ARM® Compiler toolchain v4.1 for µVision

Using ARM® C and C++ Libraries and Floating-Point Support
Release Information

The following changes have been made to this book.

<table>
<thead>
<tr>
<th>Date</th>
<th>Issue</th>
<th>Confidentiality</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>May 2007</td>
<td>A</td>
<td>Non-Confidential</td>
<td>Release for RVCT v3.1 for µVision</td>
</tr>
<tr>
<td>December 2008</td>
<td>B</td>
<td>Non-Confidential</td>
<td>Release for RVCT v4.0 for µVision</td>
</tr>
<tr>
<td>June 2011</td>
<td>C</td>
<td>Non-Confidential</td>
<td>Release for ARM Compiler toolchain v4.1 for µVision</td>
</tr>
</tbody>
</table>

Proprietary Notice

Words and logos marked with or are registered trademarks or trademarks of ARM in the EU and other countries, except as otherwise stated below in this proprietary notice. Other brands and names mentioned herein may be the trademarks of their respective owners.

Neither the whole nor any part of the information contained in, or the product described in, this document may be adapted or reproduced in any material form except with the prior written permission of the copyright holder.

The product described in this document is subject to continuous developments and improvements. All particulars of the product and its use contained in this document are given by ARM in good faith. However, all warranties implied or expressed, including but not limited to implied warranties of merchantability, or fitness for purpose, are excluded.

This document is intended only to assist the reader in the use of the product. ARM shall not be liable for any loss or damage arising from the use of any information in this document, or any error or omission in such information, or any incorrect use of the product.

Where the term ARM is used it means “ARM or any of its subsidiaries as appropriate”.

Some material in this document is based on IEEE 754 -1985 IEEE Standard for Binary Floating-Point Arithmetic. The IEEE disclaims any responsibility or liability resulting from the placement and use in the described manner.

Confidentiality Status

This document is Non-Confidential. The right to use, copy and disclose this document may be subject to license restrictions in accordance with the terms of the agreement entered into by ARM and the party that ARM delivered this document to.

Product Status

The information in this document is final, that is for a developed product.

Web Address

http://www.arm.com
Contents

ARM Compiler toolchain v4.1 for µVision Using ARM C and C++ Libraries and Floating-Point Support

Chapter 1 Conventions and feedback

Chapter 2 The ARM C and C++ libraries

2.1 Mandatory linkage with the C library ................................................................. 2-5
2.2 C and C++ runtime libraries ................................................................................ 2-6
2.3 C and C++ library features ................................................................................. 2-7
2.4 Library heap usage requirements of the ARM C and C++ libraries ................ 2-8
2.5 Compliance with the Application Binary Interface (ABI) for the ARM architecture ... 2-9
2.6 Increasing portability of object files to other CLIBABI implementations .......... 2-10
2.7 ARM C and C++ library directory structure ...................................................... 2-11
2.8 Selection of ARM C and C++ library variants based on build options .............. 2-12
2.9 Thumb C libraries ................................................................................................ 2-14
2.10 C++ and C libraries and the std namespace .................................................... 2-15
2.11 ARM C libraries and multithreading ................................................................. 2-16
2.12 ARM C libraries and reentrant functions ......................................................... 2-17
2.13 ARM C libraries and thread-safe functions ...................................................... 2-18
2.14 Use of static data in the C libraries ................................................................. 2-19
2.15 Use of the __user_libspace static data area by the C libraries ...................... 2-21
2.16 C library functions to access subsections of the __user_libspace static data area 2-22
2.17 Re-implementation of legacy function __user_libspace() in the C library ........ 2-23
2.18 Management of locks in multithreaded applications .................................... 2-24
2.19 How to ensure re-implemented mutex functions are called ......................... 2-26
2.20 Using the ARM C library in a multithreaded environment ............................. 2-27
2.21 Thread safety in the ARM C library ............................................................... 2-29
2.22 Thread safety in the ARM C++ library .......................................................... 2-30
2.23 The floating-point status word in a multithreaded environment .................. 2-32
2.24 Using the C library with an application ......................................................... 2-33
2.25 Using the C and C++ libraries with an application in a semihosting environment ............................ 2-34
2.26 Using $Sub$$ to mix semihosted and nonsemihosted I/O functionality ....................................... 2-35
2.27 Using the libraries in a nonsemihosting environment ........................................................................... 2-36
2.28 C++ exceptions in a non-semihosting environment ............................................................................. 2-37
2.29 Direct semihosting C library function dependencies ........................................................................... 2-38
2.30 Indirect semihosting C library function dependencies ........................................................................ 2-39
2.31 C library API definitions for targeting a different environment ......................................................... 2-40
2.32 Building an application without the C library .................................................................................. 2-41
2.33 Creating an application as bare machine C without the C library ..................................................... 2-44
2.34 Integer and floating-point compiler functions and building an application without the C library ........ 2-45
2.35 Bare machine integer C ...................................................................................................................... 2-46
2.36 Bare machine C with floating-point processing .................................................................................. 2-47
2.37 Customized C library startup code and access to C library functions ............................................. 2-48
2.38 Program design when exploiting the C library .................................................................................... 2-49
2.39 Using low-level functions when exploiting the C library .................................................................... 2-50
2.40 Using high-level functions when exploiting the C library ................................................................... 2-51
2.41 Using malloc() when exploiting the C library .................................................................................... 2-52
2.42 Tailoring the C library to a new execution environment ....................................................................... 2-53
2.43 How C and C++ programs use the library functions ......................................................................... 2-54
2.44 Initialization of the execution environment and execution of the application ................................... 2-55
2.45 C++ initialization, construction and destruction .................................................................................. 2-56
2.46 Legacy support for C$$pi$$ctorvec instead of .init_array ................................................................. 2-58
2.47 Exceptions system initialization ............................................................................................................ 2-59
2.48 Emergency buffer memory for exceptions ......................................................................................... 2-60
2.49 Library functions called from main() ............................................................................................... 2-61
2.50 Program exit and the assert macro ....................................................................................................... 2-62
2.51 Assembler macros that tailor locale functions in the C library .......................................................... 2-63
2.52 Link time selection of the locale subsystem in the C library ............................................................. 2-64
2.53 ISO8859-1 implementation .................................................................................................................. 2-65
2.54 Shift-JIS and UTF-8 implementation .................................................................................................... 2-66
2.55 Runtime selection of the locale subsystem in the C library ............................................................... 2-67
2.56 Definition of locale data blocks in the C library .................................................................................. 2-68
2.57 LC_CTYPE data block ........................................................................................................................ 2-71
2.58 LC_COLLATE data block ...................................................................................................................... 2-74
2.59 LC_MONETARY data block .................................................................................................................. 2-76
2.60 LC_NUMERIC data block .................................................................................................................... 2-77
2.61 LC_TIME data block ........................................................................................................................... 2-78
2.62 Modification of C library functions for error signaling, error handling, and program exit .............. 2-80
2.63 Modification of memory management functions in the C library ...................................................... 2-81
2.64 Avoiding the heap and heap-using library functions supplied by ARM ........................................ 2-82
2.65 C library support for memory allocation functions ............................................................................... 2-83
2.66 Heap1, standard heap implementation ............................................................................................... 2-84
2.67 Heap2, alternative heap implementation ............................................................................................. 2-85
2.68 Using a heap implementation from bare machine C .......................................................................... 2-86
2.69 Stack pointer initialization and heap bounds ........................................................................................ 2-87
2.70 Defining __initial_sp, __heap_base and __heap_limit ..................................................................... 2-89
2.71 Extending heap size at runtime ........................................................................................................... 2-90
2.72 Legacy support for __user_initial_stackheap() .................................................................................... 2-91
2.73 Tailoring input/output functions in the C and C++ libraries ............................................................. 2-92
2.74 Target dependencies on low-level functions in the C and C++ libraries .......................................... 2-93
2.75 The C library printf family of functions ............................................................................................ 2-95
2.76 The C library scanf family of functions ............................................................................................. 2-96
2.77 Redefining low-level library functions to enable direct use of high-level library functions ............... 2-97
2.78 The C library functions fread(), fgets() and gets() ........................................................................... 2-100
2.79 Re-implementing __backspace() in the C library .............................................................................. 2-101
2.80 Re-implementing __backspacew() in the C library ............................................................................ 2-102
2.81 Target-dependent I/O support functions in the C library ..................................................................... 2-103
Chapter 3 The ARM C micro-library
3.1 About microlib ................................................. 3-2
3.2 Differences between microlib and the default C library ......................... 3-3
3.3 Library heap usage requirements of the ARM C micro-library .................. 3-4
3.4 ISO C features missing from microlib ...................................................... 3-5
3.5 Building an application with microlib ...................................................... 3-7
3.6 Creating an initial stack pointer for use with microlib ............................... 3-8
3.7 Creating the heap for use with microlib .................................................... 3-9
3.8 Entering and exiting programs linked with microlib .................................. 3-10
3.9 Tailoring the microlib input/output functions .......................................... 3-11

Chapter 4 Floating-point support
4.1 About floating-point support ..................................................... 4-3
4.2 The software floating-point library, fplib .............................................. 4-4
4.3 Calling fplib routines .......................................................... 4-5
4.4 fplib arithmetic on numbers in a particular format ................................. 4-6
4.5 fplib conversions between floats, doubles, and ints ............................... 4-8
4.6 fplib conversion between longs, floats, and doubles ............................. 4-9
4.7 fplib comparisons between floats and doubles ...................................... 4-10
4.8 fplib C99 functions ...................................................................... 4-12
4.9 Controlling the ARM floating-point environment .................................. 4-13
4.10 Floating-point functions for compatibility with Microsoft products .......... 4-14
4.11 C99-compatible functions for controlling the ARM floating-point environment .... 4-15
4.12 C99 rounding mode and floating-point exception macros .................... 4-16
4.13 Exception flag handling .......................................................... 4-17
4.14 Functions for handling rounding modes .............................................. 4-18
4.15 Functions for saving and restoring the whole floating-point environment ... 4-19
4.16 Functions for temporarily disabling exceptions .................................... 4-20
4.17 ARM floating-point compiler extensions to the C99 interface ............... 4-21
4.18 Writing a custom exception trap handler ............................................. 4-22
4.19 Example of a custom exception handler ............................................. 4-26
4.20 Exception trap handling by signals ...................................................... 4-28
4.21 Using C99 signalling NaNs provided by mathlib (_WANT_SNAN) ............ 4-29
4.22 mathlib double and single-precision floating-point functions ................ 4-30
4.23 Nonstandard functions in mathlib ...................................................... 4-31
4.24 IEEE 754 arithmetic ............................................................... 4-32
4.25 Basic data types for IEEE 754 arithmetic .......................................... 4-33
4.26 Single precision data type for IEEE 754 arithmetic ............................... 4-34
4.27 Double precision data type for IEEE 754 arithmetic ............................ 4-36
4.28 Sample single precision floating-point values for IEEE 754 arithmetic .... 4-37
4.29 Sample double precision floating-point values for IEEE 754 arithmetic .... 4-39
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.30</td>
<td>IEEE 754 arithmetic and rounding</td>
<td>4-41</td>
</tr>
<tr>
<td>4.31</td>
<td>Exceptions arising from IEEE 754 floating-point arithmetic</td>
<td>4-42</td>
</tr>
<tr>
<td>4.32</td>
<td>Ignoring exceptions from IEEE 754 floating-point arithmetic operations</td>
<td>4-43</td>
</tr>
<tr>
<td>4.33</td>
<td>Trapping exceptions from IEEE 754 floating-point arithmetic operations</td>
<td>4-44</td>
</tr>
<tr>
<td>4.34</td>
<td>Exception types recognized by the ARM floating-point environment</td>
<td>4-45</td>
</tr>
<tr>
<td>4.35</td>
<td>Using the Vector Floating-Point (VFP) support libraries</td>
<td>4-47</td>
</tr>
</tbody>
</table>
Chapter 1
Conventions and feedback

The following describes the typographical conventions and how to give feedback:

**Typographical conventions**

The following typographical conventions are used:

- **monospace** Denotes text that can be entered at the keyboard, such as commands, file and program names, and source code.

- **monospace** Denotes a permitted abbreviation for a command or option. The underlined text can be entered instead of the full command or option name.

- **monospace italic** Denotes arguments to commands and functions where the argument is to be replaced by a specific value.

- **monospace bold** Denotes language keywords when used outside example code.

- **italic** Highlights important notes, introduces special terminology, denotes internal cross-references, and citations.

- **bold** Highlights interface elements, such as menu names. Also used for emphasis in descriptive lists, where appropriate, and for ARM® processor signal names.

**Feedback on this product**

If you have any comments and suggestions about this product, contact your supplier and give:

- your name and company
• the serial number of the product
• details of the release you are using
• details of the platform you are using, such as the hardware platform, operating system type and version
• a small standalone sample of code that reproduces the problem
• a clear explanation of what you expected to happen, and what actually happened
• the commands you used, including any command-line options
• sample output illustrating the problem
• the version string of the tools, including the version number and build numbers.

Feedback on documentation
If you have comments on the documentation, e-mail errata@arm.com. Give:
• the title
• the number, ARM DUI 0378C
• if viewing online, the topic names to which your comments apply
• if viewing a PDF version of a document, the page numbers to which your comments apply
• a concise explanation of your comments.

ARM also welcomes general suggestions for additions and improvements.

ARM periodically provides updates and corrections to its documentation on the ARM Information Center, together with knowledge articles and Frequently Asked Questions (FAQs).

Other information
Chapter 2
The ARM C and C++ libraries

The following topics describe the ARM C and C++ libraries:

- Mandatory linkage with the C library on page 2-5
- C and C++ runtime libraries on page 2-6
- C and C++ library features on page 2-7
- Library heap usage requirements of the ARM C and C++ libraries on page 2-8
- Compliance with the Application Binary Interface (ABI) for the ARM architecture on page 2-9
- Increasing portability of object files to other CLIBABI implementations on page 2-10
- ARM C and C++ library directory structure on page 2-11
- Selection of ARM C and C++ library variants based on build options on page 2-12
- Thumb C libraries on page 2-14
- C++ and C libraries and the std namespace on page 2-15
- ARM C libraries and multithreading on page 2-16
- ARM C libraries and reentrant functions on page 2-17
- ARM C libraries and thread-safe functions on page 2-18
- Use of static data in the C libraries on page 2-19
- Use of the __user_libspace static data area by the C libraries on page 2-21
- C library functions to access subsections of the __user_libspace static data area on page 2-22
- Re-implementation of legacy function __user_libspace() in the C library on page 2-23
- Management of locks in multithreaded applications on page 2-24
- How to ensure re-implemented mutex functions are called on page 2-26
- Using the ARM C library in a multithreaded environment on page 2-27
- Thread safety in the ARM C library on page 2-29
- Thread safety in the ARM C++ library on page 2-30
- The floating-point status word in a multithreaded environment on page 2-32
- Using the C library with an application on page 2-33
- Using the C library with an application on page 2-33
- Using the C and C++ libraries with an application in a semihosting environment on page 2-34
- Using $Sub$$ to mix semihosted and nonsemihosted I/O functionality on page 2-35
- Using the libraries in a nonsemihosting environment on page 2-36
- C++ exceptions in a non-semihosting environment on page 2-37
- Direct semihosting C library function dependencies on page 2-38
- Indirect semihosting C library function dependencies on page 2-39
- C library API definitions for targeting a different environment on page 2-40
- Building an application without the C library on page 2-41
- Creating an application as bare machine C without the C library on page 2-44
- Integer and floating-point compiler functions and building an application without the C library on page 2-45
- Bare machine integer C on page 2-46
- Bare machine C with floating-point processing on page 2-47
- Customized C library startup code and access to C library functions on page 2-48
- Program design when exploiting the C library on page 2-49
- Using low-level functions when exploiting the C library on page 2-50
- Using high-level functions when exploiting the C library on page 2-51
- Using malloc() when exploiting the C library on page 2-52
- Tailoring the C library to a new execution environment on page 2-53
- How C and C++ programs use the library functions on page 2-54
- Initialization of the execution environment and execution of the application on page 2-55
- C++ initialization, construction and destruction on page 2-56
- Legacy support for C$$pi_ctorvec instead of .init_array on page 2-58
• Exceptions system initialization on page 2-59
• Emergency buffer memory for exceptions on page 2-60
• Library functions called from main() on page 2-61
• Program exit and the assert macro on page 2-62
• Assembler macros that tailor locale functions in the C library on page 2-63
• Link time selection of the locale subsystem in the C library on page 2-64
• ISO8859-1 implementation on page 2-65
• Shift-JIS and UTF-8 implementation on page 2-66
• Runtime selection of the locale subsystem in the C library on page 2-67
• Definition of locale data blocks in the C library on page 2-68
  • LC_CTYPE data block on page 2-71
  • LC_COLLATE data block on page 2-74
  • LC_MONETARY data block on page 2-76
  • LC_NUMERIC data block on page 2-77
  • LC_TIME data block on page 2-78
• Modification of C library functions for error signaling, error handling, and program exit on page 2-80
• Modification of memory management functions in the C library on page 2-81
• Avoiding the heap and heap-using library functions supplied by ARM on page 2-82
• C library support for memory allocation functions on page 2-83
  • Heap1, standard heap implementation on page 2-84
  • Heap2, alternative heap implementation on page 2-85
• Using a heap implementation from bare machine C on page 2-86
• Stack pointer initialization and heap bounds on page 2-87
• Defining __initial_sp, __heap_base and __heap_limit on page 2-89
• Extending heap size at runtime on page 2-90
• Legacy support for __user_initial_stackheap() on page 2-91
• Tailoring input/output functions in the C and C++ libraries on page 2-92
• Target dependencies on low-level functions in the C and C++ libraries on page 2-93
• The C library printf family of functions on page 2-95
• The C library scanf family of functions on page 2-96
• Redefining low-level library functions to enable direct use of high-level library functions on page 2-97
• The C library functions fread(), fgets() and gets() on page 2-100
• Re-implementing __backspace() in the C library on page 2-101
• Re-implementing __backspacewc() in the C library on page 2-102
• Target-dependent I/O support functions in the C library on page 2-103
• Tailoring non-input/output C library functions on page 2-104
• Real-time integer division in the ARM libraries on page 2-105
• Selecting real-time division in the ARM libraries on page 2-106
• How the ARM C library fulfills ISO C specification requirements on page 2-107
• mathlib error handling on page 2-108
• ISO-compliant implementation of signals supported by the signal() function in the C library and additional type arguments on page 2-110
• ISO-compliant C library input/output characteristics on page 2-112
• Standard C++ library implementation definition on page 2-114
• C library functions and extensions on page 2-115
• Persistence of C and C++ library names across releases of the ARM compilation tools on page 2-116
• Link time selection of C and C++ libraries on page 2-117
• Managing projects that have explicit C or C++ library names in makefiles on page 2-118
• Compiler generated and library-resident helper functions on page 2-119
• C and C++ library naming conventions on page 2-120
• Using macro __ARM_WCHAR_NO_IO to disable FILE declaration and wide I/O function prototypes on page 2-122.
2.1 Mandatory linkage with the C library

If you write an application in C, you must link it with the C library, even if it makes no direct use of C library functions. This is because the compiler might implicitly generate calls to C library functions to improve your application, even though calls to such functions might not exist in your source code.

Even if your application does not have a `main()` function, meaning that the C library is not initialized, some C library functions are still legitimately available and the compiler might implicitly generate calls to these functions.

2.1.1 See also

Concepts
- Building an application without the C library on page 2-41.
2.2 C and C++ runtime libraries

The following ARM runtime libraries are provided to support compiled C and C++:

C standardlib

This is a C library consisting of:

- All functions defined by the ISO C99 library standard.
- Target-dependent functions used to implement the C library functions in the semihosted execution environment. You can redefine these functions in your own application.
- Functions called implicitly by the compiler.
- ARM extensions that are not defined by the ISO C library standard, but are included in the library.

C microlib

This is a C library that can be used as an alternative to C standardlib. It is a micro-library that is ideally suited for deeply embedded applications that have to fit within small-sized memory. The C micro-library, microlib, consists of:

- Functions that are highly optimized to achieve the minimum code size.
- Functions that are not compliant with the ISO C library standard.
- Functions that are not compliant with the 1985 IEEE 754 standard for binary floating-point arithmetic.

C++

This is a C++ library that can be used with C standardlib. It consists of:

- functions defined by the ISO C++ library standard
- the Rogue Wave Standard C++ library
- additional C++ functions not supported by the Rogue Wave library
- functions called implicitly by the compiler.

The C++ libraries depend on the C library for target-specific support. There are no target dependencies in the C++ libraries.

2.2.1 See also

Concepts

- Mandatory linkage with the C library on page 2-5
- Chapter 2 The ARM C and C++ libraries
- Chapter 3 The ARM C micro-library.

Other information

2.3 C and C++ library features

The C library uses the standard ARM semihosted environment to provide facilities such as file input/output. This environment is supported by the ARM RVI™ debug unit and the Real-Time Simulator Model (RTSM).

You can re-implement any of the target-dependent functions of the C library as part of your application. This enables you to tailor the C library and, therefore, the C++ library, to your own execution environment.

You can also tailor many of the target-independent functions to your own application-specific requirements. For example:

• the malloc family
• the ctype family
• all the locale-specific functions.

Many of the C library functions are independent of any other function and contain no target dependencies. You can easily exploit these functions from assembler code.

Functions in the C library are responsible for:

• Creating an environment in which a C or C++ program can execute. This includes:
  — creating a stack
  — creating a heap, if required
  — initializing the parts of the library the program uses.

• Starting execution by calling main().

• Supporting use of ISO-defined functions by the program.

• Catching runtime errors and signals and, if required, terminating execution on error or program exit.
2.4 Library heap usage requirements of the ARM C and C++ libraries

Functions such as `malloc()` and other dynamic memory allocation functions explicitly allocate memory when used. However, some library functions and mechanisms implicitly allocate memory from the heap. If heap usage requirements are significant to your code development (for example, you might be developing code for an embedded system with a tiny memory footprint), you must be aware of both implicit and explicit heap requirements.

In C standardlib, implicit heap usage occurs as a result of:

- calling the library function `fopen()` and the first time that an I/O operation is applied to the resulting stream
- passing command-line arguments into the `main()` function.

The size of heap memory allocated for `fopen()` is 80 bytes for the `FILE` structure. When the first I/O operation occurs, and not until the operation occurs, an additional default of 512 bytes of heap memory is allocated for a buffer associated with the operation. You can reconfigure the size of this buffer using `setvbuf()`.

When `fclose()` is called, the default 80 bytes of memory is kept on a freelist for possible re-use. The 512-byte buffer is freed on `fclose()`.

Declaring `main()` to take arguments requires 256 bytes of implicitly allocated memory from the heap. This memory is never freed because it is required for the duration of `main()`. In microlib, `main()` must not be declared to take arguments, so this heap usage requirement only applies to standardlib. In the standardlib context, it only applies if you have a heap.

Note

The memory sizes quoted might change in future releases.

2.4.1 See also

- Library heap usage requirements of the ARM C micro-library on page 3-4
- Modification of memory management functions in the C library on page 2-81.
2.5 Compliance with the Application Binary Interface (ABI) for the ARM architecture

The ABI for the ARM Architecture is a family of specifications that describe the processor-specific aspects of the translation of a source program into object files. Object files produced by any toolchain that conforms to the relevant aspects of the ABI can be linked together to produce a final executable image or library.

Each document in the specification covers a specific area of compatibility. For example, the C Library ABI for the ARM Architecture (CLIBABI) describes the parts of the C library that are expected to be common to all conforming implementations.

The ABI documents contain several areas that are marked as platform specific. To define a complete execution environment these platform-specific details have to be provided. This gives rise to a number of supplemental specifications.

The Base Standard ABI for the ARM Architecture (BSABI) enables you to use ARM, Thumb, and Thumb-2 objects and libraries from different producers that support the ABI for the ARM Architecture. The ARM compilation tools fully support the BSABI, including support for Debug With Arbitrary Record Format (DWARF) 3 debug tables (DWARF Debugging Standard Version 3).

The ARM C and C++ libraries conform to the standards described in the BSABI, the CLIBABI, and the C++ ABI (CPPABI) for the ARM Architecture.

2.5.1 See also

Concepts
• Increasing portability of object files to other CLIBABI implementations on page 2-10.

Other information
• DWARF Debugging Standard, http://dwarfs.org/
2.6 Increasing portability of object files to other CLIBABI implementations

You can request full CLIBABI portability to increase the portability of your object files to other implementations of the CLIBABI. To do this, either:

- specify `#define _AEABI_PORTABILITY_LEVEL 1` before you `#include` any library headers, such as `<stdlib.h>`
- specify `-D_AEABI_PORTABILITY_LEVEL=1` on the compiler command line.

**Note**
This reduces the performance of some library operations.

2.6.1 See also

Concepts

- Compliance with the Application Binary Interface (ABI) for the ARM architecture on page 2-9.

Reference

*Compiler Reference:*

- `-Dname[parm-list][=def]` on page 3-22.

Other information

2.7 ARM C and C++ library directory structure

The libraries are installed in subdirectories of the lib directory:

```
armlib  Contains the variants of the ARM C library, the floating-point arithmetic library (fplib), and the math library (mathlib).

cpllib  Contains the variants of the Rogue Wave C++ library (cpp_*) and supporting ARM C++ functions (cpprt_*), referred to collectively as the ARM C++ Libraries.
```

The accompanying header files for these libraries are installed in the inc directory.

The environment variable ARMCCnnLIB must be set to point to the lib directory, or if this variable is not set, ARMLIB. Alternatively, use the --libpath argument to the linker to identify the directory holding the library subdirectories. You must not identify the armlib and cpllib directories separately because this directory structure might change in future releases. The linker finds them from the location of lib.

--- Note ---

- The ARM C libraries are supplied in binary form only.
- The ARM libraries must not be modified. If you want to create a new implementation of a library function, place the new function in an object file, or your own library, and include it when you link the application. Your version of the function is used instead of the standard library version.
- Normally, only a few functions in the ISO C library require re-implementation to create a target-dependent application.
- The source for the Rogue Wave Standard C++ Library is not freely distributable. It can be obtained from Rogue Wave Software Inc., or through ARM, for an additional license fee.
2.8 Selection of ARM C and C++ library variants based on build options

When you build your application, you must make certain choices. For example:

Target Architecture and instruction set
ARM, Thumb®*, or Thumb-2.

Byte order Big-endian or little-endian.

Floating-point support
Software (SoftVFP), hardware (VFP), software or hardware with half-precision or double-precision extensions, or no floating-point support.

Position independence
Different ways to access your data are as follows:
• by absolute address
• relative to sb (read/write position-independent)
• relative to pc (fpic).

Different ways to access your code are as follows:
• by absolute address when appropriate
• relative to pc (read-only position independent).

The standard C libraries provide variants to support all of these options.

Position-independent C++ code can only be achieved with --apcs=fpic.

Note
Position independence is not supported in microlib.

When you link your assembler code, C or C++ code, the linker selects appropriate C and C++ library variants compatible with the build options you specified. There is a variant of the ISO C library for each combination of major build options.

2.8.1 See also

Tasks
Creating Static Software Libraries with armar:
• Creating a new object library on page 3-2.

Concepts
Using the Compiler:
• Code compatibility between separately compiled and assembled modules on page 3-21.

Reference
Compiler Reference:
• --apcs=qualifer...qualifier on page 3-7
• --arm on page 3-11
• --bigend on page 3-14
• --fpu=name on page 3-44
• --littleend on page 3-61
• --thumb on page 3-90.

Linker Reference:
• --fpu=name on page 2-57
• --ropi on page 2-105
• --rwpi on page 2-108.

Assembler Reference:
• --arm on page 2-6
• --bigend on page 2-6
• --fpu=name on page 2-13
• --littleend on page 2-16
• --thumb on page 2-23.
2.9 Thumb C libraries

The linker automatically links in the Thumb C library if it detects that one or more of the objects to be linked have been built for:

- Thumb or Thumb-2, either using the `--thumb` option or `#pragma thumb`
- interworking, using the `--apcs /interwork` option on architecture ARMv4T
- an ARMv6-M architecture target or processor, for example, Cortex-M1 or Cortex-M0
- an ARMv7-M architecture target or processor, for example, Cortex-M3.

Despite its name, the Thumb C library might not contain exclusively Thumb code. If ARM instructions are available, the Thumb library might use them to improve the performance of critical functions such as `memcpy()`, `memset()`, and `memclr()`. The bulk of the Thumb C library, however, is coded in Thumb for the best code density.

For an ARM instruction-only build, compile with the `--arm_only` option.

___ Note ___
The Thumb C library used for ARMv6-M targets contains only Thumb-1 code.

The Thumb C library used for ARMv7-M targets contains only Thumb-2 code.

2.9.1 See also

Concepts
- Chapter 2 The ARM C and C++ libraries.

Reference

Compiler Reference:
- `--arm_only` on page 3-11
- `--thumb` on page 3-90
- `#pragma thumb` on page 5-60.

Other information
2.10 C++ and C libraries and the std namespace

All C++ standard library names, including the C library names, if you include them, are defined in the namespace std using the following C++ syntax:

```cpp
#include <cstdlib> // instead of stdlib.h
```

This means that you must qualify all the library names using one of the following methods:

- specify the standard namespace, for example:
  ```cpp
  std::printf("example\n");
  ```
- use the C++ keyword `using` to import a name to the global namespace:
  ```cpp
  using namespace std;
  printf("example\n");
  ```
- use the compiler option `--using_std`.

**Note**

Note that `errno` is a macro, so it is not necessary to qualify it with a namespace.

### 2.10.1 See also

**Reference**

Compiler Reference:

- `--using_std, --no_using_std` on page 3-94.
2.11 ARM C libraries and multithreading

The ARM C libraries support multithreading, for example, where you are using a Real-Time Operating System (RTOS). In this context, the following definitions are used:

**Threads**  Mean multiple streams of execution sharing global data between them.

**Process**  Means a collection of all the threads that share a particular set of global data.

If there are multiple processes on a machine, they can be entirely separate and do not share any data (except under unusual circumstances). Each process might be a single-threaded process or might be divided into multiple threads.

Where you have single-threaded processes, there is only one flow of control. In multithreaded applications, however, several flows of control might try to access the same functions, and the same resources, concurrently. To protect the integrity of resources, any code you write for multithreaded applications must be reentrant and thread-safe.

Reentrancy and thread safety are both related to the way functions in a multithreaded application handle resources.

2.11.1 See also

**Concepts**

- ARM C libraries and reentrant functions on page 2-17
- ARM C libraries and thread-safe functions on page 2-18
- Using the ARM C library in a multithreaded environment on page 2-27.
2.12 ARM C libraries and reentrant functions

A reentrant function does not hold static data over successive calls, and does not return a pointer to static data. For this type of function, the caller provides all the data that the function requires, such as pointers to any workspace. This means that multiple concurrent invocations of the function do not interfere with each other.

Note

A reentrant function must not call non-reentrant functions.

2.12.1 See also

Concepts

• ARM C libraries and multithreading on page 2-16
• ARM C libraries and thread-safe functions on page 2-18.
2.13 ARM C libraries and thread-safe functions

A thread-safe function protects shared resources from concurrent access using locks. Thread safety concerns only how a function is implemented and not its external interface. In C, local variables are held in processor registers, or if the compiler runs out of registers, are dynamically allocated on the stack. Therefore, any function that does not use static data, or other shared resources, is thread-safe.

2.13.1 See also

Tasks

- *Management of locks in multithreaded applications* on page 2-24
- *Using the ARM C library in a multithreaded environment* on page 2-27.

Concepts

- *ARM C libraries and multithreading* on page 2-16
- *ARM C libraries and reentrant functions* on page 2-17
- *Management of locks in multithreaded applications* on page 2-24
- *Thread safety in the ARM C library* on page 2-29
- *Thread safety in the ARM C++ library* on page 2-30.
2.14 Use of static data in the C libraries

Static data refers to persistent read/write data that is not stored on the stack or the heap. This persistent data can be external or internal in scope, and is:

- at a fixed address, when compiled with --apcs /norwpi
- at a fixed address relative to the static base, register r9, when compiled with --apcs /rwpi.

Libraries that use static data might be reentrant, but this depends on their use of the __user_libspace static data area, and on the build options you choose:

- When compiled with --apcs /norwpi, read/write static data is addressed in a position-dependent fashion. This is the default. Code from these variants is single-threaded because it uses read/write static data.
- When compiled with --apcs /rwpi, read/write static data is addressed in a position-independent fashion using offsets from the static base register sb. Code from these variants is reentrant and can be multithreaded if each thread uses a different static base value.

The following describes how the C libraries use static data:

- The default floating-point arithmetic libraries fz_* and fj_* do not use static data and are always reentrant. However, the f_* and g_* libraries do use static data.
- All statically-initialized data in the C libraries is read-only.
- All writable static data is zero initialized.
- Most C library functions use no writable static data and are reentrant whether built with default build options, --apcs /norwpi or reentrant build options, --apcs /rwpi.
- Some functions have static data implicit in their definitions. You must not use these in a reentrant application unless you build it with --apcs /rwpi and the callers use different values in sb.

Note

Exactly which functions use static data in their definitions might change in future releases.

Callouts from the C library enable access to static data. C library functions that use static data can be categorized as:

- functions that do not use any static data of any kind, for example fprintf()
- functions that manage a static state, such as malloc(), rand(), and strtok()
- functions that do not manage a static state, but use static data in a way that is specific to the implementation in the ARM compiler, for example isalpha().
When the C library does something that requires implicit static data, it uses a callout to a function you can replace. These functions are shown in Table 2-1. They do not use semihosting.

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>__rt_errno_addr()</td>
<td>Called to get the address of the variable errno.</td>
</tr>
<tr>
<td>__rt_fp_status_addr()</td>
<td>Called by the floating-point support code to get the address of the floating-point status word.</td>
</tr>
<tr>
<td>locale functions</td>
<td>The function __user_libspace() creates a block of private static data for the library.</td>
</tr>
</tbody>
</table>

The default implementation of __user_libspace creates a 96-byte block in the ZI region. Even if your application does not have a main() function, the __user_libspace() function does not normally have to be redefined.

Note: Exactly which functions use static data in their definitions might change in future releases.

### 2.14.1 See also

**Concepts**
- Re-implementation of legacy function __user_libspace() in the C library on page 2-23.

**Using the Compiler:**
- Code compatibility between separately compiled and assembled modules on page 3-21.

**Reference**
- Assembler macros that tailor locale functions in the C library on page 2-63
- ARM C libraries and multithreading on page 2-16.

**Compiler Reference:**
- --apcs=qualifer...qualifer on page 3-7.

**ARM® C and C++ Libraries and Floating-Point Support Reference:**
- __rt_errno_addr() on page 2-29
- __rt_fp_status_addr() on page 2-31.
2.15 Use of the __user_libspace static data area by the C libraries

The __user_libspace static data area holds the static data for the C libraries. This is a block of 96 bytes of zero-initialized data, supplied by the C library. It is also used as a temporary stack during C library initialization.

The default ARM C libraries use the __user_libspace area to hold:

- `errno`, used by any function that is capable of setting `errno`. By default, `__rt_errno_addr()` returns a pointer to `errno`.
- The Floating-Point (FP) status word for software floating-point (exception flags, rounding mode). It is unused in hardware floating-point. By default, `__rt_fp_status_addr()` returns a pointer to the FP status word.
- A pointer to the base of the heap (that is, the __Heap_Descriptor), used by all the malloc-related functions.
- The current locale settings, used by functions such as `setlocale()`, but also used by all other library functions that depend on them. For example, the `ctype.h` functions have to access the LC_CTYPE setting.

The C++ libraries use the __user_libspace area to hold:

- the `new_handler` field and `ddtor_pointer`:
  - the `new_handler` field is used to keep track of the value passed to `std::set_new_handler()`.
  - the `ddtor_pointer`, that points to a list of destructions to be performed on program exit. For example, objects constructed outside function scope exist for the duration of the program, but require destruction on program exit. The `ddtor_pointer` is used by `__cxa_atexit()` and `__aeabi_atexit()`.
- C++ exception handling information for functions such as `std::set_terminate()` and `std::set_unexpected()`.

Note

How the C and C++ libraries use the __user_libspace area might change in future releases.

2.15.1 See also

Other information:

2.16 C library functions to access subsections of the __user_libspace static data area

Two wrapper functions are provided to return a subsection of the __user_libspace static data area:

__user_perproc_libspace()

Returns a pointer to 96 bytes used to store data that is global to an entire process. This data is shared between all threads.

__user_perthread_libspace()

Returns a pointer to 96 bytes used to store data that is local to a particular thread. This means that __user_perthread_libspace() returns a different address depending on the thread it is called from.

2.16.1 See also

Concepts

• Use of the __user_libspace static data area by the C libraries on page 2-21
• Re-implementation of legacy function __user_libspace() in the C library on page 2-23.
2.17 Re-implementation of legacy function __user_libspace() in the C library

The __user_libspace() function returns a pointer to a block of private static data for the C library. This function does not normally have to be redefined.

If you are writing an operating system or a process switcher, then typically you use the __user_perproc_libspace() and __user_perthread_libspace() functions (which are always available) rather than re-implment __user_libspace().

If you have legacy source code that re-implements __user_libspace(), you do not have to change the re-implementation for single-threaded processes. However, you are likely to be required to do so for multi-threaded applications. For multi-threaded applications, use either or both of __user_perproc_libspace() and __user_perthread_libspace(), instead of __user_libspace().

2.17.1 See also

Concepts

- C library functions to access subsections of the __user_libspace static data area on page 2-22
- Using the ARM C library in a multithreaded environment on page 2-27
- Use of the __user_libspace static data area by the C libraries on page 2-21
- Use of static data in the C libraries on page 2-19.
2.18 Management of locks in multithreaded applications

A thread-safe function protects shared resources from concurrent access using locks. There are functions in the C library that you can re-implement, that enable you to manage the locking mechanisms and so prevent the corruption of shared data such as the heap. These functions are mutex functions, where the lifecycle of a mutex is one of initialization, iterative acquisition and releasing of the mutex as required, and then optionally freeing the mutex when it is never going to be required again. The mutex functions wrap onto your own Real-Time Operating System (RTOS) calls, and their function prototypes are:

*_mutex_initialize_*

    int _mutex_initialize(mutex *m);

This function accepts a pointer to a 32-bit word and initializes it as a valid mutex. By default, _mutex_initialize_* returns zero for a nonthreaded application. Therefore, in a multithreaded application, _mutex_initialize_* must return a nonzero value on success so that at runtime, the library knows that it is being used in a multithreaded environment.

Ensure that _mutex_initialize_* initializes the mutex to an unlocked state.

This function must be supplied if you are using mutexes.

*_mutex_acquire_*

    void _mutex_acquire(mutex *m);

This function causes the calling thread to obtain a lock on the supplied mutex. 

*_mutex_acquire_* returns immediately if the mutex has no owner. If the mutex is owned by another thread, _mutex_acquire_* must block it until it becomes available.

*_mutex_acquire_* is not called by the thread that already owns the mutex.

This function must be supplied if you are using mutexes.

*_mutex_release_*

    void _mutex_release(mutex *m);

This function causes the calling thread to release the lock on a mutex acquired by _mutex_acquire_*.

The mutex remains in existence, and can be re-locked by a subsequent call to _mutex_acquire_*.

*_mutex_release_* assumes that the mutex is owned by the calling thread.

This function must be supplied if you are using mutexes.

*_mutex_free_*

    void _mutex_free(mutex *m);

This function causes the calling thread to free the supplied mutex. Any operating system resources associated with the mutex are freed. The mutex is destroyed and cannot be reused.

*_mutex_free_* assumes that the mutex is owned by the calling thread.

This function is optional. If you do not supply this function, the C library does not attempt to call it.

The mutex data structure type that is used as the parameter to the _mutex_* functions is not defined in any of the ARM compiler toolchain header files, but must be defined elsewhere. Typically, it is defined as part of RTOS code.
Functions that call _mutex_*() functions create 4 bytes of memory for holding the mutex data structure. __Heap_Initialize() is one such function.

For the C library, a mutex is specified as a single 32-bit word of memory that can be placed anywhere. However, if your mutex implementation requires more space than this, or demands that the mutex be in a special memory area, then you must treat the default mutex as a pointer to a real mutex.

A typical example of a re-implementation framework for _mutex_initialize(), _mutex_acquire(), and _mutex_release() is as follows, where SEMAPHORE_ID, CreateLock(), AcquireLock(), and ReleaseLock() are defined in the RTOS, and (...) implies additional parameters:

```c
int _mutex_initialize(SEMAPHORE_ID sid)
{
    /* Create a mutex semaphore */
    sid = CreateLock(...);
    return 1;
}
void _mutex_acquire(SEMAPHORE_ID sid)
{
    /* Task sleep until get semaphore */
    AcquireLock(sid, ...);
}
void _mutex_release(SEMAPHORE_ID sid)
{
    /* Release the semaphore. */
    ReleaseLock(sid);
}
void _mutex_free(SEMAPHORE_ID sid)
{
    /* Free the semaphore. */
    FreeLock(sid, ...);
}
```

Note
• _mutex_release() releases the lock on the mutex that was acquired by _mutex_acquire(), but the mutex still exists, and can be re-locked by a subsequent call to _mutex_acquire().

• It is only when the optional wrapper function _mutex_free() is called that the mutex is destroyed. After the mutex is destroyed, it cannot be used without first calling _mutex_initialize() to set it up again.

2.18.1 See also

Tasks
• How to ensure re-implemented mutex functions are called on page 2-26
• Using the ARM C library in a multithreaded environment on page 2-27.

Concepts
• Thread safety in the ARM C library on page 2-29
• Thread safety in the ARM C++ library on page 2-30.
2.19 How to ensure re-implemented mutex functions are called

If your re-implemented `_mutex_*()` functions are within an object that is contained within a library file, the linker does not automatically include the object. This can result in the `_mutex_*()` functions being excluded from the image you have built. To avoid this problem, that is, to ensure that your `_mutex_*()` functions are called, you can either:

- Place your mutex functions in a non-library object file. This helps to ensure that they are resolved at link time.
- Place your mutex functions in a library object file, and arrange a non-weak reference to something in the object.
- Place your mutex functions in a library object file, and have the linker explicitly extract the specific object from the library on the command line by writing `libraryname.a(objectfilename.o)` when you invoke the linker.

2.19.1 See also

Tasks
- Using the ARM C library in a multithreaded environment on page 2-27.

Concepts
- Management of locks in multithreaded applications on page 2-24
- Thread safety in the ARM C library on page 2-29
- Thread safety in the ARM C++ library on page 2-30.
2.20 Using the ARM C library in a multithreaded environment

To use the ARM C library in a multithreaded environment, you must provide:

- An implementation of __user_perthread_libspace() that returns a different block of memory for each thread. This can be achieved by either:
  - returning a different address depending on the thread it is called from
  - having a single __user_perthread_libspace block at a fixed address and swapping its contents when switching threads.

You can use either approach to suit your environment.

You do not have to re-implement __user_perproc_libspace() unless there is a specific reason to do so. In the majority of cases, there is no requirement to re-implement this function.

- A way to manage multiple stacks.

A simple way to do this is to use the ARM two-region memory model. Using this means that you keep the stack that belongs to the primary thread entirely separate from the heap. Then you must allocate more memory for additional stacks from the heap itself.

- Thread management functions, for example, to create or destroy threads, to handle thread synchronization, and to retrieve exit codes.

  **Note**

The ARM C libraries supply no thread management functions of their own so you must supply any that are required.

- A thread-switching mechanism.

  **Note**

The ARM C libraries supply no thread-switching mechanisms of their own. This is because there are many different ways to do this and the libraries are designed to work with all of them.

You only have to provide implementations of the mutex functions if you require them to be called.

In some applications, the mutex functions might not be useful. For example, a co-operatively threaded program does not have to take steps to ensure data integrity, provided it avoids calling its yield function during a critical section. However, in other types of application, for example where you are implementing preemptive scheduling, or in a Symmetric Multi-Processor (SMP) model, these functions play an important part in handling locks.

If all of these requirements are met, you can use the ARM C library in your multithreaded environment. The following behavior applies:

- some functions work independently in each thread
- some functions automatically use the mutex functions to mediate multiple accesses to a shared resource
- some functions are still nonreentrant so a reentrant equivalent is supplied
- a few functions remain nonreentrant and no alternative is available.
2.20.1 See also

Concepts
- ARM C libraries and multithreading on page 2-16
- Management of locks in multithreaded applications on page 2-24
- Thread safety in the ARM C library on page 2-29
- Thread safety in the ARM C++ library on page 2-30.

Reference
ARM® C and C++ Libraries and Floating-Point Support Reference:
- Thread-safe C library functions on page 2-63
- C library functions that are not thread-safe on page 2-66.
2.21 Thread safety in the ARM C library

In the ARM C library:

- some functions are never thread-safe, for example `setlocale()`
- some functions are inherently thread-safe, for example `memcpy()`
- some functions, such as `malloc()`, can be made thread-safe by implementing the `_mutex_*` functions
- other functions are only thread-safe if you pass the appropriate arguments, for example `tmpnam()`.

Threading problems might occur when your application makes use of the ARM C library in a way that is hidden, for example, if the compiler implicitly calls functions that you have not explicitly called in your source code. Familiarity with the thread-safe C library functions and C library functions that are not thread-safe can help you to avoid this type of threading problem, although in general, it is unlikely to arise.

2.21.1 See also

Tasks
- *Using the ARM C library in a multithreaded environment on page 2-27.*

Concepts
- *Management of locks in multithreaded applications on page 2-24*
- *Thread safety in the ARM C++ library on page 2-30.*

Reference

*ARM® C and C++ Libraries and Floating-Point Support Reference:*
- *Thread-safe C library functions on page 2-63*
- *C library functions that are not thread-safe on page 2-66.*
2.22 Thread safety in the ARM C++ library

The following summarizes thread safety in the C++ library:

- The function `std::set_new_handler()` is not thread-safe. This means that some forms of `::operator new` and `::operator delete` are not thread-safe with respect to `std::set_new_handler()`:
  - The default C++ runtime library implementations of the following use `malloc()` and `free()` and are thread-safe with respect to each other. They are not thread-safe with respect to `std::set_new_handler()`. You are permitted to replace them:
    - `::operator new(std::size_t)`
    - `::operator new[](std::size_t)`
    - `::operator new(std::size_t, const std::nothrow_t&)`
    - `::operator new[](std::size_t, const std::nothrow_t&)`
    - `::operator delete(void*)`
    - `::operator delete[](void*)`
    - `::operator delete(void*, const std::nothrow_t&)`
    - `::operator delete[](void*, const std::nothrow_t&)`
  - The following placement forms are also thread-safe. You are not permitted to replace them:
    - `::operator new(std::size_t, void*)`
    - `::operator new[](std::size_t, void*)`
    - `::operator delete(void*, void*)`
    - `::operator delete[](void*, void*)`

- Construction and destruction of global objects is not thread-safe.

- Construction of local static objects can be made thread-safe if you re-implement the functions `_cxa_guard_acquire()`, `_cxa_guard_release()`, `_cxa_guard_abort()`, `_cxa_atexit()` and `_aeabi_atexit()` appropriately. For example, with appropriate re-implementation, the following construction of `lsobj` can be made thread-safe:
  ```
  struct T { T(); };
  void f() { static T lsobj; }
  ```

- Throwing an exception is thread-safe if any user constructors and destructors that get called are also thread-safe.

- The ARM C++ library uses the ARM C library. To use the ARM C++ library in a multithreaded environment, you must provide the same functions that you would be required to provide when using the ARM C library in a multithreaded environment.

2.22.1 See also

Tasks
- *Using the ARM C library in a multithreaded environment* on page 2-27.

Concepts
- *Management of locks in multithreaded applications* on page 2-24
- *Thread safety in the ARM C library* on page 2-29.

Other information
- `_cxa_*`, `_aeabi_*` functions, C++ ABI for the ARM® Architecture,
• Exception Handling ABI for the ARM® Architecture,
2.23 The floating-point status word in a multithreaded environment

Applicable to variants of the software floating-point libraries that require a status word
(--fpmode=ieee_fixed or --fpmode=ieee_full), the floating-point status word is safe to use in a
multithreaded environment, even with software floating-point. A status word for each thread is
stored in its own __user_perthread_libspace block.

--- Note ---

In a hardware floating-point environment, the floating-point status word is stored in a Vector
Floating-Point (VFP) register. In this case, your thread-switching mechanism must keep a
separate copy of this register for each thread.

2.23.1 See also

Concepts

• Thread safety in the ARM C library on page 2-29.

Reference

• --fpmode=model on page 3-42.
2.24 Using the C library with an application

You can use the C and C++ libraries with an application in the following ways:

- Build a semihosting application that can be debugged in a semihosted environment such as with RVI.
- Build a non-hosted application that, for example, can be embedded into ROM.
- Build an application that does not use main() and does not initialize the library. This application has restricted library functionality, unless you re-implement some functions.

2.24.1 See also

Tasks

- Using the C and C++ libraries with an application in a semihosting environment on page 2-34
- Using the libraries in a nonsemihosting environment on page 2-36
- Building an application without the C library on page 2-41.
2.25 Using the C and C++ libraries with an application in a semihosting environment

If you are developing an application to run in a semihosted environment for debugging, you must have an execution environment that supports ARM or Thumb semihosting, and has sufficient memory.

The execution environment can be provided by either:

• using the standard semihosting functionality that is present by default in, for example, RVI
• implementing your own handler for the semihosting calls.

It is not necessary to write any new functions or include files if you are using the default semihosting functionality of the C and C++ libraries.

The ARM debug agents support semihosting, but the memory map assumed by the C library might require tailoring to match the hardware being debugged.

2.25.1 See also

Concepts
• Using $Sub$$ to mix semihosted and nonsemihosted I/O functionality on page 2-35.

Reference
• Direct semihosting C library function dependencies on page 2-38.
2.26 Using $Sub$$ to mix semihosted and nonsemihosted I/O functionality

You can use $Sub$$ to provide a mixture of semihosted and nonsemihosted functionality. For example, given an implementation of fputc() that writes directly to a UART, and a semihosted implementation of fputc(), you can provide both of these depending on the nature of the FILE * pointer passed into the function.

Example 2-1 Using $Sub$$ to mix semihosting and nonsemihosting I/O functionality

```c
int $Super$$fputc(int c, FILE *fp);
int $Sub$$fputc(int c, FILE *fp) {
  if (fp == (FILE *)MAGIC_NUM) // where MAGIC_NUM is a special value that
    // is different to all normal FILE * pointer
    write_to_UART(c);
    return c;
  else
    return $Super$$fputc(c, fp);
}
```

2.26.1 See also

Tasks
- Using the libraries in a nonsemihosting environment on page 2-36.

Concepts
- Using the C and C++ libraries with an application in a semihosting environment on page 2-34
- Using the libraries in a nonsemihosting environment on page 2-36

Using the Linker:
- Using $Super$$ and $Sub$$ to patch symbol definitions on page 7-28.

Other information
- ELF for the ARM® Architecture,
2.27 Using the libraries in a nonsemihosting environment

Some C library functions use semihosting. If you do not want to use semihosting, either:

• Remove all calls to semihosting functions.
• Re-implement the lower-level functions, for example, fputc(). You are not required to re-implement all semihosting functions. You must, however, re-implement the functions you are using in your application.

(You must re-implement functions that the C library uses to isolate itself from target dependencies. For example, if you use printf() you must re-implement fputc(). If you do not use the higher-level input/output functions like printf(), you do not have to re-implement the lower-level functions like fputc().)
• Implement a handler for all of the semihosting calls to be handled in your own specific way. One such example is for the handler to intercept the calls, redirecting them to your own nonsemihosted, that is, target-specific, functions.

To guarantee that no functions using semihosting are included in your application, use either:

• IMPORT __use_no_semihosting from assembly language
• #pragma import(__use_no_semihosting) from C.

________ Note _______

IMPORT __use_no_semihosting is only required to be added to a single assembly source file. Similarly, #pragma import(__use_no_semihosting) is only required to be added to a single C source file. It is unnecessary to add these inserts to every single source file.

If you include a library function that uses semihosting and also reference __use_no_semihosting, the library detects the conflicting symbols and the linker reports an error. To determine which objects are using semihosting:

1. link with --verbose --list=out.txt
2. search the output for the symbol
3. determine what object referenced it.

There are no target-dependent functions in the C++ library, although some C++ functions use underlying C library functions that are target-dependent.

2.27.1 See also

Concepts
• Mandatory linkage with the C library on page 2-5.

Reference
• Direct semihosting C library function dependencies on page 2-38.

Linker Reference:
• --list=file on page 2-77
• --verbose on page 2-142.
2.28 C++ exceptions in a non-semihosting environment

The default C++ `std::terminate()` handler is required by the C++ Standard to call `abort()`. The default C library implementation of `abort()` uses functions that require semihosting support. Therefore, if you use exceptions in a non-semihosting environment, you must provide an alternative implementation of `abort()`.

2.28.1 See also

Tasks

• Using the libraries in a nonsemihosting environment on page 2-36.
2.29 Direct semihosting C library function dependencies

Table 2-2 shows the functions that depend directly on semihosting.

Table 2-2 Direct semihosting dependencies

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>__user_setup_stackheap()</td>
<td>Sets up and returns the locations of the stack and the heap. You might have to re-implement this function if you are using a scatter file at the link stage.</td>
</tr>
<tr>
<td>_sys_exit()</td>
<td>Error signaling, error handling, and program exit.</td>
</tr>
<tr>
<td>_ttywrch()</td>
<td>Error signaling, error handling, and program exit.</td>
</tr>
<tr>
<td>_sys_command_string()</td>
<td>Tailoring input/output functions in the C and C++ libraries.</td>
</tr>
<tr>
<td>_sys_close()</td>
<td>Tailoring input/output functions in the C and C++ libraries.</td>
</tr>
<tr>
<td>_sys_iserror()</td>
<td>Tailoring input/output functions in the C and C++ libraries.</td>
</tr>
<tr>
<td>_sys_istty()</td>
<td>Tailoring input/output functions in the C and C++ libraries.</td>
</tr>
<tr>
<td>_sys_flen()</td>
<td>Tailoring input/output functions in the C and C++ libraries.</td>
</tr>
<tr>
<td>_sys_open()</td>
<td>Tailoring input/output functions in the C and C++ libraries.</td>
</tr>
<tr>
<td>_sys_read()</td>
<td>Tailoring other C library functions.</td>
</tr>
<tr>
<td>_sys_seek()</td>
<td>Tailoring other C library functions.</td>
</tr>
<tr>
<td>_sys_write()</td>
<td>Tailoring other C library functions.</td>
</tr>
<tr>
<td>_sys_tell()</td>
<td>Tailoring other C library functions.</td>
</tr>
<tr>
<td>clock()</td>
<td>Tailoring other C library functions.</td>
</tr>
<tr>
<td>_clock_init()</td>
<td>Tailoring other C library functions.</td>
</tr>
<tr>
<td>remove()</td>
<td>Tailoring other C library functions.</td>
</tr>
<tr>
<td>rename()</td>
<td>Tailoring other C library functions.</td>
</tr>
<tr>
<td>system()</td>
<td>Tailoring other C library functions.</td>
</tr>
<tr>
<td>time()</td>
<td>Tailoring other C library functions.</td>
</tr>
</tbody>
</table>

2.29.1 See also

Tasks
- *Using the libraries in a nonsemihosting environment* on page 2-36.

Concepts
- *Modification of C library functions for error signaling, error handling, and program exit* on page 2-80
- *Tailoring input/output functions in the C and C++ libraries* on page 2-92
- *Initialization of the execution environment and execution of the application* on page 2-55.

Reference
- *Indirect semihosting C library function dependencies* on page 2-39
- *Tailoring non-input/output C library functions* on page 2-104.

ARM® C and C++ Libraries and Floating-Point Support Reference:
- __user_setup_stackheap() on page 2-60.
2.30 Indirect semihosting C library function dependencies

Table 2-3 shows functions that depend indirectly on one or more of the functions listed in Table 2-2 on page 2-38. You can use Table 2-3 as an initial guide, but it is recommended that you use either of the following to identify any other functions with indirect or direct dependencies on semihosting at link time:

- #pragma import(__use_no_semihosting) in C source code
- IMPORT __use_no_semihosting in assembly language source code.

Table 2-3 Indirect semihosting dependencies

<table>
<thead>
<tr>
<th>Function</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>__raise()</td>
<td>Catching, handling, or diagnosing C library exceptions, without C signal support. (Tailoring error signaling, error handling, and program exit.)</td>
</tr>
<tr>
<td>__default_signal_handler()</td>
<td>Catching, handling, or diagnosing C library exceptions, with C signal support. (Tailoring error signaling, error handling, and program exit.)</td>
</tr>
<tr>
<td>__Heap_Initialize()</td>
<td>Choosing or redefining memory allocation. Avoiding the heap and heap-using C library functions supplied by ARM.</td>
</tr>
<tr>
<td>ferror(), fputc(), __stdout</td>
<td>Re-implementing the printf family. (Tailoring input/output functions in the C and C++ libraries.).</td>
</tr>
<tr>
<td>__backspace(), fgetc(), __stdin</td>
<td>Re-implementing the scanf family. (Tailoring input/output functions in the C and C++ libraries.).</td>
</tr>
<tr>
<td>fwrite(), fputs(), puts(), fread(), fgets(), gets(), ferror()</td>
<td>Re-implementing the stream output family. (Tailoring input/output functions in the C and C++ libraries.).</td>
</tr>
</tbody>
</table>

2.30.1 See also

Tasks
- Using the libraries in a nonsemihosting environment on page 2-36
- Avoiding the heap and heap-using library functions supplied by ARM on page 2-82.

Concepts
- Modification of C library functions for error signaling, error handling, and program exit on page 2-80
- Tailoring input/output functions in the C and C++ libraries on page 2-92.

Reference
- Tailoring non-input/output C library functions on page 2-104.
2.31 C library API definitions for targeting a different environment

In addition to the semihosting functions listed in Table 2-2 on page 2-38 and Table 2-3 on page 2-39, Table 2-4 shows functions and files that might be useful when building for a different environment.

<table>
<thead>
<tr>
<th>File or function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>_main()</td>
<td>Initializes the runtime environment and executes the user application.</td>
</tr>
<tr>
<td>_rt_entry()</td>
<td></td>
</tr>
<tr>
<td>_rt_lib_init(), _rt_exit(), _rt_lib_shutdown()</td>
<td>Initializes or finalizes the runtime library.</td>
</tr>
<tr>
<td>LC_CTYPE locale</td>
<td>Defines the character properties for the local alphabet.</td>
</tr>
<tr>
<td>rt_sys.h</td>
<td>A C header file describing all the functions whose default (semihosted) implementations use semihosting calls.</td>
</tr>
<tr>
<td>rt_heap.h</td>
<td>A C header file describing the storage management abstract data type.</td>
</tr>
<tr>
<td>rt_locale.h</td>
<td>A C header file describing the five locale category filing systems, and defining some macros that are useful for describing the contents of locale categories.</td>
</tr>
<tr>
<td>rt_misc.h</td>
<td>A C header file describing miscellaneous unrelated public interfaces to the C library.</td>
</tr>
<tr>
<td>rt_memory.s</td>
<td>An empty, but commented, prototype implementation of the memory model.</td>
</tr>
</tbody>
</table>

If you are re-implementing a function that exists in the standard ARM library, the linker uses an object or library from your project rather than the standard ARM library.

--- Caution ---

Do not replace or delete libraries supplied by ARM. You must not overwrite the supplied library files. Place your re-implemented functions in separate object files or libraries instead.

2.31.1 See also

Tasks
- Using the libraries in a nonsemihosting environment on page 2-36.

Concepts
- Assembler macros that tailor locale functions in the C library on page 2-63.

Reference

Linker Reference:
- --list=file on page 2-77
- --verbose on page 2-142.
2.32 Building an application without the C library

Creating an application that has a `main()` function causes the C library initialization functions to be included as part of `__rt_lib_init`.

If your application does not have a `main()` function, the C library is not initialized and the following functions are not available in your application:

- low-level `stdio` functions that have the prefix `_sys_`
- signal-handling functions, `signal()` and `raise()` in `signal.h`
- other functions, such as `atexit()`.

Table 2-5 shows header files, and the functions they contain, that are available with an uninitialized library. Some otherwise unavailable functions can be used if the library functions they depend on are re-implemented.

Table 2-5 Standalone C library functions

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>alloca.h</code></td>
<td>Functions in this file work without any library initialization or function re-implementation. You must know how to build an application with the C library to use this header file.</td>
</tr>
<tr>
<td><code>assert.h</code></td>
<td>Functions listed in this file require high-level <code>stdio</code>, <code>__rt_raise()</code>, and <code>_sys_exit()</code>. You must be familiar with tailoring error signaling, error handling, and program exit to use this header file.</td>
</tr>
<tr>
<td><code>ctype.h</code></td>
<td>Functions listed in this file require the locale functions.</td>
</tr>
<tr>
<td><code>errno.h</code></td>
<td>Functions in this file work without the requirement for any library initialization or function re-implementation.</td>
</tr>
<tr>
<td><code>fenv.h</code></td>
<td>Functions in this file work without the requirement for any library initialization and only require the re-implementation of <code>__rt_raise()</code>.</td>
</tr>
<tr>
<td><code>float.h</code></td>
<td>This file does not contain any code. The definitions in the file do not require library initialization or function re-implementation.</td>
</tr>
<tr>
<td><code>inttypes.h</code></td>
<td>Functions listed in this file require the locale functions.</td>
</tr>
<tr>
<td><code>limits.h</code></td>
<td>Functions in this file work without the requirement for any library initialization or function re-implementation.</td>
</tr>
</tbody>
</table>
| `locale.h` | Call `setlocale()` before calling any function that uses locale functions. For example: `setlocale(LC_ALL, "C")`. See the contents of `locale.h` for more information on the following functions and data structures:
- `setlocale()` selects the appropriate locale as specified by the category and locale arguments.
- `lconv` is the structure used by locale functions for formatting numeric quantities according to the rules of the current locale.
- `localeconv()` creates an `lconv` structure and returns a pointer to it.
- `_get_lconv()` fills the `lconv` structure pointed to by the parameter. This ISO extension removes the requirement for static data within the library.
- `locale.h` also contains constant declarations used with locale functions. |
| `math.h` | For functions in this file to work, you must first call `_fp_init()` and re-implement `__rt_raise()`. |
The ARM C and C++ libraries

Table 2-5 Standalone C library functions (continued)

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>setjmp.h</td>
<td>Functions in this file work without any library initialization or function re-implementation.</td>
</tr>
<tr>
<td>signal.h</td>
<td>Functions listed in this file are not available without library initialization. You must know how to build an application with the C library to use this header file. _rt_raise() can be re-implemented for error and exit handling. You must be familiar with tailoring error signaling, error handling, and program exit.</td>
</tr>
<tr>
<td>stdarg.h</td>
<td>Functions listed in this file work without any library initialization or function re-implementation.</td>
</tr>
<tr>
<td>stddef.h</td>
<td>This file does not contain any code. The definitions in the file do not require library initialization or function re-implementation.</td>
</tr>
<tr>
<td>stdint.h</td>
<td>This file does not contain any code. The definitions in the file do not require library initialization or function re-implementation.</td>
</tr>
<tr>
<td>stdio.h</td>
<td>The following dependencies or limitations apply to these functions: • The high-level functions such as printf(), scanf(), puts(), fgets(), fwrite(), and perror() depend on lower-level stdio functions fgetc(), fputc(), and _backspace(). You must re-implement these lower-level functions when using the standalone C library. However, you cannot re-implement the <em>sys</em> prefixed functions (for example, _sys_read()) when using the standalone C library because they require library initialization. You must be familiar with tailoring the input/output functions in the C and C++ libraries. • The printf() and scanf() family of functions require locale. • The remove() and rename() functions are system-specific and probably not usable in your application.</td>
</tr>
<tr>
<td>stdlib.h</td>
<td>Most functions in this file work without any library initialization or function re-implementation. The following functions depend on other functions being instantiated correctly: • atoi() requires locale • strtol() requires locale • malloc(), calloc(), realloc(), and free() require heap functions • atexit() is not available when building an application without the C library.</td>
</tr>
<tr>
<td>string.h</td>
<td>Functions in this file work without any library initialization, with the exception of strcoll() and strxfrm(), that require locale.</td>
</tr>
</tbody>
</table>
2.32.1 See also

Tasks

• Creating an application as bare machine C without the C library on page 2-44
• Assembler macros that tailor locale functions in the C library on page 2-63
• Tailoring input/output functions in the C and C++ libraries on page 2-92.

Concepts

• Modification of C library functions for error signaling, error handling, and program exit on page 2-80.
2.33 Creating an application as bare machine C without the C library

The following topics refer to creating applications as bare machine C without the library. These applications do not automatically use the full C runtime environment provided by the C library. Even though you are creating an application without the library, some functions from the library that are called implicitly by the compiler must be included. There are also many library functions that can be made available with only minor re-implementations.

- Integer and floating-point compiler functions and building an application without the C library on page 2-45
- Bare machine integer C on page 2-46
- Bare machine C with floating-point processing on page 2-47
- Customized C library startup code and access to C library functions on page 2-48
- Program design when exploiting the C library on page 2-49
- Using low-level functions when exploiting the C library on page 2-50
- Using high-level functions when exploiting the C library on page 2-51
- Using malloc() when exploiting the C library on page 2-52.
2.34 Integer and floating-point compiler functions and building an application without the C library

There are several compiler helper functions that the compiler uses to handle operations that do not have a short machine code equivalent. For example, integer divide uses a function that is implicitly called by the compiler if there is no divide instruction available in the target instruction set. (ARMv7-R and ARMv7-M architectures use the instructions SDIV and UDIV in Thumb state. Other versions of the ARM architecture also use compiler functions that are implicitly invoked.)

Integer divide, and all the floating-point functions if you use a floating-point mode that involves throwing exceptions, require __rt_raise() to handle math errors. Re-implementing __rt_raise() enables all the math functions, and it avoids having to link in all the signal-handling library code.

2.34.1 See also

Tasks
• Building an application without the C library on page 2-41.

Concepts
Compiler generated and library-resident helper functions on page 2-119.

Other information
• Application Binary Interface (ABI) for the ARM Architecture, http://infocenter.arm.com/help/topic/com.arm.doc.subset.swdev.abi
2.35  Bare machine integer C

If you are writing a program in C that does not use the library and is to run without any environment initialization, you must:

• Re-implement __rt_raise() if you are using the heap.
• Not define main(), to avoid linking in the library initialization code.
• Write an assembly language veneer that establishes the register state required to run C. This veneer must branch to the entry function in your application.
• Provide your own RW/ZI initialization code.
• Ensure that your initialization veneer is executed by, for example, placing it in your reset handler.
• Build your application using --fpu=none.

When you have met these requirements, link your application normally. The linker uses the appropriate C library variant to find any required compiler functions that are implicitly called.

Many library facilities require __user_libspace for static data. Even without the initialization code activated by having a main() function, __user_libspace is created automatically and uses 96 bytes in the ZI segment.

2.35.1  See also

Tasks
• Building an application without the C library on page 2-41.

Concepts
• Bare machine C with floating-point processing on page 2-47
• Use of the __user_libspace static data area by the C libraries on page 2-21.

Reference
• --fpu=name on page 3-44.
2.36 Bare machine C with floating-point processing

If you want to use floating-point processing in an application without the C library you must:

- Re-implement __rt_raise() if you are using the heap.
- Not define main(), to avoid linking in the library initialization code.
- Write an assembly language veneer that establishes the register state required to run C. This veneer must branch to the entry function in your application. The register state required to run C primarily comprises the stack pointer. It also consists of sb, the stack base, if Read/Write Position-Independent (RWPI) code applies.
- Provide your own RW/ZI initialization code.
- Ensure that your initialization veneer is executed by, for example, placing it in your reset handler.
- Use the appropriate FPU option when you build your application.
- Call _fp_init() to initialize the floating-point status register before performing any floating-point operations.

Do not build your application with the --fpu=none option.

If you are using software floating-point support and a floating-point mode that requires a floating-point status word (--fpmode=ieee_fixed or --fpmode=ieee_full), you can also define the function __rt_fp_status_addr() to return the address of a writable data word to be used instead of the floating-point status register. If you rely on the default library definition of __rt_fp_status_addr(), this word resides in the program data section, unless you define __user_perthread_libspace() (or in the case of legacy code that does not yet use __user_perthread_libspace(), __user_libspace()).

2.36.1 See also

Tasks
- Building an application without the C library on page 2-41.

Concepts
- Bare machine integer C on page 2-46
- Use of static data in the C libraries on page 2-19
- Use of the __user_libspace static data area by the C libraries on page 2-21.
2.37 Customized C library startup code and access to C library functions

When building an application without the C library, if you create an application that includes a `main()` function, the linker automatically includes the initialization code necessary for the execution environment. There are situations where this is not desirable or possible. For example, a system running a Real-Time Operating System (RTOS) might have its execution environment configured by the RTOS startup code.

You can create an application that consists of customized startup code and still use many of the library functions. You must either:

- avoid functions that require initialization
- provide the initialization and low-level support functions.

2.37.1 See also

Tasks

- Building an application without the C library on page 2-41
- Using the C library with an application on page 2-33.

Concepts

- Building an application without the C library on page 2-41
- Use of the __user_libspace static data area by the C libraries on page 2-21
- Bare machine integer C on page 2-46
- Tailoring input/output functions in the C and C++ libraries on page 2-92.
2.38  Program design when exploiting the C library

The functions you must re-implement depend on how much of the library functionality you require:

- If you want only the compiler support functions for division, structure copy, and floating-point arithmetic, you must provide __rt_raise(). This also enables very simple library functions such as those in errno.h, setjmp.h, and most of string.h to work.
- If you call setlocale() explicitly, locale-dependent functions are activated. This enables you to use the atoi family, sprintf(), sscanf(), and the functions in ctype.h.
- Programs that use floating-point must call _fp_init(). If you select software floating-point in --fpmode=ieee_fixed or --fpmode=ieee_full mode, the program must also provide __rt_fp_status_addr().
- Implementing high-level input/output support is necessary for functions that use fprintf() or fputs(). The high-level output functions depend on fputc() and ferror(). The high-level input functions depend on fgetc() and __backspace().

Implementing these functions and the heap enables you to use almost the entire library.

2.38.1  See also

Tasks
- Customized C library startup code and access to C library functions on page 2-48.

Concepts
- Use of the __user_libspace static data area by the C libraries on page 2-21.

Reference

ARM C and C++ Libraries and Floating-Point Support Reference:
- __rt_fp_status_addr() on page 2-31
- __rt_raise() on page 2-35.
2.39 Using low-level functions when exploiting the C library

If you are using the libraries in an application that does not have a `main()` function, you must re-implement some functions in the library.

_______ Caution ________
__rt_raise() is essential if you are using the heap.

_______ Note _________
If `rand()` is called, `srand()` must be called first. This is done automatically during library initialization but not when you avoid the library initialization.

2.39.1 See also

Tasks
• Customized C library startup code and access to C library functions on page 2-48.

Reference
• Building an application without the C library on page 2-41.
2.40 Using high-level functions when exploiting the C library

High-level I/O functions can be used if the low-level functions are re-implemented. High-level I/O functions are those such as fprintf(), printf(), scanf(), puts(), fgets(), fread(), fwrite(), and perror(). Low-level functions are those such as fputc(), fgetc(), and __backspace(). Most of the formatted output functions also require a call to setlocale().

Anything that uses locale must not be called before first calling setlocale(). setlocale() selects the appropriate locale. For example, setlocale(LC_ALL, "C"), where LC_ALL means that the call to setlocale() affects all locale categories, and "C" specifies the minimal environment for C translation. Locale-using functions include the functions in ctype.h and locale.h, the printf() family, the scanf() family, ato*, strto*, strcoll/strxfrm, and most of time.h.

2.40.1 See also

Tasks
• Tailoring input/output functions in the C and C++ libraries on page 2-92.

Concepts
• Customized C library startup code and access to C library functions on page 2-48
• Building an application without the C library on page 2-41.
2.41 Using `malloc()` when exploiting the C library

If heap support is required for bare machine C, `_init_alloc()` must be called first to supply initial heap bounds, and `__rt_heap_extend()` must be provided even if it only returns failure. Without `__rt_heap_extend()`, certain library functionality is included that causes problems when you are writing bare machine C.

Prototypes for both `_init_alloc()` and `__rt_heap_extend()` are in `rt_heap.h`.

2.41.1 See also

Reference

- Customized C library startup code and access to C library functions on page 2-48.
2.42 Tailoring the C library to a new execution environment

Tailoring the C library to a new execution environment involves re-implementing functions to produce an application for a new execution environment, for example, embedded in ROM or used with an RTOS.

Symbols that start with a single or double underscore name functions that are used as part of the low-level implementation. You can re-implement some of these functions. Additional information on these library functions is available in the rt_heap.h, rt_locale.h, rt_misc.h, and rt_sys.h include files and the rt_memory.s assembler file.

2.42.1 See also

Concepts

- How C and C++ programs use the library functions on page 2-54
- Initialization of the execution environment and execution of the application on page 2-55
- C++ initialization, construction and destruction on page 2-56
- Legacy support for C$$pi_ctorvec instead of .init_array on page 2-58
- Exceptions system initialization on page 2-59
- Emergency buffer memory for exceptions on page 2-60
- Library functions called from main() on page 2-61
- Program exit and the assert macro on page 2-62.

Reference

C and C++ Libraries and Floating-Point Support Reference:

- __rt_entry on page 2-28
- __rt_exit() on page 2-30
- __rt_lib_init() on page 2-33
- __rt_lib_shutdown() on page 2-34.

Other information

The following specifications include descriptions of functions that have the prefix __cxa or __aeabi:

- C Library ABI for the ARM Architecture
- Exception Handling ABI for the ARM Architecture
- C++ ABI for the ARM Architecture.
2.43 How C and C++ programs use the library functions

The following topics describe specific functions used to initialize the execution environment and application, library exit functions, and target-dependent library functions that the application might call during its execution:

- Initialization of the execution environment and execution of the application on page 2-55
- C++ initialization, construction and destruction on page 2-56
- Legacy support for C$$pi ctorvec instead of .init_array on page 2-58
- Exceptions system initialization on page 2-59
- Emergency buffer memory for exceptions on page 2-60
- Library functions called from main() on page 2-61
- Program exit and the assert macro on page 2-62
- Program exit and the assert macro on page 2-62.
2.44 Initialization of the execution environment and execution of the application

The entry point of a program is at __main in the C library where library code:

1. Copies non-root (RO and RW) execution regions from their load addresses to their execution addresses. Also, if any data sections are compressed, they are decompressed from the load address to the execution address.

2. zeroes ZI regions.

3. Branches to __rt_entry.

If you do not want the library to perform these actions, you can define your own __main that branches to __rt_entry. For example:

    IMPORT __rt_entry
    EXPORT __main
    ENTRY __main
    B __rt_entry
END

The library function __rt_entry() runs the program as follows:

1. Sets up the stack and the heap by one of a number of means that include calling __user_setup_stackheap(), calling __rt_stackheap_init(), or loading the absolute addresses of scatter-loaded regions.

2. Calls __rt_lib_init() to initialize referenced library functions, initialize the locale and, if necessary, set up argc and argv for main().
   For C++, calls the constructors for any top-level objects by way of __cpp_initialize__aeabi__.

3. Calls main(), the user-level root of the application.
   From main(), your program might call, among other things, library functions.

4. Calls exit() with the value returned by main().

2.44.1 See also

Concepts
- C++ initialization, construction and destruction on page 2-56
- Library functions called from main() on page 2-61
- How C and C++ programs use the library functions on page 2-54
- Tailoring the C library to a new execution environment on page 2-53.

Reference

ARM® C and C++ Libraries and Support Reference:
- __rt_entry on page 2-28
- __rt_lib_init() on page 2-33.
2.45 C++ initialization, construction and destruction

The C++ Standard places certain requirements on the construction and destruction of objects with static storage duration.

The ARM C++ compiler uses the .init_array area to achieve this. This is a const data array of self-relative pointers to functions. For example, you might have the following C++ translation unit, contained in the file test.cpp:

```c++
struct T {
    T();
    ~T();
} t;
int f() {
    return 4;
}
```

This translates into the following pseudocode:

```
AREA ||.text||, CODE, READONLY
int f() {
    return 4;
}
static void __sti___8_test_cpp {
    // construct 't' and register its destruction
    __aeabi_atexit(T::T(&t), &T::~T, &__dso_handle);
    i = f();
}
AREA ||.init_array||, DATA, READONLY
DCD __sti___8_test_cpp - {PC}
AREA ||.data||, DATA
t  % 4
i  % 4
```

This pseudocode is for illustration only. To see the code that is generated, compile the C++ source code with armcc -c --cpp -S.

The linker collects each .init_array from the various translation units together. It is important that the .init_array is accumulated in the same order.

The library routine __cpp_initialize__aeabi_ is called from the C library startup code, __rt_lib_init, before main. __cpp_initialize__aeabi_ walks through the .init_array calling each function in turn. On exit, __rt_lib_shutdown calls __cxa_finalize.

Usually, there is at most one function for T::$T(), mangled name _ZN1TC1Ev, one function for T::$~T(), mangled name _ZN1TD1Ev, one __sti__ function, and four bytes of .init_array for each translation unit. The mangled name for the function f() is _Z1fv. There is no way to determine the initialization order between translation units.

Function-local static objects with destructors are also handled using __aeabi_atexit.

.init_array sections must be placed contiguously within the same region for their base and limit symbols to be accessible. If they are not, the linker generates an error.
2.45.1 See also

Concepts

- *Legacy support for C**$pi_ctorvec instead of *init_array* on page 2-58
- *How C and C++ programs use the library functions* on page 2-54
- *Tailoring the C library to a new execution environment* on page 2-53.
2.46 Legacy support for `C$pi_ctorvec` instead of `.init_array`

In RVCT v2.0 and earlier, `C$pi_ctorvec` is used instead of `.init_array`. Objects with `C$pi_ctorvec` are still supported. Therefore, if you have legacy objects, your scatter file is expected to contain something similar to:

```assembly
LOAD_ROM 0x0000000
{   EXEC_ROM 0x0000000
   {       your_object.o(+RO)
            * (.init_array)
            * (C$pi_ctorvec) ; backwards compatibility
       ...
   }   RAM 0x0100000
    {        (+RW,+ZI)
    }
}
```

2.46.1 See also

Concepts
- *C++ initialization, construction and destruction on page 2-56*
- *How C and C++ programs use the library functions on page 2-54*
- *Tailoring the C library to a new execution environment on page 2-53.*
2.47 Exceptions system initialization

The exceptions system can be initialized either on demand (that is, when first used), or before `main` is entered. Initialization on demand has the advantage of not allocating heap memory unless the exceptions system is used, but has the disadvantage that it becomes impossible to throw any exception (such as `std::bad_alloc`) if the heap is exhausted at the time of first use.

The default behavior is to initialize on demand. To initialize the exceptions system before `main` is entered, include the following function in the link:

```c
extern "C" void __cxa_get_globals(void);
extern "C" void __ARM_exceptions_init(void)
{
  __cxa_get_globals();
}
```

Although you can place the call to `__cxa_get_globals` directly in your code, placing it in `__ARM_exceptions_init` ensures that it is called as early as possible. That is, before any global variables are initialized and before `main` is entered.

`__ARM_exceptions_init` is weakly referenced by the library initialization mechanism, and is called if it is present as part of `__rt_lib_init`.

**Note**
The exception system is initialized by calls to various library functions, for example, `std::set_terminate()`. Therefore, you might not have to initialize before the entry to `main`.

2.47.1 See also

**Concepts**

- *How C and C++ programs use the library functions* on page 2-54
- *Tailoring the C library to a new execution environment* on page 2-53.
2.48 Emergency buffer memory for exceptions

You can choose whether or not to allocate emergency memory that is to be used for throwing a `std::bad_alloc` exception when the heap is exhausted.

To allocate emergency memory, you must include the symbol

`__ARM_exceptions_buffer_required` in the link. A call is then made to

`__ARM_exceptions_buffer_init()` as part of the exceptions system initialization. The symbol is not included by default.

The following routines manage the exceptions emergency buffer:

```
extern "C" void *__ARM_exceptions_buffer_init()

Called once during runtime to allocate the emergency buffer memory. It returns a pointer to the emergency buffer memory, or NULL if no memory is allocated.
```

```
extern "C" void *__ARM_exceptions_buffer_allocate(void *buffer, size_t size)

Called when an exception is about to be thrown, but there is not enough heap memory available to allocate the exceptions object. `buffer` is the value previously returned by `__ARM_exceptions_buffer_init()`, or NULL if that routine was not called. `__ARM_exceptions_buffer_allocate()` returns a pointer to `size` bytes of memory that is aligned on an eight-byte boundary, or NULL if the allocation is not possible.
```

```
extern "C" void *__ARM_exceptions_buffer_free(void *buffer, void *addr)

Called to free memory possibly allocated by

`__ARM_exceptions_buffer_allocate()`. `buffer` is the value previously returned by `__ARM_exceptions_buffer_init()`, or NULL if that routine was not called. The routine determines whether the passed address has been allocated from the emergency memory buffer, and if so, frees it appropriately, then returns a non-NUL value. If the memory at `addr` was not allocated by

`__ARM_exceptions_buffer_allocate()`, the routine must return NULL.
```

Default definitions of these routines are present in the image, but you can supply your own versions to override the defaults supplied by the library. The default routines reserve enough space for a single `std::bad_alloc` exceptions object. If you do not require an emergency buffer, it is safe to redefine all these routines to return only NULL.

2.48.1 See also

Concepts

- *How C and C++ programs use the library functions* on page 2-54
- *Tailoring the C library to a new execution environment* on page 2-53.
2.49 Library functions called from main()

The function main() is the user-level root of the application. It requires the execution environment to be initialized and input/output functions to be capable of being called. While in main() the program might perform one of the following actions that calls user-customizable functions in the C library:

- Extend the stack or heap.
- Call library functions that require a callout to a user-defined function, for example __rt_fp_status_addr() or clock().
- Call library functions that use locale or CTYPE.
- Perform floating-point calculations that require the floating-point unit or floating-point library.
- Input or output directly through low-level functions, for example putc(), or indirectly through high-level input/output functions and input/output support functions, for example, fprintf() or sys_open().
- Raise an error or other signal, for example ferror.

2.49.1 See also

Tasks
- Tailoring the C library to a new execution environment on page 2-53
- Tailoring input/output functions in the C and C++ libraries on page 2-92
- Tailoring non-input/output C library functions on page 2-104.

Concepts
- Assembler macros that tailor locale functions in the C library on page 2-63
- Modification of C library functions for error signaling, error handling, and program exit on page 2-80.
2.50 Program exit and the assert macro

A program can exit normally at the end of main() or it can exit prematurely because of an error.

The behavior of the assert macro depends on the conditions in operation at the most recent occurrence of #include <assert.h>:

1. If the NDEBUG macro is defined (on the command line or as part of a source file), the assert macro has no effect.

2. If the NDEBUG macro is not defined, the assert expression (the expression given to the assert macro) is evaluated. If the result is TRUE, that is != 0, the assert macro has no more effect.

3. If the assert expression evaluates to FALSE, the assert macro calls the __aeabi_assert() function if any of the following are true:
   • you are compiling with --strict
   • you are using -O0 or -O1
   • __ASSERT_MSG is defined
   • _AEABI_PORTABILITY_LEVEL is defined and not 0.

4. If the assert expression evaluates to FALSE and the conditions specified in point 3 do not apply, the assert macro calls abort(). Then:
   a. abort() calls __rt_raise().
   b. If __rt_raise() returns, abort() tries to finalize the library.

If you are creating an application that does not use the library, __aeabi_assert() works if you re-implement abort() and the stdio functions.

Another solution for retargeting is to re-implement the __aeabi_assert() function itself. The function prototype is:

```c
void __aeabi_assert(const char *expr, const char *file, int line);
```

where:
• expr points to the string representation of the expression that was not TRUE
• file and line identify the source location of the assertion.

The behavior for __aeabi_assert() supplied in the ARM C library is to print a message on stderr and call abort().

You can restore the default behavior for __aeabi_assert() at higher optimization levels by defining __ASSERT_MSG.

2.50.1 See also

Concepts
• Tailoring the C library to a new execution environment on page 2-53.
2.51 Assembler macros that tailor locale functions in the C library

Applications use locales when they display or process data that depends on the local language or region, for example, character set, monetary symbols, decimal point, time, and date. Locale-related functions are declared in the include file, `rt_locale`.

The following topics describe assembler macros that tailor locale functions:

**Concepts**
- Link time selection of the locale subsystem in the C library on page 2-64
- Runtime selection of the locale subsystem in the C library on page 2-67
- Definition of locale data blocks in the C library on page 2-68
- LC_CTYPE data block on page 2-71
- LC_COLLATE data block on page 2-74
- LC_MONETARY data block on page 2-76
- LC_NUMERIC data block on page 2-77
- LC_TIME data block on page 2-78.

**Reference**

*ARM® C and C++ Libraries and Floating-Point Support Reference:*
- lconv structure on page 2-17
- _get_lconv() on page 2-12
- localeconv() on page 2-19
- setlocale() on page 2-37
- _findlocale() on page 2-10.
2.52 Link time selection of the locale subsystem in the C library

The locale subsystem of the C library can be selected at link time or can be extended to be selectable at runtime. The following list describes the use of locale categories by the library:

- The default implementation of each locale category is for the C locale. The library also provides an alternative, ISO8859-1 (Latin-1 alphabet) implementation of each locale category that you can select at link time.
- Both the C and ISO8859-1 default implementations usually provide one locale for each category to select at runtime.
- You can replace each locale category individually.
- You can include as many locales in each category as you choose and you can name your locales as you choose.
- Each locale category uses one word in the private static data of the library.
- The locale category data is read-only and position independent.
- scanf() forces the inclusion of the LC_CTYPE locale category, but in either of the default locales this adds only 260 bytes of read-only data to several kilobytes of code.

2.52.1 See also

Concepts
- Assembly macros that tailor locale functions in the C library on page 2-63
- ISO8859-1 implementation on page 2-65
- Shift-JIS and UTF-8 implementation on page 2-66.
2.53 ISO8859-1 implementation

Table 2-6 shows the ISO8859-1 (Latin-1 alphabet) locale categories.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>__use_iso8859_ctype</td>
<td>Selects the ISO8859-1 (Latin-1) classification of characters. This is essentially 7-bit ASCII, except that the character codes 160-255 represent a selection of useful European punctuation characters, letters, and accented letters.</td>
</tr>
<tr>
<td>__use_iso8859_collate</td>
<td>Selects the strcoll/strxfrm collation table appropriate to the Latin-1 alphabet. The default C locale does not require a collation table.</td>
</tr>
<tr>
<td>__use_iso8859_monetary</td>
<td>Selects the Sterling monetary category using Latin-1 coding.</td>
</tr>
<tr>
<td>__use_iso8859_numeric</td>
<td>Selects separation of thousands with commas in the printing of numeric values.</td>
</tr>
<tr>
<td>__use_iso8859_locale</td>
<td>Selects all the ISO8859-1 selections described in this table.</td>
</tr>
</tbody>
</table>

There is no ISO8859-1 version of the LC_TIME category.

2.53.1 See also

Concepts
- Link time selection of the locale subsystem in the C library on page 2-64.
2.54 Shift-JIS and UTF-8 implementation

Table 2-7 shows the Shift-JIS (Japanese characters) or UTF-8 (Unicode characters) locale categories.

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>__use_sjis_ctype</td>
<td>Sets the character set to the Shift-JIS multibyte encoding of Japanese characters</td>
</tr>
<tr>
<td>__use_utf8_ctype</td>
<td>Sets the character set to the UTF-8 multibyte encoding of all Unicode characters</td>
</tr>
</tbody>
</table>

The following list describes the effects of Shift-JIS and UTF-8 encoding:

- The ordinary ctype functions behave correctly on any byte value that is a self-contained character in Shift-JIS. For example, half-width katakana characters that Shift-JIS encodes as single bytes between 0xA6 and 0xDF are treated as alphabetic by isalpha(). UTF-8 encoding uses the same set of self-contained characters as the ASCII character set.

- The multibyte conversion functions such as mbtowc(), mbsrtowcs(), and wcrtomb(), all convert between wide strings in Unicode and multibyte character strings in Shift-JIS or UTF-8.

- printf("%ls") converts a Unicode wide string into Shift-JIS or UTF-8 output, and scanf("%ls") converts Shift-JIS or UTF-8 input into a Unicode wide string.

You can arbitrarily switch between multibyte locales and single-byte locales at runtime if you include more than one in your application. By default, only one locale at a time is included.

2.54.1 See also

Concepts
- [Link time selection of the locale subsystem in the C library on page 2-64](#).
2.55  Runtime selection of the locale subsystem in the C library

The C library function `setlocale()` selects a locale at runtime for the locale category, or categories, specified in its arguments. It does this by selecting the requested locale separately in each locale category. In effect, each locale category is a small filing system containing an entry for each locale.

C header files describing what must be implemented, and providing some useful support macros, are given in `rt_locale.h` and `rt_locale.s`.

2.55.1  See also

Concepts
- Assembler macros that tailor locale functions in the C library on page 2-63.

Reference
Compiler Reference:
- `setlocale()` on page 2-37
2.56 Definition of locale data blocks in the C library

The locale data blocks are defined using a set of assembly language macros provided in `rt_locale.s`. Therefore, the recommended way to define locale blocks is by writing an assembly language source file. The ARM Compiler toolchain provides a set of macros for each type of locale data block, for example `LC_CTYPE`, `LC_COLLATE`, `LC_MONETARY`, `LC_NUMERIC`, and `LC_TIME`. You define each locale block in the same way with a `_begin` macro, some data macros, and an `_end` macro.

2.56.1 Beginning the definition of a locale block

To begin defining your locale block, call the `_begin` macro. This macro takes two arguments, a prefix and the textual name, as follows:

```
LC_TYPE_begin prefix, name
```

where:

- `TYPE` is one of the following:
  - CTYPE
  - COLLATE
  - MONETARY
  - NUMERIC
  - TIME.

- `prefix` is the prefix for the assembler symbols defined within the locale data

- `name` is the textual name for the locale data.

2.56.2 Specifying the data for a locale block

To specify the data for your locale block, call the macros for that locale type in the order specified for that particular locale type. The syntax is as follows:

```
LC_TYPE_function
```

Where:

- `TYPE` is one of the following:
  - CTYPE
  - COLLATE
  - MONETARY
  - NUMERIC
  - TIME.

- `function` is a specific function, `table()`, `full_wctype()`, or `multibyte()`, related to your locale data.

When specifying locale data, you must call the macro repeatedly for each respective function.

2.56.3 Ending the definition of a locale block

To complete the definition of your locale data block, you call the `_end` macro. This macro takes no arguments, as follows:

```
LC_TYPE_end
```

where:

- `TYPE` is one of the following:
  - CTYPE
2.56.4 Example of a fixed locale block

To write a fixed function that always returns the same locale, you can use the `_start` symbol name defined by the macros. The following shows how this is implemented for the CTYPE locale:

Example 2-2 Fixed locale

```
GET rt_locale.s
AREA my_locales, DATA, READONLY
LC_CTYPE_begin my_ctype_locale, "MyLocale"
... ; include other LC_CTYPE_xxx macros here
LC_CTYPE_end
AREA my_locale_func, CODE, READONLY
_get_lc_ctype FUNCTION
LDR r0, =my_ctype_locale_start
BX lr
ENDFUNC
```

2.56.5 Example of multiple contiguous locale blocks

Contiguous locale blocks suitable for passing to the `_findlocale()` function must be declared in sequence. You must call the macro LC_index_end to end the sequence of locale blocks. The following shows how this is implemented for the CTYPE locale:

Example 2-3 Multiple locales

```
GET rt_locale.s
AREA my_locales, DATA, READONLY
my_ctype_locales
LC_CTYPE_begin my_first_ctype_locale, "MyLocale1"
... ; include other LC_CTYPE_xxx macros here
LC_CTYPE_end
LC_CTYPE_begin my_second_ctype_locale, "MyLocale2"
... ; include other LC_CTYPE_xxx macros here
LC_CTYPE_end
LC_index_end
AREA my_locale_func, CODE, READONLY
IMPORT _findlocale
_get_lc_ctype FUNCTION
LDR r0, =my_ctype_locales
B _findlocale
ENDFUNC
```

2.56.6 See also

Concepts
- Definition of locale data blocks in the C library on page 2-68
- Assembler macros that tailor locale functions in the C library on page 2-63
- `LC_CTYPE` data block on page 2-71
- `LC_COLLATE` data block on page 2-74
- `LC_MONETARY` data block on page 2-76
- `LC_NUMERIC` data block on page 2-77
- `LC_TIME` data block on page 2-78.
2.57 LC_CTYPE data block

When defining a locale data block in the C library, the macros that define an LC_CTYPE data block are as follows:

1. Call LC_CTYPE_begin with a symbol name and a locale name.
2. Call LC_CTYPE_table repeatedly to specify 256 table entries. LC_CTYPE_table takes a single argument in quotes. This must be a comma-separated list of table entries. Each table entry describes one of the 256 possible characters, and can be either an illegal character (IL) or the bitwise OR of one or more of the following flags:
   - _S whitespace characters
   - _P punctuation characters
   - _B printable space characters
   - _L lowercase letters
   - _U uppercase letters
   - _N decimal digits
   - _C control characters
   - _X hexadecimal digit letters A-F and a-f
   - _A alphabetic but neither uppercase nor lowercase, such as Japanese katakana.

   **Note**

   A printable space character is defined as any character where the result of both isprint() and isspace() is true.

   _A must not be specified for the same character as either _N or _X.

3. If required, call one or both of the following optional macros:
   - LC_CTYPE_full_wctype. Calling this macro without arguments causes the C99 wide-character ctype functions (iswalpha(), iswupper(), ...) to return useful values across the full range of Unicode when this LC_CTYPE locale is active. If this macro is not specified, the wide ctype functions treat the first 256 wchar_t values as the same as the 256 char values, and the rest of the wchar_t range as containing illegal characters.
   - LC_CTYPE_multibyte defines this locale to be a multibyte character set. Call this macro with three arguments. The first two arguments are the names of functions that perform conversion between the multibyte character set and Unicode wide characters. The last argument is the value that must be taken by the C macro MB_CUR_MAX for the respective character set. The two function arguments have the following prototypes:

     ```c
     size_t internal_mbrtowc(wchar_t *pwc, char c, mbstate_t *pstate);
     size_t internal_wcrtomb(char *s, wchar_t w, mbstate_t *pstate);
     ```

     internal_mbrtowc() takes one byte, c, as input, and updates the mbstate_t pointed to by pstate as a result of reading that byte. If the byte completes the encoding of a multibyte character, it writes the corresponding wide character into the location pointed to by pwc, and returns 1 to indicate that it has done so. If not, it returns -2 to indicate the state change of mbstate_t and that no character is output. Otherwise, it returns -1 to indicate that the encoded input is invalid.
internal_wcrtomb() takes one wide character, \( w \), as input, and writes some number of bytes into the memory pointed to by \( s \). It returns the number of bytes output, or -1 to indicate that the input character has no valid representation in the multibyte character set.

4. Call \texttt{LC\_CTYPE\_end}, without arguments, to finish the locale block definition.

The following example shows an \texttt{LC\_CTYPE} data block.

\textbf{Example 2-4 Defining the CTYPE locale}

\begin{verbatim}
LC\_CTYPE\_begin utf8 ctype, "UTF-8";
; Single-byte characters in the low half of UTF-8 are exactly
; the same as in the normal "C" locale.
LC\_CTYPE\_table "\_C, \_C, \_C, \_C, \_C, \_C, \_C, \_C"; 0x00-0x08
LC\_CTYPE\_table "\_C|\_S, \_C|\_S, \_C|\_S, \_C|\_S"; 0x09-0x0F

LC\_CTYPE\_table "\_B|\_S"; space
LC\_CTYPE\_table "\_N, \_N, \_N, \_N"; 0-9
LC\_CTYPE\_table "\_P, \_P, \_P, \_P"; :;<=>?@
LC\_CTYPE\_table "\_M, \_M, \_M, \_M"; A-F
LC\_CTYPE\_table "\_M, \_M, \_M, \_M"; G-P
LC\_CTYPE\_table "\_M, \_M, \_M, \_M"; Q-Z
LC\_CTYPE\_table "\_P, \_P, \_P, \_P"; [\^_]`

; Nothing in the top half of UTF-8 is valid on its own as a
; single-byte character, so they are all illegal characters (IL).
LC\_CTYPE\_table "IL, IL, IL, IL, IL, IL, IL, IL, IL";
LC\_CTYPE\_table "IL, IL, IL, IL, IL, IL, IL, IL, IL";
LC\_CTYPE\_table "IL, IL, IL, IL, IL, IL, IL, IL, IL";
LC\_CTYPE\_table "IL, IL, IL, IL, IL, IL, IL, IL, IL";
LC\_CTYPE\_table "IL, IL, IL, IL, IL, IL, IL, IL, IL";
LC\_CTYPE\_table "IL, IL, IL, IL, IL, IL, IL, IL, IL";
LC\_CTYPE\_table "IL, IL, IL, IL, IL, IL, IL, IL, IL";
LC\_CTYPE\_table "IL, IL, IL, IL, IL, IL, IL, IL, IL";

; The UTF-8 ctype locale wants the full version of wctype.
LC\_CTYPE\_full\_wctype;
; UTF-8 is a multibyte locale, so we must specify some
; conversion functions. MB\_CUR\_MAX is 6 for UTF-8 (the lead
; bytes 0xFC and 0xFD are each followed by five continuation
; bytes).
; The implementations of the conversion functions are not
; provided in this example.
;
IMPORT utf8\_mbtowc
\end{verbatim}
2.57.1 See also

Concepts

• *Definition of locale data blocks in the C library on page 2-68*
• *Assembler macros that tailor locale functions in the C library on page 2-63.*
2.58 LC_COLLATE data block

When defining a locale data block in the C library, the macros that define an LC_COLLATE data block are as follows:

1. Call LC_COLLATE_begin with a symbol name and a locale name.

2. Call one of the following alternative macros:
   - Call LC_COLLATE_table repeatedly to specify 256 table entries. LC_COLLATE_table takes a single argument in quotes. This must be a comma-separated list of table entries. Each table entry describes one of the 256 possible characters, and can be a number indicating its position in the sorting order. For example, if character A is intended to sort before B, then entry 65 (corresponding to A) in the table, must be smaller than entry 66 (corresponding to B).
   - Call LC_COLLATE_no_table without arguments. This indicates that the collation order is the same as the string comparison order. Therefore, strcoll() and strcmp() are identical.

3. Call LC_COLLATE_end, without arguments, to finish the locale block definition.

The following example shows an LC_COLLATE data block.

```
Example 2-5 Defining the COLLATE locale

LC_COLLATE_begin iso88591_collate, "ISO8859-1"
LC_COLLATE_table "0x00, 0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07"
LC_COLLATE_table "0x08, 0x09, 0x0a, 0x0b, 0x0c, 0x0d, 0x0e, 0x0f"
LC_COLLATE_table "0x10, 0x11, 0x12, 0x13, 0x14, 0x15, 0x16, 0x17"
LC_COLLATE_table "0x18, 0x19, 0x1a, 0x1b, 0x1c, 0x1d, 0x1e, 0x1f"
LC_COLLATE_table "0x20, 0x21, 0x22, 0x23, 0x24, 0x25, 0x26, 0x27"
LC_COLLATE_table "0x28, 0x29, 0x2a, 0x2b, 0x2c, 0x2d, 0x2e, 0x2f"
LC_COLLATE_table "0x30, 0x31, 0x32, 0x33, 0x34, 0x35, 0x36, 0x37"
LC_COLLATE_table "0x38, 0x39, 0x3a, 0x3b, 0x3c, 0x3d, 0x3e, 0x3f"
LC_COLLATE_table "0x40, 0x41, 0x42, 0x43, 0x44, 0x45, 0x46, 0x47"
LC_COLLATE_table "0x48, 0x49, 0x4a, 0x4b, 0x4c, 0x4d, 0x4e, 0x4f"
LC_COLLATE_table "0x50, 0x51, 0x52, 0x53, 0x54, 0x55, 0x56, 0x57"
LC_COLLATE_table "0x58, 0x59, 0x5a, 0x5b, 0x5c, 0x5d, 0x5e, 0x5f"
LC_COLLATE_table "0x60, 0x61, 0x62, 0x63, 0x64, 0x65, 0x66, 0x67"
LC_COLLATE_table "0x68, 0x69, 0x6a, 0x6b, 0x6c, 0x6d, 0x6e, 0x6f"
LC_COLLATE_table "0x70, 0x71, 0x72, 0x73, 0x74, 0x75, 0x76, 0x77"
LC_COLLATE_table "0x78, 0x79, 0x7a, 0x7b, 0x7c, 0x7d, 0x7e, 0x7f"
LC_COLLATE_end
```
2.58.1 See also

Concepts

• ISO8859-1 implementation on page 2-65
• Definition of locale data blocks in the C library on page 2-68
• Assembler macros that tailor locale functions in the C library on page 2-63.
2.59 LC_MONETARY data block

When defining a locale data block in the C library, the macros that define an LC_MONETARY data block are as follows:

1. Call LC_MONETARY_begin with a symbol name and a locale name.
2. Call the LC_MONETARY data macros as follows:
   a. Call LC_MONETARY_fracdigits with two arguments: frac_digits and int_frac_digits from the lconv structure.
   b. Call LC_MONETARY_positive with four arguments: p_cs_precedes, p_sep_by_space, p_sign_posn and positive_sign.
   c. Call LC_MONETARY_negative with four arguments: n_cs_precedes, n_sep_by_space, n_sign_posn and negative_sign.
   d. Call LC_MONETARY_currsymbol with two arguments: currency_symbol and int_curr_symbol.
   e. Call LC_MONETARY_point with one argument: mon_decimal_point.
   f. Call LC_MONETARY_thousands with one argument: mon_thousands_sep.
   g. Call LC_MONETARY_grouping with one argument: mon_grouping.
3. Call LC_MONETARY_end, without arguments, to finish the locale block definition.

The following example shows an LC_MONETARY data block.

Example 2-6 Defining the MONETARY locale

```c
LC_MONETARY_begin c_monetary, "C"
LC_MONETARY_fracdigits 255, 255
LC_MONETARY_positive 255, 255, 255, ""
LC_MONETARY_negative 255, 255, 255, ""
LC_MONETARY_currsymbol "", ""
LC_MONETARY_point ""
LC_MONETARY_thousands ""
LC_MONETARY_grouping ""
LC_MONETARY_end
```

2.59.1 See also

Concepts

- *Definition of locale data blocks in the C library* on page 2-68
- *Assembler macros that tailor locale functions in the C library* on page 2-63.
2.60 LC_NUMERIC data block

When defining a locale data block in the C library, the macros that define an LC_NUMERIC data block are as follows:

1. Call LC_NUMERIC_begin with a symbol name and a locale name.
2. Call the LC_NUMERIC data macros as follows:
   a. Call LC_NUMERIC_point with one argument: decimal_point from lconv structure.
   b. Call LC_NUMERIC_thousands with one argument: thousands_sep.
   c. Call LC_NUMERIC_grouping with one argument: grouping.
3. Call LC_NUMERIC_end, without arguments, to finish the locale block definition.

The following example shows an LC_NUMERIC data block.

Example 2-7 Defining the NUMERIC locale

```c
LC_NUMERIC_begin c_numeric, "C"
LC_NUMERIC_point "."
LC_NUMERIC_thousands ""
LC_NUMERIC_grouping ""
LC_NUMERIC_end
```

2.60.1 See also

Concepts

- Definition of locale data blocks in the C library on page 2-68
- Assembler macros that tailor locale functions in the C library on page 2-63.
2.61 LC_TIME data block

When defining a locale data block in the C library, the macros that define an LC_TIME data block are as follows:

1. Call LC_TIME_begin with a symbol name and a locale name.
2. Call the LC_TIME data macros as follows:
   a. Call LC_TIME_week_short seven times to provide the short names for the days of the week. Sunday being the first day. Then call LC_TIME_week_long and repeat the process for long names.
   b. Call LC_TIME_month_short twelve times to provide the short names for the days of the month. Then call LC_TIME_month_long and repeat the process for long names.
   c. Call LC_TIME_am_pm with two arguments that are respectively the strings representing morning and afternoon.
   d. Call LC_TIME_formats with three arguments that are respectively the standard date/time format used in strftime("%c"), the standard date format strftime("%x"), and the standard time format strftime("%X"). These strings must define the standard formats in terms of other simpler strftime primitives. Example 2-8 shows that the standard date/time format is permitted to reference the other two formats.
   e. Call LC_TIME_c99format with a single string that is the standard 12-hour time format used in strftime("%r") as defined in C99.
3. Call LC_TIME_end, without arguments, to finish the locale block definition.

The following example shows an LC_TIME data block.

Example 2-8 Defining the TIME locale

```c
LC_TIME_begin c_time, "C"
LC_TIME_week_short "Sun"
LC_TIME_week_short "Mon"
LC_TIME_week_short "Tue"
LC_TIME_week_short "Wed"
LC_TIME_week_short "Thu"
LC_TIME_week_short "Fri"
LC_TIME_week_short "Sat"
LC_TIME_week_long "Sunday"
LC_TIME_week_long "Monday"
LC_TIME_week_long "Tuesday"
LC_TIME_week_long "Wednesday"
LC_TIME_week_long "Thursday"
LC_TIME_week_long "Friday"
LC_TIME_week_long "Saturday"
LC_TIME_month_short "Jan"
LC_TIME_month_short "Feb"
LC_TIME_month_short "Mar"
LC_TIME_month_short "Apr"
LC_TIME_month_short "May"
LC_TIME_month_short "Jun"
LC_TIME_month_short "Jul"
LC_TIME_month_short "Aug"
LC_TIME_month_short "Sep"
LC_TIME_month_short "Oct"
LC_TIME_month_short "Nov"
LC_TIME_month_short "Dec"
LC_TIME_month_long "January"
LC_TIME_month_long "February"
```
2.61.1 See also

Concepts

- Definition of locale data blocks in the C library on page 2-68
- Assembler macros that tailor locale functions in the C library on page 2-63.
2.62 Modification of C library functions for error signaling, error handling, and program exit

All trap or error signals raised by the C library go through the __raise() function. You can re-implement this function or the lower-level functions that it uses.

Caution

The IEEE 754 standard for floating-point processing states that the default response to an exception is to proceed without a trap. You can modify floating-point error handling by tailoring the functions and definitions in fenv.h.

The rt_misc.h header file contains more information on error-related functions.

The trap and error-handling functions are shown in Table 2-8.

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>_sys_exit()</td>
<td>Called, eventually, by all exits from the library.</td>
</tr>
<tr>
<td>errno</td>
<td>Is a static variable used with error handling.</td>
</tr>
<tr>
<td>__rt_errno_addr()</td>
<td>Is called to obtain the address of the variable errno.</td>
</tr>
<tr>
<td>__raise()</td>
<td>Raises a signal to indicate a runtime anomaly.</td>
</tr>
<tr>
<td>__rt_raise()</td>
<td>Raises a signal to indicate a runtime anomaly.</td>
</tr>
<tr>
<td>__default_signal_handler()</td>
<td>Displays an error indication to the user.</td>
</tr>
<tr>
<td>_ttywrch()</td>
<td>Writes a character to the console. The default implementation of _ttywrch() is semihosted and, therefore, uses semihosting calls.</td>
</tr>
<tr>
<td>__rt_fp_status_addr()</td>
<td>This function is called to obtain the address of the floating-point status word.</td>
</tr>
</tbody>
</table>

2.62.1 See also

Reference
- Chapter 4 Floating-point support
- Tailoring the C library to a new execution environment on page 2-53.

ARM® C and C++ Libraries and Floating-Point Support Reference:
- _sys_exit() on page 2-47
- errno on page 2-9
- __rt_errno_addr() on page 2-29
- __raise() on page 2-23
- __rt_raise() on page 2-35
- __default_signal_handler() on page 2-8
- _ttywrch() on page 2-57
- __rt_fp_status_addr() on page 2-31.
2.63 Modification of memory management functions in the C library

The following topics describe the functions in `rt_heap.h` that you can define if you are tailoring memory management:

- *Avoiding the heap and heap-using library functions supplied by ARM* on page 2-82
- *C library support for memory allocation functions* on page 2-83
- *Heap1, standard heap implementation* on page 2-84
- *Heap2, alternative heap implementation* on page 2-85
- *Using a heap implementation from bare machine C* on page 2-86.

**ARM® C and C++ Libraries and Floating-Point Support Reference:**

- *alloca()* on page 2-5.

The `rt_heap.h` and `rt_memory.s` include files contain more information on memory-related functions.
2.64  Avoiding the heap and heap-using library functions supplied by ARM

If you are developing embedded systems that have limited RAM or that provide their own heap management (for example, an operating system), you might require a system that does not define a heap area. To avoid using the heap you can either:

•  re-implement the functions in your own application
•  write the application so that it does not call any heap-using function.

You can reference the __use_no_heap or __use_no_heap_region symbols in your code to guarantee that no heap-using functions are linked in from the ARM library. You are only required to import these symbols once in your application, for example, using either:

•  IMPORT __use_no_heap from assembly language
•  #pragma import(__use_no_heap) from C.

If you include a heap-using function and also reference __use_no_heap or __use_no_heap_region, the linker reports an error. For example, the following sample code results in the linker error shown:

```c
#include <stdio.h>
#include <stdlib.h>
#pragma import(__use_no_heap)

void main()
{
    char *p = malloc(256);
    ...
}
```

Error: L6915E: Library reports error: __use_no_heap was requested, but malloc was referenced

To find out which objects are using the heap, link with --verbose --list=out.txt, search the output for the relevant symbol (in this case malloc), and find out what object referenced it.

__use_no_heap guards against the use of malloc(), realloc(), free(), and any function that uses those functions. For example, calloc() and other stdio functions.

__use_no_heap_region has the same properties as __use_no_heap, but in addition, guards against other things that use the heap memory region. For example, if you declare main() as a function taking arguments, the heap region is used for collecting argc and argv.

2.64.1  See also

Concepts
•  Modification of memory management functions in the C library on page 2-81.

Reference

Linker Reference:
•  --list=file on page 2-77
•  --verbose on page 2-142.
2.65  C library support for memory allocation functions

`malloc()`, `realloc()`, `calloc()`, and `free()` are built on a heap abstract data type. You can choose between Heap1 or Heap2, the two provided heap implementations.

The default implementations of `malloc()`, `realloc()`, and `calloc()` maintain an eight-byte aligned heap.

Concepts
- Heap1, standard heap implementation on page 2-84
- Heap2, alternative heap implementation on page 2-85.

Tasks
- Using a heap implementation from bare machine C on page 2-86.

Reference

* ARM® C and C++ Libraries and Floating-Point Support:
  - `alloca()` on page 2-5.
2.66 Heap1, standard heap implementation

Heap1, the default implementation, implements the smallest and simplest heap manager. The heap is managed as a single-linked list of free blocks held in increasing address order. The allocation policy is first-fit by address.

This implementation has low overheads, but the performance cost of malloc() or free() grows linearly with the number of free blocks. The smallest block that can be allocated is four bytes and there is an additional overhead of four bytes. If you expect more than 100 unallocated blocks it is recommended that you use Heap2.

2.66.1 See also

Concepts

- C library support for memory allocation functions on page 2-83.
2.67 Heap2, alternative heap implementation

Heap2 provides a compact implementation with the performance cost of malloc() or free() growing logarithmically with the number of free blocks. The allocation policy is first-fit by address. The smallest block that can be allocated is 12 bytes and there is an additional overhead of four bytes.

Heap2 is recommended when you require near constant-time performance in the presence of hundreds of free blocks. To select the alternative standard implementation, use either of the following:

• IMPORT __use_realtime_heap from assembly language
• #pragma import(__use_realtime_heap) from C.

The Heap2 real-time heap implementation must know the maximum address space that the heap spans. The smaller the address range, the more efficient the algorithm is.

By default, the heap extent is taken to be 16MB starting at the beginning of the heap (defined as the start of the first chunk of memory given to the heap manager by __rt_initial_stackheap() or __rt_heap_extend()).

The heap bounds are given by:

```c
struct __heap_extent {
    unsigned base, range;
};
```

```c
__value_in_regs struct __heap_extent __user_heap_extent(
    unsigned defaultbase, unsigned defaultsize);
```

The function prototype for __user_heap_extent() is in rt_misc.h.

(The Heap1 algorithm does not require the bounds on the heap extent. Therefore, it never calls this function.)

You must redefine __user_heap_extent() if:

• you require a heap to span more than 16MB of address space
• your memory model can supply a block of memory at a lower address than the first one supplied.

If you know in advance that the address space bounds of your heap are small, you do not have to redefine __user_heap_extent(), but it does speed up the heap algorithms if you do.

The input parameters are the default values that are used if this routine is not defined. You can, for example, leave the default base value unchanged and only adjust the size.

Note

The size field returned must be a power of two. The library does not check this and fails in unexpected ways if this requirement is not met. If you return a size of zero, the extent of the heap is set to 4GB.

2.67.1 See also

Concepts

• C library support for memory allocation functions on page 2-83.
2.68 Using a heap implementation from bare machine C

To use a heap implementation in an application that does not define `main()` and does not initialize the C library:

1. Call `_initAlloc(base, top)` to define the base and top of the memory you want to manage as a heap.

2. Define the function `unsigned __rt_heap_extend(unsigned size, void **block)` to handle calls to extend the heap when it becomes full.

2.68.1 See also

Concepts
- C library support for memory allocation functions on page 2-83.
2.69 Stack pointer initialization and heap bounds

The C library requires you to specify where the stack pointer begins. If you intend to use ARM library functions that use the heap, for example, malloc(), calloc(), or if you define argc and argv command-line arguments for main(), the C library also requires you to specify which region of memory the heap is initially expected to use.

The region of memory used by the heap can be extended at a later stage of program execution, if required.

You can specify where the stack pointer begins, and which region of memory the heap is initially expected to use, with any of the following methods:

- Define the symbol __initial_sp to point to the top of the stack. If using the heap, also define symbols __heap_base and __heap_limit.

- In a scatter file, either:
  - define ARM_LIB_STACK and ARM_LIB_HEAP regions
  - if you do not intend to use the heap, only define an ARM_LIB_STACK region
  - define an ARM_LIB_STACKHEAP region.

If you define an ARM_LIB_STACKHEAP region, the stack starts at the top of that region. The heap starts at the bottom.

**Note**

The above two methods are the only methods that microlib supports, of defining where the stack pointer starts and of defining the heap bounds.

- Implement __user_setup_stackheap() to set up the stack pointer and return the bounds of the initial heap region.

- If you are using legacy code that uses __user_initial_stackheap(), and you do not want to replace __user_initial_stackheap() with __user_setup_stackheap(), continue to use __user_initial_stackheap().

**Note**

ARM recommends that you switch to using __user_setup_stackheap() if you are still using __user_initial_stackheap(), unless your implementation of __user_initial_stackheap() is:
  - specialized in some way such that it is complex enough to require its own temporary stack to run on before it has created the proper stack
  - has some user-specific special requirement that means it has to be implemented in C rather than in assembly language.

The initial stack pointer must be aligned to a multiple of eight bytes.

By default, if memory allocated for the heap is destined to overlap with memory that lies in close proximity with the stack, the potential collision of heap and stack is automatically detected and the requested heap allocation fails. If you do not require this automatic collision detection, you can save a small amount of code size by disabling it with #pragma import __use_two_region_memory.
Note

The memory allocation functions (`malloc()`, `realloc()`, `calloc()`, `posix_memalign()`) attempt to detect allocations that collide with the current stack pointer. Such detection cannot be guaranteed to always be successful.

Although it is possible to automatically detect expansion of the heap into the stack, it is not possible to automatically detect expansion of the stack into heap memory.

For legacy purposes, it is possible for you to bypass all of these methods and behavior. You can do this by defining the following functions to perform your own stack and heap memory management:

- `__rt_stackheap_init()`
- `__rt_heap_extend()`

2.69.1 See also

Tasks
- Defining `__initial_sp`, `__heap_base` and `__heap_limit` on page 2-89
- Creating an initial stack pointer for use with microlib on page 3-8
- Creating the heap for use with microlib on page 3-9
- Extending heap size at runtime on page 2-90.

ARM® C and C++ Libraries and Floating-Point Support Reference:
- `__rt_heap_extend()` on page 2-32
- `__rt_stackheap_init()` on page 2-36.

Using the Linker:
- Specifying stack and heap using the scatter file on page 8-11.

Concepts
- Legacy support for `__user_initial_stackheap()` on page 2-91.

Reference

ARM® C and C++ Libraries and Floating-Point Support Reference:
- `__user_heap_extend()` on page 2-58
- `__user_heap_extent()` on page 2-59
- Legacy function `__user_initial_stackheap()` on page 2-69
- `__rt_heap_extend()` on page 2-32
- `__rt_stackheap_init()` on page 2-36
- `__user_setup_stackheap()` on page 2-60
- `__vectab_stack_and_reset` on page 2-61.
2.70 Defining __initial_sp, __heap_base and __heap_limit

One of several methods you can use to specify the initial stack pointer and heap bounds is to define the following symbols:

- __initial_sp
- __heap_base
- __heap_limit.

You can define these symbols in an assembly language file, or by using the embedded assembler in C.

For example:

```c
__asm void dummy_function(void)
{
    EXPORT __initial_sp
    EXPORT __heap_base
    EXPORT __heap_limit

    __initial_sp EQU STACK_BASE
    __heap_base EQU HEAP_BASE
    __heap_limit EQU (HEAP_BASE + HEAP_SIZE)
}
```

The constants STACK_BASE, HEAP_BASE and HEAP_SIZE can be defined in a header file, for example stack.h, as follows:

```c
/* stack.h */
#define HEAP_BASE 0x20100000 /* Example memory addresses */
#define STACK_BASE 0x20200000
#define HEAP_SIZE ((STACK_BASE-HEAP_BASE)/2)
#define STACK_SIZE ((STACK_BASE-HEAP_BASE)/2)
```

--- Note

This method of specifying the initial stack pointer and heap bounds is supported by both the standard C library (standardlib) and the micro C library (microlib).

2.70.1 See also

Concepts

- *Stack pointer initialization and heap bounds* on page 2-87.
2.71 Extending heap size at runtime

To enable the heap to extend into areas of memory other than the region of memory that is specified when the program starts, you can redefine the function __user_heap_extend().

__user_heap_extend() returns blocks of memory for heap usage in extending the size of the heap.

2.71.1 See also

Concepts
• Stack pointer initialization and heap bounds on page 2-87.

Reference
Using the ARM® C and C++ Libraries and Floating-Point Support:
• __rt_heap_extend() on page 2-32.
2.72 Legacy support for __user_initial_stackheap()

Defined in rt_misc.h, __user_initial_stackheap() is supported for backwards compatibility with earlier versions of the ARM C and C++ libraries.

Note

ARM recommends that you use __user_setup_stackheap() in preference to __user_initial_stackheap().

The differences between __user_initial_stackheap() and __user_setup_stackheap() are:

• __user_initial_stackheap() receives the stack pointer (containing the same value it had on entry to __main()) in r1, and is expected to return the new stack base in r1.
  __user_setup_stackheap() receives the stack pointer in sp, and returns the stack base in sp.

• __user_initial_stackheap() is provided with a small temporary stack to run on. This temporary stack enables __user_initial_stackheap() to be implemented in C, providing that it uses no more than 88 bytes of stack space.
  __user_setup_stackheap() has no temporary stack and cannot usually be implemented in C.

Using __user_setup_stackheap() instead of __user_initial_stackheap() reduces code size, because __user_setup_stackheap() has no requirement for a temporary stack.

In the following circumstances you cannot use the provided __user_setup_stackheap() function, but you can use the __user_initial_stackheap() function:

• your implementation is sufficiently complex that it warrants the use of a temporary stack when setting up the initial heap and stack

• you have a requirement to implement the heap and stack creation code in C rather than in assembly language.

2.72.1 See also

Reference

ARM® C and C++ Libraries and Floating-Point Support Reference:

• Legacy function __user_initial_stackheap() on page 2-69
• __user_setup_stackheap() on page 2-60.
2.73 Tailoring input/output functions in the C and C++ libraries

High-level input/output, such as the functions fscanf() and fprintf(), and the C++ object std::cout, are not target-dependent. However, the higher-level functions perform input/output by calling lower-level functions that are target-dependent. To retarget input/output, you can either avoid these higher-level functions or redefine the lower-level functions.

For more information on I/O functions, see the rt_sys.h file.

2.73.1 See also

Tasks

- Re-implementing __backspace() in the C library on page 2-101
- Re-implementing __backspacewc() in the C library on page 2-102
- Redefining low-level library functions to enable direct use of high-level library functions on page 2-97.

Concepts

- Target dependencies on low-level functions in the C and C++ libraries on page 2-93
- The C library printf family of functions on page 2-95
- The C library scanf family of functions on page 2-96
- The C library functions fread(), fgets() and gets() on page 2-100
- Target-dependent I/O support functions in the C library on page 2-103
- ARM C libraries and multithreading on page 2-16.

Reference

ARM® C and C++ Libraries and Floating-Point Support Reference:

- _sys_open() on page 2-50
- _sys_close() on page 2-44
- _sys_read() on page 2-51
- _sys_write() on page 2-54
- _sys_flen() on page 2-48
- _sys_seek() on page 2-52
- _sys_istty() on page 2-49
- _sys_tmpnam() on page 2-53
- _sys_command_string() on page 2-45
- #pragma import(_main_redirection) on page 2-22.
2.74 Target dependencies on low-level functions in the C and C++ libraries

Table 2-9 shows the dependencies of the higher-level functions on lower-level functions. If you define your own versions of the lower-level functions, you can use the library versions of the higher-level functions directly.

fgets() uses __FILE, but fputs() uses __FILE and ferror().

Note You must provide definitions of __stdin and __stdout if you use any of their associated high-level functions. This applies even if your re-implementations of other functions, such as fgets() and fputs(), do not reference any data stored in __stdin and __stdout.

Table key:
1. __FILE, the file structure.
2. __stdin, the standard input object of type __FILE.
3. __stdout, the standard output object of type __FILE.
4. fputs(), outputs a character to a file.
5. ferror(), returns the error status accumulated during file I/O.
6. fgets(), gets a character from a file.
7. fgetwc()
8. fputwc()
9. __backspace(), moves the file pointer to the previous character.
10. __backspacewc().

<table>
<thead>
<tr>
<th>High-level function</th>
<th>Low-level object</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>fgets</td>
<td></td>
</tr>
<tr>
<td>fgetws</td>
<td></td>
</tr>
<tr>
<td>fprintf</td>
<td></td>
</tr>
<tr>
<td>fputs</td>
<td></td>
</tr>
<tr>
<td>fputws</td>
<td>x</td>
</tr>
<tr>
<td>fread</td>
<td>x</td>
</tr>
<tr>
<td>fscanf</td>
<td>x</td>
</tr>
<tr>
<td>fwprintf</td>
<td>x</td>
</tr>
<tr>
<td>fwrite</td>
<td>x</td>
</tr>
<tr>
<td>fwscanf</td>
<td>x</td>
</tr>
<tr>
<td>getchar</td>
<td>x</td>
</tr>
<tr>
<td>gets</td>
<td>x</td>
</tr>
<tr>
<td>getwchar</td>
<td>x</td>
</tr>
<tr>
<td>perror</td>
<td>x</td>
</tr>
</tbody>
</table>
Note

If you choose to re-implement fgetc(), fputc(), and __backspace(), be aware that fopen() and related functions use the ARM layout for the __FILE structure. You might also have to re-implement fopen() and related functions if you define your own version of __FILE.

2.74.1 See also

Tasks

- Re-implementing __backspace() in the C library on page 2-101
- Redefining low-level library functions to enable direct use of high-level library functions on page 2-97
- Tailoring input/output functions in the C and C++ libraries on page 2-92.

Concepts

- The C library printf family of functions on page 2-95
- The C library scanf family of functions on page 2-96.

Other information

2.75 The C library printf family of functions

The printf family consists of _printf(), printf(), _fprintf(), fprintf(), vprintf(), and vfprintf(). All these functions use __FILE opaquely and depend only on the functions fputc() and ferror(). The functions _printf() and _fprintf() are identical to printf() and fprintf() except that they cannot format floating-point values.

The standard output functions of the form _printf(...) are equivalent to:

fprintf(& __stdout, ...)

where __stdout has type __FILE.

2.75.1 See also

Tasks

• Tailoring input/output functions in the C and C++ libraries on page 2-92.
2.76 The C library scanf family of functions

The `scanf()` family consists of `scanf()` and `fscanf()`. These functions depend only on the functions `fgetc()`, `__FILE`, and `__backspace()`.

The standard input function of the form `scanf(...)` is equivalent to:

```c
fscanf(& __stdin, ...)
```

where `__stdin` is of type `__FILE`.

2.76.1 See also

Tasks

- Re-implementing `__backspace()` in the C library on page 2-101
- Tailoring input/output functions in the C and C++ libraries on page 2-92.
2.77 Redefining low-level library functions to enable direct use of high-level library functions

If you define your own version of __FILE, your own fputc() and ferror() functions, and the __stdout object, you can use all of the printf() family, fwrite(), fputs(), puts() and the C++ object std::cout unchanged from the library. Example 2-9 and Example 2-10 on page 2-98 show you how to do this. Consider modifying the system routines if you require real file handling.

You are not required to re-implement every function shown in these examples. Only re-implement the functions that are used in your application.

Example 2-9 Retargeting printf()

```c
#include <stdio.h>

struct __FILE
{
    int handle;
    /* Whatever you require here. If the only file you are using is */
    /* standard output using printf() for debugging, no file handling */
    /* is required. */
};

/* FILE is typedef'd in stdio.h. */
FILE __stdout;

int fputc(int ch, FILE *f)
{
    /* Your implementation of fputc(). */
    return ch;
}

int ferror(FILE *f)
{
    /* Your implementation of ferror(). */
    return 0;
}

void test(void)
{
    printf("Hello world\n");
}
```

Note

Be aware of endianness with fputc(). fputc() takes an int parameter, but contains only a character. Whether the character is in the first or the last byte of the integer variable depends on the endianness. The following code sample avoids problems with endianness:

```c
extern void sendchar(char *ch);

int fputc(int ch, FILE *f)
{
    /* example: write a character to an LCD */
    char tempch = ch; // temp char avoids endianness issue
    sendchar(&tempch);
    return ch;
}
```
sendchar(&tempch);
return ch;
}

Example 2-10 Retargeting cout

File 1: Re-implement any functions that require re-implementation.

```c
#include <stdio.h>

namespace std {

struct __FILE
{
    int handle;

    /* Whatever you require here. If the only file you are using is */
    /* standard output using printf() for debugging, no file handling */
    /* is required. */
};

FILE __stdout;
FILE __stdin;
FILE __stderr;

int fgetc(FILE *f)
{
    /* Your implementation of fgetc(). */
    return 0;
};
int fputc(int c, FILE *stream)
{
    /* Your implementation of fputc(). */
}
int ferror(FILE *stream)
{
    /* Your implementation of ferror(). */
}
long int ftell(FILE *stream)
{
    /* Your implementation of ftell(). */
}
int fclose(FILE *f)
{
    /* Your implementation of fclose(). */
    return 0;
}
int fseek(FILE *f, long nPos, int nMode)
{
    /* Your implementation of fseek(). */
    return 0;
}
int fflush(FILE *f)
{
    /* Your implementation of fflush(). */
    return 0;
}
}
```

File 2: Print "Hello world" using your re-implemented functions.
#include <stdio.h>
#include <iostream>
using namespace std;

int main()
{
    cout << "Hello world\n";
    return 0;
}

By default, fread() and fwrite() call fast block input/output functions that are part of the ARM stream implementation. If you define your own __FILE structure instead of using the ARM stream implementation, fread() and fwrite() call fgetc() instead of calling the block input/output functions.

2.77.1 See also

Tasks

- Tailoring input/output functions in the C and C++ libraries on page 2-92.
2.78 The C library functions fread(), fgets() and gets()

The functions fread(), fgets(), and gets() are implemented as fast block input/output functions where possible. These fast implementations are part of the ARM stream implementation and they bypass fgetc(). Where the fast implementation is not possible, they are implemented as a loop over fgetc() and ferror(). Each uses the FILE argument opaquely.

If you provide your own implementation of __FILE, __stdin (for gets()), fgetc(), and ferror(), you can use these functions, and the C++ object std::cin directly from the library.

2.78.1 See also

Tasks
• Tailoring input/output functions in the C and C++ libraries on page 2-92.
2.79 Re-implementing __backspace() in the C library

The function __backspace() is used by the scanf family of functions, and must be re-implemented if you retarget the stdio arrangements at the fgetc() level.

--- Note ---

Normally, you are not required to call __backspace() directly, unless you are implementing your own scanf-like function.

---

The semantics are:

```c
int __backspace(FILE *stream);
```

__backspace(stream) must only be called after reading a character from the stream. You must not call it after a write, a seek, or immediately after opening the file, for example. It returns to the stream the last character that was read from the stream, so that the same character can be read from the stream again by the next read operation. This means that a character that was read from the stream by scanf but that is not required (that is, it terminates the scanf operation) is read correctly by the next function that reads from the stream.

__backspace is separate from ungetc(). This is to guarantee that a single character can be pushed back after the scanf family of functions has finished.

The value returned by __backspace() is either 0 (success) or EOF (failure). It returns EOF only if used incorrectly, for example, if no characters have been read from the stream. When used correctly, __backspace() must always return 0, because the scanf family of functions do not check the error return.

The interaction between __backspace() and ungetc() is:

- If you apply __backspace() to a stream and then ungetc() a character into the same stream, subsequent calls to fgetc() must return first the character returned by ungetc(), and then the character returned by __backspace().

- If you ungetc() a character back to a stream, then read it with fgetc(), and then backspace it, the next character read by fgetc() must be the same character that was returned to the stream. That is the __backspace() operation must cancel the effect of the fgetc() operation. However, another call to ungetc() after the call to __backspace() is not required to succeed.

- The situation where you ungetc() a character into a stream and then __backspace() another one immediately, with no intervening read, never arises. __backspace() must only be called after fgetc(), so this sequence of calls is illegal. If you are writing __backspace() implementations, you can assume that the unget() of a character into a stream followed immediately by a __backspace() with no intervening read, never occurs.

2.79.1 See also

Tasks

- Re-implementing __backspacewc() in the C library on page 2-102
- Tailoring input/output functions in the C and C++ libraries on page 2-92.
2.80 Re-implementing __backspacewc() in the C library

__backspacewc() is the wide-character equivalent of __backspace(). __backspacewc() behaves in the same way as __backspace() except that it pushes back the last wide character instead of a narrow character.

2.80.1 See also

Tasks
• Tailoring input/output functions in the C and C++ libraries on page 2-92.

Reference
• Re-implementing __backspace() in the C library on page 2-101.
2.81 Target-dependent I/O support functions in the C library

rt_sys.h defines the type FILEHANDLE. The value of FILEHANDLE is returned by _sys_open() and identifies an open file on the host system.

Target-dependent I/O functions use semihosting. If any function is redefined, all stream-support functions must be redefined.

If the _sys_* functions are redefined, both normal character I/O and wide character I/O works. That is, you are not required to do anything extra with these functions for wide character I/O to work.

2.81.1 See also

Tasks
• Tailoring input/output functions in the C and C++ libraries on page 2-92.
2.82 Tailoring non-input/output C library functions

In addition to tailoring input/output C library functions, many C library functions that are not input/output functions can also be tailored. Implementation of these ISO standard functions depends entirely on the target operating system.

The default implementation of these functions is semihosted. That is, each function uses semihosting.

2.82.1 See also

Reference

ARM® C and C++ Libraries and Floating-Point Support Reference:
- `clock()` on page 2-6
- `_clock_init()` on page 2-7
- `time()` on page 2-56
- `remove()` on page 2-26
- `rename()` on page 2-27
- `system()` on page 2-55
- `getenv()` on page 2-13
- `_getenv_init()` on page 2-14.
2.83 Real-time integer division in the ARM libraries

The division routine supplied with the ARM libraries provides good overall performance. However, the amount of time required to perform a division depends on the input values. For example, a division that generates a four-bit quotient might require only 12 cycles while a 32-bit quotient might require 96 cycles. Depending on your target, some applications require a faster worst-case cycle count at the expense of lower average performance. For this reason, the ARM library provides two divide routines.

The real-time routine:
- always executes in fewer than 45 cycles
- is faster than the standard division routine for larger quotients
- is slower than the standard division routine for typical quotients
- returns the same results
- does not require any change in the surrounding code.

Note
- Real-time division is not available in the libraries for Cortex-M1 or Cortex-M0.
- The Cortex-R4 and Cortex-M3 processors support hardware floating-point divide, so they do not require the library divide routines.

2.83.1 See also

Tasks
- Selecting real-time division in the ARM libraries on page 2-106.
2.84 Selecting real-time division in the ARM libraries

Select the real-time divide routine, instead of the generally more efficient routine, by using either of the following methods:

- IMPORT __use_realtime_division from assembly language
- #pragma import(__use_realtime_division) from C.

2.84.1 See also

Concepts
- Real-time integer division in the ARM libraries on page 2-105.
2.85 How the ARM C library fulfills ISO C specification requirements

The ISO specification leaves some features to implementors, but requires that implementation choices be documented. The implementation of the generic ARM C library in this respect is as follows:

- The macro \texttt{NULL} expands to the integer constant \texttt{0}.
- If a program redefines a reserved external identifier, an error might occur when the program is linked with the standard libraries. If it is not linked with standard libraries, no error is diagnosed.
- The \texttt{__aeabi_assert()} function prints information on the failing diagnostic on \texttt{stderr} and then calls the \texttt{abort()} function:
  
  \begin{verbatim}
  *** assertion failed: expression, file name, line number
  \end{verbatim}

  \textbf{Note}

  The behavior of the \texttt{assert} macro depends on the conditions in operation at the most recent occurrence of \texttt{#include <assert.h>}.

- The following functions test for character values in the range \texttt{EOF} (-1) to 255 inclusive:
  - \texttt{isalnum()}
  - \texttt{isalpha()}
  - \texttt{iscntrl()}
  - \texttt{islower()}
  - \texttt{isprint()}
  - \texttt{isupper()}
  - \texttt{ispunct()}.

- The fully POSIX-compliant functions \texttt{remquo()}, \texttt{remquof()} and \texttt{remquol()} return the remainder of the division of \texttt{x} by \texttt{y} and store the quotient of the division in the pointer \texttt{quo}. An implementation-defined integer value defines the number of bits of the quotient that are stored. In the ARM C library, this value is set to 4.

- C99 behavior, with respect to mathlib error handling, is enabled by default.

  \textbf{Note}

  In RVCT 4.0, this behavior is not enabled by default, but is enabled through the use of \texttt{IMPORT __use_c99_matherr} in assembly language, or \texttt{#pragma import __use_c99_matherr} in C.

2.85.1 See also

Concepts
- mathlib error handling on page 2-108
- ISO-compliant implementation of signals supported by the signal() function in the C library and additional type arguments on page 2-110
- ISO-compliant C library input/output characteristics on page 2-112
- Standard C++ library implementation definition on page 2-114
- Program exit and the assert macro on page 2-62
- C and C++ library naming conventions on page 2-120.
2.86  mathlib error handling

In ARM Compiler 4.1 and later, the error handling of mathematical functions is consistent with Annex F of the ISO/IEC C99 standard. In RVCT 4.0 and earlier, it is not.

2.86.1  mathlib error handling in RVCT 4.0 and earlier

To invoke RVCT 4.0 and earlier behavior, you can define _use_rvct_matherr. Table 2-10 shows how the math functions respond when supplied with out-of-range arguments.

<table>
<thead>
<tr>
<th>Function</th>
<th>Condition</th>
<th>Returned value</th>
<th>Error number</th>
</tr>
</thead>
<tbody>
<tr>
<td>acos(x)</td>
<td>abs(x) &gt; 1</td>
<td>QNaN</td>
<td>EDOM</td>
</tr>
<tr>
<td>asin(x)</td>
<td>abs(x) &gt; 1</td>
<td>QNaN</td>
<td>EDOM</td>
</tr>
<tr>
<td>atan2(x, y)</td>
<td>x = 0, y = 0</td>
<td>QNaN</td>
<td>EDOM</td>
</tr>
<tr>
<td>atan2(x, y)</td>
<td>x = Inf, y = Inf</td>
<td>QNaN</td>
<td>EDOM</td>
</tr>
<tr>
<td>cos(x)</td>
<td>x = Inf</td>
<td>QNaN</td>
<td>EDOM</td>
</tr>
<tr>
<td>cosh(x)</td>
<td>Overflow</td>
<td>+Inf</td>
<td>ERANGE</td>
</tr>
<tr>
<td>exp(x)</td>
<td>Overflow</td>
<td>+Inf</td>
<td>ERANGE</td>
</tr>
<tr>
<td>exp(x)</td>
<td>Underflow</td>
<td>+0</td>
<td>ERANGE</td>
</tr>
<tr>
<td>fmod(x, y)</td>
<td>x = Inf</td>
<td>QNaN</td>
<td>EDOM</td>
</tr>
<tr>
<td>fmod(x, y)</td>
<td>y = 0</td>
<td>QNaN</td>
<td>EDOM</td>
</tr>
<tr>
<td>log(x)</td>
<td>x &lt; 0</td>
<td>QNaN</td>
<td>EDOM</td>
</tr>
<tr>
<td>log(x)</td>
<td>x = 0</td>
<td>-Inf</td>
<td>EDOM</td>
</tr>
<tr>
<td>log10(x)</td>
<td>x &lt; 0</td>
<td>QNaN</td>
<td>EDOM</td>
</tr>
<tr>
<td>log10(x)</td>
<td>x = 0</td>
<td>-Inf</td>
<td>EDOM</td>
</tr>
<tr>
<td>pow(x, y)</td>
<td>Overflow</td>
<td>+Inf</td>
<td>ERANGE</td>
</tr>
<tr>
<td>pow(x, y)</td>
<td>Underflow</td>
<td>0</td>
<td>ERANGE</td>
</tr>
<tr>
<td>pow(x, y)</td>
<td>x=0 or x=Inf, y=0</td>
<td>+1</td>
<td>EDOM</td>
</tr>
<tr>
<td>pow(x, y)</td>
<td>x=0, y&lt;0</td>
<td>-Inf</td>
<td>EDOM</td>
</tr>
<tr>
<td>pow(x, y)</td>
<td>x=0, y&lt;0 and y integer</td>
<td>-Inf</td>
<td>EDOM</td>
</tr>
<tr>
<td>pow(x, y)</td>
<td>x = -0, y&lt;0 and y non-integer</td>
<td>QNaN</td>
<td>EDOM</td>
</tr>
<tr>
<td>pow(x, y)</td>
<td>x&lt;0, y non-integer</td>
<td>QNaN</td>
<td>EDOM</td>
</tr>
<tr>
<td>pow(x, y)</td>
<td>x=1, y=Inf</td>
<td>QNaN</td>
<td>EDOM</td>
</tr>
<tr>
<td>sqrt(x)</td>
<td>x &lt; 0</td>
<td>QNaN</td>
<td>EDOM</td>
</tr>
<tr>
<td>sin(x)</td>
<td>x=Inf</td>
<td>QNaN</td>
<td>EDOM</td>
</tr>
<tr>
<td>sinh(x)</td>
<td>Overflow</td>
<td>+Inf</td>
<td>ERANGE</td>
</tr>
<tr>
<td>tan(x)</td>
<td>x=Inf</td>
<td>QNaN</td>
<td>EDOM</td>
</tr>
<tr>
<td>atan(x)</td>
<td>NaN</td>
<td>NaN</td>
<td>None</td>
</tr>
</tbody>
</table>
HUGE_VAL is an alias for Inf. Consult the errno variable for the error number. Other than the cases shown in Table 2-10 on page 2-108, all functions return QNaN when passed QNaN and throw an invalid operation exception when passed SNaN.

The string passed to C99 nan() is ignored, and the same Not a Number (NaN) is always returned, namely the one with all fraction bits clear except the topmost one. The sign bit is also clear. Passing strings of the form NAN(xxxx) to strtod has the same effect.

### 2.86.2 See also

#### Concepts

- How the ARM C library fulfills ISO C specification requirements on page 2-107
- ISO-compliant implementation of signals supported by the signal() function in the C library and additional type arguments on page 2-110
- ISO-compliant C library input/output characteristics on page 2-112
- Standard C++ library implementation definition on page 2-114.

#### Other info

2.87 ISO-compliant implementation of signals supported by the `signal()` function in the C library and additional type arguments

Table 2-11 shows the signals supported by the `signal()` function. It also shows which signals use an additional argument to give more information about the circumstance in which the signal was raised. The additional argument is given in the `type` parameter of `__raise()`. For example, division by zero results in a `SIGFPE` (signal == 2) signal with a corresponding additional argument of `FE_EX_DIVBYZERO` (type == 2).

<table>
<thead>
<tr>
<th>Signal</th>
<th>Number</th>
<th>Description</th>
<th>Additional argument</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIGABRT</td>
<td>1</td>
<td>Returned when any untrapped exception is thrown, such as:</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• a negative array size is allocated through the <code>new</code> operator</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• an invalid dynamic cast.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>This signal is only used if <code>abort()</code> or <code>assert()</code> are called by your C++ application, and <code>--exceptions</code> is specified.</td>
<td></td>
</tr>
<tr>
<td>SIGFPE</td>
<td>2</td>
<td>Used to signal any arithmetic exception, for example, division by zero. Used by hard and soft floating-point and by integer division.</td>
<td>A set of bits from <code>{FE_EX_INEXACT, FE_EX_UNDERFLOW, FE_EX_OVERFLOW, FE_EX_DIVBYZERO, FE_EX_INVALID, DIVBYZERO}</code></td>
</tr>
<tr>
<td>SIGILL a</td>
<td>3</td>
<td>Illegal instruction.</td>
<td>None</td>
</tr>
<tr>
<td>SIGINT a</td>
<td>4</td>
<td>Attention request from user.</td>
<td>None</td>
</tr>
<tr>
<td>SIGSEGV a</td>
<td>5</td>
<td>Bad memory access.</td>
<td>None</td>
</tr>
<tr>
<td>SIGTERM a</td>
<td>6</td>
<td>Termination request.</td>
<td>None</td>
</tr>
<tr>
<td>SIGSTAK</td>
<td>7</td>
<td>Obsolete.</td>
<td>None</td>
</tr>
<tr>
<td>SIGRTRED</td>
<td>8</td>
<td>Redirection failed on a runtime library input/output stream.</td>
<td>Name of file or device being re-opened to redirect a standard stream</td>
</tr>
<tr>
<td>SIGRTMEM</td>
<td>9</td>
<td>Out of heap space during initialization or after corruption.</td>
<td>Size of failed request</td>
</tr>
<tr>
<td>SIGUSR1</td>
<td>10</td>
<td>User-defined.</td>
<td>User-defined</td>
</tr>
<tr>
<td>SIGUSR2</td>
<td>11</td>
<td>User-defined.</td>
<td>User-defined</td>
</tr>
<tr>
<td>SIGPVFN</td>
<td>12</td>
<td>A pure virtual function was called from C++.</td>
<td>-</td>
</tr>
<tr>
<td>SIGCPPL</td>
<td>13</td>
<td>Not normally used.</td>
<td>-</td>
</tr>
<tr>
<td>SIGOUTOFHEAP b</td>
<td>14</td>
<td>Returned by the C++ function <code>::operator new</code> when out of heap space.</td>
<td>Size of failed request</td>
</tr>
</tbody>
</table>

| reserved | 15-31 | Reserved.                                                                                          | Reserved |
| other    | > 31  | User-defined.                                                                                      | User-defined |

a. This signal is never generated by the library. It is available for you to raise manually, if required.

b. Not used in RVCT 2.1, and later.
Although `SIGSTAK` exists in `signal.h`, this signal is not generated by the C library and is considered obsolete.

A signal number greater than `SIGUSR2` can be passed through `__raise()` and caught by the default signal handler, but it cannot be caught by a handler registered using `signal()`.

`signal()` returns an error code if you try to register a handler for a signal number greater than `SIGUSR2`.

The default handling of all recognized signals is to print a diagnostic message and call `exit()`. This default behavior applies at program startup and until you change it.

Caution

The IEEE 754 standard for floating-point processing states that the default action to an exception is to proceed without a trap. A raised exception in floating-point calculations does not, by default, generate `SIGFPE`. You can modify floating-point error handling by tailoring the functions and definitions in `fenv.h`. However, you must compile these functions with a non-default FP model, such as `--fpmode=ieee_fixed` and upwards.

For all the signals in Table 2-11 on page 2-110, when a signal occurs, if the handler points to a function, the equivalent of `signal(sig, SIG_DFL)` is executed before the call to the handler.

If the `SIGILL` signal is received by a handler specified to by the `signal()` function, the default handling is reset.

2.87.1 See also

Concepts

- How the ARM C library fulfills ISO C specification requirements on page 2-107
- mathlib error handling on page 2-108
- ISO-compliant C library input/output characteristics on page 2-112
- Standard C++ library implementation definition on page 2-114
- Modification of C library functions for error signaling, error handling, and program exit on page 2-80
- Exception types recognized by the ARM floating-point environment on page 4-45.

Reference

ARM® C and C++ Libraries and Floating-Point Support Reference:
- `__raise()` on page 2-23
- `__rt_raise()` on page 2-35.

Compiler Reference:
- `--exceptions, --no_exceptions` on page 3-37
- `--fpmode=model` on page 3-42.

Other information

2.88 ISO-compliant C library input/output characteristics

The generic ARM C library has the following input/output characteristics:

- The last line of a text stream does not require a terminating newline character.
- Space characters written out to a text stream immediately before a newline character do appear when read back in.
- No NUL characters are appended to a binary output stream.
- The file position indicator of an append mode stream is initially placed at the end of the file.
- A write to a text stream causes the associated file to be truncated beyond the point where the write occurred if this is the behavior of the device category of the file.
- If semihosting is used, the maximum number of open files is limited by the available target memory.
- A zero-length file exists, that is, where no characters have been written by an output stream.
- A file can be opened many times for reading, but only once for writing or updating. A file cannot simultaneously be open for reading on one stream, and open for writing or updating on another.
- Local time zones and Daylight Saving Time are not implemented. The values returned indicate that the information is not available. For example, the gmtime() function always returns NULL.
- The status returned by exit() is the same value that was passed to it. For definitions of EXIT_SUCCESS and EXIT_FAILURE, see the header file stdlib.h. Semihosting, however, does not pass the status back to the execution environment.
- The error messages returned by the strerror() function are identical to those given by the perror() function.
- If the size of area requested is zero, calloc() and realloc() return NULL.
- If the size of area requested is zero, malloc() returns a pointer to a zero-size block.
- abort() closes all open files and deletes all temporary files.
- fprintf() prints %p arguments in lowercase hexadecimal format as if a precision of 8 had been specified. If the variant form (%#p) is used, the number is preceded by the character @.
- fscanf() treats %p arguments exactly the same as %x arguments.
- fscanf() always treats the character "." in a %...[...] argument as a literal character.
- ftell(), fsetpos() and fgetpos() set errno to the value of EDOM on failure.
• perror() generates the messages shown in Table 2-12.

<table>
<thead>
<tr>
<th>Error</th>
<th>Message</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No error (errno = 0)</td>
</tr>
<tr>
<td>EDOM</td>
<td>EDOM - function argument out of range</td>
</tr>
<tr>
<td>ERANGE</td>
<td>ERANGE - function result not representable</td>
</tr>
<tr>
<td>ESIGNUM</td>
<td>ESIGNUM - illegal signal number</td>
</tr>
<tr>
<td>Others</td>
<td>Unknown error</td>
</tr>
</tbody>
</table>

The following characteristics are unspecified in the ARM C library. They must be specified in an ISO-compliant implementation:

• the validity of a filename
• whether remove() can remove an open file
• the effect of calling the rename() function when the new name already exists
• the effect of calling getenv() (the default is to return NULL, no value available)
• the effect of calling system()
• the value returned by clock().

2.88.1 See also

Concepts

• How the ARM C library fulfills ISO C specification requirements on page 2-107
• ISO-compliant implementation of signals supported by the signal() function in the C library and additional type arguments on page 2-110
• mathlib error handling on page 2-108
• Standard C++ library implementation definition on page 2-114.
2.89  **Standard C++ library implementation definition**

The ARM C++ library provides all of the library defined in the *ISO/IEC 14822 :1998(E) C++ Standard*, aside from some limitations described in Table 2-13.

The Standard C++ library is distributed in binary form only.

Table 2-13 describes the most important features missing from the current release.

<table>
<thead>
<tr>
<th>Standard</th>
<th>Implementation differences</th>
</tr>
</thead>
<tbody>
<tr>
<td>locale</td>
<td>The locale message facet is not supported. It fails to open catalogs at runtime because the ARM C library does not support <code>catopen</code> and <code>catclose</code> through <code>nl_types.h</code>. One of two locale definitions can be selected at link time. Other locales can be created by user-redefinable functions.</td>
</tr>
<tr>
<td>Timezone</td>
<td>Not supported by the ARM C library.</td>
</tr>
</tbody>
</table>
2.90  C library functions and extensions

The ARM C library is fully compliant with the ISO C99 library standard. See Table 2-14 for POSIX, BSD-derived, and ARM compiler-specific extensions.

Table 2-14 C library extensions

<table>
<thead>
<tr>
<th>Function</th>
<th>Header file definition</th>
<th>Extension</th>
</tr>
</thead>
<tbody>
<tr>
<td>wcstombs()</td>
<td>stdlib.h</td>
<td>POSIX extended functionality</td>
</tr>
<tr>
<td>posix_memalign()</td>
<td>stdlib.h</td>
<td>POSIX extended functionality</td>
</tr>
<tr>
<td>alloca()</td>
<td>alloca.h</td>
<td>Common non standard extension to many C libraries</td>
</tr>
<tr>
<td>strlcpy()</td>
<td>string.h</td>
<td>Common BSD-derived extension to many C libraries</td>
</tr>
<tr>
<td>strlcat()</td>
<td>string.h</td>
<td>Common BSD-derived extension to many C libraries</td>
</tr>
<tr>
<td>strcasecmp()</td>
<td>string.h</td>
<td>Standardized by POSIX.</td>
</tr>
<tr>
<td>strncasecmp()</td>
<td>string.h</td>
<td>Standardized by POSIX.</td>
</tr>
<tr>
<td>_fisatty()</td>
<td>stdio.h</td>
<td>Specific to the ARM compiler</td>
</tr>
<tr>
<td>__heapstats()</td>
<td>stdlib.h</td>
<td>Specific to the ARM compiler</td>
</tr>
<tr>
<td>__heapvalid()</td>
<td>stdlib.h</td>
<td>Specific to the ARM compiler</td>
</tr>
</tbody>
</table>

2.90.1  See also

Reference

ARM® C and C++ Libraries and Floating-Point Support Reference:

- wcstombs() on page 2-62
- alloca() on page 2-5
- strlcpy() on page 2-43
- strlcat() on page 2-42
- strcasecmp() on page 2-40
- strncasecmp() on page 2-41
- _fisatty() on page 2-11
- __heapstats() on page 2-15
- __heapvalid() on page 2-16.
2.91 Persistence of C and C++ library names across releases of the ARM compilation tools

The library naming convention described in this documentation applies to the current release of the ARM compilation tools.

--- Note ---
Do not rely on C and C++ library names. They might change in future releases.

2.91.1 See also

Tasks
• Managing projects that have explicit C or C++ library names in makefiles on page 2-118.

Concepts
• Link time selection of C and C++ libraries on page 2-117
• Compiler generated and library-resident helper functions on page 2-119
• C and C++ library naming conventions on page 2-120.
2.92 Link time selection of C and C++ libraries

Normally, you do not have to list any of the C and C++ libraries explicitly on the linker command line. The ARM linker automatically selects the correct C or C++ libraries to use, and it might use several, based on the accumulation of the object attributes.

2.92.1 See also

Tasks
- Managing projects that have explicit C or C++ library names in makefiles on page 2-118.

Concepts
- Persistence of C and C++ library names across releases of the ARM compilation tools on page 2-116
- Compiler generated and library-resident helper functions on page 2-119
- C and C++ library naming conventions on page 2-120.
2.93 Managing projects that have explicit C or C++ library names in makefiles

If library names are explicitly named in a makefile, you must rebuild your project as follows:

1. Remove the explicit references to the old library names from the linker command-line.
2. Add `--info libraries` to the linker command-line and rebuild the project. This produces a list of all the libraries in use.
3. Add the new list of libraries to the linker command-line.

A specific library can be included in a scatter-loading file.

2.93.1 See also

**Tasks**

*Using the Linker:*

- About placing ARM C and C++ library code on page 8-45.

**Concepts**

- Persistence of C and C++ library names across releases of the ARM compilation tools on page 2-116
- Link time selection of C and C++ libraries on page 2-117
- Compiler generated and library-resident helper functions on page 2-119
- C and C++ library naming conventions on page 2-120.

**Reference**

*Linker Reference:*

- `--info=topic[,topic,...]` on page 2-59.
2.94 Compiler generated and library-resident helper functions

Compiler support or helper functions specific to the compilation tools are typically used when the compiler cannot easily produce a suitable code sequence itself.

In RVCT v4.0 and later, the helper functions are generated by the compiler in the resulting object files.

In RVCT v3.1 and earlier, the helper functions reside in libraries. Because these libraries are specific to the ARM C compiler, they are intended to be redistributed as necessary with your own code. For example, if you are distributing a library to a third party, they might also require the appropriate helper library to link their final application successfully. Be aware of redistribution rights of the libraries, as specified in your End User License Agreement.

2.94.1 See also

Tasks
• Managing projects that have explicit C or C++ library names in makefiles on page 2-118.

Concepts
• Persistence of C and C++ library names across releases of the ARM compilation tools on page 2-116
• Link time selection of C and C++ libraries on page 2-117
• C and C++ library naming conventions on page 2-120.
2.95  C and C++ library naming conventions

The library filename identifies how the variant was built. The values for the fields of the
filename, and the relevant build options are:

```
*root*/prefix_arch[fpu][entrant].endian
```

- root         armlib  An ARM C library.
- cpplib       An ARM C++ library.
- prefix       c       ISO C and C++ basic runtime support.
- cpp          Rogue Wave C++ library.
- cpprt        The ARM C++ runtime libraries.
- f            --fpmode=ieee_fixed.
                IEEE-compliant library with a fixed rounding mode (round to nearest)
                and no inexact exceptions.
- fj           --fpmode=ieee_no_fenv.
                IEEE-compliant library with a fixed rounding mode (round to nearest)
                and no exceptions.
- fz           --fpmode=fast or --fpmode=std.
                Behaves like the fj library, but additionally flushes denormals and
                infinities to zero.
                This library behaves like the ARM VFP in Fast mode. This is the
                default.
- g            --fpmode=ieee_full.
                IEEE-compliant library with configurable rounding mode and all
                IEEE exceptions.
- h            Compiler support (helper) library.
- m            Transcendental math functions.
- mc           Non ISO C-compliant ISO C micro-library basic runtime support.
- mf           Non IEEE 754 floating-point compliant micro-library support.
- n            Compatible with the compiler option, --enum_is_int.
- u            Compatible with the compiler option, --wchar32.

- arch         4       An ARM only library for use with ARMv4.
- t            An ARM/Thumb interworking library for use with ARMv4T.
- s            An ARM/Thumb interworking library for use with ARMv5T and later.
- w            A Thumb-2 only library for use with Cortex-M3.
- p            A Thumb-1 only library for use with Cortex-M1 and Cortex-M0.
- 2            A combined ARM and Thumb-2 library for use with Cortex-R series
                processor cores.

- fpu          v       Uses VFP instruction set.
- s            Soft VFP.

--- Note ---
If neither v nor s is present in a library name, the library provides no
floating-point support.

- entrant      e       Position-independent access to static data.
FPIC addressing is enabled.

--- Note ---
If neither e nor f is present in a library name, the library uses position-dependent access to static data.

---

e  

b  Big-endian.

For example:

*armlib/c_4.b
*cpplib/cpprt_5f.l

--- Note ---
Not all variant/name combinations are valid. See the armlib and cpplib directories for the libraries that are supplied with the ARM compilation tools.

---

The linker command-line option --info libraries provides information on every library that is automatically selected for the link stage.

2.95.1 See also

Concepts

Introducing the ARM Compiler toolchain:

- ARM architectures supported by the toolchain on page 2-14.

Reference

- Compiler generated and library-resident helper functions on page 2-119.

Linker Reference:

- --info=topic[,topic,...] on page 2-59.
2.96 Using macro __ARM_WCHAR_NO_IO to disable FILE declaration and wide I/O function prototypes

In strict C/C++ mode, the header files wchar.h and wchar do not declare the FILE type. You can also define the macro __ARM_WCHAR_NO_IO to cause these header files not to declare FILE or the wide I/O function prototypes.

(Declaring the FILE type can lead to better consistency in debug information.)
Chapter 3
The ARM C micro-library

The following topics describe the C micro-library (microlib):

- About microlib on page 3-2
- Differences between microlib and the default C library on page 3-3
- Library heap usage requirements of the ARM C micro-library on page 3-4
- ISO C features missing from microlib on page 3-5
- Building an application with microlib on page 3-7
- Creating an initial stack pointer for use with microlib on page 3-8
- Creating the heap for use with microlib on page 3-9
- Entering and exiting programs linked with microlib on page 3-10
- Tailoring the microlib input/output functions on page 3-11.
3.1 About microlib

Microlib is an alternative library to the default C library. It is intended for use with deeply embedded applications that must fit into extremely small memory footprints. These applications do not run under an operating system.

Note

Microlib does not attempt to be an ISO C-compliant library.

Microlib is highly optimized for small code size. It has less functionality than the default C library and some ISO C features are completely missing. Some library functions are also slower.

Functions in microlib are responsible for:

- Creating an environment that a C program can execute in. This includes:
  - creating a stack
  - creating a heap, if required
  - initializing the parts of the library the program uses.
- Starting execution by calling `main()`.

3.1.1 See also

Concepts

- *Differences between microlib and the default C library on page 3-3*
- *ISO C features missing from microlib on page 3-5.*
3.2 Differences between microlib and the default C library

The main differences between microlib and the default C library are:

- Microlib is not compliant with the ISO C library standard. Some ISO features are not supported and others have less functionality.
- Microlib is not compliant with the IEEE 754 standard for binary floating-point arithmetic.
- Microlib is highly optimized for small code size.
- Locales are not configurable. The default C locale is the only one available.
- `main()` must not be declared to take arguments and must not return.
- Microlib provides limited support for C99 functions.
- Microlib does not support C++.
- Microlib does not support operating system functions.
- Microlib does not support position-independent code.
- Microlib does not provide mutex locks to guard against code that is not thread safe.
- Microlib does not support wide characters or multibyte strings.
- Microlib does not support selectable one or two region memory models as the standard library (stdlib) does. Microlib provides only the two region memory model with separate stack and heap regions.
- Microlib does not support the bit-aligned memory functions `_membitcpy[b|h|w][b|l]()` and `_membitmove[b|h|w][b|l]()`.
- Microlib can be used with either `--fpmode=std` or `--fpmode=fast`.
- The level of ANSI C stdio support that is provided can be controlled with `#pragma import(__use_full_stdio)`.
- `setvbuf()` and `setbuf()` always fail because all streams are unbuffered.
- `feof()` and `ferror()` always return 0 because the error and EOF indicators are not supported.

3.2.1 See also

Concepts

- *ISO C features missing from microlib* on page 3-5.

Reference

Compiler Reference:

- `--fpmode=model` on page 3-42
- `#pragma import(__use_full_stdio)` on page 5-53.
3.3 **Library heap usage requirements of the ARM C micro-library**

Library heap usage requirements for microlib differ to those of standardlib as follows:

- The size of heap memory allocated for `fopen()` is 20 bytes for the `FILE` structure.
- No buffer is ever allocated.

You must not declare `main()` to take arguments if you are using microlib.

**Note**

The size of heap memory allocated for `fopen()` might change in future releases.

3.3.1 **See also**

- *Library heap usage requirements of the ARM C and C++ libraries on page 2-8.*
3.4 ISO C features missing from microlib

Major ISO C90 features not supported by microlib are:

Wide character and multibyte support
All functions dealing with wide characters or multibyte strings are not supported by microlib. A link error is generated if these are used. For example, mbtowc(), wctomb(), mbstowcs() and wcstombs(). All functions defined in Normative Addendum 1 are not supported by microlib.

Operating system interaction
All functions that interact with an operating system are not supported by microlib. For example, abort(), exit(), atexit(), clock(), assert(), time(), system() and getenv().

File I/O
By default, all the stdio functions that interact with a file pointer return an error if called. The only exceptions to this are the three standard streams stdin, stdout and stderr.

You can change this behavior using #pragma import(__use_full_stdio). Use of this pragma provides a microlib version of stdio that supports ANSI C, with only the following exceptions:

- the error and EOF indicators are not supported, so feof() and ferror() return 0
- all streams are unbuffered, so setvbuf() and setbuf() fail.

Configurable locale
The default C locale is the only one available.

Signals
The functions signal() and raise() are provided but microlib does not generate signals. The only exception to this is if the program explicitly calls raise().

Floating-point support
Floating-point support diverges from IEEE 754 in the following ways, but uses the same data formats and matches IEEE 754 in operations involving only normalized numbers:

- Operations involving NaNs, infinities or input denormals produce unpredictable results. Operations that produce a result that is nonzero but very small in value, return zero.
- IEEE exceptions cannot be flagged by microlib, and there is no fp_status() register in microlib.
- The sign of zero is not treated as significant by microlib, and zeroes that are output from microlib floating-point arithmetic have an unpredictable sign bit.
- Only the default rounding mode is supported.

Position independent and thread safe code
Microlib has no reentrant variant. Microlib does not provide mutex locks to guard against code that is not thread safe. Use of microlib is not compatible with FPIC or RWPI compilation modes, and although ROPI code can be linked with microlib, the resulting binary is not ROPI-compliant overall.
3.4.1 See also

Concepts
- *Differences between microlib and the default C library* on page 3-3
- *C library API definitions for targeting a different environment* on page 2-40
- *Building an application without the C library* on page 2-41.

Reference
*Compiler Reference:*
- `#pragma import(__use_full_stdio)` on page 5-53.
3.5 Building an application with microlib

To build a program using microlib, you must use the command-line option --library_type=microlib. This option can be used by the compiler, assembler or linker. Use it with the linker to override all other options.

Example 3-1 shows --library_type=microlib being used by the compiler. Specifying --library_type=microlib when compiling main.c results in an object file containing an attribute that asks the linker to use microlib. Compiling extra.c with --library_type=microlib is unnecessary, because the request to link against microlib exists in the object file generated by compiling main.c.

Example 3-1  Compiler option

```bash
armcc --library_type=microlib -c main.c armcc -c extra.c armlink -o image.axf main.o extra.o
```

Example 3-2 shows this option being used by the assembler. The request to the linker to use microlib is made as a result of assembling more.s with --library_type=microlib.

Example 3-2  Assembler option

```bash
armcc -c main.c armcc -c extra.c armasm --library_type=microlib more.s armlink -o image.axf main.o extra.o more.o
```

Example 3-3 shows this option being used by the linker. Neither object file contains the attribute requesting that the linker link against microlib, so the linker selects microlib as a result of being explicitly asked to do so on the command line.

Example 3-3  Linker option

```bash
armcc -c main.c armcc -c extra.c armlink --library_type=microlib -o image.axf main.o extra.o
```

3.5.1 See also

Tasks
- Creating an initial stack pointer for use with microlib on page 3-8
- Creating the heap for use with microlib on page 3-9
- Entering and exiting programs linked with microlib on page 3-10.

Reference

Compiler Reference:
- --library_type=lib on page 3-58.

Linker Reference:
- input-file-list on page 2-66.
3.6 Creating an initial stack pointer for use with microlib

To use microlib, you must specify an initial pointer for the stack. You can use either of the following methods to do this:

- use a scatter file
- define a symbol, __initial_sp, to be equal to the top of the stack.

The scatter file method uses ARM_LIB_STACK and ARM_LIB_STACKHEAP.

Otherwise, specify the initial stack pointer by defining a symbol, __initial_sp, to be equal to the top of the stack. The initial stack pointer must be aligned to a multiple of eight bytes.

Example 3-4 shows how to set up the initial stack pointer using assembly language.

**Example 3-4 Assembly language**

```
EXPORT __initial_sp
__initial_sp EQU 0x100000 ; equal to the top of the stack
```

Example 3-5 shows how to set up the initial stack pointer using embedded assembler in C.

**Example 3-5 Embedded Assembler in C**

```
__asm void dummy_function(void)
{
   EXPORT __initial_sp
   __initial_sp EQU 0x100000 ; equal to the top of the stack
}
```

3.6.1 See also

Tasks

- Defining __initial_sp, __heap_base and __heap_limit on page 2-89
- Creating the heap for use with microlib on page 3-9
- Entering and exiting programs linked with microlib on page 3-10.

Using the Linker:
- Chapter 8 Using scatter files.
3.7 Creating the heap for use with microlib

To use the heap functions, for example, `malloc()`, `calloc()`, `realloc()` and `free()`, you must specify the location and size of the heap region.

To specify the start and end of the heap you can use either of the following methods:

- use a scatter file
- define symbols `__heap_base` and `__heap_limit`.

The scatter file method uses `ARM_LIB_HEAP` and `ARM_LIB_STACKHEAP`.

Otherwise, specify the start and end of the heap by defining symbols `__heap_base` and `__heap_limit` respectively. On completion, you can use the heap functions in the normal way.

Note

The `__heap_limit` must point to the byte beyond the last byte in the heap region.

Example 3-6 shows how to set up the heap pointers using assembly language.

### Example 3-6 Assembly language

```assembly
EXPORT __heap_base
__heap_base EQU 0x400000 ; equal to the start of the heap

EXPORT __heap_limit
__heap_limit EQU 0x800000 ; equal to the end of the heap
```

Example 3-7 shows how to set up the heap pointer using embedded assembler in C.

### Example 3-7 Embedded Assembler in C

```assembly
__asm void dummy_function(void)
{
    EXPORT __heap_base
    __heap_base EQU 0x400000 ; equal to the start of the heap
    EXPORT __heap_limit
    __heap_limit EQU 0x800000 ; equal to the end of the heap
}
```

3.7.1 See also

Tasks

- Creating an initial stack pointer for use with microlib on page 3-8
- Entering and exiting programs linked with microlib on page 3-10
- Defining `__initial_sp`, `__heap_base` and `__heap_limit` on page 2-89.

Using the Linker:

- Chapter 8 Using scatter files.
3.8 Entering and exiting programs linked with microlib

Use `main()` to begin your program. Do not declare `main()` to take arguments.

Your program must not return from `main()`. This is because Microlib does not contain any code to handle exit from `main()`. You can ensure that your `main()` function does not return, by inserting an endless loop at the end of the function. For example:

```c
void main()
{
    ...
    while (1); // endless loop to prevent return from main()
}
```

Microlib does not support:
- command-line arguments from an operating system
- programs that call `exit()`.
3.9 Tailoring the microlib input/output functions

Microlib provides a limited stdio subsystem that supports unbuffered stdin, stdout and stderr only. This enables you to use printf() for displaying diagnostic messages from your application.

To use high-level I/O functions you must provide your own implementation of the following base functions so that they work with your own I/O device.

- `fputc()` Implement this base function for all output functions. For example, fprintf(), printf(), fwrite(), fputs(), puts(), putc() and putchar().

- `fgetc()` Implement this base function for all input functions. For example, fscanf(), scanf(), fread(), read(), fgets(), gets(), getc() and getchar().

- `__backspace()` Implement this base function if your input functions use scanf() or fscanf().

Note
Conversions that are not supported in microlib are %lc, %ls and %a.

3.9.1 See also

Reference

- Tailoring input/output functions in the C and C++ libraries on page 2-92.
Chapter 4
Floating-point support

The following topics describe the ARM support for floating-point computations:

- About floating-point support on page 4-3
- The software floating-point library, fplib on page 4-4
- Calling fplib routines on page 4-5
- fplib arithmetic on numbers in a particular format on page 4-6
- fplib conversions between floats, doubles, and ints on page 4-8
- fplib conversion between long longs, floats, and doubles on page 4-9
- fplib comparisons between floats and doubles on page 4-10
- fplib C99 functions on page 4-12
- Controlling the ARM floating-point environment on page 4-13
- Floating-point functions for compatibility with Microsoft products on page 4-14
- C99-compatible functions for controlling the ARM floating-point environment on page 4-15
- C99 rounding mode and floating-point exception macros on page 4-16
- Exception flag handling on page 4-17
- Functions for handling rounding modes on page 4-18
- Functions for saving and restoring the whole floating-point environment on page 4-19
- Functions for temporarily disabling exceptions on page 4-20
- ARM floating-point compiler extensions to the C99 interface on page 4-21
- Writing a custom exception trap handler on page 4-22
- Example of a custom exception handler on page 4-26
- Exception trap handling by signals on page 4-28
- Using C99 signalling NaNs provided by mathlib (_WANT_SNAN) on page 4-29
• mathlib double and single-precision floating-point functions on page 4-30
• Nonstandard functions in mathlib on page 4-31
• IEEE 754 arithmetic on page 4-32
• Basic data types for IEEE 754 arithmetic on page 4-33
• Single precision data type for IEEE 754 arithmetic on page 4-34
• Double precision data type for IEEE 754 arithmetic on page 4-36
• Sample single precision floating-point values for IEEE 754 arithmetic on page 4-37
• Sample double precision floating-point values for IEEE 754 arithmetic on page 4-39
• IEEE 754 arithmetic and rounding on page 4-41
• Exceptions arising from IEEE 754 floating-point arithmetic on page 4-42
• Ignoring exceptions from IEEE 754 floating-point arithmetic operations on page 4-43
• Trapping exceptions from IEEE 754 floating-point arithmetic operations on page 4-44
• Exception types recognized by the ARM floating-point environment on page 4-45
• Using the Vector Floating-Point (VFP) support libraries on page 4-47.
4.1 About floating-point support

The ARM floating-point environment is an implementation of the IEEE 754-1985 standard for binary floating-point arithmetic.

An ARM system might have:
• a VFP coprocessor
• no floating-point hardware.

If you compile for a system with a hardware VFP coprocessor, the ARM compiler makes use of it. If you compile for a system without a coprocessor, the compiler implements the computations in software. For example, the compiler option `--fpu=vfp` selects a hardware VFP coprocessor and the option `--fpu=softvfp` specifies that arithmetic operations are to be performed in software, without the use of any coprocessor instructions.

4.1.1 See also

Concepts
• IEEE 754 arithmetic on page 4-32
• The software floating-point library, fplib on page 4-4.

Reference
Compiler Reference:
• `--fpu=NAME` on page 3-44.
4.2 The software floating-point library, fplib

When programs are compiled to use a floating-point coprocessor, they perform basic floating-point arithmetic by means of floating-point machine instructions for the target coprocessor. When programs are compiled to use software floating-point, there is no floating-point instruction set available, so the ARM libraries provide a set of procedure calls to do floating-point arithmetic. These procedures are in the software floating-point library, fplib.

4.2.1 See also

Tasks
• Calling fplib routines on page 4-5.

Concepts
• fplib arithmetic on numbers in a particular format on page 4-6
• fplib conversions between floats, doubles, and ints on page 4-8
• fplib conversion between long longs, floats, and doubles on page 4-9
• fplib comparisons between floats and doubles on page 4-10
• fplib C99 functions on page 4-12.
4.3 Calling fplib routines

Floating-point routines have names like __aeabi_dadd (add two doubles) and __aeabi_fdiv (divide two floats). User programs can call these routines directly. Even in environments with a coprocessor, the routines are provided. They are typically only a few instructions long because all they do is execute the appropriate coprocessor instruction.

All the fplib routines are called using a software floating-point variant of the calling standard. This means that floating-point arguments are passed and returned in integer registers. By contrast, if the program is compiled for a coprocessor, floating-point data is passed in its floating-point registers.

So, for example, __aeabi_dadd takes a double in registers r0 and r1, and another double in registers r2 and r3, and returns the sum in r0 and r1.

--- Note ---

For a double in registers r0 and r1, the register that holds the high 32 bits of the double depends on whether your program is little-endian or big-endian.

---

Except for the software floating-point library routines that implement C99 functionality, the fplib routines are declared in the header file rt_fp.h. You can include this file if you want to call an fplib routine directly. Software floating-point library routines that implement C99 functionality are declared in the standard header file math.h.

To call a function from assembler, the software floating-point function is named __softfp_fn. For example, to call the cos() function, implement the following code:

IMPORT __softfp_cos
BL __softfp_cos

4.3.1 See also

Concepts
• fplib C99 functions on page 4-12
• The software floating-point library, fplib on page 4-4.

Using the Compiler:
• Compiler support for floating-point computations and linkage on page 5-63.

Other information
• Application Binary Interface (ABI) for the ARM Architecture, http://infocenter.arm.com/help/topic/com.arm.doc.subset.swdev.abi
4.4  fplib arithmetic on numbers in a particular format

Table 4-1 describes routines to perform arithmetic on numbers in a particular format. Arguments and return types are always in the same format.

<table>
<thead>
<tr>
<th>Function</th>
<th>Argument types</th>
<th>Return type</th>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>__aeabi_fadd</td>
<td>2 float</td>
<td>float</td>
<td>Return x plus y</td>
</tr>
<tr>
<td>__aeabi_fsub</td>
<td>2 float</td>
<td>float</td>
<td>Return x minus y</td>
</tr>
<tr>
<td>__aeabi_frsub</td>
<td>2 float</td>
<td>float</td>
<td>Return y minus x</td>
</tr>
<tr>
<td>__aeabi_fmul</td>
<td>2 float</td>
<td>float</td>
<td>Return x times y</td>
</tr>
<tr>
<td>__aeabi_fdiv</td>
<td>2 float</td>
<td>float</td>
<td>Return x divided by y</td>
</tr>
<tr>
<td>_frdiv</td>
<td>2 float</td>
<td>float</td>
<td>Return y divided by x</td>
</tr>
<tr>
<td>_frem</td>
<td>2 float</td>
<td>float</td>
<td>Return remainder of x by y (see a in Notes on arithmetic routines)</td>
</tr>
<tr>
<td>_frnd</td>
<td>float</td>
<td>float</td>
<td>Return x rounded to an integer (see b in Notes on arithmetic routines)</td>
</tr>
<tr>
<td>_fsqrt</td>
<td>float</td>
<td>float</td>
<td>Return square root of x</td>
</tr>
<tr>
<td>__aeabi_dadd</td>
<td>2 double</td>
<td>double</td>
<td>Return x plus y</td>
</tr>
<tr>
<td>__aeabi_dsub</td>
<td>2 double</td>
<td>double</td>
<td>Return x minus y</td>
</tr>
<tr>
<td>__aeabi_drsub</td>
<td>2 double</td>
<td>double</td>
<td>Return y minus x</td>
</tr>
<tr>
<td>__aeabi_dmul</td>
<td>2 double</td>
<td>double</td>
<td>Return x times y</td>
</tr>
<tr>
<td>__aeabi_ddiv</td>
<td>2 double</td>
<td>double</td>
<td>Return x divided by y</td>
</tr>
<tr>
<td>_drdiv</td>
<td>2 double</td>
<td>double</td>
<td>Return y divided by x</td>
</tr>
<tr>
<td>_drem</td>
<td>2 double</td>
<td>double</td>
<td>Return remainder of x by y (see a and c in Notes on arithmetic routines)</td>
</tr>
<tr>
<td>_drnd</td>
<td>double</td>
<td>double</td>
<td>Return x rounded to an integer (see b in Notes on arithmetic routines)</td>
</tr>
<tr>
<td>_dsqrt</td>
<td>double</td>
<td>double</td>
<td>Return square root of x</td>
</tr>
</tbody>
</table>

4.4.1  Notes on arithmetic routines

a  Functions that perform the IEEE 754 remainder operation. This is defined to take two numbers, x and y, and return a number z so that z = x – n * y, where n is an integer. To return an exactly correct result, n is chosen so that z is no bigger than half of x (so that z might be negative even if both x and y are positive). The IEEE 754 remainder function is not the same as the operation performed by the C library function fmod, where z always has the same sign as x. Where the IEEE 754 specification gives two acceptable choices of n, the even one is chosen. This behavior occurs independently of the current rounding mode.
b Functions that perform the IEEE 754 round-to-integer operation. This takes a number and rounds it to an integer (in accordance with the current rounding mode), but returns that integer in the floating-point number format rather than as a C \texttt{int} variable. To convert a number to an \texttt{int} variable, you must use the \_ffix routines described in Table 4-2 on page 4-8.

c The IEEE 754 remainder() function is a synonym for _drem. remainder() is defined in math.h.

4.4.2 See also

Concepts
• \texttt{fplib conversions between floats, doubles, and ints} on page 4-8
• \texttt{fplib conversion between long longs, floats, and doubles} on page 4-9
• \texttt{fplib comparisons between floats and doubles} on page 4-10
• \texttt{fplib C99 functions} on page 4-12
• \texttt{The software floating-point library, fplib} on page 4-4.

Other information
• \textit{Application Binary Interface} (ABI) for the ARM Architecture, http://infocenter.arm.com/help/topic/com.arm.doc.subset.swdev.abi
4.5  fplib conversions between floats, doubles, and ints

Table 4-2 describes routines to perform conversions between number formats, excluding long types.

<table>
<thead>
<tr>
<th>Function</th>
<th>Argument types</th>
<th>Return type</th>
</tr>
</thead>
<tbody>
<tr>
<td>__aeabi_f2d</td>
<td>float</td>
<td>double</td>
</tr>
<tr>
<td>__aeabi_d2f</td>
<td>double</td>
<td>float</td>
</tr>
<tr>
<td>_fflt</td>
<td>int</td>
<td>float</td>
</tr>
<tr>
<td>_ffltu</td>
<td>unsigned int</td>
<td>float</td>
</tr>
<tr>
<td>_dflt</td>
<td>int</td>
<td>double</td>
</tr>
<tr>
<td>_dfltu</td>
<td>unsigned int</td>
<td>double</td>
</tr>
<tr>
<td>_ffix</td>
<td>float</td>
<td>int (see Notes on rounding)</td>
</tr>
<tr>
<td>_ffix_r</td>
<td>float</td>
<td>int</td>
</tr>
<tr>
<td>_ffixu</td>
<td>float</td>
<td>unsigned int (see Notes on rounding)</td>
</tr>
<tr>
<td>_ffixu_r</td>
<td>float</td>
<td>unsigned int</td>
</tr>
<tr>
<td>_dfix</td>
<td>double</td>
<td>int (see Notes on rounding)</td>
</tr>
<tr>
<td>_dfix_r</td>
<td>double</td>
<td>int</td>
</tr>
<tr>
<td>_dfixu</td>
<td>double</td>
<td>unsigned int (see Notes on rounding)</td>
</tr>
<tr>
<td>_dfixu_r</td>
<td>double</td>
<td>unsigned int</td>
</tr>
</tbody>
</table>

4.5.1 Notes on rounding

Rounded toward zero, independently of the current rounding mode. This is because the C standard requires implicit conversions to integers to round this way, so it is convenient not to have to change the rounding mode to do so. Each function has a corresponding function with _r on the end of its name, that performs the same operation but rounds according to the current mode.

4.5.2 See also

Concepts
- fplib conversions between floats, doubles, and ints
- fplib conversion between long longs, floats, and doubles on page 4-9
- fplib comparisons between floats and doubles on page 4-10
- fplib C99 functions on page 4-12
- The software floating-point library, fplib on page 4-4.

Other information
4.6  fplib conversion between long longs, floats, and doubles

Table 4-3 describes routines to perform conversions between long longs, floats, and doubles.

<table>
<thead>
<tr>
<th>Function</th>
<th>Argument types</th>
<th>Return type</th>
</tr>
</thead>
<tbody>
<tr>
<td>_ll_sto_f</td>
<td>long long</td>
<td>float</td>
</tr>
<tr>
<td>_ll_uto_f</td>
<td>unsigned long long</td>
<td>float</td>
</tr>
<tr>
<td>_ll_sto_d</td>
<td>long long</td>
<td>double</td>
</tr>
<tr>
<td>_ll_uto_d</td>
<td>unsigned long long</td>
<td>double</td>
</tr>
<tr>
<td>_ll_sfrom_f</td>
<td>float</td>
<td>long long (see Notes on rounding)</td>
</tr>
<tr>
<td>_ll_sfrom_f_r</td>
<td>float</td>
<td>long long</td>
</tr>
<tr>
<td>_ll_ufrom_f</td>
<td>float</td>
<td>unsigned long long (see Notes on rounding)</td>
</tr>
<tr>
<td>_ll_ufrom_f_r</td>
<td>float</td>
<td>unsigned long long</td>
</tr>
<tr>
<td>_ll_sfrom_d</td>
<td>double</td>
<td>long long (see Notes on rounding)</td>
</tr>
<tr>
<td>_ll_sfrom_d_r</td>
<td>double</td>
<td>long long</td>
</tr>
<tr>
<td>_ll_ufrom_d</td>
<td>double</td>
<td>unsigned long long (see Notes on rounding)</td>
</tr>
<tr>
<td>_ll_ufrom_d_r</td>
<td>double</td>
<td>unsigned long long</td>
</tr>
</tbody>
</table>

4.6.1  Notes on rounding

Rounded toward zero, independently of the current rounding mode. This is because the C standard requires implicit conversions to integers to round this way, so it is convenient not to have to change the rounding mode to do so. This function has a corresponding function with _r on the end of its name. This function performs the same operation but rounds according to the current mode.

4.6.2  See also

Concepts
-  fplib arithmetic on numbers in a particular format on page 4-6
-  fplib conversions between floats, doubles, and ints on page 4-8
-  fplib comparisons between floats and doubles on page 4-10
-  fplib C99 functions on page 4-12
-  The software floating-point library, fplib on page 4-4.
## 4.7 fplib comparisons between floats and doubles

Table 4-4 describes routines to perform comparisons between floating-point numbers. See Notes on floating-point comparison routines on page 4-11 for more information as indicated in the Notes column.

<table>
<thead>
<tr>
<th>Function</th>
<th>Argument types</th>
<th>Return type</th>
<th>Condition tested</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>_fcmpeq</td>
<td>2 float</td>
<td>Flags, EQ/NE</td>
<td>x equal to y</td>
<td>a</td>
</tr>
<tr>
<td>_fcmpge</td>
<td>2 float</td>
<td>Flags, HS/LO</td>
<td>x greater than or equal to y</td>
<td>a, b</td>
</tr>
<tr>
<td>_fcmpeq</td>
<td>2 float</td>
<td>Flags, HI/LS</td>
<td>x less than or equal to y</td>
<td>a, b</td>
</tr>
<tr>
<td>_fcmpeq</td>
<td>2 float</td>
<td>Boolean</td>
<td>x equal to y</td>
<td>-</td>
</tr>
<tr>
<td>_fcmpeq</td>
<td>2 float</td>
<td>Boolean</td>
<td>x not equal to y</td>
<td>-</td>
</tr>
<tr>
<td>_fcmpeq</td>
<td>2 float</td>
<td>Boolean</td>
<td>x greater than or equal to y</td>
<td>b</td>
</tr>
<tr>
<td>_fcmpeq</td>
<td>2 float</td>
<td>Boolean</td>
<td>x less than or equal to y</td>
<td>b</td>
</tr>
<tr>
<td>_fcmpeq</td>
<td>2 float</td>
<td>Boolean</td>
<td>x less than y</td>
<td>b</td>
</tr>
<tr>
<td>_fcmpeq</td>
<td>2 double</td>
<td>Flags, EQ/NE</td>
<td>x equal to y</td>
<td>a</td>
</tr>
<tr>
<td>_fcmpeq</td>
<td>2 double</td>
<td>Flags, HS/LO</td>
<td>x greater than or equal to y</td>
<td>a, b</td>
</tr>
<tr>
<td>_fcmpeq</td>
<td>2 double</td>
<td>Flags, HI/LS</td>
<td>x less than or equal to y</td>
<td>a, b</td>
</tr>
<tr>
<td>_fcmpeq</td>
<td>2 double</td>
<td>Boolean</td>
<td>x equal to y</td>
<td>-</td>
</tr>
<tr>
<td>_fcmpeq</td>
<td>2 double</td>
<td>Boolean</td>
<td>x not equal to y</td>
<td>-</td>
</tr>
<tr>
<td>_fcmpeq</td>
<td>2 double</td>
<td>Boolean</td>
<td>x greater than or equal to y</td>
<td>b</td>
</tr>
<tr>
<td>_fcmpeq</td>
<td>2 double</td>
<td>Boolean</td>
<td>x less than or equal to y</td>
<td>b</td>
</tr>
<tr>
<td>_fcmpeq</td>
<td>2 double</td>
<td>Boolean</td>
<td>x less than y</td>
<td>b</td>
</tr>
<tr>
<td>_fcmpeq</td>
<td>2 float</td>
<td>Flags, VFP</td>
<td>x less than or equal to y</td>
<td>c</td>
</tr>
<tr>
<td>_fcmpeq</td>
<td>2 float</td>
<td>Flags, VFP</td>
<td>x less than or equal to y</td>
<td>b, c</td>
</tr>
<tr>
<td>_fcmpeq</td>
<td>2 float</td>
<td>Flags, VFP</td>
<td>x less than or equal to y</td>
<td>b, c</td>
</tr>
<tr>
<td>_fcmpeq</td>
<td>2 double</td>
<td>Flags, VFP</td>
<td>x less than or equal to y</td>
<td>c</td>
</tr>
<tr>
<td>_fcmpeq</td>
<td>2 double</td>
<td>Flags, VFP</td>
<td>x less than or equal to y</td>
<td>b, c</td>
</tr>
<tr>
<td>_fcmpeq</td>
<td>2 double</td>
<td>Flags, VFP</td>
<td>x less than or equal to y</td>
<td>c</td>
</tr>
<tr>
<td>_fcmpeq</td>
<td>double, float</td>
<td>Flags, VFP</td>
<td>x less than or equal to y</td>
<td>b, c</td>
</tr>
<tr>
<td>_fcmpeq</td>
<td>double, float</td>
<td>Flags, VFP</td>
<td>x less than or equal to y</td>
<td>c</td>
</tr>
<tr>
<td>_fcmpeq</td>
<td>double, float</td>
<td>Flags, VFP</td>
<td>x less than or equal to y</td>
<td>b, c</td>
</tr>
</tbody>
</table>
4.7.1 Notes on floating-point comparison routines

a Returns results in the ARM condition flags. This is efficient in assembly language, because you can directly follow a call to the function with a conditional instruction, but it means there is no way to use this function from C. This function is not declared in rt_fp.h.

b Causes an Invalid Operation exception if either argument is a NaN, even a quiet NaN. Other functions only cause Invalid Operation if an argument is an SNaN. QNaNs return not equal when compared to anything, including other QNaNs (so comparing a QNaN to the same QNaN still returns not equal).

c Returns VFP-type status flags in the CPSR. Also returns VFP-type status flags in the top four bits of r0, meaning that it is possible to use this function from C. This function is declared in rt_fp.h.

4.7.2 See also

Concepts
• fplib arithmetic on numbers in a particular format on page 4-6
• fplib conversions between floats, doubles, and ints on page 4-8
• fplib conversion between long longs, floats, and doubles on page 4-9
• fplib comparisons between floats and doubles on page 4-10
• fplib C99 functions on page 4-12
• The software floating-point library, fplib on page 4-4.
4.8 fplib C99 functions

Table 4-5 describes fplib functions that implement C99 functionality.

<table>
<thead>
<tr>
<th>Function</th>
<th>Argument types</th>
<th>Return type</th>
<th>Returns section</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>ilogb</td>
<td>double</td>
<td>int</td>
<td>Exponent of argument x</td>
<td>7.12.6.5</td>
</tr>
<tr>
<td>ilogbf</td>
<td>float</td>
<td>int</td>
<td>Exponent of argument x</td>
<td>7.12.6.5</td>
</tr>
<tr>
<td>ilogbl</td>
<td>long double</td>
<td>int</td>
<td>Exponent of argument x</td>
<td>7.12.6.5</td>
</tr>
<tr>
<td>logb</td>
<td>double</td>
<td>double</td>
<td>Exponent of argument x</td>
<td>7.12.6.11</td>
</tr>
<tr>
<td>logbf</td>
<td>float</td>
<td>float</td>
<td>Exponent of argument x</td>
<td>7.12.6.11</td>
</tr>
<tr>
<td>logbl</td>
<td>long double</td>
<td>long double</td>
<td>Exponent of argument x</td>
<td>7.12.6.11</td>
</tr>
<tr>
<td>scalbn</td>
<td>double, int</td>
<td>double</td>
<td>x * (FLT_RADIX ** n)</td>
<td>7.12.6.13</td>
</tr>
<tr>
<td>scalbnf</td>
<td>float, int</td>
<td>float</td>
<td>x * (FLT_RADIX ** n)</td>
<td>7.12.6.13</td>
</tr>
<tr>
<td>scalbln</td>
<td>long double, int</td>
<td>long double</td>
<td>x * (FLT_RADIX ** n)</td>
<td>7.12.6.13</td>
</tr>
<tr>
<td>scalbln</td>
<td>double, long int</td>
<td>double</td>
<td>x * (FLT_RADIX ** n)</td>
<td>7.12.6.13</td>
</tr>
<tr>
<td>scalblnf</td>
<td>float, long int</td>
<td>float</td>
<td>x * (FLT_RADIX ** n)</td>
<td>7.12.6.13</td>
</tr>
<tr>
<td>scalblnl</td>
<td>long double, long int</td>
<td>long double</td>
<td>x * (FLT_RADIX ** n)</td>
<td>7.12.6.13</td>
</tr>
<tr>
<td>nextafter</td>
<td>2 double</td>
<td>double</td>
<td>Next representable value after x towards y</td>
<td>7.12.11.3</td>
</tr>
<tr>
<td>nextafterf</td>
<td>2 float</td>
<td>float</td>
<td>Next representable value after x towards y</td>
<td>7.12.11.3</td>
</tr>
<tr>
<td>nextafterl</td>
<td>2 long double</td>
<td>long double</td>
<td>Next representable value after x towards y</td>
<td>7.12.11.3</td>
</tr>
<tr>
<td>nexttoward</td>
<td>double, long double</td>
<td>double</td>
<td>Next representable value after x towards y</td>
<td>7.12.11.4</td>
</tr>
<tr>
<td>nexttowardf</td>
<td>float, long double</td>
<td>float</td>
<td>Next representable value after x towards y</td>
<td>7.12.11.4</td>
</tr>
<tr>
<td>nexttowardl</td>
<td>2 long double</td>
<td>long double</td>
<td>Next representable value after x towards y</td>
<td>7.12.11.4</td>
</tr>
</tbody>
</table>

4.8.1 See also

Concepts
- [fplib arithmetic on numbers in a particular format](#)
on page 4-6
- [fplib conversions between floats, doubles, and ints](#)on page 4-8
- [fplib conversion between long longs, floats, and doubles](#)on page 4-9
- [fplib comparisons between floats and doubles](#)on page 4-10
- [fplib C99 functions](#)
- [The software floating-point library, fplib](#)on page 4-4.
4.9 Controlling the ARM floating-point environment

The ARM compilation tools supply several different interfaces to the floating-point environment, for compatibility and porting ease. These interfaces enable you to change the rounding mode, enable and disable trapping of exceptions, and install your own custom exception trap handlers.

4.9.1 See also

Concepts
- Floating-point functions for compatibility with Microsoft products on page 4-14
- C99-compatible functions for controlling the ARM floating-point environment on page 4-15
- ARM floating-point compiler extensions to the C99 interface on page 4-21.

Reference
ARM® C and C++ Libraries and Floating-Point Support Reference:
- __ieee_status() on page 3-8
- __fp_status() on page 3-5.
4.10 Floating-point functions for compatibility with Microsoft products

Some functions give compatibility with Microsoft products to ease porting of floating-point code to the ARM architecture. They are defined in float.h. These functions require you to select a floating-point model that supports exceptions. For example, --fpmode=ieee_full or --fpmode=ieee_fixed.

4.10.1 See also

Tasks
• Controlling the ARM floating-point environment on page 4-13.

Reference
• _controlfp() on page 3-3
• _clearfp() on page 3-2
• _statusfp() on page 3-13.
4.11 C99-compatible functions for controlling the ARM floating-point environment

Note
The following functionality requires you to select a floating-point model that supports exceptions, such as --fpmode=ieee_full or --fpmode=ieee_fixed.

The compiler supports all functions defined in the C99 standard, and functions that are not C99-standard. The C99-compatible functions are the only interface that enables you to install custom exception trap handlers with the ability to define your own return value. All the function prototypes, data types, and macros for this functionality are defined in fenv.h.

C99 defines two data types, fenv_t and fexcept_t. The C99 standard does not give information about these types, so for portable code you must treat them as opaque. The compiler defines them to be structure types.

The type fenv_t is defined to hold all the information about the current floating-point environment. This comprises:
• the rounding mode
• the exception sticky flags
• whether each exception is masked
• what handlers are installed, if any.

The type fexcept_t is defined to hold all the information relevant to a given set of exceptions.

4.11.1 See also

Tasks
• Controlling the ARM floating-point environment on page 4-13.

Concepts
• ARM floating-point compiler extensions to the C99 interface on page 4-21
• C99 rounding mode and floating-point exception macros on page 4-16
• Exception flag handling on page 4-17
• Functions for handling rounding modes on page 4-18
• Functions for saving and restoring the whole floating-point environment on page 4-19
• Functions for temporarily disabling exceptions on page 4-20.

Reference
Compiler Reference:
• --fpmode=model on page 3-42.
4.12 C99 rounding mode and floating-point exception macros

Note

The following functionality requires you to select a floating-point model that supports exceptions, such as --fpmode=ieee_full or --fpmode=ieee_fixed.

C99 defines a macro for each rounding mode and each exception. The macros are:

• FE_DIVBYZERO
• FE_INEXACT
• FE_INVALID
• FE_OVERFLOW
• FE_UNDERFLOW
• FE_ALL_EXCEPT
• FE_DOWNWARD
• FE_TONEAREST
• FE_TOWARDZERO
• FE_UPWARD.

The exception macros are bit fields. The macro FE_ALL_EXCEPT is the bitwise OR of all of them.

4.12.1 See also

Concepts

• C99-compatible functions for controlling the ARM floating-point environment on page 4-15.

Reference

Compiler Reference:

• --fpmode=model on page 3-42.
4.13 Exception flag handling

Note

The following functionality requires you to select a floating-point model that supports exceptions, such as --fpmode=ieee_full or --fpmode=ieee_fixed.

C99 provides the following functions to clear, test and raise exceptions:

\[
\text{void feclearexcept(int excepts);} \quad \text{int fetestexcept(int excepts);} \quad \text{void feraiseexcept(int excepts);} \\
\]

The `feclearexcept()` function clears the sticky flags for the given exceptions. The `fetestexcept()` function returns the bitwise OR of the sticky flags for the given exceptions, so that if the Overflow flag was set but the Underflow flag was not, then calling `fetestexcept(FE_OVERFLOW|FE_UNDERFLOW)` would return `FE_OVERFLOW`.

The `feraiseexcept()` function raises the given exceptions, in unspecified order. If an exception trap is enabled for an exception raised this way, it is called.

C99 also provides functions to save and restore everything about a given exception. This includes the sticky flag, whether the exception is trapped, and the address of the trap handler, if any. These functions are:

\[
\text{void fegetexceptflag(fexcept_t *flagp, int excepts);} \quad \text{void fesetexceptflag(const fexcept_t *flagp, int excepts);} \\
\]

The `fegetexceptflag()` function copies all the information relating to the given exceptions into the `fexcept_t` variable provided. The `fesetexceptflag()` function copies all the information relating to the given exceptions from the `fexcept_t` variable into the current floating-point environment.

Note

`fesetexceptflag()` can be used to set the sticky flag of a trapped exception to 1 without calling the trap handler, whereas `feraiseexcept()` calls the trap handler for any trapped exception.

4.13.1 See also

Concepts

• C99-compatible functions for controlling the ARM floating-point environment on page 4-15.

Reference

Compiler Reference:

• --fpmode=model on page 3-42.
4.14 Functions for handling rounding modes

Note
The following functionality requires you to select a floating-point model that supports exceptions, such as --fpmode=ieee_full or --fpmode=ieee_fixed.

C99 provides the following functions for handling rounding modes:

```c
int fegetround(void); int fesetround(int round);
```

The `fegetround()` function returns the current rounding mode. The current rounding mode has a value equal to one of the C99 rounding mode macros or exceptions.

The `fesetround()` function sets the current rounding mode to the value provided. `fesetround()` returns zero for success, or nonzero if its argument is not a valid rounding mode.

4.14.1 See also

Concepts
- C99 rounding mode and floating-point exception macros on page 4-16
- C99-compatible functions for controlling the ARM floating-point environment on page 4-15.

Reference

Compiler Reference:
- --fpmode=model on page 3-42.
4.15 Functions for saving and restoring the whole floating-point environment

Note

The following functionality requires you to select a floating-point model that supports exceptions, such as --fpmode=ieee_full or --fpmode=ieee_fixed.

C99 provides the following functions to save and restore the entire floating-point environment:

```c
void fegetenv(fenv_t *envp);
void fesetenv(const fenv_t *envp);
```

The fegetenv() function stores the current state of the floating-point environment into the fenv_t variable provided. The fesetenv() function restores the environment from the variable provided.

Like fesetexceptflag(), fesetenv() does not call trap handlers when it sets the sticky flags for trapped exceptions.

4.15.1 See also

Concepts

- C99-compatible functions for controlling the ARM floating-point environment on page 4-15.

Reference

Compiler Reference:

- --fpmode=model on page 3-42.
4.16 Functions for temporarily disabling exceptions

Note

The following functionality requires you to select a floating-point model that supports exceptions, such as --fpmode=ieee_full or --fpmode=ieee_fixed.

C99 provides two functions that enable you to avoid risking exception traps when executing code that might cause exceptions. This is useful when, for example, trapped exceptions are using the ARM default behavior. The default is to cause SIGFPE and terminate the application.

```c
int feholdexcept(fenv_t *envp);
void feupdateenv(const fenv_t *envp);
```

The `feholdexcept()` function saves the current floating-point environment in the `fenv_t` variable provided, sets all exceptions to be untrapped, and clears all the exception sticky flags. You can then execute code that might cause unwanted exceptions, and make sure the sticky flags for those exceptions are cleared. Then you can call `feupdateenv()`. This restores any exception traps and calls them if necessary. For example, suppose you have a function, `frob()`, that might cause the Underflow or Invalid Operation exceptions (assuming both exceptions are trapped). You are not interested in Underflow, but you want to know if an invalid operation is attempted. You can implement the following code to do this:

```c
fenv_t env;
feholdexcept(&env);
frob();
feclearexcept(FE_UNDERFLOW);
feupdateenv(&env);
```

Then, if the `frob()` function raises Underflow, it is cleared again by `feclearexcept()`, so no trap occurs when `feupdateenv()` is called. However, if `frob()` raises Invalid Operation, the sticky flag is set when `feupdateenv()` is called, so the trap handler is invoked.

This mechanism is provided by C99 because C99 specifies no way to change exception trapping for individual exceptions. A better method is to use `__ieee_status()` to disable the Underflow trap while leaving the Invalid Operation trap enabled. This has the advantage that the Invalid Operation trap handler is provided with all the information about the invalid operation (that is, what operation was being performed, and on what data), and can invent a result for the operation. Using the C99 method, the Invalid Operation trap handler is called after the fact, receives no information about the cause of the exception, and is called too late to provide a substitute result.

4.16.1 See also

Concepts

- C99-compatible functions for controlling the ARM floating-point environment on page 4-15.

Reference

ARM® C and C++ Libraries and Floating-Point Support Reference:

- `__ieee_status()` on page 3-8.

Compiler Reference:

- `--fpmode=model` on page 3-42.
4.17 ARM floating-point compiler extensions to the C99 interface

Note
The following functionality requires you to select a floating-point model that supports exceptions, such as --fpmode=ieee_full or --fpmode=ieee_fixed.

The ARM C library provides some extensions to the C99 interface to enable it to do everything that the ARM floating-point environment is capable of. This includes trapping and untrapping individual exception types, and installing custom trap handlers.

The types fenv_t and fexcept_t are not defined by C99 to be anything in particular. The ARM compiler defines them both to be the same structure type:

```c
typedef struct {
    unsigned statusword;
    __ieee_handler_t __invalid_handler;
    __ieee_handler_t __divbyzero_handler;
    __ieee_handler_t __overflow_handler;
    __ieee_handler_t __underflow_handler;
    __ieee_handler_t __inexact_handler;
} fenv_t, fexcept_t;
```

The members of this structure are:

- statusword, the same status variable that the function __ieee_status() sees, laid out in the same format.
- Five function pointers giving the address of the trap handler for each exception. By default, each is NULL. This means that if the exception is trapped, the default exception trap action happens. The default is to cause a SIGFPE signal.

4.17.1 See also

Tasks
- Writing a custom exception trap handler on page 4-22
- Controlling the ARM floating-point environment on page 4-13.

Concepts
- C99-compatible functions for controlling the ARM floating-point environment on page 4-15
- Example of a custom exception handler on page 4-26.

Reference

ARM® C and C++ Libraries and Floating-Point Support Reference:
- __ieee_status() on page 3-8.

Compiler Reference:
- --fpmode=model on page 3-42.
4.18 Writing a custom exception trap handler

Note

The following functionality requires you to select a floating-point model that supports exceptions, such as --fpmode=ieee_full or --fpmode=ieee_fixed.

If you want to install a custom exception trap handler, declare it as a function like this:

```c
__softfp__ieee_value_t myhandler(__ieee_value_t op1,
    __ieee_value_t op2,
    __ieee_edata_t edata);
```

The parameters to this function are:

- `op1, op2` These are used to give the operands, or the intermediate result, for the operation that caused the exception:
  - For the Invalid Operation and Divide by Zero exceptions, the original operands are supplied.
  - For the Inexact Result exception, all that is supplied is the ordinary result that would have been returned anyway. This is provided in `op1`.
  - For the Overflow exception, an intermediate result is provided. This result is calculated by working out what the operation would have returned if the exponent range had been big enough, and then adjusting the exponent so that it fits in the format. The exponent is adjusted by 192 (0xC0) in single-precision, and by 1536 (0x600) in double-precision.
    If Overflow happens when converting a `double` to a `float`, the result is supplied in `double` format, rounded to single-precision, with the exponent biased by 192.
  - For the Underflow exception, a similar intermediate result is produced, but the bias value is added to the exponent instead of being subtracted. The `edata` parameter also contains a flag to show whether the intermediate result has had to be rounded up, down, or not at all.

The type `__ieee_value_t` is defined as a union of all the possible types that an operand can be passed as:

```c
typedef union{
    float __f;
    float __s;
    double __d;
    short __h;
    unsigned short __uh;
    int __i;
    unsigned int __ui;
    long long __l;
    unsigned long long __ul;
    ...
} __ieee_value_t; /* in and out values passed to traps */
```

Note

If you do not compile with --strict, and you have code that used the older definition of `__ieee_value_t`, your older code still works. See the file fenv.h for more information.
edata This contains flags that give information about the exception that occurred, and what operation was being performed. (The type __ieee_edata_t is a synonym for unsigned int.)

__softfp__ieee_value_t myhandler

The return value from the function is used as the result of the operation that caused the exception.

4.18.1 edata flags for exception trap handler

The flags contained in edata are:

edata & FE_EX_RODIR

This is nonzero if the intermediate result in Underflow was rounded down, and 0 if it was rounded up or not rounded. (The difference between the last two is given in the Inexact Result bit.) This bit is meaningless for any other type of exception.

edata & FE_EX_exception

This is nonzero if the given exception (INVALID, DIVBYZERO, OVERFLOW, UNDERFLOW, or INEXACT) occurred. This enables you to:

• use the same handler function for more than one exception type (the function can test these bits to tell what exception it is supposed to handle)
• determine whether Overflow and Underflow intermediate results have been rounded or are exact.

Because the FE_EX_INEXACT bit can be set in combination with either FE_EX_OVERFLOW or FE_EX_UNDERFLOW, you must determine the type of exception that actually occurred by testing Overflow and Underflow before testing Inexact.

edata & FE_EX_FLUSHZERO

This is nonzero if the FZ bit was set when the operation was performed.

edata & FE_EX_ROUND_MASK

This gives the rounding mode that applies to the operation. This is normally the same as the current rounding mode, unless the operation that caused the exception was a routine such as _ffix, that always rounds toward zero. The available rounding mode values are FE_EX_ROUND_NEAREST, FE_EX_ROUND_PLUSINF, FE_EX_ROUND_MINUSINF and FE_EX_ROUND_ZERO.

edata & FE_EX_INTYPE_MASK

This gives the type of the operands to the function, as one of the type values shown in Table 4-6.

<table>
<thead>
<tr>
<th>Flag</th>
<th>Operand type</th>
</tr>
</thead>
<tbody>
<tr>
<td>FE_EX_INTYPE_FLOAT</td>
<td>float</td>
</tr>
<tr>
<td>FE_EX_INTYPE_DOUBLE</td>
<td>double</td>
</tr>
<tr>
<td>FE_EX_INTYPE_FD</td>
<td>float double</td>
</tr>
<tr>
<td>FE_EX_INTYPE_DF</td>
<td>double float</td>
</tr>
<tr>
<td>FE_EX_INTYPE_HALF</td>
<td>short</td>
</tr>
<tr>
<td>FE_EX_INTYPE_INT</td>
<td>int</td>
</tr>
</tbody>
</table>

Table 4-6 FE_EX_INTYPE_MASK operand type flags
Floating-point support

Table 4-6 FE_EX_INTYPE_MASK operand type flags (continued)

<table>
<thead>
<tr>
<th>Flag</th>
<th>Operand type</th>
</tr>
</thead>
<tbody>
<tr>
<td>FE_EX_INTYPE_UINT</td>
<td>unsigned int</td>
</tr>
<tr>
<td>FE_EX_INTYPE_LONGLONG</td>
<td>long long</td>
</tr>
<tr>
<td>FE_EX_INTYPE_ULONGLONG</td>
<td>unsigned long long</td>
</tr>
</tbody>
</table>

edata & FE_EX_OUTTYPE_MASK

This gives the type of the operands to the function, as one of the type values shown in Table 4-7.

Table 4-7 FE_EX_OUTTYPE_MASK operand type flags

<table>
<thead>
<tr>
<th>Flag</th>
<th>Operand type</th>
</tr>
</thead>
<tbody>
<tr>
<td>FE_EX_OUTTYPE_FLOAT</td>
<td>float</td>
</tr>
<tr>
<td>FE_EX_OUTTYPE_DOUBLE</td>
<td>double</td>
</tr>
<tr>
<td>FE_EX_OUTTYPE_HALF</td>
<td>short</td>
</tr>
<tr>
<td>FE_EX_OUTTYPE_INT</td>
<td>int</td>
</tr>
<tr>
<td>FE_EX_OUTTYPE_UINT</td>
<td>unsigned int</td>
</tr>
<tr>
<td>FE_EX_OUTTYPE_LONGLONG</td>
<td>long long</td>
</tr>
<tr>
<td>FE_EX_OUTTYPE_ULONGLONG</td>
<td>unsigned long long</td>
</tr>
</tbody>
</table>

edata & FE_EX_FN_MASK

This gives the nature of the operation that caused the exception, as one of the operation codes shown in Table 4-8.

Table 4-8 FE_EX_FN_MASK operation type flags

<table>
<thead>
<tr>
<th>Flag</th>
<th>Operation type</th>
</tr>
</thead>
<tbody>
<tr>
<td>FE_EX_FN_ADD</td>
<td>Addition.</td>
</tr>
<tr>
<td>FE_EX_FN_SUB</td>
<td>Subtraction.</td>
</tr>
<tr>
<td>FE_EX_FN_MUL</td>
<td>Multiplication.</td>
</tr>
<tr>
<td>FE_EX_FN_DIV</td>
<td>Division.</td>
</tr>
<tr>
<td>FE_EX_FN_REM</td>
<td>Remainder.</td>
</tr>
<tr>
<td>FE_EX_FN_RND</td>
<td>Round to integer.</td>
</tr>
<tr>
<td>FE_EX_FN_SQRT</td>
<td>Square root.</td>
</tr>
<tr>
<td>FE_EX_FN_CMP</td>
<td>Compare.</td>
</tr>
<tr>
<td>FE_EX_FN_CVT</td>
<td>Convert between formats.</td>
</tr>
<tr>
<td>FE_EX_FN_LOGB</td>
<td>Exponent fetching.</td>
</tr>
</tbody>
</table>
When the operation is a comparison, the result must be returned as if it were an `int`, and must be one of the four values shown in Table 4-9.

Input and output types are the same for all operations except Compare and Convert.

### Table 4-9 FE_EX_CMPRET_MASK comparison type flags

<table>
<thead>
<tr>
<th>Flag</th>
<th>Comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td>FE_EX_CMPRET_LESS</td>
<td>op1 is less than op2</td>
</tr>
<tr>
<td>FE_EX_CMPRET_EQUAL</td>
<td>op1 is equal to op2</td>
</tr>
<tr>
<td>FE_EX_CMPRET_GREATER</td>
<td>op1 is greater than op2</td>
</tr>
<tr>
<td>FE_EX_CMPRET_UNORDERED</td>
<td>op1 and op2 are not comparable</td>
</tr>
</tbody>
</table>

### 4.18.2 See also

#### Tasks
- Controlling the ARM floating-point environment on page 4-13.

#### Concepts
- Example of a custom exception handler on page 4-26.
- ARM floating-point compiler extensions to the C99 interface on page 4-21
- C99-compatible functions for controlling the ARM floating-point environment on page 4-15.

#### Reference
*ARM® C and C++ Libraries and Floating-Point Support Reference:

- `__ieee_status()` on page 3-8.

*Compiler Reference:

- `--fpmode=model` on page 3-42
- `--strict, --no_strict` on page 3-88.
4.19 Example of a custom exception handler

Note

The following functionality requires you to select a floating-point model that supports exceptions, such as --fpmode=ieee_full or --fpmode=ieee_fixed.

Example 4-1 shows a custom exception handler. Suppose you are converting some Fortran code into C. The Fortran numerical standard requires 0 divided by 0 to be 1, whereas IEEE 754 defines 0 divided by 0 to be an Invalid Operation and so by default it returns a quiet NaN. The Fortran code is likely to rely on this behavior, and rather than modifying the code, it is probably easier to make 0 divided by 0 return 1.

When compiling, you must select a floating-point model that supports exceptions, for example --fpmode=ieee_full or --fpmode=ieee_fixed.

After the handler is installed, dividing 0.0 by 0.0 returns 1.0.

Example 4-1 Custom exception handler

```c
#include <fenv.h>
#include <signal.h>
#include <stdio.h>
__softfp __ieee_value_t myhandler(__ieee_value_t op1, __ieee_value_t op2,
    __ieee_edata_t edata)
{
   __ieee_value_t ret;
   if ((edata & FE_EX_FN_MASK) == FE_EX_FN_DIV)
   {
      if ((edata & FE_EX_INTYPE_MASK) == FE_EX_INTYPE_FLOAT)
      {
         if (op1.f == 0.0 && op2.f == 0.0)
         {
            ret.f = 1.0;
            return ret;
         }
      }
      if ((edata & FE_EX_INTYPE_MASK) == FE_EX_INTYPE_DOUBLE)
      {
         if (op1.d == 0.0 && op2.d == 0.0)
         {
            ret.d = 1.0;
            return ret;
         }
      }
   }
   /* For all other invalid operations, raise SIGFPE as usual */
   raise(SIGFPE);
}
int main(void)
{
   float i, j, k;
   fenv_t env;
   fegetenv(&env);
   env.statusword |= FE_IEEE_MASK_INVALID;
   env.invalid_handler = myhandler;
   fesetenv(&env);
   i = 0.0;
   j = 0.0;
```
4.19.1 See also

Tasks
- Writing a custom exception trap handler on page 4-22
- Controlling the ARM floating-point environment on page 4-13.

Concepts
- ARM floating-point compiler extensions to the C99 interface on page 4-21
- C99-compatible functions for controlling the ARM floating-point environment on page 4-15.

Reference
Compiler Reference:
- --fpmode=model on page 3-42.
4.20 Exception trap handling by signals

--- Note ---
The following functionality requires you to select a floating-point model that supports
exceptions, such as --fpmode=ieee_full or --fpmode=ieee_fixed.

---

If an exception is trapped but the trap handler address is set to NULL, a default trap handler is used.

The default trap handler raises a SIGFPE signal. The default handler for SIGFPE prints an
error message and terminates the program.

If you trap SIGFPE, you can declare your signal handler function to have a second parameter
that tells you the type of floating-point exception that occurred. This feature is provided for
compatibility with Microsoft products. The values are _FPE_INVALID, _FPE_ZERODIVIDE,
_FPE_OVERFLOW, _FPE_UNDERFLOW and _FPE_INEXACT. They are defined in float.h. For example:

```c
void sigfpe(int sig, int etype){
    printf("SIGFPE (%s)\n", 
        etype == _FPE_INVALID ? "Invalid Operation" :
        etype == _FPE_ZERODIVIDE ? "Divide by Zero" :
        etype == _FPE_OVERFLOW ? "Overflow" :
        etype == _FPE_UNDERFLOW ? "Underflow" :
        etype == _FPE_INEXACT ? "Inexact Result" :
            "Unknown");
}

signal(SIGFPE, (void(*)(int))sigfpe);
```

To generate your own SIGFPE signals with this extra information, you can call the function
__rt_raise() instead of the ISO function raise(). For example:

```c
__rt_raise(SIGFPE, _FPE_INVALID);
__rt_raise() is declared in rt_misc.h.
```

4.20.1 See also

Tasks
- Writing a custom exception trap handler on page 4-22
- Controlling the ARM floating-point environment on page 4-13.

Concepts
- ARM floating-point compiler extensions to the C99 interface on page 4-21
- C99-compatible functions for controlling the ARM floating-point environment on
page 4-15.

Reference

ARM® C and C++ Libraries and Floating-Point Support Reference:
- __rt_raise() on page 2-35.

Compiler Reference:
- --fpmode=model on page 3-42.
4.21 Using C99 signalling NaNs provided by mathlib (_WANT_SNAN)

If you want to use signalling NaNs, you must indicate this to the compiler by defining the macro _WANT_SNAN in your application. This macro must be defined before you include any standard C headers. If your application is comprised of two or more translation units, either all or none of them must define _WANT_SNAN. That is, the definition must be consistent for any given application.

You must also use the relevant command-line option when you compile your source code. This is associated with the predefined macro, __SUPPORT_SNAN__.

4.21.1 See also

Reference

Compiler Reference:
• Predefined macros on page 5-98.

Other information
• WG14 - C N965, Optional support for Signaling NaNs, http://www.open-std.org/
4.22 mathlib double and single-precision floating-point functions

The math library, mathlib, provides double and single-precision functions for mathematical calculations. For example, to calculate a cube root, you can use cbrt() (double-precision) or cbrtf() (single-precision).

ISO/IEC 14882 specifies that in addition to the double versions of the math functions in `cmath`, C++ adds float (and long double) overloaded versions of these functions. The ARM implementation extends this in scope to include the additional math functions that do not exist in C89, but that do exist in C99.

In C++, std::cbrt() on a float argument selects the single-precision version of the function, and the same type of selection applies to other floating-point functions in C++.
4.23 Nonstandard functions in mathlib

See the following topics for nonstandard mathlib functions:

- `gamma()`, `gamma_r()` on page 3-7
- `j0()`, `j1()`, `jn()`, Bessel functions of the first kind on page 3-11
- `y0()`, `yl()`, `yn()`, Bessel functions of the second kind on page 3-14.
- `significand()`, fractional part of a number on page 3-12.
4.24 IEEE 754 arithmetic

The ARM floating-point environment is an implementation of the IEEE 754 standard for binary floating-point arithmetic. See the following topics for a summary of the standard as it is implemented by the ARM compiler:

- Basic data types for IEEE 754 arithmetic on page 4-33
- IEEE 754 arithmetic and rounding on page 4-41
- Exceptions arising from IEEE 754 floating-point arithmetic on page 4-42.
4.25 Basic data types for IEEE 754 arithmetic

ARM floating-point values are stored in one of two data types, *single-precision* and *double-precision*. In this documentation, they are called *float* and *double*, these being the corresponding C data types.

4.25.1 See also

Concepts
- *Single precision data type for IEEE 754 arithmetic* on page 4-34
- *Double precision data type for IEEE 754 arithmetic* on page 4-36
- *Sample single precision floating-point values for IEEE 754 arithmetic* on page 4-37
- *Sample double precision floating-point values for IEEE 754 arithmetic* on page 4-39.

Other information
- *IEEE Standard for Floating-Point Arithmetic* (IEEE 754), 1985 version,
  http://ieeexplore.ieee.org
4.26 Single precision data type for IEEE 754 arithmetic

A float value is 32 bits wide. The structure is shown in Figure 4-1.

![Figure 4-1 IEEE 754 single-precision floating-point format](image)

The S field gives the sign of the number. It is 0 for positive, or 1 for negative.

The Exp field gives the exponent of the number, as a power of two. It is biased by 0x7F (127), so that very small numbers have exponents near zero and very large numbers have exponents near 0xFF (255).

So, for example:
- if Exp = 0x7D (125), the number is between 0.25 and 0.5 (not including 0.5)
- if Exp = 0x7E (126), the number is between 0.5 and 1.0 (not including 1.0)
- if Exp = 0x7F (127), the number is between 1.0 and 2.0 (not including 2.0)
- if Exp = 0x80 (128), the number is between 2.0 and 4.0 (not including 4.0)
- if Exp = 0x81 (129), the number is between 4.0 and 8.0 (not including 8.0).

The Frac field gives the fractional part of the number. It usually has an implicit 1 bit on the front that is not stored to save space.

So if Exp is 0x7F, for example:
- if Frac = 00000000000000000000000 (binary), the number is 1.0
- if Frac = 10000000000000000000000 (binary), the number is 1.5
- if Frac = 01000000000000000000000 (binary), the number is 1.25
- if Frac = 11000000000000000000000 (binary), the number is 1.75.

So in general, the numeric value of a bit pattern in this format is given by the formula:

\[ (-1)^S \times 2^{(Exp-0x7F)} \times (1 + Frac \times 2^{-23}) \]

Numbers stored in this form are called normalized numbers.

The maximum and minimum exponent values, 0 and 255, are special cases. Exponent 255 is used to represent infinity, and store Not a Number (NaN) values. Infinity can occur as a result of dividing by zero, or as a result of computing a value that is too large to store in this format. NaN values are used for special purposes. Infinity is stored by setting Exp to 255 and Frac to all zeros. If Exp is 255 and Frac is nonzero, the bit pattern represents a NaN.

Exponent 0 is used to represent very small numbers in a special way. If Exp is zero, then the Frac field has no implicit 1 on the front. This means that the format can store 0.0, by setting both Exp and Frac to all 0 bits. It also means that numbers that are too small to store using Exp >= 1 are stored with less precision than the ordinary 23 bits. These are called denormals.

4.26.1 See also

Concepts
- Basic data types for IEEE 754 arithmetic on page 4-33.

Reference
- Sample single precision floating-point values for IEEE 754 arithmetic on page 4-37.
Other information

- *IEEE Standard for Floating-Point Arithmetic* (IEEE 754), 1985 version,
  http://ieeexplore.ieee.org
4.27  Double precision data type for IEEE 754 arithmetic

A double value is 64 bits wide. Figure 4-2 shows its structure.

```
        63  62  52  51  0
    +---------------+----+
    |       S       |  Exp | Frac |
    +---------------+----+
```

Figure 4-2 IEEE 754 double-precision floating-point format

As before, S is the sign, Exp the exponent, and Frac the fraction. Most of the detail of float values remains true for double values, except that:

- The Exp field is biased by 0x3FF (1023) instead of 0x7F, so numbers between 1.0 and 2.0 have an Exp field of 0x3FF.
- The Exp value used to represent infinity and NaNs is 0x7FF (2047) instead of 0xFFF.

4.27.1  See also

Concepts
- Single precision data type for IEEE 754 arithmetic on page 4-34
- Basic data types for IEEE 754 arithmetic on page 4-33.

Reference
- Sample double precision floating-point values for IEEE 754 arithmetic on page 4-39.

Other information
- IEEE Standard for Floating-Point Arithmetic (IEEE 754), 1985 version,
  http://ieeexplore.ieee.org
4.28 Sample single precision floating-point values for IEEE 754 arithmetic

Some sample float bit patterns, together with their mathematical values, are given in Table 4-10.

<table>
<thead>
<tr>
<th>Float value</th>
<th>S</th>
<th>Exp</th>
<th>Frac</th>
<th>Mathematical value</th>
<th>Notes^a</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x3F8000000</td>
<td>0</td>
<td>0x7F</td>
<td>000...000</td>
<td>1.0</td>
<td>-</td>
</tr>
<tr>
<td>0x8F8000000</td>
<td>1</td>
<td>0x7F</td>
<td>000...000</td>
<td>-1.0</td>
<td>-</td>
</tr>
<tr>
<td>0x3F800001</td>
<td>0</td>
<td>0x7F</td>
<td>000...001</td>
<td>1.000 000 119</td>
<td>a</td>
</tr>
<tr>
<td>0x3F4000000</td>
<td>0</td>
<td>0x7E</td>
<td>100...000</td>
<td>0.75</td>
<td>-</td>
</tr>
<tr>
<td>0x008000000</td>
<td>0</td>
<td>0x01</td>
<td>000...000</td>
<td>1.18*10^-38</td>
<td>b</td>
</tr>
<tr>
<td>0x00000001</td>
<td>0</td>
<td>0x00</td>
<td>000...001</td>
<td>1.40*10^-45</td>
<td>c</td>
</tr>
<tr>
<td>0x7F7FFFFF</td>
<td>0</td>
<td>0xFE</td>
<td>111...111</td>
<td>3.40*10^38</td>
<td>d</td>
</tr>
<tr>
<td>0x7F800000</td>
<td>0</td>
<td>0xFF</td>
<td>000...000</td>
<td>Plus infinity</td>
<td>-</td>
</tr>
<tr>
<td>0xFF800000</td>
<td>1</td>
<td>0xFF</td>
<td>000...000</td>
<td>Minus infinity</td>
<td>-</td>
</tr>
<tr>
<td>0x00000000</td>
<td>0</td>
<td>0x00</td>
<td>000...000</td>
<td>0.0</td>
<td>c</td>
</tr>
<tr>
<td>0x7F800001</td>
<td>0</td>
<td>0xFF</td>
<td>000...001</td>
<td>Signaling NaN</td>
<td>f</td>
</tr>
<tr>
<td>0x7FC00000</td>
<td>0</td>
<td>0xFF</td>
<td>100...000</td>
<td>Quiet NaN</td>
<td>f</td>
</tr>
</tbody>
</table>

^a. See Notes on sample single precision floating-point values for more information.

4.28.1 Notes on sample single precision floating-point values

a. The smallest representable number that can be seen to be greater than 1.0. The amount that it differs from 1.0 is known as the machine epsilon. This is 0.000 000 119 in float, and 0.000 000 000 000 000 222 in double. The machine epsilon gives a rough idea of the number of significant figures the format can keep track of. float can do six or seven places. double can do fifteen or sixteen.

b. The smallest value that can be represented as a normalized number in each format. Numbers smaller than this can be stored as denormals, but are not held with as much precision.

c. The smallest positive number that can be distinguished from zero. This is the absolute lower limit of the format.

d. The largest finite number that can be stored. Attempting to increase this number by addition or multiplication causes overflow and generates infinity (in general).

e. Zero. Strictly speaking, they show plus zero. Zero with a sign bit of 1, minus zero, is treated differently by some operations, although the comparison operations (for example == and !=) report that the two types of zero are equal.

f. There are two types of NaNs, signaling NaNs and quiet NaNs. Quiet NaNs have a 1 in the first bit of Frac, and signaling NaNs have a zero there. The difference is that signaling NaNs cause an exception when used, whereas quiet NaNs do not.
4.28.2 See also

Concepts
• Single precision data type for IEEE 754 arithmetic on page 4-34
• Basic data types for IEEE 754 arithmetic on page 4-33
• Exceptions arising from IEEE 754 floating-point arithmetic on page 4-42.

Other information
4.29 Sample double precision floating-point values for IEEE 754 arithmetic

Some sample double bit patterns, together with their mathematical values, are given in Table 4-11.

Table 4-11 Sample double-precision floating-point values

<table>
<thead>
<tr>
<th>Double value</th>
<th>S</th>
<th>Exp</th>
<th>Frac</th>
<th>Mathematical value</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x3FF00000 00000000</td>
<td>0</td>
<td>0x3FF00000 00000000</td>
<td>1.0</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>0xBF00000 00000000</td>
<td>1</td>
<td>0x3FF00000 00000000</td>
<td>-1.0</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>0x3FF00000 00000001</td>
<td>0</td>
<td>0x3FF00000 00000001</td>
<td>1.000 000 000 000 000 222</td>
<td>a</td>
<td></td>
</tr>
<tr>
<td>0x3FE00000 00000000</td>
<td>0</td>
<td>0x3FE00000 00000000</td>
<td>0.75</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>0x00100000 00000000</td>
<td>0</td>
<td>0x00100000 00000000</td>
<td>2.23×10⁻³⁰⁸</td>
<td>b</td>
<td></td>
</tr>
<tr>
<td>0x00000000 00000001</td>
<td>0</td>
<td>0x00000000 00000001</td>
<td>4.94×10⁻³²⁴</td>
<td>c</td>
<td></td>
</tr>
<tr>
<td>0x7FEEEEEEE FFFFFFFF</td>
<td>0</td>
<td>0x7FEEEEEEE FFFFFFFF</td>
<td>1.80×10³⁰⁸</td>
<td>d</td>
<td></td>
</tr>
<tr>
<td>0x7F000000 00000000</td>
<td>0</td>
<td>0x7F000000 00000000</td>
<td>Plus infinity</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>0xFFF00000 00000000</td>
<td>1</td>
<td>0xFFF00000 00000000</td>
<td>Minus infinity</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>0x00000000 00000000</td>
<td>0</td>
<td>0x00000000 00000000</td>
<td>0.0</td>
<td>e</td>
<td></td>
</tr>
<tr>
<td>0xFFF00000 00000001</td>
<td>0</td>
<td>0xFFF00000 00000001</td>
<td>Signaling NaN</td>
<td>f</td>
<td></td>
</tr>
<tr>
<td>0xFFF80000 00000000</td>
<td>0</td>
<td>0xFFF80000 00000000</td>
<td>Quiet NaN</td>
<td>f</td>
<td></td>
</tr>
</tbody>
</table>

a. See Notes on sample double precision floating-point values for more information.

4.29.1 Notes on sample double precision floating-point values

a The smallest representable number that can be seen to be greater than 1.0. The amount that it differs from 1.0 is known as the machine epsilon. This is 0.000 000 119 in float, and 0.000 000 000 000 000 222 in double. The machine epsilon gives a rough idea of the number of significant figures the format can keep track of. float can do six or seven places. double can do fifteen or sixteen.

b The smallest value that can be represented as a normalized number in each format. Numbers smaller than this can be stored as denormals, but are not held with as much precision.

c The smallest positive number that can be distinguished from zero. This is the absolute lower limit of the format.

d The largest finite number that can be stored. Attempting to increase this number by addition or multiplication causes overflow and generates infinity (in general).

e Zero. Strictly speaking, they show plus zero. Zero with a sign bit of 1, minus zero, is treated differently by some operations, although the comparison operations (for example == and !=) report that the two types of zero are equal.

f There are two types of NaNs, signaling NaNs and quiet NaNs. Quiet NaNs have a 1 in the first bit of Frac, and signaling NaNs have a zero there. The difference is that signaling NaNs cause an exception when used, whereas quiet NaNs do not.
4.29.2 See also

Concepts
- Exceptions arising from IEEE 754 floating-point arithmetic on page 4-42
- Double precision data type for IEEE 754 arithmetic on page 4-36
- Basic data types for IEEE 754 arithmetic on page 4-33.

Other information
4.30 IEEE 754 arithmetic and rounding

Arithmetic is generally performed by computing the result of an operation as if it were stored exactly (to infinite precision), and then rounding it to fit in the format. Apart from operations whose result already fits exactly into the format (such as adding 1.0 to 1.0), the correct answer is generally somewhere between two representable numbers in the format. The system then chooses one of these two numbers as the rounded result. It uses one of the following methods:

Round to nearest

The system chooses the nearer of the two possible outputs. If the correct answer is exactly halfway between the two, the system chooses the output where the least significant bit of Frac is zero. This behavior (round-to-even) prevents various undesirable effects.

This is the default mode when an application starts up. It is the only mode supported by the ordinary floating-point libraries. Hardware floating-point environments and the enhanced floating-point libraries support all four rounding modes.

Round up, or round toward plus infinity

The system chooses the larger of the two possible outputs (that is, the one further from zero if they are positive, and the one closer to zero if they are negative).

Round down, or round toward minus infinity

The system chooses the smaller of the two possible outputs (that is, the one closer to zero if they are positive, and the one further from zero if they are negative).

Round toward zero, or chop, or truncate

The system chooses the output that is closer to zero, in all cases.

4.30.1 See also

Concepts

- IEEE 754 arithmetic on page 4-32.

Reference

- C and C++ library naming conventions on page 2-120.

Other information

4.31 Exceptions arising from IEEE 754 floating-point arithmetic

Floating-point arithmetic operations can run into various problems. For example, the result computed might be either too big or too small to fit into the format, or there might be no way to calculate the result (as in trying to take the square root of a negative number, or trying to divide zero by zero). These are known as exceptions, because they indicate unusual or exceptional situations.

The ARM floating-point environment can handle an exception by inventing a plausible result for the operation and returning that result, or by trapping the exception.

4.31.1 See also

Concepts
- Ignoring exceptions from IEEE 754 floating-point arithmetic operations on page 4-43
- Trapping exceptions from IEEE 754 floating-point arithmetic operations on page 4-44
- Exception types recognized by the ARM floating-point environment on page 4-45
- IEEE 754 arithmetic on page 4-32.

Other information
4.32 Ignoring exceptions from IEEE 754 floating-point arithmetic operations

The system invents a plausible result for the operation and returns that result. For example, the square root of a negative number can produce a NaN, and trying to compute a value too big to fit in the format can produce infinity. If an exception occurs and is ignored, a flag is set in the floating-point status word to tell you that something went wrong at some time in the past.

4.32.1 See also

Concepts
- Exceptions arising from IEEE 754 floating-point arithmetic on page 4-42
- IEEE 754 arithmetic on page 4-32.

Other information
4.33 Trapping exceptions from IEEE 754 floating-point arithmetic operations

When an exception occurs, a piece of code called a trap handler is run. The system provides a default trap handler that prints an error message and terminates the application. However, you can supply your own trap handlers to clean up the exceptional condition in whatever way you choose. Trap handlers can even supply a result to be returned from the operation.

For example, if you had an algorithm where it was convenient to assume that 0 divided by 0 was 1, you could supply a custom trap handler for the Invalid Operation exception to identify that particular case and substitute the answer you required.

4.33.1 See also

Concepts
• Exceptions arising from IEEE 754 floating-point arithmetic on page 4-42
• IEEE 754 arithmetic on page 4-32.

Other information
### 4.34 Exception types recognized by the ARM floating-point environment

The ARM floating-point environment recognizes the following types of exception:

- The **Invalid Operation** exception. This occurs when there is no sensible result for an operation. This can happen for any of the following reasons:
  - performing any operation on a signaling NaN, except the simplest operations (copying and changing the sign)
  - adding plus infinity to minus infinity, or subtracting an infinity from itself
  - multiplying infinity by zero
  - dividing 0 by 0, or dividing infinity by infinity
  - taking the remainder from dividing anything by 0, or infinity by anything
  - taking the square root of a negative number (not including minus zero)
  - converting a floating-point number to an integer if the result does not fit
  - comparing two numbers if one of them is a NaN.

  If the Invalid Operation exception is not trapped, these operations return a quiet NaN. The exception is conversion to an integer. This returns zero because there are no quiet NaNs in integers.

- The **Divide by Zero** exception. This occurs if you divide a finite nonzero number by zero. Be aware that:
  - Dividing zero by zero gives an Invalid Operation exception.
  - Dividing infinity by zero is valid and returns infinity.

  If Divide by Zero is not trapped, the operation returns infinity.

- The **Overflow** exception. This occurs when the result of an operation is too big to fit into the format. This happens, for example, if you add the largest representable number to itself. The largest float value is \(0x7F7FFFFF\).

  If Overflow is not trapped, the operation returns infinity, or the largest finite number, depending on the rounding mode.

- The **Underflow** exception. This can occur when the result of an operation is too small to be represented as a normalized number (with \(\text{Exp}\) at least 1).

  The situations that cause Underflow depend on whether it is trapped or not:
  - If Underflow is trapped, it occurs whenever a result is too small to be represented as a normalized number.
  - If Underflow is not trapped, it only occurs if the result requires rounding. So, for example, dividing the float number \(0x00800000\) by 2 does not signal Underflow, because the result \(0x00400000\) is exact. However, trying to multiply the float number \(0x00000001\) by 1.5 does signal Underflow.

  **Note**

  For readers familiar with the IEEE 754 specification, the chosen implementation options in the ARM compiler are to detect tininess before rounding, and to detect loss of accuracy as an inexact result.

  If Underflow is not trapped, the result is rounded to one of the two nearest representable denormal numbers, according to the current rounding mode. The loss of precision is ignored and the system returns the best result it can.
The Inexact Result exception happens whenever the result of an operation requires rounding. This would cause significant loss of speed if it had to be detected on every operation in software, so the ordinary floating-point libraries do not support the Inexact Result exception. The enhanced floating-point libraries, and hardware floating-point systems, all support Inexact Result.

If Inexact Result is not trapped, the system rounds the result in the usual way. The flag for Inexact Result is also set by Overflow and Underflow if either one of those is not trapped.

All exceptions are untrapped by default.

### 4.34.1 See also

#### Tasks
- *Writing a custom exception trap handler on page 4-22.*

#### Concepts
- *Exception flag handling on page 4-17*
- *Example of a custom exception handler on page 4-26*
- *Exception trap handling by signals on page 4-28*
- *IEEE 754 arithmetic on page 4-32*
- *Exceptions arising from IEEE 754 floating-point arithmetic on page 4-42*
- *Ignoring exceptions from IEEE 754 floating-point arithmetic operations on page 4-43*
- *Trapping exceptions from IEEE 754 floating-point arithmetic operations on page 4-44.*

#### Reference
- *Sample single precision floating-point values for IEEE 754 arithmetic on page 4-37.*

#### Other information
- *IEEE Standard for Floating-Point Arithmetic (IEEE 754)*, 1985 version, 
  http://ieeexplore.ieee.org
4.35 Using the Vector Floating-Point (VFP) support libraries

The VFP support libraries are used by the VFP Support Code. The VFP Support Code is executed from an undefined instruction trap that is triggered when an exceptional floating-point condition occurs.

4.35.1 See also

Concepts

Using the Compiler:
• Limitations on hardware handling of floating-point arithmetic on page 5-59
• Implementation of Vector Floating-Point (VFP) support code on page 5-60.

Other information
• Using VFP with RVDS, Application Note 133,