Arm® Compiler
Version 6.14

Arm C and C++ Libraries and Floating-Point Support User Guide
Arm® Compiler
Arm® C and C++ Libraries and Floating-Point Support User Guide
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Preface

This preface introduces the *Arm* Compiler Arm C and C++ Libraries and Floating-Point Support User Guide.

It contains the following:

- *About this book on page 11.*
About this book

Arm® Compiler Arm C and C++ Libraries and Floating-Point Support User Guide. This manual provides user information for the Arm libraries and floating-point support. It is also available as a PDF.

Using this book

This book is organized into the following chapters:

- **Chapter 1 The Arm® C and C++ Libraries**
  Describes the Arm C and C++ libraries.

- **Chapter 2 The Arm® C Micro-library**
  Describes microlib, the C micro-library.

- **Chapter 3 Floating-point Support**
  Describes Arm support for floating-point computations.

- **Chapter 4 The C and C++ Library Functions Reference**
  Describes the standard C and C++ library functions that are extensions to the C Standard or that differ in some way to the standard.

- **Chapter 5 Floating-point Support Functions Reference**
  Describes Arm support for floating-point functions.

Glossary

The Arm® Glossary is a list of terms used in Arm documentation, together with definitions for those terms. The Arm Glossary does not contain terms that are industry standard unless the Arm meaning differs from the generally accepted meaning.

See the *Arm® Glossary* for more information.

Typographic conventions

**italic**
Introduces special terminology, denotes cross-references, and citations.

**bold**
Highlights interface elements, such as menu names. Denotes signal names. Also used for terms in descriptive lists, where appropriate.

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

**monospace**
Denotes a permitted abbreviation for a command or option. You can enter the underlined text instead of the full command or option name.

**monospace italic**
Denotes arguments to monospace text where the argument is to be replaced by a specific value.

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

**<and>**
Encloses replaceable terms for assembler syntax where they appear in code or code fragments. For example:

```
MRC p15, 0, <Rd>, <CRn>, <CRm>, <Opcode_2>
```
SMALL CAPITALS
Used in body text for a few terms that have specific technical meanings, that are defined in the
Arm\textsuperscript{®} Glossary. For example, IMPLEMENTATION DEFINED, IMPLEMENTATION SPECIFIC, UNKNOWN, and
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• Arm\textsuperscript{®} Technical Support Knowledge Articles.
• Technical Support.
• Arm\textsuperscript{®} Glossary.
Chapter 1
The Arm® C and C++ Libraries

Describes the Arm C and C++ libraries.

It contains the following sections:

- 1.1 Support level definitions on page 1-15.
- 1.2 Mandatory linkage with the C library on page 1-19.
- 1.3 C and C++ runtime libraries on page 1-20.
- 1.4 C and C++ library features on page 1-25.
- 1.5 C++ and C libraries and the std namespace on page 1-26.
- 1.6 Multithreaded support in Arm® C libraries on page 1-27.
- 1.7 Multithreaded support in Arm® C++ libraries [ALPHA] on page 1-36.
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• 1.28 Using macro__ARM_WCHAR_NO_IO to disable FILE declaration and wide I/O function prototypes on page 1-107.
• 1.29 Using library functions with execute-only memory on page 1-108.
1.1 Support level definitions

This describes the levels of support for various Arm Compiler 6 features.

Arm Compiler 6 is built on Clang and LLVM technology. Therefore, it has more functionality than the set of product features described in the documentation. The following definitions clarify the levels of support and guarantees on functionality that are expected from these features.

Arm welcomes feedback regarding the use of all Arm Compiler 6 features, and intends to support users to a level that is appropriate for that feature. You can contact support at https://developer.arm.com/support.

Identification in the documentation

All features that are documented in the Arm Compiler 6 documentation are product features, except where explicitly stated. The limitations of non-product features are explicitly stated.

Product features

Product features are suitable for use in a production environment. The functionality is well-tested, and is expected to be stable across feature and update releases.

- Arm intends to give advance notice of significant functionality changes to product features.
- If you have a support and maintenance contract, Arm provides full support for use of all product features.
- Arm welcomes feedback on product features.
- Any issues with product features that Arm encounters or is made aware of are considered for fixing in future versions of Arm Compiler.

In addition to fully supported product features, some product features are only alpha or beta quality.

Beta product features

Beta product features are implementation complete, but have not been sufficiently tested to be regarded as suitable for use in production environments.

Beta product features are indicated with [BETA].

- Arm endeavors to document known limitations on beta product features.
- Beta product features are expected to eventually become product features in a future release of Arm Compiler 6.
- Arm encourages the use of beta product features, and welcomes feedback on them.
- Any issues with beta product features that Arm encounters or is made aware of are considered for fixing in future versions of Arm Compiler.

Alpha product features

Alpha product features are not implementation complete, and are subject to change in future releases, therefore the stability level is lower than in beta product features.

Alpha product features are indicated with [ALPHA].

- Arm endeavors to document known limitations of alpha product features.
- Arm encourages the use of alpha product features, and welcomes feedback on them.
- Any issues with alpha product features that Arm encounters or is made aware of are considered for fixing in future versions of Arm Compiler.

Community features

Arm Compiler 6 is built on LLVM technology and preserves the functionality of that technology where possible. This means that there are additional features available in Arm Compiler that are not listed in the documentation. These additional features are known as community features. For information on these community features, see the documentation for the Clang/LLVM project.
Where community features are referenced in the documentation, they are indicated with [COMMUNITY].

• Arm makes no claims about the quality level or the degree of functionality of these features, except when explicitly stated in this documentation.
• Functionality might change significantly between feature releases.
• Arm makes no guarantees that community features will remain functional across update releases, although changes are expected to be unlikely.

Some community features might become product features in the future, but Arm provides no roadmap for this. Arm is interested in understanding your use of these features, and welcomes feedback on them. Arm supports customers using these features on a best-effort basis, unless the features are unsupported. Arm accepts defect reports on these features, but does not guarantee that these issues will be fixed in future releases.

**Guidance on use of community features**

There are several factors to consider when assessing the likelihood of a community feature being functional:

• The following figure shows the structure of the Arm Compiler 6 toolchain:
Figure 1-1 Integration boundaries in Arm Compiler 6.

The dashed boxes are toolchain components, and any interaction between these components is an integration boundary. Community features that span an integration boundary might have significant limitations in functionality. The exception to this is if the interaction is codified in one of the standards supported by Arm Compiler 6. See Application Binary Interface (ABI) for the Arm® Architecture. Community features that do not span integration boundaries are more likely to work as expected.

- Features primarily used when targeting hosted environments such as Linux or BSD might have significant limitations, or might not be applicable, when targeting bare-metal environments.
- The Clang implementations of compiler features, particularly those that have been present for a long time in other toolchains, are likely to be mature. The functionality of new features, such as support
for new language features, is likely to be less mature and therefore more likely to have limited functionality.

**Deprecated features**

A deprecated feature is one that Arm plans to remove from a future release of Arm Compiler. Arm does not make any guarantee regarding the testing or maintenance of deprecated features. Therefore, Arm does not recommend using a feature after it is deprecated.

For information on replacing deprecated features with supported features, refer to the Arm Compiler documentation and Release Notes.

**Unsupported features**

With both the product and community feature categories, specific features and use-cases are known not to function correctly, or are not intended for use with Arm Compiler 6.

Limitations of product features are stated in the documentation. Arm cannot provide an exhaustive list of unsupported features or use-cases for community features. The known limitations on community features are listed in *Community features on page 1-15*.

**List of known unsupported features**

The following is an incomplete list of unsupported features, and might change over time:

- The Clang option `-stdlib=libstdc++` is not supported.
- C++ static initialization of local variables is not thread-safe when linked against the standard C++ libraries. For thread-safety, you must provide your own implementation of thread-safe functions as described in *Standard C++ library implementation definition*.

  **Note**

  This restriction does not apply to the [ALPHA]-supported multithreaded C++ libraries.

- Use of C11 library features is unsupported.
- Any community feature that is exclusively related to non-Arm architectures is not supported.
- Compilation for targets that implement architectures older than Armv7 or Armv6-M is not supported.
- The *long double* data type is not supported for AArch64 state because of limitations in the current Arm C library.
- C complex arithmetic is not supported, because of limitations in the current Arm C library.
- C++ complex numbers are supported with *float* and *double* types, but not *long double* type because of limitations in the current Arm C library.
1.2 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.

Related concepts
1.3.1 Summary of the C and C++ runtime libraries on page 1-20
1.8.4 Using the libraries in a nonsemihosting environment on page 1-49

Related references
1.9.1 Building an application without the C library on page 1-54
1.3 C and C++ runtime libraries

Arm provides the C standardlib, C microlib, and C++ runtime libraries to support compiled C and C++.

This section contains the following subsections:
• 1.3.1 Summary of the C and C++ runtime libraries on page 1-20.
• 1.3.2 Compliance with the Application Binary Interface (ABI) for the Arm® architecture on page 1-21.
• 1.3.3 Increasing portability of object files to other CLIBABI implementations on page 1-21.
• 1.3.4 Arm® C and C++ library directory structure on page 1-22.
• 1.3.5 Selection of Arm® C and C++ library variants based on build options on page 1-22.
• 1.3.6 T32 C libraries on page 1-24.

1.3.1 Summary of the C and C++ runtime libraries

A summary of the C and C++ runtime libraries provided by Arm.

C standardlib
This is a C library consisting of:
• All functions defined by the ISO C99 library standard.
• Target-dependent functions that 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 libc++ library.

Note

Arm does not guarantee the compatibility of C++ compilation units compiled with different major or minor versions of Arm Compiler and linked into a single image. Therefore, Arm recommends that you always build your C++ code from source with a single version of the toolchain.

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

Related concepts
1.2 Mandatory linkage with the C library on page 1-19

Related references
1.9.1 Building an application without the C library on page 1-54
Chapter 1 The Arm® C and C++ Libraries on page 1-13
Chapter 2 The Arm® C Micro-library on page 2-109
1.25.5 Standard C++ library implementation definition on page 1-99
1.3.2 Compliance with the Application Binary Interface (ABI) for the Arm® architecture

The ABI for the Arm Architecture is a family of specifications that describes 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, for example the Arm® GNU/Linux ABI supplement.

The Base Standard ABI for the Arm® Architecture (BSABI) enables you to use A32 and T32 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 and the CLIBABI. The libc++ library conforms to the C++ ABI for the Arm architecture (CPPABI), with the exception of Array Construction and Delete helper functions.

Related tasks
1.3.3 Increasing portability of object files to other CLIBABI implementations on page 1-21

Related references
1.25.5 Standard C++ library implementation definition on page 1-99

Related information
Application Binary Interface (ABI) for the Arm Architecture
DWARF Debugging Standard

1.3.3 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.

Note
This reduces the performance of some library operations.

There are a number of methods you can use to request full CLIBABI portability.

Procedure
• 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.

Related concepts
1.3.2 Compliance with the Application Binary Interface (ABI) for the Arm® architecture on page 1-21

Related information
Application Binary Interface (ABI) for the Arm Architecture
1.3.4 Arm® C and C++ library directory structure

The libraries are installed in the armlib and libcxx subdirectories within install_directory\lib.

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

libcxx
Contains all libc++ and libc++abi libraries.

The accompanying header files for these libraries are installed in:
install_directory\include

--- Note ---
Comments inside source files and header files that are provided by Arm might not be accurate and must not be treated as documentation about the product.

---

To specify an alternative top-level lib directory, set either one of the environment variables ARMCOMPILER6LIB or ARMLIB, to point to the new directory, or use the --libpath option.

You must not identify the armlib and libcxx directories separately because the 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 libc++ and libc++abi libraries provided with Arm Compiler 6 are based on the open source libc++ and libc++abi libraries. The modifications made by Arm are covered by restrictions described in the end user license agreement.

1.3.5 Selection of Arm® C and C++ library variants based on build options

When you build your application, you must make certain choices such as the target architecture, instruction set, and byte order. You communicate these choices to the compiler using build options. The linker then selects appropriate C and C++ library variants compatible with these build options.

Choices that influence the Arm C and C++ library variant include the following:

Target Architecture and instruction set
A32 or T32 (AArch32 state instruction sets).

--- Note ---
Microlib is not supported for AArch64 state.

---

Byte order
Big-endian or little-endian.
Floating-point support

- Software (SoftVFP).
- Hardware (VFP).
- Software or hardware with half-precision or double-precision extensions.
- No floating-point support.

Note
In Armv8, VFP hardware is integral to the architecture. Software floating-point is supported for AArch32 state, but is not supported for AArch64 state.

Position independence

Position independent code uses PC-relative addressing modes where possible and otherwise accesses global data through the Global Offset Table (GOT).

Different ways to access your data are as follows:
- By absolute address.
- Relative to $sb$ (read/write position-independent).
- Relative to $pc$ ($-fbare-metal-pie$).

Different ways to access your code are as follows:
- By absolute address when appropriate.
- Relative to $pc$ (read-only position independent).

A bare-metal Position Independent Executable (PIE) is an executable that does not need to be executed at a specific address but can be executed at any suitably aligned address.

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

You can only achieve position-independent C++ code with $-fbare-metal-pie$.

Note
- Position independence is supported only in AArch32 state, and is not supported in microlib.
- Bare-metal PIE support is deprecated in this release.

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.

Related information
- $-fropi$, $fnoropi$ compiler option
- $-frwpi$, $fnorwpi$ option
- $-marm$ compiler option
- $-mbig-endian$ compiler option
- $-mfpu$ compiler option
- $-mlittle-endian$ compiler option
- $-mthumb$ compiler option
- $--fpu$=name linker option
- $--ropi$ linker option
- $--rwpi$ linker option
- $--arm$ assembler option
- $--bigend$ assembler option
- $--fpu$ assembler option
- $--littleend$ assembler option
1.3.6 T32 C libraries

There are several variations of the T32 libraries. It depends on the architecture target or processor as to which one is used.

Armv7-A and Armv7-R use a T32 library. It contains a small number of A32 instructions that are used to significantly improve performance.

Armv7-M, Armv7E-M, and Armv8-M.mainline have their own T32 library.

Armv6-M and Armv8-M.baseline have their own T32 library.
1.4 **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 DSTREAM debug and trace unit, the Arm RVI debug unit, and the *Fixed Virtual Platform* (FVP) models.

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.
1.5 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.

Standard library names are defined 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");
  ```

**Note**

`errno` is a macro, so it is not necessary to qualify it with a namespace.
1.6 Multithreaded support in Arm® C libraries

Describes the features that are supported by the Arm C libraries for creating multithreaded applications.

This section contains the following subsections:

- 1.6.1 Arm® C libraries and multithreading on page 1-27.
- 1.6.2 Arm® C libraries and reentrant functions on page 1-27.
- 1.6.3 Arm® C libraries and thread-safe functions on page 1-28.
- 1.6.4 Use of static data in the C libraries on page 1-28.
- 1.6.5 Use of the __user_libspace static data area by the C libraries on page 1-29.
- 1.6.6 C library functions to access subsections of the __user_libspace static data area on page 1-30.
- 1.6.7 Re-implementation of legacy function __user_libspace() in the C library on page 1-30.
- 1.6.8 Management of locks in multithreaded applications on page 1-31.
- 1.6.9 How to ensure re-implemented mutex functions are called on page 1-33.
- 1.6.10 Using the Arm® C library in a multithreaded environment on page 1-33.
- 1.6.11 Thread safety in the Arm® C library on page 1-34.
- 1.6.12 Thread local storage in C [COMMUNITY] on page 1-34.
- 1.6.13 The floating-point status word in a multithreaded environment on page 1-35.

1.6.1 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.

**Related concepts**

- 1.6.2 Arm® C libraries and reentrant functions on page 1-27
- 1.6.3 Arm® C libraries and thread-safe functions on page 1-28

**Related references**

- 1.6.10 Using the Arm® C library in a multithreaded environment on page 1-33

1.6.2 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.

Related concepts
1.6.3 Arm® C libraries and thread-safe functions on page 1-28
1.6.1 Arm® C libraries and multithreading on page 1-27

1.6.3 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.

Related concepts
1.6.2 Arm® C libraries and reentrant functions on page 1-27
1.6.1 Arm® C libraries and multithreading on page 1-27
1.6.11 Thread safety in the Arm® C library on page 1-34
1.7.7 Thread safety in the Arm® C++ library on page 1-42

Related references
1.6.8 Management of locks in multithreaded applications on page 1-31
1.6.10 Using the Arm® C library in a multithreaded environment on page 1-33

1.6.4 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. Callouts from the C library enable access to static data.

Static data can be external or internal in scope, and is:

• At a fixed address, when compiled with -fnorwp1. This is the default.
• At a fixed address relative to the static base, register r9, when compiled with -frwp1.
• At a fixed address relative to the program counter (pc), when compiled with -fbare-metal-pie.

Note
Bare-metal PIE support is deprecated in this release.

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 -fnorwp1, 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 -frwp1, 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. For software floating-point, the f_* and g_* libraries use static data to store the Floating-Point (FP) status word. For hardware floating-point, the f_* and g_* libraries do not 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, -fnorwpi.
  — Reentrant build options, -frwp1.
• Some functions have static data implicit in their definitions. You must not use these in a reentrant
  application unless you build it with -frwp1 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 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 the following table. 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.

Related concepts
1.6.7 Re-implementation of legacy function __user_libspace() in the C library on page 1-30
1.11 Assembler macros that tailor locale functions in the C library on page 1-65
1.6.1 Arm® C libraries and multithreading on page 1-27

Related references
4.25 __rt_fp_status_addr() on page 4-167

Related information
-fropi, -fnoropi option
-frwp1, -fnorwp1 option
Semihosting for AArch32 and AArch64

1.6.5 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. The C libraries use the
__user_libspace area to store a number of different types of data.

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.

Note

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

Related concepts

1.6.6 C library functions to access subsections of the __user_libspace static data area on page 1-30

Related information

__aeabi_atexit() in C++ ABI for the Arm Architecture

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

The __user_perproc_libspace() and __user_perthread_libspace() functions return subsections of the __user_libspace static data area.

__user_perproc_libspace()

Returns a pointer to memory for storing data that is global to an entire process. This data is shared between all threads.

In AArch32 state, returns a pointer to 96 bytes of 4-byte aligned memory.
In AArch64 state, returns a pointer to 192 bytes of 8-byte aligned memory.

__user_perthread_libspace()

Returns a pointer to memory for storing 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.

In AArch32 state, returns a pointer to 96 bytes of 4-byte aligned memory.
In AArch64 state, returns a pointer to 192 bytes of 8-byte aligned memory.

Related concepts

1.6.7 Re-implementation of legacy function __user_libspace() in the C library on page 1-30

Related references

1.6.5 Use of the __user_libspace static data area by the C libraries on page 1-29

1.6.7 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-implement __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...
multithreaded applications. For multithreaded applications, use either or both of __user_perproc_libspace() and __user_perthread_libspace(), instead of __user_libspace().

Related concepts
1.6.6 C library functions to access subsections of the __user_libspace static data area on page 1-30
1.6.4 Use of static data in the C libraries on page 1-28

Related references
1.6.10 Using the Arm® C library in a multithreaded environment on page 1-33
1.6.5 Use of the __user_libspace static data area by the C libraries on page 1-29

1.6.8 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()

```c
int _mutex_initialize(mutex *m);
```

This function accepts a pointer to a pointer-sized 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()

```c
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 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()

```c
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()

```c
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 AArch32 and 8 bytes of memory for AArch64. This memory holds the mutex data structure. _Heap_Initialize() is one such function.

For the C library, a mutex is specified as a single pointer-sized 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-implemention 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.

---

**Related concepts**

1.6.9 How to ensure re-implemented mutex functions are called on page 1-33
1.6.11 Thread safety in the Arm® C library on page 1-34
1.7.7 Thread safety in the Arm® C++ library on page 1-42

**Related references**

1.6.10 Using the Arm® C library in a multithreaded environment on page 1-33
1.6.9 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 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 \texttt{libraryname.a(objectfilename.o)} when you invoke the linker.

Related concepts

1.6.11 Thread safety in the Arm\textsuperscript{®} C library on page 1-34
1.7.7 Thread safety in the Arm\textsuperscript{®} C++ library on page 1-42

Related references

1.6.10 Using the Arm\textsuperscript{®} C library in a multithreaded environment on page 1-33
1.6.8 Management of locks in multithreaded applications on page 1-31

1.6.10 Using the Arm\textsuperscript{®} C library in a multithreaded environment

There are a number of requirements you must fulfill before you can use the Arm C library in a multithreaded environment.

To use the Arm C library in a multithreaded environment, you must provide:
• An implementation of \texttt{\_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 \texttt{\_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 \texttt{\_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.

\textbf{Note}\hspace{1cm}

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

\textbf{Note}\hspace{1cm}

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.

**Related concepts**

- 1.6.9 How to ensure re-implemented mutex functions are called on page 1-33
- 1.6.11 Thread safety in the Arm® C library on page 1-34
- 1.7.7 Thread safety in the Arm® C++ library on page 1-42
- 1.6.1 Arm® C libraries and multithreading on page 1-27

**Related references**

- 1.6.8 Management of locks in multithreaded applications on page 1-31
- 4.58 Thread-safe C library functions on page 4-201
- 4.59 C library functions that are not thread-safe on page 4-203

### 1.6.11 Thread safety in the Arm® C library

Arm C library functions are either always thread-safe, never thread-safe, or thread-safe in certain circumstances.

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.

**Related concepts**

- 1.6.9 How to ensure re-implemented mutex functions are called on page 1-33
- 1.7.7 Thread safety in the Arm® C++ library on page 1-42

**Related references**

- 1.6.10 Using the Arm® C library in a multithreaded environment on page 1-33
- 1.6.8 Management of locks in multithreaded applications on page 1-31
- 4.58 Thread-safe C library functions on page 4-201
- 4.59 C library functions that are not thread-safe on page 4-203

### 1.6.12 Thread local storage in C [COMMUNITY]

The __thread keyword is supported in C only when used in conjunction with the `-femulated-tls` command-line option.
Note
This topic describes a [COMMUNITY] feature. See Support level definitions on page 1-15.

Related information
Language extension compatibility: keywords

1.6.13 The floating-point status word in a multithreaded environment

Applicable to variants of the software floating-point libraries that require a status word, 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.

In Arm Compiler 6, floating-point library variants are selected by default. For more information see the armclang command-line option -ffp-mode.

Related concepts
1.6.11 Thread safety in the Arm® C library on page 1-34
1.7 Multithreaded support in Arm® C++ libraries [ALPHA]

Describes the features that the Arm C++ libraries support for creating multithreaded applications. These features are [ALPHA]-supported.

--- Note ---
This topic describes an [ALPHA] feature. See Support level definitions on page 1-15.

This section contains the following subsections:

- 1.7.1 Arm® C++ libraries and multithreading [ALPHA] on page 1-36.
- 1.7.2 Clocks [ALPHA] on page 1-37.
- 1.7.3 Mutexes [ALPHA] on page 1-38.
- 1.7.4 Condition variables [ALPHA] on page 1-39.
- 1.7.5 Threads [ALPHA] on page 1-40.
- 1.7.6 Miscellaneous functions [ALPHA] on page 1-41.
- 1.7.7 Thread safety in the Arm® C++ library on page 1-42.
- 1.7.8 Supported C++ Concurrency Features [ALPHA] on page 1-42.
- 1.7.9 Guard variables [ALPHA] on page 1-42.
- 1.7.10 Exceptions [ALPHA] on page 1-43.
- 1.7.11 Thread local storage in C++ [ALPHA and COMMUNITY] on page 1-44.
- 1.7.12 Standard library concurrency constructs [ALPHA] on page 1-44.
- 1.7.13 Thread-safe initialization of Mutexes and Condition variables [ALPHA] on page 1-45.

1.7.1 Arm® C++ libraries and multithreading [ALPHA]

The C++ Thread Porting Application Programming Interface (API) is an [ALPHA]-supported API that enables the use of C++11 concurrency constructs with Arm Compiler 6. Operating system or library vendors must provide an implementation of this API to enable the seamless use of C++11 concurrency constructs within user applications.

--- Note ---
This topic describes an [ALPHA] feature. See Support level definitions on page 1-15.

The C++11 standard offers several high-level concurrency constructs intended to simplify parallel programming and make multithreaded programs portable across platforms. Future versions of the C++ standard are set to introduce additional high-level concurrency constructs. For more information, see https://isocpp.org/std/status.

Most standard library implementations expect an underlying operating system or library platform to provide a comprehensive set of primitive concurrency constructs on top of which these higher level constructs can be built.

The default standard C++ library supplied with Arm Compiler 6 has been built without concurrency support to avoid passing these dependencies to target bare-metal systems.

Arm Compiler 6 includes a special variant of the standard C++ library that enables support for C++11 concurrency constructs. This library variant requires platform vendors to provide an implementation of the threading API described in this document. On certain architectures, for example the Armv6-M architecture, this threaded library variant might contain library calls to various _atomic_* functions. On these architectures, platform vendors must also provide an implementation of an atomics library as discussed in LLVM Atomic Instructions and Concurrency Guide.

To select the threaded standard C++ library variant instead of the default variant use the compiler options -std=c++11 -D_ARM_LIBCPP_EXTERNAL_THREADS together with linker option --stdlib=threaded_libc++.
Platform vendors can selectively implement subsets of the porting API based on the dependencies between the high-level C++11 concurrency constructs and the underlying platform concurrency primitives.

Arm Compiler 6 provides C++ libraries that are based on open source LLVM technology. The libraries for multithreaded applications are:

- The standard library, libc++.
- Low level support for the standard library, libc++abi.
- Exception unwinding support library, libunwind.

The C++ Thread Porting API enables these libraries to correctly operate in different multithreaded environments.

--- Note ---

The C++ Thread Porting API is independent of the multithreaded support API provided in the Arm C library. For more information, see Multithreaded support in Arm® C libraries on page 1-27. Platform vendors must implement both of these APIs, to the respective specifications, to ensure correct operation of multithreaded programs. The C++ Thread Porting API is declared in the <arm-tpl.h> header file of the Arm Compiler 6 distribution.

---

The C++ Thread Porting API functional areas include:

- Clocks.
- Mutexes.
- Conditional variables.
- Threads.
- Miscellaneous functions.

### 1.7.2 Clocks [ALPHA]

The C++ Thread Porting API provides clock functions in the <arm-tpl.h> header file.

--- Note ---

This topic describes an [ALPHA] feature. See Support level definitions on page 1-15.

---

#### Types

```c
struct __ARM_TPL_timespec_t {
    time_t tv_sec;
    long tv_nsec;
};
```

#### Functions

```c
int __ARM_TPL_clock_realtime(__ARM_TPL_timespec_t* ts);
int __ARM_TPL_clock_monotonic(__ARM_TPL_timespec_t* ts);
```

#### Usage

The function __ARM_TPL_clock_realtime() must populate the `ts` argument with the current system-wide (wall-clock) time.

The function __ARM_TPL_clock_monotonic() must populate the `ts` argument with the elapsed time since some fixed point in time.

--- Note ---

Time measurements produced by __ARM_TPL_clock_monotonic() must be steady, in that, those measurements must increase at a fixed rate relative to the real time.
Returns
These functions must return zero if successful, or return non-zero if not successful to indicate an error.

1.7.3 Mutexes [ALPHA]
The C++ Thread Porting API provides mutex functions in the `<arm-tpl.h>` header file.

Note
This topic describes an [ALPHA] feature. See Support level definitions on page 1-15.

Types
struct __ARM_TPL_mutex_t {
    _Atomic uintptr_t data;
};

Functions
int __ARM_TPL_recursive_mutex_init(__ARM_TPL_mutex_t* __m);
int __ARM_TPL_mutex_lock(__ARM_TPL_mutex_t* __m);
int __ARM_TPL_mutex_trylock(__ARM_TPL_mutex_t* __m);
int __ARM_TPL_mutex_unlock(__ARM_TPL_mutex_t* __m);
int __ARM_TPL_mutex_destroy(__ARM_TPL_mutex_t* __m);

Usage
The API uses the __ARM_TPL_mutex_t type to encapsulate a pointer to an underlying platform-specific mutex type. The semantics of these functions are:

- The functions __ARM_TPL_mutex_lock() and __ARM_TPL_mutex_trylock() must operate on an initialize-on-first-use basis with respect to __m->data. If the value __m->data is zero, an implementation must first initialize __m->data to point to a valid platform mutex before carrying out the requested locking operation. This initialization must be thread-safe. For more information, see 1.7.13 Thread-safe initialization of Mutexes and Condition variables [ALPHA] on page 1-45.

- The function __ARM_TPL_mutex_lock() must lock the mutex represented at __m, blocking the calling thread until the mutex becomes available. If the function is successful, it must return zero, with the calling thread as the owner of the underlying mutex. If the function is not successful, it must return non-zero.

- The function __ARM_TPL_mutex_trylock() is similar to __ARM_TPL_mutex_lock(), except if the mutex at __m is already locked, it must return immediately unsuccessfully. If the function successfully performs the lock, it must return zero. Otherwise, it must return non-zero.

- The function __ARM_TPL_mutex_unlock() and __ARM_TPL_mutex_destroy() must return zero if the value __m->data is zero. Otherwise, they must perform the requested operation on the platform mutex pointed to by __m->data and then return zero if successful, or return non-zero if not successful.

- The function __ARM_TPL_mutex_unlock() must unlock the mutex represented at __m. If the mutex at __m was initialized as a recursive mutex, it is unlocked only when the lock count reaches zero. This function must return zero if successful, or return non-zero if not successful.

- The function __ARM_TPL_mutex_destroy() must destroy the mutex represented at __m. It is guaranteed that an already destroyed __ARM_TPL_mutex_t object is not re-referenced through any API functions afterward. __ARM_TPL_mutex_destroy() must return zero if successful, or return non-zero if not successful.

- The function __ARM_TPL_recursive_mutex_init() must initialize the platform mutex pointed to by __m->data as a recursive mutex. There is no requirement for this initialization to be thread-safe. This function must return zero if successful, or non-zero if not successful.
Returns
These functions must return zero if successful, or return non-zero if not successful to indicate an error.

1.7.4 Condition variables [ALPHA]
The C++ Thread Porting API provides functions for condition variables in the `<arm-tpl.h>` header file.

Note
This topic describes an [ALPHA] feature. See Support level definitions on page 1-15.

Types
struct __ARM_TPL_condvar_t {
    _Atomic intptr_t data;
};

Functions
int __ARM_TPL_condvar_signal(__ARM_TPL_condvar_t* __cv);
int __ARM_TPL_condvar_broadcast(__ARM_TPL_condvar_t* __cv);
int __ARM_TPL_condvar_wait(__ARM_TPL_condvar_t* __cv, __ARM_TPL_mutex_t* __m);
int __ARM_TPL_condvar_timedwait(__ARM_TPL_condvar_t* __cv, __ARM_TPL_mutex_t* __m,
    __ARM_TPL_timespec_t* __ts);
int __ARM_TPL_condvar_destroy(__ARM_TPL_condvar_t* __cv);

Usage
The C++ Thread Porting API uses the __ARM_TPL_condvar_t type to encapsulate a pointer to an underlying platform-specific condition variable type. The semantics of the functions are:

• The functions __ARM_TPL_condvar_wait() and __ARM_TPL_condvar_timedwait() must operate on an initialize-on-first-use basis with respect to __cv->data. If the value __cv->data is zero, an implementation must first initialize __cv->data to point to a valid platform condition variable before carrying out the requested operation. This initialization must be thread-safe. For more information, see 1.7.13 Thread-safe initialization of Mutexes and Condition variables [ALPHA] on page 1-45.

• The function __ARM_TPL_condvar_wait() must cause the calling thread (which is guaranteed to be the owner of the mutex __m) to block until the condition variable, __cv, is signaled by a different thread or the calling thread is interrupted. For the duration where the calling thread is blocked, the mutex __m must be unlocked. When this function returns, the unblocked thread must be the owner of the mutex, __m, regardless of the reason for unblocking. The reason for unblocking might be:
  — Condition variable is signaled.
  — The current thread is interrupted.

  This function must return zero to indicate success when a thread is unblocked as a result of the condition variable being signaled. This function must return a non-zero value to indicate any error conditions.

• The function __ARM_TPL_condvar_timedwait() behaves similar to __ARM_TPL_condvar_wait(), except that it allows an explicit time limit to be specified for the blocking operation. If this function returns due to the timeout expiring, its return value shall be non-zero.

• The functions __ARM_TPL_condvar_signal(), __ARM_TPL_condvar_broadcast() and __ARM_TPL_condvar_destroy() must return zero if the value __cv->data is zero. Otherwise, they should perform the requested operation on the platform condition variable pointed to by __cv->data and return zero if successful, or return non-zero if not successful.

• The function __ARM_TPL_condvar_signal() must unblock at least one of the threads blocked on the condition variable __cv. The function __ARM_TPL_condvar_broadcast() must unblock all the threads blocked on the condition variable __cv. If more than one thread is unblocked as a result of a
call to one of these functions, they must all contend for the respective mutexes with which they originally invoked __ARM_TPL_condvar_wait() or __ARM_TPL_condvar_timedwait() functions.

- The function __ARM_TPL_condvar_destroy() must destroy the condition variable represented in __cv. It is guaranteed that an already destroyed __ARM_TPL_condvar_t object is not referenced through any API functions afterward. When successful, __ARM_TPL_condvar_destroy() must return zero, or a non-zero value if not successful.

Returns

These functions must return zero if successful, or return non-zero if not successful to indicate an error.

1.7.5 Threads [ALPHA]

The C++ Thread Porting API provides thread function prototypes in the <arm-tpl.h> header file.

Note

This topic describes an [ALPHA] feature. See Support level definitions on page 1-15.

Types

typedef uint32_t __ARM_TPL_thread_id;

struct __ARM_TPL_thread_t {
    uintptr_t data;
};
typedef uint32_t __ARM_TPL_tls_key;

Functions

int __ARM_TPL_thread_create(__ARM_TPL_thread_t* __t, void* (*__f)(void*), void* __arg);

__ARM_TPL_thread_id __ARM_TPL_thread_get_current_id();

__ARM_TPL_thread_id __ARM_TPL_thread_get_id(const __ARM_TPL_thread_t* __t);

int __ARM_TPL_thread_id_compare(__ARM_TPL_thread_id t1, __ARM_TPL_thread_id t2);

int __ARM_TPL_thread_join(__ARM_TPL_thread_t* __t);

int __ARM_TPL_thread_detach(__ARM_TPL_thread_t* __t);

void __ARM_TPL_thread_yield();

void __ARM_TPL_thread_nanosleep(const __ARM_TPL_timespec_t *req, __ARM_TPL_timespec_t *rem);

unsigned __ARM_TPL_thread_hw_concurrency();

int __ARM_TPL_tls_create(__ARM_TPL_tls_key* __key, void (*__at_exit) (void*));

void __ARM_TPL_tls_set(__ARM_TPL_tls_key __key, void* __p);

void* __ARM_TPL_tls_get(__ARM_TPL_tls_key __key);

Usage

The C++ Thread Porting API uses the __ARM_TPL_thread_t type to encapsulate a pointer to an underlying platform-specific thread type. The types __ARM_TPL_thread_id and __ARM_TPL_tls_key are identifiers of threads and instances of thread local storage created within the system. The semantics of the functions are:

- The __ARM_TPL_thread_create() function must initialize __t->data to point to a newly allocated system thread structure. There is no requirement for this initialization to be thread safe. The newly allocated thread must be scheduled to execute the __f routine with __arg as its sole argument.
- The function __ARM_TPL_thread_get_current_id() must return the thread identifier for the calling thread.
• The function __ARM_TPL_thread_get_id() must return the corresponding thread identifier for the argument __t.
• The function __ARM_TPL_thread_id_compare() must return positive if t1 > t2, zero if t1 == t2, and negative if t1 < t2.
• The function __ARM_TPL_thread_join() must cause the calling thread to block until the thread represented in __t terminates. This function must return zero (success) immediately if __t has already terminated. If the argument __t does not represent a joinable thread or refers to the calling thread itself, this function must return a non-zero value to indicate error. When a thread __t has been joined to, it is guaranteed not to be accessed again. Therefore, any system resources accessible through __t must be reclaimed before returning from this function. All threads are created in a joinable state, calling either __ARM_TPL_thread_join() or __ARM_TPL_thread_detach() on an argument __t makes the thread represented in __t non-joinable.
• The function __ARM_TPL_thread_detach() should cleanup any system resources accessible through __t while allowing the underlying thread to continue execution. As with __ARM_TPL_thread_join(), invoking this function on an argument __t causes the underlying thread to become non-joinable. This function must return zero on success or non-zero if not successful.
• The function __ARM_TPL_thread_yield() must force the calling thread to relinquish the processor until it becomes eligible for execution again.
• The function __ARM_TPL_thread_nanosleep() must cause the calling thread to be blocked for a minimum interval specified by req. The thread might be interrupted due to a signal being delivered to it, in which case either the corresponding signal handler must be invoked or the process must be terminated. When the argument rem is provided (non-null), and the function returns before having the requested time interval elapsed, rem must be populated to indicate the remaining time interval of the original request (time requested – actual time elapsed).
• The function __ARM_TPL_thread_hw_concurrency() must return the number of concurrent threads supported by the underlying platform. The sole use of this function is for the implementation of the std::hardware_concurrency() function.
• The __ARM_TPL_tls_create() function must initialize *__key to identify a unique process-wide thread local storage. Upon creation, each __key must be bound to a NULL value, as if __ARM_TPL_tls_set(*__key, NULL) was invoked. Individual threads within the current process might later bind thread specific values to this key using the __ARM_TPL_tls_set() function. There is no requirement for the initialization of __key to be thread safe. If the __at_exit argument is provided (non-null), and a thread has a non-null binding for that *__key at the point of termination, the system must ensure that __at_exit(void*) is invoked with the current binding for __key as the sole argument.
• The function __ARM_TPL_tls_set() must associate the value __p with *__key for the calling thread. It is guaranteed that __key has been obtained using __ARM_TPL_tls_create(). It is also guaranteed that __ARM_TPL_tls_set() will not be invoked from thread-local destructor functions registered in __ARM_TPL_tls_create(). This function must return zero if successful or a non-zero value if not successful.
• The function __ARM_TPL_tls_get() must return the value bound to the __key argument for the calling thread. It is guaranteed that __ARM_TPL_tls_get() will not be invoked from thread-local destructor functions registered in __ARM_TPL_tls_create().

Returns
These functions must return zero if successful, or return non-zero to indicate an error if not successful.

1.7.6 Miscellaneous functions [ALPHA]
The C++ Thread Porting API provides functions in the <arm-tpl.h> header file.

Note
This topic describes an [ALPHA] feature. See Support level definitions on page 1-15.
### Types

```c
typedef volatile unsigned long __ARM_TPL_exec_once_flag;
```

### Function

```c
void __ARM_TPL_execute_once(__ARM_TPL_exec_once_flag *__flag, void(*__func)(void));
```

### Usage

The first invocation of the `__ARM_TPL_execute_once()` function by any thread within the current process for a given `__func` argument must result in a call to the `__func()` routine. Subsequent calls to `__ARM_TPL_execute_once()` for the same `__func` argument must not have any effect. The argument `__flag` can be used to determine whether the routine `__func` has already been invoked or not.

### Returns

This function must return `void`.

### 1.7.7 Thread safety in the Arm® C++ library

The functions contained within the libc++ library are fully-supported for use in single-threaded environments, and [ALPHA]-supported for use in multithreaded environments.

--- Note ---

This topic includes descriptions of [ALPHA] features. See *Support level definitions* on page 1-15.

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### Related concepts

1.6.9 How to ensure re-implemented mutex functions are called on page 1-33
1.6.11 Thread safety in the Arm® C library on page 1-34

### Related references

1.6.10 Using the Arm® C library in a multithreaded environment on page 1-33
1.6.8 Management of locks in multithreaded applications on page 1-31
1.25.5 Standard C++ library implementation definition on page 1-99

### Related information

`__cxa_*`, `__aeabi_*` functions, C++ ABI for the Arm Architecture

### 1.7.8 Supported C++ Concurrency Features [ALPHA]

The following sections identify the high-level C++ concurrency constructs supported by the multithreaded Arm C++ libraries. For each of the features, the underlying section of the thread porting API required for the correct functionality of that feature is also identified.

--- Note ---

This topic describes an [ALPHA] feature. See *Support level definitions* on page 1-15.

---

Some language features require extra runtime support when operating in a multithreaded environment. The C++ language features of concern here are initialization of guard variables and exceptions.

### 1.7.9 Guard variables [ALPHA]

To ensure thread-safety of certain initializations, the compiler calls out to helper functions in the libc++abi library.

--- Note ---

This topic describes an [ALPHA] feature. See *Support level definitions* on page 1-15.
For example, in the following code snippet, the compiler must ensure that the Counter c is constructed exactly once, even when multiple threads call getCount().

```cpp
class Counter {
public:
    Counter(int x) : _m(x) {}
    int inc() {return _m++;
private:
    int _m;
}

int getCount() {
    static Counter c(42);
    return c.inc();
}
```

To support such thread-safe initializations, a platform vendor must provide the implementations for the following subset of constructs from the 1.7.3 Mutexes [ALPHA] on page 1-38 and 1.7.4 Condition variables [ALPHA] on page 1-39 sections of the API:

**Types**

```cpp
struct __ARM_TPL_mutex_t{
    _Atomic uintptr_t data;
};
struct __ARM_TPL_condvar_t{
    _Atomic intptr_t data;
};
```

**Functions**

```cpp
int __ARM_TPL_mutex_lock(__ARM_TPL_mutex_t* __m);
int __ARM_TPL_mutex_unlock(__ARM_TPL_mutex_t* __m);
int __ARM_TPL_condvar_broadcast(__ARM_TPL_condvar_t* __cv);
int __ARM_TPL_condvar_wait(__ARM_TPL_condvar_t* __cv, __ARM_TPL_mutex_t* __m);
```

The ABI functions __cxa_guard_acquire(), __cxa_guard_release(), and __cxa_guard_abort() need not be re-implemented under this scheme.

**1.7.10 Exceptions [ALPHA]**

The C++ runtime (libc++abi and libunwind) must take special measures when allocating and handling exceptions in a threaded environment.

`Note`

This topic describes an [ALPHA] feature. See Support level definitions on page 1-15.

An implementation of the following subset of the thread porting API is required for the correct operation of exceptions in such an environment:

**Types**

```cpp
struct __ARM_TPL_mutex_t{
    _Atomic uintptr_t data;
};
typedef uint32_t __ARM_TPL_tls_key;
```
Functions

```c
int __ARM_TPL_mutex_lock(__ARM_TPL_mutex_t* __m);
int __ARM_TPL_mutex_unlock(__ARM_TPL_mutex_t* __m);
int __ARM_TPL_tls_create(__ARM_TPL_tls_key* __key, void (*__at_exit) (void*));
void* __ARM_TPL_tls_get(__ARM_TPL_tls_key __key);
void __ARM_TPL_tls_set(__ARM_TPL_tls_key __key, void* __p);
void __ARM_TPL_execute_once(__ARM_TPL_exec_once_flag* flag, void(*func)(void));
```

### 1.7.11 Thread local storage in C++ [ALPHA and COMMUNITY]

The thread storage duration specifier of C++, `thread_local`, is not supported. However, the `__thread` keyword is supported in C++ only when used in conjunction with the [COMMUNITY] `-femulated-tls` command-line option.

---

**Note**

This topic includes descriptions of [ALPHA] and [COMMUNITY] features. See [Support level definitions on page 1-15](#).

---

**Related information**

*Language extension compatibility: keywords*

### 1.7.12 Standard library concurrency constructs [ALPHA]

The C++ standard library, beginning with the C++11 standard, provides various high-level concurrency constructs. Presently, these constructs are spread across the headers `<atomic>`, `<chrono>`, `<mutex>`, `<shared_mutex>`, `<condition_variable>`, `<thread>`, and `<future>`.

---

**Note**

This topic describes an [ALPHA] feature. See [Support level definitions on page 1-15](#).

---

The following sections identify how the functionality of each of these headers maps to the Arm Compiler thread porting API introduced in *1.7.1 Arm® C and C++ Libraries and multithreading [ALPHA]* on page 1-36. They also identify any additional dependencies or expected limitations.

#### <atomic>

The functionality of this header does not depend on the thread porting API.

The following table summarizes the level of support for the `<atomic>` header on various Arm architectures.

<table>
<thead>
<tr>
<th>Architecture</th>
<th>T (Template parameter)</th>
<th>atomic&lt;T&gt;</th>
<th>atomic&lt;T*&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Armv7-A, Armv7-R, Armv8-A, Armv8-R</td>
<td>Any types</td>
<td>Supported</td>
<td>Supported</td>
</tr>
<tr>
<td>Armv7-M, Armv8-M</td>
<td>Integral types (including <code>&lt;stdint.h&gt;</code> defined types)</td>
<td>Supported</td>
<td>Supported</td>
</tr>
<tr>
<td>Armv7-M, Armv8-M</td>
<td>Complex types</td>
<td>Unsupported</td>
<td>Supported</td>
</tr>
<tr>
<td>Armv6-M</td>
<td>Any types</td>
<td>Unsupported</td>
<td>Unsupported</td>
</tr>
</tbody>
</table>

None of the targets support the functions `atomic_thread_fence()` and `atomic_signal_fence()`.
<chrono>

This header requires a full implementation of the 1.7.2 Clocks [ALPHA] on page 1-37 section of the thread porting API.

<mutex>, <shared_mutex>

These headers require a full implementation of the 1.7.3 Mutexes [ALPHA] on page 1-38 section of the thread porting API. In addition, the time-related subset of constructs (for example, std::timed_mutex and std::recursive_timed_mutex) defined in these headers requires an implementation of the 1.7.2 Clocks [ALPHA] on page 1-37 section of the porting API.

<condition_variable>

This header requires a full implementation of the 1.7.4 Condition variables [ALPHA] on page 1-39 section of the thread porting API. In addition, the time-related subset of constructs (for example, std::condition_variable::wait_for()) defined in this header requires an implementation of the 1.7.2 Clocks [ALPHA] on page 1-37 section of the porting API.

<thread>, <future>

These headers require a full implementation of the 1.7.5 Threads [ALPHA] on page 1-40 section of the thread porting API. In addition, the time-related subset of constructs (for example, std::thread::sleep_until() and std::future::wait_for()) defined in these headers requires an implementation of the 1.7.2 Clocks [ALPHA] on page 1-37 section of the porting API.

1.7.13 Thread-safe initialization of Mutexes and Condition variables [ALPHA]

The Mutexes and Condition Variable parts of the porting API must adopt an initialize-on-first-use strategy. Implementations must ensure that such initializations are thread-safe.

——— Note ———

This topic describes an [ALPHA] feature. See Support level definitions on page 1-15.

Consider the following sample implementation of the __ARM_TPL_mutex_lock() function:

```c
#include <platform.h>

// Assume that platform.h declares the following types and functions:
// struct platform_mutex_t;
// platform_mutex_t *alloc_platform_mutex();
// void lock_platform_mutex(platform_mutex_t *p);
// void unlock_platform_mutex(platform_mutex_t *p);
// void destroy_platform_mutex(platform_mutex_t *p);

#include <arm-tpl.h>

// [3] Implement the Arm TPL functions according to the API that your operating
//     system provides.

void __ARM_TPL_mutex_lock(__ARM_TPL_mutex_t* __m) {
    if (__m->data == 0) {
        __m->data = static_cast<uintptr_t>(alloc_platform_mutex());
    }
    lock_platform_mutex(reinterpret_cast<platform_mutex_t*>(__m->data));
}
```
The anatomy of this snippet can be understood as follows:

1. Assume the underlying system (included through `platform.h`) provides the type `__platform_mutex_t` and the functions `alloc_platform_mutex()`, `lock_platform_mutex()`, `unlock_platform_mutex()`, and `destroy_platform_mutex()`.

2. The porting API header (`arm-tpl.h`) is then included, which defines the type `__ARM_TPL_mutex_t` and the prototypes for the various porting API functions.

3. The implementations of the various porting API functions follow.

This implementation of `__ARM_TPL_mutex_lock()` method leads to a race condition if multiple threads attempt to lock the same `std::mutex` object. Therefore, an implementation must ensure that `__m->data` initializes atomically. The following sections illustrate possible solutions to this problem.

### Global locking

An implementation may employ a platform provided mutex to guard the initialization of `*__m` as follows:

```c
static platform_mutex_t guard_mut;

void __ARM_TPL_mutex_lock(__ARM_TPL_mutex_t* __m) {
    volatile __ARM_TPL_mutex_t *__vm = __m;
    if (__vm->data == 0) {
        lock_platform_mutex(&guard_mut);
        if (__vm->data == 0)
            __vm->data = static_cast<uintptr_t>(alloc_platform_mutex());
        unlock_platform_mutex(&guard_mut);
    }
    lock_platform_mutex(static_cast<platform_mutex_t*>(*__vm));
}
```

**Note**

This solution could result in reduced performance because threads must contend for the shared mutex `guard_mut` for each initial `std::mutex` lock operation.

### Lock free

An implementation avoiding global locking is achievable using the lock-free concurrency constructs available through the `<stdatomic.h>` header. The following snippet atomically attempts to initialize `__m->data`, and undo its attempt if another thread has already done the initialization:

```c
#include <cstdint>
#include <stdatomic.h>

int __ARM_TPL_mutex_lock(__ARM_TPL_mutex_t* __m) {
    if (__m->data == 0) {
        uintptr_t mut_new = reinterpret_cast<uintptr_t>(alloc_platform_mutex());
        uintptr_t mut_null = 0;
        if (!atomic_compare_exchange_strong(&__m->data, &mut_null, mut_new))
            destroy_platform_mutex(reinterpret_cast<platform_mutex_t*>(mut_new));
    }
    return lock_platform_mutex(reinterpret_cast<platform_mutex_t*>(__m->data));
}
```

The Armv6-M architecture does not support this method.
1.8 Support for building an application with the C library

Describes the Arm Compiler features that are supported when building an application with the C library.

This section contains the following subsections:

- 1.8.1 Using the C library with an application
- 1.8.2 Using the C and C++ libraries with an application in a semihosting environment
- 1.8.3 Using $Sub$$ to mix semihosted and nonsemihosted I/O functionality
- 1.8.4 Using the libraries in a nonsemihosting environment
- 1.8.5 Direct semihosting C library function dependencies
- 1.8.6 Indirect semihosting C library function dependencies
- 1.8.7 C library API definitions for targeting a different environment

1.8.1 Using the C library with an application

Depending on how you use the C and C++ libraries with your application, you might have to re-implement particular functions.

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

- 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.

**Related concepts**

- 1.8.2 Using the C and C++ libraries with an application in a semihosting environment
- 1.8.4 Using the libraries in a nonsemihosting environment

**Related references**

- 1.9.1 Building an application without the C library

**Related information**

Semihosting for AArch32 and AArch64

1.8.2 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 A32 or T32 semihosting trap instructions for AArch32 state or A64 semihosting trap instruction for AArch64 state.

The execution environment can be provided by either:

- Using the standard semihosting functionality that is present by default in, for example, the Arm DSTREAM debug and trace unit.
- 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.

Arm Compiler supports semihosting by generating trap instructions such as HLT, SVC, or BKPT depending on the architecture or profile. Debug agents can trap these instructions to perform semihosting operations on the host.

**Note**

The HLT instruction is architecturally UNDEFINED for Armv7-A and Armv7-R architectures, in both A32 and T32 state.
Table 1-2  Semihosting trap instructions

<table>
<thead>
<tr>
<th>Architecture</th>
<th>Instruction Set</th>
<th>Trap Instruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Armv8-A and Armv8-R</td>
<td>A64</td>
<td>HLT 0xF000</td>
</tr>
<tr>
<td>Armv8-A and Armv8-R</td>
<td>A32</td>
<td>HLT 0xF000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SVC 0x123456</td>
</tr>
<tr>
<td>Armv8-A and Armv8-R</td>
<td>T32</td>
<td>HLT 0x3C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SVC 0xAB</td>
</tr>
<tr>
<td>Armv7-A and Armv7-R</td>
<td>A32</td>
<td>HLT 0xF000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SVC 0x123456</td>
</tr>
<tr>
<td>Armv7-A and Armv7-R</td>
<td>T32</td>
<td>HLT 0x3C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SVC 0xAB</td>
</tr>
<tr>
<td>Any architecture with M-profile</td>
<td>T32</td>
<td>BKPT 0xAB</td>
</tr>
</tbody>
</table>

For AArch32 in architectures with A-profile or R-profile, Arm Compiler supports two different semihosting implementations:

- Semihosting using the SVC instruction. This is the default and legacy implementation.
- Semihosting using the HLT instruction. This implementation is required for semihosting in hardware debug environments with mixed AArch32 and AArch64 states.

There are separate libraries for SVC-based and HLT-based semihosting. Arm Compiler uses the HLT-based semihosting library if your code references the symbol __use_hlt_semihosting. To do this, either:

- IMPORT __use_hlt_semihosting from assembly language.
- __asm(".global __use_hlt_semihosting\n\t") from C.

If you do not use the symbol __use_hlt_semihosting, then by default, Arm Compiler emits SVC instructions for semihosting calls. This symbol does not have an effect on M-profile architectures, or in AArch64 state.

Arm strongly discourages mixing HLT and SVC semihosting mechanisms within the same executable. The library only uses either SVC or HLT instructions, rather than a mixture. However, you must ensure that you do not mix SVC and HLT instructions when using:

- inline assembly.
- <arm_compat.h> header file.

Related references
1.8.3 Using $Sub$$ to mix semihosted and nonsemihosted I/O functionality on page 1-48
1.8.5 Direct semihosting C library function dependencies on page 1-50

Related information
Semihosting for AArch32 and AArch64

1.8.3 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:

```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);
  // values.
  return c;
} else
{  return $Super$$fputc(c, fp);
  }

Related concepts

1.8.2 Using the C and C++ libraries with an application in a semihosting environment on page 1-47
1.8.4 Using the libraries in a nonsemihosting environment on page 1-49

Related information

Semihosting for AArch32 and AArch64
Use of $Super$$ and $Sub$$ to patch symbol definitions
ELF for the Arm Architecture

1.8.4 Using the libraries in a nonsemihosting environment

Some C library functions use semihosting. If you use the libraries in a nonsemihosting environment, you
must ensure that semihosting function calls are dealt with appropriately.

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 that 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 `armasm` assembly language.
- `__asm(".global _use_no_semihosting\n\t")` for C or C++ code.

________ Note ________

IMPORT `_use_no_semihosting` is only required to be added to a single assembly source file. Similarly,
`__asm(".global _use_no_semihosting\n\t")` is only required to be added to a single C source file.
It is unnecessary to add these inserts to every 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. For example, to identify the objects
that are using semihosting when using an Armv8-M processor:

1. Link with `armlink --cpu=8-M --verbose --list err.txt`
2. Search `err.txt` for occurrences of `_I$use$semihosting`

For example:

```
... Loading member sys_exit.o from c_2.1.
  reference : __I$use$semihosting
  definition: _sys_exit
...```

1 The Arm® C and C++ Libraries

1.8 Support for building an application with the C library

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This example shows that the semihosting-using function `_sys_exit` is linked-in from the C library. To prevent the C library being linked-in, you must provide your own implementation of this function.

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

**Related concepts**

1.2 Mandatory linkage with the C library on page 1-19

**Related references**

1.8.3 Using $Sub$$ to mix semihosted and nonsemihosted I/O functionality on page 1-48

1.8.6 Indirect semihosting C library function dependencies on page 1-51

1.8.7 C library API definitions for targeting a different environment on page 1-52

**Related information**

--list=filename linker option

--verbose linker option

Semihosting for AArch32 and AArch64

### 1.8.5 Direct semihosting C library function dependencies

A table showing the functions that depend directly on semihosting.

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>__user_initial_stackheap()</td>
<td>Sets up and returns the locations of the stack and the heap. If you are using a scatter file at the link stage, you might have to re-implement this function. The linker issues an error when no semihosting is requested and __user_initial_stackheap() is not re-implemented.</td>
</tr>
<tr>
<td>__sys_exit()</td>
<td>Error signaling, error handling, and program exit.</td>
</tr>
<tr>
<td>_ttywrch()</td>
<td></td>
</tr>
</tbody>
</table>
### Table 1-3 Direct semihosting dependencies (continued)

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<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></td>
</tr>
<tr>
<td>_sys_iserror()</td>
<td></td>
</tr>
<tr>
<td>_sys_istty()</td>
<td></td>
</tr>
<tr>
<td>_sys_flen()</td>
<td></td>
</tr>
<tr>
<td>_sys_open()</td>
<td></td>
</tr>
<tr>
<td>_sys_read()</td>
<td></td>
</tr>
<tr>
<td>_sys_seek()</td>
<td></td>
</tr>
<tr>
<td>_sys_write()</td>
<td></td>
</tr>
<tr>
<td>_sys_tmpnam()</td>
<td></td>
</tr>
<tr>
<td>clock()</td>
<td>Tailoring other C library functions.</td>
</tr>
<tr>
<td>_clock_init()</td>
<td></td>
</tr>
<tr>
<td>remove()</td>
<td></td>
</tr>
<tr>
<td>rename()</td>
<td></td>
</tr>
<tr>
<td>system()</td>
<td></td>
</tr>
<tr>
<td>time()</td>
<td></td>
</tr>
</tbody>
</table>

**Related concepts**

- 1.8.2 Using the C and C++ libraries with an application in a semihosting environment on page 1-47
- 1.10.1 Initialization of the execution environment and execution of the application on page 1-61

**Related references**

- 1.12 Modification of C library functions for error signaling, error handling, and program exit on page 1-73
- 1.14 Tailoring input/output functions in the C and C++ libraries on page 1-81
- 1.8.6 Indirect semihosting C library function dependencies on page 1-51
- 1.23 Tailoring non-input/output C library functions on page 1-93
- 4.53 __user_setup_stackheap() on page 4-196

**Related information**

- Semihosting for AArch32 and AArch64

### 1.8.6 Indirect semihosting C library function dependencies

A table showing functions that depend indirectly on one or more of the directly dependent functions.

You can use this table 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:

- __asm(".global __use_no_semihosting\n\t") in C source code.
- IMPORT __use_no_semihosting in armasm assembly language source code.
Table 1-4 Indirect semihosting dependencies

<table>
<thead>
<tr>
<th>Function</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>__user_setup_stackheap()</td>
<td>Sets up and returns the locations of the stack and the heap.</td>
</tr>
<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>

Related concepts
1.8.4 Using the libraries in a nonsemihosting environment on page 1-49

Related references
1.8.5 Direct semihosting C library function dependencies on page 1-50
1.13.5 Avoiding the heap and heap-using library functions supplied by Arm on page 1-79
1.12 Modification of C library functions for error signaling, error handling, and program exit on page 1-73
1.14 Tailoring input/output functions in the C and C++ libraries on page 1-81
1.23 Tailoring non-input/output C library functions on page 1-93

Related information
Semihosting for AArch32 and AArch64

1.8.7 C library API definitions for targeting a different environment

In addition to the direct and indirect semihosting dependent functions, there are a number of functions and files that might be useful when building for a different environment.

The following table shows these functions and files.

Table 1-5 Published API definitions

<table>
<thead>
<tr>
<th>File or function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>__main(), __rt_entry()</td>
<td>Initializes the runtime environment and executes the user application</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>File or function</td>
<td>Description</td>
</tr>
<tr>
<td>------------------</td>
<td>-------------</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.

--- Related concepts ---

1.8.4 Using the libraries in a nonsemihosting environment on page 1-49
1.11 Assembler macros that tailor locale functions in the C library on page 1-65

--- Related information ---

--list=filename linker option
--verbose linker option

Semihosting for AArch32 and AArch64
1.9 Support for building an application without the C library

Describes the Arm Compiler features that are supported and not supported when building an application without the C library.

This section contains the following subsections:
- 1.9.1 Building an application without the C library on page 1-54.
- 1.9.2 Creating an application as bare machine C without the C library on page 1-56.
- 1.9.3 Integer and floating-point compiler functions and building an application without the C library on page 1-57.
- 1.9.4 Bare machine integer C on page 1-57.
- 1.9.5 Bare machine C with floating-point processing on page 1-57.
- 1.9.6 Customized C library startup code and access to C library functions on page 1-58.
- 1.9.7 Using low-level functions when exploiting the C library on page 1-59.
- 1.9.8 Using high-level functions when exploiting the C library on page 1-59.
- 1.9.9 Using malloc() when exploiting the C library on page 1-60.

1.9.1 Building an application without the C library

If your application does not initialize the C library, a number of functions are not available in your application.

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().

The following table 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>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>alloca.h</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>assert.h</td>
<td>Functions listed in this file require high-level stdio, __rt_raise(), and __sys_exit(). You must be familiar with tailoring error signaling, error handling, and program exit to use this header file.</td>
</tr>
<tr>
<td>ctype.h</td>
<td>Functions listed in this file require the locale functions.</td>
</tr>
<tr>
<td>errno.h</td>
<td>Functions listed in this file work without the requirement for any library initialization or function re-implementation.</td>
</tr>
<tr>
<td>fenv.h</td>
<td>Functions in this file work without the requirement for any library initialization and only require the re-implementation of __rt_raise().</td>
</tr>
<tr>
<td>float.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>inttypes.h</td>
<td>Functions listed in this file require the locale functions.</td>
</tr>
<tr>
<td>limits.h</td>
<td>Functions in this file work without the requirement for any library initialization or function re-implementation.</td>
</tr>
<tr>
<td>Function</td>
<td>Description</td>
</tr>
<tr>
<td>---------------</td>
<td>----------------------------------------------------------------------------</td>
</tr>
</tbody>
</table>
| locale.h      | Call `setlocale()` before calling any function that uses locale functions. For example:
<p>|               | <code>setlocale(LC_ALL, &quot;C&quot;);</code>                                                  |
|               | See the contents of <code>locale.h</code> for more information on the following functions and data structures: |
|               | • <code>setlocale()</code> selects the appropriate locale as specified by the category and locale arguments. |
|               | • <code>lconv</code> is the structure used by locale functions for formatting numeric quantities according to the rules of the current locale. |
|               | • <code>localeconv()</code> creates an <code>lconv</code> structure and returns a pointer to it. |
|               | • <code>_get_lconv()</code> fills the <code>lconv</code> structure pointed to by the parameter. This ISO extension removes the requirement for static data within the library. |
|               | <code>locale.h</code> also contains constant declarations used with locale functions. |
| math.h        | For functions in this file to work, you must first call <code>_fp_init()</code> and re-implement <code>_rt_raise()</code>. |
| setjmp.h      | Functions in this file work without any library initialization or function re-implementation. |
| signal.h      | 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. |
|               | <code>_rt_raise()</code> can be re-implemented for error and exit handling. You must be familiar with tailoring error signaling, error handling, and program exit. |
| stdarg.h      | Functions listed in this file work without any library initialization or function re-implementation. |
| stddef.h      | This file does not contain any code. The definitions in the file do not require library initialization or function re-implementation. |
| stdint.h      | This file does not contain any code. The definitions in the file do not require library initialization or function re-implementation. |
| stdio.h       | The following dependencies or limitations apply to these functions: |
|               | • The high-level functions such as <code>printf()</code>, <code>scanf()</code>, <code>puts()</code>, <code>fgets()</code>, <code>fwrite()</code>, and <code>perror()</code> depend on lower-level <code>stdio</code> functions <code>fgetc()</code>, <code>fputc()</code>, and <code>__backspace()</code>. You must re-implement these lower-level functions when using the standalone C library. |
|               | However, you cannot re-implement the <code>_sys_</code> prefixed functions (for example, <code>_sys_read()</code>) when using the standalone C library because the layer of <code>stdio</code> that calls the <code>_sys_</code> functions requires library initialization. |
|               | You must be familiar with tailoring the input/output functions in the C and C++ libraries. |
|               | • The <code>printf()</code> and <code>scanf()</code> family of functions require locale. |
|               | • The <code>remove()</code> and <code>rename()</code> functions are system-specific and probably not usable in your application. |
| stdlib.h      | Most functions in this file work without any library initialization or function re-implementation. The following functions depend on other functions being instantiated correctly: |
|               | • <code>atoi()</code> requires locale. |
|               | • <code>strto*()</code> requires locale. |
|               | • <code>malloc()</code>, <code>calloc()</code>, <code>realloc()</code>, and <code>free()</code> require heap functions. |
|               | • <code>atexit()</code> is not available when building an application without the C library. |
| string.h      | Functions in this file work without any library initialization, with the exception of <code>strcoll()</code> and <code>strxfrm()</code>, that require locale. |</p>
<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>time.h</strong></td>
<td><code>mktime()</code> and <code>localtime()</code> can be used immediately. <code>time()</code> and <code>clock()</code> are system-specific and are probably not usable unless re-implemented. <code>asctime()</code>, <code>ctime()</code>, and <code>strftime()</code> require locale.</td>
</tr>
<tr>
<td><strong>wchar.h</strong></td>
<td>Wide character library functions added to ISO C by <em>Normative Addendum 1</em> in 1994. The following dependencies or limitations apply to these functions:</td>
</tr>
<tr>
<td></td>
<td>• The high-level functions such as <code>swprintf()</code>, <code>vswprintf()</code>, <code>swscanf()</code>, and <code>vswscanf()</code> depend on lower-level <code>stdio</code> functions such as <code>fgetwc()</code> and <code>fputwc()</code>. You must re-implement these lower-level functions when using the standalone C library. See <em>1.15 Target dependencies on low-level functions in the C and C++ libraries</em> on page 1-82 for more information.</td>
</tr>
<tr>
<td></td>
<td>• The high-level functions such as <code>swprintf()</code>, <code>vswprintf()</code>, <code>swscanf()</code>, and <code>vswscanf()</code> require locale.</td>
</tr>
<tr>
<td></td>
<td>• All the conversion functions (for example, <code>btowc</code>, <code>wctob</code>, <code>mbrtowc</code>, and <code>wcrtomb</code>) require locale.</td>
</tr>
<tr>
<td></td>
<td>• <code>wcscoll()</code> and <code>wcsxfrm()</code> require locale.</td>
</tr>
<tr>
<td><strong>wctype.h</strong></td>
<td>Wide character library functions added to ISO C by <em>Normative Addendum 1</em> in 1994. This requires locale.</td>
</tr>
</tbody>
</table>
1.9.3 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. These functions require __rt_raise().

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 T32 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.

Related concepts
1.9.2 Creating an application as bare machine C without the C library on page 1-56

Related references
1.9.1 Building an application without the C library on page 1-54

1.9.4 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, there are a number of requirements you must meet.

These requirements are:

• 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.
• For AArch32 targets, build your application using -mfpu=none. For AArch64 targets, use -mcpu or -march to disable floating-point instructions and registers.

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.

Related concepts
1.9.5 Bare machine C with floating-point processing on page 1-57

1.9.5 Bare machine C with floating-point processing

If you want to use floating-point processing in an application without the C library, there are a number of requirements you must fulfill.

These requirements are:

• 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.

The register state also consists of $sb$, the static base register, 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 -mfpu=none option.

Certain floating-point modes when used with software floating-point support require a floating-point status word. This is enabled by default in Arm Compiler 6, but you can disable it with the armclang command-line option -ffp-mode=fast. In such cases, 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() )

**Related concepts**

1.9.4 Bare machine integer C on page 1-57
1.9.2 Creating an application as bare machine C without the C library on page 1-56
1.6.4 Use of static data in the C libraries on page 1-28

**Related references**

1.9.1 Building an application without the C library on page 1-54
1.6.5 Use of the __user_libspace static data area by the C libraries on page 1-29

### 1.9.6 Customized C library startup code and access to C library functions

If you build an application with customized startup code, you must either avoid functions that require initialization or provide the initialization and low-level support 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.

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.
• armclang uses full IEEE math by default, therefore __rt_fp_status_addr() is always required.
• 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 fgets() and _backspace().

Implementing these functions and the heap enables you to use almost the entire library.
1.9.7 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.

Related concepts

1.9.2 Creating an application as bare machine C without the C library on page 1-56
1.8.1 Using the C library with an application on page 1-47
1.9.4 Bare machine integer C on page 1-57
1.9.7 Using low-level functions when exploiting the C library on page 1-59
1.9.8 Using high-level functions when exploiting the C library on page 1-59
1.9.9 Using malloc() when exploiting the C library on page 1-60

Related references

1.9.1 Building an application without the C library on page 1-54
1.6.5 Use of the __user_libspace static data area by the C libraries on page 1-29
1.14 Tailoring input/output functions in the C and C++ libraries on page 1-81

1.9.8 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`.

Related concepts

1.9.7 Using low-level functions when exploiting the C library on page 1-59
1.9.2 Creating an application as bare machine C without the C library on page 1-56
1.9.6 Customized C library startup code and access to C library functions on page 1-58

Related references

1.9.1 Building an application without the C library on page 1-54
1.9.9 Using malloc() when exploiting the C library

If heap support is required for bare machine C, you must implement _init_alloc() and __rt_heap_extend().

_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.

Related concepts
1.9.2 Creating an application as bare machine C without the C library on page 1-56
1.9.6 Customized C library startup code and access to C library functions on page 1-58
1.10 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. Functions whose names start with a single or double underscore 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.

This section contains the following subsections:
- 1.10.1 Initialization of the execution environment and execution of the application on page 1-61.
- 1.10.2 C++ initialization, construction and destruction on page 1-62.
- 1.10.3 Exceptions system initialization on page 1-62.
- 1.10.4 Library functions called from main() on page 1-63.
- 1.10.5 Program exit and the assert macro on page 1-63.

### 1.10.1 Initialization of the execution environment and execution of the application

You can customize execution initialization by defining your own `__main` that branches to `__rt_entry`. 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`. Use the `-e armclang` option or `--entry armlink` option to specify `__main` as the entry point. For example:

```assembly
.global __rt_entry
.global __main
__main:
  B__rt_entry
```

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

**Related concepts**
- 1.10.4 Library functions called from main() on page 1-63
- 1.10 Tailoring the C library to a new execution environment on page 1-61
- 1.10.2 C++ initialization, construction and destruction on page 1-62

**Related references**
- 1.8.5 Direct semihosting C library function dependencies on page 1-50
- 4.23 __rt_entry on page 4-165

**Related information**
- Semihosting for AArch32 and AArch64
1.10.2 C++ initialization, construction and destruction

The C++ standard places certain requirements on the construction and destruction of objects with static storage duration. The static constructors are executed before main(), the destructors are called after the program exits.

The library must ensure that all the static constructors within a translation unit are called in the order of declaration, and the static destructors are called in reverse order of declaration. There is no way to determine the initialization order between translation units.

Each translation unit containing static constructors has an initialization function. This function calls the static constructors for the translation unit, and registers the static destructors with a call to __aeabi_atexit(). Function-local static objects with destructors also register their destructors using __aeabi_atexit().

The location of the per translation unit initialization function is stored in an .init_array section. At link time the .init_array sections must be collated together into a single contiguous .init_array section. The linker will generate an error if this is not possible.

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() which calls the static destructors registered with __aeabi_atexit().

Note

The __aeabi_atexit() function calls malloc().

Related concepts

1.10 Tailoring the C library to a new execution environment on page 1-61

1.10.3 Exceptions system initialization

The exceptions system can be initialized either on demand (that is, when first used), or before entering main().

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 entering main(), include the following function in the link:

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

Although you can place the call to __cxa_getGlobals() 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().

Related concepts

1.10 Tailoring the C library to a new execution environment on page 1-61
1.10.4 Library functions called from main()

The function `main()` can call a number of user-customizable functions in the C library.

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`.

Related concepts

1.10.1 Initialization of the execution environment and execution of the application on page 1-61
1.10 Tailoring the C library to a new execution environment on page 1-61
1.11 Assembler macros that tailor locale functions in the C library on page 1-65

Related references

1.14 Tailoring input/output functions in the C and C++ libraries on page 1-81
1.23 Tailoring non-input/output C library functions on page 1-93
1.12 Modification of C library functions for error signaling, error handling, and program exit on page 1-73

1.10.5 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 a number of conditions:

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:
   - `__OPT_SMALL_ASSERT` is defined.
   - `__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().

Related concepts
1.10 Tailoring the C library to a new execution environment on page 1-61

Related concepts
1.10.2 C++ initialization, construction and destruction on page 1-62
1.10.4 Library functions called from main() on page 1-63
1.10.1 Initialization of the execution environment and execution of the application on page 1-61
1.10.5 Program exit and the assert macro on page 1-63
1.10.3 Exceptions system initialization on page 1-62

Related references
4.23 __rt_entry on page 4-165
4.24 __rt_exit() on page 4-166
1.11  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`.

This section contains the following subsections:

- 1.11.1 Link time selection of the locale subsystem in the C library on page 1-65.
- 1.11.2 Runtime selection of the locale subsystem in the C library on page 1-66.
- 1.11.3 Definition of locale data blocks in the C library on page 1-66.
- 1.11.4 LC_CTYPE data block on page 1-68.
- 1.11.5 LC_COLLATE data block on page 1-70.
- 1.11.6 LC_MONETARY data block on page 1-71.
- 1.11.7 LC_NUMERIC data block on page 1-71.
- 1.11.8 LC_TIME data block on page 1-71.

1.11.1  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 of your own locales in each category as you choose, and you can name your own 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.

ISO8859-1 implementation

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.

The following table 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 <code>strcoll/strxfrm</code> 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_iso8859Locale</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.

**Shift-JIS and UTF-8 implementation**

The Shift-JIS and UTF-8 locales let you use Japanese and Unicode characters.

The following table 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.

**Related concepts**

*Shift-JIS and UTF-8 implementation* on page 1-66

**Related references**

*ISO8859-1 implementation* on page 1-65
**LC_TYPE_function**

Specifies the data for a locale block.

**Note**

- When specifying locale data, you must call the macro repeatedly for each respective function.
- To specify the data for your locale block, call the macros for that locale type in the order specified for that particular locale type.

**LC_TYPE_end**

Ends the definition of a locale block.

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.

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

### 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:

```assembly
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
```

### 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:

```assembly
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
```
1.11.4 LC_CTYPE data block

The LC_CTYPE data block configures character classification and conversion.

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(char32_t *pwc, char c, mbstate_t *pstate, int wchar32);
size_t internal_wcrtomb(char *s, char32_t w, mbstate_t *pstate, int wchar32);
```

- `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.

The wchar32 parameter specifies whether the wide character is 32-bit (1) or 16-bit (0). If your
code does not use the C11/C++11 headers `<uchar.h>` or `<cuchar>`, the wchar32 parameter can be
ignored because it defaults to the current definition of wchar_t.

4. Call LC_CTYPE_end, without arguments, to finish the locale block definition.

**Example LC_CTYPE data block**

```c
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, C|C, C|C, C|C, C|C" ; 0x00-0x08
LC_CTYPE_table "C|S, C|S, C|S, C|S, C|S, C|S, C|S, C|S" ; 0x09-0x0D(BS,LF,VT,FF,CR)
LC_CTYPE_table "C|C, C|C, C|C, C|C, C|C, C|C, C|C; 0x0E-0x1F
LC_CTYPE_table "B|C; space"
LC_CTYPE_table "N|N, N|N, N|N, N|N, N|N, N|N, N|N" ; 0-9
LC_CTYPE_table "P|P, P|P, P|P, P|P; ;:<=>?
LC_CTYPE_table "U|X, U|X, U|X, U|X, U|X, U|X, U|X, U|X; A-F
LC_CTYPE_table "U, U, U, U, U, U, U, U, U, U; G-P
LC_CTYPE_table "U, U, U, U, U, U, U, U, U, U; Q-Z
LC_CTYPE_table "C|C; 0x7F
;
; 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, Il; UTF-8 cttype locale wants the full version of wcctype.
LC_CTYPE_full_wctype
;
; UTF-8 is a multibyte locale, so we must specify some
```
Related references
1.11.3 Definition of locale data blocks in the C library on page 1-66

1.11.5 LC_COLLATE data block

The LC_COLLATE data block configures collation of strings.

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, \texttt{strcoll()} and \texttt{strcmp()} are identical.
3. Call LC_COLLATE_end, without arguments, to finish the locale block definition.

Example LC_COLLATE data block

\begin{verbatim}
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_table "0x80, 0x81, 0x82, 0x83, 0x84, 0x85, 0x86, 0x87"
LC_COLLATE_table "0x88, 0x89, 0x8a, 0x8b, 0x8c, 0x8d, 0x8e, 0x8f"
LC_COLLATE_table "0x90, 0x91, 0x92, 0x93, 0x94, 0x95, 0x96, 0x97"
LC_COLLATE_table "0x98, 0x99, 0x9a, 0x9b, 0x9c, 0x9d, 0x9e, 0x9f"
LC_COLLATE_table "0xa0, 0xa1, 0xa2, 0xa3, 0xa4, 0xa5, 0xa6, 0xa7"
LC_COLLATE_table "0xa8, 0xa9, 0xaa, 0xab, 0xac, 0xad, 0xae, 0xaf"
LC_COLLATE_table "0xb0, 0xb1, 0xb2, 0xb3, 0xb4, 0xb5, 0xb6, 0xb7"
LC_COLLATE_table "0xb8, 0xb9, 0xba, 0xbb, 0xbc, 0xbd, 0xbe, 0xbf"
LC_COLLATE_table "0xc0, 0xc1, 0xc2, 0xc3, 0xc4, 0xc5, 0xc6, 0xc7"
LC_COLLATE_table "0xc8, 0xc9, 0xca, 0xcb, 0xcc, 0xcd, 0xce, 0xcf"
LC_COLLATE_table "0xd0, 0xd1, 0xd2, 0xd3, 0xd4, 0xd5, 0xd6, 0xd7"
LC_COLLATE_table "0xd8, 0xd9, 0xda, 0xdb, 0xdc, 0xdd, 0xde, 0xdf"
LC_COLLATE_table "0xe0, 0xe1, 0xe2, 0xe3, 0xe4, 0xe5, 0xe6, 0xe7"
LC_COLLATE_table "0xe8, 0xe9, 0xea, 0xeb, 0xec, 0xed, 0xee, 0xef"
LC_COLLATE_table "0xf0, 0xf1, 0xf2, 0xf3, 0xf4, 0xf5, 0xf6, 0xf7"
LC_COLLATE_table "0xf8, 0xf9, 0xfa, 0xfb, 0xfc, 0xfd, 0xfe, 0xff"
\end{verbatim}

Related references
1.11.3 Definition of locale data blocks in the C library on page 1-66
ISO8859-1 implementation on page 1-65
1.11.6  LC_MONETARY data block

The LC_MONETARY data block configures formatting of monetary values.

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.

Example LC_MONETARY data block

<table>
<thead>
<tr>
<th>Line</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>LC_MONETARY_begin c_monetary, &quot;C&quot;</td>
<td>Call LC_MONETARY_begin with symbol name and locale name.</td>
</tr>
<tr>
<td>LC_MONETARY_fracdigits 255, 255</td>
<td>Call LC_MONETARY_fracdigits with two arguments.</td>
</tr>
<tr>
<td>LC_MONETARY_positive 255, 255, 255, &quot;&quot;</td>
<td>Call LC_MONETARY_positive with four arguments.</td>
</tr>
<tr>
<td>LC_MONETARY_negative 255, 255, 255, &quot;&quot;</td>
<td>Call LC_MONETARY_negative with four arguments.</td>
</tr>
<tr>
<td>LC_MONETARY_currsymbol &quot;&quot;, &quot;&quot;</td>
<td>Call LC_MONETARY_currsymbol with two arguments.</td>
</tr>
<tr>
<td>LC_MONETARY_point &quot;&quot;</td>
<td>Call LC_MONETARY_point with one argument.</td>
</tr>
<tr>
<td>LC_MONETARY_thousands &quot;&quot;</td>
<td>Call LC_MONETARY_thousands with one argument.</td>
</tr>
<tr>
<td>LC_MONETARY_grouping &quot;&quot;</td>
<td>Call LC_MONETARY_grouping with one argument.</td>
</tr>
<tr>
<td>LC_MONETARY_end</td>
<td>Call LC_MONETARY_end to finish the locale block definition.</td>
</tr>
</tbody>
</table>

Related references
1.11.3 Definition of locale data blocks in the C library on page 1-66

1.11.7  LC_NUMERIC data block

The LC_NUMERIC data block configures formatting of numeric values that are not monetary.

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.

Example LC_NUMERIC data block

<table>
<thead>
<tr>
<th>Line</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>LC_NUMERIC_begin c_numerical, &quot;C&quot;</td>
<td>Call LC_NUMERIC_begin with symbol name and locale name.</td>
</tr>
<tr>
<td>LC_NUMERIC_point &quot;&quot;</td>
<td>Call LC_NUMERIC_point with one argument.</td>
</tr>
<tr>
<td>LC_NUMERIC_thousands &quot;&quot;</td>
<td>Call LC_NUMERIC_thousands with one argument.</td>
</tr>
<tr>
<td>LC_NUMERIC_grouping &quot;&quot;</td>
<td>Call LC_NUMERIC_grouping with one argument.</td>
</tr>
<tr>
<td>LC_NUMERIC_end</td>
<td>Call LC_NUMERIC_end to finish the locale block definition.</td>
</tr>
</tbody>
</table>

Related references
1.11.3 Definition of locale data blocks in the C library on page 1-66

1.11.8  LC_TIME data block

The LC_TIME data block configures formatting of date and time values.
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. The example below 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.

**Example LC_TIME data block**

```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"
LC_TIME_month_long "March"
LC_TIME_month_long "April"
LC_TIME_month_long "May"
LC_TIME_month_long "June"
LC_TIME_month_long "July"
LC_TIME_month_long "August"
LC_TIME_month_long "September"
LC_TIME_month_long "October"
LC_TIME_month_long "November"
LC_TIME_month_long "December"
LC_TIME_am_pm "AM", "PM"
LC_TIME_formats "%a %b %e %T %Y", "%m/%d/%y", "%H:%M:%S"
LC_TIME_c99format "%I:%M:%S%p"
LC_TIME_end
```

**Related references**

- 1.11.3 Definition of locale data blocks in the C library on page 1-66

**Related references**

- 1.8.7 C library API definitions for targeting a different environment on page 1-52
- 1.9.1 Building an application without the C library on page 1-54
1.12 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 following table shows the trap and error-handling functions.

<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>

Related references

1.8.5 Direct semihosting C library function dependencies on page 1-50
1.8.6 Indirect semihosting C library function dependencies on page 1-51
1.9.1 Building an application without the C library on page 1-54
4.40 _sys_exit() on page 4-183
4.6 errno on page 4-146
4.19 __raise() on page 4-160
4.29 __rt_raise() on page 4-171
4.5 __default_signal_handler() on page 4-145
4.50 _ttywrch() on page 4-193
4.25 __rt_fp_status_addr() on page 4-167

Related information

Semihosting for AArch32 and AArch64
1.13 Stack and heap memory allocation and the Arm® C and C++ libraries

The Arm C and C++ libraries require you to specify where the stack pointer begins, but specifying the heap is optional. However, some library functions use the heap, either explicitly (for example `malloc`) or implicitly (for example `fopen`).

If you are providing a heap, you must:

- Understand the heap usage requirements of the Arm C and C++ libraries.
- Configure the size and placement of the heap.
- Consider which heap implementation you want to use.

If you are not providing a heap, you must:

- Understand the heap usage requirements of the Arm C and C++ libraries.
- Understand how to avoid or reimplement the heap-using functions.

This section contains the following subsections:

- 1.13.1 Library heap usage requirements of the Arm® C and C++ libraries on page 1-74.
- 1.13.2 Choosing a heap implementation for memory allocation functions on page 1-75.
- 1.13.3 Stack pointer initialization and heap bounds on page 1-76.
- 1.13.4 Legacy support for `__user_initial_stackheap()` on page 1-79.
- 1.13.5 Avoiding the heap and heap-using library functions supplied by Arm on page 1-79.

1.13.1 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 free list 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.

Related concepts

- 2.3 Library heap usage requirements of microlib on page 2-113

Related references

- 1.13.5 Avoiding the heap and heap-using library functions supplied by Arm on page 1-79
- 1.13.2 Choosing a heap implementation for memory allocation functions on page 1-75
Choosing a heap implementation 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 available heap implementations are:

- Heap1, the default implementation, implements the smallest and simplest heap manager.
- Heap2 provides an implementation with the performance cost of malloc() or free() growing logarithmically with the number of free blocks.

Note

The default implementations of malloc(), realloc(), and calloc() maintain an 8-byte aligned heap for AArch32 and a 16-byte aligned heap for AArch64.

Heap1

Heap1, the default implementation, implements the smallest and simplest heap manager. The heap is managed as a single-linked list of free blocks that are held in increasing address order. This implementation has low overheads. However, the performance cost of malloc() or free() grows linearly with the number of free blocks and might be too slow for some use cases.

If you expect more than 100 unallocated blocks, Arm recommends that you use Heap2 when you require near constant-time performance.

The allocation policy is first-fit by address. For AArch32, the smallest block that can be allocated is 4 bytes and there is an extra overhead of 4 bytes. For AArch64, the smallest allocation is 8 bytes, and there is an extra overhead of 8 bytes per allocation. For AArch64 with __use_memtag_heap, the smallest allocation is 0 bytes, and there is an extra overhead of 16 bytes per allocation.

Heap2

Heap2 provides an 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. For AArch32, the smallest block that can be allocated is 12 bytes and there is an extra overhead of 4 bytes. For AArch64, the smallest allocation is 24 bytes and there is an extra overhead of 8 bytes per allocation. For AArch64 with __use_memtag_heap, the smallest allocation is 16 bytes and there is an extra overhead of 16 bytes per allocation.

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 one of the following:

- IMPORT __use_realtime_heap when using the legacy armasm-syntax assembly language.
- __asm(".global __use_realtime_heap\n\t") from C.

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

The heap must fit within 16MB of address space.

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 that is given to the heap manager by __rt_initial_stackheap() or __rt_heap_extent()).

For AArch32 targets, the heap bounds are given by:

```c
struct __heap_extent {
    unsigned base;
    size_t range;
};
__attribute__((value_in_regs)) struct __heap_extent __user_heap_extent( unsigned ignore1, size_t ignore2);
```
For AArch64 targets, the heap bounds are given by:

```c
struct __heap_extent {
    unsigned long base;
    size_t range;
};
__attribute__((value_in_regs)) struct __heap_extent __user_heap_extent(
    unsigned long ignore1, size_t ignore2);
```

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 implement __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 implement __user_heap_extent(), but it speeds up the heap algorithms if you do.

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

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

Heap protection with memory tagging

The library provides an alternative implementation of malloc(), realloc(), calloc(), and free() that provide heap protection using the memory tagging extension. These alternative implementations are only available for the AArch64 state for architectures with the memory tagging extension. The memory tagging extension is optional in Armv8.5-A and later architectures. For information on enabling the optional memory tagging extension, see the armclang option -mcpu.

To enable heap protection, you must use one of the following:

- .global __use_memtag_heap when using GNU-syntax assembly language.
- __asm(“.global __use_memtag_heap
	”) from C.

Note
You can use the implementation with heap protection irrespective of whether you are using Heap1 or Heap2.

Related references

1.13.5 Avoiding the heap and heap-using library functions supplied by Arm on page 1-79
4.2 alloca() on page 4-142

1.13.3 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.

You must always specify where the stack pointer begins. The initial stack pointer must be aligned to a multiple of 8 bytes for AArch32 and a multiple of 16 bytes for AArch64.

You might have to configure the heap if, for example:
You intend to use Arm library functions that use the heap, for example, malloc(), calloc().

You define argc and argv command-line arguments for main().

If you are using the C library's initialization code, use any of the following methods to configure the stack and heap:

- Use the symbols __initial_sp, __heap_base, and __heap_limit.
- Use a scatter file to define ARM_LIB_STACKHEAP, ARM_LIB_STACK, or ARM_LIB_HEAP regions.
- Implement __user_setup_stackheap() or __user_initial_stackheap().

**Note**
The first two methods are the only methods that microlib supports for defining where the stack pointer starts and for defining the heap bounds.

If you are not using the C library's initialization code (see 1.9.1 Building an application without the C library on page 1-54), use the following method to configure the stack and heap:

- Set up the stack pointer manually at your application's entry point.
- Call_init_alloc() to set up an initial heap region, and implement __rt_heap_extend() if you need to add memory to it later.

**Configuring the stack and heap with symbols**

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.

You can define these symbols in an assembly language file.

For example:

```c
__attribute__((naked)) void dummy_function(void)
{
    __asm("
        .global __initial_sp
        .global __heap_base
        .global __heap_limit
        .equ __initial_sp, STACK_BASE
        .equ __heap_base, HEAP_BASE
        .equ __heap_limit, (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).

**Configuring the stack and heap with a scatter file**

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.
Configuring the stack and heap with __user_setup_stackheap()

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

Configuring the heap from bare machine C using _init_alloc and __rt_heap_extend

If you are using a heap implementation from bare machine C (that is an application that does not define main() and does not initialize the C library) you must define the base and top of the heap as well as providing a heap extension function.

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

    Note
    The parameters of _init_alloc(base, top) must be eight-byte aligned.

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

Stack and heap collision detection

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 __asm(".global __use_two_region_memory\n").

    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()

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_extent().

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

Related concepts
1.13.4 Legacy support for __user_initial_stackheap() on page 1-79

Related references
4.51 __user_heap_extent() on page 4-194
4.52 __user_heap_extent() on page 4-195
4.60 Legacy function __user_initial_stackheap() on page 4-205
4.26 __rt_heap_extend() on page 4-168
4.30 __rt_stackheap_init() on page 4-172
4.53 __user_setup_stackheap() on page 4-196
4.54 __vectab_stack_and_reset on page 4-197
Related information

Specifying stack and heap using the scatter file

1.13.4 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. However Arm recommends not using this option if possible.

__________ Note __________

Arm recommends that you use __user_setup_stackheap() instead of __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.

Exceptions

When you must create the heap and stack in C code rather than in assembly code, you cannot use the __user_setup_stackheap() function. Therefore, you must use the __user_initial_stackheap() function instead.

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

• __user_setup_stackheap() and manually set up the temporary stack yourself.
• __user_initial_stackheap(), which sets up the temporary stack for you.

Related concepts

1.13.3 Stack pointer initialization and heap bounds on page 1-76

Related references

4.60 Legacy function __user_initial_stackheap() on page 4-205
4.53 __user_setup_stackheap() on page 4-196

1.13.5 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.
• __asm(".global __use_no_heap\n\t") 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>
__asm(".global __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.

**Related references**

1.13.2 Choosing a heap implementation for memory allocation functions on page 1-75
1.8.6 Indirect semihosting C library function dependencies on page 1-51

**Related information**

Semihosting for AArch32 and AArch64
--list=filename linker option
--verbose linker option
1.14 Tailoring input/output functions in the C and C++ libraries

The input/output library functions, such as the high-level `fscanf()` and `fprintf()`, and the low-level `fputc()` and `ferror()`, and the C++ object `std::cout`, are not target-dependent. However, the high-level library functions perform input/output by calling the low-level ones. These low-level functions call system I/O functions that are target-dependent.

To retarget input/output, you can:

• Avoid the high-level library functions.
• Redefine the low-level library functions.
• Redefine the system I/O functions.

Whether redefining the low-level library functions or redefining the system I/O functions is a better solution depends on your use. For example, UARTs write a single character at a time and the default `fputc()` uses buffering, so redefining this function without a buffer might suit a UART. However, where buffer operations are possible, redefining the system I/O functions would probably be more appropriate.

**Related concepts**

1.16 The C library `printf` family of functions on page 1-84
1.17 The C library `scanf` family of functions on page 1-85
1.18 Redefining low-level library functions to enable direct use of high-level library functions in the C library on page 1-86
1.19 The C library functions `fread()`, `fgets()` and `gets()` on page 1-88
1.20 Re-implementing `__backspace()` in the C library on page 1-89
1.21 Re-implementing `__backspacewc()` in the C library on page 1-90
1.22 Redefining target-dependent system I/O functions in the C library on page 1-91

**Related references**

1.15 Target dependencies on low-level functions in the C and C++ libraries on page 1-82
1.8.5 Direct semihosting C library function dependencies on page 1-50
1.8.6 Indirect semihosting C library function dependencies on page 1-51
1.9.1 Building an application without the C library on page 1-54
4.37 `_sys_close()` on page 4-180
4.38 `_sys_command_string()` on page 4-181
4.39 `_sys_ensure()` on page 4-182
4.41 `_sys_flen()` on page 4-184
4.42 `_sys_istty()` on page 4-185
4.43 `_sys_open()` on page 4-186
4.44 `_sys_read()` on page 4-187
4.45 `_sys_seek()` on page 4-188
4.46 `_sys_tmpnam()` on page 4-189
4.47 `_sys_write()` on page 4-190
4.8 `_fisatty()` on page 4-148

**Related information**

Semihosting for AArch32 and AArch64
1.15 Target dependencies on low-level functions in the C and C++ libraries

Higher-level C and C++ library input/output functions are built upon 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.

The following table shows the dependencies of the higher-level functions on lower-level functions.

fgetc() uses __FILE, but fputc() 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 fgetc() and fputc(), do not reference any data stored in __stdin and __stdout.
- When targeting the strict ANSI C standard, you must provide your own implementation of the __FILE structure. For example:

```c
struct __FILE { int handle; /* Add whatever you need here */; }
```

- 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.

---

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. fputc(), outputs a character to a file.
5. ferror(), returns the error status accumulated during file I/O.
6. fgetc(), gets a character from a file.
7. fgetwc()
8. fputwc()
9. __backspace(), moves the file pointer to the previous character.
10. __backspacewc().

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<th>High-level function</th>
<th>Low-level object</th>
</tr>
</thead>
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<tr>
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<td>fwscanf</td>
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<tr>
<td>getchar</td>
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Table 1-10 Input/output dependencies

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Table 1-10  Input/output dependencies (continued)

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<td>getwchar</td>
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**Related concepts**

1.16 The C library printf family of functions on page 1-84
1.17 The C library scanf family of functions on page 1-85
1.18 Redefining low-level library functions to enable direct use of high-level library functions in the C library on page 1-86
1.19 The C library functions fread(), fgets() and gets() on page 1-88
1.20 Re-implementing __backspace() in the C library on page 1-89
1.21 Re-implementing __backspacewc() in the C library on page 1-90
1.22 Redefining target-dependent system I/O functions in the C library on page 1-91

**Related references**

1.14 Tailoring input/output functions in the C and C++ libraries on page 1-81

**Related information**

ISO C Reference
1.16 The C library printf family of functions

The printf family consists of printf(), 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:

```c
fprintf(& __stdout, ...)
```

where __stdout has type __FILE.

Related concepts
1.17 The C library scanf family of functions on page 1-85
1.18 Redefining low-level library functions to enable direct use of high-level library functions in the C library on page 1-86
1.19 The C library functions fread(), fgets() and gets() on page 1-88
1.20 Re-implementing __backspace() in the C library on page 1-89
1.21 Re-implementing __backspacewc() in the C library on page 1-90
1.22 Redefining target-dependent system I/O functions in the C library on page 1-91

Related references
1.14 Tailoring input/output functions in the C and C++ libraries on page 1-81
1.15 Target dependencies on low-level functions in the C and C++ libraries on page 1-82
1.17 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:

```
scanf(& __stdin, ...)
```

where `__stdin` is of type `__FILE`.

Related concepts

1.16 The C library printf family of functions on page 1-84
1.18 Redefining low-level library functions to enable direct use of high-level library functions in the C library on page 1-86
1.19 The C library functions fread(), fgets() and gets() on page 1-88
1.20 Re-implementing __backspace() in the C library on page 1-89
1.21 Re-implementing __backspacewc() in the C library on page 1-90
1.22 Redefining target-dependent system I/O functions in the C library on page 1-91

Related references

1.14 Tailoring input/output functions in the C and C++ libraries on page 1-81
1.15 Target dependencies on low-level functions in the C and C++ libraries on page 1-82
1.18 Redefining low-level library functions to enable direct use of high-level library functions in the C library

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.

These examples show you how to do this. However, consider modifying the system I/O functions instead of these low-level library functions 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.

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); // sendchar(&ch) would not work everywhere
  return ch;
}
```

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)
```
File 2: Print "Hello world" using your re-implemented functions.

```c
#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.

**Related concepts**

- 1.16 The C library printf family of functions on page 1-84
- 1.17 The C library scanf family of functions on page 1-85
- 1.19 The C library functions fread(), fgets() and gets() on page 1-88
- 1.20 Re-implementing __backspace() in the C library on page 1-89
- 1.21 Re-implementing __backspacewc() in the C library on page 1-90
- 1.22 Redefining target-dependent system I/O functions in the C library on page 1-91

**Related references**

- 1.14 Tailoring input/output functions in the C and C++ libraries on page 1-81
- 1.15 Target dependencies on low-level functions in the C and C++ libraries on page 1-82
1.19 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.

Related concepts
1.16 The C library printf family of functions on page 1-84
1.17 The C library scanf family of functions on page 1-85
1.18 Redefining low-level library functions to enable direct use of high-level library functions in the C library on page 1-86
1.20 Re-implementing __backspace() in the C library on page 1-89
1.21 Re-implementing __backspacewc() in the C library on page 1-90
1.22 Redefining target-dependent system I/O functions in the C library on page 1-91

Related references
1.14 Tailoring input/output functions in the C and C++ libraries on page 1-81
1.15 Target dependencies on low-level functions in the C and C++ libraries on page 1-82
1.20 **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 re-target 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 syntax is:

```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 ungetc() of a character into a stream followed immediately by a __backspace() with no intervening read, never occurs.

**Related concepts**

- 1.16 The C library printf family of functions on page 1-84
- 1.17 The C library scanf family of functions on page 1-85
- 1.18 Redefining low-level library functions to enable direct use of high-level library functions in the C library on page 1-86
- 1.19 The C library functions fread(), fgets() and gets() on page 1-88
- 1.21 Re-implementing __backspacewc() in the C library on page 1-90
- 1.22 Redefining target-dependent system I/O functions in the C library on page 1-91

**Related references**

- 1.14 Tailoring input/output functions in the C and C++ libraries on page 1-81
- 1.15 Target dependencies on low-level functions in the C and C++ libraries on page 1-82
1.21 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.

Related concepts
1.16 The C library printf family of functions on page 1-84
1.17 The C library scanf family of functions on page 1-85
1.18 Redefining low-level library functions to enable direct use of high-level library functions in the C library on page 1-86
1.19 The C library functions fread(), fgets() and gets() on page 1-88
1.20 Re-implementing __backspace() in the C library on page 1-89
1.22 Redefining target-dependent system I/O functions in the C library on page 1-91

Related references
1.14 Tailoring input/output functions in the C and C++ libraries on page 1-81
1.15 Target dependencies on low-level functions in the C and C++ libraries on page 1-82
1.22 Redefining target-dependent system I/O functions in the C library

The default target-dependent I/O functions use semihosting. If any of these functions are redefined, then they must all be redefined.

The function prototypes are contained in `rt_sys.h`. These functions are called by the C standard I/O library functions. For example, `_sys_open()` is called by `fopen()` and `freopen()`. `_sys_open()` uses the strings `__stdin_name`, `__stdout_name`, and `__stderr_name` during C library initialization to identify which standard I/O device handle to return. You can leave their values as the default (`:tt`) if `_sys_open()` does not use them.

--- Note ---

stdin, stdout, and stderr are assumed to be interactive devices. They are line-buffered at program startup, regardless of what `_sys_istty` reports for them. An exception is if they have been redirected on the command line.

---

The following example shows you how to redefine the required functions for a device that supports writing but not reading.

**Example of retargeting the system I/O functions**

```c
/*
 * These names are used during library initialization as the
 * file names opened for stdin, stdout, and stderr.
 * As we define _sys_open() to always return the same file handle,
 * these can be left as their default values.
 */
const char __stdin_name[] = ":tt";
const char __stdout_name[] = ":tt";
const char __stderr_name[] = ":tt";

FILEHANDLE _sys_open(const char *name, int openmode)
{
    return 1; /* everything goes to the same output */
}
int _sys_close(FILEHANDLE fh)
{
    return 0;
}
int _sys_write(FILEHANDLE fh, const unsigned char *buf,
               unsigned len, int mode)
{
    your_device_write(buf, len);
    return 0;
}
int _sys_read(FILEHANDLE fh, unsigned char *buf,
              unsigned len, int mode)
{
    return -1; /* not supported */
}
void _ttywrch(int ch)
{
    char c = ch;
    your_device_write(&c, 1);
}
int _sys_istty(FILEHANDLE fh)
{
    return 0; /* buffered output */
}
int _sys_seek(FILEHANDLE fh, long pos)
{
    return -1; /* not supported */
}
long _sys_flen(FILEHANDLE fh)
{
    return -1; /* not supported */
}
```

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

**Related concepts**
1.16 The C library printf family of functions on page 1-84
1.17 The C library scanf family of functions on page 1-85
1.18 Redefining low-level library functions to enable direct use of high-level library functions in the C library on page 1-86
1.19 The C library functions fread(), fgets() and gets() on page 1-88
1.20 Re-implementing __backspace() in the C library on page 1-89
1.21 Re-implementing __backspacewc() in the C library on page 1-90

**Related references**
1.14 Tailoring input/output functions in the C and C++ libraries on page 1-81
1.15 Target dependencies on low-level functions in the C and C++ libraries on page 1-82

**Related information**
Semihosting for AArch32 and AArch64
1.23 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.

Related references
1.8.5 Direct semihosting C library function dependencies on page 1-50
1.8.6 Indirect semihosting C library function dependencies on page 1-51
4.3 clock() on page 4-143
4.4 _clock_init() on page 4-144
4.49 time() on page 4-192
4.21 remove() on page 4-163
4.22 rename() on page 4-164
4.48 system() on page 4-191
4.10 getenv() on page 4-150
4.11 _getenv_init() on page 4-151

Related information
Semihosting for AArch32 and AArch64
1.24 Real-time integer division in the Arm® libraries

The Arm library provides a real-time division routine and a standard division routine.

The standard 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 the Armv6-M and Armv8-M.baseline architecture.

Note

The Armv7-M, Armv7-R, and Armv8-M.mainline architectures support hardware floating-point divide. Code running on these architectures do not require the library divide routines.

Select the real-time divide routine using either of the following methods:

• IMPORT __use_realtime_division from assembly language.
• __asm(".global __use_realtime_division\n\t") from C.
1.25 ISO C library implementation definition

Describes how the libraries fulfill the requirements of the ISO specification.

This section contains the following subsections:

- 1.25.1 How the Arm® C library fulfills ISO C specification requirements on page 1-95.
- 1.25.2 mathlib error handling on page 1-96.
- 1.25.3 ISO-compliant implementation of signals supported by the signal() function in the C library and additional type arguments on page 1-96.
- 1.25.4 ISO-compliant C library input/output characteristics on page 1-97.
- 1.25.5 Standard C++ library implementation definition on page 1-99.

1.25.1 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 `NULL` expands to the integer constant 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 `__aeabi_assert()` function prints information on the failing diagnostic on `stderr` and then calls the `abort()` function:

```
*** assertion failed: expression, file name, line number
```

--- Note ---

The behavior of the `assert` macro depends on the conditions in operation at the most recent occurrence of `#include <assert.h>`. See 1.10.5 Program exit and the assert macro on page 1-63 for more information about the behavior of the `assert` macro.

---

- The following functions test for character values in the range EOF (-1) to 255 inclusive:
  - `isalnum`
  - `isalpha`
  - `iscntrl`
  - `islower`
  - `isprint`
  - `isupper`
  - `ispunct`
- The fully POSIX-compliant functions `remquo()`, `remquof()` and `remquol()` return the remainder of the division of `x` by `y` and store the quotient of the division in the pointer `*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.

Related concepts

1.25.4 ISO-compliant C library input/output characteristics on page 1-97
1.10.5 Program exit and the assert macro on page 1-63

Related references

1.25.2 mathlib error handling on page 1-96
1.25.3 ISO-compliant implementation of signals supported by the signal() function in the C library and additional type arguments on page 1-96
1.27 C and C++ library naming conventions on page 1-103
1.25.2 mathlib error handling

The error handling of mathematical functions is consistent with Annex F of the ISO/IEC C99 standard.

**Related concepts**

1.25.4 ISO-compliant C library input/output characteristics on page 1-97
1.25.1 How the Arm® C library fulfills ISO C specification requirements on page 1-95

**Related references**

1.25.3 ISO-compliant implementation of signals supported by the signal() function in the C library and additional type arguments on page 1-96

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

The `signal()` function supports a number of signals.

The following table 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 floating-point zero results in a SIGFPE signal with a corresponding additional argument of `FE_EX_DIVBYZERO`.

<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 the <code>abort()</code> function is called.</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td></td>
<td>The <code>abort()</code> function is triggered when there is an untrapped C++ exception, or when an assertion fails.</td>
<td></td>
</tr>
<tr>
<td>SIGFPE</td>
<td>2</td>
<td>Signals 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</code>, <code>FE_EX_UNDERFLOW</code>, <code>FE_EX_OVERFLOW</code>, <code>FE_EX_DIVBYZERO</code>, <code>FE_EX_INVALID</code>, <code>DIVBYZERO</code>^a</td>
</tr>
<tr>
<td>SIGILL</td>
<td>3</td>
<td>Illegal instruction.</td>
<td>None</td>
</tr>
<tr>
<td>SIGINT^b</td>
<td>4</td>
<td>Attention request from user.</td>
<td>None</td>
</tr>
<tr>
<td>SIGSEGV^b</td>
<td>5</td>
<td>Bad memory access.</td>
<td>None</td>
</tr>
<tr>
<td>SIGTERM^b</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 supported.</td>
<td>-</td>
</tr>
</tbody>
</table>

^a These constants are defined in `fenv.h`. `FE_EX_DIVBYZERO` is for floating-point division while `DIVBYZERO` is for integer division.

^b The library never generates this signal. It is available for you to raise manually, if required.
Table 1-11 Signals supported by the signal() function (continued)

<table>
<thead>
<tr>
<th>Signal</th>
<th>Number</th>
<th>Description</th>
<th>Additional argument</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIGOUTOFHEAP</td>
<td>14</td>
<td>Not supported.</td>
<td>Size of the failed request in bytes</td>
</tr>
<tr>
<td>reserved</td>
<td>&gt;=15</td>
<td>Reserved.</td>
<td>Reserved</td>
</tr>
</tbody>
</table>

Although SIGSTAK exists in sigal.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 using a fully-conforming floating-point model, such as the armclang default.

For all the signals in the above table, 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.

Related concepts
1.25.4 ISO-compliant C library input/output characteristics on page 1-97
1.25.1 How the Arm® C library fulfills ISO C specification requirements on page 1-95
3.4.8 Exception types recognized by the Arm® floating-point environment on page 3-136

Related references
1.25.2 mathlib error handling on page 1-96
1.12 Modification of C library functions for error signaling, error handling, and program exit on page 1-73
4.19 __raise() on page 4-160
4.29 __rt_raise() on page 4-171

Related information
IEEE Standard for Floating-Point Arithmetic (IEEE 754), 1985 version

1.25 ISO-compliant C library input/output characteristics

The generic Arm C library has defined input/output characteristics.

These input/output characteristics are as follows:

- 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.
• stdin, stdout, and stderr are assumed to be interactive devices. They are line-buffered at program startup, regardless of what _sys_istty reports for them. An exception is if they have been redirected on the command line.
• localtime() is implemented and returns the local time. mktime() is not implemented and returns NULL. Therefore converting between time-zones is not supported.
• 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 the following table.

<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().

Related concepts
1.25.1 How the Arm® C library fulfills ISO C specification requirements on page 1-95

Related references
1.25.2 mathlib error handling on page 1-96
1.25.3 ISO-compliant implementation of signals supported by the signal() function in the C library and additional type arguments on page 1-96

Related information
Semihosting for AArch32 and AArch64
1.25.5 Standard C++ library implementation definition

The Standard C++ library in Arm Compiler 6 is based on the LLVM libc++ project.

--- Note ---

This topic includes descriptions of [ALPHA] features. See Support level definitions on page 1-15.

---

The following sections describe the limitations of the Standard C++ library in Arm Compiler 6.

Support for C++98

Arm Compiler 6 C++ libraries support the C++98 standard, except where:

- The C++11 standard deviates from the C++98 standard. For example, where
  `std::deque<T>::insert()` returns an iterator, as required by the C++11 standard, but the C++98
  standard requires it to return `void`. Information about how the C++11 standard deviates from the C++
  +98 standard is available in Annex "C Compatibility" of the C++11 standard definition.
- Where the libc++ library deviates from the C++98 standard library:
  - For `std::vector<T>::const_reference`, the C++98 standard requires the `const_reference`
    type to be `bool`, but in libc++ it is an implementation-defined, read-only bit reference class.
  - For `std::bitset<N>`, the C++98 standard requires `bool operator[](size_t pos) const;` to
    return `bool`, but in libc++ it returns an implementation-defined, read-only bit reference object.
  - For `std::raw_storage_iterator`, the C++98 standard requires the `raw_storage_iterator`
    class template to be inherited from
      `std::iterator<std::output_iterator_tag,void,void,void,void>`, but in libc++ it is
    inherited from an instantiation of `std::iterator` with a different list of template arguments.

Support for C++03

Arm Compiler 6 C++ libraries support the C++03 standard, except where:

- The C++11 standard deviates from the C++03 standard. For example, where
  `std::deque<T>::insert()` returns an iterator, as required by the C++11 standard, but the C++03
  standard requires it to return `void`. Information about how the C++11 standard deviates from the C++
  +03 standard is available in Annex "C Compatibility" of the C++11 standard definition.
- Where the libc++ library deviates from the C++03 standard library:
  - For `std::vector<T>::const_reference`, the C++03 standard requires the `const_reference`
    type to be `bool`, but in libc++ it is an implementation-defined, read-only bit reference class.
  - For `std::bitset<N>`, the C++03 standard requires `bool operator[](size_t pos) const;` to
    return `bool`, but in libc++ it returns an implementation-defined, read-only bit reference object.
  - For `std::raw_storage_iterator`, the C++03 standard requires the `raw_storage_iterator`
    class template to be inherited from
      `std::iterator<std::output_iterator_tag,void,void,void,void>`, but in libc++ it is
    inherited from an instantiation of `std::iterator` with a different list of template arguments.

Support for C++11

Arm Compiler 6 C++ libraries support the majority of C++11. Thread support, `<thread>`, as well as
other concurrency features, are [ALPHA] supported.

Support for C++14

Arm Compiler 6 C++ libraries support the majority of C++14. Thread support, `<thread>`, as well as
other concurrency features, are [ALPHA] supported.

Support for exceptions

Arm Compiler 6 supports:

- C++ libraries with exceptions.
- C++ libraries without exceptions. These libraries are compiled with the `-fno-exceptions` option.
Linking objects that have been compiled with `-fno-exceptions` automatically selects the libraries without exceptions. You can use the linker option `--no_exceptions` to diagnose whether the objects being linked contain exceptions.

--- Note ---
- By default, C++ sources are compiled with exceptions support. You can use the `-fno-exceptions` option to disable exceptions support.
- By default, C sources are compiled without exceptions support. You can use the `-fexceptions` option to enable exceptions support.
- If an exception propagates into a function that has been compiled without exceptions support, then the program terminates.
- If the C++ libraries built without exception support is put in an error state, then an exception is not thrown, but the program behavior is undefined.

---

Support for Array Construction and Delete helper functions

Arm Compiler 6 is not compatible with C++ objects from other compilers that use Array Construction and Delete helper functions.

---

Support for Atomic [ALPHA]

Arm Compiler 6 provides access to the Atomic operations library `<atomic>` as an [ALPHA] feature.

--- Note ---
Arm Compiler 6 does not provide an implementation of `libatomic`. You must either provide an implementation of `libatomic` or only use the atomic operation library for types for which the hardware can provide synchronization primitives.

---

Support for multithreading [ALPHA]

The default standard C++ library shipped in Arm Compiler 6 does not support multithreading. This variant of the standard C++ library does not support the concurrency constructs available through the headers, that includes `<thread>` and `<mutex>`. A multithreaded [ALPHA]-supported variant of the C++ library is also included in Arm Compiler 6.

---

Support for thread-safe static initialization of local variables in C++

The default C++ library in Arm Compiler 6 contains trivial implementations of the following one-time construction API functions, which are not thread-safe:

```c
extern "C" int __cxa_guard_acquire(int*guard_object);
extern "C" void __cxa_guard_release(int *guard_object);
extern "C" void __cxa_guard_abort(int *guard_object);
```

--- Note ---
- This does not apply to the [ALPHA]-supported multithreaded C++ libraries. Contact the Arm Support team for more information.
- For thread-safe static initialization of local variables in C++, you must provide your own thread-safe implementation of these functions.

---

These API functions are described in more detail in the *Run-time ABI for the Arm Architecture*. On the Armv6-M architecture, you must also provide thread-safe atomic helper functions.
**Support for Arm®v6-M atomic helper functions**

The Arm Compiler 6 Armv6-M libraries contain trivial implementations of the following atomic helper functions, which are not thread-safe:

- `uint32_t __user_cmpxchg_4(uint32_t *ptr, uint32_t old, uint32_t new);`
- `uint16_t __user_cmpxchg_2(uint16_t *ptr, uint16_t old, uint16_t new);`
- `uint8_t __user_cmpxchg_1(uint8_t *ptr, uint8_t old, uint8_t new);`
- `uint64_t __atomic_exchange_8(uint64_t *dest, uint64_t val, int model);`
- `uint32_t __atomic_exchange_4(uint32_t *dest, uint32_t val, int model);`
- `uint16_t __atomic_exchange_2(uint16_t *dest, uint16_t val, int model);`
- `uint8_t __atomic_exchange_1(uint8_t *dest, uint8_t val, int model);`

**Note**

For atomic access on the Armv6-M architecture, you must provide your own thread-safe implementation of the atomic helper functions.

**Related information**

- *The LLVM Compiler Infrastructure*
- *The LLVM libc++ library*
1.26 C library functions and extensions

The Arm C library is fully compliant with the ISO C99 library standard and provides a number of GNU, POSIX, BSD-derived, and Arm Compiler-specific extensions.

The following table describes these extensions.

<table>
<thead>
<tr>
<th>Function</th>
<th>Header file definition</th>
<th>Extension</th>
</tr>
</thead>
<tbody>
<tr>
<td>wcscasecmp()</td>
<td>wchar.h</td>
<td>GNU extension with Arm library support</td>
</tr>
<tr>
<td>wcsncasecmp()</td>
<td>wchar.h</td>
<td>GNU extension with Arm library support</td>
</tr>
<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 nonstandard 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 Arm Compiler</td>
</tr>
<tr>
<td>__heapstats()</td>
<td>stdlib.h</td>
<td>Specific to Arm Compiler</td>
</tr>
<tr>
<td>__heapvalid()</td>
<td>stdlib.h</td>
<td>Specific to Arm Compiler</td>
</tr>
</tbody>
</table>

Related references

4.55 wcscasecmp() on page 4-198
4.56 wcsncasecmp() on page 4-199
4.57 wcstombs() on page 4-200
4.2 alloca() on page 4-142
4.34 strlcat() on page 4-177
4.35 strlcpy() on page 4-178
4.33 strcasecmp() on page 4-176
4.36 strncasecmp() on page 4-179
4.8 _fisatty() on page 4-148
4.12 __heapstats() on page 4-152
4.13 __heapvalid() on page 4-153
1.27 C and C++ library naming conventions

The library filename identifies how the variant was built.

Note

This topic includes descriptions of [ALPHA] and [COMMUNITY] features. See Support level definitions on page 1-15.

Note

The library naming convention described in this documentation applies to the current release of the Arm compilation tools. Do not rely on C and C++ library names. They might change in future releases.

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.

The values for the fields of the filename, and the relevant build options are:

```
root/prefix_arch[fpu][position-independence][enum][wchar][exception][threading].endian
```

- **root**
  - armlib
    - Arm C library.
  - libcxx
    - libc++ library.

- **prefix**
  - c
    - ISO C and C++ basic runtime support.
  - libc++
    - libc++ library.

- **libc++-experimental**
  - C++ library for future or incomplete C++ standards. Use of this library is a [COMMUNITY] feature.

- **libunwind**
  - C++ exception unwinder library.

- **libc++abi**
  - libc++abi runtime library.

- **f**
  - IEEE-compliant library with a fixed rounding mode (round to nearest) and no inexact exceptions.

- **fj**
  - IEEE-compliant library with a fixed rounding mode (round to nearest) and no exceptions.
<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$fz$</td>
<td>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.</td>
</tr>
<tr>
<td>$g$</td>
<td>IEEE-compliant library with configurable rounding mode and all IEEE exceptions.</td>
</tr>
<tr>
<td>$h$</td>
<td>Compiler support (helper function) library.</td>
</tr>
<tr>
<td>$m$</td>
<td>Transcendental math functions.</td>
</tr>
<tr>
<td>$mc$</td>
<td>Non ISO C-compliant ISO C micro-library basic runtime support.</td>
</tr>
<tr>
<td>$mf$</td>
<td>Non IEEE 754 floating-point compliant micro-library support.</td>
</tr>
<tr>
<td>$arch$</td>
<td></td>
</tr>
<tr>
<td>$p$</td>
<td>A T32 only library for use with the Armv6-M and Armv8-Mbaseline architectures.</td>
</tr>
<tr>
<td>$w$</td>
<td>A T32 only library for use with Armv7-M, Armv7E-M, and Armv8-Mmainline architectures.</td>
</tr>
<tr>
<td>$2$</td>
<td>A T32 interworking library, with a small number of A32 instructions, for use with Armv7-A and Armv7-R architectures.</td>
</tr>
<tr>
<td>$8$</td>
<td>A combined A32 and T32 interworking library for use with the Armv8-A and Armv8-R architectures, in AArch32 state.</td>
</tr>
<tr>
<td>$o$</td>
<td>An A64 library for use with the Armv8 architecture, in AArch64 state.</td>
</tr>
<tr>
<td>$r$</td>
<td>An A64 library for use with the Armv8.3-A and later architectures, in AArch64 state. This library has support for return address signing and branch target identification.</td>
</tr>
<tr>
<td>$a$</td>
<td>An A64 library for use with the Armv8.5-A and later architectures, in AArch64 state. This library has support for return address signing, branch target identification, and stack tagging. Use of this library is an [ALPHA] feature.</td>
</tr>
<tr>
<td>$fpu$</td>
<td></td>
</tr>
<tr>
<td>$m$</td>
<td>A variant of the library for processors that have single-precision hardware floating-point only, such as the Cortex*-M4 processor.</td>
</tr>
<tr>
<td>$v$</td>
<td>Uses VFP instruction set.</td>
</tr>
</tbody>
</table>
s
Soft VFP.

Note
If none of v, m, or s are present in a library name, the library provides no floating-point support.

position-independence

e
Position-independent access to static data.

f
FPIC addressing is enabled (used by armclang option -bare-metal-pie).

Note
• Position independence is only supported in AArch32 state. If both e and f are not present in a library name, the library uses position-dependent access to static data.
• Bare-metal PIE support is deprecated in this release.

enum

n
Compatible with the default compiler option, -fno-short-enums.

wchar

u
Indicates the size of wchar_t. When present, the library is compatible with the compiler option, -fno-short-wchar. Otherwise, it is compatible with -fshort-wchar.

exception

x
This only applies to the C++ library. x indicates that the library is built with exception handling. Libraries without x are built without exception handling.

threading

z
This only applies to the C++ library. z indicates that the library is a multithreaded variant of the C++ library. Use of this library is an [ALPHA] feature. Libraries without z are built without multithreading support.

dian

l
Little-endian.

b
Big-endian.

For example:

```
armlib/c_2.b
libcxx/libcpp_8f.l
```
Note

Not all variant/name combinations are valid. See the armlib and libcxx directories for the libraries that are supplied with the Arm Compiler.

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

**Related information**

--info=topic[,topic,...] linker option
1.28 Using macro __ARM_WCHAR_NO_IO to disable FILE declaration and wide I/O function prototypes

You can define the macro __ARM_WCHAR_NO_IO to cause the wchar.h and cwchar 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.
1.29 Using library functions with execute-only memory

Arm Compiler lets you build applications for execute-only memory. However, the Arm C and C++ libraries are not execute-only compliant.

If your application calls library functions, the library objects included in the image are not execute-only compliant. You must ensure these objects are not assigned to an execute-only memory region.

Note

Arm does not provide libraries that are built without literal pools. The libraries still use literal pools, even when you use the `mexecute-only` option.
Chapter 2
The Arm® C Micro-library

Describes microlib, the C micro-library.

It contains the following sections:

• 2.1 About microlib on page 2-110.
• 2.2 Differences between microlib and the default C library on page 2-111.
• 2.3 Library heap usage requirements of microlib on page 2-113.
• 2.4 ISO C features missing from microlib on page 2-114.
• 2.5 Building an application with microlib on page 2-116.
• 2.6 Configuring the stack and heap for use with microlib on page 2-117.
• 2.7 Entering and exiting programs linked with microlib on page 2-118.
• 2.8 Tailoring the microlib input/output functions on page 2-119.
2.1 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 has no support for AArch64 execution state.

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().

Related concepts
2.2 Differences between microlib and the default C library on page 2-111
2.3 Library heap usage requirements of microlib on page 2-113
2.4 ISO C features missing from microlib on page 2-114
2.5 Building an application with microlib on page 2-116
2.7 Entering and exiting programs linked with microlib on page 2-118
2.6 Configuring the stack and heap for use with microlib on page 2-117

Related references
2.8 Tailoring the microlib input/output functions on page 2-119
2.2 Differences between microlib and the default C library

There are a number of differences between microlib and the default C library.

The main differences 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. In `main`, `argc` and `argv` parameters are undefined and cannot be used to access command-line arguments.
- Microlib provides limited support for C99 functions. Specifically, microlib does not support the following C99 functions:
  - `<fenv.h>` functions:
    - `fclearexcept` `fegetenv` `fegetexceptflag` `fedgeexceptflag` `feraiseexcept` `fesetround`
  - Wide characters in general:
    - `btwc` `fgetwc` `fgetws` `fputwc`
    - `fpus` `fwide` `fwprintf` `fwscanf`
    - `getwc` `getwchar` `isalnum` `isalpha`
    - `iswgraph` `iswlower` `iswpunct` `iswucce`
    - `mblen` `mbmum` `mbstowcs` `mbstowcs`
    - `putwc` `putwchar` `swprintf` `swscanf`
    - `sweep` `towlower` `towupper` `towupper`
    - `ungetwc` `vfwprintf` `vwscanf`
    - `__mwcoll` `wccoll` `wcschr` `wcschr`
    - `wcsd` `wcstok` `wctol` `wctol`
    - `wcsfl` `wctomb` `wcstoml` `wcstoml`
    - `wcslen` `wcsncat` `wcsncmp` `wcsncmp`
    - `wcspec` `wcspec` `wcspec` `wcspec`
    - `wctrans` `wctype` `wmemchr` `wmemcmp`
    - `wmemcpy` `wmemmove` `wmemcpy` `wmemcpy`
    - `wmemmove` `wmemset` `wprintf` `wscanf`
  - Auxiliary `<cmath>` functions:
    - `ilogb` `ilogb` `ilogb` `ilogb`
    - `lgamma` `lgamma` `lgamma` `lgamma`
    - `logb` `logb` `logb` `logb`
    - `nextafter` `nextafter` `nextafter` `nextafter`
    - `nexttoaward` `nexttoaward` `nexttoaward` `nexttoaward`
  - Functions relating to program startup and shutdown and other OS interaction:
    - `atexit` `atexit` `atexit` `atexit`
    - `time` `time` `time` `time`
    - `exit` `exit` `exit` `exit`

- 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 `_membigstr[b|b|w][b|b|b]()` and `membigstr[b|b|w][b|b|b]()`.
- Microlib can be used only with the `armclang` command-line option `-ffp-mode=fast`.
- The level of ANSI C stdio support that is provided can be controlled with `__asm(.global_use_full_stdio\n\t)`.
• `__asm(".global __use_smaller_memcpy\n\t")` selects a smaller, but slower, version of `memcpy()`.
• `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.
• Microlib has no support in AArch64 state.
• When compiling a program that uses the microlib character classification functions in `ctype.h`, if the variable to classify does not represent an ASCII character, the behavior of these functions is undefined.

**Related concepts**

2.1 About microlib on page 2-110
2.3 Library heap usage requirements of microlib on page 2-113
2.4 ISO C features missing from microlib on page 2-114
2.5 Building an application with microlib on page 2-116
2.7 Entering and exiting programs linked with microlib on page 2-118
2.6 Configuring the stack and heap for use with microlib on page 2-117

**Related references**

2.8 Tailoring the microlib input/output functions on page 2-119
2.3 **Library heap usage requirements of microlib**

Library heap usage requirements for microlib differ to those of standardlib. The differences are:

- 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.

---

**Related concepts**

- 2.1 About microlib on page 2-110
- 2.2 Differences between microlib and the default C library on page 2-111
- 2.4 ISO C features missing from microlib on page 2-114
- 2.5 Building an application with microlib on page 2-116
- 2.7 Entering and exiting programs linked with microlib on page 2-118
- 1.13.1 Library heap usage requirements of the Arm® C and C++ libraries on page 1-74

**Related references**

- 2.8 Tailoring the microlib input/output functions on page 2-119
2.4 ISO C features missing from microlib

Microlib does not support all ISO C90 features.

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
Almost all functions that interact with an operating system are not supported by microlib. For example, abort(), exit(), atexit(), assert(), time(), system() and getenv(). An exception is clock(). A minimal implementation of clock() has been provided, which returns only -1, not the elapsed time. You may reimplement clock() (and _clock_init(), which it needs), if required.

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 __asm(".global __use_full_stdio\n\t"). Use of this assembler directive 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 indeterminate 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 unknown 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 position independent compilation modes.

Although ROPI code can be linked with microlib, the resulting binary is not ROPI-compliant overall.

Command-line arguments
In main, argc and argv parameters are undefined and cannot be used to access command-line arguments.

Related concepts
2.1 About microlib on page 2-110
2.2 Differences between microlib and the default C library on page 2-111
2.3 Library heap usage requirements of microlib on page 2-113
2.5 Building an application with microlib on page 2-116
2.7 Entering and exiting programs linked with microlib on page 2-118
2.6 Configuring the stack and heap for use with microlib on page 2-117

Related references
2.8 Tailoring the microlib input/output functions on page 2-119
1.8.7 C library API definitions for targeting a different environment on page 1-52
1.9.1 Building an application without the C library on page 1-54
4.3 clock() on page 4-143
4.4 _clock_init() on page 4-144
2.5 Building an application with microlib

To build a program using microlib, you must use the command-line option \texttt{--library\_type=microlib}. You can use this option with the legacy assembler or linker.

Use \texttt{--library\_type=microlib} with the linker to override all other options.

**Assembler option**

\begin{verbatim}
armclang --target arm-arm-none-eabi -march=armv8-a -c main.c
armclang --target arm-arm-none-eabi -march=armv8-a -c extra.c
armasm --cpu=8-A.32 --library\_type=microlib more.s
armlink --cpu=8-A.32 -o image.axf main.o extra.o more.o
\end{verbatim}

The request to the linker to use microlib is made as a result of assembling more.s with \texttt{--library\_type=microlib}.

**Linker option**

\begin{verbatim}
armclang --target arm-arm-none-eabi -march=armv8-a -c main.c
armclang --target arm-arm-none-eabi -march=armv8-a -c extra.c
armlink --cpu=8-A.32 --library\_type=microlib -o image.axf main.o extra.o
\end{verbatim}

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.

**Related concepts**

- 2.1 About microlib on page 2-110
- 2.2 Differences between microlib and the default C library on page 2-111
- 2.3 Library heap usage requirements of microlib on page 2-113
- 2.4 ISO C features missing from microlib on page 2-114
- 2.7 Entering and exiting programs linked with microlib on page 2-118
- 2.6 Configuring the stack and heap for use with microlib on page 2-117

**Related references**

- 2.8 Tailoring the microlib input/output functions on page 2-119

**Related information**

- \texttt{--library\_type=lib} assembler option
- \texttt{input-file-list} linker option
- \texttt{--library\_type=lib} linker option
2.6 Configuring the stack and heap for use with microlib

To use microlib, you must specify an initial pointer for the stack. You can specify the initial pointer in a scatter file or using the \texttt{__initial_sp} symbol.

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

To configure the stack and heap for use with microlib, use either of the following methods:

- Define the symbol \texttt{__initial_sp} to point to the top of the stack. If using the heap, also define symbols \texttt{__heap_base} and \texttt{__heap_limit}.
  \texttt{__initial_sp} must be aligned to a multiple of eight bytes.
- \texttt{__heap_limit} must point to the byte beyond the last byte in the heap region.
- In a scatter file, either:
  - Define \texttt{ARM_LIB_STACK} and \texttt{ARM_LIB_HEAP} regions. If you do not intend to use the heap, only define an \texttt{ARM_LIB_STACK} region.
  - Define an \texttt{ARM_LIB_STACKHEAP} region. If you define an \texttt{ARM_LIB_STACKHEAP} region, the stack starts at the top of that region. The heap starts at the bottom.

Examples

To set up the initial stack and heap pointers using GNU-syntax assembly language:

\begin{verbatim}
.global __initial_sp
.equ __initial_sp, 0x10000 ; top of the stack
.global __heap_base
.equ __heap_base, 0x400000 ; start of the heap
.global __heap_limit
.equ __heap_limit, 0x800000 ; end of the heap
\end{verbatim}

To set up the initial stack pointer using inline assembler in C.

\begin{verbatim}
__asm(".global __initial_sp
\t".
equ __initial_sp, 0x10000\n\t" /* equal to the top of the stack */
);
\end{verbatim}

To set up the heap pointer using inline assembler in C.

\begin{verbatim}
__asm(".global __heap_base\n\t".
equ __heap_base, 0x400000\n\t" /* equal to the start of the heap */
   ",".global __heap_limit\n\t".
equ __heap_limit, 0x800000\n\t" /* equal to the end of the heap */
);
\end{verbatim}

Related concepts

- 2.1 About microlib on page 2-110
- 2.2 Differences between microlib and the default C library on page 2-111
- 2.3 Library heap usage requirements of microlib on page 2-113
- 2.4 ISO C features missing from microlib on page 2-114
- 2.5 Building an application with microlib on page 2-116
- 2.7 Entering and exiting programs linked with microlib on page 2-118
- 1.13.3 Stack pointer initialization and heap bounds on page 1-76

Related references

- 2.8 Tailoring the microlib input/output functions on page 2-119

Related information

- About scatter-loading
2.7 Entering and exiting programs linked with microlib

Microlib requires a `main()` function that takes no arguments and never returns.

Use `main()` to begin your program. Do not declare `main()` to take arguments. Microlib does not support command-line arguments from an operating system.

Your program must not return from `main()`. This is because microlib does not contain any code to handle exit from `main()`. Microlib does not support programs that call `exit()`.

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()
}
```

Related concepts
2.1 About microlib on page 2-110
2.2 Differences between microlib and the default C library on page 2-111
2.3 Library heap usage requirements of microlib on page 2-113
2.4 ISO C features missing from microlib on page 2-114
2.5 Building an application with microlib on page 2-116
2.6 Configuring the stack and heap for use with microlib on page 2-117

Related references
2.8 Tailoring the microlib input/output functions on page 2-119
2.8 Tailoring the microlib input/output functions

Microlib provides a limited stdio subsystem. To use high-level I/O functions you must reimplement the base I/O 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(), pUTF(), 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 %l, %s and %a.

**Related concepts**

2.1 About microlib on page 2-110
2.2 Differences between microlib and the default C library on page 2-111
2.3 Library heap usage requirements of microlib on page 2-113
2.4 ISO C features missing from microlib on page 2-114
2.5 Building an application with microlib on page 2-116
2.6 Entering and exiting programs linked with microlib on page 2-118
2.7 Configuring the stack and heap for use with microlib on page 2-117
1.20 Re-implementing _backspace() in the C library on page 1-89

**Related references**

1.14 Tailoring input/output functions in the C and C++ libraries on page 1-81
Chapter 3
Floating-point Support

Describes Arm support for floating-point computations.

It contains the following sections:

- 3.1 About floating-point support on page 3-121.
- 3.2 Controlling the Arm® floating-point environment on page 3-122.
- 3.3 mathlib double and single-precision floating-point functions on page 3-130.
- 3.4 IEEE 754 arithmetic on page 3-131.
3.1 About floating-point support

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

Note

In Armv8, floating-point hardware is integral to the architecture. Software floating-point is supported for AArch32 state, but is not supported for AArch64 state.

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 `-mfloat-abi=hard` selects a hardware VFP coprocessor and the option `-mfloat-abi=soft` specifies that arithmetic operations are to be performed in software, without the use of any coprocessor instructions.

Note

In Arm Compiler 6, there is no command-line option to exclude both hardware and software floating-point computations. If the compiler encounters floating-point types in the source code, it will use software-based floating-point library functions.

Related concepts

3.4 IEEE 754 arithmetic on page 3-131
3.2 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.

——— Note ————

The Arm Compiler toolchain does not support floating-point exception trapping for AArch64 targets.

This section contains the following subsections:

• 3.2.1 Floating-point functions for compatibility with Microsoft products on page 3-122.
• 3.2.2 C99-compatible functions for controlling the Arm® floating-point environment on page 3-122.
• 3.2.3 C99 rounding mode and floating-point exception macros on page 3-123.
• 3.2.4 Exception flag handling on page 3-123.
• 3.2.5 Functions for handling rounding modes on page 3-124.
• 3.2.6 Functions for saving and restoring the whole floating-point environment on page 3-125.
• 3.2.7 Functions for temporarily disabling exceptions on page 3-125.
• 3.2.8 Arm floating-point compiler extensions to the C99 interface on page 3-126.
• 3.2.9 Example of a custom exception handler on page 3-127.
• 3.2.10 Exception trap handling by signals on page 3-128.

3.2.1 Floating-point functions for compatibility with Microsoft products

Functions defined in float.h give compatibility with Microsoft products to ease porting of floating-point code to the Arm architecture.

These functions require you to select a floating-point model that supports exceptions. In Arm Compiler 6 this is disabled by default, and can be enabled by the armclang command-line option -ffp-mode=full.

Related concepts
3.2 Controlling the Arm® floating-point environment on page 3-122

Related references
5.1 clearfp() on page 5-208
5.2 controlfp() on page 5-209
5.8 statusfp() on page 5-219

3.2.2 C99-compatible functions for controlling the Arm® floating-point environment

The compiler supports all functions defined in the C99 standard, and functions that are not C99-standard.

——— Note ————

The Arm Compiler toolchain does not support floating-point exception trapping for AArch64 targets.

——— Note ————

The following functionality requires a floating-point model that supports exceptions. In Arm Compiler 6 this is disabled by default, and can be enabled by the armclang command-line option -ffp-mode=full.

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.

**Related concepts**

- 3.2 Controlling the Arm® floating-point environment on page 3-122
- 3.2.4 Exception flag handling on page 3-123
- 3.2.5 Functions for handling rounding modes on page 3-124
- 3.2.6 Functions for saving and restoring the whole floating-point environment on page 3-125
- 3.2.7 Functions for temporarily disabling exceptions on page 3-125

**Related references**

- 3.2.3 C99 rounding mode and floating-point exception macros on page 3-123
- 3.2.8 Arm floating-point compiler extensions to the C99 interface on page 3-126

### 3.2.3 C99 rounding mode and floating-point exception macros

C99 defines a macro for each rounding mode and each exception

--- **Note** ---

The following functionality requires a floating-point model that supports exceptions. In Arm Compiler 6 this is disabled by default, and can be enabled by the `armclang` command-line option `-ffp-mode=full`.

---

The C99 rounding mode and exception 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.

**Related concepts**

- 3.2.5 Functions for handling rounding modes on page 3-124

**Related references**

- 3.2.2 C99-compatible functions for controlling the Arm® floating-point environment on page 3-122

### 3.2.4 Exception flag handling

The `feclearexcept()`, `fetestexcept()`, and `feraiseexcept()` functions let you clear, test and raise exceptions. The `fegetexceptflag()` and `fesetexceptflag()` functions let you save and restore information about a given exception.

--- **Note** ---

The Arm Compiler toolchain does not support floating-point exception trapping for AArch64 targets.

---
Note
The following functionality requires a floating-point model that supports exceptions. In Arm Compiler 6 this is disabled by default, and can be enabled by the `armclang` command-line option `-ffp-mode=full`.

C99 defines these functions as follows:

```c
void feclearexcept(int excepts);
int fetestexcept(int excepts);
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 all information 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:

```c
void fegetexceptflag(fexcept_t *flagp, int excepts);
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
You can use `fesetexceptflag()` 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.

Related references
3.2.2 C99-compatible functions for controlling the Arm® floating-point environment on page 3-122

3.2.5 Functions for handling rounding modes

The `fegetround()` and `fesetround` functions let you get and set the current rounding mode.

Note
The following functionality requires a floating-point model that supports exceptions. In Arm Compiler 6 this is disabled by default, and can be enabled by the `armclang` command-line option `-ffp-mode=full`.

C99 defines these functions as follows:

```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.

Related references
3.2.3 C99 rounding mode and floating-point exception macros on page 3-123
3.2.6 Functions for saving and restoring the whole floating-point environment

The `fegetenv` and `fesetenv` functions let you save and restore the entire floating-point environment.

--- Note ---

The following functionality requires a floating-point model that supports exceptions. In Arm Compiler 6 this is disabled by default, and can be enabled by the `armclang` command-line option `-ffp-mode=full`.

---

C99 defines these functions as follows:

```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.

Related references

3.2.2 C99-compatible functions for controlling the Arm® floating-point environment on page 3-122

3.2.7 Functions for temporarily disabling exceptions

The `feholdexcept` and `feupdateenv` functions let you temporarily disable exception trapping.

--- Note ---

The Arm Compiler toolchain does not support floating-point exception trapping for AArch64 targets.

---

--- Note ---

The following functionality requires a floating-point model that supports exceptions. In Arm Compiler 6 this is disabled by default, and can be enabled by the `armclang` command-line option `-ffp-mode=full`.

---

These functions let you 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.

**Related references**

- 3.2.2 C99-compatible functions for controlling the Arm® floating-point environment on page 3-122
- 5.5 `__ieee_status()` on page 5-214

### 3.2.8 Arm floating-point compiler extensions to the C99 interface

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.

**Note**

The Arm Compiler toolchain does not support floating-point exception trapping for AArch64 targets.

**Note**

The following functionality requires a floating-point model that supports exceptions. In Arm Compiler 6 this is disabled by default, and can be enabled by the `armclang` command-line option `-ffp-mode=full`.

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.

In AArch32 state, `fenv_t` and `fexcept_t` have the following structure:

```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.

In AArch64 state, `fenv_t` and `fexcept_t` have the following structure:

```c
typedef struct{
    unsigned __statusword;
} fenv_t, fexcept_t;
```

**Related concepts**

- 3.2 Controlling the Arm® floating-point environment on page 3-122
- 3.2.9 Example of a custom exception handler on page 3-127
3.2.9 Example of a custom exception handler

This example exception trap handler overrides the division by zero exception to return 1 rather than an invalid operation exception.

Note
The Arm Compiler toolchain does not support floating-point exception trapping for AArch64 targets.

Note
The following functionality requires a floating-point model that supports exceptions. In Arm Compiler 6 this is disabled by default, and can be enabled by the armclang command-line option -ffp-mode=full.

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.

After the handler is installed, dividing 0.0 by 0.0 returns 1.0.

Custom exception handler example

```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;
    k = i/j;
    printf("k is %f
", k);
}
```

Related concepts

3.2.10 Exception trap handling by signals on page 3-128
3.2 Controlling the Arm® floating-point environment

3.2.10 Exception trap handling by signals

You can use the SIGFPE signal to handle exceptions.

Note
The Arm Compiler toolchain does not support floating-point exception trapping for AArch64 targets.

Note
The following functionality requires a floating-point model that supports exceptions. In Arm Compiler 6 this is disabled by default, and can be enabled by the armc1ang command-line option -ffp-mode=full.

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_DIVIDE, _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_DIVIDE ? "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.

Related concepts
3.2.9 Example of a custom exception handler on page 3-127
3.4.7 Exceptions arising from IEEE 754 floating-point arithmetic on page 3-135
3.2 Controlling the Arm® floating-point environment on page 3-122

Related references
3.2.8 Arm floating-point compiler extensions to the C99 interface on page 3-126
3.2.2 C99-compatible functions for controlling the Arm® floating-point environment on page 3-122
4.29 __rt_raise() on page 4-171

Related concepts
3.2.1 Floating-point functions for compatibility with Microsoft products on page 3-122

Related references
3.2.2 C99-compatible functions for controlling the Arm® floating-point environment on page 3-122
3.2.8 Arm floating-point compiler extensions to the C99 interface on page 3-126
5.5 __ieee_status() on page 5-214
5.3 __fp_status() on page 5-211
3.3 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 C90, 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++.
3.4 IEEE 754 arithmetic

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

This section contains the following subsections:
- 3.4.1 Basic data types for IEEE 754 arithmetic on page 3-131.
- 3.4.2 Single precision data type for IEEE 754 arithmetic on page 3-131.
- 3.4.3 Double precision data type for IEEE 754 arithmetic on page 3-132.
- 3.4.4 Sample single precision floating-point values for IEEE 754 arithmetic on page 3-133.
- 3.4.5 Sample double precision floating-point values for IEEE 754 arithmetic on page 3-134.
- 3.4.6 IEEE 754 arithmetic and rounding on page 3-134.
- 3.4.7 Exceptions arising from IEEE 754 floating-point arithmetic on page 3-135.
- 3.4.8 Exception types recognized by the Arm® floating-point environment on page 3-136.

3.4.1 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.

Related concepts
3.4 IEEE 754 arithmetic on page 3-131
3.4.2 Single precision data type for IEEE 754 arithmetic on page 3-131
3.4.3 Double precision data type for IEEE 754 arithmetic on page 3-132
3.4.6 IEEE 754 arithmetic and rounding on page 3-134
3.4.7 Exceptions arising from IEEE 754 floating-point arithmetic on page 3-135

Related references
3.4.4 Sample single precision floating-point values for IEEE 754 arithmetic on page 3-133
3.4.5 Sample double precision floating-point values for IEEE 754 arithmetic on page 3-134

Related information
IEEE Standard for Floating-Point Arithmetic (IEEE 754), 1985 version

3.4.2 Single precision data type for IEEE 754 arithmetic

A float value is 32 bits wide.

The structure is:

```
+-----------------------+--------+------------------+
|           S           |  Exp   |                  |
+-----------------------+--------+------------------+
|                  31    |  30    |                  |
+-----------------------+--------+------------------+
|                  23    |  22    |                  |
+-----------------------+--------+------------------+
|                  0     |        |                  |
+-----------------------+--------+------------------+
|          Frac         |        |                  |
+-----------------------+--------+------------------+
```

Figure 3-1 IEEE 754 single-precision floating-point format

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).

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.
For example, if Exp is 0x7F:

- 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.

In general, the numeric value of a bit pattern in this format is given by the formula:

\[ (-1)^S \times 2^{(\text{Exp} - 0x7F)} \times (1 + \text{Frac} \times 2^{-23}) \]

Numbers stored in this form are called normalized numbers.

The maximum and minimum exponent values, 0 and 255, are special cases. Exponent 255 can 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 can 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.

Related concepts
3.4 IEEE 754 arithmetic on page 3-131
3.4.3 Double precision data type for IEEE 754 arithmetic on page 3-132
3.4.6 IEEE 754 arithmetic and rounding on page 3-134
3.4.7 Exceptions arising from IEEE 754 floating-point arithmetic on page 3-135

Related references
3.4.1 Basic data types for IEEE 754 arithmetic on page 3-131
3.4.4 Sample single precision floating-point values for IEEE 754 arithmetic on page 3-133
3.4.5 Sample double precision floating-point values for IEEE 754 arithmetic on page 3-134

Related information
IEEE Standard for Floating-Point Arithmetic (IEEE 754), 1985 version

3.4.3 Double precision data type for IEEE 754 arithmetic

A double value is 64 bits wide.

The structure is:

<table>
<thead>
<tr>
<th>63</th>
<th>62</th>
<th>52</th>
<th>51</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>$ $</td>
<td>Exp</td>
<td>Frac</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3-2 IEEE 754 double-precision floating-point format

As with single-precision float data types, $ 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 representing infinity and NaNs is 0x7FF (2047) instead of 0xFFF.

Related concepts
3.4 IEEE 754 arithmetic on page 3-131
3.4.2 Single precision data type for IEEE 754 arithmetic on page 3-131
3.4.6 IEEE 754 arithmetic and rounding on page 3-134
3.4.7 Exceptions arising from IEEE 754 floating-point arithmetic on page 3-135
3.4.4 Sample single precision floating-point values for IEEE 754 arithmetic

Sample float bit patterns, together with their mathematical values.

Table 3-1 Sample single-precision floating-point values

<table>
<thead>
<tr>
<th>Float value</th>
<th>S</th>
<th>Exp</th>
<th>Frac</th>
<th>Mathematical value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x3F800000</td>
<td>0</td>
<td>0x7F</td>
<td>000...000</td>
<td>1.0</td>
</tr>
<tr>
<td>0xBF800000</td>
<td>1</td>
<td>0x7F</td>
<td>000...000</td>
<td>-1.0</td>
</tr>
<tr>
<td>0x3F800001</td>
<td>0</td>
<td>0x7F</td>
<td>000...001</td>
<td>1.000 000 119</td>
</tr>
<tr>
<td>0x3F400000</td>
<td>0</td>
<td>0x7E</td>
<td>100...000</td>
<td>0.75</td>
</tr>
<tr>
<td>0x00800000</td>
<td>0</td>
<td>0x01</td>
<td>000...000</td>
<td>1.18*10^{-38}</td>
</tr>
<tr>
<td>0x00000001</td>
<td>0</td>
<td>0x00</td>
<td>000...001</td>
<td>1.40*10^{-45}</td>
</tr>
<tr>
<td>0x7F7FFFFF</td>
<td>0</td>
<td>0xFE</td>
<td>111...111</td>
<td>3.40*10^{38}</td>
</tr>
<tr>
<td>0x7F800000</td>
<td>0</td>
<td>0xFF</td>
<td>000...000</td>
<td>Plus infinity</td>
</tr>
<tr>
<td>0xFF800000</td>
<td>1</td>
<td>0xFF</td>
<td>000...000</td>
<td>Minus infinity</td>
</tr>
<tr>
<td>0x00000000</td>
<td>0</td>
<td>0x00</td>
<td>000...000</td>
<td>0.0</td>
</tr>
<tr>
<td>0x7FC00000</td>
<td>0</td>
<td>0xFF</td>
<td>100...000</td>
<td>Quiet NaN</td>
</tr>
</tbody>
</table>

Related concepts
3.4 IEEE 754 arithmetic on page 3-131
3.4.2 Single precision data type for IEEE 754 arithmetic on page 3-131
3.4.3 Double precision data type for IEEE 754 arithmetic on page 3-132
3.4.6 IEEE 754 arithmetic and rounding on page 3-134
3.4.7 Exceptions arising from IEEE 754 floating-point arithmetic on page 3-135

Related references
3.4.1 Basic data types for IEEE 754 arithmetic on page 3-131
3.4.5 Sample double precision floating-point values for IEEE 754 arithmetic on page 3-134

Related information
IEEE Standard for Floating-Point Arithmetic (IEEE 754), 1985 version

---

**c** 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.

**d** 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.

**e** The smallest positive number that can be distinguished from zero. This is the absolute lower limit of the format.

**f** The largest finite number that can be stored. Attempting to increase this number by addition or multiplication causes overflow and generates infinity (in general).

**g** 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.

**h** 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.
### 3.4.5 Sample double precision floating-point values for IEEE 754 arithmetic

Sample double bit patterns, together with their mathematical values.

<table>
<thead>
<tr>
<th>Double value</th>
<th>S Exp</th>
<th>Frac</th>
<th>Mathematical value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x3FF0000000000000</td>
<td>0</td>
<td>0x3FF 0000...000</td>
<td>1.0</td>
</tr>
<tr>
<td>0xBFF0000000000000</td>
<td>1</td>
<td>0x3FF 0000...000</td>
<td>-1.0</td>
</tr>
<tr>
<td>0x3FF0000000000001</td>
<td>0</td>
<td>0x3FF 0000...001</td>
<td>1.000 000 000 000 000 222</td>
</tr>
<tr>
<td>0x3FE0000000000000</td>
<td>0</td>
<td>0x3FE 1000...000</td>
<td>0.75</td>
</tr>
<tr>
<td>0x0010000000000000</td>
<td>0</td>
<td>0x001 0000...000</td>
<td>2.23*10^{-308}</td>
</tr>
<tr>
<td>0x0000000000000010</td>
<td>0</td>
<td>0x000 0000...001</td>
<td>4.94*10^{-324}</td>
</tr>
<tr>
<td>0x7FEFFFFFFFFFFFFF</td>
<td>0</td>
<td>0x7FE 1110...111</td>
<td>1.80*10^{308}</td>
</tr>
<tr>
<td>0x7FF0000000000000</td>
<td>0</td>
<td>0x7FF 0000...000</td>
<td>Plus infinity</td>
</tr>
<tr>
<td>0xFFF0000000000000</td>
<td>1</td>
<td>0xFFF 0000...000</td>
<td>Minus infinity</td>
</tr>
<tr>
<td>0x0000000000000000</td>
<td>0</td>
<td>0x000 0000...000</td>
<td>0.0</td>
</tr>
<tr>
<td>0x7FF0000000000000</td>
<td>0</td>
<td>0x7FF 0000...001</td>
<td>Signaling NaN</td>
</tr>
<tr>
<td>0x7FF8000000000000</td>
<td>0</td>
<td>0x7FF 1000...000</td>
<td>Quiet NaN</td>
</tr>
</tbody>
</table>

#### Related concepts
- 3.4 IEEE 754 arithmetic on page 3-131
- 3.4.2 Single precision data type for IEEE 754 arithmetic on page 3-131
- 3.4.3 Double precision data type for IEEE 754 arithmetic on page 3-132
- 3.4.6 IEEE 754 arithmetic and rounding on page 3-134
- 3.4.7 Exceptions arising from IEEE 754 floating-point arithmetic on page 3-135

#### Related references
- 3.4.1 Basic data types for IEEE 754 arithmetic on page 3-131
- 3.4.4 Sample single precision floating-point values for IEEE 754 arithmetic on page 3-133

#### Related information
- *IEEE Standard for Floating-Point Arithmetic (IEEE 754), 1985 version*

### 3.4.6 IEEE 754 arithmetic and rounding

IEEE 754 defines different rounding rules to use when calculating arithmetic results.

#### Note

The Arm Compiler toolchain does not support floating-point exception trapping for AArch64 targets.

---

1. 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.
2. 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.
3. The smallest positive number that can be distinguished from zero. This is the absolute lower limit of the format.
4. The largest finite number that can be stored. Attempting to increase this number by addition or multiplication causes overflow and generates infinity (in general).
5. 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.
6. 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.
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.

**Related concepts**

3.4 IEEE 754 arithmetic on page 3-131
3.4.2 Single precision data type for IEEE 754 arithmetic on page 3-131
3.4.3 Double precision data type for IEEE 754 arithmetic on page 3-132
3.4.7 Exceptions arising from IEEE 754 floating-point arithmetic on page 3-135

**Related references**

3.4.1 Basic data types for IEEE 754 arithmetic on page 3-131
3.4.4 Sample single precision floating-point values for IEEE 754 arithmetic on page 3-133
3.4.5 Sample double precision floating-point values for IEEE 754 arithmetic on page 3-134

**Related information**

IEEE Standard for Floating-Point Arithmetic (IEEE 754), 1985 version

### 3.4.7 Exceptions arising from IEEE 754 floating-point arithmetic

Floating-point arithmetic operations can run into various problems. These are known as exceptions, because they indicate unusual or exceptional situations.

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).

--- **Note** ---

The Arm Compiler toolchain does not support floating-point exception trapping for AArch64 targets.

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.

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.
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.

**Related concepts**

- 3.4 IEEE 754 arithmetic on page 3-131
- 3.4.2 Single precision data type for IEEE 754 arithmetic on page 3-131
- 3.4.3 Double precision data type for IEEE 754 arithmetic on page 3-132
- 3.4.6 IEEE 754 arithmetic and rounding on page 3-134
- 3.2.9 Example of a custom exception handler on page 3-127
- 3.2.10 Exception trap handling by signals on page 3-128

**Related references**

- 3.2.8 Arm floating-point compiler extensions to the C99 interface on page 3-126
- 3.2.2 C99-compatible functions for controlling the Arm® floating-point environment on page 3-122
- 4.29 __rt_raise() on page 4-171
- 3.4.1 Basic data types for IEEE 754 arithmetic on page 3-131
- 3.4.4 Sample single precision floating-point values for IEEE 754 arithmetic on page 3-133
- 3.4.5 Sample double precision floating-point values for IEEE 754 arithmetic on page 3-134

**Related information**

- IEEE Standard for Floating-Point Arithmetic (IEEE 754), 1985 version

### 3.4.8 Exception types recognized by the Arm® floating-point environment

The Arm floating-point environment recognizes a number of different types of exception.

---

**Note**

The Arm Compiler toolchain does not support floating-point exception trapping for AArch64 targets.

---

The following types of exception are recognized:

**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.
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.

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.

Underflow exception

This can occur when the result of an operation is too small to be represented as a normalized number (with 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.

Related concepts

3.2.4 Exception flag handling on page 3-123
3.2.9 Example of a custom exception handler on page 3-127
3.2.10 Exception trap handling by signals on page 3-128
3.4 IEEE 754 arithmetic on page 3-131
3.4.7 Exceptions arising from IEEE 754 floating-point arithmetic on page 3-135

Related references

1.25.3 ISO-compliant implementation of signals supported by the signal() function in the C library and additional type arguments on page 1-96
3.4.4 Sample single precision floating-point values for IEEE 754 arithmetic on page 3-133

Related information
IEEE Standard for Floating-Point Arithmetic (IEEE 754), 1985 version

Related concepts
3.4.2 Single precision data type for IEEE 754 arithmetic on page 3-131
3.4.3 Double precision data type for IEEE 754 arithmetic on page 3-132
3.4.6 IEEE 754 arithmetic and rounding on page 3-134
3.4.7 Exceptions arising from IEEE 754 floating-point arithmetic on page 3-135

Related references
3.4.1 Basic data types for IEEE 754 arithmetic on page 3-131
3.4.4 Sample single precision floating-point values for IEEE 754 arithmetic on page 3-133
3.4.5 Sample double precision floating-point values for IEEE 754 arithmetic on page 3-134
Chapter 4
The C and C++ Library Functions Reference

Describes the standard C and C++ library functions that are extensions to the C Standard or that differ in some way to the standard.

Some of the standard functions interact with the Arm retargetable semihosting environment. Such functions are also documented.

It contains the following sections:

• 4.1 __aeabi_errno_addr() on page 4-141.
• 4.2 alloca() on page 4-142.
• 4.3 clock() on page 4-143.
• 4.4 _clock_init() on page 4-144.
• 4.5 __default_signal_handler() on page 4-145.
• 4.6 errno on page 4-146.
• 4.7 findlocale() on page 4-147.
• 4.8 fisatty() on page 4-148.
• 4.9 _get_lconv() on page 4-149.
• 4.10 getenv() on page 4-150.
• 4.11 _getenv_init() on page 4-151.
• 4.12 __heapstats() on page 4-152.
• 4.13 __heapvalid() on page 4-153.
• 4.14 lconv structure on page 4-154.
• 4.15 localeconv() on page 4-156.
• 4.16_membitcpybl(), _membitcpybb(), _membitcpybh(), _membitcpyhl(), _membitcpywh(), _membitmovebl(), _membitmovebb(), _membitmovebh(), _membitmovehl(), _membitmovewb(), _membitmovewl(), _membitmovewb() on page 4-157.
• 4.17_platform_pre_stackheap_init() on page 4-158.
• 4.18 posix_memalign() on page 4-159.
• 4.19 __raise() on page 4-160.
• 4.20 _rand_r() on page 4-162.
• 4.21 remove() on page 4-163.
• 4.22 rename() on page 4-164.
• 4.23 __rt_entry on page 4-165.
• 4.24 __rt_exit() on page 4-166.
• 4.25 __rt_fp_status_addr() on page 4-167.
• 4.26 __rt_heap_extend() on page 4-168.
• 4.27 __rt_lib_init() on page 4-169.
• 4.28 __rt_lib_shutdown() on page 4-170.
• 4.29 __rt_raise() on page 4-171.
• 4.30 __rt_stackheap_init() on page 4-172.
• 4.31 setlocale() on page 4-173.
• 4.32 srand_r() on page 4-175.
• 4.33 strcasecmp() on page 4-176.
• 4.34 strlen() on page 4-177.
• 4.35 strcpy() on page 4-178.
• 4.36 strcasecmp() on page 4-179.
• 4.37 __sys_close() on page 4-180.
• 4.38 __sys_command_string() on page 4-181.
• 4.39 __sys_ensure() on page 4-182.
• 4.40 __sys_exit() on page 4-183.
• 4.41 __sys_flen() on page 4-184.
• 4.42 __sys_istty() on page 4-185.
• 4.43 __sys_open() on page 4-186.
• 4.44 __sys_read() on page 4-187.
• 4.45 __sys_seek() on page 4-188.
• 4.46 __sys_tmpnam() on page 4-189.
• 4.47 __sys_write() on page 4-190.
• 4.48 system() on page 4-191.
• 4.49 time() on page 4-192.
• 4.50 _tywrch() on page 4-193.
• 4.51 __user_heap_extend() on page 4-194.
• 4.52 __user_heap_extent() on page 4-195.
• 4.53 __user_setup_stackheap() on page 4-196.
• 4.54 __vectab_stack_and_reset on page 4-197.
• 4.55 wcscasecmp() on page 4-198.
• 4.56 wcscasecmp() on page 4-199.
• 4.57 wctomb() on page 4-200.
• 4.58 Thread-safe C library functions on page 4-201.
• 4.59 C library functions that are not thread-safe on page 4-203.
• 4.60 Legacy function __user_initial_stackheap() on page 4-205.
4.1 __aeabi_errno_addr()

The __aeabi_errno_addr() returns the address of the C library errno variable when the C library attempts to read or write errno.

Syntax

```c
volatile int *__aeabi_errno_addr(void);
```

Usage

The library provides a default implementation. It is unlikely that you have to re-implement this function. This function is not part of the C library standard, but the Arm C library supports it as an extension.

Related references

4.6 errno on page 4-146

Related information

C Library ABI for the Arm Architecture
4.2 alloca()

Defined in alloca.h, the alloca() function allocates local storage in a function. It returns a pointer to the number of bytes of memory allocated.

Syntax

```c
void *alloca(size_t size);
```

Usage

The default implementation returns an eight-byte aligned block of memory on the stack. Memory returned from alloca() must never be passed to free(). Instead, the memory is de-allocated automatically when the function that called alloca() returns.

Note

alloca() must not be called through a function pointer. You must take care when using alloca() and setjmp() in the same function, because memory allocated by alloca() between calling setjmp() and longjmp() is de-allocated by the call to longjmp().

This function is a common nonstandard extension to many C libraries.

Returns

Returns in size a pointer to the number of bytes of memory allocated.

Related concepts

1.6.3 Arm® C libraries and thread-safe functions on page 1-28

Related references

1.9.1 Building an application without the C library on page 1-54
4.58 Thread-safe C library functions on page 4-201
4.3 clock()

This is the standard C library clock function from `time.h`.

**Syntax**

clock_t clock(void);

**Usage**

The default implementation of this function uses semihosting.

If the units of `clock_t` differ from the default of centiseconds, you must define `__CLK_TCK` on the compiler command line or in your own header file. The value in the definition is used for `CLK_TCK` and `CLOCKS_PER_SEC`. The default value is 100 for centiseconds.

---

**Note**

If you re-implement `clock()` you must also re-implement `_clock_init()`.

---

**Returns**

The returned value is an unsigned integer.

**Related references**

1.8.5 Direct semihosting C library function dependencies on page 1-50

**Related information**

Semihosting for AArch32 and AArch64
4.4 _clock_init()

Defined in rt_misc.h, the _clock_init() function is an initialization function for clock().

It is not part of the C library standard, but the Arm C library supports it as an extension.

Syntax

void _clock_init(void);

Usage

This is a function that you can re-implement in an implementation-specific way. It is called from the library initialization code, so you do not have to call it from your application code.

Note

You must re-implement this function if you re-implement clock().

The initialization that _clock_init() applies enables clock() to return the time that has elapsed since the program was started.

An example of how you might re-implement _clock_init() might be to set the timer to zero. However, if your implementation of clock() relies on a system timer that cannot be reset, then _clock_init() could instead read the time at startup (when called from the library initialization code), with clock() subsequently subtracting the time that was read at initialization, from the current value of the timer. In both cases, some form of initialization is required of _clock_init().

Related references

1.8.5 Direct semihosting C library function dependencies on page 1-50

Related information

Semihosting for AArch32 and AArch64
4.5 __default_signal_handler()

Defined in rt_misc.h, the __default_signal_handler() function handles a raised signal. The default action is to print an error message and exit.

This function is not part of the C library standard, but the Arm C library supports it as an extension.

Syntax

```c
int __default_signal_handler(int signal, intptr_t type);
```

Usage

The default signal handler returns a nonzero value to indicate that the caller has to arrange for the program to exit. You can replace the default signal handler by defining:

```c
int __default_signal_handler(int signal, intptr_t type);
```

The interface is the same as __raise(), but this function is only called after the C signal handling mechanism has declined to process the signal.

A complete list of the defined signals is in signal.h.

Note

The signals used by the libraries might change in future releases of Arm Compiler.

Related references

- 4.19 __raise() on page 4-160
- 4.50 _ttywrch() on page 4-193
- 4.40 _sys_exit() on page 4-183
- 4.29 __rt_raise() on page 4-171
- 1.25.3 ISO-compliant implementation of signals supported by the signal() function in the C library and additional type arguments on page 1-96
- 1.8.6 Indirect semihosting C library function dependencies on page 1-51
4.6 errno

The C library errno variable is defined in the implicit static data area of the library. This area is identified by __user_libspace(). The function that returns the address of errno is:

```c
(*volatile int *)__aeabi_errno_addr()
```

You can define __aeabi_errno_addr() if you want to place errno at a user-defined location instead of the default location identified by __user_libspace().

Note

Legacy versions of errno.h might define errno in terms of __rt_errno_addr() rather than __aeabi_errno_addr(). The function name __rt_errno_addr() is a legacy from pre-ABI versions of the tools, and is still supported to ensure that object files generated with those tools link successfully.

Returns

The return value is a pointer to a variable of type int, containing the currently applicable instance of errno.

Related concepts

1.6.4 Use of static data in the C libraries on page 1-28

Related references

4.1 __aeabi_errno_addr() on page 4-141

1.6.5 Use of the __user_libspace static data area by the C libraries on page 1-29

Related information

Application Binary Interface for the Arm Architecture
4.7 \texttt{\_findlocale()}

Defined in \texttt{rt\_locale.h}, \texttt{\_findlocale()} searches a set of contiguous locale data blocks for the requested locale, and returns a pointer to that locale.

This function is not part of the C library standard, but the Arm C library supports it as an extension.

\textbf{Syntax}

\begin{verbatim}
void const *\_findlocale(void const *index, const char *name);
\end{verbatim}

Where:

\textit{index}

is a pointer to a set of locale data blocks that are contiguous in memory and that end with a terminating value (set by the \texttt{LC\_index\_end} macro).

\textit{name}

is the name of the locale to find.

\textbf{Usage}

You can use \texttt{\_findlocale()} as an optional helper function when defining your own locale setup.

The \texttt{\_get\_lc\_*()} functions, for example, \texttt{\_get\_lc\_ctype()}, are expected to return a pointer to a locale definition created using the assembler macros. If you only want to write one locale definition, you can write an implementation of \texttt{\_get\_lc\_ctype()} that always returns the same pointer. However, if you want to use different locale definitions at runtime, then the \texttt{\_get\_lc\_*()} functions have to be able to return a different data block depending on the name passed to them as an argument. \texttt{\_findlocale()} provides an easy way to do this.

\textbf{Returns}

Returns a pointer to the requested data block.

\textbf{Related concepts}

1.11 Assembler macros that tailor locale functions in the C library on page 1-65
1.11.2 Runtime selection of the locale subsystem in the C library on page 1-66

\textbf{Related references}

4.14 \texttt{lconv structure} on page 4-154
4.9 \texttt{\_get\_lconv()} on page 4-149
4.15 \texttt{localeconv()} on page 4-156
4.31 \texttt{setlocale()} on page 4-173
1.11.1 Link time selection of the locale subsystem in the C library on page 1-65
1.11.3 Definition of locale data blocks in the C library on page 1-66
4.8 _fisatty()

Defined in stdio.h, the _fisatty() function determines whether the given stdio stream is attached to a terminal device or a normal file. It calls the _sys_istty() low-level function on the underlying file handle. This function is not part of the C library standard, but the Arm C library supports it as an extension.

Syntax

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

The return value indicates the stream destination:

0

A file.

1

A terminal.

Negative

An error.

Related references

4.42 _sys_istty() on page 4-185
4.9 _get_lconv()

Defined in locale.h, _get_lconv() performs the same function as the standard C library function, localeconv(), except that it delivers the result in user-provided memory instead of an internal static variable.

_get_lconv() sets the components of an lconv structure with values appropriate for the formatting of numeric quantities.

Syntax

```c
void _get_lconv(struct lconv *lc);
```

Usage

This extension to the ISO C library does not use any static data. If you are building an application that must conform strictly to the ISO C standard, use localeconv() instead.

Returns

The existing lconv structure lc is filled with formatting data.

Related references

- 4.7 _findlocale() on page 4-147
- 4.14 lconv structure on page 4-154
- 4.15 localeconv() on page 4-156
- 4.31 setlocale() on page 4-173
4.10 getenv()

This is the standard C library getenv() function from stdlib.h. It gets the value of a specified environment variable.

Syntax

```c
char *getenv(const char *name);
```

Usage

The default implementation returns NULL, indicating that no environment information is available.

If you re-implement getenv(), Arm recommends that you re-implement it in such a way that it searches some form of environment list for the input string, *name*. The set of environment names and the method for altering the environment list are implementation-defined. getenv() does not depend on any other function, and no other function depends on getenv().

A function closely associated with getenv() is _getenv_init(). _getenv_init() is called during startup if it is defined, to enable a user re-implementation of getenv() to initialize itself.

Returns

The return value is a pointer to a string associated with the matched list member. The array pointed to must not be modified by the program, but might be overwritten by a subsequent call to getenv().
4.11 _getenv_init()

Defined in rt_misc.h, the _getenv_init() function enables a user version of getenv() to initialize itself.

This function is not part of the C library standard, but the Arm C library supports it as an extension.

**Syntax**

```c
void _getenv_init(void);
```

**Usage**

If this function is defined, the C library initialization code calls it when the library is initialized, that is, before main() is entered.
4.12 __heapstats()

Defined in stdlib.h, the __heapstats() function displays statistics on the state of the storage allocation heap.

Syntax

\[
\text{void} \quad \text{__heapstats}(\text{int} \ (*\text{dprint})(\text{void} \ *\text{param}, \text{char} \ \text{const} \ *\text{format}, \ldots), \ \text{void} \ *\text{param});
\]

Usage

The default implementation in the compiler gives information on how many free blocks exist, and estimates their size ranges.

The __heapstats() function generates output as follows:

\[
\begin{align*}
32272 \text{ bytes in 2 free blocks (avg size 16136)} \\
1 \text{ blocks 2}^\text{12}+1 \text{ to } 2^\text{13} \\
1 \text{ blocks 2}^\text{13}+1 \text{ to } 2^\text{14}
\end{align*}
\]

Line 1 of the output displays the total number of bytes, the number of free blocks, and the average size. The following lines give an estimate of the size of each block in bytes, expressed as a range. __heapstats() does not give information on the number of used blocks.

The function outputs its results by calling the output function dprint(), that must work like fprintf(). The first parameter passed to dprint() is the supplied pointer param. You can pass fprintf() itself, provided you cast it to the right function pointer type. This type is defined as a typedef for convenience. It is called __heapprt. For example:

\[
\text{__heapstats(__heapprt)fprintf, stderr);}
\]

Note

If you call fprintf() on a stream that you have not already sent output to, the library calls malloc() internally to create a buffer for the stream. If this happens in the middle of a call to __heapstats(), the heap might be corrupted. Therefore, you must ensure you have already sent some output to stderr.

If you are using the default one-region memory model, heap memory is allocated only as it is required. This means that the amount of free heap changes as you allocate and deallocate memory. For example, the sequence:

\[
\begin{align*}
\text{int} \ *\text{ip}; \\
\text{__heapstats(__heapprt)fprintf,stderr);} & \quad \text{// print initial free heap size} \\
\text{ip} = \text{malloc}(200000); \\
\text{free(ip);} \\
\text{__heapstats(__heapprt)fprintf,stderr);} & \quad \text{// print heap size after freeing}
\end{align*}
\]

gives output such as:

\[
\begin{align*}
4076 \text{ bytes in 1 free blocks (avg size 4076)} \\
1 \text{ blocks 2}^\text{10}+1 \text{ to } 2^\text{11} \\
2008180 \text{ bytes in 1 free blocks (avg size 2008180)} \\
1 \text{ blocks 2}^\text{19}+1 \text{ to } 2^\text{20}
\end{align*}
\]

This function is not part of the C library standard, but the Arm C library supports it as an extension.
4.13 __heapvalid()

Defined in stdlib.h, the __heapvalid() function performs a consistency check on the heap.

Syntax

```c
int __heapvalid(int (*dprint)(void *param, char const *format,...), void *param, int verbose);
```

Usage

__heapvalid() outputs full information about every free block if the verbose parameter is nonzero. Otherwise, it only outputs errors.

The function outputs its results by calling the output function dprint(), that must work like fprintf(). The first parameter passed to dprint() is the supplied pointer param. You can pass fprintf() itself, provided you cast it to the right function pointer type. This type is defined as a typedef for convenience. It is called __heapprt. For example:

```c
__heapvalid((__heapprt) fprintf, stderr, 0);
```

Note

If you call fprintf() on a stream that you have not already sent output to, the library calls malloc() internally to create a buffer for the stream. If this happens in the middle of a call to __heapvalid(), the heap might be corrupted. You must therefore ensure you have already sent some output to stderr. The example code fails if you have not already written to the stream.

This function is not part of the C library standard, but the Arm C library supports it as an extension.
4.14 lconv structure

Defined in locale.h, the lconv structure contains numeric formatting information.

The structure is filled by the functions _get_lconv() and localeconv().

The definition of lconv from locale.h is as follows.

```c
struct lconv {
    char *decimal_point;
    /* The decimal point character used to format non monetary quantities */
    char *thousands_sep;
    /* The character used to separate groups of digits to the left of the */
    /* decimal point character in formatted non monetary quantities. */
    char *grouping;
    /* A string whose elements indicate the size of each group of digits */
    /* in formatted non monetary quantities. See below for more details. */
    char *int_curr_symbol;
    /* The international currency symbol applicable to the current locale.*/
    /* The first three characters contain the alphabetic international */
    /* currency symbol in accordance with those specified in ISO 4217. */
    /* Codes for the representation of Currency and Funds. The fourth */
    /* character (immediately preceding the null character) is the */
    /* character used to separate the international currency symbol from */
    /* the monetary quantity. */
    char *currency_symbol;
    /* The local currency symbol applicable to the current locale. */
    char *mon_decimal_point;
    /* The decimal point used to format monetary quantities. */
    char *mon_thousands_sep;
    /* The separator for groups of digits to the left of the decimal point*/
    /* in formatted monetary quantities. */
    char *mon_grouping;
    /* A string whose elements indicate the size of each group of digits */
    /* in formatted monetary quantities. See below for more details. */
    char *positive_sign;
    /* The string used to indicate a non negative-valued formatted */
    /* monetary quantity. */
    char *negative_sign;
    /* The string used to indicate a negative-valued formatted monetary */
    /* quantity. */
    int int_frac_digits;
    /* The number of fractional digits (those to the right of the */
    /* decimal point) to be displayed in an internationally formatted */
    /* monetary quantities. */
    char *mon_decimal_point;
    /* The number of fractional digits (those to the right of the */
    /* decimal point) to be displayed in a formatted monetary quantity. */
    char *mon_grouping;
    /* Set to 1 or 0 if the currency_symbol respectively precedes or */
    /* succeeds the value for a non negative formatted monetary quantity. */
    char *mon_sep_by_space;
    /* Set to 1 or 0 if the currency_symbol respectively is or is not */
    /* separated by a space from the value for a non negative formatted */
    /* monetary quantity. */
    char *n_cs_precedes;
    /* Set to 1 or 0 if the currency_symbol respectively precedes or */
    /* succeeds the value for a negative formatted monetary quantity. */
    char *n_sep_by_space;
    /* Set to 1 or 0 if the currency_symbol respectively is or is not */
    /* separated by a space from the value for a negative formatted */
    /* monetary quantity. */
    char *n_sign_posn;
    /* Set to a value indicating the position of the positive_sign for a */
    /* non negative formatted monetary quantity. See below for more details*/
    char *n_sign_posn;
    /* Set to a value indicating the position of the negative_sign for a */
    /* negative formatted monetary quantity. */
};
```

The elements of grouping and mon_grouping are interpreted as follows:

**CHAR_MAX**

No additional grouping is to be performed.

**0**

The previous element is repeated for the remainder of the digits.
other

The value is the number of digits that comprise the current group. The next element is examined to determine the size of the next group of digits to the left of the current group.

The value of _p_sign_posn and _n_sign_posn are interpreted as follows:

0

Parentheses surround the quantity and currency symbol.

1

The sign string precedes the quantity and currency symbol.

2

The sign string is after the quantity and currency symbol.

3

The sign string immediately precedes the currency symbol.

4

The sign string immediately succeeds the currency symbol.

Related references

4.7 _findlocale() on page 4-147
4.9 _get_lconv() on page 4-149
4.15 localeconv() on page 4-156
4.31 setlocale() on page 4-173
4.15 localeconv()

Defined in stdlib.h, localeconv() creates and sets the components of an lconv structure with values appropriate for the formatting of numeric quantities according to the rules of the current locale.

Syntax

```c
struct lconv *localeconv(void);
```

Usage

The members of the structure with type `char *` are strings. Any of these, except for `decimal_point`, can point to an empty string, "", to indicate that the value is not available in the current locale or is of zero length.

The members with type `char` are non-negative numbers. Any of the members can be `CHAR_MAX` to indicate that the value is not available in the current locale.

This function is not thread-safe, because it uses an internal static buffer. `_get_lconv()` provides a thread-safe alternative.

Returns

The function returns a pointer to the filled-in object. The structure pointed to by the return value is not modified by the program, but might be overwritten by a subsequent call to the `localeconv()` function. In addition, calls to the `setlocale()` function with categories `LC_ALL`, `LC_MONETARY`, or `LC_NUMERIC` might overwrite the contents of the structure.

Related references

- 4.7 _findlocale() on page 4-147
- 4.14 lconv structure on page 4-154
- 4.9 _get_lconv() on page 4-149
- 4.31 setlocale() on page 4-173
4.16 _membitcpybl(), _membitcpybb(), _membitcpyhl(), _membitcpyhb(), _membitcpywl(), _membitcpywb(), _membitmovebl(), _membitmovebb(), _membitmovehl(), _membitmovehb(), _membitmovewl(), _membitmovewb()

Similar to the standard C library memcpy() and memmove() functions, these nonstandard C library functions provide bit-aligned memory operations.

They are defined in string.h.

Syntax

```c
void _membitcpy[b|h|w][b|l](void *dest, const void *src, int dest_offset, int src_offset, size_t nbits);
void _membitmove[b|h|w][b|l](void *dest, const void *src, int dest_offset, int src_offset, size_t nbits);
```

Usage

The number of contiguous bits specified by nbits is copied, or moved (depending on the function being used), from a memory location starting src_offset bits after (or before if a negative offset) the address pointed to by src, to a location starting dest_offset bits after (or before if a negative offset) the address pointed to by dest.

To define a contiguous sequence of bits, a form of ordering is required. The variants of each function define this order, as follows:

- Functions whose second-last character is b, for example _membitcpybl(), are byte-oriented. Byte-oriented functions consider all of the bits in one byte to come before the bits in the next byte.
- Functions whose second-last character is h are halfword-oriented.
- Functions whose second-last character is w are word-oriented.

Within each byte, halfword, or word, the bits can be considered to go in different order depending on the endianness. Functions ending in b, for example _membitmovewb(), are bitwise big-endian. This means that the Most Significant Bit (MSB) of each byte, halfword, or word (as appropriate) is considered to be the first bit in the word, and the Least Significant Bit (LSB) is considered to be the last. Functions ending in 1 are bitwise little-endian. They consider the LSB to come first and the MSB to come last.

As with memcpy() and memmove(), the bitwise memory copying functions copy as fast as they can in their assumption that source and destination memory regions do not overlap, whereas the bitwise memory move functions ensure that source data in overlapping regions is copied before being overwritten.

On a little-endian platform, the bitwise big-endian functions are distinct, but the bitwise little-endian functions use the same bit ordering, so they are synonymous symbols that refer to the same function. On a big-endian platform, the bitwise big-endian functions are all effectively the same, but the bitwise little-endian functions are distinct.
4.17 _platform_pre_stackheap_init()

If defined, _platform_pre_stackheap_init is called by __rt_entry before stack and heap initialization. Define this function to perform hardware initialization after scatter-loading but before stack and heap initialization.

Because _platform_pre_stackheap_init is called before the stack initialization, either it must not use the stack or the SP must already be valid.

Invalidating the Arm®v8 instruction cache

To invalidate the Armv8 instruction cache after scatter-loading and before initialization of the stack and heap, you must:

- Implement instruction cache invalidation code in _platform_pre_stackheap_init.
- Ensure that all code that is executed from the program entry, up to and including _platform_pre_stackheap_init, is located in a root region.

Where a processor starts in AArch64 state, then switches to AArch32 state, it is possible that addresses are speculatively prefetched, and therefore cached, while in AArch64 state. If the MMU has remained off while in AArch64 state, a processor is allowed to speculatively prefetch from any address either within:

- The same page as an architecturally executed instruction.
- The following page, where page is the smallest supported granule sizeof for the processor.

If you have AArch64 startup code that switches to AArch32 state to run __main and then run C/C++ applications, then the cache invalidation must be done in AArch32 state.

Example

Invalidate caches in AArch64 as follows:

```assembly
_platform_pre_stackheap_init:
    dsb ish     // ensure all previous stores have completed
    /* before invalidating */
    ic ialluis  // I cache invalidate all inner shareable to PoU
                // (which includes secondary cores)
    dsb ish    // ensure completion on inner shareable domain
                // (which includes secondary cores)
    isb
    b InvalidateUDCaches // only needed if the MMU is on at this point
```

Note

b is a tail-call to avoid saving the return address.

Related references

4.23 __rt_entry on page 4-165

Related information

Placing code in a root region
4.18  posix_memalign()

Defined in stdlib.h, the posix_memalign() function provides aligned memory allocation.
This function is fully POSIX-compliant.

**Syntax**

```c
int posix_memalign(void **memptr, size_t alignment, size_t size);
```

**Usage**

This function allocates size bytes of memory at an address that is a multiple of alignment.
The value of alignment must be a power of two and a multiple of sizeof(void *).
You can free memory allocated by posix_memalign() using the standard C library free() function.

**Returns**

The returned address is written to the void * variable pointed to by memptr.
The integer return value from the function is zero on success, or an error code on failure.
If no block of memory can be found with the requested size and alignment, the function returns ENOMEM and the value of *memptr is undefined.

**Related information**

The Open Group Base Specifications, IEEE Std 1003.1
4.19 __raise()

Defined in rt_misc.h, the __raise() function raises a signal to indicate a runtime anomaly.
It is not part of the C library standard, but the Arm C library supports it as an extension.

Syntax

```c
int __raise(int signal, intptr_t type);
```

where:

- `signal` is an integer that holds the signal number.
- `type` is an integer, string constant or variable that provides additional information about the circumstances that the signal was raised in, for some kinds of signal.

Usage

If the user has configured the handling of the signal by calling `signal()` then __raise() takes the action specified by the user. That is, either to ignore the signal or to call the user-provided handler function. Otherwise, __raise() calls __default_signal_handler(), which provides the default signal handling behavior.

You can replace the __raise() function by defining:

```c
int __raise(int signal, intptr_t type);
```

This enables you to bypass the C signal mechanism and its data-consuming signal handler vector, but otherwise gives essentially the same interface as:

```c
int __default_signal_handler(int signal, intptr_t type);
```

The default signal handler of the library uses the `type` parameter of __raise() to vary the messages it outputs.

Returns

There are three possibilities for a __raise() return condition:

- **no return**
  The handler performs a long jump or restart.

- **0**
  The signal was handled.

- **nonzero**
  The calling code must pass that return value to the exit code. The default library implementation calls _sys_exit(rc) if __raise() returns a nonzero return code `rc`.

Related concepts

1.6.11 Thread safety in the Arm® C library on page 1-34

Related references

4.5 __default_signal_handler() on page 4-145
4.50 _ttywrch() on page 4-193
4.40 _sys_exit() on page 4-183
4.29 __rt_raise() on page 4-171
1.25.3 ISO-compliant implementation of signals supported by the signal() function in the C library and additional type arguments on page 1-96

1.8.6 Indirect semihosting C library function dependencies on page 1-51
4.20  _rand_r()

Defined in stdlib.h, the _rand_r() function is a reentrant version of the rand() function.

Syntax

```c
int _rand_r(struct _rand_state * buffer);
```

where:

- `buffer` is a pointer to a user-supplied buffer storing the state of the random number generator.

Usage

This function enables you to explicitly supply your own buffer in thread-local storage.

Related references

- 4.32 _srand_r() on page 4-175
- 4.59 C library functions that are not thread-safe on page 4-203
4.21 remove()

This is the standard C library remove() function from stdio.h.

Syntax

```c
int remove(const char *filename);
```

Usage

The default implementation of this function uses semihosting.

remove() causes the file whose name is the string pointed to by filename to be removed. Subsequent attempts to open the file result in failure, unless it is created again. If the file is open, the behavior of the remove() function is implementation-defined.

Returns

Returns zero if the operation succeeds or nonzero if it fails.

Related references

1.8.5 Direct semihosting C library function dependencies on page 1-50

Related information

Semihosting for AArch32 and AArch64
4.22 rename()

This is the standard C library rename() function from stdio.h.

Syntax

```c
int rename(const char *old, const char *new);
```

Usage

The default implementation of this function uses semihosting.

rename() causes the file whose name is the string pointed to by old to be subsequently known by the name given by the string pointed to by new. The file named old is effectively removed. If a file named by the string pointed to by new exists prior to the call of the rename() function, the behavior is implementation-defined.

Returns

Returns zero if the operation succeeds or nonzero if it fails. If the operation returns nonzero and the file existed previously it is still known by its original name.

Related references

1.8.5 Direct semihosting C library function dependencies on page 1-50

Related information

Semihosting for AArch32 and AArch64
4.23 __rt_entry

The symbol __rt_entry is the starting point for a program using the Arm C library.

Control passes to __rt_entry after all scatter-loaded regions have been relocated to their execution addresses.

Usage
The default implementation of __rt_entry:
1. Performs hardware initialization by calling _platform_pre_stackheap_init(), if this function is defined.
2. Sets up the heap and stack.
3. Initializes the C library by calling __rt_lib_init.
4. Calls main().
5. Shuts down the C library, by calling __rt_lib_shutdown.

__rt_entry must end with a call to one of the following functions:

exit()
Calls atexit()-registered functions and shuts down the library.

__rt_exit()
Shuts down the library but does not call atexit() functions.

_sys_exit()
Exits directly to the execution environment. It does not shut down the library and does not call atexit() functions.

Related references
4.17 _platform_pre_stackheap_init() on page 4-158
4.24 __rt_exit()

Defined in rt_misc.h, the __rt_exit() function shuts down the library but does not call functions registered with atexit().

atexit()-registered functions are called by exit().

The __rt_exit() function is not part of the C library standard, but the Arm C library supports it as an extension.

Syntax

```c
void __rt_exit(int code);
```

Where `code` is not used by the standard function.

Usage

Shuts down the C library by calling __rt_lib_shutdown(), and then calls _sys_exit() to terminate the application. Reimplement _sys_exit() rather than __rt_exit().

Returns

This function does not return.

Related references

4.40 _sys_exit() on page 4-183
4.25 __rt_fp_status_addr()

Defined in rt_fp.h, the __rt_fp_status_addr() function returns the address of the floating-point status word.

By default, the floating-point status word resides in __user_libspace.

This function is not part of the C library standard, but the Arm C library supports it as an extension.

Syntax

\[
\text{unsigned } *\text{__rt_fp_status_addr(\text{void});}
\]

Usage

If __rt_fp_status_addr() is not defined, the default implementation from the C library is used. The value is initialized when __rt_lib_init() calls _fp_init(). The constants for the status word are listed in fenv.h. The default floating-point status is 0.

Returns

The address of the floating-point status word.

Related concepts

1.6.11 Thread safety in the Arm® C library on page 1-34
4.26 __rt_heap_extend()

Defined in rt_heap.h, the __rt_heap_extend() function returns a new aligned block of memory to add to the heap, if possible.

If you reimplement __rt_stackheap_init(), you must reimplement this function. An incomplete prototype implementation is in rt_memory.s.

This function is not part of the C library standard, but the Arm C library supports it as an extension.

Syntax

```c
extern size_t __rt_heap_extend(size_t size, void **block);
```

Usage

The calling convention is ordinary AAPCS. On entry, r0 is the minimum size of the block to add, and r1 holds a pointer to a location to store the base address.

The default implementation has the following characteristics:

- The returned size is one of the following:
  - In AArch32 state, a multiple of 8 bytes of at least the requested size.
  - In AArch64 state, a multiple of 16 bytes of at least the requested size.
  - 0, denoting that the request cannot be honored.
- The returned base address is aligned on:
  - In AArch32 state, an 8-byte boundary.
  - In AArch64 state, a 16-byte boundary.
- Size is measured in bytes.
- The function is subject only to Arm® Architecture Procedure Call Standard (AAPCS) constraints.

Returns

The default implementation extends the heap if there is sufficient free heap memory. If it cannot, it calls __user_heap_extend() if it is implemented. On exit, r0 is the size of the block acquired, or 0 if nothing could be obtained, and the memory location r1 pointed to on entry contains the base address of the block.

Related concepts
1.13.3 Stack pointer initialization and heap bounds on page 1-76

Related references
4.30 __rt_stackheap_init() on page 4-172
4.51 __user_heap_extend() on page 4-194
4.52 __user_heap_extent() on page 4-195
4.53 __user_setup_stackheap() on page 4-196

Related information
Procedure Call Standard for the Arm Architecture
4.27 __rt_lib_init()

Defined in rt_misc.h, this is the library initialization function and is the companion to __rt_lib_shutdown().

Syntax

For AArch32 targets:

```c
extern __attribute__((value_in_regs)) struct __argc_argv __rt_lib_init(unsigned heapbase, unsigned heaptop);
```

For AArch64 targets:

```c
extern __attribute__((value_in_regs)) struct __argc_argv __rt_lib_init(unsigned long heapbase, unsigned long heaptop);
```

where:

- `heapbase` is the start of the heap memory block.
- `heaptop` is the end of the heap memory block.

Usage

This function is called immediately after __rt_stackheap_init() and is passed an initial chunk of memory to use as a heap. This function is the standard Arm C library initialization function and it must not be reimplemented.

Returns

This function returns argc and argv ready to be passed to main(). The structure is returned in the registers.

For AArch32 targets:

```c
struct __argc_argv
{
    int argc;
    char **argv;
    void *r2;  // optional extra arguments that on entry to main() are
    void *r3;  // found in registers R2 and R3.
};
```

For AArch64 targets:

```c
struct __argc_argv
{
    long argc;
    char **argv;
    void *r2;  // optional extra arguments that on entry to main() are
    void *r3;  // found in registers X2 (alias for R2) and X3 (alias for R3).
};
```
4.28 __rt_lib_shutdown()

Defined in rt_misc.h, __rt_lib_shutdown() is the library shutdown function and is the companion to __rt_lib_init().

Syntax

```c
void __rt_lib_shutdown(void);
```

Usage

This function is provided in case a user must call it directly. This is the standard Arm C library shutdown function and it must not be reimplemented.
4.29 __rt_raise()

Defined in rt_misc.h, the __rt_raise() function raises a signal to indicate a runtime anomaly. This function is not part of the C library standard, but the Arm C library supports it as an extension.

Syntax

```c
void __rt_raise(int signal, intptr_t type);
```

where:

- `signal` is an integer that holds the signal number.
- `type` is an integer, string constant or variable that provides additional information about the circumstances that the signal was raised in, for some kinds of signal.

Usage

Redefine this function to replace the entire signal handling mechanism for the library. The default implementation calls __raise().

Depending on the value returned from __raise():

- **no return**
  - The handler performed a long jump or restart and __rt_raise() does not regain control.
- **0**
  - The signal was handled and __rt_raise() exits.
- **nonzero**
  - The default library implementation calls __sys_exit(rc) if __raise() returns a nonzero return code `rc`.

Related references

4.5 __default_signal_handler() on page 4-145
4.19 __raise() on page 4-160
4.50 ttywrch() on page 4-193
4.40 __sys_exit() on page 4-183
1.25.3 ISO-compliant implementation of signals supported by the signal() function in the C library and additional type arguments on page 1-96
4.30 __rt_stackheap_init()

The __rt_stackheap_init() function sets up the stack pointer and returns a region of memory for use as the initial heap.

It is called from the library initialization code.

On return from this function, SP must point to the top of the stack region, r0 must point to the base of the heap region, and r1 must point to the limit of the heap region.

A user-defined memory model (that is, __rt_stackheap_init() and __rt_heap_extend()) is allocated 16 bytes of storage from the __user_perproc_libspace area if wanted. It accesses this storage by calling __rt_stackheap_storage() to return a pointer to its 16-byte region.

This function is not part of the C library standard, but the Arm C library supports it as an extension.

Related concepts
1.13.3 Stack pointer initialization and heap bounds on page 1-76

Related references
4.26 __rt_heap_extend() on page 4-168
4.51 __user_heap_extend() on page 4-194
4.52 __user_heap_extent() on page 4-195
4.53 __user_setup_stackheap() on page 4-196
4.31 setlocale()

Defined in locale.h, the setlocale() function selects the appropriate locale as specified by the category and locale arguments.

Syntax

char *setlocale(int category, const char *locale);

Usage

Use the setlocale() function to change or query part or all of the current locale. The effect of the category argument for each value is:

LC_COLLATE
Affects the behavior of strcoll().

LC_CTYPE
Affects the behavior of the character handling functions.

LC_MONETARY
Affects the monetary formatting information returned by localeconv().

LC_NUMERIC
Affects the decimal-point character for the formatted input/output functions and the string conversion functions and the numeric formatting information returned by localeconv().

LC_TIME
Can affect the behavior of strftime(). For currently supported locales, the option has no effect.

LC_ALL
Affects all locale categories. This is the bitwise OR of all the locale categories.

A value of "C" for locale specifies the minimal environment for C translation. An empty string, "", for locale specifies the implementation-defined native environment. At program startup, the equivalent of setlocale(LC_ALL, "C") is executed.

Valid locale values depend on which __use_X_ctype symbol is imported (__use_iso8859_ctype, __use_sjis_ctype, or __use_utf8_ctype), and on user-defined locales.

Note

Only one __use_X_ctype symbol can be imported.

Returns

If a pointer to a string is given for locale and the selection is valid, the string associated with the specified category for the new locale is returned. If the selection cannot be honored, a null pointer is returned and the locale is not changed.

A null pointer for locale causes the string associated with the category for the current locale to be returned and the locale is not changed.

If category is LC_ALL and the most recent successful locale-setting call uses a category other than LC_ALL, a composite string might be returned. The string returned when used in a subsequent call with its associated category restores that part of the program locale. The string returned is not modified by the program, but might be overwritten by a subsequent call to setlocale().
Related concepts
Shift-JIS and UTF-8 implementation on page 1-66

Related references
4.7 _findlocale() on page 4-147
4.14 lconv structure on page 4-154
4.9 _get_lconv() on page 4-149
4.15 localeconv() on page 4-156
ISO8859-1 implementation on page 1-65
1.11.3 Definition of locale data blocks in the C library on page 1-66
4.32  _srand_r()

Defined in stdlib.h, this is a reentrant version of the srand() function.

Syntax

```c
int _srand_r(struct _rand_state * buffer, unsigned int seed);
```

where:

- `buffer` is a pointer to a user-supplied buffer storing the state of the random number generator.
- `seed` is a seed for a new sequence of pseudo-random numbers to be returned by subsequent calls to _rand_r().

Usage

This function enables you to explicitly supply your own buffer that can be used for thread-local storage. If _srand_r() is repeatedly called with the same seed value, the same sequence of pseudo-random numbers is repeated. If _rand_r() is called before any calls to _srand_r() have been made with the same buffer, undefined behavior occurs because the buffer is not initialized.

Related references

4.20  _rand_r() on page 4-162
4.59  C library functions that are not thread-safe on page 4-203
4.33 `strcasecmp()`

Defined in `string.h`, the `strcasecmp()` function performs a case-insensitive string comparison test.

**Syntax**

```c
extern _ARMABI int strcasecmp(const char *s1, const char *s2);
```

**Related information**

*Application Binary Interface for the Arm Architecture*
4.34 strcat()

Defined in string.h, the strcat() function concatenates two strings.

**Syntax**

```c
extern size_t strcat(char *dst, const char *src, size_t size);
```

**Usage**

strcat() appends up to size-strlen(dst)-1 bytes from the NUL-terminated string src to the end of dst. It takes the full size of the buffer, not only the length, and terminates the result with NUL as long as size is greater than 0. Include a byte for the NUL in your size value.

The strcat() function returns the total length of the string that would have been created if there was unlimited space. This might or might not be equal to the length of the string actually created, depending on whether there was enough space. This means that you can call strcat() once to find out how much space is required, then allocate it if you do not have enough, and finally call strcat() a second time to create the required string.

This function is a common BSD-derived extension to many C libraries.
## 4.35 strlcpy()

Defined in `string.h`, the `strlcpy()` function copies up to `size-1` characters from the NUL-terminated string `src` to `dst`.

**Syntax**

```c
extern size_t strlcpy(char *dst, const char *src, size_t size);
```

**Usage**

`strlcpy()` takes the full size of the buffer, not only the length, and terminates the result with NUL as long as `size` is greater than 0. Include a byte for the NUL in your `size` value.

The `strlcpy()` function returns the total length of the string that *would* have been copied if there was unlimited space. This might or might not be equal to the length of the string *actually* copied, depending on whether there was enough space. This means that you can call `strlcpy()` once to find out how much space is required, then allocate it if you do not have enough, and finally call `strlcpy()` a second time to do the required copy.

This function is a common BSD-derived extension to many C libraries.
4.36 strncasecmp()

Defined in string.h, the strncasecmp() function performs a case-insensitive string comparison test of not more than a specified number of characters.

Syntax

```
extern _ARMABI int strncasecmp(const char *s1, const char *s2, size_t n);
```

Related information

Application Binary Interface for the Arm Architecture
4.37 _sys_close()

Defined in rt_sys.h, the _sys_close() function closes a file previously opened with _sys_open().

Syntax

```c
int _sys_close(FILEHANDLE fh);
```

Usage

This function must be defined if any input/output function is to be used.

Returns

The return value is 0 if successful. A nonzero value indicates an error.

Related references

1.8.5 Direct semihosting C library function dependencies on page 1-50

Related information

Semihosting for AArch32 and AArch64
4.38  _sys_command_string()

Defined in rt_sys.h, the _sys_command_string() function retrieves the command line that invoked the current application from the environment that called the application.

Syntax

```c
char *sys_command_string(char *cmd, int len);
```

where:

* `cmd` is a pointer to a buffer that can store the command line. It is not required that the command line is stored in *cmd*.

* `len` is the length of the buffer.

Usage

This function is called by the library startup code to set up *argv* and *argc* to pass to `main()`.

——— Note ———

You must not assume that the C library is fully initialized when this function is called. For example, you must not call `malloc()` from within this function. This is because the C library startup sequence calls this function before the heap is fully configured.

———

Returns

The function must return either:

* A pointer to the command line, if successful. This can be either a pointer to the *cmd* buffer if it is used, or a pointer to wherever else the command line is stored.

* NULL, if not successful.

Related references

1.8.5 Direct semihosting C library function dependencies on page 1-50

Related information

Semihosting for AArch32 and AArch64
4.39 _sys_ensure()

This function is deprecated. It is never called by any other library function, and you are not required to re-implement it if you are retargeting standard I/O (stdio).
4.40  _sys_exit()

Defined in rt_sys.h, this is the library exit function. All exits from the library eventually call _sys_exit().

Syntax

```c
void _sys_exit(int return_code);
```

Usage

This function must not return. You can intercept application exit at a higher level by either:

- Implementing the C library function `exit()` as part of your application. You lose `atexit()` processing and library shutdown if you do this.
- Implementing the function `__rt_exit(int n)` as part of your application. You lose library shutdown if you do this, but `atexit()` processing is still performed when `exit()` is called or `main()` returns.

Returns

The return code is advisory. An implementation might attempt to pass it to the execution environment.

Related references

4.5 __default_signal_handler() on page 4-145
4.19 __raise() on page 4-160
4.50 __ttywrch() on page 4-193
4.29 __rt_raise() on page 4-171
1.8.5 Direct semihosting C library function dependencies on page 1-50
4.24 __rt_exit() on page 4-166

Related information

Semihosting for AArch32 and AArch64
4.41 _sys_flen()

Defined in rt_sys.h, the _sys_flen() function returns the current length of a file.

**Syntax**

```c
long _sys_flen(FILEHANDLE fh);
```

**Usage**

This function is used by _sys_seek() to convert an offset relative to the end of a file into an offset relative to the beginning of the file.

You do not have to define _sys_flen() if you do not intend to use fseek().

If you retarget at system _sys_*() level, you must supply _sys_flen(), even if the underlying system directly supports seeking relative to the end of a file.

**Returns**

This function returns the current length of the file fh, or a negative error indicator.

**Related references**

1.8.5 Direct semihosting C library function dependencies on page 1-50

**Related information**

Semihosting for AArch32 and AArch64
4.42  _sys_istty()

Declared in rtsys.h, the _sys_istty() function determines whether a file handle is attached to an interactive device.

Syntax

```c
int _sys_istty(FILEHANDLE fh);
```

Usage

The Arm libraries call _sys_istty() to determine whether a file handle (that is being used for an output file stream) is attached to an interactive device.

For file streams that are attached to interactive devices, the Arm library:

- Provides unbuffered behavior by default, in the absence of a call to setbuf() or setvbuf().
- Prohibits seeking.

Restriction

stdin, stdout, and stderr are assumed to be interactive devices. They are line-buffered at program startup, regardless of what _sys_istty reports for them. An exception is if they have been redirected on the command line.

__________ Note __________

This restriction does not apply when using microlib. In microlib, stdin, stdout, and stderr are always unbuffered.

__________

Returns

The return value is one of the following values:

0  
fh is not attached to an interactive device.

1  
fh is attached to an interactive device.

other  
An error occurred.

Related references

1.8.5 Direct semihosting C library function dependencies on page 1-50
4.8  _fisatty() on page 4-148

Related information

Semihosting for AArch32 and AArch64
4.43  _sys_open()

Defined in rt_sys.h, the _sys_open() function opens a file.

Syntax

FILEHANDLE _sys_open(const char *name, int openmode);

Usage

The _sys_open() function is required by fopen() and freopen(). These functions in turn are required if any file input/output function is to be used.

The openmode parameter is a bitmap whose bits mostly correspond directly to the ISO mode specification. Target-dependent extensions are possible, but freopen() must also be extended.

Returns

The return value is -1 if an error occurs.

Related references

1.8.5 Direct semihosting C library function dependencies on page 1-50

Related information

Semihosting for AArch32 and AArch64
Defined in rt_sys.h, the _sys_read() function reads the contents of a file into a buffer.

Syntax

```c
int _sys_read(FILEHANDLE fh, unsigned char *buf, unsigned len, int mode);
```

Note

The mode parameter is here for historical reasons. It contains nothing useful and must be ignored.

Returns

The return value is one of the following:

- The number of bytes not read (that is, \textit{len} minus the number of bytes that were read).
- An error indication.
- An EOF indicator. The EOF indication involves the setting of \texttt{0x80000000} in the normal result.

Reading up to and including the last byte of data does not turn on the EOF indicator. The EOF indicator is only reached when an attempt is made to read beyond the last byte of data. The target-independent code is capable of handling:

- The EOF indicator being returned in the same read as the remaining bytes of data that precede the EOF.
- The EOF indicator being returned on its own after the remaining bytes of data have been returned in a previous read.

Related references

1.8.5 Direct semihosting C library function dependencies on page 1-50

Related information

Semihosting for AArch32 and AArch64
4.45 _sys_seek()

Defined in rt_sys.h, the _sys_seek() function puts the file pointer at offset pos from the beginning of the file.

Syntax

```c
int _sys_seek(FILEHANDLE fh, long pos);
```

Usage

This function sets the current read or write position to the new location pos relative to the start of the current file fh.

Returns

The result is:

- Negative if an error occurs.
- Non-negative if no error occurs.

Related references

1.8.5 Direct semihosting C library function dependencies on page 1-50

Related information

Semihosting for AArch32 and AArch64
4.46 _sys_tmpnam()

Defined in rt_sys.h, the _sys_tmpnam() function converts the file number fileno for a temporary file to a unique filename, for example, tmp0001.

Syntax

```c
void _sys_tmpnam(char *name, int fileno, unsigned maxlength);
```

Usage

The function must be defined if tmpnam() or tmpfile() is used.

Returns

Returns the filename in name.

Related references

1.8.5 Direct semihosting C library function dependencies on page 1-50

Related information

Semihosting for AArch32 and AArch64
4.47 _sys_write()

Defined in rt.sys.h, the _sys_write() function writes the contents of a buffer to a file previously opened with _sys_open().

Syntax

```c
int _sys_write(FILEHANDLE fh, const unsigned char *buf, unsigned len, int mode);
```

--- Note ---
The mode parameter is here for historical reasons. It contains nothing useful and must be ignored.

---

Returns
The return value is either:

- A positive number representing the number of characters not written (so any nonzero return value denotes a failure of some sort).
- A negative number indicating an error.

Related references
1.8.5 Direct semihosting C library function dependencies on page 1-50

Related information
Semihosting for AArch32 and AArch64
4.48 system()

This is the standard C library system() function from stdlib.h.

Syntax

```
int system(const char *string);
```

Usage

The default implementation of this function uses semihosting.

system() passes the string pointed to by string to the host environment to be executed by a command processor in an implementation-defined manner. A null pointer can be used for string, to inquire whether a command processor exists.

Returns

If the argument is a NULL pointer, the system function returns nonzero only if a command processor is available.

If the argument is not a NULL pointer, the system() function returns an implementation-defined value.

Related references

1.8.5 Direct semihosting C library function dependencies on page 1-50

Related information

Semihosting for AArch32 and AArch64
4.49 time()

This is the standard C library time() function from time.h.
The default implementation of this function uses semihosting.

Syntax

```c
time_t time(time_t *timer);
```

The return value is an approximation of the current calendar time.

Returns

The value ((time_t)-1) is returned if the calendar time is not available. If `timer` is not a NULL pointer, the return value is also stored in `timer`.

Related references

1.8.5 Direct semihosting C library function dependencies on page 1-50

Related information

Semihosting for AArch32 and AArch64
4.50 _ttywrch()

Defined in rt_sys.h, the _ttywrch() function writes a character to the console.

The console might have been redirected. You can use this function as a last resort error handling routine.

**Syntax**

```c
void _ttywrch(int ch);
```

**Usage**

The default implementation of this function uses semihosting.

You can redefine this function, or __raise(), even if there is no other input/output. For example, it might write an error message to a log kept in nonvolatile memory.

**Related references**

4.5 __default_signal_handler() on page 4-145
4.19 __raise() on page 4-160
4.40 _sys_exit() on page 4-183
4.29 __rt_raise() on page 4-171
1.8.5 Direct semihosting C library function dependencies on page 1-50

**Related information**

Semihosting for AArch32 and AArch64
4.51 __user_heap_extend()

Defined in rt_misc.h, the __user_heap_extend() function can be defined to return extra blocks of memory, separate from the initial one, to be used by the heap.

If defined, this function must return the size and base address of an eight-byte aligned heap extension block.

Syntax

```c
extern size_t __user_heap_extend(int var0, void **base, size_t requested_size);
```

Usage

There is no default implementation of this function. If you define this function, it must have the following characteristics:

- The returned size is one of the following:
  - In AArch32 state, a multiple of 8 bytes of at least the requested size.
  - In AArch64 state, a multiple of 16 bytes of at least the requested size.
  - 0, denoting that the request cannot be honored.
- The returned base address is aligned on:
  - In AArch32 state, an 8-byte boundary.
  - In AArch64 state, a 16-byte boundary.
- Size is measured in bytes.
- The function is subject only to Procedure Call Standard for the Arm® Architecture (AAPCS) constraints.
- The first argument is always zero on entry and can be ignored. The base is returned in the register holding this argument.

Note

The function __user_heap_extend() is only weakly referenced by the C library. This means that unused section elimination might unexpectedly remove this function at link time, and in this case, the heap cannot be extended. To prevent this, you can use armlink --keep to prevent the function being eliminated. Alternatively, include an explicit reference to __user_heap_extend() from a part of the application code that you are sure will not be removed at link time.

Returns

This function places a pointer to a block of at least the requested size in *base and returns the size of the block. 0 is returned if no such block can be returned, in which case the value stored at *base is never used.

Related concepts

1.13.3 Stack pointer initialization and heap bounds on page 1-76

Related references

4.26 __rt_heap_extend() on page 4-168
4.30 __rt_stackheap_init() on page 4-172
4.52 __user_heap_extent() on page 4-195
4.53 __user_setup_stackheap() on page 4-196

Related information

Procedure Call Standard for the Arm Architecture
4.52 __user_heap_extent()

If defined, the __user_heap_extent() function returns the bounds of the memory available to the Heap2 allocator.

See rt_misc.h.

Syntax

For AArch32 targets:

```c
extern __attribute__((value_in_regs)) struct __heap_extent __user_heap_extent(unsigned ignore1, size_t ignore2);
```

For AArch64 targets:

```c
extern __attribute__((value_in_regs)) struct __heap_extent __user_heap_extent(unsigned long ignore1, size_t ignore2);
```

Usage

The parameters `ignore1` and `ignore2` are the default values for the base address and size of the heap. They are for information only and can be ignored.

You only need to implement this function if you are using the Heap2 allocator, which is also part of the C library. This function has no default implementation. The Heap2 allocator calls it during heap initialization to determine the maximum address range that the heap can occupy. The function returns the base address of the heap and the total number of bytes available to the heap, rounded up to the next power of two.

For example, if you want to specify that all your heap allocations will come from address 0x80000000 and above, and that the heap has a total maximum size of 3MiB, __user_heap_extent() should return `base=0x80000000` and `range=0x400000`, which is 3MiB rounded up to the next power of two.

Related concepts

1.13.3 Stack pointer initialization and heap bounds on page 1-76

Related references

4.26 __rt_heap_extend() on page 4-168
4.30 __rt_stackheap_init() on page 4-172
4.51 __user_heap_extent() on page 4-194
4.53 __user_setup_stackheap() on page 4-196
1.13.2 Choosing a heap implementation for memory allocation functions on page 1-75
4.53 __user_setup_stackheap()

__user_setup_stackheap() sets up and returns the locations of the initial stack and heap.

If you define this function, it is called by the C library during program start-up.

When __user_setup_stackheap() is called, sp has the same value it had on entry to the application. If this was set to a valid value before calling the C library initialization code, it can be left at this value. If sp is not valid, __user_setup_stackheap() must change this value before using any stack and before returning.

__user_setup_stackheap() returns the:

- Heap base, if the program uses the heap.
  - In AArch32 state, register R0 contains the heap base.
  - In AArch64 state, register X0 contains the heap base.
- Stack base in sp.
- Heap limit, if the program uses the heap and uses two-region memory.
  - In AArch32 state, register R2 contains the heap limit.
  - In AArch64 state, register X2 contains the heap limit.

If this function is re-implemented, it must:

- Preserve the registers required by the PCS, except for SP.
- Ensure alignment of the stack and heap:
  - In AArch32 state, ensure that the stack base and heap base are a multiple of 8 to maintain 8-byte alignment of the stack and heap.
  - In AArch64 state, ensure that the stack base and heap base are a multiple of 16 to maintain 16-byte alignment of the stack and heap.

To create a version of __user_setup_stackheap() that inherits sp from the execution environment and does not have a heap:

- In AArch32 state, set r0 and r2 to zero and return.
- In AArch64 state, set x0 and x2 to zero and return.

There is no limit to the size of the stack. However, if the heap region grows into the stack, malloc() attempts to detect the overlapping memory and fails the new memory allocation request.

__________ Note _________

Any re-implementation of __user_setup_stackheap() must be in assembler.

Related concepts

1.13.3 Stack pointer initialization and heap bounds on page 1-76
1.13.4 Legacy support for __user_initial_stackheap() on page 1-79

Related references

4.26 __rt_heap_extend() on page 4-168
4.30 __rt_stackheap_init() on page 4-172
4.51 __user_heap_extend() on page 4-194
4.52 __user_heap_extent() on page 4-195
1.8.5 Direct semihosting C library function dependencies on page 1-50
4.60 Legacy function __user_initial_stackheap() on page 4-205

Related information

Semihosting for AArch32 and AArch64
4.54 __vectab_stack_and_reset

__vectab_stack_and_reset is a library section that provides a way for the initial values of sp and pc to be placed in the vector table, starting at address 0 for M-profile processors, such as Cortex-M1 and Cortex-M3 embedded applications.

__vectab_stack_and_reset requires the existence of a main() function in your source code. Without a main() function, if you place the __vectab_stack_and_reset section in a scatter file, an error is generated to the following effect:

Error: L6236E: No section matches selector - no section to be FIRST/LAST

If the normal start-up code is bypassed, that is, if there is intentionally no main() function, you are responsible for setting up the vector table without __vectab_stack_and_reset.

The following segment is part of a scatter file. It includes a minimal vector table illustrating the use of __vectab_stack_and_reset to place the initial sp and pc values at addresses 0x0 and 0x4 in the vector table:

```assembly
;; Maximum of 256 exceptions (256*4 bytes == 0x400)
VECTORS 0x0 0x400
{
    ; First two entries provided by library
    ; Remaining entries provided by the user in exceptions.c
    * (:gdef:__vectab_stack_and_reset, +FIRST)
    * (exceptions_area)
}
CODE 0x400 FIXED
{
    * (+RO)
}
```

Related concepts
1.13.3 Stack pointer initialization and heap bounds on page 1-76

Related information
About scatter-loading
4.55 **wcscasecmp()**

Defined in `wchar.h`, the `wcscasecmp()` function performs a case-insensitive string comparison test on wide characters.

This function is a GNU extension to the libraries. It is not POSIX-standardized.

**Syntax**

```
int wcscasecmp(const wchar_t * __restrict s1, const wchar_t * __restrict s2);
```
4.56 wcsncasecmp()

Defined in wchar.h, the wcsncasecmp() function performs a case-insensitive string comparison test of not more than a specified number of wide characters.

This function is a GNU extension to the libraries. It is not POSIX-standardized.

Syntax

```
int wcsncasecmp(const wchar_t * __restrict s1, const wchar_t * __restrict s2, size_t n);
```
4.57 \texttt{wcstombs()}

Defined in \texttt{wchar.h}, the \texttt{wcstombs()} function works as described in the ISO C standard, with extended functionality as specified by POSIX.

That is, if \texttt{s} is a NULL pointer, \texttt{wcstombs()} returns the length required to convert the entire array regardless of the value of \texttt{n}, but no values are stored.

\textbf{Syntax}

\begin{verbatim}
size_t wcstombs(char *s, const wchar_t *pwcs, size_t n);
\end{verbatim}
## 4.58 Thread-safe C library functions

The following table shows the C library functions that are thread-safe.

<table>
<thead>
<tr>
<th>Functions</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>calloc(), free(), malloc(), realloc()</td>
<td>The heap functions are thread-safe if the <em>mutex</em>* functions are implemented. All threads share a single heap and use mutexes to avoid data corruption when there is concurrent access. Each heap implementation is responsible for doing its own locking. If you supply your own allocator, it must also do its own locking. This enables it to do fine-grained locking if required, rather than protecting the entire heap with a single mutex (coarse-grained locking).</td>
</tr>
<tr>
<td>alloca()</td>
<td>alloca() is thread-safe because it allocates memory on the stack.</td>
</tr>
<tr>
<td>abort(), raise(), signal(), fenv.h</td>
<td>The Arm signal handling functions and floating-point exception traps are thread-safe. The settings for signal handlers and floating-point traps are global across the entire process and are protected by locks. Data corruption does not occur if multiple threads call signal() or an fenv.h function at the same time. However, be aware that the effects of the call act on all threads and not only on the calling thread.</td>
</tr>
</tbody>
</table>
| clearerr(), fclose(), feof(), ferror(), fflush(), fgetc(), fgetpos(), fgets(), fopen(), fputc(), fputs(), fread(), freopen(), fseek(), fsetpos(), ftell(), fwrite(), getc(), getwchar(), gets(), perror(), putc(), putchar(), puts(), rewind(), setbuf(), setvbuf(), tmpfile(), tmpnam(), ungetc() | The stdio library is thread-safe if the _mutex_* functions are implemented. Each individual stream is protected by a lock, so two threads can each open their own stdio stream and use it, without interfering with one another. If two threads both want to read or write the same stream, locking at the fgetc() and fputc() level prevents data corruption, but it is possible that the individual characters output by each thread might be interleaved in a confusing way.  

_________ Note _________

tmpnam() also contains a static buffer but this is only used if the argument is NULL. To ensure that your use of tmpnam() is thread-safe, supply your own buffer space.  

_________ Note _________

| fprintf(), printf(), vfprintf(), vprintf(), fscanf(), scanf() | When using these functions:  
• The standard C printf() and scanf() functions use stdio so they are thread-safe.  
• The standard C printf() function is susceptible to changes in the locale settings if called in a multithreaded program. |
<p>| clock()         | clock() contains static data that is written once at program startup and then only ever read. Therefore, clock() is thread-safe provided no extra threads are already running at the time that the library is initialized. |
| errno           | errno is thread-safe. Each thread has its own errno stored in a __user_perthread_libspace block. This means that each thread can call errno-setting functions independently and then check errno afterwards without interference from other threads. |
| atexit()        | The list of exit functions maintained by atexit() is process-global and protected by a lock. In the worst case, if more than one thread calls atexit(), the order that exit functions are called cannot be guaranteed. |</p>
<table>
<thead>
<tr>
<th>Functions</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>abs(), acos(), asin(), atan(), atan2(), atof(), atol(), atoi(), bsearch(), ceil(), cos(), cosh(), difftime(), div(), exp(), fabs(), floor(), fmod(), frexp(), labs(), ldexp(), ldiv(), log(), log10(), memchr(), memcmp(), memccpy(), memmove(), memset(), mktime(), modf(), pow(), qsort(), sin(), sinh(), sqrt(), strcat(), strchr(), strcmp(), strcpy(), strcspn(), strlcat(), strlcpy(), strlen(), strncat(), strncmp(), strncpy(), strpbrk(), strrchr(), strspn(), strstr(), strxfrm(), tan(), tanh()</td>
<td>These functions are inherently thread-safe.</td>
</tr>
<tr>
<td>longjmp(), setjmp()</td>
<td>Although setjmp() and longjmp() keep data in __user_libspace, they call the _<em>alloca</em>* functions, that are thread-safe.</td>
</tr>
<tr>
<td>remove(), rename(), time()</td>
<td>These functions use interrupts that communicate with the Arm debugging environments. Typically, you have to reimplement these for a real-world application.</td>
</tr>
<tr>
<td>snprintf(), sprintf(), vsnprintf(), vsprintf(), sscanff(), isalnum(), isalpha(), iscntrl(), isdigit(), isgraph(), islower(), isprint(), ispunct(), isspace(), isupper(), isxdigit(), tolower(), toupper(), strcoll(), strtod(), strtol(), strftime()</td>
<td>When using these functions, the string-based functions read the locale settings. Typically, they are thread-safe. However, if you change locale in mid-session, you must ensure that these functions are not affected. The string-based functions, such as sprintf() and sscanff(), do not depend on the stdio library.</td>
</tr>
<tr>
<td>stdin, stdout, stderr</td>
<td>These functions are thread-safe.</td>
</tr>
</tbody>
</table>
### 4.59 C library functions that are not thread-safe

The following table shows the C library functions that are not thread-safe.

<table>
<thead>
<tr>
<th>Functions</th>
<th>Description</th>
</tr>
</thead>
</table>
| `asctime()`, `localtime()`, `strtok()` | These functions are all thread-unsafe. Each contains a static buffer that might be overwritten by another thread between a call to the function and the subsequent use of its return value. Armstrong supplies reentrant versions, `_asctime_r()`, `_localtime_r()`, and `_strtok_r()`. Arm recommends that you use these functions instead to ensure safety.  
________ Note _________  
These reentrant versions take additional parameters. `_asctime_r()` takes an additional parameter that is a pointer to a buffer that the output string is written into. `_localtime_r()` takes an additional parameter that is a pointer to a `struct tm`, that the result is written into. `_strtok_r()` takes an additional parameter that is a pointer to a `char` pointer to the next token. |
| `exit()`              | Do not call `exit()` in a multithreaded program even if you have provided an implementation of the underlying `_sys_exit()` that actually terminates all threads. In this case, `exit()` cleans up before calling `_sys_exit()` so disrupts other threads. |
| `gamma()`, `lgamma()`, `lgammaf()`, `lgammal()` | These extended mathlib functions use a global variable, `_signgam`, so are not thread-safe.                                                                                                                    |
| `mbrlen()`, `mbsrtowcs()`, `mbrtowc()`, `wcrtomb()`, `wcsrtombs()` | The C90 multibyte conversion functions (defined in `stdlib.h`) are not thread-safe, for example `mblen()` and `mbtowc()`, because they contain internal static state that is shared between all threads without locking.  
However, the extended restartable versions (defined in `wchar.h`) are thread-safe, for example `mbrtowc()` and `wcrtomb()`, provided you pass in a pointer to your own `mbstate_t` object. You must exclusively use these functions with non-NULL `mbstate_t` * parameters if you want to ensure thread-safety when handling multibyte strings. |

---

* If migrating from RVCT, be aware that `gamma()` is deprecated in Arm Compiler 4.1 and later.
<table>
<thead>
<tr>
<th>Functions</th>
<th>Description</th>
</tr>
</thead>
</table>
| rand(), srand() | These functions keep internal state that is both global and unprotected. This means that calls to rand() are never thread-safe.  
Arm recommends that you do one of the following:  
• Use the reentrant versions _rand_r() and _srand_r() supplied by Arm. These use user-provided buffers instead of static data within the C library.  
• Use your own locking to ensure that only one thread ever calls rand() at a time, for example, by defining $Sub$$rand() if you want to avoid changing your code.  
• Arrange that only one thread ever needs to generate random numbers.  
• Supply your own random number generator that can have multiple independent instances.  
|              | Note _rand_r() and _srand_r() both take an additional parameter that is a pointer to a buffer storing the state of the random number generator.                                                                 |
| setlocale(), localeconv() | setlocale() is used for setting and reading locale settings. The locale settings are global across all threads, and are not protected by a lock. If two threads call setlocale() to simultaneously modify the locale settings, or if one thread reads the settings while another thread is modifying them, data corruption might occur. Also, many other functions, for example strtod() and sprintf(), read the current locale settings. Therefore, if one thread calls setlocale() concurrently with another thread calling such a function, there might be unexpected results.  
Multiple threads reading the settings simultaneously is thread-safe in simple cases and if no other thread is simultaneously modifying those settings, but where internally an intermediate buffer is required for more complicated returned results, unexpected results can occur unless you use a reentrant version of setlocale().  
Arm recommends that you either:  
• Choose the locale you want and call setlocale() once to initialize it. Do this before creating any additional threads in your program so that any number of threads can read the locale settings concurrently without interfering with one another.  
• Use the reentrant version _setlocale_r() supplied by Arm. This returns a string that is either a pointer to a constant string, or a pointer to a string stored in a user-supplied buffer that can be used for thread-local storage, rather than using memory within the C library. The buffer must be at least _SETLOCALE_R_BUFSIZE bytes long, including space for a trailing NUL.  
Be aware that _setlocale_r() is not fully thread-safe when accessed concurrently to change locale settings. This access is not lock-protected.  
Also, be aware that localeconv() is not thread-safe. Call the Arm function _get_lconv() with a pointer to a user-supplied buffer instead.  

Related concepts  
1.6.11 Thread safety in the Arm® C library on page 1-34

Related references  
4.20 _rand_r() on page 4-162  
4.32 _srand_r() on page 4-175
4.60 Legacy function __user_initial_stackheap()

If you have legacy source code you might see __user_initial_stackheap(), from rt_misc.h. This is an old function that is only supported for backwards compatibility with legacy source code.

Note

Arm recommends not using __user_initial_stackheap() in new code. Instead, use its modern equivalent, __user_setup_stackheap().

Syntax

For AArch32 targets:

```c
extern __attribute__((value_inregs)) struct __initial_stackheap __user_initial_stackheap(unsigned R0, unsigned SP, unsigned R2, unsigned SL);
```

For AArch64 targets:

```c
extern __attribute__((value_inregs)) struct __initial_stackheap __user_initial_stackheap(unsigned long R0, unsigned long SP, unsigned long R2, unsigned long SL);
```

Usage

__user_initial_stackheap() returns the:

- Heap base in r0.
- Stack base in r1, that is, the highest address in the stack region.
- Heap limit in r2.

If this function is reimplemented, it must:

- Use no more than 88 bytes of stack.
- Not corrupt registers other than r12 (ip) when targeting AArch32.
- Not corrupt registers other than r16 (ip0) and r17 (ip1) when targeting AArch64.
- Maintain 8-byte alignment of the heap when targeting AArch32.
- Maintain 16-byte alignment of the heap when targeting AArch64.

When __user_initial_stackheap() is called, the argument in r1 is the value that sp had when __main() was called. The default implementation of __user_initial_stackheap(), using the semihosting SYS_HEAPINFO, is given by the library in module sys_stackheap.o.

To create a version of __user_initial_stackheap() that inherits sp from the execution environment and does not have a heap, set r0 and r2 to the value of r1 and return.

There is no limit to the size of the stack. However, if the heap region grows into the stack, malloc() attempts to detect the overlapping memory and fails the new memory allocation request.

For AArch32 targets, the definition of __initial_stackheap in rt_m misc. h is:

```c
struct __initial_stackheap {
    unsigned heap_base; /* low-address end of initial heap */
    unsigned stack_base; /* high-address end of initial stack */
    unsigned heap_limit; /* high-address end of initial heap */
    unsigned stack_limit; /* unused */
);
```

For AArch64 targets, the definition of __initial_stackheap in rt_m misc. h is:

```c
struct __initial_stackheap {
    unsigned long heap_base; /* low-address end of initial heap */
    unsigned long stack_base; /* high-address end of initial stack */
    unsigned long heap_limit; /* high-address end of initial heap */
    unsigned long stack_limit; /* unused */
};
```
——— Note ———

The value of `stack_base` is `0x1` greater than the highest address used by the stack because a full-descending stack is used.

---

**Related concepts**

1.13.3 Stack pointer initialization and heap bounds on page 1-76  
1.13.4 Legacy support for `__user_initial_stackheap()` on page 1-79

**Related references**

4.53 `__user_setup_stackheap()` on page 4-196  
1.8.5 Direct semihosting C library function dependencies on page 1-50

**Related information**

Semihosting for AArch32 and AArch64
Chapter 5
Floating-point Support Functions Reference

Describes Arm support for floating-point functions.

It contains the following sections:

- 5.1 _clearfp() on page 5-208.
- 5.2 _controlfp() on page 5-209.
- 5.3 __fp_status() on page 5-211.
- 5.4 gamma(), gamma_r() on page 5-213.
- 5.5 __ieee_status() on page 5-214.
- 5.6 j0(), j1(), jn(), Bessel functions of the first kind on page 5-217.
- 5.7 significand(), fractional part of a number on page 5-218.
- 5.8 _statusfp() on page 5-219.
- 5.9 y0(), y1(), yn(), Bessel functions of the second kind on page 5-220.
5.1 __clearfp()

Defined in float.h, the __clearfp() function is provided for compatibility with Microsoft products. __clearfp() clears all five exception sticky flags and returns their previous values. You can use the __controlfp() argument macros, for example __EM_INVALID and __EM_ZERODIVIDE, to test bits of the returned result.

The function prototype for __clearfp() is:

```
unsigned __clearfp(void);
```

Note: This function requires a floating-point model that supports exceptions. In Arm Compiler 6 this is disabled by default, and can be enabled by the armclang command-line option -ffp-mode=full.

Related concepts
3.2.1 Floating-point functions for compatibility with Microsoft products on page 3-122

Related references
5.2 __controlfp() on page 5-209
5.8 __statusfp() on page 5-219
5.2 _controlfp()

Defined in float.h, the _controlfp() function is provided for compatibility with Microsoft products. It enables you to control exception traps and rounding modes.

Note
The Arm Compiler toolchain does not support floating-point exception trapping for AArch64 targets.

The function prototype for _controlfp() is:

```
unsigned int _controlfp(unsigned int new, unsigned int mask);
```

Note
This function requires a floating-point model that supports exceptions. In Arm Compiler 6 this is disabled by default, and can be enabled by the armclang command-line option -ffp-mode=full.

_controlfp() also modifies a control word using a mask to isolate the bits to modify. For every bit of mask that is zero, the corresponding control word bit is unchanged. For every bit of mask that is nonzero, the corresponding control word bit is set to the value of the corresponding bit of new. The return value is the previous state of the control word.

Note
This is different behavior to that of __ieee_status() or __fp_status(), where you can toggle a bit by setting a zero in the mask word and a one in the flags word.

The following table describes the macros you can use to form the arguments to _controlfp().

<table>
<thead>
<tr>
<th>Macro</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>_MCW_EM</td>
<td>Mask containing all exception bits</td>
</tr>
<tr>
<td>_EM_INVALID</td>
<td>Bit describing the Invalid Operation exception</td>
</tr>
<tr>
<td>_EM_ZERODIVIDE</td>
<td>Bit describing the Divide by Zero exception</td>
</tr>
<tr>
<td>_EM_OVERFLOW</td>
<td>Bit describing the Overflow exception</td>
</tr>
<tr>
<td>_EM_UNDERFLOW</td>
<td>Bit describing the Underflow exception</td>
</tr>
<tr>
<td>_EM_INEXACT</td>
<td>Bit describing the Inexact Result exception</td>
</tr>
<tr>
<td>_MCW_RC</td>
<td>Mask for the rounding mode field</td>
</tr>
<tr>
<td>_RC_CHOP</td>
<td>Rounding mode value describing Round Toward Zero</td>
</tr>
<tr>
<td>_RC_UP</td>
<td>Rounding mode value describing Round Up</td>
</tr>
<tr>
<td>_RC_DOWN</td>
<td>Rounding mode value describing Round Down</td>
</tr>
<tr>
<td>_RC_NEAR</td>
<td>Rounding mode value describing Round To Nearest</td>
</tr>
</tbody>
</table>

Note
The values of these macros are not guaranteed to remain the same in future versions of Arm products. To ensure that your code continues to work if the value changes in future releases, use the macro rather than its value.
For example, to set the rounding mode to round down, call:

```c
_controlfp(_RC_DOWN, _MCW_RC);
```

To trap the Invalid Operation exception and untrap all other exceptions:

```c
_controlfp(_EM_INVALID, _MCW_EM);
```

To untrap the Inexact Result exception:

```c
_controlfp(0, _EM_INEXACT);
```

**Related concepts**

3.2.1 Floating-point functions for compatibility with Microsoft products on page 3-122

**Related references**

5.1 `_clearfp()` on page 5-208
5.8 `_statusfp()` on page 5-219
5.5 `__ieee_status()` on page 5-214
5.3 `__fp_status()` on page 5-211
5.3 __fp_status()

The Arm Compiler toolchain supports an interface to the status word in the floating-point environment. Some older versions of the Arm libraries implemented a function called __fp_status() to provide this interface.

Note
The Arm Compiler toolchain does not support floating-point exception trapping for AArch64 targets.

__fp_status() is the same as __ieee_status() but it uses an older style of status word layout. The compiler still supports the __fp_status() function for backwards compatibility. __fp_status() is defined in stdlib.h.

The function prototype for __fp_status() is:

```
unsigned int __fp_status(unsigned int mask, unsigned int flags);
```

Note
This function requires a floating-point model that supports exceptions. In Arm Compiler 6 this is disabled by default, and can be enabled by the armclang command-line option -ffp-mode=full.

The layout of the status word as seen by __fp_status() is as follows:

```
<table>
<thead>
<tr>
<th>31</th>
<th>24</th>
<th>23</th>
<th>21</th>
<th>20</th>
<th>16</th>
<th>15</th>
<th>12</th>
<th>8</th>
<th>7</th>
<th>5</th>
<th>4</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>System ID</td>
<td>R</td>
<td>Masks</td>
<td>R</td>
<td>FPA only</td>
<td>R</td>
<td>Sticky</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
```

Figure 5-1 Floating-point status word layout

The fields in the status word are as follows:

- Bits 0 to 4 (values 0x1 to 0x10, respectively) are the sticky flags, or cumulative flags, for each exception. The sticky flag for an exception is set to 1 whenever that exception happens and is not trapped. Sticky flags are never cleared by the system, only by the user. The mapping of exceptions to bits is:
  - Bit 0 (0x01) is for the Invalid Operation exception
  - Bit 1 (0x02) is for the Divide by Zero exception.
  - Bit 2 (0x04) is for the Overflow exception.
  - Bit 3 (0x08) is for the Underflow exception.
  - Bit 4 (0x10) is for the Inexact Result exception.
- Bits 8 to 12 (values 0x100 to 0x1000) control various aspects of the Floating-Point Architecture (FPA). The FPA is obsolete and the Arm compilation tools do not support it. Any attempt to write to these bits is ignored.
- Bits 16 to 20 (values 0x10000 to 0x100000) are the exception masks. These control whether each exception is trapped or not. If a bit is set to 1, the corresponding exception is trapped. If a bit is set to 0, the corresponding exception sets its sticky flag and returns a plausible result.
- Bits 24 to 31 contain the system ID that cannot be changed. It is set to 0x40 for software floating-point, to 0x80 or above for hardware floating-point, and to 0 or 1 if a hardware floating-point environment is being faked by an emulator.
- Bits marked R are reserved. They cannot be written to by the __fp_status() call, and you must ignore anything you find in them.

The rounding mode cannot be changed with the __fp_status() call.
In addition to defining the \texttt{__fp_status()} call itself, \texttt{stdlib.h} also defines the following constants to be used for the arguments:

\begin{verbatim}
#define __fpsr_IXE  0x100000
#define __fpsr_UFE  0x80000
#define __fpsr_OFE  0x40000
#define __fpsr_DZE  0x20000
#define __fpsr_IOE  0x10000
#define __fpsr_IXC  0x10
#define __fpsr_UFC  0x8
#define __fpsr_OFC  0x4
#define __fpsr_DZC  0x2
#define __fpsr_IOC  0x1
\end{verbatim}

For example, to trap the Invalid Operation exception and untrap all other exceptions, you would call \texttt{__fp_status()} with the following input parameters:

\begin{verbatim}
__fp_status(__fpsr_IXE | __fpsr_UFE | __fpsr_OFE | __fpsr_DZE | __fpsr_IOE, __fpsr_IOE);
\end{verbatim}

To untrap the Inexact Result exception:

\begin{verbatim}
__fp_status(__fpsr_IXE, 0);
\end{verbatim}

To clear the Underflow sticky flag:

\begin{verbatim}
__fp_status(__fpsr_UFC, 0);
\end{verbatim}

\textbf{Related concepts}

3.2 Controlling the Arm\textsuperscript{*} floating-point environment on page 3-122

\textbf{Related references}

5.5 \texttt{__ieee_status()} on page 5-214
5.4 gamma(), gamma_r()

The `gamma()` and `gamma_r()` functions both compute the logarithm of the gamma function. They are synonyms for `lgamma` and `lgamma_r`.

```c
double gamma(double x);
double gamma_r(double x, int *);
```

——— Note ———

Despite their names, these functions compute the logarithm of the gamma function, not the gamma function itself. To compute the gamma function itself, use `tgamma()`.

——— Note ———

These functions are deprecated.
5.5 __ieee_status()

The Arm Compiler toolchain supports an interface to the status word in the floating-point environment. This interface is provided as function __ieee_status() and it is generally the most efficient function to use for modifying the status word for VFP.

Note

The Arm Compiler toolchain does not support floating-point exception trapping for AArch64 targets.

__ieee_status() is defined in fenv.h.

The function prototype for __ieee_status() is:

```c
unsigned int __ieee_status(unsigned int mask, unsigned int flags);
```

Note

This function requires a floating-point model that supports exceptions. In Arm Compiler 6 this is disabled by default, and can be enabled by the armclang command-line option -ffp-mode=full.

__ieee_status() modifies the writable parts of the status word according to the parameters, and returns the previous value of the whole word.

The writable bits are modified by setting them to:

```c
new = (old & ~mask) ^ flags;
```

Four different operations can be performed on each bit of the status word, depending on the corresponding bits in mask and flags.

<table>
<thead>
<tr>
<th>Bit of mask</th>
<th>Bit of flags</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>Leave alone</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>Toggle</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>Set to 0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>Set to 1</td>
</tr>
</tbody>
</table>

The layout of the status word as seen by __ieee_status() is as follows:

```
<table>
<thead>
<tr>
<th>31</th>
<th>28</th>
<th>27</th>
<th>26</th>
<th>25</th>
<th>24</th>
<th>23</th>
<th>22</th>
<th>21</th>
<th>20</th>
<th>19</th>
<th>18</th>
<th>17</th>
<th>16</th>
<th>15</th>
<th>14</th>
<th>13</th>
<th>12</th>
<th>11</th>
<th>10</th>
<th>9</th>
<th>8</th>
<th>7</th>
<th>6</th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>QC</td>
<td>R</td>
<td>FZ</td>
<td>RM</td>
<td>VFP</td>
<td>R</td>
<td>VFP</td>
<td>R</td>
<td>VFP</td>
<td>R</td>
<td>Masks</td>
<td>R</td>
<td>S</td>
<td>Sticky</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
```

The fields in the status word are as follows:

- Bits 0 to 4 (values 0x1 to 0x10, respectively) are the sticky flags, or cumulative flags, for each exception. The sticky flag for an exception is set to 1 whenever that exception happens and is not trapped. Sticky flags are never cleared by the system, only by the user. The mapping of exceptions to bits is:
  - Bit 0 (0x01) is for the Invalid Operation exception
  - Bit 1 (0x02) is for the Divide by Zero exception.
  - Bit 2 (0x04) is for the Overflow exception.
— Bit 3 (0x08) is for the Underflow exception.
— Bit 4 (0x10) is for the Inexact Result exception.

- Bits 8 to 12 (values 0x100 to 0x1000) are the exception masks. These control whether each exception is trapped or not. If a bit is set to 1, the corresponding exception is trapped. If a bit is set to 0, the corresponding exception sets its sticky flag and returns a plausible result.
- Bits 16 to 18, and bits 20 and 21, are used by VFP hardware to control the VFP vector capability. The __ieee_status() call does not let you modify these bits.
- Bits 22 and 23 control the rounding mode. See the following table.

### Table 5-3 Rounding mode control

<table>
<thead>
<tr>
<th>Bits</th>
<th>Rounding mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>Round to nearest</td>
</tr>
<tr>
<td>01</td>
<td>Round up</td>
</tr>
<tr>
<td>10</td>
<td>Round down</td>
</tr>
<tr>
<td>11</td>
<td>Round toward zero</td>
</tr>
</tbody>
</table>

---

**Note**
The relevant libraries are selected by default in Arm Compiler 6. For more information, see the armclang command-line option `-ffp-mode`.

---

- Bit 24 enables FZ (Flush to Zero) mode if it is set. In FZ mode, denormals are forced to zero to speed up processing because denormals can be difficult to work with and slow down floating-point systems. Setting this bit reduces accuracy but might increase speed.

**Note**
- The FZ bit in the IEEE status word is not supported by any of the fplib variants. This means that switching between flushing to zero and not flushing to zero is not possible with any variant of fplib at runtime. However, flushing to zero or not flushing to zero can be set at compile time as a result of the library you choose to build with.
- Some functions are not provided in hardware. They exist only in the software floating-point libraries. So these functions cannot support the FZ mode, even when you are compiling for a hardware VFP architecture. As a result, behavior of the floating-point libraries is not consistent across all functions when you change the FZ mode dynamically.

---

- Bit 27 indicates that saturation has occurred in an Advanced SIMD saturating integer operation. This is accessible through the __ieee_status() call.
- Bits marked R are reserved. They cannot be written to by the __ieee_status() call, and you must ignore anything you find in them.

In addition to defining the __ieee_status() call itself, fenv.h also defines the following constants to be used for the arguments:

```c
#define FE_IEEE_FLUSHZERO     0x01000000
#define FE_IEEE_ROUND_TONEAREST 0x00000000
#define FE_IEEE_ROUND_UPWARD 0x00400000
#define FE_IEEE_ROUND_DOWNWARD 0x00800000
#define FE_IEEE_ROUND_TOWARDZERO 0x00C00000
#define FE_IEEE_MASK_INVALID   0x00000100
#define FE_IEEE_MASK_DIVBYZERO 0x00000200
#define FE_IEEE_MASK_OVERFLOW 0x00000400
#define FE_IEEE_MASK_UNDERFLOW 0x00000800
#define FE_IEEE_MASK_INEXACT 0x00001000
#define FE_IEEE_MASK_ALL_EXCEPT 0x00001F00
#define FE_IEEE_INVALID 0x00000001
#define FE_IEEE_DIVBYZERO 0x00000002
#define FE_IEEE_OVERFLOW 0x00000004
#define FE_IEEE_UNDERFLOW 0x00000008
```
For example, to set the rounding mode to round down, you would call:

```c
__ieee_status(FE_IEEE_ROUND_MASK, FE_IEEE_ROUND_DOWNWARD);
```

To trap the Invalid Operation exception and untrap all other exceptions:

```c
__ieee_status(FE_IEEE_MASK_ALL_EXCEPT, FE_IEEE_MASK_INVALID);
```

To untrap the Inexact Result exception:

```c
__ieee_status(FE_IEEE_MASK_INEXACT, 0);
```

To clear the Underflow sticky flag:

```c
__ieee_status(FE_IEEE_UNDERFLOW, 0);
```

**Related concepts**

- 3.2 Controlling the Arm® floating-point environment on page 3-122
- 3.4.7 Exceptions arising from IEEE 754 floating-point arithmetic on page 3-135

**Related references**

- 3.2.8 Arm floating-point compiler extensions to the C99 interface on page 3-126
- 1.27 C and C++ library naming conventions on page 1-103
5.6  j0(), j1(), jn(), Bessel functions of the first kind

These functions compute Bessel functions of the first kind.

j0 and j1 compute the functions of order 0 and 1 respectively. jn computes the function of order n.

```c
double j0(double x);
double j1(double x);
double jn(int n, double x);
```

If the absolute value of x exceeds pi times 2^52, these functions return an ERANGE error, denoting total loss of significance in the result.

__________ Note __________

These functions are deprecated.
5.7 significand(), fractional part of a number

The significand() function returns the fraction part of \( x \), as a number between 1.0 and 2.0 (not including 2.0).

```c
double significand(double x);
```

Note
This function is deprecated.
5.8 _statusfp()

Defined in float.h, the _statusfp() function is provided for compatibility with Microsoft products. It returns the current value of the exception sticky flags.

You can use the _controlfp() argument macros, for example _EM_INVALID and _EM_ZERODIVIDE, to test bits of the returned result.

The function prototype for _statusfp() is:

```
unsigned _statusfp(void);
```

——— Note ————

This function requires a floating-point model that supports exceptions. In Arm Compiler 6 this is disabled by default, and can be enabled by the armclang command-line option -ffp-mode=full.

———

Related concepts
3.2.1 Floating-point functions for compatibility with Microsoft products on page 3-122

Related references
5.1 _clearfp() on page 5-208
5.2 _controlfp() on page 5-209
5.9 y0(), y1(), yn(), Bessel functions of the second kind

These functions compute Bessel functions of the second kind.

\( y_0 \) and \( y_1 \) compute the functions of order 0 and 1 respectively. \( y_n \) computes the function of order \( n \).

\[
\begin{align*}
\text{double} & \ y0(\text{double} \ x); \\
\text{double} & \ y1(\text{double} \ x); \\
\text{double} & \ yn(\text{int}, \text{double}); \\
\end{align*}
\]

If \( x \) is positive and exceeds \( \pi \times 2^{52} \), these functions return an \text{ERANGE} error, denoting total loss of significance in the result.

---

**Note**

These functions are deprecated.