Run-time ABI for the Arm® Architecture

2021Q1

Date of Issue: 12th April 2021

arm

1 Preamble

1.1 Abstract

This document defines a run-time helper-function ABI for programs written in Arm-Thumb assembly language, C, and C++.

1.2 Keywords

Run-time ABI, run-time library, helper functions

1.3 Latest release and defects report

Please check Application Binary Interface for the Arm® Architecture for the latest release of this document.

Please report defects in this specification to the issue tracker page on GitHub.

1.4 License

1.5 About the license

As identified more fully in the License section, this project is licensed under CC-BY-SA-4.0 along with an additional patent license. The language in the additional patent license is largely identical to that in Apache-2.0 (specifically, Section 3 of Apache-2.0 as reflected at https://www.apache.org/licenses/LICENSE-2.0) with two exceptions.

First, several changes were made related to the defined terms so as to reflect the fact that such defined terms need to align with the terminology in CC-BY-SA-4.0 rather than Apache-2.0 (e.g., changing “Work” to “Licensed Material”).

Second, the defensive termination clause was changed such that the scope of defensive termination applies to “any licenses granted to You” (rather than “any patent licenses granted to You”). This change is intended to help maintain a healthy ecosystem by providing additional protection to the community against patent litigation claims.

1.6 Contributions

Contributions to this project are licensed under an inbound=outbound model such that any such contributions are licensed by the contributor under the same terms as those in the License section.

1.7 Trademark notice

1.8 Copyright

Contents

1 Preamble **2**

1.1 Abstract 2

1.2 Keywords 2

1.3 Latest release and defects report 2

1.4 License 3

1.5 About the license 3

1.6 Contributions 3

1.7 Trademark notice 3

1.8 Copyright 3

2 About this document **6**

2.1 Change control 6

2.1.1 Current status and anticipated changes 6

2.1.2 Change history 6

2.2 References 7

2.3 Terms and abbreviations 8

2.4 Acknowledgements 8

3 Scope **9**

4 Introduction **9**

4.1 References between separately built relocatable files 10

4.2 Standardized compiler helper functions 10

4.2.1 Rationale for standardizing helper functions 10

4.3 Private helper functions must be carried with the using file 11

4.4 Some private functions might nonetheless be standardized 11

4.5 Many run-time functions do not have a standard ABI 11

4.6 A run-time library is all or nothing 11

4.7 Important corollaries of this library standardization model 11

4.8 Private names for private and AEABI-specific helper functions 12

4.9 Library file organization 13

4.10 __hardfp_ name mangling 13

5 The Standard Compiler Helper Function Library **14**

5.1 Floating-point library 14

5.1.1 The floating point model 14

5.1.2 The floating-point helper functions 16

5.2 The long long helper functions 20

5.3 Other C and assembly language helper functions 21

5.3.1 Integer (32/32 → 32) division functions 21

5.3.2 Division by zero 22

5.3.3 Unaligned memory access 23
5.3.4 Memory copying, clearing, and setting 23
5.3.5 Thread-local storage (new in v2.01) 24
5.4 C++ helper functions 24
5.4.1 Pure virtual function calls 24
5.4.2 One-time construction API for (function-local) static objects 24
5.4.3 Construction and destruction of arrays 25
5.4.4 Controlling object construction order 27
5.4.5 Static object finalization 27
5.4.6 Name demangling 28
5.4.7 Exception-handling support 28

2 About this document

2.1 Change control

2.1.1 Current status and anticipated changes

The following support level definitions are used by the Arm ABI specifications:

Release

Arm considers this specification to have enough implementations, which have received sufficient testing, to verify that it is correct. The details of these criteria are dependent on the scale and complexity of the change over previous versions: small, simple changes might only require one implementation, but more complex changes require multiple independent implementations, which have been rigorously tested for cross-compatibility. Arm anticipates that future changes to this specification will be limited to typographical corrections, clarifications and compatible extensions.

Beta

Arm considers this specification to be complete, but existing implementations do not meet the requirements for confidence in its release quality. Arm may need to make incompatible changes if issues emerge from its implementation.

Alpha

The content of this specification is a draft, and Arm considers the likelihood of future incompatible changes to be significant.

All content in this document is at the **Release** quality level.

2.1.2 Change history

If there is no entry in the change history table for a release, there are no changes to the content of the document for that release.

Issue	Date	Change
1.0	30th October 2003	First public release.
2.0	24th March 2005	Second public release.
2.01	6th October 2005	Added specifications of __aeabi_read_tp() (Thread-local storage (new in v2.01)) and __cxa_get_exception_ptr() (Exception-handling support).
2.02	23rd January 2007	Deprecated fneg/dneg in The floating-point helper functions.
2.03	10th October 2007	In Private names for private and AEABI-specific helper functions, replaced table by table shared with AAELF. Clarified Integer (32/32 → 32) division functions, integer division. Updated the Arm ARM reference to include the version from www.arm.com.
A, r2.06	25th October 2007	Document renumbered (formerly GENC-003537 v2.03).
B, r2.07	10th October 2008	Add return value comments to __aeabi_* helper functions in Helper functions defined by the C++ ABI for the Arm Architecture.

Issue	Date	Change
C, r2.08	19^{th} October 2009	Added __hardfp_ name mangling to explain legacy, deprecated __hardfp_ name mangling; in The floating-point helper functions, declared fneg/dneg *obsolete*; improved text specifying the registers maybe affected by a call to an FP helper; added conversion helpers between VFPv3 half-precision and float to Standard conversions between floating types.
D, r2.09	30^{th} November 2012	In Base requirements on AEABI-complying FP helper functions, updated [ARM ARM] reference for signaling NaNs. In The floating-point helper functions, removed __aeabi_dneg and __aeabi_fneg obsoleted in r2.08, and added conversion helpers from double to VFPv3 half-precision to Standard conversions between floating types.
2018Q4	21^{st} December 2018	In Standard conversions between floating types, specified handling of infinity and NaN in f2h_alt and d2h_alt.
2020Q4	21^{st} December 2020	• document released on Github • new License: CC-BY-SA-4.0 • new sections on Contributions, Trademark notice, and Copyright

2.2 References

This document refers to, or is referred to by, the following.

Ref	URL or other reference	Title
AAELF32		ELF for the Arm Architecture.
AAPCS32		Procedure Call Standard for the Arm Architecture
BSABI32		ABI for the Arm Architecture (Base Standard)
CLIBABI32		C Library ABI for the Arm Architecture
CPPABI32		C++ ABI for the Arm Architecture
EHABI32		Exception Handling ABI for the Arm Architecture
RTABI32		Run-time ABI for the Arm Architecture (*This document*)
Addenda32		Addenda to, and Errata in, the ABI for the Arm Architecture
ARMARM ARMv7MARM	https://developer.arm.com/docs/ddi0406/c/arm-architecture-reference-manual-armv7-a-and-armv7-r-edition	Arm DDI 0406: Arm Architecture Reference Manual Arm v7-A and Arm v7-R edition
	https://developer.arm.com/products/architecture/m-profile/docs/ddi0403/e/armv7-m-architecture-reference-manual	Arm DDI 0403C: Armv7-M Architecture Reference Manual

Ref	URL or other reference	Title
ARMV5ARM	https://developer.arm.com/docs/ddi0100/latest/armv5-architecture-reference-manual	Arm DDI 0100I: Armv5 Architecture Reference Manual
GCPPABI	http://itanium-cxx-abi.github.io/cxx-abi/abi.html	Generic C++ ABI
IEEE754	http://grouper.ieee.org/groups/754/	IEEE P754 Standard for Floating-Point Arithmetic

2.3 Terms and abbreviations

The *ABI for the Arm Architecture* uses the following terms and abbreviations.

AAPCS

Procedure Call Standard for the Arm Architecture.

ABI

Application Binary Interface:

1. The specifications to which an executable must conform in order to execute in a specific execution environment. For example, the *Linux ABI for the Arm Architecture*.
2. A particular aspect of the specifications to which independently produced relocatable files must conform in order to be statically linkable and executable. For example, the CPPABI32, the RTABI32, the CLIBABI32.

AEABI

(Embedded) ABI for the Arm architecture (this ABI...)

Arm-based

... based on the Arm architecture ...

core registers

The general purpose registers visible in the Arm architecture's programmer's model, typically r0-r12, SP, LR, PC, and CPSR.

EABI

An ABI suited to the needs of embedded, and deeply embedded (sometimes called free standing), applications.

Q-o-I

Quality of Implementation – a quality, behavior, functionality, or mechanism not required by this standard, but which might be provided by systems conforming to it. Q-o-I is often used to describe the tool-chain-specific means by which a standard requirement is met.

VFP

The Arm architecture's Floating Point architecture and instruction set. In this ABI, this abbreviation includes all floating point variants regardless of whether or not vector (V) mode is supported.

2.4 Acknowledgements

This specification has been developed with the active support of the following organizations. In alphabetical order: Arm, CodeSourcery, Intel, Metrowerks, Montavista, Nexus Electronics, PalmSource, Symbian, Texas Instruments, and Wind River.

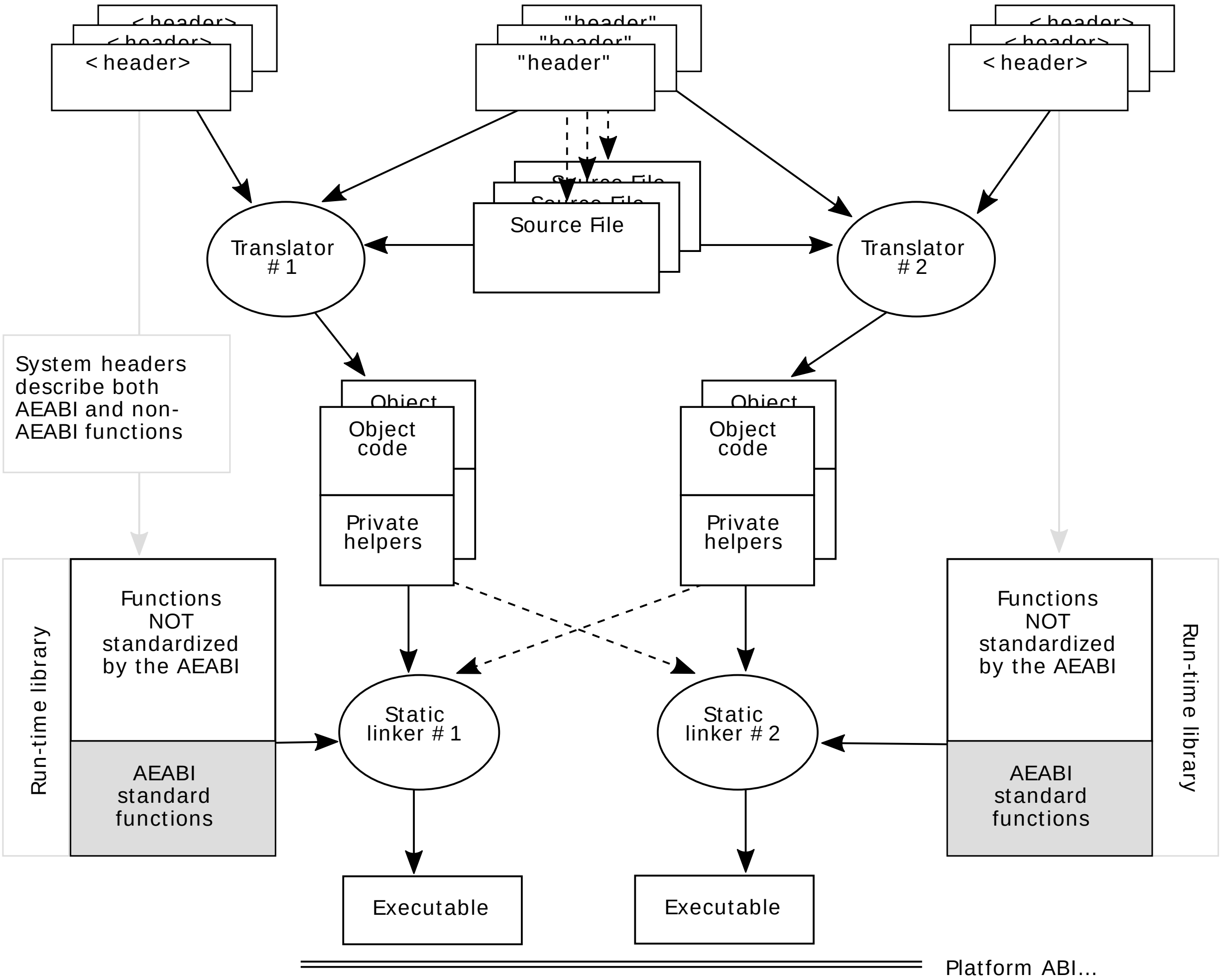
3 Scope

Conformance to the *ABI for the Arm architecture* is intended to support inter-operation between:

- Relocatable files generated by different tool chains.
- Executable and shared object files generated for the same execution environment by different tool chains.

This *standard for run-time helper functions* allows a relocatable file built by one conforming tool chain from Arm-Thumb assembly language, C, or stand alone C++ to be compatible with the static linking environment provided by a different conforming tool chain.

Inter-operation between relocatable files



In this model of inter-working, the standard headers used to build a relocatable file are those associated with the tool chain building it, not those associated with the library with which the relocatable fille will, ultimately, be linked.

4 Introduction

A number of principles of inter-operation are implicit in, or compatible with, Inter-operation between relocatable files above. This section describes these principles as they apply to run-time helper functions, and gives a rationale for each one. The corresponding section of CLIBABI32 discusses the same issues as they apply to C library functions.

4.1 References between separately built relocatable files

A relocatable file can refer to functions and data defined in other relocatable files or libraries.

Application headers describe application entities

Entities defined in application relocatable files are declared in application header files (*"header"* in Inter-operation between relocatable files).

- An application header file must describe the same binary interface to declared data and functions, to every ABI-conforming compiler that reads it.
- Tool-chain-specific information in such header files must affect only the quality of implementation of the relocatable files whose sources includes the headers, not their binary interfaces.

Rationale: A relocatable file or library is distributed with a set of header files describing its interface. Different compilers must interpret the underlying binary interface description identically. Nevertheless, some compilers might comprehend pragmas or pre-processor-guarded language extensions that cause better code to be generated, or that trigger behavior that does not affect the binary compatibility of interfaces.

Standard (system) headers describe run-time libraries

In general, entities defined in run-time libraries are declared in standard (or system) header files (*<header>* in Inter-operation between relocatable files). A standard header need not be intelligible to any tool chain other than the one that provides it.

Rationale: Some language-standardized behavior cannot be securely or conveniently described in source-language terms that all compilers implement identically (for example, va_start and va_arg from C's stdarg.h).

So, a relocatable file must be built using the standard headers associated with the compiler building it.

4.2 Standardized compiler helper functions

Each static linking environment shall provide a set of standard *helper functions* defined by this ABI. See The Standard Compiler Helper Function Library, for a list of standardized helper functions.

A helper function is one that a relocatable file might refer to even though its source includes no standard headers (or, indeed, no headers at all). A helper function usually implements some aspect of a programming language not implemented by its standard library (for example, from C, floating-point to integer conversions).

In some cases, a helper function might implement some aspect of standard library behavior not implemented by any of its interface functions (for example, from the C library, *errno*).

A helper function might also implement an operation not implemented by the underlying hardware, for example, integer division, floating-point arithmetic, or reading and writing misaligned data.

Examples of run-time helper functions include those to perform integer division, and floating-point arithmetic by software, and those required to support the processing of C++ exceptions.

Each such function has a defined type signature, a precise (often simple) meaning, and a small set of standard names (there may be more than one name for a helper function).

4.2.1 Rationale for standardizing helper functions

There is a mixture of convenience, opportunism, and necessity.

- Without standard helper functions, each relocatable file would have to carry all of its support functions with it, either in ELF COMDAT groups within the relocatable file itself or in an adjunct library.
- Multiple tool chains (at least from Arm and GNU) implement essentially compatible floating-point arithmetic functions. (Corresponding functions have identical type signatures and semantics, but different names).
- In C++, even if no system headers are included, inter-working is only possible if implementations agree on the helpers to use in construction, destruction, and throwing exceptions.

4.3 Private helper functions must be carried with the using file

A needed helper function that is not available in all ABI-complying environments—any helper not standardized by this ABI component—must be supplied with the relocatable file that needs it. There are two ways to do this.

- Provide the required helpers in a separate library (see Library file organization) and provide the library with any relocatable file that might refer to it.
- Include the helpers in additional sections within the relocatable file in named ELF COMDAT groups. This is the standard way to distribute C++ constructors, destructors, out-of-line copies of inline functions, etc.

We encourage use of the second (COMDAT group) method, though the choice of method is properly a quality of implementation concern for each tool chain provider.

4.4 Some private functions might nonetheless be standardized

The first issue of this ABI defines no functions in this class. However, new helper functions would first be added as standardized private helper functions, until implementations of helper-function libraries caught up.

4.5 Many run-time functions do not have a standard ABI

In general, it is very hard to standardize the C++ library using the approach to library standardization outlined here and in CLIBABI32. The C++ standard allows an implementation to inline any of the library functions [17.4.4.3, 17.4.4.4] and to add private members to any C++ library class [17.3.2.3]. In general, implementations use this latitude, and there is no ubiquitous standard implementation of the C++ library.

In effect, C++ library headers define an API, not an ABI. To inter-work with a particular C++ library implementation requires that the compiler read the matching header files, breaking the model depicted in Inter-operation between relocatable files, above.

4.6 A run-time library is all or nothing

In general, we cannot expect a helper function from vendor A's library to work with a different helper function from vendor B's library. Although most helper functions will be independent leaf (or near leaf) functions, tangled clumps of implementation could underlie apparently independent parts of a run-time library's public interface.

In some cases, there may be inter-dependencies between run-time libraries, the static linker, and the ultimate execution environment. For example, the way that a program acquires its startup code (sometimes called crt0.o) may depend on the run-time library and the static linker.

This leads to a major conclusion for statically linked executables: **the static linker and the run-time libraries must be from the same tool chain**.

Accepting this constraint gives considerable scope for private arrangements (not governed by this ABI) between these tool chain components, restricted only by the requirement to provide a well defined binary interface (ABI) to the functions described in The Standard Compiler Helper Function Library.

4.7 Important corollaries of this library standardization model

System headers *can* require compiler-specific functionality (e.g. for handling va_start, va_arg, etc). The resulting binary code must conform to this ABI.

As far as this ABI is concerned, a standard library header is processed only by a matching compiler. A platform ABI can impose further constraints that cause more compilers to match, but this ABI does not.

This ABI defines the full set of public helper functions available in every conforming execution environment.

Every tool chain's run-time library must implement the full set of public helper functions defined by this ABI.

Private helper functions can call other private helper functions, public helper functions, and language-standard-defined library functions. A private helper function must not call any function that requires a specific implementation of a language run-time library or helper library.

The implementation of a private helper function (and that of each private helper function it calls) must be offered in a COMDAT group within the ELF [AAELF32] relocatable file that needs it, or in a *freely re-distributable* library (Library file organization) provided by the tool chain as an adjunct to the relocatable file.

(*Freely re-distributable* means: Distributable on terms no more restrictive than those applying to any generated relocatable file).

4.8 Private names for private and AEABI-specific helper functions

External names used in the implementation of private helper functions and private helper data must be in the vendor-specific name space reserved by this ABI. All such names have the form __*vendor-prefix*_*name*.

The vendor prefix must be registered with the maintainers of this ABI specification. Prefixes must not contain underscore ('_') or dollar ('$'). Prefixes starting with *Anon* and *anon* are reserved for unregistered private use.

For example (from the C++ exception handling ABI):

__**aeabi**_unwind_cpp_pr0 __**ARM**_Unwind_cpp_prcommon

The current list of registered vendor, and pseudo vendor, prefixes is given in the following table.

Registered Vendors

Name	Vendor
`ADI`	Analog Devices
`acle`	Reserved for use by Arm C Language Extensions.
`aeabi`	Reserved to the ABI for the Arm Architecture (EABI pseudo-vendor)
`Anon`*Xyz* `anon`*Xyz*	Reserved to private experiments by the Xyz vendor. Guaranteed not to clash with any registered vendor name.
`ARM`	Arm Ltd (Note: the company, not the processor).
`cxa`	C++ ABI pseudo-vendor
`FSL`	Freescale Semiconductor Inc.
`GHS`	Green Hills Systems
`gnu`	GNU compilers and tools (Free Software Foundation)
`iar`	IAR Systems
`icc`	ImageCraft Creations Inc (*ImageCraft C Compiler*)
`intel`	Intel Corporation
`ixs`	Intel Xscale
`llvm`	The LLVM/Clang projects
`PSI`	PalmSource Inc.

Name	Vendor
`RAL`	Rowley Associates Ltd
`SEGGER`	SEGGER Microcontroller GmbH
`somn`	SOMNIUM Technologies Limited.
`TASKING`	Altium Ltd.
`TI`	TI Inc.
`tls`	Reserved for use in thread-local storage routines.
`WRS`	Wind River Systems.

To register a vendor prefix with Arm, please E-mail your request to arm.eabi at arm.com.

4.9 Library file organization

Libraries that must be portable between complying tool chains – such as adjunct libraries of private helper functions (Private helper functions must be carried with the using file), and libraries of run-time helper functions that comply with this specification (The Standard Compiler Helper Function Library) and are intended to be used with other tool chains' linkers – must satisfy the following conditions.

- The library file format is the **ar** format described in BSABI32.
- It must not matter whether libraries are searched once or repeatedly (this is Q-o-I).
- Multiple adjunct libraries can appear in any order in the list of libraries given to the linker provided that they precede all libraries contributing to the run-time environment.

In general, this requires accepting the following organizational constraints.

- No member of an adjunct library can refer to a member of any other library other than to an entity specified by this ABI that contributes to the run-time environment.
- The names of adjunct members must be in a vendor-private name space (Private names for private and AEABI-specific helper functions).
- If run-time environment support functions are provided in multiple libraries, and these are intended to be usable by other ABI-conforming linkers, it must be possible to list the libraries in at least one order in which each reference between them is from a library to one later in the order. This order must be documented.

4.10 __hardfp_ name mangling

This section describes a name-mangling convention adopted by armcc (Arm Limited's commercial compiler) six years before this ABI was published and three years before ABI development began. The name mangling is unnecessary under this ABI so we now deprecate it. Obviously, compilers in service will continue to generate the names for some time.

A goal of this ABI is to support the development of portable binary code but the lack of ubiquity of the floating-point (FP) instruction set causes a problem if the code uses FP values in its interface functions.

- Code that makes no use of FP values can be built to the *Base Procedure Call Standard* [AAPCS32] and will be compatible with an application built to the base standard or the VFP procedure call standard [AAPCS32, section 'The Standard Variants'].
- Portable binary code that makes heavy use of FP will surely be offered in two variants: base-standard for environments that lack FP hardware and VFP-standard otherwise.

- Portable binary code that makes only light use of floating point might reasonably be offered in the base standard only with its FP-using functions declared in its supporting header files as base-standard interfaces using some Q-o-I means such as decoration with `__softfp`` or `__ATTRIBUTE((softfp))__`.

The third use case causes a potential problem.

- Both the portable code and the application that uses it might refer to the same standard library function (such as `strtod()` or `sin()`).
- The portable code will expect a base-standard interface and the application will expect a VFP-standard interface. The variants are not call-compatible.

The scope of this problem is precisely: all non-variadic standard library functions taking floating-point parameters or delivering floating-point results.

Implicit calls to conversion functions that arise from expressions such as `double d = (double) int_val` can also cause difficulties. A call is either to a floating-point (FP) helper function (such as `__aeabi_i2d`, Standard integer to floating-point conversions, below]) defined by this ABI (The floating-point helper functions) or to a private helper function. The FP helpers defined by this ABI cause no difficulties because they always use a base-standard interface but a private helper function would suffer the same problem as `strtod()` or `sin()` if the same tool chain were used to build the application and the portable binary and the helper function were not forced to have a base-standard interface.

The 1999 (pre-ABI) solution to this problem (first adopted by ADS 1.0) was as follows.

- Identify those functions that would be expected to have VFP-standard interfaces when used in a VFP-standard application (such as `strtod` and `sin`).
- Mangle the name of the VFP-standard variant of each of these functions using the prefix `__hardfp`.

In 1999, VFP was not widely deployed in Arm-based products so it was reasonable to load these inter-operation costs on users of the VFP calling standard.

Today, this ABI defines a clean way for tool chains to support this functionality without resorting to encoding the interface standard in a function's name. The `Tag_ABI_VFP_args` build attribute in Addenda32 records the interface intentions of a producer. In principle, this tag gives enough information to a tool chain to allow it to solve, using its own Q-o-I means, the problem described in this section that arises from the third use case.

The problem described in this section arises in the most marginal of the three portable-code use cases described in the bullet points at the beginning of this section so we now recommend that tool chains should *not* mangle the affected names (essentially the functions described by the C library's `<math.h>` and some from `<stdlib.h>`).

5 The Standard Compiler Helper Function Library

5.1 Floating-point library

5.1.1 The floating point model

The floating point model is based on [IEEE754] floating-point number representations and arithmetic. Base requirements on helper functions and restrictions on usage by client code are listed below.

ABI-complying helper function libraries may provide more functionality than is specified here, perhaps a full implementation of the IEEE 754 specification, but ABI-complying application code must not require more than the specified subset (save by private contract with the execution environments).

The set of helper functions has been designed so that:

- A full IEEE implementation is a natural super-set.
- A producer can ensure that, by carefully choosing the correct helper function for the purpose, the intended application behavior does not change inappropriately if the helper-function implementations support more than the ABI-required, IEEE 754-specified behavior.

5.1.1.1 Base requirements on AEABI-complying FP helper functions

Helper functions must correctly process all IEEE 754 single- and double-precision numbers, including -0 and ±infinity, using the *round to nearest* rounding mode.

Floating-point exceptions are untrapped, so invalid operations must generate a default result.

If the implementation supports NaNs, the following requirements hold in addition to those imposed on processing by IEEE 754.

- All IEEE NaN bit patterns with the most significant bit of the significand set are quiet, and all with the most significant bit clear are signaling (as defined by [ARM ARM], chapter A2, Application Level Programmers' Model).
- When not otherwise specified by IEEE 754, the result on an invalid operation should be the quiet bit pattern with only the most significant bit of the significand set, and all other significand bits zero.

Dispensation – de-normal numbers

De-normal numbers may be flushed to zero in an implementation-defined way.

We permit de-normal flushing in deference to hardware implementations of floating-point, where correct IEEE 754 behavior might require supporting code that would be an unwelcome burden to an embedded system.

Implementations that flush to zero will violate the Java numerical model, but we recognize that:

- Often, higher performance and smaller code size legitimately outweigh floating-point accuracy concerns.
- High quality floating-point behavior inevitably requires application code to be aware of the floating-point properties of its execution environment. Floating-point code that has onerous requirements (rare in embedded applications) must advertise this.

Software-only implementations should correctly support de-normal numbers.

Dispensations relating to NaNs

An implementation need not process or generate NaNs. In this case, the result of each invalid operation is implementation defined (and could, for example, simply be ±zero).

If NaNs are supported, it is only required to recognize, process, and convert those values with at least one bit set in the 20 most significant bits of the mantissa. Remaining bits should be zero and can be ignored. When a quiet NaN of one precision is converted to a quiet of the other precision, the most significant 20 bits of the mantissa must be preserved. Consequently:

- A NaN can be recognized by processing the most significant or only word of the representation. The least significant word of a double can be ignored (it should be zero).
- Each ABI-complying value has a single-precision representation, and a corresponding double-precision representation in which the least significant word is zero.
- Each ABI-complying NaN value is converted between single- and double-precision in the same way that Arm VFP VCVT instructions convert the values.

5.1.1.2 Restrictions on FP usage by ABI-complying programs

The rounding mode is fixed as round to nearest. This is the IEEE 754 default when a program starts and the state required by the Java numerical model. A conforming client must not change the rounding mode.

Conforming clients must not fabricate bit patterns that correspond to de-normal numbers. A de-normal number must only be generated as a result of operating on normal numbers (for example, subtracting two very close values). A de-normal number may be flushed to zero on input to, or on output from, a helper function.

There are no floating-point exceptions. This is the IEEE 754 default when a program starts. A conforming client must not change the exception trap state or attempt to trap IEEE exceptions.

Conforming clients must not directly fabricate bit patterns that correspond to NaNs. A NaN can only be generated as a result of an operation on normal numbers (for example, subtracting +infinity from +infinity or multiplying ±infinity by ±zero).

A conforming client must not rely on generating a NaN by operating on normal numbers as described above.

A NaN-using client must use only those values having at least one bit set in the 20 most significant mantissa bits, and all other mantissa bits zero.

5.1.2 The floating-point helper functions

The functions defined in this section use software floating-point (*Base Procedure Call Standard* [AAPCS32]) calling and result-returning conventions, even when they are implemented using floating-point hardware. That is, parameters to and results from them are passed in *integer core registers*.

The functions defined in Standard double precision floating-point arithmetic helper functions, Standard double precision floating-point comparison helper functions, Standard single precision floating-point arithmetic helper functions, and Standard single precision floating-point comparison helper functions together implement the floating-point (FP) arithmetic operations from the FP instruction set. The functions defined in Standard floating-point to integer conversions, Standard conversions between floating types, and Standard integer to floating-point conversions implement the floating-point (FP) conversion operations from the FP instruction set, the conversions between FP values and {unsigned} long long, and the conversions between the VFPv3 half-precision storage-only binary format and IEEE 754 binary32 (single precision) binary format.

Implementations of these helper functions are allowed to corrupt the integer core registers permitted to be corrupted by the AAPCS32 (r0-r3, ip, lr, and CPSR).

If the FP instruction set is available, implementations of these functions may use it. Consequently, FP hardware-using code that calls one of these helper functions directly, *or indirectly by calling a function with a base-standard interface*, must assume that the FP parameter, result, scratch, and status registers might be altered by a call to it.

Binary functions take their arguments in source order where the order matters. For example, `__aeabi_op(x, y)` computes x *op* y, not y *op* x. The exceptions are **r**sub, and **r**cmple whose very purpose is to operate the other way round.

Standard double precision floating-point arithmetic helper functions

Name and type signature	Description
`double __aeabi_dadd(double, double)`	double-precision addition
`double __aeabi_ddiv(double n, double d)`	double-precision division, n / d
`double __aeabi_dmul(double, double)`	double-precision multiplication
`double __aeabi_drsub(double x, double y)`	double-precision reverse subtraction, y – x
`double __aeabi_dsub(double x, double y)`	double-precision subtraction, x – y

Standard double precision floating-point comparison helper functions

Name and type signature	Description
`void __aeabi_cdcmpeq(double, double)`	non-excepting equality comparison [1], result in PSR ZC flags
`void __aeabi_cdcmple(double, double)`	3-way (<, =, ?>) compare [1], result in PSR ZC flags
`void __aeabi_cdrcmple(double, double)`	reversed 3-way (<, =, ?>) compare [1], result in PSR ZC flags
`int __aeabi_dcmpeq(double, double)`	result (1, 0) denotes (=, ?<>) [2], use for C == and !=
`int __aeabi_dcmplt(double, double)`	result (1, 0) denotes (<, ?>=) [2], use for C <
`int __aeabi_dcmple(double, double)`	result (1, 0) denotes (<=, ?>) [2], use for C <=
`int __aeabi_dcmpge(double, double)`	result (1, 0) denotes (>=, ?<) [2], use for C >=
`int __aeabi_dcmpgt(double, double)`	result (1, 0) denotes (>, ?<=) [2], use for C >
`int __aeabi_dcmpun(double, double)`	result (1, 0) denotes (?, <=>) [2], use for C99 `isunordered()`

Note

Notes on Standard double precision floating-point comparison helper functions, above, and Standard single precision floating-point comparison helper functions, below

1. The 3-way comparison functions `c*cmple`, `c*cmpeq` and `c*rcmple` return their results in the CPSR Z and C flags. C is clear only if the operands are ordered and the first operand is less than the second. Z is set only when the operands are ordered and equal.

   This means that `c*cmple` is the appropriate helper to use for C language < and ≤ comparisons.

   For > and ≥ comparisons, the order of operands to the comparator and the sense of the following branch condition must both be reversed. For example, to implement `if (a > b) {...} else L1`, use:

   `__aeabi_cdcmple(b, a); BHS L1`; or
   `__aeabi_cdrcmple(a, b); BHS L1`.

   The `*rcmple` functions may be implemented as operand swapping veneers that tail-call the corresponding versions of `cmple`.

   When implemented to the full IEEE specification, `*le` helpers potentially throw exceptions when comparing with quiet NaNs. The `*eq` helpers do not. Of course, all comparisons will potentially throw exceptions when comparing with signaling NaNs.

   Minimal implementations never throw exceptions. In the absence of NaNs, `c*cmpeq` can be an alias for `c*cmple`.

   The 3-way, status-returning comparison functions preserve all core registers except ip, lr, and the CPSR.

2. The six Boolean versions `*cmp*` return 1 or 0 in r0 to denote the truth or falsity of the IEEE predicate they test. As in note1, all except `*cmpeq` and `*cmpun` can throw an exception when comparing a quiet.

Standard single precision floating-point arithmetic helper functions

Name and type signature	Description
`float __aeabi_fadd(float, float)`	single-precision addition

Name and type signature	Description
`float __aeabi_fdiv(float n, float d)`	single-precision division, n / d
`float __aeabi_fmul(float, float)`	single-precision multiplication
`float __aeabi_frsub(float x, float y)`	single-precision reverse subtraction, y – x
`float __aeabi_fsub(float x, float y)`	single-precision subtraction, x – y

Standard single precision floating-point comparison helper functions

Name and type signature	Description
`void __aeabi_cfcmpeq(float, float)`	non-excepting equality comparison [1], result in PSR ZC flags
`void __aeabi_cfcmple(float, float)`	3-way (<, =, ?>) compare [1], result in PSR ZC flags
`void __aeabi_cfrcmple(float, float)`	reversed 3-way (<, =, ?>) compare [1], result in PSR ZC flags
`int __aeabi_fcmpeq(float, float)`	result (1, 0) denotes (=, ?<>) [2], use for C == and !=
`int __aeabi_fcmplt(float, float)`	result (1, 0) denotes (<, ?>=) [2], use for C <
`int __aeabi_fcmple(float, float)`	result (1, 0) denotes (<=, ?>) [2], use for C <=
`int __aeabi_fcmpge(float, float)`	result (1, 0) denotes (>=, ?<) [2], use for C >=
`int __aeabi_fcmpgt(float, float)`	result (1, 0) denotes (>, ?<=) [2], use for C >
`int __aeabi_fcmpun(float, float)`	result (1, 0) denotes (?, <=>) [2], use for C99 `isunordered()`

Standard floating-point to integer conversions

Name and type signature	Description
`int __aeabi_d2iz(double)`	double to integer C-style conversion [3]
`unsigned __aeabi_d2uiz(double)`	double to unsigned C-style conversion [3]
`long long __aeabi_d2lz(double)`	double to long long C-style conversion [3]
`unsigned long long __aeabi_d2ulz(double)`	double to unsigned long long C-style conversion [3]
`int __aeabi_f2iz(float)`	float (single precision) to integer C-style conversion [3]
`unsigned __aeabi_f2uiz(float)`	float (single precision) to unsigned C-style conversion [3]
`long long __aeabi_f2lz(float)`	float (single precision) to long long C-style conversion [3]
`unsigned long long __aeabi_f2ulz(float)`	float to unsigned long long C-style conversion [3]

Note

3. The conversion-to-integer functions whose names end in *z* always round towards zero, rather than going with the current or default rounding mode. This makes them the appropriate ones to use for C casts-to-integer, which are required by the C standard to round towards zero.

Standard conversions between floating types

Name and type signature	Description
`float __aeabi_d2f(double)`	double to float (single precision) conversion
`double __aeabi_f2d(float)`	float (single precision) to double conversion
`float __aeabi_h2f(short hf)` `float __aeabi_h2f_alt(short hf)`	IEEE 754 binary16 storage format (*VFP half precision*) to binary32 (float) conversion [4, 5]; `__aeabi_h2f_alt` converts from VFP *alternative format* [7].
`short __aeabi_f2h(float f)` `short __aeabi_f2h_alt(float f)`	IEEE 754 binary32 (float) to binary16 storage format (*VFP half precision*) conversion [4, 6]; `__aeabi_f2h_alt` converts to VFP *alternative format* [8].
`short __aeabi_d2h(double)` `short __aeabi_d2h_alt(double)`	IEEE 754 binary64 (double) to binary16 storage format (*VFP half precision*) conversion [4, 9]; `__aeabi_d2h_alt` converts to VFP *alternative format* [10].

Note

4. IEEE P754 binary16 format is a *storage-only* format on which no floating-point operations are defined. Loading and storing such values is supported through the integer instruction set rather than the floating-point instruction set. Hence these functions convert between 16-bit short and 32-bit or 64-bit float. In the *VFPv3 alternative format* there are no NaNs or infinities and encodings with maximum exponent value encode numbers.
5. h2f converts a 16-bit binary floating point bit pattern to the 32-bit binary floating point bit pattern representing the same number, infinity, zero, or NaN. A is converted by appending 13 0-bits to its representation.
6. f2h converts a 32-bit binary floating point bit pattern to the 16-bit binary floating point bit pattern representing the same number, infinity, zero, or NaN. The least significant 13 bits of the representation of a are lost in conversion. Unless altered by Q-o-I means, rounding is RN, underflow flushes to zero, and overflow generates infinity.
7. h2f_alt converts a VFPv3 alternative-format 16-bit binary floating point bit pattern to the IEEE-format 32-bit binary floating point bit pattern that represents the same number.
8. f2h_alt converts an IEEE-format 32-bit binary floating point bit pattern to the VFPv3 alternative-format 16-bit binary floating point bit pattern that represents the same number. Unless altered by Q-o-I means, rounding is RN, underflow flushes to zero, overflows and infinite inputs generate the largest representable number with the input sign, and NaN inputs generate a zero with the input sign.
9. d2h converts a 64-bit binary floating point bit pattern to the 16-bit binary floating point bit pattern representing the same number, infinity, zero, or NaN. The least significant 42 bits of the representation of a NaN are lost in conversion. Unless altered by Q-o-I means, rounding is RN, underflow flushes to zero, and overflow generates infinity.
10. d2h_alt converts an IEEE-format 64-bit binary floating point bit pattern to the VFPv3 alternative-format 16-bit binary floating point bit pattern that represents the same number. Unless altered by Q-o-I means, rounding is RN, underflow flushes to zero, overflows and infinite inputs generate the largest representable number with the input sign, and NaN inputs generate a zero with the input sign.

Standard integer to floating-point conversions

Name and type signature	Description
`double __aeabi_i2d(int)`	integer to double conversion
`double __aeabi_ui2d(unsigned)`	unsigned to double conversion
`double __aeabi_l2d(long long)`	long long to double conversion
`double __aeabi_ul2d(unsigned long long)`	unsigned long long to double conversion
`float __aeabi_i2f(int)`	integer to float (single precision) conversion
`float __aeabi_ui2f(unsigned)`	unsigned to float (single precision) conversion
`float __aeabi_l2f(long long)`	long long to float (single precision) conversion
`float __aeabi_ul2f(unsigned long long)`	unsigned long long to float (single precision) conversion

5.2 The long long helper functions

The long long helper functions support 64-bit integer arithmetic. They are listed in the following table.

Most long operations can be inlined in fewer instructions than it takes to marshal arguments to, and a result from, a function call. The difficult functions that usually need to be implemented out of line are listed in the table below.

As in The floating-point helper functions, binary functions operate between the operands given in source text order (div(a, b) = a/b).

The division functions produce both the quotient and the remainder, an important optimization opportunity, because the function is large and slow.

The shift functions only need to work for shift counts in 0..63. Compilers can efficiently inline constant shifts.

Long long functions

Name and type signature	Description
`long long __aeabi_lmul(` `long long, long long)`	multiplication [1]
`__value_in_regs lldiv_t __aeabi_ldivmod(` `long long n, long long d)`	signed long long division and remainder, {q, r} = n / d [2]

`__value_in_regs ulldiv_t __aeabi_uldivmod(`
`unsigned long long n,`
`unsigned long long d)`
	unsigned long long division and remainder, {q, r} = n / d [2]

`long long __aeabi_llsl(long long, int)`	logical shift left [1]
`long long __aeabi_llsr(long long, int)`	logical shift right [1]
`long long __aeabi_lasr(long long, int)`	arithmetic shift right [1]
`int __aeabi_lcmp(long long, long long)`	signed long long comparison [3]
`int __aeabi_ulcmp(unsigned long long,` `unsigned long long)`	unsigned long long comparison [3]

Note

1. Because of 2's complement number representation, these functions work identically with long long replaced uniformly by unsigned long long. Each returns its result in {r0, r1}, as specified by the AAPCS32.
2. A pair of (unsigned) long longs is returned in {{r0, r1}, {r2, r3}}, the quotient in {r0, r1}, and the remainder in {r2, r3}. The description above is written using Arm-specific function prototype notation, though no prototype need be read by any compiler. (In the table above, think of __value_in_regs as a *structured comment*).
3. The comparison functions return negative, zero, or a positive integer according to whether the comparison result is <, ==, or >, respectively (like strcmp). In practice, compilers can inline all comparisons using SUBS, SBCS (the test for equality needs 3 Thumb instructions).

Implementations of ldivmod and uldivmod have full AAPCS32 privileges and may corrupt any register permitted to be corrupted by an AAPCS-conforming call. Thus, for example, an implementation may use a co-processor that has a division, or division-step, operation. The effect that such use has on the co-processor state is documented in a co-processor supplement.

Otherwise, implementations of the long long helper functions are allowed to corrupt only the integer core registers permitted to be corrupted by the AAPCS (r0-r3, ip, lr, and CPSR).

5.3 Other C and assembly language helper functions

Other helper functions include 32-bit (32/32 → 32) integer division (Integer (32/32 → 32) division functions), unaligned data access functions (Unaligned memory access) and functions to copy, move, clear, and set memory (Memory copying, clearing, and setting).

5.3.1 Integer (32/32 → 32) division functions

The 32-bit integer division functions return the quotient in r0 or both quotient and remainder in {r0, r1}. Below the 2-value-returning functions are described using Arm-specific prototype notation, though it is clear that no prototype need be read by any compiler (think of __value_in_regs as a *structured comment*).

```
int __aeabi_idiv(int numerator, int denominator);
unsigned __aeabi_uidiv(unsigned numerator, unsigned denominator);

typedef struct { int quot; int rem; } idiv_return;
typedef struct { unsigned quot; unsigned rem; } uidiv_return;

__value_in_regs idiv_return __aeabi_idivmod(int numerator, int denominator);
__value_in_regs uidiv_return __aeabi_uidivmod(unsigned numerator, unsigned denominator);
```

Aside

Separate modulo functions would have little value because modulo on its own is rare. Division by a constant and constant modulo can be inlined efficiently using (64-bit) multiplication. For implementations in C, __value_in_regs can be emulated by tail-calling an assembler function that receives the values to be returned as arguments and, itself, returns immediately.

Implementations of idiv, uidiv, idivmod, and uidivmod have full AAPCS32 privileges and may corrupt any register an AAPCS-conforming call may corrupt. Thus, for example, an implementation may use a co-processor that has a division, or division-step, operation. The effect that such use has on co-processor state is documented in a separate co-processor supplement.

The division functions take the numerator and denominator in that order, and produce the quotient in r0 or the quotient and the remainder in {r0, r1} respectively.

Integer division truncates towards zero and the following identities hold if the quotient can be represented.

```
(numerator / denominator) = –(numerator / -denominator)
(numerator / denominator) * denominator + (numerator % denominator) = numerator
```

The quotient can be represented for all input values except the following.

- `denominator = 0` (discussed in Division by zero).
- `numerator = -2147483648` (bit pattern `0x80000000`), `denominator = -1`. (the number `2147483648` has no representation as a signed `int`).

In the second case an implementation may return any convenient value, possibly the original numerator.

5.3.2 Division by zero

If an integer or long long division helper function is called upon to divide by 0, it should return as quotient the value returned by a call to __aeabi_idiv0 or __aeabi_ldiv0, respectively. A *divmod helper should return as remainder either 0 or the original numerator.

Aside

Ideally, a *divmod function should return {infinity, 0} or {0, numerator}, where *infinity* is an approximation.

The *div0 functions:

- Return the value passed to them as a parameter.
- Or, return a fixed value defined by the execution environment (such as 0).
- Or, raise a signal (often SIGFPE) or throw an exception, and do not return.

```
int __aeabi_idiv0(int return_value);
long long __aeabi_ldiv0(long long return_value);
```

An application may provide its own implementations of the *div0 functions to force a particular behavior from *div and *divmod functions called out of line. Implementations of *div0 have full AAPCS32 privileges just like the *div and *divmod functions.

The *div and *divmod functions may be inlined by a tool chain. It is Q-o-I whether an inlined version calls *div0 out of line or returns the values that would have been returned by a particular value-returning version of *div0.

Out of line implementations of the *div and *divmod functions call *div0 with the following parameter values.

- 0 if the numerator is 0.
- The largest value of the type manipulated by the calling division function if the numerator is positive.
- The least value of the type manipulated by the calling division function if the numerator is negative.

5.3.3 Unaligned memory access

These functions read and write 4-byte and 8-byte values at arbitrarily aligned addresses. An unaligned 2-byte value can always be read or written more efficiently using inline code.

```
int __aeabi_uread4(void *address);
int __aeabi_uwrite4(int value, void *address);
long long __aeabi_uread8(void *address);
long long __aeabi_uwrite8(long long value, void *address);
```

We expect unaligned floating-point values to be read and written as integer bit patterns (if at all).

Write functions return the value written, read functions the value read.

Implementations of these functions are allowed to corrupt only the integer core registers permitted to be corrupted by the AAPCS32 (r0-r3, ip, lr, and CPSR).

5.3.4 Memory copying, clearing, and setting

Memory copying

Memcpy-like helper functions are needed to implement structure assignment. We define three functions providing various levels of service, in addition to the normal ANSI C memcpy, and three variants of memmove.

```
void __aeabi_memcpy8(void *dest, const void *src, size_t n);
void __aeabi_memcpy4(void *dest, const void *src, size_t n);
void __aeabi_memcpy(void *dest, const void *src, size_t n);
void __aeabi_memmove8(void *dest, const void *src, size_t n);
void __aeabi_memmove4(void *dest, const void *src, size_t n);
void __aeabi_memmove(void *dest, const void *src, size_t n);
```

These functions work like the ANSI C memcpy and memmove functions. However, __aeabi_memcpy8 may assume that both of its arguments are 8-byte aligned, __aeabi_memcpy4 that both of its arguments are 4-byte aligned. None of the three functions is required to return anything in r0.

Each of these functions can be smaller or faster than the general memcpy or each can be an alias for memcpy itself, similarly for memmove.

Compilers can replace calls to memcpy with calls to one of these functions if they can deduce that the constraints are satisfied. For example, any memcpy whose return value is ignored can be replaced with __aeabi_memcpy. If the copy is between 4-byte-aligned pointers it can be replaced with __aeabi_memcpy4, and so on.

The size_t argument does not need to be a multiple of 4 for the 4/8-byte aligned versions, which allows copies with a non-constant size to be specialized according to source and destination alignment.

Small aligned copies are likely to be inlined by compilers, so these functions should be optimized for larger copies.

Memory clearing and setting

In similar deference to run-time efficiency we define reduced forms of memset and memclr.

```
void __aeabi_memset8(void *dest, size_t n, int c);
void __aeabi_memset4(void *dest, size_t n, int c);
void __aeabi_memset(void *dest, size_t n, int c);
void __aeabi_memclr8(void *dest, size_t n);
void __aeabi_memclr4(void *dest, size_t n);
void __aeabi_memclr(void *dest, size_t n);
```

Note that relative to ANSI memset, __aeabi_memset has the order of its second and third arguments reversed. This allows __aeabi_memclr to tail-call __aeabi_memset.

The memclr functions simplify a very common special case of memset, namely the one in which c = 0 and the memory is being cleared to all zeroes.

The size_t argument does not need to be a multiple of 4 for the 4/8-byte aligned versions, which allows clears and sets with a non-constant size to be specialized according to the destination alignment.

In general, implementations of these functions are allowed to corrupt only the integer core registers permitted to be corrupted by the AAPCS32 (r0-r3, ip, lr, and CPSR).

If there is an attached device with efficient memory copying or clearing operations (such as a DMA engine), its device supplement specifies whether it may be used in implementations of these functions and what effect such use has on the device's state.

5.3.5 Thread-local storage (new in v2.01)

In Addenda32 (section 'Linux for Arm static (initial exec) model'), the description of thread-local storage addressing refers to the thread pointer denoted by **$tp** but does not specify how to obtain its value.

```
void *__aeabi_read_tp(void);  /* return the value of $tp */
```

Implementations of this function should corrupt only the result register (r0) and the non-parameter integer core registers allowed to be corrupted by the AAPCS32 (ip, lr, and CPSR). Registers r1-r3 must be preserved.

5.4 C++ helper functions

The C++ helper functions defined by this ABI closely follow those defined by the *Generic C++ ABI* (see [GCPPABI]). In this section, we list the required helper functions with references to their generic definitions and explain where the Arm C++ ABI diverges from the generic one.

5.4.1 Pure virtual function calls

See GC++ABI, §3.2.6, Pure Virtual Function API. This ABI specification follows the generic ABI exactly.

The v-table entry for a pure virtual function must be initialized to __cxa_pure_virtual. The effect of calling a pure virtual function is not defined by the C++ standard. This ABI requires that the pure virtual helper function shall be called which takes an abnormal termination action defined by, and appropriate to, the execution environment.

The pure virtual helper function

Name and type signature	Description
`void __cxa_pure_virtual(void)`	The initial value of a pure virtual function. Called if a not overridden pure virtual function is called.

5.4.2 One-time construction API for (function-local) static objects

See GC++ABI, §3.3.2, One-time Construction API, and CPPABI32, section 'Guard variables and the one-time construction API'.

This ABI specification diverges from the Itanium ABI by using 32-bit guard variables and specifying the use of the least significant two bits of a guard variable rather than first byte of it.

A static object must be guarded against being constructed more than once. In a threaded environment, the guard variable must also act as a semaphore or a handle for a semaphore. Typically, only the construction of function-local static objects needs to be guarded this way.

A guard variable is a 32-bit, 4-byte aligned, static data value (described in the following table, as int). The least significant 2 bits must be statically initialized to zero. The least significant bit (2^0) is set to 1 when the guarded object has been successfully constructed. The next most significant bit (2^1) may be used by the guard acquisition and release helper functions. The value and meaning of other bits is unspecified.

One-time construction API

Name and type signature	Description
Guard variable	A 32-bit, 4-byte-aligned static data value. The least significant 2 bits must be statically initialized to 0.
`int __cxa_guard_acquire(int *gv)`	If *gv guards an object under construction, wait for construction to complete (guard released) or abort (guard aborted). Then, if *gv guards a not-yet-constructed object, acquire the guard and return non-0. Otherwise, if *gv guards a constructed object, return 0.
`void __cxa_guard_release(int *gv)`	**Pre-condition**: *gv acquired, guarded object constructed. **Post-condition**: ((*gv & 1) = 1), *gv released.
`void __cxa_guard_abort(int *gv)`	**Pre-condition**: *gv acquired, guarded object not constructed. **Post-condition**: ((*gv & 3) = 0), *gv released.

The one-time construction API functions may corrupt only the integer core registers permitted to be corrupted by the AAPCS32 (r0-r3, ip, lr, and CPSR).

The one-time construction API is expected to be used in the following way.

```
if ((obj_guard & 1) == 0) {
    if ( __cxa_guard_acquire(&obj_guard) ) {
        ... initialize the object ...;
        ... queue object destructor with __cxa_atexit(); // See §4.4.5.
        __cxa_guard_release(&obj_guard);
        // Assert: (obj_guard & 1) == 1
    }
}
```

If the object constructor throws an exception, cleanup code can call __cxa_guard_abort to release the guard and reset its state to the initial state.

5.4.3 Construction and destruction of arrays

See GC++ABI, §3.3.3, Array Construction and Destruction API, and CPPABI32, section 'Array construction and destruction'.

5.4.3.1 Helper functions defined by the generic C++ ABI

This ABI follows the generic ABI closely. Differences from the generic ABI are as follows.

- This ABI gives __cxa_vec_ctor and __cxa_vec_cctor a void * return type instead of void. The value returned is the same as the first parameter – a pointer to the array being constructed
- This ABI specifies the same array cookie format whenever an array cookie is needed. The cookie occupies 8 bytes, 8-byte aligned. It contains two 4-byte fields, the element size followed by the element count.

Below we list the functions and their arguments. For details see the references cited at the start of Construction and destruction of arrays.

```
void *__cxa_vec_new(
    size_t count, size_t element_size, size_t cookie_size,
    void (*ctor)(void *), void (dtor)(void *));
void *__cxa_vec_new2(
    size_t count, size_t element_size, size_t cookie_size,
    void (*ctor)(void *this), void (*dtor)(void *this),
    void *(*alloc)(size_t size), void (*dealloc)(void *object));
void *__cxa_vec_new3(
    size_t count, size_t element_size, size_t cookie_size,
    void (*ctor)(void *this), void (*dtor)(void *this),
    void *(*alloc)(size_t size), void (*dealloc)(void *object, size_t size));
void *__cxa_vec_ctor(
    void *vector, size_t count, size_t element_size,
    void (*ctor)(void *this),  void (*dtor)(void *this));
void __cxa_vec_dtor(
    void *vector, size_t count, size_t element_size,
    void (*dtor)(void *this));
void __cxa_vec_cleanup(
    void *vector, size_t count, size_t element_size,
    void (*dtor)(void *this));
void __cxa_vec_delete(
    void *vector, size_t element_size, size_t cookie_size,
    void (*dtor)(void *this));
void __cxa_vec_delete2(
    void *vector, size_t element_size, size_t cookie_size,
    void (*dtor)(void *this),
    void (*dealloc)(void *object));
void __cxa_vec_delete3(
    void *vector, size_t element_size, size_t cookie_size,
    void (*dtor)(void *this),
    void (*dealloc)(void *object, size_t size));
void *__cxa_vec_cctor(
    void *destination, void *source, size_t count, size_t element_size,
    void (*copy_ctor)(void *this, void *source),
    void (*dtor)(void *this));
```

5.4.3.2 Helper functions defined by the C++ ABI for the Arm Architecture

This ABI define the following new helpers which can be called more efficiently.

```
__aeabi_vec_ctor_nocookie_nodtor
__aeabi_vec_ctor_cookie_nodtor
__aeabi_vec_cctor_nocookie_nodtor
__aeabi_vec_new_cookie_noctor
__aeabi_vec_new_nocookie
__aeabi_vec_new_cookie_nodtor
__aeabi_vec_new_cookie
__aeabi_vec_dtor
__aeabi_vec_dtor_cookie
__aeabi_vec_delete
__aeabi_vec_delete3
__aeabi_vec_delete3_nodtor
__aeabi_atexit
```

Compilers are not required to use these functions but runtime libraries complying with this ABI must supply them. Below we list the functions and their arguments. For details see CPPABI32 section 'Array construction and destruction'. Each function is declared extern “C”.

```
void *__aeabi_vec_ctor_nocookie_nodtor(
    void *user_array, void *(*constructor)(void *),
    size_t element_size, size_t element_count);         // Returns: user_array
void *__aeabi_vec_ctor_cookie_nodtor(                   // Returns:
    array_cookie *cookie, void *(*constructor)(void *), //   (cookie==NULL) ? NULL :
    size_t element_size, size_t element_count);         //   array associated with cookie
void *__aeabi_vec_cctor_nocookie_nodtor(                // Returns: user_array_dest
    void *user_array_dest, void *user_array_src,
    size_t element_size, size_t element_count, void *(*copy_constructor)(void *, void *));
void *__aeabi_vec_new_cookie_noctor(
    size_t element_size, size_t element_count);         // Returns: new array
void *__aeabi_vec_new_nocookie(                         // Returns: new array
    size_t  element_size, size_t  element_count, void *(*constructor)(void *));
void *__aeabi_vec_new_cookie_nodtor(                    // Returns: new array
    size_t  element_size, size_t  element_count, void *(*constructor)(void *));
void *__aeabi_vec_new_cookie(                           // Returns: new array
    size_t  element_size, size_t  element_count,
    void *(*constructor)(void *), void *(*destructor)(void *));
void *__aeabi_vec_dtor(                                 // Returns:
    void *user_array, void *(*destructor)(void *),      //   cookie associated with user_array
    size_t element_size, size_t element_count);         //   (if there is one)
void *__aeabi_vec_dtor_cookie(                          // Returns:
    void *user_array, void *(*destructor)(void *));     //   cookie associated with user_array
void __aeabi_vec_delete(
    void *user_array, void *(*destructor)(void *));
void __aeabi_vec_delete3(
    void *user_array, void *(*destructor)(void *), void (*dealloc)(void *, size_t));
void __aeabi_vec_delete3_nodtor(
    void *user_array, void (*dealloc)(void *, size_t));
int  __aeabi_atexit(                                   // Returns: 0 => OK; non-0 => failed
    void *object, void (*destroyer)(void *), void *dso_handle);
```

5.4.4 Controlling object construction order

See GC++ABI, §3.3.4, Controlling Object Construction Order.

This ABI currently defines no helper functions to control object construction order.

5.4.5 Static object finalization

See GC++ABI, §3.3.5, DSO Object Destruction API, and CPPABI32, section 'Static object construction and destruction'.

The generic C++ ABI and this ABI both define the destruction protocol for static objects created by dynamically linked shared objects in separate platform supplements. Here we define only the interface used to destroy static objects in the correct order.

When a static object is created that will require destruction on program exit, its destructor and a pointer to the object must be registered with the run-time system by calling __aeabi_atexit (which calls __cxa_atexit).

```
int __aeabi_atexit(void *object, void (*dtor)(void *this), void *handle);
int __cxa_atexit(void (*dtor)(void *this), void *object, void *handle);
```

(It is slightly more efficient for the caller to call __aeabi_exit, and calling this function supports static allocation of memory for the list of destructions – see CPPABI32 section 'Static object destruction').

The handle argument should be NULL unless the object was created by a dynamically loaded shared library (DSO or DLL). On exit, dtor(object) is called in the correct order relative to other static object destructors.

When a user function F is registered by calling the C/C++ library function atexit, it must be registered by calling __aeabi_exit(NULL, F, NULL) or __cxa_atexit(F, NULL, NULL).

The handle argument and the dynamically loaded shared object (DSOor DLL) finalization function __cxa_finalize (listed below) are relevant only in the presence of DSOs or DLLs. The handle is the value passed to __cxa_finalize. See the relevant platform supplement or the generic C++ ABI for further information.

```
void __cxa_finalize(void *handle);  // Not used in the absence of DLLs/DSOs
```

When a DSO is involved, *handle* must be an address that uniquely identifies the DSO. Conventionally, handle = &__dso_handle, where __dso_handle is a label defined while statically linking the DSO.

5.4.6 Name demangling

See GC++ABI, §3.4, Demangler API. This API is not supported by this ABI.

In particular, it is likely that bare metal environments neither need, nor want the overhead of, this functionality.

Separate (virtual) platform supplements may require support for name demangling, and where they do, this ABI follows the generic C++ ABI precisely.

5.4.7 Exception-handling support

For details see EHABI32, section 'ABI routines'. Here we merely list the required helper functions and their type signatures (each function is declared extern "C").

5.4.7.1 Compiler helper functions

```
void *__cxa_allocate_exception(size_t size);
void __cxa_free_exception(void *p);
void __cxa_throw(void *, const std::type_info *, void (*dtor)(void *));
void __cxa_rethrow(void);
void *__cxa_begin_catch(void *);
void *__cxa_get_exception_ptr(_Unwind_Control_Block *);
              /* new in EHABI v2.02, ABI r2.02 */
void __cxa_end_catch(void);
void __cxa_end_cleanup(void);
bool __cxa_begin_cleanup(_Unwind_Control_Block *ucbp)
void __cxa_call_unexpected(_Unwind_Control_Block *ucbp)
```

For details see EHABI32, section 'ABI routines'.

5.4.7.2 Personality routine helper functions

```
bool __cxa_begin_cleanup(_Unwind_Control_Block *ucbp)
__cxa_type_match_result __cxa_type_match(
        _Unwind_Control_Block *ucbp,
        const std::type_info *rttip, bool is_ref_type, void **matched_object)
void __cxa_call_terminate(_Unwind_Control_Block *ucbp)
void __cxa_call_unexpected(_Unwind_Control_Block *ucbp)
```

For details see EHABI32, section 'ABI routines'.

5.4.7.3 Auxiliary functions related to exception processing

```
void __cxa_bad_cast();      // Throw a bad cast exception
void __cxa_bad_typeid();    // Throw a bad typeid exception
struct __cxa_eh_globals *__cxa_get_globals(void);
                      // Get a pointer to the implementation-defined, per-thread EH state
const std::type_info *__cxa_current_exception_type(void);
```

For details see EHABI32, section 'ABI routines'.