C Library ABI for the ARM® Architecture

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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++.

Keywords

C library ABI, run-time library

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1 ABOUT THIS DOCUMENT

1.1 Change control

1.1.1 Current status and anticipated changes

This document has been released publicly. Anticipated changes to this document include:

- Typographical corrections.
- Clarifications.
- Compatible extensions.

1.1.2 Change history

Issue	Date	By	Change
0.1	30th October 2003	LS	First public DRAFT.
2.0	24th March 2005	LS	First public release.
2.01	4th July 2005	LS	First batch of typographical corrections. Added stdbool.h.
2.02	5th October 2005	LS	Clarified the intention behind __B and isblank() in §5.3.1.1. Fixed the clash with the C99 specification.
2.03	5th May 2006	LS	Corrected misinformation in §5.12 concerning (non-)atomic access to 8-byte types using ldrd/strd/ldm/stm.
2.04 / A	25th October 2007	LS	In §3.4, used the common table of registered vendor names Document renumbered (formerly GENC-003539 v2.04).
B	4th November 2009	LS	Added §4.2.4.2 explaining why, in C++ generating portable binary, standard library functions should be used via extern “C” linkage.

1.2 References

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

Ref	URL or other reference	Title
AAELF		ELF for the ARM Architecture.
AAPCS		Procedure Call Standard for the ARM Architecture.
BSABI		ABI for the ARM Architecture (Base Standard).
CLIBABI	*This document*	C Library ABI for the ARM Architecture
CPPABI		C++ ABI for the ARM Architecture
RTABI		Run-time ABI for the ARM Architecture.

1.3 Terms and abbreviations

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

Term	Meaning
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 *C++ ABI for the ARM Architecture*, the *Run-time ABI for the ARM Architecture*, the *C Library ABI for the ARM Architecture.*
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

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1.5 Acknowledgements

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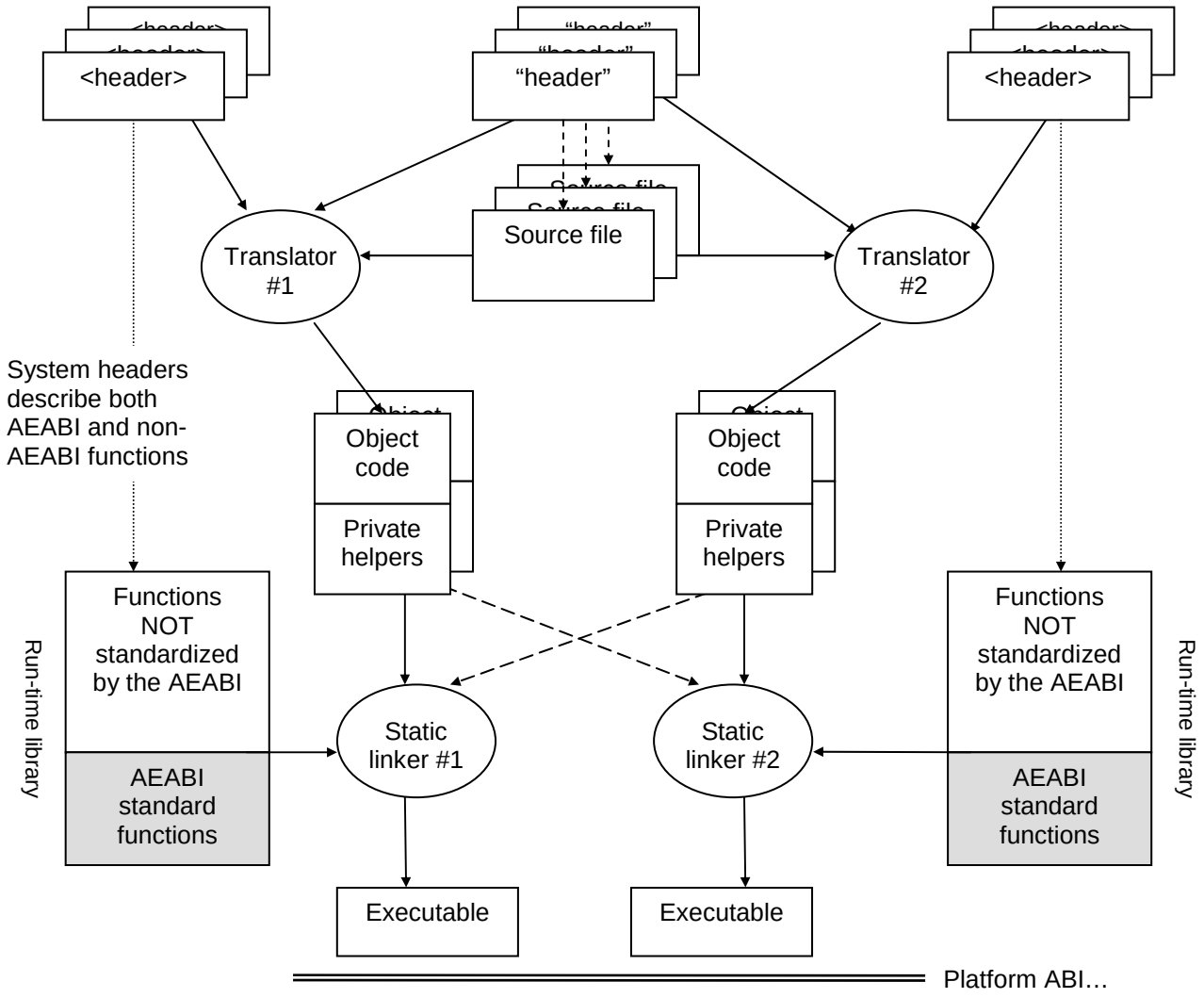
2 SCOPE

Conformance to the *ABI for the ARM architecture* [BSABI] supports inter-operation between:

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

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

Figure 1, 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 tool chain building it, not those associated with the library with which the object will, ultimately, be linked.

3 INTRODUCTION

A number of principles of inter-operation are implicit in, or compatible with, Figure 1, above. This section describes these principles precisely, as they apply to a C library, and gives a rationale for each one. The corresponding section (§3) of [RTABI] discusses the same principles as they apply to run-time helper functions.

3.1 Most C library functions have a standard ABI

C library functions are declared explicitly in standard headers.

As shown in §4, 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 [AAPCS]. 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.

3.1.1 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.

3.1.2 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.

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).

3.1.3 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 §4, below, these functions are considered case by case under the library sub-sections that declare them.

3.1.4 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*. §5.4, 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 §5.3, below.

3.2 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 tool chains (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.

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 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 §3.1, above.

3.3 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 tool chain'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. **End aside**).

3.4 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.

The table of registered vendor prefixes is given below.

Table of registered vendor prefixes

Name	Vendor
`aeabi`	Reserved to the ABI for the ARM Architecture (EABI pseudo-vendor)

Name	Vendor
`AnonXyz` `anonXyz`	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
`GHS`	Green Hills Systems
`gnu`	GNU compilers and tools (Free Software Foundation)
`iar`	IAR Systems
`intel`	Intel Corporation
`ixs`	Intel Xscale
`PSI`	PalmSource Inc.
`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 THE C LIBRARY

4.1 C Library overview

The C Library ABI for the ARM architecture is associated with the headers listed in Table 1 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'.

Table 1, C library headers

Header	Origin	Comment
assert.h	C	See §5.2. Standardize __aeabi_assert(const char*, const char*, int).
ctype.h	C	See §5.3. Inlined macros cause difficulties for standardization.
errno.h	C	See §5.4.
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 §5.8. Defined by the AAPCS (save for MB_LEN_MAX).
locale.h	C	See §5.9.
math.h	C	See §5.10. 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 §5.12. 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 §5.17. Inlined macros and properties of the environment cause difficulties.
stdlib.h	C	See §5.18. 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 §5.20. CLOCKS_PER_SEC is a property of the execution environment.
wchar.h	C	See §5.21. No issues apart from mbstate_t.
wctype.h	C	See §5.22. Defined by the AAPCS and commonsense.

4.2 The C library standardization model

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

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.

4.2.2 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.
  - 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.

4.2.2.1 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.

4.2.2.2 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 *.

4.2.2.3 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.

4.2.2.4 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).

4.2.3 Our approach to defining a C library ABI

4.2.3.1 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.
- 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 EDOM, ERANGE, and EILSEQ from errno.h. This is a grey list category because there is consensus that EDOM = 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 §4.2.1. 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 tool chains and execution environments, and only a small tax on portable binaries.

4.2.3.2 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[];
```


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. **End aside**).

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.

4.2.3.3 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).

  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 §5.3, 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.

4.2.4 Naming issues in C++ header files

4.2.4.1 Names introduced by this C library ABI into <c*yyy*> 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.

4.2.4.2 C++ names of C library functions

In most C++ implementations an encoding of a function’s type signature forms part of the *mangled name* [CPPABI] used to name binary functions. If two sides of an interface (built using different tool chains) 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` [CPPABI]. 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.

4.2.5 Library file organization

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

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

4.3 Summary of the inter-tool-chain 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 tool chain, 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 tool chains. 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 tool chain is implementation defined (Q-o-I).

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 [RTABI]).
- 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 tool chains to use the same header files (defined by the platform). Such objects are not portable, but exportable only to a single environment.

5 THE C LIBRARY SECTION BY SECTION

5.1 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 [AAPCS].

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.

5.1.1 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 §6 for a summary). The application can test whether _AEABI_PORTABLE is defined after the inclusion, and #error if not.

Table 2, Detecting when AEABI portability obligations have been met

Application	Library header

`#define _AEABI_PORTABILITY_LEVEL 1`
`#undef _AEABI_PORTABLE`
 	
`#include <header.h>`
 	
`#ifndef _AEABI_PORTABLE`
`#  error "AEABI not supported by header.h"`
`#endif`
	`#if defined _AEABI_PORTABILITY_LEVEL &&`
	`   !defined _AEABI_PORTABLE`
	`#  define _AEABI_PORTABLE`
	`#endif`

5.2 assert.h

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

Table 3, Assert.h declarations

Name	Required definition (when generating a message)
assert	void __aeabi_assert(const char *expr, const char *file, int line); #define assert(__e) ((__e) ? (void)0 : __aeabi_assert(#__e, __FILE__, __LINE__))

A conforming implementation must signal its conformance as described in §5.1.1.

5.3 ctype.h

The ctype *functions* are fully defined by the C standard and the [AAPCS]. 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 §5.1.1.

5.3.1 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];

#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 §5.3.1.1, in a COMDAT section or in an adjunct library. **End aside**).

5.3.1.1 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 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.

5.4 errno.h

There are many reasons why accessing errno should call a function call. We define it as shown in Table 4, below.

Table 4, 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 EDOM and ERANGE. There is little consensus about EILSEQ. 47 is claimed to be the IEEE 1003.1 POSIX value. **End aside**).

5.5 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 (§5.1.1).

5.6 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 [AAPCS].

This header does not define _AEABI_PORTABLE (§5.1.1).

5.7 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 (§5.1.1).

5.8 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 §5.1.1)

Table 5, 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)`

5.9 locale.h

Locale.h defines 6 macros for controlling constants (Table 8) 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 §5.1.1.

Table 6, struct __aeabi_lconv

```
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;
  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;
};
```

Table 7, locale.h required portable definitions

Name	Required portable definition
`__aeabi_lconv`	As in Table 6, above.
`__aeabi_localeconv`	`struct __aeabi_lconv *__aeabi_localeconv(void)`

Table 8, 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)`

5.10 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, NAN 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 Table 9 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 §5.1.1.

Table 9, math.h definitions

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

Name	Required value	Alternative portable definition	Comment
NAN	0f_7FC00000	extern const float __aeabi_NAN	Quiet NaN

5.11 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. A minimum size to accommodate ARM + VFPv2 is 8 + 16 = 24 double-words (but implementation requirements will vary and can be more than this minimum).

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.

Table 10, setjmp.h definitions

Name	Recommended definition (_AEABI_PORTABILITY_LEVEL = 0)	Required portable definition (_AEABI_PORTABILITY_LEVEL != 0)
jmp_buf	typedef __int64 jmp_buf[24]	typedef __int64 jmp_buf[ ];
__aeabi_JMP_BUF_SIZE	A value not less than 8.	extern const int __aeabi_JMP_BUF_SIZE = …

When _AEABI_PORTABILITY_LEVEL != 0, conforming implementations should define _AEABI_PORTABLE as specified in §5.1.1.

5.12 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 Table 11, 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 Table 12. 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 §5.1.1.

Table 11, 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)

Table 12, 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)
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)

5.13 stdarg.h

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

This header does not define _AEABI_PORTABLE (§5.1.1).

5.14 stdbool.h

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

This header does not define _AEABI_PORTABLE (§5.1.1).

5.15 stddef.h

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

This header does not define _AEABI_PORTABLE (§5.1.1).

5.16 stdint.h

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

This header does not define _AEABI_PORTABLE (§5.1.1).

5.17 stdio.h

5.17.1 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:

- 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 §4.2.2.4.

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 §5.1.1.

5.17.2 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.

Table 13, 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!
SEEK_SET SEEK_CUR SEEK_END	0 1 2	Not contentious. *Everybody* agrees!

5.17.3 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).

Table 14, Dificult stdio.h definitions

Name	Recommended value	Required portable definition
getc, putc getchar, putchar		Must be functions, must not be inlined (except as equivalent calls to other stdio functions)
stdin stdout stderr		extern FILE * __aeabi_stdin; extern FILE *__aeabi_stdout; extern FILE *__aeabi_stderr;

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

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
 	
L_tmpnam
	≥ 256	extern const int __aeabi_FILENAME_MAX = 256;
		(__aeabi_FILENAME_MAX)
		extern const int __aeabi_L_tmpnam = 256;
		(__aeabi_L_tmpnam)

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.

Note 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. **End aside**).

5.18 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 §5.1.1.

Table 15, 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 EXIT_FAILURE	0 1	*Everyone agrees.*
MB_CUR_MAX	(__aeabi_MB_CUR_MAX())	int __aeabi_MB_CUR_MAX(void);

5.19 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 (§5.1.1).

5.20 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 §5.1.1.

Table 16, 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 §4.2.3.2, above).
CLOCKS_PER_SEC	extern const int __aeabi_CLOCKS_PER_SEC; (__aeabi_CLOCKS_PER_SEC)

5.21 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 wint_t to be other than int, and for WEOF to be 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 §5.1.1.

Table 17, wchar.h definitions

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

5.22 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 §5.1.1.

Table 18, wctype.h definitions

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

6 SUMMARY OF REQUIREMENTS ON C LIBRARIES

Table 19, Summary of conformance requirements when _AEABI_PORTABILITY_LEVEL != 0

Header	Affected	Summary of conformance requirements
assert.h	Yes	Must declare __aeabi_assert (Table 3).
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 §5.3.1.
errno.h	Yes	errno is (*__aeabi_errno()); EDOM, ERANGE, etc are link-time constants (Table 4)
float.h	No	
inttypes.h	No	
iso646.h	No	
limits.h	Yes	MB_LEN_MAX is a link-time constant (Table 5).
locale.h	Yes	Must hide struct lconv and localeconv and declare struct __aeabi_lconv and __aeabi_localeconv (Table 6, Table 7). LC_* are link-time constants (Table 8).
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 (Table 9).
setjmp.h	Yes	Must declare jmp_buf[] to preclude creating such objects. __aeabi_JMP_BUF_SIZE is a link-time constant (Table 10).
signal.h	Yes	SIG_* are defined by the library (Table 11); SIG* are link-time const (Table 12).
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 Table 13; other controlling values become link-time constants as defined in Table 14.
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 Table 15.
string.h	No	
time.h	Yes	time_t ,clock_t, and struct tm must be as specified in Table 16. CLOCKS_PER_SEC must be a link-time constant.
wchar.h	Yes	wint_t, WEOF, and mbstate_t must be declared as specified in Table 17.
wctype.h	Yes	wctype_t and wctrans_t must be opaque handles as specified in Table 18.

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 (§5.1.1).

Table 20, 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
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 [AAELF], and linked statically with client code. Dynamic linking is possible, but will almost always be significantly less efficient.

Table 21, 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 [AAELF], and linked statically with client code. Dynamic linking is possible, but will almost always be significantly less efficient.