if the value being converted can be represented in fewer digits, it is expanded with leading zeros. The default precision is 1. The result of converting a zero value with a precision of zero is no characters.

o, u, x, X

The unsigned int argument is converted to unsigned octal (o), unsigned decimal (u), or unsigned hexadecimal notation (x or X) in the style dddd; the letters abcd ef are used for x conversion and the letters ABCDEF for X conversion. The precision specifies the minimum number of digits to appear; if the value being converted can be represented in fewer digits, it is expanded with leading zeros. The default precision is 1. The result of converting a zero value with a precision of zero is no characters.

f, F

A double argument representing a (finite) floating-point number is converted to decimal notation in the style [-]ddd.d, where the number of digits after the decimal-point character is equal to the precision specification. If the precision is missing, it is taken as 6; if the precision is zero and the # flag is not specified, no decimal-point character appears. If a decimal-point character appears, at least one digit appears before it. The value is rounded to the appropriate number of digits.

(C99) A double argument representing an infinity is converted in one of the styles [-]inf or [-]/infinity — which style is implementation-defined. A double argument representing a NaN is converted in one of the styles [-]nan or [-]/nan(n-char-sequence) — which style, and the meaning of any n-char-sequence, is implementation-defined. The F conversion specifier produces INF, INFINITY, or NAN instead of inf, infinity, or nan, respectively. (When
applied to infinite and NaN values, the -, +, and space flags have their usual meaning; the # and 0 flags have no effect.)

e, E

A double argument representing a (finite) floating-point number is converted in the style \([-/+]d.\,d\,d\,d\,d\,d\,d\,d\,d\,d\,d\,d\), where there is one digit (which is nonzero if the argument is nonzero) before the decimal-point character and the number of digits after it is equal to the precision; if the precision is missing, it is taken as 6; if the precision is zero and the # flag is not specified, no decimal-point character appears. The value is rounded to the appropriate number of digits. The E conversion specifier produces a number with E instead of e introducing the exponent. The exponent always contains at least two digits, and only as many more digits as necessary to represent the exponent. If the value is zero, the exponent is zero.

(C99) A double argument representing an infinity or NaN is converted in the style of an f or F conversion specifier.

g, G

A double argument representing a (finite) floating-point number is converted in style f or e (or in style F or E in the case of a G conversion specifier), with the precision specifying the number of significant digits. If the precision is zero, it is taken as 1. The style used depends on the value converted; style e (or E) is used only if the exponent resulting from such a conversion is less than \(-4\) or greater than or equal to the precision. Trailing zeros are removed from the fractional portion of the result unless the # flag is specified; a decimal-point character appears only if it is followed by a digit.

(C99) A double argument representing an infinity or NaN is converted in the style of an f or F conversion specifier.

a, A

(C99) A double argument representing a (finite) floating-point number is converted in the style \([-/+]0xh.\,h\,h\,h\,h\,p\,\pm\,d\), where there is one hexadecimal digit (which is nonzero if the argument is a normalized floating-point number and is otherwise unspecified) before the decimal-point character (Binary implementations can choose the hexadecimal digit to the left of the decimal-point character so that subsequent digits align to nibble [4-bit] boundaries.) and the number of hexadecimal digits after it is equal to the precision; if the precision is missing and FLT_RADIX is a power of 2, then the precision is sufficient for an exact representation of the value; if the precision is missing and FLT_RADIX is not a power of 2, then the precision is sufficient to distinguish (The precision \(p\) is sufficient to distinguish values of the source type if \(16^{p-1} > b^n\) where \(b\) is FLT_RADIX and \(n\) is the number of base-\(b\) digits in the significand of the source type. A smaller \(p\) might suffice depending on the implementation's scheme for determining the digit to the left of the decimal-point character.) values of type double, except that trailing zeros may be omitted; if the precision is zero and the # flag is not specified, no decimal-point character appears. The letters abcdef are used for a conversion and the letters ABCDEF for A conversion. The A conversion specifier produces a number with X and P instead of x and p. The exponent always contains at least one digit, and only as many more digits as necessary to represent the decimal exponent of 2. If the value is zero, the exponent is zero.

A double argument representing an infinity or NaN is converted in the style of an f or F conversion specifier.
If no length modifier is present, the int argument is converted to an unsigned char, and the resulting character is written.

(C99) If an length modifier is present, the wint_t argument is converted as if by an ls conversion specification with no precision and an argument that points to the initial element of a two-element array of wchar_t, the first element containing the wint_t argument to the lc conversion specification and the second a null wide character.

If no length modifier is present, the argument shall be a pointer to the initial element of an array of character type. (No special provisions are made for multibyte characters.) Characters from the array are written up to (but not including) the terminating null character. If the precision is specified, no more than that many characters are written. If the precision is not specified or is greater than the size of the array, the array shall contain a null character.

(C99) If an length modifier is present, the argument shall be a pointer to the initial element of an array of wchar_t type. Wide characters from the array are converted to multibyte characters (each as if by a call to the wcrtomb function, with the conversion state described by an mbstate_t object initialized to zero before the first wide character is converted) up to and including a terminating null wide character. The resulting multibyte characters are written up to (but not including) the terminating null character (byte). If no precision is specified, the array shall contain a null wide character. If a precision is specified, no more than that many characters (bytes) are written (including shift sequences, if any), and the array shall contain a null wide character if, to equal the multibyte character sequence length given by the precision, the function would need to access a wide character one past the end of the array. In no case is a partial multibyte character written. (Redundant shift sequences may result if multibyte characters have a state-dependent encoding.)

The argument shall be a pointer to void. The value of the pointer is converted to a sequence of printable characters, in an implementation-defined manner.

The argument shall be a pointer to signed integer into which is written the number of characters written to the output stream so far by this call to fprintf. No argument is converted, but one is consumed. If the conversion specification includes any flags, a field width, or a precision, the behavior is undefined.

A % character is written. No argument is converted. The complete conversion specification shall be %%.

If a conversion specification is invalid, the behavior is undefined. If any argument is not the correct type for the corresponding conversion specification, the behavior is undefined.
In no case does a nonexistent or small field width cause truncation of a field; if the result of a conversion is wider than the field width, the field is expanded to contain the conversion result.

For `a` and `A` conversions, if `FLT_RADIX` is a power of 2, the value is correctly rounded to a hexadecimal floating number with the given precision.

It is recommended practice that if `FLT_RADIX` is not a power of 2, the result should be one of the two adjacent numbers in hexadecimal floating style with the given precision, with the extra stipulation that the error should have a correct sign for the current rounding direction.

It is recommended practice that for `e`, `E`, `f`, `F`, `g`, and `G` conversions, if the number of significant decimal digits is at most `DECIMAL_DIG`, then the result should be correctly rounded. (For binary-to-decimal conversion, the result format’s values are the numbers representable with the given format specifier. The number of significant digits is determined by the format specifier, and in the case of fixed-point conversion by the source value as well.) If the number of significant decimal digits is more than `DECIMAL_DIG` but the source value is exactly representable with `DECIMAL_DIG` digits, then the result should be an exact representation with trailing zeros. Otherwise, the source value is bounded by two adjacent decimal strings $L < U$, both having `DECIMAL_DIG` significant digits; the value of the resultant decimal string $D$ should satisfy $L \leq D \leq U$, with the extra stipulation that the error should have a correct sign for the current rounding direction.

The `fprintf` function returns the number of characters transmitted, or a negative value if an output or encoding error occurred.

The `printf` function is equivalent to `fprintf` with the argument `stdout` interposed before the arguments to `printf`. It returns the number of characters transmitted, or a negative value if an output error occurred.

The `sprintf` function is equivalent to `fprintf`, except that the argument `s` specifies an array into which the generated input is to be written, rather than to a stream. A null character is written at the end of the characters written; it is not counted as part of the returned sum. If copying takes place between objects that overlap, the behavior is undefined. The function returns the number of characters written in the array, not counting the terminating null character.

The `vfprintf` function is equivalent to `fprintf`, with the variable argument list replaced by `arg`, which shall have been initialized by the `va_start` macro (and possibly subsequent `va_arg` calls). The `vfprintf` function does not invoke the `va_end` macro. The function returns the number of characters transmitted, or a negative value if an output error occurred.

The `vprintf` function is equivalent to `printf`, with the variable argument list replaced by `arg`, which shall have been initialized by the `va_start` macro (and possibly subsequent `va_arg` calls). The `vprintf` function does not invoke the `va_end` macro. The function returns the number of characters transmitted, or a negative value if an output error occurred.

The `vsprintf` function is equivalent to `sprintf`, with the variable argument list replaced by `arg`, which shall have been initialized by the `va_start` macro (and possibly subsequent `va_arg` calls). The `vsprintf` function does not invoke the `va_end` macro. If copying takes place between objects that overlap, the behavior is undefined. The function returns the number of characters written into the array, not counting the terminating null character.
20.12 References

fr:Programmation C/Entrées/sorties
pl:C/Czytanie i pisanie do plików

9 https://fr.wikibooks.org/wiki/Programmation%20C%2FEntr%C3%A9es%2Fsorties
10 https://pl.wikibooks.org/wiki/C%2FCzytanie%20i%20pisanie%20do%20plik%C3%B3w
21 Beginning exercises

21.1 Variables

21.1.1 Naming

1. Can a variable name start with a number?
2. Can a variable name start with a typographical symbol (e.g. #, *, _)?
3. Give an example of a C variable name that would not work. Why doesn't it work?

21.1.2 Data Types

1. List at least three data types in C
   a) On your computer, how much memory does each require?
   b) Which ones can be used in place of another? Why?
      i. Are there any limitations on these uses?
      ii. If so, what are they?
      iii. Is it necessary to do anything special to use the alternative?
2. Can the name we use for a data type (e.g. 'int', 'float') be used as a variable?

21.1.3 Assignment

1. How would you assign the value 3.14 to a variable called pi?
2. Is it possible to assign an int to a double?
   a) Is the reverse possible?

21.1.4 Referencing

1. A common mistake for new students is reversing the assignment statement. Suppose you want to assign the value stored in the variable "pi" to another variable, say "pi2":
   a) What is the correct statement?
   b) What is the reverse? Is this a valid C statement (even if it gives incorrect results)?
   c) What if you wanted to assign a constant value (like 3.1415) to "pi2":
      a. What would the correct statement look like?
      b. Would the reverse be a valid or invalid C statement?
21.2 Simple I/O

21.2.1 String manipulation

1. Write a program that prompts the user for a string, and prints its reverse.
2. Write a program that prompts the user for a sentence, and prints each word on its own line.

21.2.2 Loops

1. Write a function that outputs a right isosceles triangle of height and width $n$, so $n = 3$ would look like

```
*
**
***
```

2. Write a function that outputs a sideways triangle of height $2n-1$ and width $n$, so the output for $n = 4$ would be:

```
*
**
***
****
***
**
*
```

3. Write a function that outputs a right-side-up triangle of height $n$ and width $2n-1$; the output for $n = 6$ would be:

```
*
****
********
```

21.3 Program Flow

1. Build a program where control passes from main to four different functions with 4 calls.
2. Now make a while loop in main with the function calls inside it. Ask for input at the beginning of the loop. End the while loop if the user hits Q
3. Next add conditionals to call the functions when the user enters numbers, so 1 goes to function1, 2 goes to function 2, etc.
4. Have function 1 call function a, which calls function b, which calls function c
5. Draw out a diagram of program flow, with arrows to indicate where control goes

### 21.4 Functions

1. Write a function to check if an integer is negative; the declaration should look like `bool is_positive(int i);`

2. Write a function to raise a floating point number to an integer power, so for example to when you use it
   ```
   float a = raise_to_power(2, 3);  // a gets 8
   float b = raise_to_power(9, 2);  // b gets 81
   float raise_to_power(float f, int power);  // make this your declaration
   ```

### 21.5 Math

1. Write a function to calculate if a number is prime. Return 1 if it is prime and 0 if it is not a prime.

2. Write a function to determine the number of prime numbers below n.

3. Write a function to find the square root by using Newton's method.

4. Write functions to evaluate the trigonometric functions:

5. Try to write a random number generator.

6. Write a function to determine the prime number between 2 and 100:

### 21.6 Recursion

**Merge sort**

1. Write a C program to generate a random integer array with a given length n, and sort it recursively using the Merge sort algorithm.

   - The merge sort algorithm is a recursive algorithm.

   - sorting a one element array is easy.

   - sorting two one-element arrays, requires the merge operation. The merge operation looks at two sorted arrays as lists, and compares the head of the list, and which ever head is smaller, this element is put on the sorted list and the head of that list is ticked off, so the next element becomes the head of that list. This is done until one of the lists is exhausted, and the other list is then copied onto the end of the sorted list.

   - the recursion occurs, because merging two one-element arrays produces one two-element sorted array, which can be merged with another two-element sorted array produced the same way. This produces a sorted 4 element array, and the same applies for another 4 element sorted array.
- so the basic merge sort, is to check the size of list to be sorted, and if it is greater than
one, divide the array into two, and call merge sort again on the two halves. After wards,
merge the two halves in a temporary space of equal size, and then copy back the final sorted
array onto the original array.

Binary heaps

2. Binary heaps:

- A binary max-heap or min-heap, is an ordered structure where some nodes are guaranteed
greater than other nodes, e.g. the parent vs two children. A binary heap can be stored
in an array , where ,

- given a position i (the parent) , i*2 is the left child, and i*2+1 is the right child.

- ( C arrays begin at position 0, but 0 * 2 = 0, and 0 *2 + 1= 1, which is incorrect , so
start the heap at position 1, or add 1 for parent-to-child calculations, and subtract 1 for
child-to-parent calculations ).

- try to model this using with a pencil and paper, using 10 random unsorted numbers, and
inserting each of them into a "heapsort" array of 10 elements.

- To insert into a heap, end-add and swap-parent if higher, until parent higher.

- To delete the top of a heap, move end-to-top, and defer-higher-child or sift-down ,
until no child is higher.

- try it on a pen and paper the numbers 10, 4, 6 ,3 ,5 , 11.

- the answer was 11, 5, 10, 3, 4 , 6.

- EXERCISE: Now try removing each top element of 11, 5, 10, 3, 4, 6 , using end-to-top
and sift-down ( or swap-higher-child) to get the numbers
in descending order.

- a priority queue allows elements to be inserted with a priority , and extracted according
to priority. ( This can happen usefully, if the element has a paired structure, one part is
the key, and the other part the data. Otherwise, it is just a mechanism for sorting ).

- EXERCISE: Using the above technique of insert-back/challenge-parent, and delete-
front/last-to-front/defer-higher-child, implement either heap sort or a priority queue.

Dijkstra's algorithm

Dijkstra's algorithm is a searching algorithm using a priority queue. It begins with inserting
the start node with a priority value of 0. All other nodes are inserted with priority values
of large N. Each node has an adjacency list of other nodes, a current distance to start node,
and previous pointer to previous node used to calculate current node. Alternative to an
adjacency list, is an adjacency matrix, which needs n x n boolean adjacencies.

The algorithm basically iterates over the priority queue, removing the front node, examining
the adjacent nodes, and updating with a distance equal to the sum of the front nodes
distance for each adjacent node, and the distance given by the adjacency information for an adjacent node.

After each node's update, the extra operation "update priority" is used on that node:

while the node's distance is less than it's parents node (for this priority queue, parents have lesser distances than the children), the node is swapped with the parent.

After this, while the node is greater distance than one or more of its children, it is swapped with the least distant child, so the least distant child becomes parent of its greater distant sibling, and parent to the greater distant current node.

With updating the priority, the adjacent node to the current node has a back pointer changed to the current node.

The algorithm ends when the target node becomes the current node removed, and the path to the start node can be recorded in an array by following back pointers, and then doing something like a quick sort partition to reverse the order of the array, to give the shortest path to target node from the start node.

Quick sort

3. Write a C program to recursively sort using the Quick sort partition exchange algorithm.

- you can use the "driver", or the random number test data from Q1. on mergesort. This is "re-use", which is encouraged in general.

- an advantage of reuse is less writing time, debugging time, testing time.

- the concept of partition exchange is that a partition element is (randomly) selected, and every thing that needs sorted is put into 3 equivalence classes: those elements less than the partition value, the partition element, and everything above (and equal to ) the partition element.

- this can be done without allocating more space than one temporary element space for swapping two elements. e.g a temporary integer for integer data.

- However, where the partition element should be using the original array space is not known.

- This is usually implemented with putting the partition on the end of the array to be sorted, and then putting two pointers, one at the start of the array, and one at the element next to the partition element, and repeatedly scanning the left pointer right, and the right pointer left.

- the left scan stops when an element equal to or greater than the partition is found, and the right scan stops for a smaller element than the partition value,

and these are swapped, which uses the temporary extra space.

- the left scan will always stop if it reaches the partition element, which is the last element; this means the entire array is less than partition value.

- the right scan could reach the first element, if the entire array is greater than the partition , and this needs to be tested for, else the scan doesn't stop.
• the outer loop exits when then left and right pointers cross. Testing for pointer crossing and outer loop exit should occur before swapping, otherwise the right pointer may be swapping a less-than-partition element previously scanned by the left pointer.

• finally, the partition element needs to be put between the left and right partitions, once the pointers cross.
• At pointer crossing, the left pointer may be stopped at the partition element's last position in the array, and the right pointer not progressed past the element just before the last element. This happens when all the elements are less than the partition.

  - if the right pointer is chosen to swap with the partition, then an incorrect state results where the last element of the left array becomes less than the partition element value.
  - if the left pointer is chosen to swap with the partition, then the left array will be less than the partition, and partition will have swapped with an element with value greater than the partition or the partition itself.

• The corner case of quicksorting a 2 element out-of-order array has to be examined.

  - The left pointer stops on the first out of order element. The right pointer begins on the first out-of-order element, but the outer loop exits because this is the leftmost element. The partition element is then swapped with the left pointer's first element, and the two elements are now in order.

  - In the case of a 2 element in order array, the leftmost pointer skips the first element which is less than the partition, and stops on the partition. The right pointer begins on the first element and exits because it is the first position. The pointers have crossed so the outer loop exits. The partition swaps with itself, so the in-ordering is preserved.

• After doing a swap, the left pointer should be incremented and right pointer decremented, so the same positions aren't scanned again, because an endless loop can result (possibly when the left pointer exits when the element is equal to or greater than the partition, and the right element is equal to the partition value). One implementation, Sedgewick, starts the pointers with the left pointer minus one and right pointer the plus one the intended initial scan positions, and use the pre-increment and pre-decrement operators e.g. (++i, --i).

fr:Exercices en langage C¹ et:Programmeerimiskeel C/Harjutused² pl:C/Ćwiczenia dla początkujących³

---

¹ https://fr.wikibooks.org/wiki/Exercices%20en%20langage%20C
² https://et.wikibooks.org/wiki/Programmeerimiskeel%20C%2FHаржутед
³ https://pl.wikibooks.org/wiki/C%2FC%28wiczenia%20dla%20pocz%C5%82tkuj%C5%82ych
22 In-depth C ideas
23 Arrays

Arrays in C act to store related data under a single variable name with an index, also known as a subscript. It is easiest to think of an array as simply a list or ordered grouping for variables of the same type. As such, arrays often help a programmer organize collections of data efficiently and intuitively.

Later we will consider the concept of a pointer, fundamental to C, which extends the nature of the array (array can be termed as a constant pointer). For now, we will consider just their declaration and their use.

23.1 Arrays

C arrays are declared in the following form:

```c
type name[number of elements];
```

For example, if we want an array of six integers (or whole numbers), we write in C:

```c
int numbers[6];
```

For a six character array called letters,

```c
char letters[6];
```

and so on.

You can also initialize as you declare. Just put the initial elements in curly brackets separated by commas as the initial value:

```c
type name[number of elements]={comma-separated values}
```

For example, if we want to initialize an array with six integers, with 0, 0, 1, 0, 0, 0 as the initial values:

```c
int point[6]={0,0,1,0,0,0};
```

Though when the array is initialized as in this case, the array dimension may be omitted, and the array will be automatically sized to hold the initial data:

```c
int point[6]={0,0,1,0,0,0};
```

This is very useful in that the size of the array can be controlled by simply adding or removing initializer elements from the definition without the need to adjust the dimension.

If the dimension is specified, but not all elements in the array are initialized, the remaining elements will contain a value of 0. This is very useful, especially when we have very large arrays.

```c
int numbers[2000]={245};
```
The above example sets the first value of the array to 245, and the rest to 0.

If we want to access a variable stored in an array, for example with the above declaration, the following code will store a 1 in the variable \(x\)

```c
int x;
x = point[2];
```

Arrays in C are indexed starting at 0, as opposed to starting at 1. The first element of the array above is \(point[0]\). The index to the last value in the array is the array size minus one. In the example above the subscripts run from 0 through 5. C does not guarantee bounds checking on array accesses. The compiler may not complain about the following (though the best compilers do):

```c
char y;
int z = 9;
char point[6] = { 1, 2, 3, 4, 5, 6 };
//examples of accessing outside the array. A compile error is not always raised
y = point[15];
y = point[-4];
y = point[z];
```

During program execution, an out of bounds array access does not always cause a run time error. Your program may happily continue after retrieving a value from \(point[-1]\). To alleviate indexing problems, the `sizeof()` expression is commonly used when coding loops that process arrays.

Many people use a macro that in turn uses `sizeof()` to find the number of elements in an array, a macro variously named "lengthof()",1 "MY_ARRAY_SIZE()" or "NUM_ELEM()",2 "SIZEOF_STATIC_ARRAY()",3 etc.

```c
int ix;
short anArray[ ] = { 3, 6, 9, 12, 15 };
for (ix=0; ix< (sizeof(anArray)/sizeof(short)); ++ix) {
  DoSomethingWith("%d", anArray[ix] );
}
```

Notice in the above example, the size of the array was not explicitly specified. The compiler knows to size it at 5 because of the five values in the initializer list. Adding an additional value to the list will cause it to be sized to six, and because of the `sizeof` expression in the `for` loop, the code automatically adjusts to this change. Good programming practice is to declare a variable `size`, and store the number of elements in the array in it.

```c
size = sizeof(anArray)/sizeof(short)
```

C also supports multi dimensional arrays (or, rather, arrays of arrays). The simplest type is a two dimensional array. This creates a rectangular array - each row has the same number of columns. To get a char array with 3 rows and 5 columns we write in C

```
1 Pádraig Brady. "C and C++ notes" (http://www.pixelbeat.org/programming/gcc/c_c++_notes.html).
2 C Programming/Pointers and arrays (Chapter 24 on page 167)
To access/modify a value in this array we need two subscripts:

```c
char ch;
ch = two_d[2][4];
```

or

```c
two_d[0][0] = 'x';
```

Similarly, a multi-dimensional array can be initialized like this:

```c
int two_d[2][3] = {{ 5, 2, 1 },
                   { 6, 7, 8 }};
```

The amount of columns must be explicitly stated; however, the compiler will find the appropriate amount of rows based on the initializer list.

There are also weird notations possible:

```c
int a[100];
int i = 0;
if (a[i] == i[a])
{
    printf("Hello world!\n");
}
```

a[i] and i[a] refer to the same location. (This is explained later in the next Chapter.)

### 23.2 Strings

![Figure 1](image)

**Figure 1** String "Merkkijono" stored in memory

C has no string handling facilities built in; consequently, strings are defined as arrays of characters. C allows a character array to be represented by a character string rather than a list of characters, with the null terminating character automatically added to the end. For example, to store the string "Merkkijono", we would write

```c
char string[] = "Merkkijono";
```

or

```c
char string[] = {'M', 'e', 'r', 'k', 'k', 'i', 'j', 'o', 'n', 'o', '\0'};
```

In the first example, the string will have a null character automatically appended to the end by the compiler; by convention, library functions expect strings to be terminated by a null character. The latter declaration indicates individual elements, and as such the null terminator needs to be added manually.
Strings do not always have to be linked to an explicit variable. As you have seen already, a string of characters can be created directly as an unnamed string that is used directly (as with the printf functions.)

To create an extra long string, you will have to split the string into multiple sections, by closing the first section with a quote, and recommencing the string on the next line (also starting and ending in a quote):

```c
char string[] = "This is a very, very long "
    "string that requires two lines."
```

While strings may also span multiple lines by putting the backslash character at the end of the line, this method is deprecated.

There is a useful library of string handling routines which you can use by including another header file.

```c
#include <string.h>  // new header file
```

This standard string library will allow various tasks to be performed on strings, and is discussed in the Strings chapter.

### 23.3 References

et:Programmeerimiskeel C/Massiivid
fr:Programmation C/Tableaux
it:C/Vettori e puntatori/Vettori
pl:C/Tablice
fi:C/Taulukot

---

4 Chapter 26 on page 187
5 https://et.wikibooks.org/wiki/Programmeerimiskeel%20C%20Massiivid
6 https://fr.wikibooks.org/wiki/Programmation%20C%20Tableaux
7 https://it.wikibooks.org/wiki/C%20Vettori%20e%20Puntatori%20Vettori
8 https://pl.wikibooks.org/wiki/C%20Tablice
9 https://fi.wikibooks.org/wiki/C%20Taulukot
24 Pointers and arrays

A pointer\(^1\) is a value that designates the address (i.e., the location in memory), of some value. Pointers are variables that hold a memory location.

There are four fundamental things you need to know about pointers:

- How to declare them (with the address operator \`&\`: `int *pointer = &variable;`)
- How to assign to them (`pointer = NULL;`)
- How to reference the value to which the pointer points (known as dereferencing, by using the dereferencing operator `*`: `value = *pointer;`)
- How they relate to arrays (the vast majority of arrays in C are simple lists, also called "1 dimensional arrays", but we will briefly cover multi-dimensional arrays with some pointers in a later chapter\(^2\)).

\(^1\) [https://en.wikipedia.org/wiki/Pointer%20%28computing%29](https://en.wikipedia.org/wiki/Pointer%20%28computing%29)
\(^2\) Chapter 29.1 on page 211
Pointers can reference any data type, even functions. We'll also discuss the relationship of pointers with text strings and the more advanced concept of function pointers.

24.1 Declaring pointers

Consider the following snippet of code which declares two pointers:

```c
struct MyStruct {
    int m_aNumber;
    float num2;
};

int main()
{
    int *pJ2;
    struct MyStruct *pAnItem;
}
```

Lines 1-4 define a structure. Line 8 declares a variable which points to an `int`, and line 9 declares a variable which points to something with structure `MyStruct`. So to declare a variable as something which points to some type, rather than contains some type, the asterisk (`*`) is placed before the variable name.

In the following, line 1 declares `var1` as a pointer to a long and `var2` as a long and not a pointer to a long. In line 2, `p3` is declared as a pointer to a pointer to an `int`.

```c
long * var1, var2;
int ** p3;
```

Pointer types are often used as parameters to function calls. The following shows how to declare a function which uses a pointer as an argument. Since C passes function arguments by value, in order to allow a function to modify a value from the calling routine, a pointer to the value must be passed. Pointers to structures are also used as function arguments even when nothing in the struct will be modified in the function. This is done to avoid copying the complete contents of the structure onto the stack. More about pointers as function arguments later.

```c
int MyFunction( struct MyStruct *pStruct );
```

24.2 Assigning values to pointers

So far we've discussed how to declare pointers. The process of assigning values to pointers is next. To assign the address of a variable to a pointer, the `&` or 'address of' operator is used.

```c
int myInt;
int *pPointer;
struct MyStruct dvorak;
struct MyStruct *pKeyboard;

pPointer = &myInt;
pKeyboard = &dvorak;
```
Here, pPointer will now reference myInt and pKeyboard will reference dvorak.

Pointers can also be assigned to reference dynamically allocated memory. The malloc() and calloc() functions are often used to do this.

```c
#include <stdlib.h>
/* ... */
struct MyStruct *pKeyboard;
/* ... */
pKeyboard = malloc(sizeof *pKeyboard);
```

The malloc function returns a pointer to dynamically allocated memory (or NULL if unsuccessful). The size of this memory will be appropriately sized to contain the MyStruct structure.

The following is an example showing one pointer being assigned to another and of a pointer being assigned a return value from a function.

```c
static struct MyStruct val1, val2, val3, val4;

struct MyStruct *ASillyFunction( int b )
{
    struct MyStruct *myReturn;
    if (b == 1) myReturn = &val1;
    else if (b==2) myReturn = &val2;
    else if (b==3) myReturn = &val3;
    else myReturn = &val4;

    return myReturn;
}

struct MyStruct *strPointer;
int *c, *d;
int j;

c = &j; /* pointer assigned using & operator */
d = c; /* assign one pointer to another */
strPointer = ASillyFunction( 3 ); /* pointer returned from a function. */
```

When returning a pointer from a function, do not return a pointer that points to a value that is local to the function or that is a pointer to a function argument. Pointers to local variables become invalid when the function exits. In the above function, the value returned points to a static variable. Returning a pointer to dynamically allocated memory is also valid.

### 24.3 Pointer dereferencing

![Figure 3](image)

Figure 3  The pointer p points to the variable a.
To access a value to which a pointer points, the * operator is used. Another operator, the -> operator is used in conjunction with pointers to structures. Here's a short example.

```c
int c, d;
int *pj;
struct MyStruct astruct;
struct MyStruct *bb;

c = 10;
pj = &c;  /* pj points to c */
d = *pj;  /* d is assigned the value to which pj points, 10 */
pj = &d;  /* now points to d */
*pj = 12;  /* d is now 12 */

bb = &astruct;
(*bb).m_aNumber = 3;  /* assigns 3 to the m_aNumber member of astruct */
bb->num2 = 44.3;  /* assigns 44.3 to the num2 member of astruct */
*pj = bb->m_aNumber;  /* equivalent to d = astruct.m_aNumber; */
```

The expression `bb->m_aNumber` is entirely equivalent to `(bb).m_aNumber`. They both access the `m_aNumber` element of the structure pointed to by `bb`. There is one more way of dereferencing a pointer, which will be discussed in the following section.

When dereferencing a pointer that points to an invalid memory location, an error often occurs which results in the program terminating. The error is often reported as a segmentation error. A common cause of this is failure to initialize a pointer before trying to dereference it.

C is known for giving you just enough rope to hang yourself, and pointer dereferencing is a prime example. You are quite free to write code that accesses memory outside that which you have explicitly requested from the system. And many times, that memory may appear as available to your program due to the vagaries of system memory allocation. However, even if 99 executions allow your program to run without fault, that 100th execution may be the time when your "memory pilfering" is caught by the system and the program fails. Be careful to ensure that your pointer offsets are within the bounds of allocated memory!

The declaration `void *somePointer;` is used to declare a pointer of some nonspecified type. You can assign a value to a void pointer, but you must cast the variable to point to some specified type before you can dereference it. Pointer arithmetic is also not valid with `void *` pointers.

### 24.4 Pointers and Arrays

Up to now, we've carefully been avoiding discussing arrays in the context of pointers. The interaction of pointers and arrays can be confusing but here are two fundamental statements about it:

- A variable declared as an array of some type acts as a pointer to that type. When used by itself, it points to the first element of the array.
- A pointer can be indexed like an array name.

The first case often is seen to occur when an array is passed as an argument to a function. The function declares the parameter as a pointer, but the actual argument may be the name of an array. The second case often occurs when accessing dynamically allocated memory.
Let's look at examples of each. In the following code, the call to calloc() effectively allocates an array of struct MyStruct items.

```c
float KrazyFunction( struct MyStruct *parm1, int p1size, int bb )
{
    int ix; //declaring an integer variable/
    for (ix=0; ix<p1size; ix++)
    {
        if (parm1[ix].m_aNumber == bb)
            return parm1[ix].num2;
    }
    return 0.0f;
}
/* ... */
struct MyStruct myArray[4];
#define MY_ARRAY_SIZE (sizeof(myArray)/sizeof(*myArray))
float v3;
struct MyStruct *secondArray;
int someSize;
int ix;
/* initialization of myArray ... */
v3 = KrazyFunction( myArray, MY_ARRAY_SIZE, 4 );
/* ... */
secondArray = calloc( someSize, sizeof(*myArray) );
for (ix=0; ix<someSize; ix++)
{
    secondArray[ix].m_aNumber = ix * 2;
    secondArray[ix].num2 = .304 * ix * ix;
}
```

Pointers and array names can pretty much be used interchangeably. There are exceptions. You cannot assign a new pointer value to an array name. The array name will always point to the first element of the array. In the function KrazyFunction above, you could however assign a new value to parm1, as it is just a pointer to the first element of myArray. It is also valid for a function to return a pointer to one of the array elements from an array passed as an argument to a function. A function should never return a pointer to a local variable, even though the compiler will probably not complain.

When declaring parameters to functions, declaring an array variable without a size is equivalent to declaring a pointer. Often this is done to emphasize the fact that the pointer variable will be used in a manner equivalent to an array.

```c
/* two equivalent function definitions */
int LittleFunction( int *param1 );
int LittleFunction( int param1[] );
```

Now we're ready to discuss pointer arithmetic. You can add and subtract integer values to/from pointers. If myArray is declared to be some type of array, the expression *(myArray+j), where j is an integer, is equivalent to myArray[jj]. So for instance in the above example where we had the expression secondArray[i].num2, we could have written that as *(secondArray+i).num2 or more simply (secondArray+i)->num2.

Note that for addition and subtraction of integers and pointers, the value of the pointer is not adjusted by the integer amount, but is adjusted by the amount multiplied by the size (in bytes) of the type to which the pointer refers. One pointer may also be subtracted from another, provided they point to elements of the same array (or the position just beyond the end of the array). If you have a pointer that points to an element of an array, the index of the element is the result when the array name is subtracted from the pointer. Here's an example.
Pointers and arrays

struct MyStruct someArray[20];
struct MyStruct *p2;
int idx;

/* array initialization ... */

for (p2 = someArray; p2 < someArray+20; ++p2) {
    if (p2->num2 > testValue) break;
}
idx = p2 - someArray;

You may be wondering how pointers and multidimensional arrays interact. Let’s look at
this a bit in detail. Suppose A is declared as a two dimensional array of floats (float
A[D1][D2];) and that pf is declared a pointer to a float. If pf is initialized to point to
A[0][0], then *(pf+1) is equivalent to A[0][1] and *(pf+D2) is equivalent to A[1][0]. The
elements of the array are stored in row-major order.

float A[6][8];
float *pf;
pf = &A[0][0];
*(pf+1) = 1.3; /* assigns 1.3 to A[0][1] */
*(pf+8) = 2.3; /* assigns 2.3 to A[1][0] */

Let’s look at a slightly different problem. We want to have a two dimensional array, but we
don’t need to have all the rows the same length. What we do is declare an array of pointers.
The second line below declares A as an array of pointers. Each pointer points to a float.
Here’s some applicable code:

float linearA[30];
float *A[6];
A[0] = linearA; /* 5 - 0 = 5 elements in row */
A[1] = linearA + 5; /* 11 - 5 = 6 elements in row */
*A[3][-3] = 1.44; /* refers to linearA[12]; */
/* negative indices are sometimes useful. But avoid
using them as much as possible. */

We also note here something curious about array indexing. Suppose myArray is an array and
idx is an integer value. The expression myArray[idx] is equivalent to idx[myArray]. The
first is equivalent to *(myArray+idx), and the second is equivalent to *(idx+myArray). These
turn out to be the same, since the addition is commutative.

Pointers can be used with preincrement or post decrement, which is sometimes done within
a loop, as in the following example. The increment and decrement applies to the pointer,
not to the object to which the pointer refers. In other words, *pArray++ is equivalent to
*(pArray++).

long myArray[20];
long *pArray;
int i;

/* Assign values to the entries of myArray */
pArray = myArray;
for (i=0; i<10; ++i) {

172
24.5 Pointers in Function Arguments

Often we need to invoke a function with an argument that is itself a pointer. In many instances, the variable is itself a parameter for the current function and may be a pointer to some type of structure. The ampersand character is not needed in this circumstance to obtain a pointer value, as the variable is itself a pointer. In the example below, the variable `pStruct`, a pointer, is a parameter to function `FunctTwo`, and is passed as an argument to `FunctOne`. The second parameter to `FunctOne` is an int. Since in function `FunctTwo`, `mValue` is a pointer to an int, the pointer must first be dereferenced using the `*` operator, hence the second argument in the call is `*mValue`. The third parameter to function `FunctOne` is a pointer to a long. Since `pAA` is itself a pointer to a long, no ampersand is needed when it is used as the third argument to the function.

```c
int FunctOne( struct SomeStruct *pValue, int iValue, long *lValue )
{
    /* do some stuff ... */
    return 0;
}

int FunctTwo( struct someStruct *pStruct, int *mValue )
{
    int j;
    long AnArray[25];
    long *pAA;

    pAA = &AnArray[13];
    j = FunctOne( pStruct, *mValue, pAA );
    return j;
}
```

24.6 Pointers and Text Strings

Historically, text strings in C have been implemented as arrays of characters, with the last byte in the string being a zero, or the null character '\0'. Most C implementations come with a standard library of functions for manipulating strings. Many of the more commonly used functions expect the strings to be null terminated strings of characters. To use these functions requires the inclusion of the standard C header file "string.h".

A statically declared, initialized string would look similar to the following:

```c
static const char *myFormat = "Total Amount Due: %d";
```

The variable `myFormat` can be viewed as an array of 21 characters. There is an implied null character ('\0') tacked on to the end of the string after the 'd' as the 21st item in the array. You can also initialize the individual characters of the array as follows:

```c
static const char myFlower[] = { 'P', 'e', 't', 'u', 'n', 'i', 'a', '\0' };
```

An initialized array of strings would typically be done as follows:

```c
static const char *myColors[] = {
    "Red", "Orange", "Yellow", "Green", "Blue", "Violet";
};
```
The initialization of an especially long string can be split across lines of source code as follows.

```c
static char *longString = "Hello. My name is Rudolph and I work as a reindeer "
    "around Christmas time up at the North Pole. My boss is a really swell guy."
    "He likes to give everybody gifts."
```

The library functions that are used with strings are discussed in a later chapter.

## 24.7 Pointers to Functions

C also allows you to create pointers to functions. Pointers to functions can get rather messy. Declaring a typedef to a function pointer generally clarifies the code. Here's an example that uses a function pointer, and a void * pointer to implement what's known as a callback. The `DoSomethingNice` function invokes a caller supplied function `TalkJive` with caller data. Note that `DoSomethingNice` really doesn't know anything about what `dataPointer` refers to.

```c
typedef int (*MyFunctionType)( int, void *);  /* a typedef for a function pointer */

#define THE_BIGGEST 100

int DoSomethingNice( int aVariable, MyFunctionType aFunction, void *dataPointer )
{
    int rv = 0;
    if (aVariable < THE_BIGGEST) {
        /* invoke function through function pointer (old style) */
        rv = (*aFunction)(aVariable, dataPointer);
    } else {
        /* invoke function through function pointer (new style) */
        rv = aFunction(aVariable, dataPointer);
    }
    return rv;
}

typedef struct {
    int colorSpec;
    char *phrase;
} DataINeed;

int TalkJive( int myNumber, void *someStuff )
{
    /* recast void * to pointer type specifically needed for this function */
    DataINeed *myData = someStuff;
    /* talk jive. */
    return 5;
}

static DataINeed sillyStuff = { BLUE, "Whatcha talkin 'bout Willis?" };

/* ... */
DoSomethingNice( 41, &TalkJive, &sillyStuff );
```

Some versions of C may not require an ampersand preceding the `TalkJive` argument in the `DoSomethingNice` call. Some implementations may require specifically casting the argument to the `MyFunctionType` type, even though the function signature exactly matches that of the typedef.
Function pointers can be useful for implementing a form of polymorphism in C. First one declares a structure having as elements function pointers for the various operations to that can be specified polymorphically. A second base object structure containing a pointer to the previous structure is also declared. A class is defined by extending the second structure with the data specific for the class, and static variable of the type of the first structure, containing the addresses of the functions that are associated with the class. This type of polymorphism is used in the standard library when file I/O functions are called.

A similar mechanism can also be used for implementing a state machine in C. A structure is defined which contains function pointers for handling events that may occur within state, and for functions to be invoked upon entry to and exit from the state. An instance of this structure corresponds to a state. Each state is initialized with pointers to functions appropriate for the state. The current state of the state machine is in effect a pointer to one of these states. Changing the value of the current state pointer effectively changes the current state. When some event occurs, the appropriate function is called through a function pointer in the current state.

### 24.8 Practical use of function pointers in C

Function pointers are mainly used to reduce the complexity of switch statement. Example with switch statement:

```c
#include <stdio.h>

int add(int a, int b);
int sub(int a, int b);
int mul(int a, int b);
int div(int a, int b);

int main()
{
    int i, result;
    int a=10;
    int b=5;
    printf("Enter the value between 0 and 3 : ");
    scanf("%d",&i);
    switch(i)
    {
        case 0: result = add(a,b); break;
        case 1: result = sub(a,b); break;
        case 2: result = mul(a,b); break;
        case 3: result = div(a,b); break;
    }
}

int add(int i, int j)
{
    return (i+j);
}

int sub(int i, int j)
{
    return (i-j);
}

int mul(int i, int j)
{
    return (i*j);
}

int div(int i, int j)
{
    return (i/j);
}
```

Without using a switch statement:

```c
#include <stdio.h>
int add(int a, int b);
int sub(int a, int b);
int mul(int a, int b);
int div(int a, int b);
int (*oper[4])(int a, int b) = {add, sub, mul, div};

int main()
{
    int i, result;
    int a=10;
    int b=5;
    printf("Enter the value between 0 and 3 : ");
    scanf("%d",&i);
    result = oper[i](a,b);
}

int add(int i, int j)
{
    return (i+j);
}

int sub(int i, int j)
{
    return (i-j);
}

int mul(int i, int j)
{
    return (i*j);
}

int div(int i, int j)
{
    return (i/j);
}
```

Function pointers may be used to create a struct member function:

```c
typedef struct
{
    int (*open)(void);
    void (*close)(void);
    int (*reg)(void);
} device;

int my_device_open(void)
{
    /* ... */
}

void my_device_close(void)
{
    /* ... */
}

void register_device(void)
{
    /* ... */
}

device create(void)
{
    device my_device;
    my_device.open = my_device_open;
    my_device.close = my_device_close;
    my_device.reg = register_device;
    my_device.reg();
    return my_device;
}
```
Examples of pointer constructs

Use to implement this pointer (following code must be placed in library).

```c
static struct device_data
{
    /* ... here goes data of structure ... */
};

static struct device_data obj;

typedef struct
{
    int (*open)(void);
    void (*close)(void);
    int (*reg)(void);
} device;

static struct device_data create_device_data(void)
{
    struct device_data my_device_data;
    /* ... here goes constructor ... */
    return my_device_data;
}

device create_device(void)
{
    device my_device;
    my_device.open = my_device_open;
    my_device.close = my_device_close;
    my_device.reg = register_device;
    my_device.reg();
    return my_device;
}
```

24.9 Examples of pointer constructs

Below are some example constructs which may aid in creating your pointer.

```c
int i;       // integer variable 'i'
int *p;      // pointer 'p' to an integer
int a[];     // array 'a' of integers
int f();     // function 'f' with return value of type integer
int **pp;    // pointer 'pp' to a pointer to an integer
int (*pa)[]; // pointer 'pa' to an array of integer
int (*pf)(); // pointer 'pf' to a function with return value integer
int *ap[];   // array 'ap' of pointers to an integer
int **ppp;   // function 'fp' which returns a pointer to an integer
int (*ppa)[]; // pointer 'ppa' to a pointer to an array of integers
int (**ppf); // pointer 'ppf' to a pointer to a function with return value of type integer
int **app[]; // array of pointers 'app' that point to pointers to integer values
int (*apa[])[]; // array of pointers 'apa' to arrays of integers
int (*apf[]); // pointer 'apf' to function with return value of type integer
int ***fpp(); // function 'fpf' which returns a pointer to a pointer to a pointer to an integer
int (**fpa)[]; // function 'fpa' with return value of a pointer to array of integers
```
Pointers and arrays

```c
int (*fpf())(); // function 'fpf' with return value of a pointer to function
which returns an integer
```

24.10 sizeof

The sizeof operator is often used to refer to the size of a static array declared earlier in the same function.

To find the end of an array (example from wikipedia: Buffer overflow⁴):

```c
/* better.c - demonstrates one method of fixing the problem */
#include <stdio.h>
#include <string.h>
int main(int argc, char *argv[])
{
    char buffer[10];
    if (argc < 2)
    {
        fprintf(stderr, "USAGE: %s string\n", argv[0]);
        return 1;
    }
    strncpy(buffer, argv[1], sizeof(buffer));
    buffer[sizeof(buffer) - 1] = '\0';
    return 0;
}
```

To iterate over every element of an array, use

```c
#define NUM_ELEM(x) (sizeof (x) / sizeof (*(x)))
for( i = 0; i < NUM_ELEM(array); i++ )
{
    /* do something with array[i] */
}
```

Note that the sizeof operator only works on things defined earlier in the same function. The compiler replaces it with some fixed constant number. In this case, the `buffer` was declared as an array of 10 char's earlier in the same function, and the compiler replaces `sizeof(buffer)` with the number 10 at compile time (equivalent to us hard-coding 10 into the code in place of `sizeof(buffer)`). The information about the length of `buffer` is not actually stored anywhere in memory (unless we keep track of it separately) and cannot be programmatically obtained at run time from the array/pointer itself.

Often a function needs to know the size of an array it was given -- an array defined in some other function. For example,

```c
/* broken.c - demonstrates a flaw */
#include <stdio.h>
#include <string.h>
#define NUM_ELEM(x) (sizeof (x) / sizeof (*(x)))
int sum(int input_array[])
{
    int sum_so_far = 0;
    int i;
```

⁴ https://en.wikipedia.org/wiki/Buffer%20overflow

178
for( i = 0; i < NUM_ELEM(input_array); i++ ) // WON'T WORK -- input_array wasn't defined in this function.
{  
  sum_so_far += input_array[i];
};  
return( sum_so_far );
}

int main(int argc, char *argv[])
{
  int left_array[] = { 1, 2, 3 };  
  int right_array[] = { 10, 9, 8, 7, 6, 5, 4, 3, 2, 1 };  
  int the_sum = sum( left_array );  
  printf( "the sum of left_array is: \%d", the_sum );  
  the_sum = sum( right_array );  
  printf( "the sum of right_array is: \%d", the_sum );  
  return 0;
}

int sum( int input_array[], size_t length )
{
int sum_so_far = 0;
int i;
for( i = 0; i < length; i++ )
{  
  sum_so_far += input_array[i];
};  
return( sum_so_far );
}

int main(int argc, char *argv[])
{
  int left_array[] = { 1, 2, 3, 4 };  
  int right_array[] = { 10, 9, 8, 7, 6, 5, 4, 3, 2, 1 };  
  int the_sum = sum( left_array, NUM_ELEM(left_array) ); // works here, because  
  left_array is defined in this function  
  printf( "the sum of left_array is: \%d", the_sum );  
  the_sum = sum( right_array, NUM_ELEM(right_array) ); // works here, because  
  right_array is defined in this function  
  printf( "the sum of right_array is: \%d", the_sum );

Unfortunately, (in C and C++) the length of the array cannot be obtained from an array passed in at run time, because (as mentioned above) the size of an array is not stored anywhere. The compiler always replaces sizeof with a constant. This sum() routine needs to handle more than just one constant length of an array.

There are some common ways to work around this fact:

- Write the function to require, for each array parameter, a "length" parameter (which has type "size_t"). (Typically we use sizeof at the point where this function is called).
- Use of a convention, such as a null-terminated string5 to mark the end of the array.
- Instead of passing raw arrays, pass a structure that includes the length of the array (such as "".length") as well as the array (or a pointer to the first element); similar to the string or vector classes in C++.

/* fixed.c - demonstrates one work-around */
#include <stdio.h>
#include <string.h>
#define NUM_ELEM(x) (sizeof (x) / sizeof (*(x)))

int sum( int input_array[], size_t length )
{
int sum_so_far = 0;
int i;
for( i = 0; i < length; i++ )
{  
  sum_so_far += input_array[i];
};  
return( sum_so_far );
}

int main(int argc, char *argv[])
{
  int left_array[] = { 1, 2, 3, 4 };  
  int right_array[] = { 10, 9, 8, 7, 6, 5, 4, 3, 2, 1 };  
  int the_sum = sum( left_array, NUM_ELEM(left_array) ); // works here, because  
  left_array is defined in this function  
  printf( "the sum of left_array is: \%d", the_sum );  
  the_sum = sum( right_array, NUM_ELEM(right_array) ); // works here, because  
  right_array is defined in this function  
  printf( "the sum of right_array is: \%d", the_sum );

5 https://en.wikipedia.org/wiki/null-terminated%20string
return 0;
}

It's worth mentioning that sizeof operator has two variations: sizeof \textbf{(type)} (for instance: sizeof (int) or sizeof (struct some_structure)) and sizeof \textbf{expression} (for instance: sizeof some_variable.some_field or sizeof 1).

### 24.11 External Links

- C Reference Card (ANSI)\(^6\)
- "Common Pointer Pitfalls"\(^7\) by Dave Marshall

\(^7\) [http://www.cs.cf.ac.uk/Dave/C/node10.html#SECTION001080000000000000000](http://www.cs.cf.ac.uk/Dave/C/node10.html#SECTION001080000000000000000)
\(^8\) [https://de.wikibooks.org/wiki/C-Programmierung%3A%20Zeiger](https://de.wikibooks.org/wiki/C-Programmierung%3A%20Zeiger)
\(^9\) [https://fr.wikibooks.org/wiki/Programmation%20C%2FPointeurs](https://fr.wikibooks.org/wiki/Programmation%20C%2FPointeurs)
\(^10\) [https://it.wikibooks.org/wiki/C%2FVettori%20e%20puntatori/Interscambiabilit%C3%A0%20tra%20puntatori%20e%20vettori](https://it.wikibooks.org/wiki/C%2FVettori%20e%20puntatori/Interscambiabilit%C3%A0%20tra%20puntatori%20e%20vettori)
\(^11\) [https://pl.wikibooks.org/wiki/C%2FWska%C5%BAniki](https://pl.wikibooks.org/wiki/C%2FWska%C5%BAniki)
25 Memory management

In C, you have already considered creating variables for use in the program. You have created some arrays for use, but you may have already noticed some limitations:

- the size of the array must be known beforehand
- the size of the array cannot be changed in the duration of your program

*Dynamic memory allocation* in C is a way of circumventing these problems.

25.1 The `malloc` function

```c
#include <stdlib.h>
void *calloc(size_t nmemb, size_t size);
void free(void *ptr);
void *malloc(size_t size);
void *realloc(void *ptr, size_t size);
```

The C function `malloc` is the means of implementing dynamic memory allocation. It is defined in stdlib.h or malloc.h, depending on what operating system you may be using. Malloc.h contains only the definitions for the memory allocation functions and not the rest of the other functions defined in stdlib.h. Usually you will not need to be so specific in your program, and if both are supported, you should use `<stdlib.h>`, since that is ANSI C, and what we will use here.

The corresponding call to release allocated memory back to the operating system is `free`.

When dynamically allocated memory is no longer needed, `free` should be called to release it back to the memory pool. Overwriting a pointer that points to dynamically allocated memory can result in that data becoming inaccessible. If this happens frequently, eventually the operating system will no longer be able to allocate more memory for the process. Once the process exits, the operating system is able to free all dynamically allocated memory associated with the process.

Let’s look at how dynamic memory allocation can be used for arrays.

Normally when we wish to create an array we use a declaration such as

```c
int array[10];
```

Recall `array` can be considered a pointer which we use as an array. We specify the length of this array is 10 ints. After `array[0]`, nine other integers have space to be stored consecutively.

Sometimes it is not known at the time the program is written how much memory will be needed for some data. In this case we would want to dynamically allocate required memory after the program has started executing. To do this we only need to declare a pointer,
and invoke `malloc` when we wish to make space for the elements in our array, or, we can tell `malloc` to make space when we first initialize the array. Either way is acceptable and useful.

We also need to know how much an int takes up in memory in order to make room for it; fortunately this is not difficult, we can use C's builtin `sizeof` operator. For example, if `sizeof(int)` yields 4, then one int takes up 4 bytes. Naturally, `2*sizeof(int)` is how much memory we need for 2 ints, and so on.

So how do we `malloc` an array of ten ints like before? If we wish to declare and make room in one hit, we can simply say

```
int *array = malloc(10*sizeof(int));
```

We only need to declare the pointer; `malloc` gives us some space to store the 10 ints, and returns the pointer to the first element, which is assigned to that pointer.

**Important note!** `malloc` does *not* initialize the array; this means that the array may contain random or unexpected values! Like creating arrays without dynamic allocation, the programmer must initialize the array with sensible values before using it. Make sure you do so, too. *(See later the function `memset` for a simple method.)*

It is not necessary to immediately call `malloc` after declaring a pointer for the allocated memory. Often a number of statements exist between the declaration and the call to `malloc`, as follows:

```
int *array = NULL;
p这几行的作用是在声明后打印信息，延迟分配和使用数组。
```

### 25.1.1 Error checking

When we want to use `malloc`, we have to be mindful that the pool of memory available to the programmer is *finite*. As such, we can conceivably run out of memory! In this case, `malloc` will return `NULL`. In order to stop the program crashing from having no more memory to use, one should always check that malloc has not returned `NULL` before attempting to use the memory; we can do this by

```
int *pt = malloc(3 * sizeof(int));
if(pt == NULL)
{
    fprintf(stderr, "Out of memory, exiting\n");
    exit(1);
}
```

Of course, suddenly quitting as in the above example is not always appropriate, and depends on the problem you are trying to solve and the architecture you are programming for. For example, if the program is a small, non critical application that's running on a desktop quitting may be appropriate. However if the program is some type of editor running on a desktop, you may want to give the operator the option of saving their tediously entered information instead of just exiting the program. A memory allocation failure in an embedded processor, such as might be in a washing machine, could cause an automatic reset of
the machine. For this reason, many embedded systems designers avoid dynamic memory allocation altogether.

25.2 The calloc function

The calloc function allocates space for an array of items and initializes the memory to zeros. The call `mArray = calloc( count, sizeof(struct V))` allocates `count` objects, each of whose size is sufficient to contain an instance of the structure `struct V`. The space is initialized to all bits zero. The function returns either a pointer to the allocated memory or, if the allocation fails, `NULL`.

25.3 The realloc function

```c
void * realloc ( void * ptr, size_t size );
```

The realloc function changes the size of the object pointed to by `ptr` to the size specified by `size`. The contents of the object shall be unchanged up to the lesser of the new and old sizes. If the new size is larger, the value of the newly allocated portion of the object is indeterminate. If `ptr` is a null pointer, the realloc function behaves like the malloc function for the specified size. Otherwise, if `ptr` does not match a pointer earlier returned by the calloc, malloc, or realloc function, or if the space has been deallocated by a call to the free or realloc function, the behavior is undefined. If the space cannot be allocated, the object pointed to by `ptr` is unchanged. If `size` is zero and `ptr` is not a null pointer, the object pointed to is freed. The realloc function returns either a null pointer or a pointer to the possibly moved allocated object.

25.4 The free function

Memory that has been allocated using malloc, realloc, or calloc must be released back to the system memory pool once it is no longer needed. This is done to avoid perpetually allocating more and more memory, which could result in an eventual memory allocation failure. Memory that is not released with free is however released when the current program terminates on most operating systems. Calls to free are as in the following example.

```c
int *myStuff = malloc( 20 * sizeof(int));
if (myStuff != NULL) {
    /* more statements here */
    /* time to release myStuff */
    free( myStuff );
}
```
25.4.1 free with recursive data structures

It should be noted that free is neither intelligent nor recursive. The following code that depends on the recursive application of free to the internal variables of a struct does not work.

```c
typedef struct BSTNode {
    int value;
    struct BSTNode* left;
    struct BSTNode* right;
} BSTNode;

// Later: ...
BSTNode* temp = (BSTNode*) calloc(1, sizeof(BSTNode));
temp->left = (BSTNode*) calloc(1, sizeof(BSTNode));
// Later: ...
free(temp); // WRONG! don't do this!
```

The statement "free(temp);" will not free temp->left, causing a memory leak. The correct way to free the allocated memory is as follows.

```c
free(temp->left);
free(temp->right);
free(temp);
```

Because C does not have a garbage collector, C programmers are responsible for making sure there is a free() exactly once for each time there is a malloc(). If a tree has been allocated one node at a time, then it needs to be freed one node at a time.

25.4.2 Don't free undefined pointers

Furthermore, using free when the pointer in question was never allocated in the first place often crashes or leads to mysterious bugs further along.

To avoid this problem, always initialize pointers when they are declared. Either use malloc at the point they are declared (as in most examples in this chapter), or set them to NULL when they are declared (as in the "delayed allocation" example in this chapter).

25.4.3 Write constructor/destructor functions

One way to get memory initialization and destruction right is to imitate object-oriented programming. In this paradigm, objects are constructed after raw memory is allocated for them, live their lives, and when it is time for them to be destructed, a special function called a destructor destroys the object's innards before the object itself is destroyed.

For example:

---

2. "Bug 478901 ... libpng-1.2.34 and earlier might free undefined pointers" [https://bugzilla.mozilla.org/show_bug.cgi?id=478901]
```c
#include <stdlib.h> /* need malloc and friends */

/* this is the type of object we have, with a single int member */
typedef struct WIDGET_T {
    int member;
} WIDGET_T;

/* functions that deal with WIDGET_T */

/* constructor function */
void WIDGETctor (WIDGET_T *this, int x)
{
    this->member = x;
}

/* destructor function */
void WIDGETdtor (WIDGET_T *this)
{
    /* In this case, I really don't have to do anything, but
    if WIDGET_T had internal pointers, the objects they point to
    would be destroyed here. */
    this->member = 0;
}

/* create function - this function returns a new WIDGET_T */
WIDGET_T * WIDGETcreate (int m)
{
    WIDGET_T *x = 0;
    x = malloc (sizeof (WIDGET_T));
    if (x == 0) abort (); /* no memory */
    WIDGETctor (x, m);
    return x;
}

/* destroy function - calls the destructor, then frees the object */
void WIDGETdestroy (WIDGET_T *this)
{
    WIDGETdtor (this);
    free (this);
}

/* END OF CODE */

25.5 References

- Memory Management³

³ https://en.wikibooks.org/wiki/Memory%20Management

185
26 Strings

A string in C is merely an array of characters. The length of a string is determined by a terminating null character: '\0'. So, a string with the contents, say, "abc" has four characters: 'a', 'b', 'c', and the terminating null character.

The terminating null character has the value zero.

26.1 Syntax

In C, string constants (literals) are surrounded by double quotes ("), e.g. "Hello world!" and are compiled to an array of the specified char values with an additional null terminating character (0-valued) code to mark the end of the string. The type of a string constant is char [].

26.1.1 backslash escapes

String literals may not directly in the source code contain embedded newlines or other control characters, or some other characters of special meaning in string.

To include such characters in a string, the backslash escapes may be used, like this:

<table>
<thead>
<tr>
<th>Escape</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>\</td>
<td>Literal backslash</td>
</tr>
<tr>
<td>&quot;</td>
<td>Double quote</td>
</tr>
<tr>
<td>'</td>
<td>Single quote</td>
</tr>
<tr>
<td>\n</td>
<td>Newline (line feed)</td>
</tr>
<tr>
<td>\r</td>
<td>Carriage return</td>
</tr>
<tr>
<td>\b</td>
<td>Backspace</td>
</tr>
<tr>
<td>\t</td>
<td>Horizontal tab</td>
</tr>
<tr>
<td>\f</td>
<td>Form feed</td>
</tr>
<tr>
<td>\a</td>
<td>Alert (bell)</td>
</tr>
<tr>
<td>\v</td>
<td>Vertical tab</td>
</tr>
<tr>
<td>?</td>
<td>Question mark (used to escape trigraphs¹)</td>
</tr>
<tr>
<td>\nnn</td>
<td>Character with octal value nnn</td>
</tr>
<tr>
<td>\xhh</td>
<td>Character with hexadecimal value hh</td>
</tr>
</tbody>
</table>

¹ https://en.wikibooks.org/wiki/%2FC%20trigraph%2F
26.1.2 Wide character strings

C supports wide character strings, defined as arrays of the type `wchar_t`, 16-bit (at least) values. They are written with an `L` before the string like this

```c
wchar_t *p = L"Hello world!";
```

This feature allows strings where more than 256 different possible characters are needed (although also variable length `char` strings can be used). They end with a zero-valued `wchar_t`. These strings are not supported by the `<string.h>` functions. Instead they have their own functions, declared in `<wchar.h>`.

26.1.3 Character encodings

What character encoding the `char` and `wchar_t` represent is not specified by the C standard, except that the value 0x00 and 0x0000 specify the end of the string and not a character. It is the input and output code which are directly affected by the character encoding. Other code should not be too affected. The editor should also be able to handle the encoding if strings shall be able to written in the source code.

There are three major types of encodings:

- One byte per character. Normally based on ASCII. There is a limit of 255 different characters plus the zero termination character.
- Variable length `char` strings, which allows many more than 255 different characters. Such strings are written as normal `char`-based arrays. These encodings are normally ASCII-based and examples are UTF-8\(^2\) or Shift JIS\(^3\).
- Wide character strings. They are arrays of `wchar_t` values. UTF-16\(^4\) is the most common such encoding, and it is also variable-length, meaning that a character can be two `wchar_t`.

26.2 The `<string.h>` Standard Header

Because programmers find raw strings cumbersome to deal with, they wrote the code in the `<string.h>` library. It represents not a concerted design effort but rather the accretion of contributions made by various authors over a span of years.

First, three types of functions exist in the string library:

- the `mem` functions manipulate sequences of arbitrary characters without regard to the null character;
- the `str` functions manipulate null-terminated sequences of characters;
- the `strn` functions manipulate sequences of non-null characters.

---

26.2.1 The more commonly-used string functions

The nine most commonly used functions in the string library are:

- `strcat` - concatenate two strings
- `strchr` - string scanning operation
- `strcmp` - compare two strings
- `strcpy` - copy a string
- `strlen` - get string length
- `strncat` - concatenate one string with part of another
- `strncmp` - compare parts of two strings
- `strncpy` - copy part of a string
- `strrchr` - string scanning operation

The `strcat` function

```c
char *strcat(char * restrict s1, const char * restrict s2);
```

Some people recommend using `strncat()` or `strlcat()` instead of `strcat`, in order to avoid buffer overflow.

The `strcat()` function shall append a copy of the string pointed to by `s2` (including the terminating null byte) to the end of the string pointed to by `s1`. The initial byte of `s2` overwrites the null byte at the end of `s1`. If copying takes place between objects that overlap, the behavior is undefined. The function returns `s1`.

This function is used to attach one string to the end of another string. It is imperative that the first string (`s1`) have the space needed to store both strings.

Example:

```c
#include <stdio.h>
#include <string.h>
...
static const char *colors[] = {
    "Red","Orange","Yellow","Green","Blue","Purple" 
};
static const char *widths[] = {
    "Thin","Medium","Thick","Bold" 
};
...
char penText[20];
...
int penColor = 3, penThickness = 2;
strcpy(penText, colors[penColor]);
strcat(penText, widths[penThickness]);
printf("My pen is %s\n", penText); // prints 'My pen is GreenThick'
```

Before calling `strcat()`, the destination must currently contain a null terminated string or the first character must have been initialized with the null character (e.g. `penText[0] = '\0';`).

The following is a public-domain implementation of `strcat`:

```c
/* strcat */
```

Strings

`char *(strcat)(char *restrict s1, const char *restrict s2)`

`{`
`    char *s = s1;`
`    /* Move s so that it points to the end of s1. */`
`    while (*s != '\0') s++;`
`    /* Copy the contents of s2 into the space at the end of s1. */`
`    strcpy(s, s2);`
`    return s1;`
`}`

**The strchr function**

`char *strchr(const char *s, int c);`

The `strchr()` function shall locate the first occurrence of `c` (converted to a `char`) in the string pointed to by `s`. The terminating null byte is considered to be part of the string. The function returns the location of the found character, or a null pointer if the character was not found.

This function is used to find certain characters in strings.

At one point in history, this function was named `index`. The `strchr` name, however cryptic, fits the general pattern for naming.

The following is a public-domain implementation of `strchr`:

```
#include <string.h>
/* strchr */
char *(strchr)(const char *s, int c)
{`
    char ch = c;`
    /* Scan s for the character. When this loop is finished, `s` will either point to the end of the string or the character we were looking for. */`
    while (*s != '\0' && *s != ch) s++;
    return (*s == ch) ? (char *) s : NULL;
}`
```

**The strcmp function**

`int strcmp(const char *s1, const char *s2);`

A rudimentary form of string comparison is done with the `strcmp()` function. It takes two strings as arguments and returns a value less than zero if the first is lexicographically less than the second, a value greater than zero if the first is lexicographically greater than the second, or zero if the two strings are equal. The comparison is done by comparing the coded (ascii) value of the characters, character by character.

This simple type of string comparison is nowadays generally considered unacceptable when sorting lists of strings. More advanced algorithms exist that are capable of producing lists in dictionary sorted order. They can also fix problems such as `strcmp()` considering the string "Alpha2" greater than "Alpha12". (In the previous example, "Alpha2" compares greater than "Alpha12" because '2' comes after '1' in the character set.) What we're saying is, don't use this `strcmp()` alone for general string sorting in any commercial or professional code.
The `strcmp()` function shall compare the string pointed to by `s1` to the string pointed to by `s2`. The sign of a non-zero return value shall be determined by the sign of the difference between the values of the first pair of bytes (both interpreted as type `unsigned char`) that differ in the strings being compared. Upon completion, `strcmp()` shall return an integer greater than, equal to, or less than 0, if the string pointed to by `s1` is greater than, equal to, or less than the string pointed to by `s2`, respectively.

Since comparing pointers by themselves is not practically useful unless one is comparing pointers within the same array, this function lexically compares the strings that two pointers point to.

This function is useful in comparisons, e.g.

```c
if (strcmp(s, "whatever") == 0) /* do something */
;
```

The collating sequence used by `strcmp()` is equivalent to the machine's native character set. The only guarantee about the order is that the digits from '0' to '9' are in consecutive order.

The following is a public-domain implementation of `strcmp`:

```c
#include <string.h>
/* strcmp */
int (strcmp)(const char *s1, const char *s2)
{
    unsigned char uc1, uc2;
    /* Move s1 and s2 to the first differing characters
     * in each string, or the ends of the strings if they
     * are identical. */
    while (*s1 != '\0' && *s1 == *s2) {
        s1++;
        s2++;
    }
    /* Compare the characters as unsigned char and
     * return the difference. */
    uc1 = (*(unsigned char *) s1);
    uc2 = (*(unsigned char *) s2);
    return ((uc1 < uc2) ? -1 : (uc1 > uc2));
}
```

The `strcpy()` function

```c
char *strcpy(char *restrict s1, const char *restrict s2);
```

Some people recommend always using `strncpy()` instead of `strcpy`, to avoid buffer overflow.

The `strcpy()` function shall copy the C string pointed to by `s2` (including the terminating null byte) into the array pointed to by `s1`. If copying takes place between objects that overlap, the behavior is undefined. The function returns `s1`. There is no value used to indicate an error: if the arguments to `strcpy()` are correct, and the destination buffer is large enough, the function will never fail.

Example:

```c
#include <stdio.h>
#include <string.h>
```
Important: You must ensure that the destination buffer (\texttt{s1}) is able to contain all the characters in the source array, including the terminating null byte. Otherwise, \texttt{strcpy()} will overwrite memory past the end of the buffer, causing a buffer overflow, which can cause the program to crash, or can be exploited by hackers to compromise the security of the computer.

The following is a public-domain implementation of \texttt{strcpy}:

```c
#include <string.h>
char *(strcpy)(char *restrict s1, const char *restrict s2)
{
    char *dst = s1;
    const char *src = s2;
    /* Do the copying in a loop. */
    while ((*dst++ = *src++) != '\0')
        ;
    /* Return the destination string. */
    return s1;
}
```

The \texttt{strlen} function

```c
size_t strlen(const char *s);
```

The \texttt{strlen()} function shall compute the number of bytes in the string to which \texttt{s} points, not including the terminating null byte. It returns the number of bytes in the string. No value is used to indicate an error.

The following is a public-domain implementation of \texttt{strlen}:

```c
#include <string.h>
size_t (strlen)(const char *s)
{
    const char *p = s;
    /* Loop over the data in \texttt{s}. */
    while (*p != '\0')
        p++;
    return (size_t)(p - s);
}
```

The \texttt{strncat} function

```c
char *strncat(char *restrict s1, const char *restrict s2, size_t n);
```

The \texttt{strncat()} function shall append not more than \texttt{n} bytes (a null byte and bytes that follow it are not appended) from the array pointed to by \texttt{s2} to the end of the string pointed to by \texttt{s1}. The initial byte of \texttt{s2} overwrites the null byte at the end of \texttt{s1}. A terminating null byte is always appended to the result. If copying takes place between objects that overlap, the behavior is undefined. The function returns \texttt{s1}. 

192
The following is a public-domain implementation of `strncat`:

```c
#include <string.h>
/* strncat */
char *(strncat)(char *restrict s1, const char *restrict s2, size_t n) {
    char *s = s1;
    /* Loop over the data in s1. */
    while (*s != '\0')
        s++;
    /* s now points to s1's trailing null character, now copy
       up to n bytes from s2 into s stopping if a null character
       is encountered in s2.
       It is not safe to use strncpy here since it copies EXACTLY n
       characters, NULL padding if necessary. */
    while (n != 0 && (*s = *s2++) != '\0') {
        n--;
        s++;
    }
    if (*s != '\0')
        *s = '\0';
    return s1;
}
```

The `strnncmp` function

```c
int strncmp(const char *s1, const char *s2, size_t n);
```

The `strncmp()` function shall compare not more than n bytes (bytes that follow a null byte are not compared) from the array pointed to by `s1` to the array pointed to by `s2`. The sign of a non-zero return value is determined by the sign of the difference between the values of the first pair of bytes (both interpreted as type `unsigned char`) that differ in the strings being compared. See `strcmp` for an explanation of the return value.

This function is useful in comparisons, as the `strcmp` function is.

The following is a public-domain implementation of `strnncmp`:

```c
#include <string.h>
/* strncmp */
int (strncmp)(const char *s1, const char *s2, size_t n) {
    unsigned char uc1, uc2;
    /* Nothing to compare? Return zero. */
    if (n == 0)
        return 0;
    /* Loop, comparing bytes. */
    while (n-- > 0 && *s1 == *s2) {
        /* If we've run out of bytes or hit a null, return zero
           since we already know *s1 == *s2. */
        if (n == 0 || *s1 == '\0')
            return 0;
        s1++;
        s2++;
    }
    uc1 = (*(unsigned char *) s1);
    uc2 = (*(unsigned char *) s2);
    return ((uc1 < uc2) ? -1 : (uc1 > uc2));
}
```
The `strncpy` function

```c
char *strncpy(char *restrict s1, const char *restrict s2, size_t n);
```

The `strncpy()` function shall copy not more than `n` bytes (bytes that follow a null byte are not copied) from the array pointed to by `s2` to the array pointed to by `s1`. If copying takes place between objects that overlap, the behavior is undefined. If the array pointed to by `s2` is a string that is shorter than `n` bytes, null bytes shall be appended to the copy in the array pointed to by `s1`, until `n` bytes in all are written. The function shall return `s1`; no return value is reserved to indicate an error.

It is possible that the function will not return a null-terminated string, which happens if the `s2` string is longer than `n` bytes.

The following is a public-domain version of `strncpy`:

```c
#include <string.h>
/* strncpy */
char *(strncpy)(char *restrict s1, const char *restrict s2, size_t n) {
    char *dst = s1;
    const char *src = s2;
    /* Copy bytes, one at a time. */
    while (n > 0) {
        n--;
        if (*((char**)dst++ = *(char**)src++) == '\0') {
            /* If we get here, we found a null character at the end
               of s2, so use memset to put null bytes at the end of
               s1. */
            memset(dst, '\0', n);
            break;
        }
    }
    return s1;
}
```

The `strrchr` function

```c
char *strrchr(const char *s, int c);
```

The `strrchr` function is similar to the `strchr` function, except that `strrchr` returns a pointer to the last occurrence of `c` within `s` instead of the first.

The `strrchr()` function shall locate the last occurrence of `c` (converted to a `char`) in the string pointed to by `s`. The terminating null byte is considered to be part of the string. Its return value is similar to `strchr`'s return value.

At one point in history, this function was named `rindex`. The `strrchr` name, however cryptic, fits the general pattern for naming.

The following is a public-domain implementation of `strrchr`:

```c
#include <string.h>
/* strrchr */
char *(strrchr)(const char *s, int c) {
    const char *last = NULL;
    /* If the character we're looking for is the terminating null,
       we just need to look for that character as there's only one
```
of them in the string. */
if (c == '\0')
    return strchr(s, c);
/* loop through, finding the last match before hitting NULL. */
while ((s = strchr(s, c)) != NULL) {
    last = s;
    s++;
}
return (char *) last;

26.2.2 The less commonly-used string functions

The less-used functions are:

- memchr - Find a byte in memory
- memcmp - Compare bytes in memory
- memcpy - Copy bytes in memory
- memmove - Copy bytes in memory with overlapping areas
- memset - Set bytes in memory
- strcoll - Compare bytes according to a locale-specific collating sequence
- strcsn - Get the length of a complementary substring
- strerror - Get error message
- strpbrk - Scan a string for a byte
- strspn - Get the length of a substring
- strstr - Find a substring
- strtok - Split a string into tokens
- strxfrm - Transform string

Copying functions

The memcpy function

void *memcpy(void * restrict s1, const void * restrict s2, size_t n);

The memcpy() function shall copy n bytes from the object pointed to by s2 into the object pointed to by s1. If copying takes place between objects that overlap, the behavior is undefined. The function returns s1.

Because the function does not have to worry about overlap, it can do the simplest copy it can.

The following is a public-domain implementation of memcpy:

```c
#include <string.h>
/* memcpy */
void *(memcpy)(void * restrict s1, const void * restrict s2, size_t n)
{
    char *dst = s1;
    const char *src = s2;
    /* Loop and copy. */
    while (n-- != 0)
        *dst++ = *src++;
    return s1;
}
```
The `memmove` function

```c
void *memmove(void *s1, const void *s2, size_t n);
```

The `memmove()` function shall copy `n` bytes from the object pointed to by `s2` into the object pointed to by `s1`. Copying takes place as if the `n` bytes from the object pointed to by `s2` are first copied into a temporary array of `n` bytes that does not overlap the objects pointed to by `s1` and `s2`, and then the `n` bytes from the temporary array are copied into the object pointed to by `s1`. The function returns the value of `s1`.

The easy way to implement this without using a temporary array is to check for a condition that would prevent an ascending copy, and if found, do a descending copy.

The following is a public-domain, though not completely portable, implementation of `memmove`:

```c
#include <string.h>
/* memmove */
void *(memmove)(void *s1, const void *s2, size_t n)
{
    char *p1 = s1;
    const char *p2 = s2;
    /* test for overlap that prevents an ascending copy */
    if (p2 < p1 && p1 < p2 + n) {
        /* do a descending copy */
        p2 += n;
        p1 += n;
        while (n-- != 0)
            *--p1 = *--p2;
    } else
        while (n-- != 0)
            *p1++ = *p2++;
    return s1;
}
```

Comparison functions

The `memcmp` function

```c
int memcmp(const void *s1, const void *s2, size_t n);
```

The `memcmp()` function shall compare the first `n` bytes (each interpreted as `unsigned char`) of the object pointed to by `s1` to the first `n` bytes of the object pointed to by `s2`. The sign of a non-zero return value shall be determined by the sign of the difference between the values of the first pair of bytes (both interpreted as type `unsigned char`) that differ in the objects being compared.

The following is a public-domain implementation of `memcmp`:

```c
#include <string.h>
/* memcmp */
int memcmp(const void *s1, const void *s2, size_t n)
{
    const unsigned char *us1 = (const unsigned char *) s1;
    const unsigned char *us2 = (const unsigned char *) s2;
    while (n-- != 0) {
        if (*us1 != *us2)
            return (*us1 < *us2) ? -1 : +1;
        us1++;
        us2++;
    }
}```
The `strcoll` and `strxfrm` functions

```c
int strcoll(const char *s1, const char *s2);
size_t strxfrm(char *s1, const char *s2, size_t n);
```

The ANSI C Standard specifies two locale-specific comparison functions.

The `strcoll` function compares the string pointed to by `s1` to the string pointed to by `s2`, both interpreted as appropriate to the `LC_COLLATE` category of the current locale. The return value is similar to `strcmp`.

The `strxfrm` function transforms the string pointed to by `s2` and places the resulting string into the array pointed to by `s1`. The transformation is such that if the `strcmp` function is applied to the two transformed strings, it returns a value greater than, equal to, or less than zero, corresponding to the result of the `strcoll` function applied to the same two original strings. No more than `n` characters are placed into the resulting array pointed to by `s1`, including the terminating null character. If `n` is zero, `s1` is permitted to be a null pointer. If copying takes place between objects that overlap, the behavior is undefined. The function returns the length of the transformed string.

These functions are rarely used and nontrivial to code, so there is no code for this section.

Search functions

The `memchr` function

```c
void *memchr(const void *s, int c, size_t n);
```

The `memchr()` function shall locate the first occurrence of `c` (converted to an `unsigned char`) in the initial `n` bytes (each interpreted as `unsigned char`) of the object pointed to by `s`. If `c` is not found, `memchr` returns a null pointer.

The following is a public-domain implementation of `memchr`:

```c
#include <string.h>
/* memchr */
void *(memchr)(const void *s, int c, size_t n)
{
    const unsigned char *src = s;
    unsigned char uc = c;
    while (n-- != 0) {
        if (*src == uc)
            return (void *) src;
        src++;
    }
    return NULL;
}
```

The `strcspn`, `strpbrk`, and `strspn` functions

```c
size_t strcspn(const char *s1, const char *s2);
char *strpbrk(const char *s1, const char *s2);
```
size_t strspn(const char *s1, const char *s2);

The strcspn function computes the length of the maximum initial segment of the string pointed to by s1 which consists entirely of characters not from the string pointed to by s2.

The strpbrk function locates the first occurrence in the string pointed to by s1 of any character from the string pointed to by s2, returning a pointer to that character or a null pointer if not found.

The strspn function computes the length of the maximum initial segment of the string pointed to by s1 which consists entirely of characters from the string pointed to by s2.

All of these functions are similar except in the test and the return value.

The following are public-domain implementations of strcspn, strpbrk, and strspn:

```c
#include <string.h>

size_t (strcspn)(const char *s1, const char *s2)
{
    const char *sc1;
    for (sc1 = s1; *sc1 != '\0'; sc1++)
        if (strchr(s2, *sc1) != NULL)
            return (sc1 - s1);
    return sc1 - s1; /* terminating nulls match */
}

char *(strpbrk)(const char *s1, const char *s2)
{
    const char *sc1;
    for (sc1 = s1; *sc1 != '\0'; sc1++)
        if (strchr(s2, *sc1) != NULL)
            return (char *)sc1;
    return NULL; /* terminating nulls match */
}

size_t (strspn)(const char *s1, const char *s2)
{
    const char *sc1;
    for (sc1 = s1; *sc1 != '\0'; sc1++)
        if (strchr(s2, *sc1) == NULL)
            return (sc1 - s1);
    return sc1 - s1; /* terminating nulls don’t match */
}
```

The strstr function
char *strstr(const char *haystack, const char *needle);

The strstr() function shall locate the first occurrence in the string pointed to by haystack of the sequence of bytes (excluding the terminating null byte) in the string pointed to by needle. The function returns the pointer to the matching string in haystack or a null pointer if a match is not found. If needle is an empty string, the function returns haystack.

The following is a public-domain implementation of strstr:

```c
#include <string.h>

/* strstr */
```
char *(strstr)(const char *haystack, const char *needle) {
    size_t needlelen;
    /* Check for the null needle case. */
    if (*needle == '\0')
        return (char *) haystack;
    needlelen = strlen(needle);
    for (; (haystack = strchr(haystack, *needle)) != NULL; haystack++)
        if (memcmp(haystack, needle, needlelen) == 0)
            return (char *) haystack;
    return NULL;
}

The `strtok` function

char *strtok(char *restrict s1, const char *restrict delimiters);

A sequence of calls to `strtok()` breaks the string pointed to by `s1` into a sequence of tokens, each of which is delimited by a byte from the string pointed to by `delimiters`. The first call in the sequence has `s1` as its first argument, and is followed by calls with a null pointer as their first argument. The separator string pointed to by `delimiters` may be different from call to call.

The first call in the sequence searches the string pointed to by `s1` for the first byte that is not contained in the current separator string pointed to by `delimiters`. If no such byte is found, then there are no tokens in the string pointed to by `s1` and `strtok()` shall return a null pointer. If such a byte is found, it is the start of the first token.

The `strtok()` function then searches from there for a byte (or multiple, consecutive bytes) that is contained in the current separator string. If no such byte is found, the current token extends to the end of the string pointed to by `s1`, and subsequent searches for a token shall return a null pointer. If such a byte is found, it is overwritten by a null byte, which terminates the current token. The `strtok()` function saves a pointer to the following byte, from which the next search for a token shall start.

Each subsequent call, with a null pointer as the value of the first argument, starts searching from the saved pointer and behaves as described above.

The `strtok()` function need not be reentrant. A function that is not required to be reentrant is not required to be thread-safe.

Because the `strtok()` function must save state between calls, and you could not have two tokenizers going at the same time, the Single Unix Standard defined a similar function, `strtok_r()`, that does not need to save state. Its prototype is this:

char *strtok_r(char *s, const char *delimiters, char **lasts);

The `strtok_r()` function considers the null-terminated string `s` as a sequence of zero or more text tokens separated by spans of one or more characters from the separator string `delimiters`. The argument lasts points to a user-provided pointer which points to stored information necessary for `strtok_r()` to continue scanning the same string.

In the first call to `strtok_r()`, `s` points to a null-terminated string, `delimiters` to a null-terminated string of separator characters, and the value pointed to by `lasts` is ignored. The `strtok_r()` function shall return a pointer to the first character of the first token, write a
null character into \texttt{s} immediately following the returned token, and update the pointer to which \texttt{lasts} points.

In subsequent calls, \texttt{s} is a null pointer and \texttt{lasts} shall be unchanged from the previous call so that subsequent calls shall move through the string \texttt{s}, returning successive tokens until no tokens remain. The separator string \texttt{delimiters} may be different from call to call. When no token remains in \texttt{s}, a NULL pointer shall be returned.

The following public-domain code for \texttt{strtok} and \texttt{strtok\_r} codes the former as a special case of the latter:

\begin{verbatim}
#include <string.h>
/* strtok_r */
char **(strtok_r)(char *s, const char *delimiters, char **lasts)
{
    char *begin, *send;
    begin = s ? s : *lasts;
    begin += strspn(begin, delimiters);
    if (*begin == '\0') {
        *lasts = "";
        return NULL;
    }
    send = begin + strcspn(begin, delimiters);
    if (*send != '\0')
        *send++ = '\0';
    *lasts = send;
    return begin;
}
/* strtok */
char *(strtok)(char *restrict s1, const char *restrict delimiters)
{
    static char *ssave = "";
    return strtok_r(s1, delimiters, &ssave);
}
\end{verbatim}

Miscellaneous functions

These functions do not fit into one of the above categories.

The \texttt{memset} function

\begin{verbatim}
void *memset(void *s, int c, size_t n);
\end{verbatim}

The \texttt{memset()} function converts \texttt{c} into unsigned char, then stores the character into the first \texttt{n} bytes of memory pointed to by \texttt{s}.

The following is a public-domain implementation of \texttt{memset}:

\begin{verbatim}
#include <string.h>
/* memset */
void *(memset)(void *s, int c, size_t n)
{
    unsigned char *us = s;
    unsigned char uc = c;
    while (us-- != 0)
        *us++ = uc;
    return s;
}
\end{verbatim}

200
The `strerror` function

```c
char *strerror(int errorcode);
```

This function returns a locale-specific error message corresponding to the parameter. Depending on the circumstances, this function could be trivial to implement, but this author will not do that as it varies.

The Single Unix System Version 3 has a variant, `strerror_r`, with this prototype:

```c
int strerror_r(int errcode, char *buf, size_t buflen);
```

This function stores the message in `buf`, which has a length of size `buflen`.

### 26.3 Examples

To determine the number of characters in a string, the `strlen()` function is used:

```c
#include <stdio.h>
#include <string.h>
...
int length, length2;
char *turkey;
static char *flower= "begonia";
static char *gemstone= "ruby ";

length = strlen(flower);
printf("Length = %d\n", length); // prints 'Length = 7'
length2 = strlen(gemstone);
turkey = malloc( length + length2 + 1);
if (turkey) {
    strcpy( turkey, gemstone);
    strcat( turkey, flower);
    printf( "%s\n", turkey); // prints 'ruby begonia'
    free( turkey);
}
```

Note that the amount of memory allocated for 'turkey' is one plus the sum of the lengths of the strings to be concatenated. This is for the terminating null character, which is not counted in the lengths of the strings.

### 26.3.1 Exercises

1. The string functions use a lot of looping constructs. Is there some way to portably unravel the loops?
2. What functions are possibly missing from the library as it stands now?

### 26.4 References

- A Little C Primer/C String Function Library

Strings

- C++ Programming/Code/IO/Streams/string\(^7\)
- Because so many functions in the standard `string.h` library are vulnerable to buffer overflow errors, some people\(^8\) recommend avoiding the `string.h` library and "C style strings" and instead using a dynamic string API, such as the ones listed in the String library comparison\(^9\).
- There's a tiny public domain concat() function, which will allocate memory and safely concatenate any number of strings in portable C/C++ code\(^10\)

fr:Programmation C/Chaînes de caractères\(^11\) pl:C/Napisy\(^12\) pt:Programar em C/Strings\(^13\)

---

\(^7\) https://en.wikibooks.org/wiki/C%2B%2B%20Programming%2FCode%2FIO%2FStreams%2Fstring
\(^8\) http://www.and.org/vstr/security
\(^9\) http://www.and.org/vstr/comparison
\(^10\) http://openwall.info/wiki/people/solar/software/public-domain-source-code(concat
\(^11\) https://fr.wikibooks.org/wiki/Programmation%20C%2FCha%C3%A8nes%20de%20caract%C3%A8res
\(^12\) https://pl.wikibooks.org/wiki/C%2FNapisy
\(^13\) https://pt.wikibooks.org/wiki/Programar%20em%20C%2FStrings
27 Complex types

In the chapter Variables\(^1\) we looked at the primitive data types. However \textit{advanced} data types allow us greater flexibility in managing data in our program, and also some novel uses.

27.1 Data structures

A data structure ("struct") contains multiple pieces of data. Each piece of data (called a "member") can be accessed by the name of the variable, followed by a ".", then the name of the member. (Another way to access a member is using the member operator ".->"). The member variables of a struct can be of any data type and can even be an array or a pointer.

27.1.1 Structs

A data structure contains multiple pieces of data. One defines a data structure using the \textbf{struct} keyword. For example,

```
struct mystruct {
    int int_member;
    double double_member;
    char string_member[25];
} variable;
```

\texttt{variable} is an instance of \texttt{mystruct}. You can omit it from the end of the \textbf{struct} declaration and declare it later using:

```
struct mystruct variable;
```

It is often common practice to make a \textit{type synonym} so we don't have to type "struct mystruct" all the time. C allows us the possibility to do so using a \texttt{typedef} statement, which aliases a type:

```
typedef struct {
    ...
} Mystruct;
```

The \textbf{struct} itself has no name (by the absence of a name on the first line), but it is aliased as \texttt{Mystruct}. Then you can use

```
Mystruct structure;
```

Note that it is commonplace, and good style to capitalize the \textbf{first letter} of a type synonym. However in the actual definition we need to give the struct a \textit{tag} so we can refer to it: we may have a \textit{recursive data structure} of some kind. For trees or chained lists, we need a

---

\(^1\) Chapter 10 on page 39
Complex types

pointer to the same data type in the struct. During compilation, the type synonym is not known to the compiler and there will be an error. To avoid this, it is necessary to let the compiler know the name right from the start (Note that the struct keyword is used only inside the structure! After the declaration, the compiler knows that the type synonym refers to a struct):

```c
typedef struct Mystruct {
    ...
    struct Mystruct *pMystruct
} Mystruct;
```

27.1.2 Unions

The definition of a union is similar to that of a struct. The difference between the two is that in a struct, the members occupy different areas of memory, but in a union, the members occupy the same area of memory. Thus, in the following type, for example:

```c
union {
    int i;
    double d;
} u;
```

The programmer can access either `u.i` or `u.d`, but not both at the same time. Since `u.i` and `u.d` occupy the same area of memory, modifying one modifies the value of the other, sometimes in unpredictable ways.

The size of a union is the size of its largest member.

27.2 Enumerations

Enumerations are artificial data types representing associations between labels and integers. Unlike structs or unions, they are not composed of other data types. An example declaration:

```c
enum color {
    red, orange, yellow, green, cyan, blue, purple,
} crayon_color;
```

In the example above, red equals 0, orange equals 1, ... and so each subsequent label is by 1 larger than the previous one. It is possible to assign values to labels within the integer range, but they must be constant.

Similar declaration syntax that applies for structs and unions also applies for enums. Also, one normally doesn't need to be concerned with the integers that labels represent:

```c
enum weather weather_outside = rain;
```

This peculiar property makes enums especially convienent in switch-case statements:
enum weather {
    sunny,
    windy,
    cloudy,
    rain,
} weather_outside;

switch (weather_outside) {
    case sunny:
        wear_sunglasses();
        break;
    case windy:
        wear_windbreaker();
        break;
    case cloudy:
        get_umbrella();
        break;
    case rain:
        get_umbrella();
        wear_raincoat();
        break;
}

---

2 https://de.wikibooks.org/wiki/C-Programmierung%3A%20Komplexe%20Datentypen
3 https://fr.wikibooks.org/wiki/Programmation%20C%2FTypes%20avanc%C3%A9s
4 https://pl.wikibooks.org/wiki/C%2FTypy%20zlo%BCone
28 Networking in UNIX

Network programming under UNIX is relatively simple in C. This guide assumes you already have a good general idea about C, UNIX and networks.

28.1 A simple client

To start with, we'll look at one of the simplest things you can do: initialize a stream connection and receive a message from a remote server.

```c
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <unistd.h>
#include <arpa/inet.h>
#include <sys/types.h>
#include <netinet/in.h>
#include <sys/socket.h>

#define MAXRCVLEN 500
#define PORTNUM 2300

int main(int argc, char *argv[]) {
    char buffer[MAXRCVLEN + 1]; /* +1 so we can add null terminator */
    int len, mysocket;
    struct sockaddr_in dest;

    mysocket = socket(AF_INET, SOCK_STREAM, 0);
    memset(&dest, 0, sizeof(dest)); /* zero the struct */
    dest.sin_family = AF_INET;
    dest.sin_addr.s_addr = htonl(INADDR_LOOPBACK); /* set destination IP number - localhost, 127.0.0.1 */
    dest.sin_port = htons(PORTNUM); /* set destination port number */

    connect(mysocket, (struct sockaddr *)&dest, sizeof(struct sockaddr_in));

    len = recv(mysocket, buffer, MAXRCVLEN, 0);

    /* We have to null terminate the received data ourselves */
    buffer[len] = '\0';

    printf("Received %s (%d bytes).\n", buffer, len);

    close(mysocket);
    return EXIT_SUCCESS;
}
```

This is the very bare bones of a client; in practice, we would check every function that we call for failure, however, error checking has been left out for clarity.
As you can see, the code mainly revolves around `dest` which is a struct of type `sockaddr_in`. This struct stores information about the machine we want to connect to.

```c
mysocket = socket(AF_INET, SOCK_STREAM, 0);
```

The `socket()` function tells our OS that we want a file descriptor for a socket which we can use for a network stream connection; what the parameters mean is mostly irrelevant for now.

```c
memset(&dest, 0, sizeof(dest)); /* zero the struct */
```

```c
dest.sin_family = AF_INET;
dest.sin_addr.s_addr = inet_addr("127.0.0.1"); /* set destination IP number */
dest.sin_port = htons(PORTNUM); /* set destination port number */
```

Now we get onto the interesting part:

The first line uses `memset()` to zero the struct.

The second line sets the address family. This should be the same value that was passed as the first parameter to `socket()`, for most purposes `AF_INET` will serve.

The third line is where we set the IP of the machine we need to connect to. The variable `dest.sin_addr.s_addr` is just an integer stored in Big Endian format, but we don't have to know that as the `inet_addr()` function will do the conversion from string into Big Endian integer for us.

The fourth line sets the destination port number. The `htons()` function converts the port number into a Big Endian short integer. If your program is going to be run solely on machines which use Big Endian numbers as default then `dest.sin_port = 21` would work just as well. However, for portability reasons `htons()` should always be used.

Now that all of the preliminary work is done, we can actually make the connection and use it:

```c
connect(mysocket, (struct sockaddr *)&dest, sizeof(struct sockaddr_in));
```

This tells our OS to use the socket `mysocket` to create a connection to the machine specified in `dest`.

```c
len = recv(mysocket, buffer, MAXRCVLEN, 0);
```

Now this receives up to `MAXRCVLEN` bytes of data from the connection and stores them in the buffer string. The number of characters received is returned by `recv()`. It is important to note that the data received will not automatically be null terminated when stored in the buffer, so we need to do it ourselves with `buffer[len] = \'\0\'.

And that's about it!

The next step after learning how to receive data is learning how to send it. If you've understood the previous section then this is quite easy. All you have to do is use the `send()` function, which uses the same parameters as `recv()`. If in our previous example `buffer` had the text we wanted to send and its length was stored in `len` we would write `send(mysocket, buffer, len, 0)`. `send()` returns the number of bytes that were sent. It is important to remember that `send()`, for various reasons, may not be able to send all of the bytes, so it is important to check that its return value is equal to the number of bytes you tried to send. In most cases this can be resolved by resending the unsent data.
28.2 A simple server

```c
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <unistd.h>
#include <arpa/inet.h>
#include <sys/types.h>
#include <netinet/in.h>
#include <sys/socket.h>

#define PORTNUM 2300

int main(int argc, char *argv[])
{
    char* msg = "Hello World !\n";
    struct sockaddr_in dest; /* socket info about the machine connecting to us */
    struct sockaddr_in serv; /* socket info about our server */
    int mysocket; /* socket used to listen for incoming connections */
    socklen_t socksize = sizeof(struct sockaddr_in);
    memset(&serv, 0, sizeof(serv)); /* zero the struct before filling the fields */
    serv.sin_family = AF_INET; /* set the type of connection to TCP/IP */
    serv.sin_addr.s_addr = htonl(INADDR_ANY); /* set our address to any interface */
    serv.sin_port = htons(PORTNUM); /* set the server port number */

    mysocket = socket(AF_INET, SOCK_STREAM, 0);
    /* bind serv information to mysocket */
    bind(mysocket, (struct sockaddr *)&serv, sizeof(serv));
    /* start listening, allowing a queue of up to 1 pending connection */
    listen(mysocket, 1);
    int consocket = accept(mysocket, (struct sockaddr *)&dest, &socksize);
    while(consocket)
    {
        printf("Incoming connection from %s - sending welcome\n", inet_ntoa(dest.sin_addr));
        send(consocket, msg, strlen(msg), 0);
        close(consocket);
        consocket = accept(mysocket, (struct sockaddr *)&dest, &socksize);
    }
    close(mysocket);
    return EXIT_SUCCESS;
}
```

Superficially, this is very similar to the client. The first important difference is that rather
than creating a `sockaddr_in` with information about the machine we’re connecting to, we
create it with information about the server, and then we `bind()` it to the socket. This allows
the machine to know the data received on the port specified in the `sockaddr_in` should be
handled by our specified socket.

The `listen()` function then tells our program to start listening using the given socket. The
second parameter of `listen()` allows us to specify the maximum number of connections
that can be queued. Each time a connection is made to the server it is added to the
queue. We take connections from the queue using the `accept()` function. If there is no
connection waiting on the queue the program waits until a connection is received. The
`accept()` function returns another socket. This socket is essentially a "session" socket, and
can be used solely for communicating with connection we took off the queue. The original
socket (`mysocket`) continues to listen on the specified port for further connections.

Once we have "session" socket we can handle it in the same way as with the client, using
`send()` and `recv()` to handle data transfers.

Note that this server can only accept one connection at a time; if you want to simultaneously
handle multiple clients then you'll need to `fork()` off separate processes, or use threads, to
handle the connections.

### 28.3 Useful network functions

```c
int gethostname(char *hostname, size_t size);
```

The parameters are a pointer to an array of chars and the size of that array. If possible, it
finds the hostname and stores it in the array. On failure it returns -1.

```c
struct hostent *gethostbyname(const char *name);
```

This function obtains information about a domain name and stores it in a `hostent` struct.
The most useful part of a `hostent` structure is the (char**) `h_addr_list` field, which is a
null terminated array of the IP addresses associated with that domain. The field `h_addr`
is a pointer to the first IP address in the `h_addr_list` array. Returns NULL on failure.

### 28.4 FAQs

#### 28.4.1 What about stateless connections?

If you don't want to exploit the properties of TCP in your program and would rather just
use a UDP connection, then you can just replace `SOCK_STREAM` with `SOCK_DGRAM` in your
call to `socket()` and use the result in the same way. It is important to remember that UDP
does not guarantee delivery of packets and order of delivery, so checking is important.

If you want to exploit the properties of UDP, then you can use `sendto()` and `recvfrom()`,
which operate like `send()` and `recv()` except you need to provide extra parameters speci-
fying who you are communicating with.

#### 28.4.2 How do I check for errors?

The functions `socket()`, `recv()` and `connect()` all return -1 on failure and use `errno` for
further details.
29 Common practices

With its extensive use, a number of common practices and conventions have evolved to help avoid errors in C programs. These are simultaneously a demonstration of the application of good software engineering principles to a language and an indication of the limitations of C. Although few are used universally, and some are controversial, each of these enjoys wide use.

29.1 Dynamic multidimensional arrays

Although one-dimensional arrays are easy to create dynamically using malloc, and fixed-size multidimensional arrays are easy to create using the built-in language feature, dynamic multidimensional arrays are trickier. There are a number of different ways to create them, each with different tradeoffs. The two most popular ways to create them are:

- They can be allocated as a single block of memory, just like static multidimensional arrays. This requires that the array be rectangular (i.e. subarrays of lower dimensions are static and have the same size). The disadvantage is that the syntax of declaration the pointer is a little tricky for programmers at first. For example, if one wanted to create an array of ints of 3 columns and rows rows, one would do

  ```c
  int (*multi_array)[3] = malloc(rows * sizeof(int[3]));
  ```

  (Note that here multi_array is a pointer to an array of 3 ints.)

  Because of array-pointer interchangeability, you can index this just like static multidimensional arrays, i.e. `multi_array[5][2]` is the element at the 6th row and 3rd column.

- Dynamic multidimensional arrays can be allocated by first allocating an array of pointers, and then allocating subarrays and storing their addresses in the array of pointers.¹

  (This approach is also known as an Iliffe vector²). The syntax for accessing elements is the same as for multidimensional arrays described above (even though they are stored very differently). This approach has the advantage of the ability to make ragged arrays (i.e. with subarrays of different sizes). However, it also uses more space and requires more levels of indirection to index into, and can have worse cache performance. It also requires many dynamic allocations, each of which can be expensive.

  For more information, see the comp.lang.c FAQ, question 6.16³.

---

In some cases, the use of multi-dimensional arrays can best be addressed as an array of structures. Before user-defined data structures were available, a common technique was to define a multi-dimensional array, where each column contained different information about the row. This approach is also frequently used by beginner programmers. For example, columns of a two-dimensional character array might contain last name, first name, address, etc.

In cases like this, it is better to define a structure that contains the information that was stored in the columns, and then create an array of pointers to that structure. This is especially true when the number of data points for a given record might vary, such as the tracks on an album. In these cases, it is better to create a structure for the album that contains information about the album, along with a dynamic array for the list of songs on the album. Then an array of pointers to the album structure can be used to store the collection.

• Another useful way to create a dynamic multi-dimensional array is to flatten the array and index manually. For example, a 2-dimensional array with sizes x and y has $x^y$ elements, therefore can be created by

```c
int dynamic_multi_array[x*y];
```

The index is slightly trickier than before, but can still be obtained by $y^i+j$. You then access the array with

```c
static_multi_array[i][j];
dynamic_multi_array[y*i+j];
```

Some more examples with higher dimensions:

```c
int dim1[w];
int dim2[w*x];
int dim3[w*x*y];
int dim4[w*x*y*z];
dim1[i]
dim2[w*i+j];
dim3[w*(x*i+j)+k] // index is k + w*j + w*x*i
dim4[w*(x*(y*i+j)+k)+l] // index is w*z*y*i + w*z*j + w*k + l
```

Note that $w^*(x^*(y^i+j)+k)+l$ is equal to $w^x*y^i + w^x*j + w^k + l$, but uses fewer operations (see Horner's Method\(^5\)). It uses the same number of operations as accessing a static array by `static_multi_array[i][j][k][l]`, so should not be any slower to use.

The advantage to using this method is that the array can be passed freely between functions without knowing the size of the array at compile time (since C sees it as a 1-dimensional array, although some way of passing the dimensions is still necessary), and the entire array is contiguous in memory, so accessing consecutive elements should be fast. The disadvantage is that it can be difficult at first to get used to how to index the elements.

---


212
29.2 Constructors and destructors

In most object-oriented languages, objects cannot be created directly by a client that wishes to use them. Instead, the client must ask the class to build an instance of the object using a special routine called a constructor. Constructors are important because they allow an object to enforce invariants about its internal state throughout its lifetime. Destructors, called at the end of an object's lifetime, are important in systems where an object holds exclusive access to some resource, and it is desirable to ensure that it releases these resources for use by other objects.

Since C is not an object-oriented language, it has no built-in support for constructors or destructors. It is not uncommon for clients to explicitly allocate and initialize records and other objects. However, this leads to a potential for errors, since operations on the object may fail or behave unpredictably if the object is not properly initialized. A better approach is to have a function that creates an instance of the object, possibly taking initialization parameters, as in this example:

```c
struct string {
    size_t size;
    char *data;
};

struct string *create_string(const char *initial) {
    assert (initial != NULL);
    struct string *new_string = malloc(sizeof(*new_string));
    if (new_string != NULL) {
        new_string->size = strlen(initial);
        new_string->data = strdup(initial);
    }
    return new_string;
}
```

Similarly, if it is left to the client to destroy objects correctly, they may fail to do so, causing resource leaks. It is better to have an explicit destructor which is always used, such as this one:

```c
void free_string(struct string *s) {
    assert (s != NULL);
    free(s->data); /* free memory held by the structure */
    free(s); /* free the structure itself */
}
```

It is often useful to combine destructors with #Nulling freed pointers

Sometimes it is useful to hide the definition of the object to ensure that the client does not allocate it manually. To do this, the structure is defined in the source file (or a private header file not available to users) instead of the header file, and a forward declaration is put in the header file:

```c
struct string;
struct string *create_string(const char *initial);
void free_string(struct string *s);
```

---

6 Chapter 29.3 on page 214
29.3 Nulling freed pointers

As discussed earlier, after `free()` has been called on a pointer, it becomes a dangling pointer. Worse still, most modern platforms cannot detect when such a pointer is used before being reassigned.

One simple solution to this is to ensure that any pointer is set to a null pointer immediately after being freed:

```c
free(p);
p = NULL;
```

Unlike dangling pointers, a hardware exception will arise on many modern architectures when a null pointer is dereferenced. Also, programs can include error checks for the null value, but not for a dangling pointer value. To ensure it is done at all locations, a macro can be used:

```c
#define FREE(p) do { free(p); (p) = NULL; } while(0)
```

(To see why the macro is written this way, see "Macro conventions".) Also, when this technique is used, destructors should zero out the pointer that they are passed, and their argument must be passed by reference to allow this. For example, here's the destructor from "Constructors and destructors" updated:

```c
void free_string(struct string **s) {
    assert(s != NULL && *s != NULL);
    FREE((*s)->data); /* free memory held by the structure */
    FREE(*s);    /* free the structure itself */
    *s=NULL;    /* zero the argument */
}
```

Unfortunately, this idiom will not do anything to any other pointers that may be pointing to the freed memory. For this reason, some C experts regard this idiom as dangerous due to creating a false sense of security.

29.4 Macro conventions

Because preprocessor macros in C work using simple token replacement, they are prone to a number of confusing errors, some of which can be avoided by following a simple set of conventions:

1. Placing parentheses around macro arguments wherever possible. This ensures that, if they are expressions, the order of operations does not affect the behavior of the expression. For example:
   - Wrong: `#define square(x) x*x`
   - Better: `#define square(x) (x)*(x)`

---

7 comp.lang.c FAQ list: "Why isn’t a pointer null after calling free?" ^{http://c-faq.com/malloc/ptrafterfree.html} mentions that "it is often useful to set [pointer variables] to NULL immediately after freeing them".

8 Chapter 29.4 on page 214

9 Chapter 29.2 on page 213
2. Placing parentheses around the entire expression if it is a single expression. Again, this avoids changes in meaning due to the order of operations.
   • Wrong: `#define square(x) (x)*(x)`
   • Better: `#define square(x) ((x)*(x))`
   • Dangerous, remember it replaces the text in verbatim. Suppose your code is `square(x++)`, after the macro invocation will `x` be incremented by 2

3. If a macro produces multiple statements, or declares variables, it can be wrapped in a `do { ... } while(0)` loop, with no terminating semicolon. This allows the macro to be used like a single statement in any location, such as the body of an if statement, while still allowing a semicolon to be placed after the macro invocation without creating a null statement. Care must be taken that any new variables do not potentially mask portions of the macro’s arguments.
   • Wrong: `#define FREE(p) free(p); p = NULL;`
   • Better: `#define FREE(p) do { free(p); p = NULL; } while(0)`

4. Avoiding using a macro argument twice or more inside a macro, if possible; this causes problems with macro arguments that contain side effects, such as assignments.

5. If a macro may be replaced by a function in the future, considering naming it like a function.

29.5 Further reading

There are a huge number of C style guidelines.

- "C and C++ Style Guides" by Chris Lott lists many popular C style guides.

pl:C/Powszechne praktyki

10 http://www.chris-lott.org/resources/cstyle/
12 https://pl.wikibooks.org/wiki/C%2FPowszechne%20praktyki
30 C and beyond
31 Particularities of C

C is an efficient, minimalist language that has some peculiarities that a programmer must be aware of. To address these, sometimes a good solution is to combine another language with C for added flexibility and power, like the combination of Emacs-LISP and C used for Emacs. Sometimes they can be addressed at the cost of slower speed and increased complexity by using special constructs that will guarantee function and security. Mostly however, through practice, C programmers have no trouble with the things mentioned here, and prefer using a language that closely models the general purpose, Von Neumann hardware architecture.

Below are several of these particularities of ANSI C (that sometimes are also its strengths), some minor and some major:

Lack of differentiation between arrays and pointers

The very first C (around 1973) did not have arrays at all; modern implementations are contiguous areas in memory accessed with pointer arithmetic (note: a declared array cannot be assigned to like a pointer), which circumvents the need to declare arrays with a fixed size. This ability, however, can cause buffer overflow errors with careless use.

Arrays do not store their length

A consequence of the above feature. This means that the program might need to explicitly perform a bounds check before accessing an array. Unless a function is passed an array of a fixed size, there is no way for it to discover the length of the array it was given: So the function must be given the length, perhaps passed to the function as a separate variable or in a structure. Because of this, most implementations do not provide automatic array bounds checking, and manual bounds checking is error prone.

If a C (or C++) program attempts to access an array element outside of the actual allocated memory, then a buffer overflow occurs, typically crashing the program. Buffer overflow bugs are a common security vulnerability too. Many other computer languages provide automatic bounds checking, and so they are nearly immune to such bugs.\(^1\)\(^2\)\(^3\)\(^4\)\(^5\)

Variable Length Arrays

A VLA – variable length array – can only be used for function parameters and auto variables. VLAs cannot be allocated on the heap or used inside a structure (except as the last item in the structure). It’s not possible to define a structure that corresponds to

---

1 http://projects.webappsec.org/Buffer-Overflow
2 http://www.dwheeler.com/secure-programs/Secure-Programs-HOWTO/buffer-overflow.html
3 http://searchsecurity.techtarget.com/news/article/0,289142,sid14_gci860185,00.html
4 http://www.owasp.org/index.php/Buffer_Overflows
5 http://cyclone.thelanguage.org/wiki/Why%20Cyclone
the standard Forth\(^6\) dictionary definition (which has 2 variable-length parts), except as an undifferentiated array of char.

**Arbitrary-size built-in 2D or 3D arrays are not widely supported**

This feature has been added starting with the C99 specification for variable-length arrays, although many C compilers still do not support it. Without VLAs, there is no way for a function to accept 2D or 3D arrays of arbitrary size. In particular, it's impossible to define a function that accepts `int a[5][4][3];` on one call, and later accepts `int b[10][10][10];` in a later call. Instead of using the built-in 2D or 3D array data type, C programmers use some other data type to hold (mathematical) 2D or 3D arrays of arbitrary size (multi-dimensional arrays) -- see C Programming/Common practices#Dynamic multidimensional arrays\(^7\) for details.

**No formal String data type**

Strings are character arrays (lacking any abstraction) and inherit all their constraints (structs can provide an abstraction, to an extent).

**Weak type safety**

C is not very type-safe. The memory management functions operate on untyped pointers, there is no built-in run-time type enforcement, and the type system can be circumvented with pointers and casts. Additionally, typedef does not create a new type but only an alias, thus it serves solely for code legibility. However, it is possible to use single member structs to enforce type safety.

**No garbage collection**

As a low-level language designed for minimum overhead, C features only manual memory management, which can allow simple memory leaks to go on unchecked.

**Local variables are uninitialized upon declaration**

Local (but not global) variables must be initialized manually; before this, they contain whatever was already in memory at the time. This is not unusual, but the C standard does not forbid access to uninitialized variables (which is).

**Unwieldy function pointer syntax**

Function pointers take the form of `return type name([arg1 type])([arg2 type])`, making them somewhat difficult to use. Typedefs can alleviate this burdensome syntax. For example, `typedef int fn(int i);` See C Programming/Pointers and arrays#Pointers to Functions\(^8\) for more details.

**No reflection**

It is not possible for a C program -- at runtime -- to evaluate a string as if it were a source C code statement.

**Nested functions are not standard**

---

\(^6\) [https://en.wikibooks.org/wiki/Forth](https://en.wikibooks.org/wiki/Forth)

\(^7\) Chapter 29.1 on page 211

\(^8\) Chapter 24.7 on page 174

220
However, many C compilers do support nested functions, including GNU C.¹⁰

**No formal exception handling**

Some standard functions return special values that must be handled manually. For example, `malloc()` returns null upon failure. For example, one must store the return value of `getchar()` in an `int` (not, as one might expect, in a `char`) in order to reliably detect the end-of-file -- see EOF pitfall¹¹. Programs that do not include appropriate error handling might work fine most of the time, but can crash or otherwise malfunction when exceptional cases occur. POSIX systems often use `signal()` to handle some kinds of exceptions. (See "where can I read more about signal()?" for details). Some programs use `setjmp()`, `longjmp()` or `goto` to manually handle some kinds of exceptions. (See C Programming/Control#One last thing: goto¹² and C Programming/Coroutines¹³ for details).

**No anonymous function definitions**

### 31.1 References

---


¹¹ Chapter 20.10.2 on page 140

¹² Chapter 15.3 on page 90

32 Language Overloading and Extensions

Most C compilers have one or more "extensions" to the standard C language, to do things that are inconvenient to do in standard, portable C.

Some examples of language extensions:

- in-line assembly language
- interrupt service routines
- variable-length data structure (a structure whose last item is a "zero-length array").

- re-sizeable multidimensional arrays
- various "#pragma" settings to compile quickly, to generate fast code, or to generate compact code.
- bit manipulation, especially bit-rotations and things involving the "carry" bit
- storage alignment
- Arrays whose length is computed at run time.

32.1 External links

- GNU C: Extensions to the C Language
- C/C++ interpreter Ch extensions to the C language for scripting
- SDCC: Storage Class Language Extensions

---

1 comp.lang.c FAQ list: Question 2.6: "http://c-faq.com/struct/structhack.html": "C99 introduces the concept of a flexible array member, which allows the size of an array to be omitted if it is the last member in a structure, thus providing a well-defined solution."
2 http://gcc.gnu.org/onlinedocs/gcc-4.0.2/gcc/C-Extensions.html#C-Extensions
3 http://www.softintegration.com/support/faq/general.html#4
4 http://sdcc.sourceforge.net/doc/sdccman.html/node56.html
33 Combining Languages

33.1 Assembler

See Embedded Systems/Mixed C and Assembly Programming.

33.2 Cg

Make the main program (for CPU) in C, which loads and run the Cg program (for GPU).

33.2.1 Header Files

Add to C program:

```c
#include <Cg/cg.h> /* To include the core Cg runtime API into your program */
#include <Cg/cgGL.h> /* to include the OpenGL-specific Cg runtime API */
```

33.2.2 Minimal program

- by bobobobo

---

2. [https://en.wikibooks.org/wiki/Cg_%28programming_language%29](https://en.wikibooks.org/wiki/Cg_%28programming_language%29)
4. Cg Bumpmapping by Razvan Surdulescu at GameDev [http://www.gamedev.net/reference/articles/article1903.asp]
7. Absolutely minimal CG program for good fundamentals understanding [http://bobobobo.wordpress.com/2008/10/05/cg-1/](http://bobobobo.wordpress.com/2008/10/05/cg-1/)
33.3 Java

Using the Java native interface (JNI), Java applications can call C libraries.

See also

- Java_Programming/Keywords/native

33.4 Perl

To mix Perl and C, we can use XS. XS is an interface description file format used to create an extension interface between Perl and C code (or a C library) which one wishes to use with Perl.

The basic procedure is very simple. We can create the necessary subdirectory structure by running "h2xs" application (e.g. "h2xs -A -n Modulename"). This will create - among others - a Makefile.PL, a .pm Perl module and a .xs XSUB file in the subdirectory tree. We can edit the .xs file by adding our code to that, let's say:

```c
void
hello()
CODE:
    printf("Hello, world!\n");
```

and we can successfully use our new command at Perl side, after running a "perl Makefile.PL" and "make".

Further details can be found on the perlxstut page.

33.5 Python

Here can be found some details about extending Python with modules written in C. You might read about Cython and Pyrex as well, that makes easier to create modules in C, translating a Python-like code into C. Using the Python ctypes module, one can write C code directly into Python.

---

8 https://en.wikibooks.org/wiki/Java_Programming%2FKeywords%2Fnative
9 http://perldoc.perl.org/perlxstut.html
10 http://perldoc.perl.org
11 http://docs.python.org/3/extending/extending.html
12 http://cython.org/
13 http://www.cosc.canterbury.ac.nz/greg.ewing/python/Pyrex/
14 https://docs.python.org/2/library/ctypes.html
33.6 For further reading

- Embedded Systems/Mixed C and Assembly Programming

33.7 References

pl:C/Łączenie z innymi językami
34 Object Oriented Programming: The GObject System

Since the C Programming-Language was not created with Object Oriented Programming in mind, it has no explicit support for classes, inheritance, polymorphism and other OO Concepts. Neither does it have its own Virtual Table, which is found in object-oriented languages such as C++, Java and C#. Therefore, it might not be as easy to implement an object-oriented programming paradigm using only C's language features and standard library. However, it can be done using structures which contain both function pointers as well as data, for example, or by using third-party libraries.

There are many third-party libraries designed to add support for object-oriented programming in C. The most general-purpose and widely used among these is the GObject System, which is part of Glib. The GObject System comes with its own virtual table. To create an object in C using the GObject system, it has to be sub-classed from the GObject struct.

34.1 Object-Creation

In this example a new object will be implemented directly derived from GObject. For simplicity, the object is named MyObject.

34.1.1 Declaring An Object

To create a simple object, two structs must be declared. The instance and the class. They are usually declared in this manner:

```c
/* in myobject.h */
typedef struct _MyObject MyObject;
typedef struct _MyObjectClass MyObjectClass;

struct _MyObject
{
  GObject parent_instance;
  /* instance members */
};

struct _MyObjectClass
{
  GObjectClass parent_class;
```

3  https://en.wikibooks.org/wiki/C_Sharp_Programming
/* class members */

34.1.2 Boiler-Plate Code

Since the GObject System is just a third-party library and therefore cannot make any changes to the C Language itself, creating a new object requires a lot of boiler-plate code.

/* in myobject.h */
#define MY_TYPE_OBJECT (my_object_get_type ())
#define MY_OBJECT(obj) (G_TYPE_CHECK_INSTANCE_CAST ((obj), MY_TYPE_OBJECT, MyObject))
#define MY_IS_OBJECT(obj) (G_TYPE_CHECK_INSTANCE_TYPE ((obj), MY_TYPE_OBJECT))
#define MY_OBJECT_CLASS(_class) (G_TYPE_CHECK_CLASS_CAST ((_class), MY_TYPE_OBJECT, MyObjectClass))
#define MY_IS_OBJECT_CLASS(_class) (G_TYPE_CHECK_CLASS_TYPE ((_class), MY_TYPE_OBJECT))
#define MY_OBJECT_GET_CLASS(obj) (G_TYPE_INSTANCE_GET_CLASS ((obj), MY_TYPE_OBJECT, MyObjectClass))

34.1.3 Defining The Object

Before use, the newly created object must be defined.

/* in myobject.c */
G_DEFINE_TYPE(MyObject, my_object, G_TYPE_OBJECT);

34.1.4 Static Functions

There are a few static functions that may or may not to be defined, depending on your object. For a minimal object these ones are compulsory:

/* in myobject.c */
static void my_object_class_init(MyObjectClass *_class)
{
    /* code */
}

static void my_object_init(MyObject* obj)
{
    /* code */
}

34.1.5 The Constructor

There is no internal way of allocating memory for an object in C. Therefore an explicit constructor must be declared for the new object.

/* in myobject.c */
GObject* my_object_new(void)
{
    return g_object_new(MY_TYPE_OBJECT , 0);
}
34.1.6 Object-Usage

Although creating the object using its own pointer-type is perfectly valid, it is recommended to use the pointer-type of the object at the top of the hierarchy i.e the furthest off base class. The newly created object may now be used like this:

```c
/* in main.c */
/* Note: GObject is at the top of the hierarchy. */
/* declaration and construction */
GObject* myobj = my_object_new();
/* destruction */
g_object_unref(myobj);
```

34.2 Inheritance

34.2.1 Concept

Inheritance is one of the most widely used and useful OO Concepts. It provides an efficient way to reuse existing code by wrapping it up into an object and then sub-classing it. The new classes are known as derived classes. Many object hierarchies can be created using inheritance. Inheritance is also one of the most efficient ways of abstracting code.

34.2.2 Implementation

In the GObject System, inheritance can be achieved by sub-classing GObject. Since C provides no keyword or operator for inheritance, a derived object is usually made by declaring the base instance and base class as a member of the derived instance and derived class respectively. In C code:

```c
/* derived object instance */
struct DerivedObject
{
    /* the base instance is a member of the derived instance */
    BaseObject parent_instance;
};

/* derived object class */
struct DerivedObjectClass
{
    /* the base class is a member of the derived class */
    BaseObjectClass parent_class;
};
```
34.3 Further reading

- Hanser. "Object-oriented programming with ANSI-C". 1994. Hanser describes another way of implementing classes, inheritance, instances, methods, objects, vtables, polymorphism, late binding, etc. in standard ANSI C.

4 http://www.cs.rit.edu/~ats/books/ooc.pdf
35 Computer Programming

The following articles are C adaptations from articles of the Computer programming\textsuperscript{1} book.

\footnote{\url{https://en.wikibooks.org/wiki/Computer\%20programming}}
36 Statements

A statement is a command given to the computer that instructs the computer to take a specific action, such as display to the screen, or collect input. A computer program is made up of a series of statements.

In C, a statement can be any of the following:

36.1 Labeled Statements

A statement can be preceded by a label. Three types of labels exist in C.

A simple identifier followed by a colon (:) is a label. Usually, this label is the target of a goto statement.

Within switch statements, case and default labeled statements exist. A statement of the form

```c
    case constant-expression : statement
```

indicates that control will pass to this statement if the value of the control expression of the switch statement matches the value of the constant-expression. A statement of the form

```c
    default : statement
```

indicates that control will pass to this statement if the control expression of the switch statement does not match any of the constant-expressions within the switch statement. If the default statement is omitted, the control will pass to the statement following the switch statement.

36.2 Compound Statements

A compound statement is the way C groups multiple statements into a single statement. It consists of multiple statements and declarations within braces (i.e. { and }). In the ANSI C Standard of 1989-1990, a compound statement contained an optional list of declarations followed by an optional list of statements; in more recent revisions of the Standard, declarations and statements can be freely interwoven through the code. The body of a function is also a compound statement by rule.
36.3 Expression Statements

An expression statement consists of an optional expression followed by a semicolon (;). If the expression is present, the statement may have a value. If no expression is present, the statement is often called the null statement.

The printf function calls are expressions, so statements such as printf ("Hello World!\n") are expression statements.

36.4 Selection Statements

Three types of selection statements exist in C:

if ( expression ) statement

In this type of if-statement, the sub-statement will only be executed iff the expression is non-zero.

if ( expression ) statement else statement

In this type of if-statement, the first sub-statement will only be executed iff the expression is non-zero; otherwise, the second sub-statement will be executed. Each else matches up with the closest unmatched if, so that the following two snippets of code are not equal:

if (expression)
   if (secondexpression) statement1;
else
   statement2;

if (expression)
  {
    if (secondexpression) statement1;
  }
else
  statement2;

because in the first, the else statement matches up with the if statement that has secondexpression for a control, but in the second, the braces force the else to match up with the if that has expression for a control.

Switch statements are also a type of selection statement. They have the format

switch ( expression ) statement

The statement here is usually compound and it contains case-labeled statements and optionally a default-labeled statement.

36.5 Iteration Statements

C has three kinds of iteration statements. The first is a while-statement with the form

while ( expression ) statement
The substatement of a while runs repeatedly as long as the control expression evaluates to non-zero at the beginning of each iteration. If the control expression evaluates to zero the first time through, the substatement may not run at all.

The second is a do-while statement of the form

\[\text{do statement while ( expression ) ;}\]

This is similar to a while loop, except that the controlling expression is evaluated at the end of the loop instead of the beginning and consequently the sub-statement must execute at least once.

The third type of iteration statement is the for-statement. In ANSI C 1989, it has the form

\[\text{for ( expression_{opt} ; expression_{opt} ; expression_{opt} ) statement}\]

In more recent versions of the C standard, a declaration can substitute for the first expression. The \texttt{opt} subscript indicates that the expression is optional.

The statement

\[
\text{for (e1; e2; e3)}
\text{s;}
\]

is the rough equivalent of

\[
\{ \\
  e1; \\
  \text{while (e2)} \\
  \{ \\
   \text{s;} \\
   e3; \\
  \}
\}
\]

except for the behavior of \texttt{continue} statements within \texttt{s}.

The \texttt{e1} expression represents an initial condition; \texttt{e2} a control expression; and \texttt{e3} what to happen on each iteration of the loop. If \texttt{e2} is missing, the expression is considered to be non-zero on every iteration, and only a \texttt{break} statement within \texttt{s} (or a call to a non-returning function such as \texttt{exit} or \texttt{abort}) will end the loop.

### 36.6 Jump Statements

C has four types of jump statements. The first, the \texttt{goto} statement, is used sparingly and has the form

\[\text{goto identifier ;}\]

This statement transfers control flow to the statement labeled within the given identifier.

The second, the \texttt{break} statement, with the form

\[\text{break ;}\]

is used within iteration statements and \texttt{switch} statements to pass control flow to the statement following the while, do-while, for, or switch.
The third, the continue statement, with the form

```c
continue;
```

is used within the substatement of interaction statements to transfer control flow to the place just before the end of the substatement. In `for` statements the iteration expression will then be executed before the controlling expression is evaluated.

The fourth type of jump statement is the return statement with the form

```c
return expression_{opt};
```

This statement returns from the function. If the function return type is `void`, the function may not return a value; otherwise, the expression represents the value to be returned.
37 C Reference Tables

This section has some tables and lists of C entities.
38 C Language Reference

38.1 Table of keywords

38.1.1 ANSI C (C89)/ISO C (C90)

Very old compilers may not recognize some or all of the C89 keywords `const`, `enum`, `signed`, `void`, `volatile`, as well as any later standards' keywords.

- `auto`
- `break`
- `case`
- `char`
- `const`
- `continue`
- `default`
- `do`
- `double`
- `else`
- `enum`
- `extern`
- `float`
- `for`
- `goto`
- `if`
- `int`
- `long`
- `register`
- `return`
- `short`
- `signed`
- `sizeof`
- `static`
- `struct`
- `switch`
- `typedef`
- `union`
- `unsigned`
- `void`
- `volatile`
- `while`

38.1.2 ISO C (C99)

These are supported in most new compilers.

- `_Bool`
- `_Imaginary`
- `_Complex`
- `inline`
- `restrict`

38.1.3 ISO C (C11)

These are supported only in some newer compilers.

- `alignof`
- `_Generic`
- `_Atomic`
- `_Alignas`
- `_Alignof`
- `_Noreturn`
- `_Static_assert`
- `_Thread_local`

---

Although not technically a keyword, C99-capable preprocessors/compilers additionally recognize the special preprocessor operator \_Pragma, which acts as an alternate form of the \#pragma directive that can be used from within macro expansions. For example, the following code will cause some compilers (incl. GCC, Clang) to emit a diagnostic message:

```c
#define EMIT MESSAGE(str) EMIT PRAGMA(message(str))
#define EMIT PRAGMA(content) _Pragma(#content)
EMIT MESSAGE("Hello, world!")
```

Some compilers use a slight variant syntax; in particular, MSVC supports __pragma instead of _Pragma.

Specific compilers may also—in a non-standards-compliant mode, or with additional syntactic markers like __extension__—treat some other words as keywords, including asm, cdecl, far, fortran, huge, interrupt, near, pascal, or typeof. However, they typically allow these keywords to be overridden by declarations when operating in standards-compliant modes (e.g., by defining a variable named typeof), in order to avoid introducing incompatibilities with existing programs. In order to ensure the compiler can maintain access to extension features, these compilers usually have an additional set of proper keywords beginning with two underscores (__). For example, GCC treats asm, __asm__, and __asm__ somewhat identically, but the latter two are always guaranteed to have the expected meaning since they can't be overridden.

Many of the newly introduced keywords—namely, those beginning with an underscore and capital letter like __noreturn or __Imaginary—are intended to be used only indirectly in most situations. Instead, the programmer should prefer the use of standard headers such as <stdbool.h> or <stdalign.h>, which typically use the preprocessor to establish an all-lower-case variant of the keyword (e.g., complex or noreturn). These headers serve the purpose of enabling C and C++ code, as well as code targeting different compilers or language versions, to interoperate more cleanly. For example, by including <stdbool.h>, the tokens bool, true, and false can be used identically in either C99 or C++ without having to explicitly use __Bool in C99 or bool in C++.

See also the list of reserved identifiers 2.

### 38.2 Table of operators

Operators in the same row of this table have the same precedence and the order of evaluation is decided by the associativity (left-to-right or right-to-left). Operators closer to the top of this table have higher precedence than those in a subsequent group.

<table>
<thead>
<tr>
<th>Operators</th>
<th>Description</th>
<th>Example Usage</th>
<th>Associativity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Postfix operators</td>
<td>( )</td>
<td>function call operator</td>
<td>swap (x, y)</td>
</tr>
<tr>
<td></td>
<td>[ ]</td>
<td>array index operator</td>
<td>arr [i]</td>
</tr>
<tr>
<td></td>
<td>.</td>
<td>member access operator</td>
<td>obj.member</td>
</tr>
</tbody>
</table>

2 http://publib.boulder.ibm.com/infocenter/comphelp/v7v91/topic/com.ibm.vacpp7a.doc/language/ref/clrc02reserved_identifiers.htm list of reserved identifiers
<table>
<thead>
<tr>
<th>Operator</th>
<th>Description</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>-&gt;</code></td>
<td>member access operator for a pointer to an object of struct/union type</td>
<td><code>ptr-&gt;member</code></td>
</tr>
<tr>
<td><code>!</code></td>
<td>logical not operator</td>
<td><code>!eof_reached</code></td>
</tr>
<tr>
<td><code>-</code></td>
<td>bitwise not operator</td>
<td><code>~mask</code></td>
</tr>
<tr>
<td><code>+ -</code></td>
<td>unary plus/minus operators</td>
<td><code>-num</code></td>
</tr>
<tr>
<td><code>++ --</code></td>
<td>post-increment/decrement operators</td>
<td><code>num++</code></td>
</tr>
<tr>
<td><code>++ --</code></td>
<td>pre-increment/decrement operators</td>
<td><code>++num</code></td>
</tr>
<tr>
<td><code>&amp;</code></td>
<td>address-of operator</td>
<td><code>&amp;data</code></td>
</tr>
<tr>
<td><code>*</code></td>
<td>indirection operator</td>
<td><code>*ptr</code></td>
</tr>
<tr>
<td><code>sizeof</code></td>
<td>sizeof operator for expressions</td>
<td><code>sizeof 123</code></td>
</tr>
<tr>
<td><code>sizeof()</code></td>
<td>sizeof operator for types</td>
<td><code>sizeof (int)</code></td>
</tr>
<tr>
<td><code>(type)</code></td>
<td>cast operator</td>
<td><code>(float)i</code></td>
</tr>
</tbody>
</table>

**Unary Operators**

**Multiplicative Operators** Left to right

- `* / %`
- `celsius_diff * 9.0 / 5.0`

**Additive Operators** Left to right

- `+ -`
- `end - start + 1`

**Bitwise Shift Operators** Left to right

- `<<`
- `bits << shift_len`

- `>>`
- `bits >> shift_len`

**Relational Inequality Operators** Left to right

- `< > <= >=`
- `i < num_elements`

**Relational Equality Operators** Left to right

- `== !=`
- `choice != 'n'`

**Bitwise And Operator** Left to right

- `&`
- `bits &`

**Bitwise Xor Operator** Left to right

- `&`
- `clear_mask_complement`

---

3 Very old compilers may not recognize the unary `+` operator.
C Language Reference

^ bits ^ invert_mask

Bitwise Or Operator
| bits | set_mask | Left to right

Logical And Operator
&&
arr != 0 && arr->len != 0

Logical Or Operator
||
arr == 0 || arr->len == 0

Conditional Operator
?:
size != 0 ? size : 0

Assignment Operators
= assignment operator
i = 0
Right to left
+= -= *= /=
shorthand assignment
num /= 10
operators
%& &= |= ^=

(\textit{foo op= bar represents}
\textit{foo = foo op bar})

Comma Operator
,
i = 0, j = i + 1, k = 0
Left to right

38.3 Table of data types
<table>
<thead>
<tr>
<th>Type</th>
<th>Size in Bits</th>
<th>Comments</th>
<th>Alternative Names</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>char</code></td>
<td>≥ 8</td>
<td>• <code>sizeof</code> gives the size in units of <code>char</code>.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• These &quot;C bytes&quot; need not be 8-bit bytes (though commonly they are); the number of</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>bits is given by the <code>CHAR_BIT</code> macro in the <code>limits.h</code> header.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Signedness is implementation-defined.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Any encoding of 8 bits or less (e.g. ASCII) can be used to store characters.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Integer operations can be performed portably only for the range 0 ~ 127.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• All bits contribute to the value of the <code>char</code>, i.e. there are no &quot;holes&quot; or &quot;padding&quot;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>bits.</td>
<td></td>
</tr>
<tr>
<td><code>signed char</code></td>
<td>same as <code>char</code></td>
<td>• Characters stored like for type <code>char</code>.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Can store integers in the range -127 ~ 127 portably.</td>
<td></td>
</tr>
<tr>
<td><code>unsigned char</code></td>
<td>same as <code>char</code></td>
<td>• Characters stored like for type <code>char</code>.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Can store integers in the range 0 ~ 255 portably.</td>
<td></td>
</tr>
<tr>
<td><code>short</code></td>
<td>≥ 16, ≥ size of <code>char</code></td>
<td>• Can store integers in the range -32767 ~ 32767 portably.</td>
<td>short int, signed short, signed short int</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Used to reduce memory usage (although the resulting executable may be larger and</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>probably slower as compared to using <code>int</code>.</td>
<td></td>
</tr>
<tr>
<td><code>unsigned short</code></td>
<td>same as <code>short</code></td>
<td>• Can store integers in the range 0 ~ 65535 portably.</td>
<td>unsigned short int</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Used to reduce memory usage (although the resulting executable may be larger and</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>probably slower as compared to using <code>int</code>.</td>
<td></td>
</tr>
</tbody>
</table>

4 -128 can be stored in two's-complement machines (i.e. most machines in existence). Very old compilers may not recognize the `signed` keyword.

5 -32768 can be stored in two's-complement machines (i.e. most machines in existence). Very old compilers may not recognize the `signed` keyword.
<table>
<thead>
<tr>
<th>Type</th>
<th>Size in Bits</th>
<th>Comments</th>
<th>Alternative Names</th>
</tr>
</thead>
</table>
| **int**      | ≥ 16, ≥ size of short | • Represents the "normal" size of data the processor deals with (the word-size); this is the integral data-type used normally.  
• Can store integers in the range -32767 ~ 32767 portably\(^6\). | signed, signed int       |
| unsigned int | same as int  | • Can store integers in the range 0 ~ 65535 portably.                     | unsigned                  |
| long         | ≥ 32, ≥ size of int | • Can store integers in the range -2147483647 ~ 2147483647 portably\(^7\). | long int, signed long, signed long int |
| unsigned long| same as long | • Can store integers in the range 0 ~ 4294967295 portably.                | unsigned long int         |
| float        | ≥ size of char | • Used to reduce memory usage when the values used do not vary widely.    | —                         |
|              |              | • The floating-point format used is implementation defined and need not be the IEEE single-precision format. | —                         |
|              |              | • unsigned cannot be specified.                                          | —                         |
| double       | ≥ size of float | • Represents the "normal" size of data the processor deals with; this is the floating-point data-type used normally.  
• The floating-point format used is implementation defined and need not be the IEEE double-precision format.  
• unsigned cannot be specified. | —                         |
| long double  | ≥ size of double | • unsigned cannot be specified.                                          | —                         |

Primitives Types added to ISO C (C99)

\(^6\) -32768 can be stored in two's-complement machines (i.e. most machines in existence). Very old compilers may not recognize the signed keyword.

\(^7\) -2147483648 can be stored in two's-complement machines (i.e. most machines in existence). Very old compilers may not recognize the signed keyword.
<table>
<thead>
<tr>
<th>Type</th>
<th>Size in Bits</th>
<th>Comments</th>
<th>Alternative Names</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Primitive Types in ANSI C (C89)/ISO C (C90)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>long long</td>
<td>≥ 64, ≥ size of long</td>
<td>• Can store integers in the range -9223372036854775807 ~ 9223372036854775807 portably.</td>
<td>long long int, signed long long, signed long long int</td>
</tr>
<tr>
<td>unsigned long long</td>
<td>same as long long</td>
<td>• Can store integers in the range 0 ~ 18446744073709551615 portably.</td>
<td>unsigned long long int</td>
</tr>
<tr>
<td>intmax_t</td>
<td>the maximum width supported by the platform</td>
<td>• Can store integers in the range -(1 &lt;&lt; n-1)+1 ~ (1 &lt;&lt; n)-1, with 'n' the width of intmax_t. &lt;br&gt;• Used by the 'j' length modifier in the C Programming/File IO:Formatted output functions: the printf family of functions.</td>
<td>—</td>
</tr>
<tr>
<td>uintmax_t</td>
<td>same as intmax_t</td>
<td>• Can store integers in the range 0 ~ (1 &lt;&lt; n)-1, with 'n' the width of uintmax_t.</td>
<td>—</td>
</tr>
<tr>
<td><strong>User Defined Types</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>struct</td>
<td>≥ sum of size of each member</td>
<td>• Said to be an aggregate type.</td>
<td>—</td>
</tr>
<tr>
<td>union</td>
<td>≥ size of the largest member</td>
<td>• Said to be an aggregate type.</td>
<td>—</td>
</tr>
<tr>
<td>enum</td>
<td>≥ size of char</td>
<td>• Enumerations are a separate type from ints, though they are mutually convertible.</td>
<td>—</td>
</tr>
<tr>
<td>typedef</td>
<td>same as the type being given a name</td>
<td>• typedef has syntax similar to a storage class like static, register or extern.</td>
<td>—</td>
</tr>
<tr>
<td><strong>Derived Types</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type</td>
<td>Size in Bits</td>
<td>Comments</td>
<td>Alternative Names</td>
</tr>
<tr>
<td>---------------------------------</td>
<td>--------------</td>
<td>--------------------------------------------------------------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>Primitive Types in ANSI C (C89)/ISO C (C90)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| type*                           | $\geq$ size of char | • 0 always represents the null pointer (an address where no data can be placed), irrespective of what bit sequence represents the value of a null pointer.  
• Pointers to different types may have different representations, which means they could also be of different sizes. So they are not convertible to one another.  
• Even in an implementation which guarantees all data pointers to be of the same size, function pointers and data pointers are in general incompatible with each other.  
• For functions taking variable number of arguments, the arguments passed must be of appropriate type, so even 0 must be cast to the appropriate type in such function-calls. |                   |
| type (integer^{n})              | $\geq$ integer $\times$ sizeof type | • The brackets ([]) follow the identifier name in a declaration.  
• In a declaration which also initializes the array (including a function parameter declaration), the size of the array (the integer) can be omitted.  
• type [] is not the same as type*. Only under some circumstances one can be converted to the other. |                   |
| type (comma-delimited list of types/declarations) |             | • Functions declared without any storage class are extern.  
• The parentheses (()) follow the identifier name in a declaration, e.g. a 2-arg function pointer: int (* fptr) (int arg1, int arg2). |                   |

10 The standards do NOT place any restriction on the size/type of the integer, it’s implementation dependent. The only mention in the standards is a reference that an implementation may have limits to the maximum size of memory block which can be allocated, and as such the limit on integer will be size_of_max_block/sizeof(type)
38.4 Character sets

Programs written in C can read and write any character set, provided the libraries that support them are included/used.

The source code for C programs, however, is usually limited to the ASCII character set.

In a file containing source code, the end of a line is sometimes, depending on the operating system it was created on not a newline character but compilers treat the end of each line as if it were a single newline character.

Virtually all compilers allow the $, @, and ` characters in string constants. Many compilers also allow literal multibyte Unicode characters, but they are not portable.

Certain characters must be escaped with a backslash to represent themselves in a string or character constant. These are:

- `\` Literal backslash
- `"` Literal double quote
- `'` Literal single quote
- `\n` Newline
- `\t` Horizontal tab
- `\f` Form feed
- `\r` Carriage return
- `\a` Alert (audible bell)
- `\b` Backspace
- `\xhh`, where hh is a hexadecimal number, is used to represent arbitrary bytes (including `\x00`, the zero byte)
- `\uhhhhh` or `\Uhhhhhh`, where h is a hexadecimal number, is used to portably represent Unicode characters.

Additionally, some compilers allow these characters:

- `\r` Carriage return
- `\a` Alert (audible bell)
- `\b` Backspace

38.5 References

et:Programmeerimiskeel C/Operaatorid
fr:Programmation C/Types de base
pl:C/Składnia

11 https://et.wikibooks.org/wiki/Programmeerimiskeel%20C%20Operaatorid
12 https://fr.wikibooks.org/wiki/Programmation%20C%20Types%20de%20base
13 https://pl.wikibooks.org/wiki/C%2FSk%C5%82adnia
39 POSIX Reference

The C POSIX library is a language-independent library (using C calling conventions) that adds functions specific to POSIX systems. POSIX (and the Single Unix Specification) specifies a number of routines that should be available over and above those in the C standard library proper. It was developed at the same time as the ANSI C standard and is closely related to C. Some effort was made to make the C and POSIX libraries compatible, but there are a few POSIX functions that were never introduced into ANSI C.

Facilities are often implemented alongside the C standard library functionality, with varying degrees of closeness. For example, glibc implements functions such as fork within libc.so, but before NPTL was merged into glibc it constituted a separate library with its own linker flag. Often, this POSIX-specified functionality will be regarded as part of the library; the C library proper may be identified as the ANSI or ISO C library.

39.1 Header files

<table>
<thead>
<tr>
<th>Header File</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>aio.h</td>
<td>Asynchronous input and output.</td>
</tr>
<tr>
<td>arpa/inet.h</td>
<td>Definitions for internet operations.</td>
</tr>
<tr>
<td>assert.h</td>
<td>Verify program assertion.</td>
</tr>
<tr>
<td>complex.h</td>
<td>Complex arithmetic.</td>
</tr>
<tr>
<td>cpio.h</td>
<td>Magic numbers for the cpio archive format.</td>
</tr>
<tr>
<td>ctype.h</td>
<td>Character types.</td>
</tr>
<tr>
<td>dirent.h</td>
<td>Allows the opening and listing of directories.</td>
</tr>
<tr>
<td>fcntl.h</td>
<td>File opening, locking and other operations.</td>
</tr>
<tr>
<td>fenv.h</td>
<td>Floating-point environment.</td>
</tr>
<tr>
<td>float.h</td>
<td>Floating types.</td>
</tr>
<tr>
<td>fmtmsg.h</td>
<td>Message display structures.</td>
</tr>
<tr>
<td>fnmatch.h</td>
<td>Filename-matching types.</td>
</tr>
<tr>
<td>ftw.h</td>
<td>File tree traversal.</td>
</tr>
<tr>
<td>glob.h</td>
<td>Pathname pattern-matching types.</td>
</tr>
<tr>
<td>grp.h</td>
<td>User group information and control.</td>
</tr>
<tr>
<td>iconv.h</td>
<td>Codeset conversion facility.</td>
</tr>
<tr>
<td>inttypes.h</td>
<td>Fixed size integer types.</td>
</tr>
<tr>
<td>iso646.h</td>
<td>Alternative spellings.</td>
</tr>
<tr>
<td>langinfo.h</td>
<td>Language information constants.</td>
</tr>
<tr>
<td>libgen.h</td>
<td>Definitions for pattern matching functions.</td>
</tr>
<tr>
<td>limits.h</td>
<td>Implementation-defined constants.</td>
</tr>
<tr>
<td>locale.h</td>
<td>Category macros.</td>
</tr>
<tr>
<td>math.h</td>
<td>Mathematical declarations.</td>
</tr>
<tr>
<td>File</td>
<td>Description</td>
</tr>
<tr>
<td>----------------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>monetary.h</td>
<td>Monetary types.</td>
</tr>
<tr>
<td>mqueue.h</td>
<td>Message queues (REALTIME).</td>
</tr>
<tr>
<td>ndbm.h</td>
<td>Definitions for ndbm database operations.</td>
</tr>
<tr>
<td>net/if.h</td>
<td>Sockets local interfaces.</td>
</tr>
<tr>
<td>netdb.h</td>
<td>Definitions for network database operations.</td>
</tr>
<tr>
<td>netinet/in.h</td>
<td>Internet address family.</td>
</tr>
<tr>
<td>netinet/tcp.h</td>
<td>Definitions for the Internet Transmission Control Protocol (TCP).</td>
</tr>
<tr>
<td>nl_types.h</td>
<td>Data types.</td>
</tr>
<tr>
<td>poll.h</td>
<td>Definitions for the poll() function.</td>
</tr>
<tr>
<td>pthread.h</td>
<td>Defines an API for creating and manipulating POSIX threads.</td>
</tr>
<tr>
<td>pwd.h</td>
<td>Passwd (user information) access and control.</td>
</tr>
<tr>
<td>regex.h</td>
<td>Regular expression matching types.</td>
</tr>
<tr>
<td>sched.h</td>
<td>Execution scheduling.</td>
</tr>
<tr>
<td>search.h</td>
<td>Search tables.</td>
</tr>
<tr>
<td>semaphore.h</td>
<td>Semaphores.</td>
</tr>
<tr>
<td>setjmp.h</td>
<td>Stack environment declarations.</td>
</tr>
<tr>
<td>signal.h</td>
<td>Signals.</td>
</tr>
<tr>
<td>spawn.h</td>
<td>Create a new process to run an executable program.</td>
</tr>
<tr>
<td>stdarg.h</td>
<td>Handle variable argument list.</td>
</tr>
<tr>
<td>stdbool.h</td>
<td>Boolean type and values.</td>
</tr>
<tr>
<td>stddef.h</td>
<td>Standard typedefinitions.</td>
</tr>
<tr>
<td>stdint.h</td>
<td>Integer types.</td>
</tr>
<tr>
<td>stdio.h</td>
<td>Standard buffered input/output.</td>
</tr>
<tr>
<td>stdlib.h</td>
<td>Standard library definitions.</td>
</tr>
<tr>
<td>string.h</td>
<td>String operations.</td>
</tr>
<tr>
<td>strings.h</td>
<td>String operations.</td>
</tr>
<tr>
<td>stropts.h</td>
<td>STREAMS interface (STREAMS).</td>
</tr>
<tr>
<td>sys/ipc.h</td>
<td>Inter-process communication (IPC).</td>
</tr>
<tr>
<td>sys/mman.h</td>
<td>POSIX memory management declarations.</td>
</tr>
<tr>
<td>sys/msg.h</td>
<td>POSIX message queues.</td>
</tr>
<tr>
<td>sys/resource.h</td>
<td>Definitions for XSI resource operations.</td>
</tr>
<tr>
<td>sys/select.h</td>
<td>Select types.</td>
</tr>
<tr>
<td>sys/sem.h</td>
<td>POSIX semaphores.</td>
</tr>
<tr>
<td>sys/shm.h</td>
<td>XSI shared memory facility.</td>
</tr>
<tr>
<td>sys/socket.h</td>
<td>Main sockets header.</td>
</tr>
<tr>
<td>sys/stat.h</td>
<td>File information (stat et al.).</td>
</tr>
<tr>
<td>sys/statvfs.h</td>
<td>VFS File System information structure.</td>
</tr>
<tr>
<td>sys/time.h</td>
<td>Time and date functions and structures.</td>
</tr>
<tr>
<td>sys/times.h</td>
<td>File access and modification times structure.</td>
</tr>
<tr>
<td>sys/types.h</td>
<td>Various data types used elsewhere.</td>
</tr>
<tr>
<td>sys/un.h</td>
<td>Definitions for UNIX domain sockets.</td>
</tr>
<tr>
<td>sys/utsname.h</td>
<td>uname and related structures.</td>
</tr>
<tr>
<td>sys/wait.h</td>
<td>Status of terminated child processes.</td>
</tr>
</tbody>
</table>
### 39.2 References

- Official List of headers in the POSIX library on opengroup.org
- Lists headers in the POSIX library
- Description of the posix library from the Flux OSKit

### 39.3 Bibliography

- POSIX.4 Programmers Guide: Programming for the Real World

---

4. [oreilly.com/catalog/9781565920743/](http://oreilly.com/catalog/9781565920743/)
40 C Compilers Reference List

For a brief introduction to setting up and using some of the more beginner-friendly compilers and IDEs, see ./Using a Compiler/1.

40.1 Free (or with a free version)

- Ch_interpreter2 (http://www.softintegration.com) - The software works in Windows, Linux, Mac OS X, Freebsd, Solaris, AIX and HP-UX. The Ch Standard Edition is free for non-commercial use.
- Interactive C3 (http://www.botball.org/educational-resources/ic.php).
  - target platform: Handy Board (Freescale 68HC11); Lego RCX
  - CINT4 is an interpreter for C and C++ code, included in the data-analysis package ROOT5. The CINT interpreter is licensed under the X11/MIT license. (https://root.cern.ch/drupal/content/cint).
  - PicoC6
  - Extensible Interactive C (EiC)7
- GNU Compiler Collection9 (http://gcc.gnu.org) - GNU Compiler Collection. GNU General Public License / GNU Lesser General Public License.
  - MinGW10 (http://www.mingw.org/) provides GCC for Windows
  - clang (LLVM)11 (http://clang.llvm.org/) - Almost everywhere but Windows
- Open Watcom12 (http://www.openwatcom.org) Open Source development community to maintain and enhance the Watcom C/C++ and Fortran cross compilers and tools. Version 1.4 released in December 2005.
  - Host Platforms: Win32 systems (IDE and command line), 32-bit OS/2 (IDE and command line), DOS (command line), and Windows 3.x (IDE)

---
2 https://en.wikipedia.org/wiki/Ch_interpreter
3 https://en.wikipedia.org/wiki/Interactive%20C
4 https://en.wikipedia.org/wiki/CINT
5 https://en.wikibooks.org/wiki/ROOT
6 https://github.com/zsaleeba/picoc
7 http://sourceforge.net/projects/eic/
9 https://en.wikipedia.org/wiki/GNU%20Compiler%20Collection
10 https://en.wikipedia.org/wiki/MinGW
- **Target Platforms:** DOS (16-bit), Windows 3.x (16-bit), OS/2 1.x (16-bit), Extended DOS, Win32s, Windows 95/98/Me, Windows NT/2000/XP, 32-bit OS/2, and Novell NLMS
- **Experimental / Development:** Linux, BSD, *nix, PowerPC, Alpha AXP, MIPS, and Sparc v8
- Tiny C Compiler\(^\text{13}\)
- Portable C Compiler\(^\text{14}\) (http://pcc.ludd.ltu.se) - Portable C Compiler. BSD Style License(s).
- Small Device C Compiler\(^\text{15}\) (SDCC)
  - target platforms: Intel 8051-compatibles; Freescale (Motorola) HC08; Microchip PIC16 and PIC18.
- FpgaC\(^\text{16}\). Target platform: FPGA hardware via XNF or VHDL files.
- C compilers for many digital signal processors (DSPs), many of them are free, and are listed in the comp.dsp FAQ\(^\text{17}\).
- Microsoft Visual C++\(^\text{18}\) (http://msdn.microsoft.com/visualc) - Free (partially limited) version available (Express edition)

### 40.2 Paid

- Impulse C\(^\text{20}\) - Target platform: FPGA hardware via Hardware Description Language (HDL) files.

---

13 https://en.wikipedia.org/wiki/TinyCCompiler
14 https://en.wikipedia.org/wiki/PortableCCompiler
16 https://en.wikipedia.org/wiki/FpgaC
17 http://www.bdti.com/faq/3.htm
20 https://en.wikipedia.org/wiki/ImpulseC
# 41 Contributors

<table>
<thead>
<tr>
<th>Edits</th>
<th>User</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0x7c001</td>
</tr>
<tr>
<td>1</td>
<td>16@r2</td>
</tr>
<tr>
<td>2</td>
<td>2nth0nyj~enwikibooks3</td>
</tr>
<tr>
<td>1</td>
<td>78.264</td>
</tr>
<tr>
<td>26</td>
<td>A thing5</td>
</tr>
<tr>
<td>1</td>
<td>A-Day6</td>
</tr>
<tr>
<td>8</td>
<td>A3mm7</td>
</tr>
<tr>
<td>1</td>
<td>AB7 rule8</td>
</tr>
<tr>
<td>1</td>
<td>Aatryon9</td>
</tr>
<tr>
<td>1</td>
<td>Ab8uu10</td>
</tr>
<tr>
<td>2</td>
<td>Abdull11</td>
</tr>
<tr>
<td>1</td>
<td>Ablonus12</td>
</tr>
<tr>
<td>13</td>
<td>Adam majewski13</td>
</tr>
<tr>
<td>1</td>
<td>AdamPro14</td>
</tr>
<tr>
<td>13</td>
<td>Adrignola15</td>
</tr>
<tr>
<td>1</td>
<td>Aentity16</td>
</tr>
<tr>
<td>1</td>
<td>Ah3kal17</td>
</tr>
<tr>
<td>1</td>
<td>Ahoeerstemeier18</td>
</tr>
<tr>
<td>3</td>
<td>Akaberto19</td>
</tr>
<tr>
<td>1</td>
<td>Akihabara20</td>
</tr>
</tbody>
</table>

1. [https://en.wikibooks.org/w/index.php?title=User:0x7c00&action=edit&redlink=1](https://en.wikibooks.org/w/index.php?title=User:0x7c00&action=edit&redlink=1)
2. [https://en.wikibooks.org/wiki/User:16@r](https://en.wikibooks.org/wiki/User:16@r)
Contributors

6 Akilaa
5 AlbertCahalan
6 Albmont
1 AlistairMcMillan
2 Alka\nissi\non
3 AllenZh
1 Alsocal
1 Alvin-cs
2 Amine Brikci N
1 Amskidraven
1 Andkore
4 Andrew Eugene
1 Animajosser
1 Arbitrarily0
1 Armandd
1 Arvindn~enwikibooks
1 Aseidl
1 Ashwini2008
1 AsphyxiateDrake
40 Astone42
1 Asymmetric
4 Atcold
2 Atcovi
1 Athantor

33 https://en.wikibooks.org/wiki/User:Arbitrarily0
44
7 Avicennasis
1 AvinashMeetoo
1 Axle07
4 Az1568
2 BIL
1 BL
1 BOTarate
1 Basie
1 Belteshazzar
3 Bevo
1 Billinghurst
9 BimBot
2 Binksternet
1 BioTube
1 Blanchardb
1 Bluemoose~enwikibooks
1 Bobo192
1 Bogdangiusca
1 Bpringlemeir
5 British0zzy
1 Bts1911
1 Buggi22
1 B~enwikibooks
1 C. A. Russell
1 CCFS

64 https://en.wikibooks.org/w/index.php?title=User:British0zzy&action=edit&redlink=1
2 Davidam~enwikibooks
1 Decltype
5 Deepakwgp
2 Deepthawtz
4 Dehomas
1 Der Künstler
13 Derbeth
1 Deryck Chan
1 Dethomas~enwikibooks
8 Dirk Hänniger
2 Doodle77
1 Doshell
1 DouglasGreen~enwikibooks
1 Dr.alf
2 Duplode
2 Dwandelt
50 Dysprosia~enwikibooks
1 Echoray
22 EdC
1 Edudobay
1 Elonka
1 Elturo
1 Elwood j blues
8 Emperorbma

https://en.wikibooks.org/wiki/User:Dr.alf&action=edit&redlink=1
Contributors

1 Eneville
5 Eric119
1 Erkan Yilmaz
2 Ervinn
1 Esquivalience
1 Eumolpo
4 Explorer09
1 Eyalevin
1 FUNIX
1 Fahidka
1 Fayis um
2 Fazalca ~enwikibooks
3 Fdarkangel
1 Feb30th1712 ~enwikibooks
3 Felipebm
1 Fernando2812l
35 Fernandopabon
1 Filemon
10 Fishpi
1 Fopam
1 Fotuenti ~enwikibooks
10 Fresheneesz ~enwikibooks
1 Frigotoni
2 Fusion ~enwikibooks

118 https://en.wikibooks.org/w/index.php%3ftitle=User:Eneville&action=edit&redlink=1
125 https://en.wikibooks.org/w/index.php%3ftitle=User:Eyalevin&action=edit&redlink=1
126 https://en.wikibooks.org/w/index.php%3ftitle=User:FUNIX&action=edit&redlink=1
128 https://en.wikibooks.org/w/index.php%3ftitle=User:Fayis_um&action=edit&redlink=1
130 https://en.wikibooks.org/w/index.php%3ftitle=User:Fdarkangel&action=edit&redlink=1
133 https://en.wikibooks.org/w/index.php%3ftitle=User:Fernando2812l&action=edit&redlink=1
137 https://en.wikibooks.org/w/index.php%3ftitle=User:Fopam&action=edit&redlink=1
139 https://en.wikibooks.org/w/index.php%3ftitle=User:Fresheneesz ~enwikibooks&action=edit&redlink=1
141 https://en.wikibooks.org/w/index.php%3ftitle=User:Fusion ~enwikibooks&action=edit&redlink=1
1 Fuumo
2 Fuxx
3 Fxxk14i
4 Gabim
5 Gandhisagar
6 Garo~enwikibooks
7 Garrett oreilly
8 Gavodel
9 Ge9580
10 GeorgeBarnick
11 Giftlite
12 Glenn~enwikibooks
13 Gon1332
14 Gpietsch
15 Gpietsch~enwikibooks
16 Graue
17 Gsonnenf
18 Guanabot~enwikibooks
19 Gulmammad
20 Gwern
21 Hagindaz
22 HakanIST
23 Hakkla
24 Happaballer12~enwikibooks

Contributors

1 Harp166
3 Hassanibraheem167
1 Henrywizard168
3 Herbythyme169
1 HethrirBot170
1 Hijarian171
1 Hongooi172
6 Hoxel~enwikibooks173
2 Hypergeek14174
4 Hythem1979175
7 I0sisir~enwikibooks176
1 Icewedge177
3 Imran~enwikibooks178
3 Ingcake179
41 Intermediate-Hacker180
5 InverseHypercube181
1 Iopq182
1 Istirbu183
2 Ivan Pozdeev184
2 Ixtli185
2 J.delanoy186
1 JAnDbot187
49 JackPotte188
1 Jafeluv189
1 Jakec190

11 James Dennett
1 Jayadevp13
26 Jfmantis
1 Jfreyre "enwikibooks
4 Jguk
2 Jianhui67
1 Jianhui68
1 Jimbobob "enwikibooks
3 Jjdicharry
1 Jleedev
1 Jni
2 JohnOwens
23 Jomegat
1 Jorgenev
1 Josephpiche
1 Jsherman256 "enwikibooks
1 Jwmcmanus
1 Jwricks
1 Kane77 "enwikibooks
1 Karl Dickman
1 Kayau
1 Kazabubu
1 Ke6jjj

197 https://en.wikibooks.org/wiki/User:Jianhui68
201 https://en.wikibooks.org/wiki/User:Jni
<table>
<thead>
<tr>
<th>Rank</th>
<th>User</th>
<th>Contributions</th>
</tr>
</thead>
<tbody>
<tr>
<td>23</td>
<td>Kevinpaladin</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>Keytotime</td>
<td>21</td>
</tr>
<tr>
<td>1</td>
<td>Kiensvay</td>
<td>217</td>
</tr>
<tr>
<td>2</td>
<td>Kinglag</td>
<td>218</td>
</tr>
<tr>
<td>1</td>
<td>Kj</td>
<td>219</td>
</tr>
<tr>
<td>1</td>
<td>Kjoehass</td>
<td>220</td>
</tr>
<tr>
<td>18</td>
<td>Kpengboy</td>
<td>221</td>
</tr>
<tr>
<td>36</td>
<td>Krischik</td>
<td>222</td>
</tr>
<tr>
<td>1</td>
<td>Ks-M9</td>
<td>223</td>
</tr>
<tr>
<td>2</td>
<td>Latios</td>
<td>224</td>
</tr>
<tr>
<td>2</td>
<td>Leaderboard</td>
<td>225</td>
</tr>
<tr>
<td>2</td>
<td>Liam987</td>
<td>226</td>
</tr>
<tr>
<td>3</td>
<td>Lincher</td>
<td>227</td>
</tr>
<tr>
<td>1</td>
<td>Lkesteloot</td>
<td>228</td>
</tr>
<tr>
<td>1</td>
<td>Loadmaster</td>
<td>229</td>
</tr>
<tr>
<td>3</td>
<td>Logictheo</td>
<td>230</td>
</tr>
<tr>
<td>4</td>
<td>LucaBertoni</td>
<td>231</td>
</tr>
<tr>
<td>1</td>
<td>Luckas-bot</td>
<td>232</td>
</tr>
<tr>
<td>1</td>
<td>Lupin</td>
<td>233</td>
</tr>
<tr>
<td>2</td>
<td>Lyetz</td>
<td>234</td>
</tr>
<tr>
<td>1</td>
<td>Lynx7725</td>
<td>235</td>
</tr>
<tr>
<td>8</td>
<td>M2s87</td>
<td>236</td>
</tr>
<tr>
<td>1</td>
<td>MF-Warburg</td>
<td>237</td>
</tr>
<tr>
<td>1</td>
<td>Ma.mazmaz</td>
<td>238</td>
</tr>
<tr>
<td>5</td>
<td>MadCowpoke</td>
<td>239</td>
</tr>
</tbody>
</table>

[216](https://en.wikibooks.org/wiki/User:Keytotime)
[217](https://en.wikibooks.org/wiki/User:Kiensvay)
[218](https://en.wikibooks.org/wiki/User:Kinglag)
[219](https://en.wikibooks.org/wiki/User:Kj)
[222](https://en.wikibooks.org/wiki/User:Krischik)
[223](https://en.wikibooks.org/wiki/User:Ks-M9)
[225](https://en.wikibooks.org/wiki/User:Leaderboard)
[226](https://en.wikibooks.org/wiki/User:Liam987)
[227](https://en.wikibooks.org/wiki/User:Lincher)
[233](https://en.wikibooks.org/wiki/User:Lupin)
[235](https://en.wikibooks.org/wiki/User:Lynx7725)
[236](https://en.wikibooks.org/wiki/User:M2s87)
[239](https://en.wikibooks.org/wiki/User:MadCowpoke)
4 Maffblaster240
51 Maffu241
1 Mahanga242
1 Malcolma243
1 ManiacK244
1 ManuelGR245
2 Marianocecowski246
1 Markhobley247
1 Martinkuney248
1 Martyn Lovell249
4 Matillo250
1 Mattb12885251
1 Mattflaschen252
1 Mdhowe~enwikibooks253
3 Memoria254
1 Mecanismo255
1 Mechsoft256
8 Merrheim257
2 Mfidelis258
10 Michael9422259
8 Mickraus260
3 Mike.lifeguard261
6 Mike92591~enwikibooks262
6 Mikeblas263
2 Mindmatrix264

Contributors

1 MithrandirAgain
1 Miyoko Moua
1 Mkgreene
5 Mmine10
3 Monobi
1 Morte
2 Mortense
1 Mr.Z-man
1 MrJones ~enwikibooks
4 Mrquick
1 Mshonle
1 Musiphil
1 Mwtoews
2 Myxomatosis ~enwikibooks
2 Naderra
3 Napalm Llama
2 Nashirj
1 Nastoshka
8 Ncmathsadist
1 Neb 401
9 Nefthy
1 Nelsonkam
1 Newagelink
1 Newmanbe
1 Nick

1 Nijdam
1 Nilson Cain
1 Nimur
2 NithinBekal
1 Nixphoeni
1 Nnh (usurped)
10 Noogz
1 OMouse
2 Offlaw
2 Old Wolf
1 Oligomous
1 Olspookishmagus
1 Onion Bull
1 Orangedog
202 Orderud
1 OriginalHotrodder
2 Otus
2 Ovidiu b13
1 PGIbbons
18 Paddu
1 Panchoy
41 Panic2k4
1 Parleybaerformayor
6 Patrickdepinguin

Contributors

19 Pcu123456789
1 Pedram.salehpoo
35 Pelzflorian
3 PhilippWeissenbacher~enwikibooks
9 Phosgram
2 Pi zero
4 Pickfire
3 Pietrodin
1 Piw0066
1 Pratik deshpande
1 Pred
6 PurplePieman
3 QUBot
1 Queeg (usurped)
28 QuiteUnusual
8 Qwerky
2 RJDGadit
4 RSchomburg
1 RadiX
1 Ralmin
3 Ralmoritz
3 Ram epigon
1 Rama mahesh
1 Raoni Domingues

316 https://en.wikibooks.org/w/index.php%3ftitle=User:Pelzflorian&action=edit&redlink=1
320 https://en.wikibooks.org/w/index.php%3ftitle=User:Pickfire&action=edit&redlink=1
322 https://en.wikibooks.org/w/index.php%3ftitle=User:Piw0066&action=edit&redlink=1
334 https://en.wikibooks.org/w/index.php%3ftitle=User:Ralmoritz&action=edit&redlink=1
335 https://en.wikibooks.org/w/index.php%3ftitle=User:Rama_mahesh&action=edit&redlink=1

270
1 RaphaelQS
2 Rathgemz
2 Raylier~enwikibooks
1 Recent Runes
2 RedWolf
1 Redlentil
7 Reep
2 Reinderien
2 ReiniUrban
15 Remi0o
1 Rich Farmbrough
1 Richfife
1 Riffraffselbow
5 RodrigoBaroni
2 RogierBrussee
1 Ronark
2 RotLink
2 Rouslan Nabioullin~enwikibooks
1 Rschen7754
4 RustyBSD
2 Ruud Koot
3 Ryanlitton
1 SPat
1 SakJur
347 https://en.wikibooks.org/wiki/User:Remi0o
Contributors

1 Santoshsy~enwikibooks
1 Sarimura
1 Saughmraat~enwikibooks
2 Savh
1 Schzmo
2 Sfliberal
1 Shadow.seeker
2 Shotwell
1 Sietse Snel
97 Sigma
1 Signedlongint
1 Sigterm~enwikibooks
1 SimonP
1 SkyLeo
4 SmackBot
2 Snipsnap
1 Snowolf
2 Someoneinmyheadbutit'snotme
1 Somercet
3 SoniyaR
1 Soumyash
1 Sourcejedi
1 SpaceLem~enwikibooks
9 Spoon

2 Sprink386
4 Spundun387
2 SssSss388
1 Stassats389
1 Steven jones390
137 Strange quark391
1 Stryn392
2 Suruena393
1 Sutekh destroyer394
1 SvartMan395
2 Syum90396
10 Tados397
5 TakuyaMurata398
3 Tang0delta399
1 Tardis400
1 Tedickey401
1 TelecomNut402
2 Thiagol403
1 ThoBe~enwikibooks404
33 Thunderbunny~enwikibooks405
1 TimR406
1 Toussaint407
1 Trasz408
1 Ttv~enwikibooks409
3 V-a-xvi410

Contributors

1  Vadmium
3  Vinodkrishnan91
1  VitoFrancisco
3  Vsoro00
1  Wagnerok
4  Webaware
35 Whiteknight
4  Whizzer
4  Whym
1  WikiHead
2  WikiPeterD
1  Wikidemon
1  Wik~enwikibooks
2  Wj32
1  Wragge
5  Xania
1  Xerol
1  Xiainx
1  Xianwen Chen
1  Xuhdev
16 Yacht
4  Yuuki Mayuki~enwikibooks
1  Zoohouse
1  Zvn

434
1 Александр Цамутали
3 XXXXX robot
List of Figures

- cc-by-sa-3.0: Creative Commons Attribution ShareAlike 3.0 License.  http://creativecommons.org/licenses/by-sa/3.0/
- cc-by-sa-2.5: Creative Commons Attribution ShareAlike 2.5 License.  http://creativecommons.org/licenses/by-sa/2.5/
- cc-by-sa-2.0: Creative Commons Attribution ShareAlike 2.0 License.  http://creativecommons.org/licenses/by-sa/2.0/
- cc-by-sa-1.0: Creative Commons Attribution ShareAlike 1.0 License.  http://creativecommons.org/licenses/by-sa/1.0/
- cc-by-2.0: Creative Commons Attribution 2.0 License.  http://creativecommons.org/licenses/by/2.0/
- cc-by-2.0: Creative Commons Attribution 2.0 License.  http://creativecommons.org/licenses/by/2.0/deed.en
- cc-by-2.5: Creative Commons Attribution 2.5 License.  http://creativecommons.org/licenses/by/2.5/deed.en
- cc-by-3.0: Creative Commons Attribution 3.0 License.  http://creativecommons.org/licenses/by/3.0/deed.en
- PD: This image is in the public domain.
- ATTR: The copyright holder of this file allows anyone to use it for any purpose, provided that the copyright holder is properly attributed. Redistribution, derivative work, commercial use, and all other use is permitted.
- EURO: This is the common (reverse) face of a euro coin. The copyright on the design of the common face of the euro coins belongs to the European Commission. Authorised is reproduction in a format without relief (drawings, paintings, films) provided they are not detrimental to the image of the euro.
- CFR: Copyright free use.

Copies of the GPL, the LGPL as well as a GFDL are included in chapter Licenses\textsuperscript{437}. Please note that images in the public domain do not require attribution. You may click on the image numbers in the following table to open the webpage of the images in your webbrowser.

\textsuperscript{437} Chapter 42 on page 281
<table>
<thead>
<tr>
<th></th>
<th>No machine-readable author provided. Jarkko Piirainen assumed (based on copyright claims). No machine-readable author provided. Jarkko Piirainen assumed (based on copyright claims).</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Daniel B (^{440})</td>
</tr>
<tr>
<td>3</td>
<td>Pietrodn</td>
</tr>
</tbody>
</table>

The "Corresponding Source" for a work in object code form means all the source code for the object code, and specifically means all of the source code for all of the nonpermissible functions and data items modified or created during the production of the object code by the program. The specific requirements for "Corresponding Source" correspond to the program specified in paragraph one of this License. The Corresponding Source for a work in object code form must be made available under the terms of Paragraph 4.b, the requirement to preserve the Corresponding Source from the object code, and must include all the notices stated in paragraph 4.a, including those regarding availability and other terms specified by you for subsequent modification by others. You must make available a "work based on the Corresponding Source" under this License, in object code or source code form, as appropriate, exactly as you received it and as published by the copyright holder; only as part of a whole aggregate work, and only under that license. The Corresponding Source for a work in object code form shall be made available under the terms of Paragraph 4.b, the requirement to preserve the Corresponding Source from the object code, and must include all the notices stated in paragraph 4.a, including those regarding availability and other terms specified by you for subsequent modification by others. You must make available a "work based on the Corresponding Source" under this License, in object code or source code form, as appropriate, exactly as you received it and as published by the copyright holder; only as part of a whole aggregate work, and only under that license. The Corresponding Source for a work in object code form shall be made available under the terms of Paragraph 4.b, the requirement to preserve the Corresponding Source from the object code, and must include all the notices stated in paragraph 4.a, including those regarding availability and other terms specified by you for subsequent modification by others. You must make available a "work based on the Corresponding Source" under this License, in object code or source code form, as appropriate, exactly as you received it and as published by the copyright holder; only as part of a whole aggregate work, and only under that license.

The "Corresponding Source" for a work in object code form means all the source code for the object code, and specifically means all of the source code for all of the nonpermissible functions and data items modified or created during the production of the object code by the program. The specific requirements for "Corresponding Source" correspond to the program specified in paragraph one of this License. The Corresponding Source for a work in object code form must be made available under the terms of Paragraph 4.b, the requirement to preserve the Corresponding Source from the object code, and must include all the notices stated in paragraph 4.a, including those regarding availability and other terms specified by you for subsequent modification by others. You must make available a "work based on the Corresponding Source" under this License, in object code or source code form, as appropriate, exactly as you received it and as published by the copyright holder; only as part of a whole aggregate work, and only under that license. The Corresponding Source for a work in object code form shall be made available under the terms of Paragraph 4.b, the requirement to preserve the Corresponding Source from the object code, and must include all the notices stated in paragraph 4.a, including those regarding availability and other terms specified by you for subsequent modification by others. You must make available a "work based on the Corresponding Source" under this License, in object code or source code form, as appropriate, exactly as you received it and as published by the copyright holder; only as part of a whole aggregate work, and only under that license.

The "Corresponding Source" for a work in object code form means all the source code for the object code, and specifically means all of the source code for all of the nonpermissible functions and data items modified or created during the production of the object code by the program. The specific requirements for "Corresponding Source" correspond to the program specified in paragraph one of this License. The Corresponding Source for a work in object code form must be made available under the terms of Paragraph 4.b, the requirement to preserve the Corresponding Source from the object code, and must include all the notices stated in paragraph 4.a, including those regarding availability and other terms specified by you for subsequent modification by others. You must make available a "work based on the Corresponding Source" under this License, in object code or source code form, as appropriate, exactly as you received it and as published by the copyright holder; only as part of a whole aggregate work, and only under that license.

The "Corresponding Source" for a work in object code form means all the source code for the object code, and specifically means all of the source code for all of the nonpermissible functions and data items modified or created during the production of the object code by the program. The specific requirements for "Corresponding Source" correspond to the program specified in paragraph one of this License. The Corresponding Source for a work in object code form must be made available under the terms of Paragraph 4.b, the requirement to preserve the Corresponding Source from the object code, and must include all the notices stated in paragraph 4.a, including those regarding availability and other terms specified by you for subsequent modification by others. You must make available a "work based on the Corresponding Source" under this License, in object code or source code form, as appropriate, exactly as you received it and as published by the copyright holder; only as part of a whole aggregate work, and only under that license.

The "Corresponding Source" for a work in object code form means all the source code for the object code, and specifically means all of the source code for all of the nonpermissible functions and data items modified or created during the production of the object code by the program. The specific requirements for "Corresponding Source" correspond to the program specified in paragraph one of this License. The Corresponding Source for a work in object code form must be made available under the terms of Paragraph 4.b, the requirement to preserve the Corresponding Source from the object code, and must include all the notices stated in paragraph 4.a, including those regarding availability and other terms specified by you for subsequent modification by others. You must make available a "work based on the Corresponding Source" under this License, in object code or source code form, as appropriate, exactly as you received it and as published by the copyright holder; only as part of a whole aggregate work, and only under that license.
A section "Entitled XYZ" means a named subunit of the Document which does not have any title page as such, "TitlePage" means the text XML for which the DTD and/or processing tools are not generally transparent if used for any substantial amount of text. A copy or absence of markup, has been arranged to thwart or discourage modifications made by others.

The purpose of this License is to make a manual, textbook, or other work, in any medium, freely available to all users beyond what the individual works permit. The rights under this License are defined generally to include all interactions that would normally be considered copyright infringement under copyright law.

A "Secondary Section" is a named appendix or a front-matter section contributed by an entity other than the principal author of the Document.

A "Third Party" is a publisher, distributor, electronic content provider, or other entity that provides a service or facility for which the use of the Work is not normally considered to be associated with the exercise of copyright.

Include an unaltered copy of this License. You may also add a section Entitled "Endorsements" in which you review the importance of adopting the free software license.

Your license from a particular copyright holder is reinstated if the new license is identical to this License, if the new license is the first version of this License to incorporate the original public license statements of the work (or the first version of this License released under the License), or if you have a valid written statement of the copyright holder giving you a copy of the License, and if the new licenseifting the notice that says that no other terms, including no royalty-free conditions, apply to the combination. Such a notice may be included in the copyright notice or copyright disclaimer in the license or by means other than copyright notice or copyright disclaimer as the owner of the rear-cover text, or if it has no rear-cover text. However, you may add a coverTexts, you must insert it immediately after (or replace an existing one), or if it has noTitlePage, as authors, one or more persons or entities responsible for creating the Document.

A "Third Party" is a publisher, distributor, electronic content provider, or other entity that provides a service or facility for which the use of the Work is not normally considered to be associated with the exercise of copyright.

The Free Software Foundation may publish new, revised versions of the GNU Free Documentation License from time to time. Such new versions will be similar in spirit to the present version, but may differ in detail to address new problems or concerns.

A "Transparency" is a notice similar to the "Transparency" section, except that the notice is not a TransparenText notice, and instead is a notice similar to that given in section 4 of this License. If a document is included in an aggregate, this License does not apply to the other documents in the aggregate.

These new versions are covered by the GNU Free Documentation License in the same way as is section 3.0 from the Creative Commons Project.

You may not copy, modify, sublicense, or distribute this work unless you first obtain the required permission and other than those terms and this License would be to refrain entirely from making changes.

The Free Software Foundation may publish new, revised versions of the GNU Free Documentation License from time to time. Such new versions will be similar in spirit to the present version, but may differ in detail to address new problems or concerns.

A "Transparency" is a notice similar to the "Transparency" section, except that the notice is not a TransparenText notice, and instead is a notice similar to that given in section 4 of this License. If a document is included in an aggregate, this License does not apply to the other documents in the aggregate.

These new versions are covered by the GNU Free Documentation License in the same way as is section 3.0 from the Creative Commons Project.

You may not copy, modify, sublicense, or distribute this work unless you first obtain the required permission and other than those terms and this License would be to refrain entirely from making changes.

The Free Software Foundation may publish new, revised versions of the GNU Free Documentation License from time to time. Such new versions will be similar in spirit to the present version, but may differ in detail to address new problems or concerns.

A "Transparency" is a notice similar to the "Transparency" section, except that the notice is not a TransparenText notice, and instead is a notice similar to that given in section 4 of this License. If a document is included in an aggregate, this License does not apply to the other documents in the aggregate.

These new versions are covered by the GNU Free Documentation License in the same way as is section 3.0 from the Creative Commons Project.

You may not copy, modify, sublicense, or distribute this work unless you first obtain the required permission and other than those terms and this License would be to refrain entirely from making changes.

The Free Software Foundation may publish new, revised versions of the GNU Free Documentation License from time to time. Such new versions will be similar in spirit to the present version, but may differ in detail to address new problems or concerns.

You may convey a Combined Work under terms of your choice that, taken together, effectively do not restrict modification of the portions of the Library contained in the Combined Work and are consistent with Section 6 of the GNU GPL. You may convey corresponding source code under terms of your choice that are consistent with Section 6 of the GNU GPL.


You may place library facilities that are a work based on the Library side by side in a single library together with other library facilities that are not Applications and are not covered by this License, and convey such a work under terms of your choice, if you do both of the following:

a) Accompany the combined library with a read of the same work based on the Library, uncombined with any other library facilities, uncombined under the terms of this License. b) Give prominent notice to the end user that this Library is available under this License, and explain how to obtain a copy of this License by reasonable means.

6. Revised Versions of the GNU Lesser General Public License.

The Free Software Foundation may publish revised and/or new versions of the GNU Lesser General Public License from time to time. Each version is given a distinguishing version number. If the Library as you received it does not specify a version number, then the version of the GNU Lesser General Public License without a license notice directing the user to the copies of the GNU GPL and this license document. If the Library as you received it specifies that it is unpublished version or of any later version published by the Free Software Foundation. Each new version is published with the expectation that it will be used by certain users as a library in a personal home work environment, and such users will want to modify the library to fit their needs. Therefore, each new version contains certain "Additional Definitions" that, it is supposed, will be used to make the Library more compatible with other libraries.

The "Corresponding Application Code" for a Combined Work means the object code and/or source code for the Application, including any data and utility programs needed for reproducing the Combined Work from the Application, but excluding the System Libraries of the Combined Work.

The "Corresponding Source" for the Combined Work, in the manner specified by section 6 of the GNU GPL.

The "Corresponding Source Code" for a Combined Work means the object code and/or source code for the Application, including any data and utility programs needed for reproducing the Combined Work from the Application, but excluding any source code for the System Libraries of the Combined Work.

The "Corresponding Source" for the Combined Work, in the manner specified by section 6 of the GNU GPL.

The "Minimal Corresponding Source" for a Combined Work means the object code and/or source code for the Application, including any data and utility programs needed for reproducing the Combined Work from the Application, but excluding any source code for the System Libraries of the Combined Work.

The "Corresponding Source Code" for a Combined Work means the object code and/or source code for the Application, including any data and utility programs needed for reproducing the Combined Work from the Application, but excluding the System Libraries of the Combined Work.

The "Corresponding Source Code" for a Combined Work means the object code and/or source code for the Application, including any data and utility programs needed for reproducing the Combined Work from the Application, but excluding any source code for the System Libraries of the Combined Work.