C Library ABI for the Arm® Architecture

2023Q3

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1 Preamble

1.1 Abstract

This document defines an ANSI C (C89) run-time library ABI for programs written in Arm and Thumb assembly language, C, and stand alone C++.

1.2 Keywords

C library ABI, run-time library

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.

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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
0.1		First public DRAFT.
2.0	24th March 2005	First public release.
2.01	4th July 2005	First batch of typographical corrections. Added stdbool.h.
2.02	5th October 2005	Clarified the intention behind __B and isblank() in Encoding of ctype table entries and macros (_AEABI_PORTABILITY_LEVEL != 0). Fixed the clash with the C99 specification.
2.03	5th May 2006	Corrected misinformation in signal.h concerning (non-)atomic access to 8-byte types using ldrd/strd/ldm/stm.
2.04 / A	25th October 2007	In Private names for private and AEABI-specific helper functions, used the common table of registered vendor names Document renumbered (formerly GENC-003539 v2.04).
B	4th November 2009	Added C++ names of C library functions explaining why, in C++ generating portable binary, standard library functions should be used via extern “C” linkage.
C r2.09	30th November 2012	assert.h Clarified the intended method of customizing assert(). setjmp.h Corrected calculation of minimum jmp_buf size (previously given as 24 double-words).

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Issue	Date	Change
D r2.10	24th November 2015	wchar.h Permit wint_t to be unsigned int.
2018Q4	21st December 2018	Minor typographical fixes, updated links.
2020Q3	1st October 2020	• document released on Github • new Licence: CC-BY-SA-4.0 • new sections on Contributions, Trademark notice, and Copyright
2021Q1	12th April 2021	Suggest placement of *BTI* after *setjmp* calls.

This document refers to, and is referred to by, the following documents.

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	*This document*	C Library ABI for the Arm Architecture
CPPABI32		C++ ABI for the Arm Architecture
RTABI32		Run-time ABI for the Arm Architecture.

2.2 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 AAELF32, RTABI32, ...

AEABI

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

Arm-based

... based on the Arm architecture ...

Branch Target Identification

Security technique ensuring a degree of control flow integrity by marking valid targets of indirect branches.

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.

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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 toolchain-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.

2.3 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* [BSABI32] supports inter-operation between:

- Relocatable objects generated by different toolchains.
- Executables and shared objects generated for the same execution environment by different toolchains.

This standard for C library functions allows a relocatable object built by one conforming toolchain from Arm-Thumb assembly language, C, or standalone C++ to be compatible with the static linking environment provided by a different conforming toolchain.

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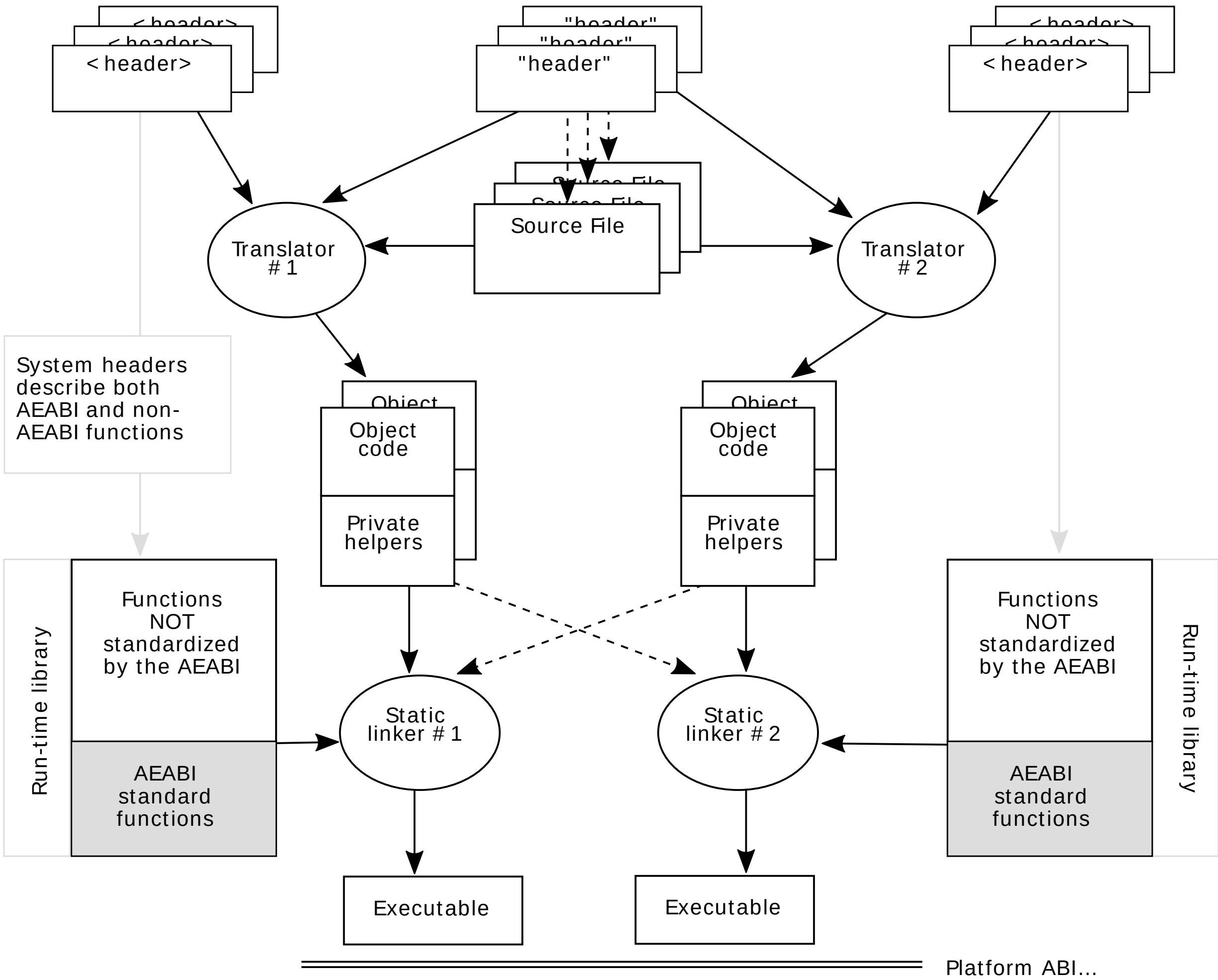

Inter-operation between relocatable objects

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

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4 Introduction

A number of principles of inter-operation are implicit in, or compatible with, clibabi32-fig1, above. This section describes these principles precisely, as they apply to a C library, and gives a rationale for each one. The corresponding section of [RTABI32] discusses the same principles as they apply to run-time helper functions.

4.1 Most C library functions have a standard ABI

C library functions are declared explicitly in standard headers.

As shown in The C library, below, it is possible to standardize the interface to almost all the C library. However, it is very difficult to treat the C++ library the same way. Too much of the implementation of the C++ library is in the standard headers. Standardizing a binary interface to the C++ library is equivalent to standardizing its implementations.

Among C library functions we can distinguish the following categories.

- Functions whose type signatures and argument ranges are precisely defined by a combination of the C standard and this ABI standard for data type size and alignment given in the [AAPCS32]. These functions already have a standardized binary interface.
- Functions that would fall in the above category if there were agreement about the layout of a structure that is only partly defined by the C standard, or agreement about the range and meaning of controlling values passed to the function for which the C standard gives only a macro name.
- Functions that take as arguments pointers to structures whose fields are not defined by the standard (FILE, mbstate_t, fpos_t, jmp_buf), that can be standardized by considering the structures to be opaque. (But beware FILE, which is also expected to be accessed non-opaquely).
- Miscellanea such as errno, va_arg, va_start, and the ctype functions that are expected to be implemented by macros in ways that are unspecified by the standard. These must be examined case by case.

The C library declares few data objects, so standardization is concerned almost exclusively with functions.

Some standard functions may be inlined

The C and C++ standards allows compilers to recognize standard library functions and treat them specially, provided that such recognition does not depend on the inclusion of header files. In practice, this allows a compiler to inline any library function that neither reads nor writes program state (such as the state of the heap or the locale) managed by the library.

4.1.1 Already standardized C library functions

Already standardized functions include those whose type signatures include only primitive types, defined synonyms for primitive types (such as `size_t`), or obvious synonyms for primitive types (such as `time_t` and `clock_t`). Whole sections of the C library (for example, that described by string.h) fall into this category.

Each such function is already very precisely defined.

- Its type signature is fixed.
- Its name is fixed by the C language standard.
- With some exceptions clearly identified by the C language standard (for example, whether malloc(0) ≠ NULL), Its behavior is fixed by the C language standard.

4.1.2 Nearly standardized C library functions

Functions that would already be standardized were it not for depending on the layout of a structure or the value of a controlling constant are prime candidates for standardizing. In many cases, there is already general consensus about layout or values.

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Structure layout

The C standard defines only the fields that *must* be present in the structures it defines (lconv, tm, div_t, ldiv_t). It does not define the order of fields, and it gives latitude to implementers to add fields.

In practice, most implementations use only the defined fields in the order listed in the C standard. In conjunction with the POD structure layout rules given in the AAPCS this effectively standardizes the ABI to functions that manipulate these structures.

> ***Note***
>
> fpos_t, mbstate_t, and FILE, which have no standard-defined fields, do not have this property.

Controlling values

For controlling values there are some universal agreements (for example, about the values of NULL, SEEK_*, EXIT_*) and some disagreements (about the values of LC_*, _IO*BF, etc).

4.1.3 C library functions operating on potentially opaque structures

Functions that take as arguments pointers to structures whose fields are not defined by the standard (FILE, mbstate_t, fpos_t, jmp_buf) can be standardized only if those structures are made opaque.

- Unfortunately, we must be able to define objects of all of these types except FILE (a library client only ever allocates objects of type FILE *), so the size of each object must be standardized even if the contents are not.
- Functions that manipulate types opaquely cannot be implemented inline. Thus getc, putc, getchar, putchar, and so on must be out of line functions. This might be acceptable in a deeply embedded application, but is unlikely to be unconditionally acceptable in high performance platform ABIs where there is a history of these functions being implemented by macros that operate on the implementation of FILE.

In The C library, below, these functions are considered case by case under the library sub-sections that declare them.

4.1.4 Miscellanea

The implementations of macros such as errno, va_arg, va_start, and the ctype functions are unspecified by the C standard. These must be considered case by case.

- The va_* macros essentially disappear. The type va_list and the binary interface to variadic functions are standardized by the AAPCS. We simply require compilers to inline what remains.
- There is probably no completely satisfactory cross platform definition of *errno*. errno.h, below, proposes a definition well suited to deeply embedded use, and adequately efficient elsewhere.
- For the ctype macros there is no escaping calling a function in the general case.

(Consider how to handle changing locale, as must be done by an application that processes Chinese, Japanese, or Korean characters, because the C library is defined to start in the “C” locale).

The ctype functions are discussed further in ctype.h, below.

4.2 A C library is all or nothing

In general, a function (for example, malloc) from vendor A's C library will not work with a function (for example, free) from vendor B's C library. Granted, large tracts of C library will be independent leaf (or near leaf) functions, portable between toolchains (strlen, strcpy, strstr, etc), and vendors will work hard to ensure that a statically linked program will only include the functions it needs. Nonetheless, tangled clumps of implementation might underlie many apparently independent parts of a run-time library's public interface.

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In some cases, there may be an element of conspiracy between the 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 library and the static linker, as well as the execution environment.

This leads us to a major conclusion for statically linked executables:

- **The static linker and the language run-time libraries must be from the same toolchain**.

Accepting this constraint gives considerable scope for private arrangements (not governed by this ABI) between these toolchain components, restricted only by the requirement to provide a well defined binary interface (ABI) to the functions described in Most C library functions have a standard ABI, above.

4.3 Important corollaries of this C 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 the 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 required to support portable access to a C library. Every ABI-conforming toolchain's run-time library must implement these helper functions.

The header describing an ABI-conforming object must contain only standard-conforming source language.

> ***Aside***
>
> That does not preclude compiler-specific directives that are properly guarded in a standard conforming way. For example: #ifdef __CC_ARM... #pragma..., and so on. However, such directives must not change the ABI conformance of the generated binary.

4.4 Private names for private and AEABI-specific helper functions

External names used by private helper functions and private helper data must be in the vendor-specific name space reserved by this ABI. All such names use the format __vendor_name.

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

__aeabi_unwind_cpp_pr0 **__ARM**_Unwind_cpp_prcommon

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

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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
`dig`	Dignus, LLC
`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.
`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.

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5 The C library

5.1 C Library overview

The C Library ABI for the Arm architecture is associated with the headers listed in C library headers below. Some are defined by the ANSI 1989 (ISO 1990) standard for C (called C89 in this document), some by addenda to it, and some by the 1999 standard for C (called C99 in this document). Most are in the set of headers considered by §17.4.1.2 of the ANSI 1998 C++ standard to provide *Headers for C Library Facilities*. These are denoted in the table below by ‘C’.

C library headers

Header	Origin	Comment
assert.h	C	See assert.h. Standardize __aeabi_assert(const char*, const char*, int).
ctype.h	C	See ctype.h. Inlined macros cause difficulties for standardization.
errno.h	C	See errno.h.
float.h	C	Defined by Arm’s choice of 32 and 64-bit IEEE 2’s complement format.
inttypes.h	C99	Defined by the AAPCS and commonsense.
iso646.h	C	Defined by entirely the C standard.
limits.h	C	See limits.h. Defined by the AAPCS (save for MB_LEN_MAX).
locale.h	C	See locale.h.
math.h	C	See math.h. All fixed apart from HUGE_VAL and related C99 definitions.
setjmp.h	C	jmp_buf must be defined, setjmp and longjmp must not be inlined.
signal.h	C	See signal.h. Definitions of SIG_DFL, SIG_IGN, SIG_ERR, & signal #s are controversial.
stdarg.h	C	va_list is defined by AAPCS. Other artifacts are inline (compiler-defined)
stdbool.h	C99	Defined by entirely the C standard
stddef.h	C	Defined by the AAPCS.
stdint.h	C99	Defined by the Arm architecture + AAPCS + C standard.
stdio.h	C	See stdio.h. Inlined macros and properties of the environment cause difficulties.
stdlib.h	C	See stdlib.h. All fixed apart from MB_CUR_MAX.
string.h	C	The interface is fixed by the AAPCS data type size rules.
time.h	C	See time.h. CLOCKS_PER_SEC is a property of the execution environment.
wchar.h	C	See wchar.h. No issues apart from mbstate_t.
wctype.h	C	See wctype.h. Defined by the AAPCS and commonsense.

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5.2 The C library standardization model

5.2.1 Purpose and principles

The purpose of standardizing a binary interface to the ANSI C library is to support creating portable binaries that can use that library. To this end we want to categorize developments as being of one of two kinds:

- Those that develop applications.
- Those that develop portable binaries.

An application is built using a single toolchain. The executable may include statically linkable binary code from a 3rd party, built using a different toolchain. It may later be dynamically linked into an execution environment based on, or built by, yet another toolchain.

A portable binary may be relocatable object code for static linking or an executable for dynamic linking.

Principles

Whatever we do to support the creation of an ABI standard for the C library must be compatible with the library sections of the C and C++ language standards, from the perspective of application code. It can conflict with and overrule these language standards only if invited to do so by portable code.

Corollary: Anything reducing the guarantees given by a language standard must be guarded by:

```
#if _AEABI_PORTABILITY_LEVEL != 0
```

The ability to make portable binaries must impose no costs on non-portable application code. Portable code may incur costs including reduced performance and, or, loss of standard language guarantees.

The cost of supporting portable binaries must be moderate for run-time libraries. Ideally, we should restrict the requirements to that which existing run-time libraries can support via pure extension and additional veneers.

5.2.2 Obstacles to creating a C library ABI

Within a C library header file there are several different sorts of declaration that affect binary inter-working.

- Function declarations. Most of these have no consequences for binary compatibility because:

  - For non-variadic functions the C standard guarantees that a function with that name will exist (because the user is entitled to declare it without including any library header).
  - The meaning of the function is specified by the standard.
  - The type signature involves only primitive types, and these are tightly specified by the AAPCS.

  An ABI standardization issue arises where an argument is not a primitive type.

- Macro definitions. Many expand to constants, a few to implementation functions.

  - Many of the constant values follow from the C standard, the IEEE 754 FP standard, and the AAPCS. There is no choice of value for Arm-Thumb.
  - Some constants such as EOF and NULL are uncontroversial and can be standardized.

  An ABI issue arises if a constant does not have a consensus value and if a function is inlined.

- Structure and type definitions.

  - Most C library typedefs name primitive types fully defined by the AAPCS.

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- Structure declarations affect binary inter-working only if there is variation in the size, alignment, or order of fields.

An ABI issue arises if the content and field order of a structure is not fully specified by the standard.

5.2.2.1 Compile-time constants that cannot be constant at compile time

The C library binds many constants at compile time that are properties of the target execution environment. Examples include _IO*BF, LC_*, EDOM, ERANGE, EILSEQ, SIG*, CLOCKS_PER_SEC, FILENAME_MAX.

In some cases, there is consensus about the values of controlling constants. For example, there is near universal consensus about the values of NULL, SEEK_*, EXIT_*, EDOM, ERANGE (but not EILSEQ), most of SIG* (but not, universally, SIGABRT).

These constants simply cannot be bound at compile time (as required by ANSI) if we want a portable binary. Instead, they must be bound at link time, or queried at run-time.

5.2.2.2 Inadequately specified structures

The interface to the C library includes inadequately specified structures such as lconv, tm, and *div_t.

In fact, lconv, tm, and *div_t are the only structures not defined opaquely. For the others, we need to know at most the size and alignment. Even FILE is unproblematic, because (save for access by inline functions) it is always accessed opaquely via a FILE *.

5.2.2.3 Inline functions that expose implementation details

The C Library permits and encourages certain functions to be implemented inline via macros that expose otherwise hidden details of the implementation.

The ctype functions provide a clear illustration, though getc, putc, getchar, putchar, and sometimes feof and ferror, are equally difficult.

Of the ctype functions, isdigit and isxdigit can be inlined without reference to the target environment, though in practice, only isdigit can be efficiently inlined without helper functions or helper tables.

- Isdigit can be inlined in 2 Arm or Thumb instructions.
- Inline isxdigit takes 5 Arm or 8 Thumb instructions compared to 2-3 using a 256 byte helper table.

5.2.2.4 Under-specified exported data

There are some under-specified data exported by the C library, specifically errno, stdin, stdout, and stderr.

In the case of errno, the requirement is to expand to a modifiable l-value. The most general form of modifiable l-value is something like (*__aeabi_errno()), and this can be layered efficiently on any environment.

Stdin, stdout, and stderr must expand to expressions of type *pointer to FILE*. In practice, execution environments either define stdin to have type FILE * or define stdin to be the address of a FILE object. The former definition is slightly more general in that it can be trivially layered on an underlying environment of either sort (either by being a synonym for the underlying FILE *, or a location statically initialized to the address of the FILE).

5.2.3 Our approach to defining a C library ABI

5.2.3.1 Compile time constants

The first step is to deal with the controlling values C89 treats as compile-time constants that cannot be constant at compile time. We can categorize each group of such constants in one of three ways.

- Everyone agrees all the values. Examples include NULL, SEEK_*, EXIT_*. These remain constants.

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- Different implementations disagree about the values. Examples include _IO*BF, LC_*. This is the *black* list.
- Most implementations agree about most of the values. Examples include EDOM, ERANGE, and SIG* excluding SIGABRT. This is the *grey* list.

Black list items must become link-time constants or run-time queries. Link-time constants are more efficient for the client and no more difficult for the execution environment. In both cases they can be supported as a thin veneer on an existing execution environment. Name-space pollution is the only serious standardization issue, but use of names of the form __aeabi_xxx and _AEABI_XXX deals with that for C.

Because this change violates the ANSI standard, it must be guarded by:

```
#if _AEABI_PORTABILITY_LEVEL != 0.
```

Grey list items are a little more difficult. There are two options.

- Treat each group as *black* or *white* on a case by case basis.
- Treat the consensus members as *white* and the remainder as *black*.

Consider , ERANGE, and EILSEQ from errno.h. This is a grey list category because there is consensus that = 33 and ERANGE = 34, but no consensus (even among Unix-like implementations) about EILSEQ.

In practice, these values will be rarely accessed by portable code, so there is no associated performance or size issue, and they should all be considered *black* to maximize portability.

A similar argument suggests all the SIG* values should be considered *black*. Portable code will rarely raise a signal, and there is no overhead on the run-time environment to define the link-time constants, so we might as well err on the side of portability.

Thus a clear principle emerges that seems to work robustly and satisfy all of principles and goals stated in Purpose and principles. Namely, if any member of a related group of manifest constants does not have a consensus value, the whole group become link-time constants when _AEABI_PORTABILITY_LEVEL != 0.

A general template for managing this is:

```
#if _AEABI_PORTABILITY_LEVEL == 0
#  define XXXX ....
#else
   extern const int __aeabi_XXXX;
#  define XXXX  (__aeabi_XXXX)
#endif
```

In other words, the compile time constant XXXX becomes the constant value __aeabi_XXXX (unless XXXX begins with an underscore, in which case underscores are omitted until only one remains after __aeabi)..

This much imposes no overheads on non-portable (application) code, only trivial compliance overhead (provide a list of constant definitions) on toolchains and execution environments, and only a small tax on portable binaries.

5.2.3.2 Structures used in the C library interface

Opaque structures

Some structures are used opaquely by library code. Examples include fpos_t, mbstate_t, and jmp_buf. The key issue for a portable client using such a structure is to allocate sufficient space, properly aligned. In most cases this involves a straightforward decision.

The trickiest case of these three is jmp_buf, whose size is really a feature of the execution environment. When _AEABI_PORTABILITY_LEVEL != 0 the definition should be reduced to one that is adequate for declaring parameters and extern data, but inadequate for reserving space. A suitable definition is:

```
typedef long long jmp_buf[];
```


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A portable binary must contrive to obtain any needed jmp_buf structures from its client environment, either via parameters or extern data, and neither setjmp nor longjmp can be inlined.

> ### Aside
>
> A link-time value __aeabi_JMP_BUF_SIZE would support allocating a jmp_buf using malloc.

The *div_t structures are formal requirements of the C standard. They are unlikely to be used in the Arm world. We will define them consistent with the Arm helper functions for division. When _AEABI_PORTABILITY_LEVEL != 0 the definitions should simply disappear (in order to remove a marginal portability hazard).

Two structures – tm and lconv – are definitely not opaque, and we discuss them further below.

struct tm

Most implementers agree that struct tm should be declared to be the C89/C99 fields in the order listed in the standards. BSD systems add two additional fields at the end relating to the time zone. It is a defect in BSD that a call to strftime() with a struct tm in which the additional fields have not been initialized properly can crash, even when the format string has no need to access the fields. We have reported this defect to the BSD maintainers.

This ABI defines struct tm to contain two extra, trailing words that must not be used by ABI-conforming code.

struct lconv

Unfortunately, lconv has been extended between C89 and C99 (with 6 additional fields) and the C89 field order has changed in the C99 standard (though the new fields are listed last). Fortunately, lconv is generated by a C library, but not consumed by a C library. It is output only. That allows us to define the field order for portable objects, provided a portable object never passes a struct lconv to a non-portable object. In other words, when _AEABI_PORTABILITY_LEVEL != 0, struct lconv should be replaced by struct __aeabi_lconv, and localeconv by __aeabi_localeconv. We define the field order to be the C89 order followed by the new fields, so in many cases __aeabi_localeconv will simply be a synonym for localeconv. At worst it will be a small veneer.

5.2.3.3 Inline functions

Inline functions damage portability if they refer directly to details of a hidden implementation. In C89, this problem is usually caused by the ctype functions *is*xxxxx and *toyyyy*, and the stdio functions getc, putc, getchar, putchar, and feof. (When new inline/macro functions are added to a header, the inline/macro implementations must be hidden when _AEABI_PORTABILITY_LEVEL != 0).

In stdio, only feof generates a cogent case on performance grounds for being inline (a case weakened by getc etc returning EOF). The get and put functions are so complex – inevitably embedding a function call – that being inline saves little other than the cost of the function call itself. The C standard requires functions to exist in every case, so the required header change when _AEABI_PORTABILITY_LEVEL != 0 is simply to hide some macro definitions

That leaves the ctype *is*xxxxx functions, excluding isdigit() which can always be inlined most efficiently without helper functions or tables. For these functions there is a choice when _AEABI_PORTABILITY_LEVEL != 0.

- They can be out of line (isdigit excepted). This always works, imposes no overhead on the execution environment, and delivers the semantic guarantees of the standard to portable code.
- There can be a defined tabular implementation that the execution environment must support.

The second option can be a near zero cost addition to an existing execution environment provided a portable binary can bind statically to its ctype locale. All that needs to be provided are tables with defined names. No upheaval is required in the underlying ctype/locale system.

The choice available to a user building a portable binary is then between the following.

- All ctype functions are out of line (save isdigit and, perhaps, isxdigit).

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This is the appropriate choice when ctype performance does not matter, or the code must depend on the dynamic choice of ctype locale.

- All ctype functions are inlined using a helper table appropriate to the statically chosen ctype locale.

  The implementation is sketched in ctype.h, below. The binding is managed by defining _AEABI_LC_CTYPE to be one of C, ISO8859_1, or SJIS.

  This is the appropriate choice when the ctype locale is known statically and performance *does* matter.

5.2.4 Naming issues in C++ header files

5.2.4.1 Names introduced by this C library ABI into <cyyy> headers

Identifiers introduced by the AEABI are of the form __aeabi_*xxxx* or _AEABI_*XXX* (macros only).

Identifiers with linkage are all of the form __aeabi_*xxxx* and must be declared with extern “C” linkage.

An __aeabi_*xxxx* identifier introduced into a <c*yyy*> header by expanding a macro XXXX defined by the ANSI C standard for <*yyy*.h> belongs to a C++ name-space chosen by the implementation. The C++ standard permits implementations to extend the global namespace and, or, the *std* namespace with names that begin with an underscore. After including <c*yyy*> the expansion of XXXX shall be usable directly by a C++ program.

A small number of type names and function names are introduced into the <c*yyy*> headers by this ABI other than by macro expansion. These are all of the form __aeabi_*xxxx*. These shall be usable with std:: or global (::) namespace qualification after including the <c*yyy*> headers in which they are declared.

5.2.4.2 C++ names of C library functions

In most C++ implementations an encoding of a function’s type signature forms part of the *mangled name* [CPPABI32] used to name binary functions. If two sides of an interface (built using different toolchains) specify different language types to map the same binary type, a naming incompatibility will arise across the interface.

As a simple example consider `void fn(int)` binary compatible under this ABI with `void fn(long)`. The first will have the mangled name `_Z2fni` and the second `_Z2fnl` [CPPABI32]. A similar incompatibility occurs between int and unsigned int (`i` vs `j`) describing values restricted to the range 0-MAXINT.

To avoid such difficulties, portable binary code built from C++ source should refer to standard library functions using their (not mangled) C names by declaring them to have `extern` "C" {...} linkage.

5.2.5 Library file organization

The file format for libraries of linkable files is the **ar** format described in [BSABI32].

Some factors that need to be considered when making a library file for use by multiple ABI-conforming toolchains are discussed in [RTABI32] (in the *Library file organization* section).

5.3 Summary of the inter-toolchain compatibility model

When a C-library-using source file is compiled to a portable relocatable file we assume to following.

The source file includes C-library header files associated with the compiler, not header files associated with the C library binary with which the object might ultimately be linked (which can be from a different toolchain, not visible when the object is compiled).

The compiler conforms to the ANSI C standard. If it exercises its right to recognize C library functions as being special, it will nonetheless support a mode in which this is done without damaging inter-operation between toolchains. Thus, for example, functions that read or write program state managed by the library (heap state, locale state, etc) must not be inlined in this operating mode.

How a user requests the AEABI-conforming mode from a toolchain is implementation defined (Q-o-I).

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A compiler generates references to 3 kinds of library entity.

- Those declared in the standard interface to the C library. In many cases a user can legitimately declare these in a source program without including any library header file.
- Those defined by the AEABI to be standard helper functions or data (this specification and [RTABI32]).
- Those provided with the relocatable file (as part of the relocatable file, or as a separate, freely distributable library provided with the relocatable file).

When generating a portable relocatable file, a compiler must not generate a reference to any other library entity.

Note that a platform environment will often require all platform-targeted toolchains to use the same header files (defined by the platform). Such objects are not portable, but exportable only to a single environment.

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6 The C library section by section

6.1 Introduction and conventions

For each section of the C library we describe what must be specified that is not precisely specified by the ANSI C standard in conjunction with the data type size and alignment rules given in the [AAPCS32].

Aspects not listed explicitly are either fully specified as a consequence of the AAPCS data type size and alignment rules or (like NULL and EOF) have obvious consensus definitions.

For all aspects mentioned explicitly in this section we tabulate either:

- The required definition (independent of _AEABI_PORTABILITY_LEVEL).
- Or, the recommended definition when _AEABI_PORTABILITY_LEVEL = 0 (if there is one), and the required definition when _AEABI_PORTABILITY_LEVEL != 0.

6.1.1 Detecting whether a header file honors an AEABI portability request

An application must be able to detect whether its request for AEABI portability has been honored.

An application should #define _AEABI_PORTABILITY_LEVEL and #undef _AEABI_PORTABLE before including a C library header file that has obligations under this standard (see Summary of requirements on C Libraries for a summary). The application can test whether _AEABI_PORTABLE is defined after the inclusion, and #error if not.

Detecting when AEABI portability obligations have been met

<table>
<tr><th>Application</th><th>Library header</th></tr>
<tr><td>

```
#define _AEABI_PORTABILITY_LEVEL 1
#undef _AEABI_PORTABLE

#include <header.h>

#ifndef _AEABI_PORTABLE
# error "AEABI not supported by header.h"
#endif
```

</td><td>

```
#if defined _AEABI_PORTABILITY_LEVEL &&
  !defined _AEABI_PORTABLE
# define _AEABI_PORTABLE
#endif
```

</td></tr>
</table>

6.2 assert.h

Although the standard does not specify it, a failing *assert* macro must eventually call a function of 3 arguments as shown in Assert.h declarations, below. As specified by the C standard, this function must print details of the failing diagnostic then terminate by calling abort. A C library implementation can fabricate a lighter weight, no arguments, non-printing, non-conformant version of assert() by calling abort directly, so we define no variants of __aeabi_assert().

Assert.h declarations

<table>
<tr><th>Name</th><th>Required definition (when generating a message)</th></tr>
<tr><td>assert</td><td>

```
void __aeabi_assert(const char *expr, const char *file, int line);
#define assert(__e) ((__e) ? (void)0 : __aeabi_assert(#__e, __FILE__, __LINE__))
```

</td></tr>
</table>

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A conforming implementation must signal its conformance as described in Detecting whether a header file honors an AEABI portability request.

6.3 ctype.h

The ctype *functions* are fully defined by the C standard and the [AAPCS32]. Each function takes an int parameter whose value is restricted to the values {unsigned char, EOF}, and returns an int result.

The ctype functions are often implemented inline as macros that test attributes encoded in a table indexed by the character's value (from EOF = -1 to UCHAR_MAX = 255). Using a fixed data table does not sit comfortably with being able to change locale in an execution environment in which all tables are in ROM.

The functions isdigit and isxdigit have locale-independent definitions so they can be inlined under the assumption that the encoding of common characters will follow 7-bit ASCII in all locales. Under this assumption, isdigit can be defined as an unsigned range test that takes just two instructions.

```
#define isdigit(c) (((unsigned)(c) - '0') < 10)
```

The analogous implementation of isxdigit takes 12 Thumb or 7 Arm instructions (24-28 bytes), which is usually unattractive to inline. However, implementations can inline this without creating a portability hazard.

```
#define isxdigit(c) (((unsigned)(c) & ~0x20) – 0x41) < 6 || isdigit(c))
```

When _AEABI_PORTABILITY_LEVEL != 0 an implementation of ctype.h can choose:

- Not to inline the ctype functions (other than isdigit and, perhaps, isxdigit, as described above).
- To implement these functions inline as described in the next subsection.

A conforming C library implementation must support *both* alternatives. A conforming ctype.h must signal its conformance as described in Detecting whether a header file honors an AEABI portability request.

6.3.1 ctype.h when _AEABI_PORTABILITY_LEVEL != 0 and isxxxxx inline

The general form of the **is**xxxxx macros is:

```
#define isxxxxx(c) (expxxxxx(((__aeabi_ctype_table + 1)[c]))
```

Where **exp**xxxxx is an expression that evaluates it's the argument *c* only once and __aeabi_ctype_table is a table of character attributes indexed from 0 to 256 inclusive.

We define link-time selection of the attribute table in a locale-dependent way using the following structure. The same character translations and locale bindings should be used by the **to***xxxx* macros and functions.

```
/* Mandatory character attribute arrays indexed from 0 to 256 */
extern unsigned char const __aeabi_ctype_table_C[257];      /* "C" locale */
extern unsigned char const __aeabi_ctype_table_[257];       /* default locale */
                                  /* The default locale might be the C locale */
/* Optional character attribute arrays indexed from 0 to 256.        */
/* These do not have to be provided by every execution environment   */
/* but, if provided, shall be provided with these names and meaning. */
extern unsigned char const __aeabi_ctype_table_ISO8859_1[257];
extern unsigned char const __aeabi_ctype_table_SJIS[257];
extern unsigned char const __aeabi_ctype_table_BIG5[257];
extern unsigned char const __aeabi_ctype_table_UTF8[257];
```


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```
#ifdef _AEABI_LC_CTYPE
#  define _AEABI_CTYPE_TABLE(_X) __aeabi_ctype_table_ ## _X
#  define _AEABI_CTYPE(_X) _AEABI_CTYPE_TABLE(_X)
#  define __aeabi_ctype_table _AEABI_CTYPE(_AEABI_LC_CTYPE)
#else
#  define __aeabi_ctype_table __aeabi_ctype_table_
#endif
```

To make a link-time selection of the ctype locale for this compilation unit, define _AEABI_PORTABILITY_LEVEL != 0 and _AEABI_LC_CTYPE to one of the values listed below before including ctype.h.

- Leave _AEABI_LC_CTYPE undefined or defined with no value (–D_AEABI_LC_CTYPE= or #define _AEABI_LC_CTYPE) to statically bind to the default locale.
- Define _AEABI_LC_CTYPE to be *C*, to statically bind to the C locale.
- Define _AEABI_LC_CTYPE to be one of the defined locale names *ISO8859_1*, *SJIS*, *BIG5*, or *UTF8* to bind to the corresponding locale name.

Aside

A conforming environment shall support the C locale and a default locale for ctype. The default locale may be the C locale. Relocatable files binding statically to any other ctype locale shall provide the ctype table encoded as described in Encoding of ctype table entries and macros (_AEABI_PORTABILITY_LEVEL != 0), in a COMDAT section or in an adjunct library.

6.3.1.1 Encoding of ctype table entries and macros (_AEABI_PORTABILITY_LEVEL != 0)

Each character in a locale belongs to one or more of the eight categories enumerated below. Categories are carefully ordered so that membership of multiple categories can be determined using a simple test.

```
#define __A    1       /* alphabetic        */  /* The names of these macros */
#define __X    2       /* A-F, a-f and 0-9  */  /* are illustrative only and */
#define __P    4       /* punctuation       */  /* are not mandated by this  */
#define __B    8       /* printable blank   */  /* standard.                 */
#define __S   16       /* white space       */
#define __L   32       /* lower case letter */
#define __U   64       /* upper case letter */
#define __C  128       /* control chars     */

isspace(x)  ((__aeabi_ctype_table+1)[x] & __S)
isalpha(x)  ((__aeabi_ctype_table+1)[x] & __A)
isalnum(x)  ((__aeabi_ctype_table+1)[x] << 30)  // test for __A and __X
isprint(x)  ((__aeabi_ctype_table+1)[x] << 28)  // test for __A, __X, __P and __B
isupper(x)  ((__aeabi_ctype_table+1)[x] & __U)
islower(x)  ((__aeabi_ctype_table+1)[x] & __L)
isxdigit(x) ((__aeabi_ctype_table+1)[x] & __X)
isblank(x)  (isblank)(x)              /* C99 isblank() is not a simple macro */
isgraph(x)  ((__aeabi_ctype_table+1)[x] << 29)  // test for __A, __X and __P
iscntrl(x)  ((__aeabi_ctype_table+1)[x] & __C)
ispunct(x)  ((__aeabi_ctype_table+1)[x] & __P)
```

In the "C" locale, the C99 function isblank() returns true for precisely space and tab while the C89 function isprint() returns true for any character that occupies *one printing position* (hence excluding tab). isblank(x) can be simply

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implemented as `(x == '\t' || ((__aeabi_ctype_table+1)[x] & __B))`, but because 'x' is evaluated twice in this expression, it is not a satisfactory (standard conforming) macro. A compiler may, nonetheless, safely inline this implementation of the isblank() function.

6.4 errno.h

There are many reasons why accessing errno should call a function call. We define it as shown in errno.h definitions

errno.h definitions

Name and signature	Recommended value	Required portable definition
errno	(*__aeabi_errno_addr())	`volatile int *__aeabi_errno_addr(void);` `(*__aeabi_errno_addr())`
EDOM	33	`extern const int __aeabi_EDOM = 33;` `(__aeabi_EDOM)`
ERANGE	34	`extern const int __aeabi_ERANGE = 34;` `(__aeabi_ERANGE)`
EILSEQ (C89 NA 1/ C99)	47 (42, or 84)	`extern const int __aeabi_EILSEQ = 47;` `(__aeabi_EILSEQ)`

Aside

There seems to be general agreement on 33 and 34, the long established Unix values of and ERANGE. There is little consensus about EILSEQ. 47 is claimed to be the IEEE 1003.1 POSIX value.

6.5 float.h

The values in float.h follow from the choice of 32/64-bit 2s complement IEEE format floating point arithmetic.

This header does not define _AEABI_PORTABLE (Detecting whether a header file honors an AEABI portability request).

6.6 inttypes.h

This C99 header file refers only to types and values standardized by the AEABI. It declares only constants and real functions whose type signatures involve only primitive types. Note that plain char is unsigned [AAPCS32].

This header does not define _AEABI_PORTABLE (Detecting whether a header file honors an AEABI portability request).

6.7 iso646.h

This header contains macros only. The definitions are standardized by a C89 normative addendum (and by C++).

This header does not define _AEABI_PORTABLE (Detecting whether a header file honors an AEABI portability request).

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6.8 limits.h

Other than MB_LEN_MAX, the values of the macros defined by limits.h follow from the data type sizes given in the AAPCS and the use of 2's complement representations.

Conforming implementations must also define the C99 macros LLONG_MIN, LLONG_MAX, and ULLONG_MAX, and define _AEABI_PORTABLE when _AEABI_PORTABILITY_LEVEL != 0 (as specified in Detecting whether a header file honors an AEABI portability request)

The value of MB_LEN_MAX

Name	Recommended value	Required portable definition
MB_LEN_MAX	6	`extern const int __aeabi_MB_LEN_MAX = 6;` `(__aeabi_MB_LEN_MAX)`

6.9 locale.h

Locale.h defines 6 macros for controlling constants (LC_* macros) and struct lconv. The setlocale and localeconv functions are otherwise tightly specified by their type signatures, and AAPCS data type size and alignment.

The C standard requires a minimum set of fields in struct lconv and places no constraints on their order. The C99 standard mandates an additional six fields, and lists them last. Unfortunately, it lists the C89 fields in a different order to that given in the C89 standard. Prior art generally defines the C89 fields in the same order as listed in the C89 standard, or the C99 fields in the same order as in the C99 standard. No order is compatible with both.

The localeconv function returns a pointer to a struct lconv. This must be correctly interpreted by clients using the C89 specification and clients using the C99 specification. Consequently:

- The structure must contain all the C99-specified fields.
- The order of the C89-specified fields must be as listed in the C89 standard.

To support layering on run-time libraries that do not implement the full C99 definition of struct lconv, or that implement it with a different field order, we define struct __aeabi_lconv and __aeabi_localeconv.

In the C++ header <clocale> both must be declared in namespace std::.

When _AEABI_PORTABILITY_LEVEL != 0, the declarations of struct lconv and localeconv must be hidden, and _AEABI_PORTABLE should be defined as specified in Detecting whether a header file honors an AEABI portability request.

```
struct __aeabi_lconv {
   char *decimal_point;
   char *thousands_sep;
   char *grouping;
   char *int_curr_symbol;
   char *currency_symbol;
   char *mon_decimal_point;
   char *mon_thousands_sep;
   char *mon_grouping;
   char *positive_sign;
   char *negative_sign;
   char int_frac_digits;
   char frac_digits;
   char p_cs_precedes;
   char p_sep_by_space;
   char n_cs_precedes;
```


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```
  char n_sep_by_space;
  char p_sign_posn;
  char n_sign_posn;
 /* The following fields are added by C99 */
  char int_p_cs_precedes;
  char int_n_cs_precedes;
  char int_p_sep_by_space;
  char int_n_sep_by_space;
  char int_p_sign_posn;
  char int_n_sign_posn;
};
```

locale.h required portable definitions

Name	Required portable definition
`__aeabi_lconv`	As above.
`__aeabi_localeconv`	`struct __aeabi_lconv *__aeabi_localeconv(void)`

LC_* macros

Macro	Required portable definition
LC_COLLATE	`extern const int __aeabi_LC_COLLATE = ...; (__aeabi_LC_COLLATE)`
LC_CTYPE	`extern const int __aeabi_LC_CTYPE = ...; (__aeabi_LC_CTYPE)`
LC_MONETARY	`extern const int __aeabi_LC_MONETARY = ...; (__aeabi_LC_MONETARY)`
LC_NUMERIC	`extern const int __aeabi_LC_NUMERIC = ...; (__aeabi_LC_NUMERIC)`
LC_TIME	`extern const int __aeabi_LC_TIME = ...; (__aeabi_LC_TIME)`
LC_ALL	`extern const int __aeabi_LC_ALL = ...; (__aeabi_LC_ALL)`

6.10 math.h

Math.h functions are functions of primitive types only and raise no standardization issues.

The definitions of HUGE_VAL and its C99 counterparts HUGE_VALF, HUGE_VALL, and INFINITY are slightly problematic in strict C89. HUGE_VAL must either expand to a constant specified by some non-C89 means (for example, as a C99 hexadecimal FP bit pattern), or it must expand to a location in the C library initialized with the appropriate value by some non-C89 means (for example, using assembly language).

Tool chains that define these macros as listed in the *required value* column of math.h definitions can use the same definitions inline when _AEABI_PORTABILITY_LEVEL != 0. Otherwise, the alternative portable definition must be used when _AEABI_PORTABILITY_LEVEL != 0.

The macro _AEABI_PORTABLE should be defined as described in Detecting whether a header file honors an AEABI portability request.

math.h definitions

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Name	Required value	Alternative portable definition	Comment
HUGE_VAL	0d_7FF0000000000000	extern const double __aeabi_HUGE_VAL	Double infinity
HUGE_VALL	0d_7FF0000000000000	extern const long double __aeabi_HUGE_VALL	Long double infinity
HUGE_VALF	0d_7F800000	extern const float __aeabi_HUGE_VALF	Float infinity
INFINITY	0f_7F800000	extern const float __aeabi_INFINITY	Float infinity
NAN	0f_7FC00000	extern const float __aeabi_NAN	Quiet

6.11 setjmp.h

The type and size of jmp_buf are defined by setjmp.h. Its contents are opaque, so setjmp and longjmp must be from the same library, and called out of line.

In deference to VFP, XScale Wireless MMX, and other co-processors manipulating 8-byte aligned types, a jmp_buf must be 8-byte aligned.

The minimum jmp_buf size is calculated as follows:

SP, LR: 2x4; reserved to setjmp implementation: 4x4; Total 3x8 bytes

General purpose register save: 8x4; Total 4x8 bytes

Floating point register save: 8x8; Total 8x8 bytes

WMMX (if present): 5x8; Total 5x8 bytes

Total: 20x8 = 160 bytes = 20 8-byte double-words.

If WMMX can be guaranteed not to be present this can be reduced to 15x8 = 120 bytes.

If floating point hardware can be guaranteed not to be present this can be further reduced to 7x8 = 56 bytes.

An implementation may define the size of a jmp_buf to be larger than the ABI-defined minimum size.

If code allocates a jmp_buf statically using a compile-time constant size smaller than the "maximum minimum" value of 160 bytes, the size of the jmp_buf becomes part of its interface contract. Portable code is urged not to do this.

The link-time constant __aeabi_JMP_BUF_SIZE gives the actual size of a target system jmp_buf measured in 8-byte double-words.

When _AEABI_PORTABILITY_LEVEL != 0, the required definition of jmp_buf cannot be used to create jmp_buf objects. Instead, a jmp_buf must be passed as a parameter or allocated dynamically.

If the Branch Target Identification mechanism is enabled, longjmp may transfer control using a BTI-setting instruction that requires a BTI-clearing instruction at the destination.

setjmp.h definitions

Name	Recommended definition (_AEABI_PORTABILITY_LEVEL = 0)	Required portable definition (_AEABI_PORTABILITY_LEVEL != 0)
jmp_buf	`typedef __int64 jmp_buf[20]`	`typedef __int64 jmp_buf[];`
__aeabi_JMP_BUF_SIZE	A value not less than 20.	extern const int __aeabi_JMP_BUF_SIZE = ...

When _AEABI_PORTABILITY_LEVEL != 0, conforming implementations should define _AEABI_PORTABLE as specified in Detecting whether a header file honors an AEABI portability request.

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6.12 signal.h

Signal.h declares the typedef sig_atomic_t which is unused in the signal interface.

Arm processors from architecture v4 onwards support uni-processor atomic access to 1, 2, and 4 byte data. Uni-processors that do not use low latency mode *might* support atomic access to 8-byte data via LDM/STM and/or LDRD/STRD. In architecture v6, LDREX/STREX gives multi-processor-safe atomic access to 4-byte data, and from v7 onwards the load/store exclusive instruction family gives MP-safe atomic access to 1, 2, 4, and 8 byte data.

The only access size likely to work with *all* Arm CPUs, buses, and memory systems is 4-bytes, so we strongly recommend sig_atomic_t to be int (and require this definition when _AEABI_PORTABILITY_LEVEL != 0).

Also declared are function pointer constants SIG_DFL, SIG_IGN, and SIG_ERR. Usually, these are defined to be suitably cast integer constants such as 0, 1, and -1. Unfortunately, when facing an unknown embedded system, there are no address values that can be safely reserved, other than addresses in the program itself.

It is a quality of implementation whether at least one byte of program image space will be allocated to each of __aeabi_SIG_* listed in signal.h standard handler definitions, or whether references to those values will be relocated to distinct, target-dependent constants.

Signal.h defines six SIGXXX macros. We recommend the common Linux/Unix values listed in Standard signal names and values. All signal values are less than 64. With the exception of SIGABRT, these are also the Windows SIGXXX values.

When _AEABI_PORTABILITY_LEVEL != 0, conforming implementations should define _AEABI_PORTABLE as specified in Detecting whether a header file honors an AEABI portability request.

signal.h standard handler definitions

Name	Required portable definition
sig_atomic_t	`typedef int sig_atomic_t;`
SIG_DFL	`extern void __aeabi_SIG_DFL(int);` `#define SIG_DFL  (__aeabi_SIG_DFL)`
SIG_IGN	`extern void __aeabi_SIG_IGN(int);` `#define SIG_IGN  (__aeabi_SIG_IGN)`
SIG_ERR	`extern void __aeabi_SIG_ERR(int);` `#define SIG_ERR  (__aeabi_SIG_ERR)`

Standard signal names and values

Name	Recommended value	Required portable definition
sigabrt	6	`extern const int __aeabi_SIGABRT = ...` `(__aeabi_SIGABRT)`
SIGFPE	8	`extern const int __aeabi_SIGFPE = ...` `(__aeabi_SIGFPE)`

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Name	Recommended value	Required portable definition
SIGILL	4	`extern const int __aeabi_SIGILL = ... (__aeabi_SIGILL)`
SIGINT	2	`extern const int __aeabi_SIGINT = ... (__aeabi_SIGINT)`
SIGSEGV	11	`extern const int __aeabi_SIGSEGV = ... (__aeabi_SIGSEGV)`
SIGTERM	15	`extern const int __aeabi_SIGTERM = ... (__aeabi_SIGTERM)`

6.13 stdarg.h

Stdarg.h declares the type va_list defined by the [AAPCS32] and three macros, va_start, va_arg, and va_end. Only va_list appears in binary interfaces.

This header does not define _AEABI_PORTABLE (Detecting whether a header file honors an AEABI portability request).

6.14 stdbool.h

Stdbool.h defines the type bool and the values true and false.

This header does not define _AEABI_PORTABLE (Detecting whether a header file honors an AEABI portability request).

6.15 stddef.h

The size and alignment of each typedef declared in stddef.h is specified by the [AAPCS32].

This header does not define _AEABI_PORTABLE (Detecting whether a header file honors an AEABI portability request).

6.16 stdint.h

The types declared in this C99 header are defined by the Arm architecture and [AAPCS32].

This header does not define _AEABI_PORTABLE (Detecting whether a header file honors an AEABI portability request).

6.17 stdio.h

6.17.1 Background discussion and rationale

Stream-oriented library functions can only be useful if the end user (of a deeply embedded program), or the underlying operating environment, can implement the stream object (that is, the FILE structure).

To standardize portably what can be standardized in binary form:

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- A FILE must be opaque.
- Writing to a stream must reduce to a sequence of calls to a lowest common denominator stream operation such as fputc (sensible for fprintf, but less so for fwrite).
- Similarly, reading from a stream must reduce to a sequence of calls to fgetc.
- putc, putchar, getc, and getchar cannot be inlined in applications, but must expand to an out of line call to a function from the library.
- We must take care with stdin, stdout, and stderr, as discussed in Under-specified exported data.

Surprisingly, these constraints *can* be compatible with high performance implementations of fread, fwrite, and fprintf. For example, if __flsbuf is included from the RVCT C library (effectively Arm's implementation of fputc), a faster fwrite, aware of the FILE implementation, replaces use of the generic fputc-using fwrite.

In principle the same trick can be used with fprintf (probably not worthwhile) and fread (definitely worthwhile).

The most contentious issue remaining is that of not being able to inline getc and putc. However, the effect of such inlining on performance will usually be much less dramatic than might be imagined.

- The essential work of putc takes about 10 cycles (Arm9-class CPU) and uses four registers in almost any plausible implementation. Getc is similar, but needs only 3 registers.
- Fputc and fgetc both embed a conditional tail continuation and use most of the AAPCS scratch registers, so the difference in effect on register allocation between putc inline and a call to fputc will often be small.

In essence, the inescapable *additional* cost of putc out of line (getc is similar) is only:

- The cost of the call and return, typically about 6 cycles.
- A move of the stream handle to r1 (r0 for getc), costing 1 cycle.

Given some loop overhead and some, even trivial, processing of each character, it is hard to see how moving putc (or getc) out of line could add more than 25% to the directly visible per-character cycle count. Given that buffer flushing and filling probably doubles the visible per-character cycle count, the overall impact on performance is unlikely to be more than 10-15%, even when almost no work is being done on each character written or read.

When _AEABI_PORTABILITY_LEVEL != 0, conforming implementations should define _AEABI_PORTABLE as specified in Detecting whether a header file honors an AEABI portability request.

6.17.2 Easy stdio.h definitions

The definitions listed in this section are commonly accepted values, or values easily distinguishable from legacy values. Together with the definition of fpos_t they make all the functions listed in stdio.h precisely defined.

Easy stdio.h definitions

Name	Required definition	Comment
fpos_t	`struct { long long pos; mbstate_t mbstate; }`	Only ever passed and returned by reference, and really opaque, so 32-bit systems need use only the first word of pos. C99 virtually requires an mbstate_t member in support of multi-byte stream I/O.
EOF	(-1)	Not contentious. *Everybody* agrees!

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Name	Required definition	Comment
SEEK_SET	0	Not contentious. *Everybody* agrees!
SEEK_CUR	1	
SEEK_END	2	

6.17.3 Difficult stdio.h definitions

When _AEABI_PORTABILITY_LEVEL !=0, getc, putc, getchar, and putchar must expand to calls to out of line functions (or to other stdio functions), and the standard streams must expand to references to FILE * variables (this is more general than expanding directly to the addresses of the FILE objects themselves because it is compatible with execution environments in which standard FILE objects do not have link-time addresses).

Difficult stdio.h definitions

Name	Recommended value	Required portable definition
getc, putc		Must be functions, must not be inlined (except as equivalent calls to other stdio functions)
getchar, putchar		

stdin		`extern FILE * __aeabi_stdin;`
		`extern FILE *__aeabi_stdout;`
		`extern FILE *__aeabi_stderr;`

stdout		
stderr		

_IOFBF	0	`extern const int __aeabi_IOFBF = 0; (__aeabi_IOFBF)`
		`extern const int __aeabi_IOLBF = 1; (__aeabi_IOLBF)`
		`extern const int __aeabi_IONBF = 2; (__aeabi_IONBF)`

_IOLBF	1	
_IONBF	2	
BUFSIZ	≥ 256	`extern const int __aeabi_BUFSIZ = 256; (__aeabi_BUFSIZ)`
FOPEN_MAX	≥ 8	`extern const int __aeabi_FOPEN_MAX = 8; (__aeabi_FOPEN_MAX)`
TMP_MAX	≥ 256	`extern const int __aeabi_TMP_MAX = 256; (__aeabi_TMP_MAX)`
FILENAME_MAX	≥ 256	`extern const int __aeabi_FILENAME_MAX = 256; (__aeabi_FILENAME_MAX)` `extern const int __aeabi_L_tmpnam = 256; (__aeabi_L_tmpnam)`
L_tmpnam		

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Note

- Among these difficult constants, BUFSIZ is least difficult. It is merely the default for a value that can be specified by calling setvbuf. A cautious application can use a more appropriate value.
- FOPEN_MAX is the *minimum* number of files the execution environment guarantees can be open simultaneously. Similarly, TMP_MAX is the *minimum* number of distinct temporary file names generated by calling tmpnam.

Aside

In the 1.7M lines of source code in the Arm code size database – encompassing a broad spectrum of applications from deeply embedded to gcc_cc1 and povray – L_tmpnam is unused, FILENAME_MAX is used just 5 times [in 1 application], and there are no uses of TMP_MAX save in one application that simulates a run-time environment.

6.18 stdlib.h

Stdlib.h contains the following interface difficulties.

- The div_t and ldiv_t structures and div and ldiv functions. We think these functions are little used, so we define the structures in the obvious way. Because the functions are pure, compilers are entitled to inline them.
- The values of EXIT_FAILURE and EXIT_SUCCESS. There is near universal agreement that success is 0 and failure is non-0, usually 1.
- MB_CUR_MAX. This can only expand into a function call (to get the current maximum length of a locale-specific multi-byte sequence. This is a marginal issue for embedded applications, though not for platforms..
- We do not standardize the sequence computed by rand(). If an application depends on pseudo-random numbers, we believe it will use its own generator.
- Getenv and system are both questionable candidates for an embedded (rather than platform) ABI standard. We do not standardize either function.

When _AEABI_PORTABILITY_LEVEL != 0, a conforming implementation must define _AEABI_PORTABLE as specified in Detecting whether a header file honors an AEABI portability request.

stdlib.h definitions

Name	Required definition	Comment / Required portable definition

div_t
ldiv_t
lldiv_t
	`struct { int quot, rem; }`
	`struct { long int quot, rem; }`
	`struct { long long int quot, rem; }`
		div and ldiv are pure and can be inlined. lldiv_t and lldiv are C99 extensions.

EXIT_SUCCESS	0	*Everyone agrees.*
EXIT_FAILURE	1	

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Name	Required definition	Comment / Required portable definition
MB_CUR_MAX	(__aeabi_MB_CUR_MAX())	int __aeabi_MB_CUR_MAX(void);

6.19 string.h

String.h poses no interface problems. It contains only function declarations using standard basic types.

With the exception of strtok (which has static state), and strcoll and strxfrm (which depend on the locale setting), all functions are pure may be inlined by a compiler.

This header does not define _AEABI_PORTABLE (Detecting whether a header file honors an AEABI portability request).

6.20 time.h

The time.h header defines typedefs clock_t and time_t, struct tm, and the constant CLOCKS_PER_SEC. The constant is properly a property of the execution environment.

Portable code should not assume that time_t or clock_t are either signed or unsigned, and should generate only positive values no larger than INT_MAX.

When _AEABI_PORTABILITY_LEVEL != 0, a conforming implementation must define _AEABI_PORTABLE as specified in Detecting whether a header file honors an AEABI portability request.

time.h definitions

Name	Required portable definition
time_t; clock_t;	`unsigned int;` `unsigned int;`
struct tm {...}	All and only the fields listed in the C89 standard, in the published order, together with 2 additional 4-byte trailing fields (as discussed in Structures used in the C library interface, above).
CLOCKS_PER_SEC	`extern const int __aeabi_CLOCKS_PER_SEC;` `(__aeabi_CLOCKS_PER_SEC)`

6.21 wchar.h

The interface to entities declared in this header is largely defined by the AAPCS. It must also define wint_t, WEOF, and mbstate_t. There is little reason for WEOF to be anything other than -1.

For mbstate_t we define a structure field big enough to hold the data from an incomplete multi-byte character together with its shift state. 32-bits suffice for any CJK-specific encoding such as shift-JIS, Big-5, UTF8, and UTF16. Because the structure is always addressed indirectly, we also include some headroom.

When _AEABI_PORTABILITY_LEVEL != 0, conforming implementations must not inline functions read or write an mbstate_t, and should define _AEABI_PORTABLE as specified in Detecting whether a header file honors an AEABI portability request.

wchar.h definitions

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Name	Required definition	Comment
wint_t	int or unsigned int	
WEOF	((wint_t)-1)	
mbstate_t	`struct { unsigned state1, state2;}`	Big enough for CJK-specifics, UTF8 and UTF16, and some headroom.

6.22 wctype.h

This header is mostly defined by the AAPCS and wchar.h. The only additional types defined are wctype_t and wctrans_t. Both are handles passed to or produced by wide character functions.

When _AEABI_PORTABILITY_LEVEL != 0, conforming implementations must not inline functions that accept or produce these handles, and should define _AEABI_PORTABLE as specified in Detecting whether a header file honors an AEABI portability request.

wctype.h definitions

Name	Required definition	Comment
wctype_t	void *	Opaque handle.
wctrans_t	void *	Opaque handle.

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7 Summary of requirements on C Libraries

Summary of conformance requirements when _AEABI_PORTABILITY_LEVEL != 0

Header	Affected	Summary of conformance requirements
assert.h	Yes	Must declare __aeabi_assert (Assert.h declarations).
ctype..h	Yes	Must define **is**xxxx(c) to be ((**is**xxxx)(c)) etc [no inline implementation] or implement the inline versions as described in ctype.h when _AEABI_PORTABILITY_LEVEL != 0 and isxxxxx inline.
errno.h	Yes	errno is (*__aeabi_errno()); , ERANGE, etc are link-time constants (errno.h definitions)
float.h	No	
inttypes.h	No	
iso646.h	No	
limits.h	Yes	MB_LEN_MAX is a link-time constant (The value of MB_LEN_MAX).
locale.h	Yes	Must hide struct lconv and localeconv and declare struct __aeabi_lconv and __aeabi_localeconv (__aeabi_lconv, locale.h required portable definitions). LC_* are link-time constants (LC_* macros).
math.h	Yes	Must define HUGE_VAL and similar using non-C89 means (e.g. C99 hex float notation) or provide suitably initialized const library members (math.h definitions).
setjmp.h	Yes	Must declare jmp_buf[] to preclude creating such objects. __aeabi_JMP_BUF_SIZE is a link-time constant (setjmp.h definitions).
signal.h	Yes	SIG_* are defined by the library (signal.h standard handler definitions); SIG* are link-time const (Standard signal names and values).
stdarg.h	No	
stdbool.h	No	
stddef.h	No	
stdint.h	No	
stdio.h	Yes	**Get/put macros must expand to function-calls; stdin, stdout, and stderr must expand to pointers, not addresses of FILE objects; FILE must be opaque. Some consensus constants must be defined as in Easy stdio.h definitions table; other controlling values become link-time constants as defined in** Difficult stdio.h definitions table
stdlib.h	Yes	MB_CUR_MAX must expand to the function call __aeabi_MB_CUR_MAX(); div_t, ldiv_t, EXIT_* must be declared as described in stdlib.h definitions.
string.h	No	

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Header	Affected	Summary of conformance requirements
time.h	Yes	time_t ,clock_t, and struct tm must be as specified in time.h definitions. CLOCKS_PER_SEC must be a link-time constant.
wchar.h	Yes	wint_t, WEOF, and mbstate_t must be declared as specified in wchar.h definitions.
wctype.h	Yes	wctype_t and wctrans_t must be opaque handles as specified in wctype.h definitions.

Affected headers (only) must #define _AEABI_PORTABLE if (and only if) they honor their portability obligations and _AEABI_PORTABILITY_LEVEL has been defined by the user (Detecting whether a header file honors an AEABI portability request).

Summary of link-time constants (when _AEABI_PORTABILITY_LEVEL != 0)

Header	ANSI C macro	AEABI name (extern const int __attribute__(STV_HIDDEN) …)
errno.h	`EDOM`	`__aeabi_EDOM`
	`ERANGE`	`__aeabi_ERANGE`
	`EILSEQ`	`__aeabi_EILSEQ`
limits.h	`MB_LEN_MAX`	`__aeabi_MB_LEN_MAX`
locale.h	`LC_COLLATE`	`__aeabi_LC_COLLATE`
	`LC_CTYPE`	`__aeabi_LC_CTYPE`
	`LC_MONETARY`	`__aeabi_LC_MONETARY`
	`LC_NUMERIC`	`__aeabi_LC_NUMERIC`
	`LC_TIME`	`__aeabi_LC_TIME`
	`LC_ALL`	`__aeabi_LC_ALL`
setjmp.h	None	`__aeabi_JMP_BUF_SIZE` (in 64-bit words)
signal.h	`SIGABRT`	`__aeabi_SIGABRT`
	`SIGFPE`	`__aeabi_SIGFPE`
	`SIGILL`	`__aeabi_SIGILL`
	`SIGINT`	`__aeabi_SIGINT`
	`SIGSEGV`	`__aeabi_SIGSEGV`
	`SIGTERM`	`__aeabi_SIGTERM`

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Header	ANSI C macro	AEABI name (extern const int __attribute__(STV_HIDDEN) …)
stdio.h	_IOFBF	__aeabi_IOFBF
	_IOLBF	__aeabi_IOLBF
	_IONBF	__aeabi_IONBF
	BUFSIZ	__aeabi_BUFSIZ
	FOPEN_MAX	__aeabi_FOPEN_MAX
	TMP_MAX	__aeabi_TMP_MAX
	FILENAME_MAX	__aeabi_FILENAME_MAX
	L_tmpnam	__aeabi_L_tmpnam
time.h	CLOCKS_PER_SEC	__aeabi_CLOCKS_PER_SEC

If possible, link-time constants should be defined with visibility STV_HIDDEN [AAELF32], and linked statically with client code. Dynamic linking is possible, but will almost always be significantly less efficient.

Additional functions (when _AEABI_PORTABILITY_LEVEL != 0)

Header	ANSI C macro	AEABI function
assert.h	assert	`void __aeabi_assert(` `    const char *expr, const char *file, int line);`
errno.h	errno	`volatile int *__aeabi_errno_addr(void);` `(*__aeabi_errno_addr())`
locale.h	None	`struct __aeabi_lconv *__aeabi_localeconv(void);`
signal.h	SIG_DFL	`extern void __aeabi_SIG_DFL(int);`
	SIG_IGN	`extern void __aeabi_SIG_IGN(int);`
	SIG_ERR	`extern void __aeabi_SIG_ERR(int);`
stdlib.h	MB_CUR_MAX	`int __aeabi_MB_CUR_MAX(void);`

It is an implementation choice whether __aeabi_SIG_* occupy space in the run-time library, or whether they resolve to absolute symbols.

As with other link-time constants, these should be defined with visibility STV_HIDDEN [AAELF32], and linked statically with client code. Dynamic linking is possible, but will almost always be significantly less efficient.

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