



# RISC-V ABIs Specification

Version 1.1, June 21, 2025: Pre-release

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# Preamble



*This document is in the [Development state](#)*

*Assume everything can change.*

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Please cite as: `RISC-V ABIs Specification, Document Version June 21, 2025-draft', Editors Kito Cheng and Jessica Clarke, RISC-V International, June 2025.

The latest version of this document can be found here: [github.com/riscv-non-isa/riscv-elf-psabi-doc](https://github.com/riscv-non-isa/riscv-elf-psabi-doc).

This specification is written in collaboration with the development communities of the major open-source toolchain and operating system communities, and as such specifies what has been agreed upon and implemented. As a result, any changes to this specification that are not backwards-compatible would break ABI compatibility for those toolchains, which is not permitted unless for features explicitly marked as experimental, and so will not be made unless absolutely necessary, regardless of whether the specification is a pre-release version, ratified version or anything in between. This means any version of this specification published at the above link can be regarded as stable in the technical sense of the word (but not necessarily in the official RISC-V International specification state meaning), with the official specification state being an indicator of the completeness, clarity and general editorial quality of the specification.

# Introduction

This specification provides the processor-specific application binary interface document for RISC-V.

This specification consists of the following three parts:

- Calling convention
- ELF specification
- DWARF specification

A future revision of this ABI will include a canonical set of mappings for memory model synchronization primitives.

# Terms and Abbreviations

This specification uses the following terms and abbreviations:

| Term              | Meaning  |
|-------------------|--|
| ABI               | Application Binary Interface   |
| gABI              | Generic System V Application Binary Interface  |
| ELF               | Executable and Linking Format  |
| psABI             | Processor-Specific ABI   |
| DWARF             | Debugging With Arbitrary Record Formats  |
| GOT               | Global Offset Table  |
| PLT               | Procedure Linkage Table  |
| PC                | Program Counter  |
| TLS               | Thread-Local Storage   |
| NTBS              | Null-Terminated Byte String  |
| XLEN              | The width of an integer register in bits   |
| FLEN              | The width of a floating-point register in bits   |
| Linker relaxation | A mechanism for optimizing programs at link-time, see <a href="#">Chapter 9</a> for more detail. |
| RVWMO             | RISC-V Weak Memory Order, as defined in the RISC-V specification.                                |

# Status of ABI

| ABI Name   | Status   |
|------------|----------|
| ILP32      | Ratified |
| ILP32F     | Ratified |
| ILP32D     | Ratified |
| ILP32E     | Draft    |
| LP64       | Ratified |
| LP64F      | Ratified |
| LP64D      | Ratified |
| LP64Q      | Ratified |
| RV64ILP32  | Draft    |
| RV64ILP32F | Draft    |
| RV64ILP32D | Draft    |
| RV64ILP32Q | Draft    |



ABI for big-endian is **NOT** included in this specification, we intend to define that in future version of this specification.



# RISC-V Calling Conventions

# Chapter 1. Register Convention

## 1.1. Integer Register Convention

Table 1. Integer register convention

| Name      | ABI Mnemonic | Meaning                | Preserved across calls? |
|-----------|--------------|------------------------|-------------------------|
| x0        | zero         | Zero                   | — (Immutable)           |
| x1        | ra           | Return address         | No                      |
| x2        | sp           | Stack pointer          | Yes                     |
| x3        | gp           | Global pointer         | — (Unallocatable)       |
| x4        | tp           | Thread pointer         | — (Unallocatable)       |
| x5 - x7   | t0 - t2      | Temporary registers    | No                      |
| x8 - x9   | s0 - s1      | Callee-saved registers | Yes                     |
| x10 - x17 | a0 - a7      | Argument registers     | No                      |
| x18 - x27 | s2 - s11     | Callee-saved registers | Yes                     |
| x28 - x31 | t3 - t6      | Temporary registers    | No                      |

In the standard ABI, procedures should not modify the integer registers `tp` and `gp`, because signal handlers may rely upon their values.

The presence of a frame pointer is optional. If a frame pointer exists, it must reside in `x8` (`s0`); the register remains callee-saved.

If a platform requires use of a dedicated general-purpose register for a platform-specific purpose, it is recommended to use `gp` (`x3`). The platform ABI specification must document the use of this register. For such platforms, care must be taken to ensure all code (compiler generated or otherwise) avoids using `gp` in a way incompatible with the platform specific purpose, and that global pointer relaxation is disabled in the toolchain.

## 1.2. Frame Pointer Convention

The presence of a frame pointer is optional. If a frame pointer exists, it must reside in `x8` (`s0`); the register remains callee-saved.

Code that uses a frame pointer will construct a linked list of stack frames, where each frame links to its caller using a "frame record". A frame record consists of two XLEN values on the stack; the return address and the link to the next frame record. The frame pointer register will point to the innermost frame, thereby starting the linked list. By convention, the lowest XLEN value shall point to the previous frame, while the next XLEN value shall be the return address. The end of the frame record chain is indicated by the address zero appearing as the next link in the chain.

After the prologue, the frame pointer register will point to the Canonical Frame Address or CFA, which is the stack pointer value on entry to the current procedure. The previous frame pointer and

return address pair will reside just prior to the current stack address held in `fp`. This puts the return address at `fp - XLEN/8`, and the previous frame pointer at `fp - 2 * XLEN/8`.

It is left to the platform to determine the level of conformance with this convention. A platform may choose:

- not to maintain a frame chain and use the frame pointer register as a general purpose callee-saved register.
- to allow the frame pointer register be used as a general purpose callee-saved register, but provide a platform specific mechanism to reliably detect this condition.
- to use a frame pointer to address a valid frame record at all times, but allow any procedure to choose to forgo creating a frame record.
- to use the frame pointer to address a valid frame record at all times, except leaf functions, who may elect to forgo creating a frame record.

## 1.3. Floating-Point Register Convention

Table 2. Floating-point register convention

| Name      | ABI Mnemonic | Meaning                | Preserved across calls? |
|-----------|--------------|------------------------|-------------------------|
| f0 - f7   | ft0 - ft7    | Temporary registers    | No                      |
| f8 - f9   | fs0 - fs1    | Callee-saved registers | Yes*                    |
| f10 - f17 | fa0 - fa7    | Argument registers     | No                      |
| f18 - f27 | fs2 - fs11   | Callee-saved registers | Yes*                    |
| f28 - f31 | ft8 - ft11   | Temporary registers    | No                      |

\*: Floating-point values in callee-saved registers are only preserved across calls if they are no larger than the width of a floating-point register in the targeted ABI. Therefore, these registers can always be considered temporaries if targeting the base integer calling convention.

The Floating-Point Control and Status Register (fcsr) must have thread storage duration in accordance with C11 section 7.6 "Floating-point environment <fenv.h>".

## 1.4. Vector Register Convention

### 1.4.1. Standard Calling Convention

Table 3. Standard vector register calling convention

| Name   | ABI Mnemonic | Meaning                                   | Preserved across calls? |
|--------|--------------|---|-------------------------|
| v0-v31 |              | Temporary registers                       | No                      |
| vl     |              | Vector length                             | No                      |
| vtype  |              | Vector data type register                 | No                      |
| vxrm   |              | Vector fixed-point rounding mode register | No                      |

| Name  | ABI Mnemonic | Meaning                                     | Preserved across calls? |
|-------|--------------|---|-------------------------|
| vxsat |              | Vector fixed-point saturation flag register | No                      |



Vector registers are not used for passing arguments or return values in this calling convention. Use the calling convention variant to pass arguments and return values in vector registers.

The `vxrm` and `vxsat` fields of `vcsr` are not preserved across calls and their values are unspecified upon entry.

Procedures may assume that `vstart` is zero upon entry. Procedures may assume that `vstart` is zero upon return from a procedure call.



Application software should normally not write `vstart` explicitly. Any procedure that does explicitly write `vstart` to a nonzero value must zero `vstart` before either returning or calling another procedure.

## 1.4.2. Calling Convention Variant

Table 4. Variant vector register calling convention\*

| Name    | ABI Mnemonic | Meaning                                     | Preserved across calls? |
|---------|--------------|---|-------------------------|
| v0      |              | Argument register                           | No                      |
| v1-v7   |              | Callee-saved registers                      | Yes                     |
| v8-v23  |              | Argument registers                          | No                      |
| v24-v31 |              | Callee-saved registers                      | Yes                     |
| vl      |              | Vector length                               | No                      |
| vtype   |              | Vector data type register                   | No                      |
| vxrm    |              | Vector fixed-point rounding mode register   | No                      |
| vxsat   |              | Vector fixed-point saturation flag register | No                      |

\*: Functions that use vector registers to pass arguments and return values must follow this calling convention. Some programming languages can require extra functions to follow this calling convention (e.g. C/C++ functions with attribute `riscv_vector_cc`).

Please refer to the [Section 2.3](#) section for more details about standard vector calling convention variant.



The `vxrm` and `vxsat` fields of `vcsr` follow the same behavior as the standard calling convention.

# Chapter 2. Procedure Calling Convention

This chapter defines standard calling conventions and standard calling convention variants, and describes how to pass arguments and return values.

Functions must follow the register convention defined in calling convention: the contents of any register without specifying it as an argument register in the calling convention are unspecified upon entry, and the content of any register without specifying it as a return value register or callee-saved in the calling convention are unspecified upon exit, the contents of all callee-saved registers must be restored to what was set on entry, and the contents of any fixed registers like `gp` and `tp` never change.



Calling convention for big-endian is **NOT** included in this specification yet, we intend to define that in future version of this specification.

## 2.1. Integer Calling Convention

The base integer calling convention provides eight argument registers, `a0-a7`, the first two of which are also used to return values.

Scalars that are at most `XLEN` bits wide are passed in a single argument register, or on the stack by value if none is available. When passed in registers or on the stack, integer scalars narrower than `XLEN` bits are widened according to the sign of their type up to 32 bits, then sign-extended to `XLEN` bits. When passed in registers or on the stack, floating-point types narrower than `XLEN` bits are widened to `XLEN` bits, with the upper bits undefined.

Scalars that are  $2 \times \text{XLEN}$  bits wide are passed in a pair of argument registers, with the low-order `XLEN` bits in the lower-numbered register and the high-order `XLEN` bits in the higher-numbered register. If no argument registers are available, the scalar is passed on the stack by value. If exactly one register is available, the low-order `XLEN` bits are passed in the register and the high-order `XLEN` bits are passed on the stack.

Scalars wider than  $2 \times \text{XLEN}$  bits are passed by reference and are replaced in the argument list with the address.

Aggregates whose total size is no more than `XLEN` bits are passed in a register, with the fields laid out as though they were passed in memory. If no register is available, the aggregate is passed on the stack. Aggregates whose total size is no more than  $2 \times \text{XLEN}$  bits are passed in a pair of registers; if only one register is available, the first `XLEN` bits are passed in a register and the remaining bits are passed on the stack. If no registers are available, the aggregate is passed on the stack. Bits unused due to padding, and bits past the end of an aggregate whose size in bits is not divisible by `XLEN`, are undefined.

Aggregates or scalars passed on the stack are aligned to the greater of the type alignment and `XLEN` bits, but never more than the stack alignment.

Aggregates larger than  $2 \times \text{XLEN}$  bits are passed by reference and are replaced in the argument list with the address, as are C++ aggregates with nontrivial copy constructors, destructors, or vtables.

Fixed-length vectors are treated as aggregates.

Empty structs or union arguments or return values are ignored by C compilers which support them as a non-standard extension. This is not the case for C++, which requires them to be sized types.

Arguments passed by reference may be modified by the callee.

Floating-point reals are passed the same way as aggregates of the same size; complex floating-point numbers are passed the same way as a struct containing two floating-point reals. (This constraint changes when the integer calling convention is augmented by the hardware floating-point calling convention.)

In the base integer calling convention, variadic arguments are passed in the same manner as named arguments, with one exception. Variadic arguments with  $2 \times \text{XLEN}$ -bit alignment and size at most  $2 \times \text{XLEN}$  bits are passed in an **aligned** register pair (i.e., the first register in the pair is even-numbered), or on the stack by value if none is available. After a variadic argument has been passed on the stack, all future arguments will also be passed on the stack (i.e. the last argument register may be left unused due to the aligned register pair rule).

Values are returned in the same manner as a first named argument of the same type would be passed. If such an argument would have been passed by reference, the caller allocates memory for the return value, and passes the address as an implicit first parameter.



There is no requirement that the address be returned from the function and so software should not assume that a0 will hold the address of the return value on return.

The stack grows downwards (towards lower addresses) and the stack pointer shall be aligned to a 128-bit boundary upon procedure entry. The first argument passed on the stack is located at offset zero of the stack pointer on function entry; following arguments are stored at correspondingly higher addresses.

In the standard ABI, the stack pointer must remain aligned throughout procedure execution. Non-standard ABI code must realign the stack pointer prior to invoking standard ABI procedures. The operating system must realign the stack pointer prior to invoking a signal handler; hence, POSIX signal handlers need not realign the stack pointer. In systems that service interrupts using the interruptee's stack, the interrupt service routine must realign the stack pointer if linked with any code that uses a non-standard stack-alignment discipline, but need not realign the stack pointer if all code adheres to the standard ABI.

Procedures must not rely upon the persistence of stack-allocated data whose addresses lie below the stack pointer.

Registers s0-s11 shall be preserved across procedure calls. No floating-point registers, if present, are preserved across calls. (This property changes when the integer calling convention is augmented by the hardware floating-point calling convention.)

## 2.2. Hardware Floating-Point Calling Convention

The hardware floating-point calling convention adds eight floating-point argument registers, fa0-fa7, the first two of which are also used to return values. Values are passed in floating-point registers whenever possible, whether or not the integer registers have been exhausted.

The remainder of this section applies only to named arguments. Variadic arguments are passed according to the integer calling convention.

ABI\_FLEN refers to the width of a floating-point register in the ABI. The ABI\_FLEN must be no wider than the ISA's FLEN. The ISA might have wider floating-point registers than the ABI.

For the purposes of this section, "struct" refers to a C struct with its hierarchy flattened, including any array fields. That is, `struct { struct { float f[1]; } a[2]; }` and `struct { float f0; float f1; }` are treated the same. Fields containing empty structs or unions are ignored while flattening, even in C++, unless they have nontrivial copy constructors or destructors. Fields containing zero-length bit-fields or zero-length arrays are ignored while flattening. Attributes such as `aligned` or `packed` do not interfere with a struct's eligibility for being passed in registers according to the rules below, i.e. `struct { int i; double d; }` and `struct __attribute__((__packed__)) { int i; double d; }` are treated the same, as are `struct { float f; float g; }` and `struct { float f; float g __attribute__((aligned(8))) }; }`.



One exceptional case for the flattening rule is an array of empty structs or unions; C treats it as an empty field, but C++ treats it as a non-empty field since C++ defines the size of an empty struct or union as 1. i.e. for `struct { struct {} e[1]; float f; }` as the first argument, C will treat it like `struct { float f; }` and pass `f` in `fa0` as described below, whereas C++ will pass the entire aggregate in `a0` (XLEN = 64) or `a0` and `a1` (XLEN = 32), as described in the integer calling convention. Zero-length arrays of empty structs or union will be ignored for both C and C++. i.e. For `struct { struct {} e[0]; float f; };`, as the first argument, C and C++ will treat it like `struct { float f; }` and pass `f` in `fa0` as described below.

A real floating-point argument is passed in a floating-point argument register if it is no more than ABI\_FLEN bits wide and at least one floating-point argument register is available. Otherwise, it is passed according to the integer calling convention. When a floating-point argument narrower than FLEN bits is passed in a floating-point register, it is 1-extended (NaN-boxed) to FLEN bits.

A struct containing just one floating-point real is passed as though it were a standalone floating-point real.

A struct containing two floating-point reals is passed in two floating-point registers, if neither real is more than ABI\_FLEN bits wide and at least two floating-point argument registers are available. (The registers need not be an aligned pair and are assigned to the two reals in memory order.) Otherwise, it is passed according to the integer calling convention.

A complex floating-point number, or a struct containing just one complex floating-point number, is passed as though it were a struct containing two floating-point reals.

A struct containing one floating-point real and one integer (or bitfield), in either order, is passed in

a floating-point register and an integer register, provided the floating-point real is no more than ABI\_FLEN bits wide and the integer is no more than XLEN bits wide, and at least one floating-point argument register and at least one integer argument register is available. If the struct is passed in this manner, and the integer is narrower than XLEN bits, the remaining bits are unspecified. If the struct is not passed in this manner, then it is passed according to the integer calling convention.

Unions are never flattened and are always passed according to the integer calling convention.

Values are returned in the same manner as a first named argument of the same type would be passed.

Floating-point registers fs0-fs11 shall be preserved across procedure calls, provided they hold values no more than ABI\_FLEN bits wide.

## 2.3. Standard Vector Calling Convention Variant

The *RISC-V V Vector Extension*[\[riscv-v-extension\]](#) defines a set of thirty-two vector registers, v0-v31. The *RISC-V Vector Extension Intrinsic Document*[\[rvv-intrinsic-doc\]](#) defines vector types which include vector mask types, vector data types, and tuple vector data types. A value of vector type can be stored in vector register groups.

The remainder of this section applies only to named vector arguments, other named arguments and return values follow the standard calling convention. Variadic vector arguments are passed by reference.

v0 is used to pass the first vector mask argument to a function, and to return vector mask result from a function. v8-v23 are used to pass vector data arguments, tuple vector data arguments and the rest vector mask arguments to a function, and to return vector data and vector tuple results from a function.

It must ensure that the entire contents of v1-v7 and v24-v31 are preserved across the call.

Each vector data type and vector tuple type has an LMUL attribute that indicates a vector register group. The value of LMUL indicates the number of vector registers in the vector register group and requires the first vector register number in the vector register group must be a multiple of it. For example, the LMUL of `vint64m8_t` is 8, so v8-v15 vector register group can be allocated to this type, but v9-v16 can not because the v9 register number is not a multiple of 8. If LMUL is less than 1, it is treated as 1. If it is a vector mask type, its LMUL is 1.

Each vector tuple type also has an NFIELDs attribute that indicates how many vector register groups the type contains. Thus a vector tuple type needs to take up LMUL×NFIELDs registers.

The rules for passing vector arguments are as follows:

1. For the first vector mask argument, use v0 to pass it.
2. For vector data arguments or rest vector mask arguments, starting from the v8 register, if a vector register group between v8-v23 that has not been allocated can be found and the first register number is a multiple of LMUL, then allocate this vector register group to the argument and mark these registers as allocated. Otherwise, pass it by reference and are replaced in the



argument list with the address.

3. For tuple vector data arguments, starting from the v8 register, if NFIELDS consecutive vector register groups between v8-v23 that have not been allocated can be found and the first register number is a multiple of LMUL, then allocate these vector register groups to the argument and mark these registers as allocated. Otherwise, pass it by reference and are replaced in the argument list with the address.



The registers assigned to the tuple vector data argument must be consecutive. For example, for the function `void foo(vint32m1_t a, vint32m2_t b, vint32m1x2_t c)`, v8 will be allocated to `a`, v10-v11 will be allocated to `b`, v12-v13 instead of v9 and v12 will be allocated to `c`.



It should be stressed that the search for the appropriate vector register groups starts at v8 each time and does not start at the next register after the registers are allocated for the previous vector argument. Therefore, it is possible that the vector register number allocated to a vector argument can be less than the vector register number allocated to previous vector arguments. For example, for the function `void foo (vint32m1_t a, vint32m2_t b, vint32m1_t c)`, according to the rules of allocation, v8 will be allocated to `a`, v10-v11 will be allocated to `b` and v9 will be allocated to `c`. This approach allows more vector registers to be allocated to arguments in some cases.

Vector values are returned in the same manner as the first named argument of the same type would be passed.

Vector types are disallowed in struct or union.

Vector arguments and return values are disallowed to pass to an unprototyped function.



Functions that use the standard vector calling convention variant must be marked with `STO_RISCV_VARIANT_CC`, see [Chapter 6](#) for the meaning of `STO_RISCV_VARIANT_CC`.



`setjmp/longjmp` follow the standard calling convention, which clobbers all vector registers. Hence, the standard vector calling convention variant won't disrupt the `jmp_buf` ABI.

## 2.4. ILP32E Calling Convention



RV32E is not a ratified base ISA and so we cannot guarantee the stability of ILP32E, in contrast with the rest of this document. This documents the current implementation in GCC as of the time of writing, but may be subject to change.

The ILP32E calling convention is designed to be usable with the RV32E ISA. This calling convention is the same as the integer calling convention, except for the following differences. The stack pointer need only be aligned to a 32-bit boundary. Registers x16-x31 do not participate in the calling convention, so there are only six argument registers, a0-a5, only two callee-saved registers, s0-s1,

and only three temporaries, t0-t2.

If used with an ISA that has any of the registers x16-x31 and f0-f31, then these registers are considered temporaries.

The ILP32E calling convention is not compatible with ISAs that have registers that require load and store alignments of more than 32 bits. In particular, this calling convention must not be used with the D ISA extension.

## 2.5. RV64ILP32\* Calling Convention



RV64ILP32\* ABIs are experimental.

The RV64ILP32\* calling convention is designed to be usable with the RV64\* ISA. These calling conventions are composed of the integer & floating-point & vector calling conventions. When passed in registers or on the stack, pointer scalars (32-bit), narrower than XLEN bits (64-bit), are sign-extended to XLEN bits.

## 2.6. Named ABIs

This specification defines the following named ABIs:

### ILP32

Integer calling-convention only, hardware floating-point calling convention is not used (i.e. [ELFCLASS32](#) and [EF\\_RISCV\\_FLOAT\\_ABI\\_SOFT](#)).

### ILP32F

ILP32 with hardware floating-point calling convention for ABI\_FLEN=32 (i.e. [ELFCLASS32](#) and [EF\\_RISCV\\_FLOAT\\_ABI\\_SINGLE](#)).

### ILP32D

ILP32 with hardware floating-point calling convention for ABI\_FLEN=64 (i.e. [ELFCLASS32](#) and [EF\\_RISCV\\_FLOAT\\_ABI\\_DOUBLE](#)).

### ILP32E

[ILP32E calling-convention](#) only, hardware floating-point calling convention is not used (i.e. [ELFCLASS32](#), [EF\\_RISCV\\_FLOAT\\_ABI\\_SOFT](#), and [EF\\_RISCV\\_RVE](#)).

### LP64

Integer calling-convention only, hardware floating-point calling convention is not used (i.e. [ELFCLASS64](#) and [EF\\_RISCV\\_FLOAT\\_ABI\\_SOFT](#)).

### LP64F

LP64 with hardware floating-point calling convention for ABI\_FLEN=32 (i.e. [ELFCLASS64](#) and [EF\\_RISCV\\_FLOAT\\_ABI\\_SINGLE](#)).

## LP64D

LP64 with hardware floating-point calling convention for ABI\_FLEN=64 (i.e. [ELFCLASS64](#) and [EF\\_RISCV\\_FLOAT\\_ABI\\_DOUBLE](#)).

## LP64Q

LP64 with hardware floating-point calling convention for ABI\_FLEN=128 (i.e. [ELFCLASS64](#) and [EF\\_RISCV\\_FLOAT\\_ABI\\_QUAD](#)).

## RV64ILP32

Integer calling-convention only, hardware floating-point calling convention is not used (i.e. [ELFCLASS32](#) and [EF\\_RISCV\\_FLOAT\\_ABI\\_SINGLE](#)).

## RV64ILP32F

RV64ILP32 with hardware floating-point calling convention for ABI\_FLEN=32 (i.e. [ELFCLASS32](#) and [EF\\_RISCV\\_FLOAT\\_ABI\\_SINGLE](#)).

## RV64ILP32D

RV64ILP32 with hardware floating-point calling convention for ABI\_FLEN=64 (i.e. [ELFCLASS32](#) and [EF\\_RISCV\\_FLOAT\\_ABI\\_DOUBLE](#)).

## RV64ILP32Q

RV64ILP32 with hardware floating-point calling convention for ABI\_FLEN=128 (i.e. [ELFCLASS32](#) and [EF\\_RISCV\\_FLOAT\\_ABI\\_QUAD](#)).

The LP64\* ABIs are only compatible with RV64\* ISAs. The ILP32\* are compatible with RV32\* and RV64\* ISAs.



RV64ILP32\* ABIs are experimental.

The \*F ABIs require the \*F ISA extension, the \*D ABIs require the \*D ISA extension, and the LP64Q ABI requires the Q ISA extension.



This means code targeting the Zfinx extension always uses the ILP32, ILP32E or LP64 integer calling-convention only ABIs as there is no dedicated hardware floating-point register file.

## 2.7. Default ABIs

While various different ABIs are technically possible, for software compatibility reasons it is strongly recommended to use the following default ABIs for specific architectures:

on RV32G    [ILP32D](#)

on RV64G    [LP64D](#)



Although RV64GQ systems can technically use [LP64Q](#), it is strongly recommended to use LP64D on general-purpose RV64GQ systems for compatibility with standard

RV64G software.

# Chapter 3. Calling Convention for System Calls

The calling convention for system calls does not fall within the scope of this document. Please refer to the documentation of the RISC-V execution environment interface (e.g OS kernel ABI, SBI).

# Chapter 4. C/C++ Type Details

## 4.1. C/C++ Type Sizes and Alignments

There are two conventions for C/C++ type sizes and alignments.

### ILP32, ILP32F, ILP32D, and ILP32E

Use the following type sizes and alignments (based on the ILP32 convention):

*Table 5. C/C++ type sizes and alignments for ILP32*

| Type           | Size<br>(Bytes) | Alignment<br>(Bytes) | Note  |
|----------------|-----------------|----------------------|---|
| bool/_Bool     | 1               | 1                    |   |
| char           | 1               | 1                    |   |
| short          | 2               | 2                    |   |
| int            | 4               | 4                    |   |
| long           | 4               | 4                    |   |
| long long      | 8               | 8                    |   |
| void *         | 4               | 4                    |   |
| __bf16         | 2               | 2                    | Half precision<br>floating point<br>(bfloat16)                              |
| _Float16       | 2               | 2                    | Half precision<br>floating point<br>(binary16 in<br>IEEE 754-2008)          |
| float          | 4               | 4                    | Single precision<br>floating point<br>(binary32 in<br>IEEE 754-2008)        |
| double         | 8               | 8                    | Double<br>precision<br>floating point<br>(binary64 in<br>IEEE 754-2008)     |
| long double    | 16              | 16                   | Quadruple<br>precision<br>floating point<br>(binary128 in<br>IEEE 754-2008) |
| float _Complex | 8               | 4                    |   |

| Type                    | Size<br>(Bytes) | Alignment<br>(Bytes) | Note |
|-------------------------|-----------------|----------------------|------|
| double<br>_Complex      | 16              | 8                    |      |
| long double<br>_Complex | 32              | 16                   |      |

### LP64, LP64F, LP64D, and LP64Q

Use the following type sizes and alignments (based on the LP64 convention):

Table 6. C/C++ type sizes and alignments for LP64

| Type       | Size<br>(Bytes) | Alignment<br>(Bytes) | Note  |
|------------|-----------------|----------------------|---|
| bool/_Bool | 1               | 1                    |   |
| char       | 1               | 1                    |   |
| short      | 2               | 2                    |   |
| int        | 4               | 4                    |   |
| long       | 8               | 8                    |   |
| long long  | 8               | 8                    |   |
| __int128   | 16              | 16                   |   |
| void *     | 8               | 8                    |   |
| __bf16     | 2               | 2                    | Half precision<br>floating point<br>(bfloat16)                          |
| _Float16   | 2               | 2                    | Half precision<br>floating point<br>(binary16 in<br>IEEE 754-2008)      |
| float      | 4               | 4                    | Single precision<br>floating point<br>(binary32 in<br>IEEE 754-2008)    |
| double     | 8               | 8                    | Double<br>precision<br>floating point<br>(binary64 in<br>IEEE 754-2008) |

| Type                 | Size<br>(Bytes) | Alignment<br>(Bytes) | Note  |
|----------------------|-----------------|----------------------|---|
| long double          | 16              | 16                   | Quadruple precision floating point (binary128 in IEEE 754-2008) |
| float _Complex       | 8               | 4                    |   |
| double _Complex      | 16              | 8                    |   |
| long double _Complex | 32              | 16                   |   |

The alignment of `max_align_t` is 16.

`CHAR_BIT` is 8.

Structs and unions are aligned to the alignment of their most strictly aligned member. The size of any object is a multiple of its alignment.

## 4.2. Fixed-Length Vector

Various compilers have support for fixed-length vector types, for example GCC and Clang both support declaring a type with `__attribute__((vector_size(N)))`, where N is a positive number larger than zero.

The alignment requirement for the fixed length vector shall be equivalent to the alignment requirement of its elemental type.

The size of the fixed length vector is determined by multiplying the size of its elemental type by the total number of elements within the vector.

## 4.3. C/C++ Type Representations

`char` is unsigned.

Booleans (`bool/_Bool`) stored in memory or when being passed as scalar arguments are either `0` (`false`) or `1` (`true`).

A null pointer (for all types) has the value zero.

`_Float16` is as defined in the C ISO/IEC TS 18661-3 extension.

`__bf16` has the same parameter passing and return rules as for `_Float16`.

`_Complex` types have the same layout as a struct containing two fields of the corresponding real type (`float`, `double`, or `long double`), with the first member holding the real part and the second member



holding the imaginary part.

The type `size_t` is defined as `unsigned int` for RV32 and `unsigned long` for RV64.

The type `ptrdiff_t` is defined as `int` for RV32 and `long` for RV64.

## 4.4. Bit-Fields

Bit-fields are packed in little-endian fashion. A bit-field that would span the alignment boundary of its integer type is padded to begin at the next alignment boundary. For example, `struct { int x : 10; int y : 12; }` is a 32-bit type with `x` in bits 9-0, `y` in bits 21-10, and bits 31-22 undefined. By contrast, `struct { short x : 10; short y : 12; }` is a 32-bit type with `x` in bits 9-0, `y` in bits 27-16, and bits 31-28 and bits 15-10 undefined.

Bit-fields which are larger than their integer types are only present in C++ and are defined by the *Itanium C++ ABI* [\[itanium-cxx-abi\]](#). The bit-field and containing struct are aligned on a boundary corresponding to the largest integral type smaller than the bit-field, up to 64-bit alignment on RV32 or 128-bit alignment on RV64. Any bits in excess of the size of the declared type are treated as padding. For example `struct { char x : 9; char y; }` is a 24-bit type with `x` in bits 7-0, `y` in bit 23-16, and bits 15-8 undefined; `struct { char x : 9; char y : 2 }` is a 16-bit type with `x` in bits 7-0, `y` in bit 10-9, and bits 8 and 15-11 undefined.

Unnamed nonzero length bit-fields allocate space in the same fashion as named bitfields but do not affect the alignment of the containing struct.

Zero length bit-fields are aligned relative to the start of the containing struct according to their declared type and, since they must be unnamed, do not affect the struct alignment. C requires bit-fields on opposite sides of a zero-length bitfield to be treated as separate memory locations for the purposes of data races.

## 4.5. `va_list`, `va_start`, and `va_arg`

The `va_list` type has the same representation as `void*` and points to a sequence of zero or more arguments with preceding padding for alignment, formatted and aligned as variadic arguments passed on the stack according to the integer calling convention ([Section 2.1](#)). All standard calling conventions use the same representation for variadic arguments to allow `va_list` types to be shared between them.

The `va_start` macro in a function initializes its `va_list` argument to point to the first address at which a variadic argument could be passed to the function. If all integer argument registers are used for named formal arguments, the first variadic argument will have been passed on the stack by the caller, and the `va_list` can point to the address immediately after the last named argument passed on the stack, or the `sp` value on entry if no named arguments were passed on the stack. If some integer argument registers were not used for named formal arguments, then the first variadic argument may have been passed in a register. The function is then expected to construct a *varargs save area* immediately below the entry `sp` and fill it with the entry values of all integer argument registers not used for named arguments, in sequence. The `va_list` value can then be initialized to the start of the *varargs save area*, and it will iterate through any variadic arguments passed via

registers before continuing to variadic arguments passed on the stack, if any.

The `va_arg` macro will align its `va_list` argument, fetch a value, and increment the `va_list` according to the alignment and size of a variadic argument of the given type, which may not be the same as the alignment and size of the given type in memory. If the type is passed by reference, the size and alignment used will be those of a pointer, and the fetched pointer will be used as the address of the actual argument. The `va_copy` macro is a single pointer copy and the `va_end` macro performs no operation.

## 4.6. Vector Type Sizes and Alignments

This section defines the sizes and alignments for the vector types defined in the *RISC-V Vector Extension Intrinsic Document*[\[rvv-intrinsic-doc\]](#). The actual size of each type is determined by the hardware configuration, which is based on the content of the `vlenb` register.

There are three classes of vector types: the vector mask types, the vector data types and the vector tuple types.

Table 7. Type sizes and alignments for vector mask types

| Internal Name                | Type                   | Size (Bytes)                  | Alignment (Bytes) |
|------------------------------|------------------------|-------------------------------|-------------------|
| <code>__rvv_vbool1_t</code>  | <code>vbool1_t</code>  | <code>VLENB</code>            | 1                 |
| <code>__rvv_vbool2_t</code>  | <code>vbool2_t</code>  | <code>VLENB / 2</code>        | 1                 |
| <code>__rvv_vbool4_t</code>  | <code>vbool4_t</code>  | <code>VLENB / 4</code>        | 1                 |
| <code>__rvv_vbool8_t</code>  | <code>vbool8_t</code>  | <code>ceil(VLENB / 8)</code>  | 1                 |
| <code>__rvv_vbool16_t</code> | <code>vbool16_t</code> | <code>ceil(VLENB / 16)</code> | 1                 |
| <code>__rvv_vbool32_t</code> | <code>vbool32_t</code> | <code>ceil(VLENB / 32)</code> | 1                 |
| <code>__rvv_vbool64_t</code> | <code>vbool64_t</code> | <code>ceil(VLENB / 64)</code> | 1                 |

Table 8. Type sizes and alignments for vector data types

| Internal Name                   | Type                      | Size (Bytes)                | Alignment (Bytes) |
|---------------------------------|---------------------------|-----------------------------|-------------------|
| <code>__rvv_vint8mf8_t</code>   | <code>vint8mf8_t</code>   | <code>(VLEN / 8) / 8</code> | 1                 |
| <code>__rvv_vuint8mf8_t</code>  | <code>vuint8mf8_t</code>  | <code>(VLEN / 8) / 8</code> | 1                 |
| <code>__rvv_vfloat8mf8_t</code> | <code>vfloat8mf8_t</code> | <code>(VLEN / 8) / 8</code> | 1                 |
| <code>__rvv_vint8mf4_t</code>   | <code>vint8mf4_t</code>   | <code>(VLEN / 8) / 4</code> | 1                 |
| <code>__rvv_vuint8mf4_t</code>  | <code>vuint8mf4_t</code>  | <code>(VLEN / 8) / 4</code> | 1                 |
| <code>__rvv_vfloat8mf4_t</code> | <code>vfloat8mf4_t</code> | <code>(VLEN / 8) / 4</code> | 1                 |
| <code>__rvv_vint8mf2_t</code>   | <code>vint8mf2_t</code>   | <code>(VLEN / 8) / 2</code> | 1                 |
| <code>__rvv_vuint8mf2_t</code>  | <code>vuint8mf2_t</code>  | <code>(VLEN / 8) / 2</code> | 1                 |
| <code>__rvv_vfloat8mf2_t</code> | <code>vfloat8mf2_t</code> | <code>(VLEN / 8) / 2</code> | 1                 |

| Internal Name        | Type           | Size (Bytes)   | Alignment (Bytes) |
|----------------------|----------------|----------------|-------------------|
| __rvv_vint8m1_t      | vint8m1_t      | (VLEN / 8)     | 1                 |
| __rvv_vuint8m1_t     | vuint8m1_t     | (VLEN / 8)     | 1                 |
| __rvv_vfloat8m1_t    | vfloat8m1_t    | (VLEN / 8)     | 1                 |
| __rvv_vint8m2_t      | vint8m2_t      | (VLEN / 8) * 2 | 1                 |
| __rvv_vuint8m2_t     | vuint8m2_t     | (VLEN / 8) * 2 | 1                 |
| __rvv_vfloat8m2_t    | vfloat8m2_t    | (VLEN / 8) * 2 | 1                 |
| __rvv_vint8m4_t      | vint8m4_t      | (VLEN / 8) * 4 | 1                 |
| __rvv_vuint8m4_t     | vuint8m4_t     | (VLEN / 8) * 4 | 1                 |
| __rvv_vfloat8m4_t    | vfloat8m4_t    | (VLEN / 8) * 4 | 1                 |
| __rvv_vint8m8_t      | vint8m8_t      | (VLEN / 8) * 8 | 1                 |
| __rvv_vuint8m8_t     | vuint8m8_t     | (VLEN / 8) * 8 | 1                 |
| __rvv_vfloat8m8_t    | vfloat8m8_t    | (VLEN / 8) * 8 | 1                 |
| __rvv_vint16mf8_t    | vint16mf8_t    | (VLEN / 8) / 8 | 2                 |
| __rvv_vuint16mf8_t   | vuint16mf8_t   | (VLEN / 8) / 8 | 2                 |
| __rvv_vbfloat16mf8_t | vbfloat16mf8_t | (VLEN / 8) / 8 | 2                 |
| __rvv_vint16mf4_t    | vint16mf4_t    | (VLEN / 8) / 4 | 2                 |
| __rvv_vuint16mf4_t   | vuint16mf4_t   | (VLEN / 8) / 4 | 2                 |
| __rvv_vbfloat16mf4_t | vbfloat16mf4_t | (VLEN / 8) / 4 | 2                 |
| __rvv_vint16mf2_t    | vint16mf2_t    | (VLEN / 8) / 2 | 2                 |
| __rvv_vuint16mf2_t   | vuint16mf2_t   | (VLEN / 8) / 2 | 2                 |
| __rvv_vbfloat16mf2_t | vbfloat16mf2_t | (VLEN / 8) / 2 | 2                 |
| __rvv_vint16m1_t     | vint16m1_t     | (VLEN / 8)     | 2                 |
| __rvv_vuint16m1_t    | vuint16m1_t    | (VLEN / 8)     | 2                 |
| __rvv_vbfloat16m1_t  | vbfloat16m1_t  | (VLEN / 8)     | 2                 |
| __rvv_vint16m2_t     | vint16m2_t     | (VLEN / 8) * 2 | 2                 |
| __rvv_vuint16m2_t    | vuint16m2_t    | (VLEN / 8) * 2 | 2                 |
| __rvv_vbfloat16m2_t  | vbfloat16m2_t  | (VLEN / 8) * 2 | 2                 |
| __rvv_vint16m4_t     | vint16m4_t     | (VLEN / 8) * 4 | 2                 |
| __rvv_vuint16m4_t    | vuint16m4_t    | (VLEN / 8) * 4 | 2                 |
| __rvv_vbfloat16m4_t  | vbfloat16m4_t  | (VLEN / 8) * 4 | 2                 |
| __rvv_vint16m8_t     | vint16m8_t     | (VLEN / 8) * 8 | 2                 |
| __rvv_vuint16m8_t    | vuint16m8_t    | (VLEN / 8) * 8 | 2                 |
| __rvv_vbfloat16m8_t  | vbfloat16m8_t  | (VLEN / 8) * 8 | 2                 |

| Internal Name       | Type          | Size (Bytes)     | Alignment (Bytes) |
|---------------------|---------------|------------------|-------------------|
| __rvv_vint32mf8_t   | vint32mf8_t   | $(VLEN / 8) / 8$ | 4                 |
| __rvv_vuint32mf8_t  | vuint32mf8_t  | $(VLEN / 8) / 8$ | 4                 |
| __rvv_vfloat32mf8_t | vfloat32mf8_t | $(VLEN / 8) / 8$ | 4                 |
| __rvv_vint32mf4_t   | vint32mf4_t   | $(VLEN / 8) / 4$ | 4                 |
| __rvv_vuint32mf4_t  | vuint32mf4_t  | $(VLEN / 8) / 4$ | 4                 |
| __rvv_vfloat32mf4_t | vfloat32mf4_t | $(VLEN / 8) / 4$ | 4                 |
| __rvv_vint32mf2_t   | vint32mf2_t   | $(VLEN / 8) / 2$ | 4                 |
| __rvv_vuint32mf2_t  | vuint32mf2_t  | $(VLEN / 8) / 2$ | 4                 |
| __rvv_vfloat32mf2_t | vfloat32mf2_t | $(VLEN / 8) / 2$ | 4                 |
| __rvv_vint32m1_t    | vint32m1_t    | $(VLEN / 8)$     | 4                 |
| __rvv_vuint32m1_t   | vuint32m1_t   | $(VLEN / 8)$     | 4                 |
| __rvv_vfloat32m1_t  | vfloat32m1_t  | $(VLEN / 8)$     | 4                 |
| __rvv_vint32m2_t    | vint32m2_t    | $(VLEN / 8) * 2$ | 4                 |
| __rvv_vuint32m2_t   | vuint32m2_t   | $(VLEN / 8) * 2$ | 4                 |
| __rvv_vfloat32m2_t  | vfloat32m2_t  | $(VLEN / 8) * 2$ | 4                 |
| __rvv_vint32m4_t    | vint32m4_t    | $(VLEN / 8) * 4$ | 4                 |
| __rvv_vuint32m4_t   | vuint32m4_t   | $(VLEN / 8) * 4$ | 4                 |
| __rvv_vfloat32m4_t  | vfloat32m4_t  | $(VLEN / 8) * 4$ | 4                 |
| __rvv_vint32m8_t    | vint32m8_t    | $(VLEN / 8) * 8$ | 4                 |
| __rvv_vuint32m8_t   | vuint32m8_t   | $(VLEN / 8) * 8$ | 4                 |
| __rvv_vfloat32m8_t  | vfloat32m8_t  | $(VLEN / 8) * 8$ | 4                 |
| __rvv_vint64mf8_t   | vint64mf8_t   | $(VLEN / 8) / 8$ | 8                 |
| __rvv_vuint64mf8_t  | vuint64mf8_t  | $(VLEN / 8) / 8$ | 8                 |
| __rvv_vfloat64mf8_t | vfloat64mf8_t | $(VLEN / 8) / 8$ | 8                 |
| __rvv_vint64mf4_t   | vint64mf4_t   | $(VLEN / 8) / 4$ | 8                 |
| __rvv_vuint64mf4_t  | vuint64mf4_t  | $(VLEN / 8) / 4$ | 8                 |
| __rvv_vfloat64mf4_t | vfloat64mf4_t | $(VLEN / 8) / 4$ | 8                 |
| __rvv_vint64mf2_t   | vint64mf2_t   | $(VLEN / 8) / 2$ | 8                 |
| __rvv_vuint64mf2_t  | vuint64mf2_t  | $(VLEN / 8) / 2$ | 8                 |
| __rvv_vfloat64mf2_t | vfloat64mf2_t | $(VLEN / 8) / 2$ | 8                 |
| __rvv_vint64m1_t    | vint64m1_t    | $(VLEN / 8)$     | 8                 |
| __rvv_vuint64m1_t   | vuint64m1_t   | $(VLEN / 8)$     | 8                 |
| __rvv_vfloat64m1_t  | vfloat64m1_t  | $(VLEN / 8)$     | 8                 |

| Internal Name      | Type         | Size (Bytes)     | Alignment (Bytes) |
|--------------------|--------------|------------------|-------------------|
| __rvv_vint64m2_t   | vint64m2_t   | $(VLEN / 8) * 2$ | 8                 |
| __rvv_vuint64m2_t  | vuint64m2_t  | $(VLEN / 8) * 2$ | 8                 |
| __rvv_vfloat64m2_t | vfloat64m2_t | $(VLEN / 8) * 2$ | 8                 |
| __rvv_vint64m4_t   | vint64m4_t   | $(VLEN / 8) * 4$ | 8                 |
| __rvv_vuint64m4_t  | vuint64m4_t  | $(VLEN / 8) * 4$ | 8                 |
| __rvv_vfloat64m4_t | vfloat64m4_t | $(VLEN / 8) * 4$ | 8                 |
| __rvv_vint64m8_t   | vint64m8_t   | $(VLEN / 8) * 8$ | 8                 |
| __rvv_vuint64m8_t  | vuint64m8_t  | $(VLEN / 8) * 8$ | 8                 |
| __rvv_vfloat64m8_t | vfloat64m8_t | $(VLEN / 8) * 8$ | 8                 |

Table 9. Type sizes and alignments for vector tuple types

| Internal Name        | Type           | Size (Bytes)         | Alignment (Bytes) |
|----------------------|----------------|----------------------|-------------------|
| __rvv_vint8mf8x2_t   | vint8mf8x2_t   | $(VLEN / 8) / 4$     | 1                 |
| __rvv_vuint8mf8x2_t  | vuint8mf8x2_t  | $(VLEN / 8) / 4$     | 1                 |
| __rvv_vfloat8mf8x2_t | vfloat8mf8x2_t | $(VLEN / 8) / 4$     | 1                 |
| __rvv_vint8mf8x3_t   | vint8mf8x3_t   | $(VLEN / 8) * 0.375$ | 1                 |
| __rvv_vuint8mf8x3_t  | vuint8mf8x3_t  | $(VLEN / 8) * 0.375$ | 1                 |
| __rvv_vfloat8mf8x3_t | vfloat8mf8x3_t | $(VLEN / 8) * 0.375$ | 1                 |
| __rvv_vint8mf8x4_t   | vint8mf8x4_t   | $(VLEN / 8) / 2$     | 1                 |
| __rvv_vuint8mf8x4_t  | vuint8mf8x4_t  | $(VLEN / 8) / 2$     | 1                 |
| __rvv_vfloat8mf8x4_t | vfloat8mf8x4_t | $(VLEN / 8) / 2$     | 1                 |
| __rvv_vint8mf8x5_t   | vint8mf8x5_t   | $(VLEN / 8) * 0.625$ | 1                 |
| __rvv_vuint8mf8x5_t  | vuint8mf8x5_t  | $(VLEN / 8) * 0.625$ | 1                 |
| __rvv_vfloat8mf8x5_t | vfloat8mf8x5_t | $(VLEN / 8) * 0.625$ | 1                 |
| __rvv_vint8mf8x6_t   | vint8mf8x6_t   | $(VLEN / 8) * 0.75$  | 1                 |
| __rvv_vuint8mf8x6_t  | vuint8mf8x6_t  | $(VLEN / 8) * 0.75$  | 1                 |
| __rvv_vfloat8mf8x6_t | vfloat8mf8x6_t | $(VLEN / 8) * 0.75$  | 1                 |
| __rvv_vint8mf8x7_t   | vint8mf8x7_t   | $(VLEN / 8) * 0.875$ | 1                 |
| __rvv_vuint8mf8x7_t  | vuint8mf8x7_t  | $(VLEN / 8) * 0.875$ | 1                 |
| __rvv_vfloat8mf8x7_t | vfloat8mf8x7_t | $(VLEN / 8) * 0.875$ | 1                 |
| __rvv_vint8mf8x8_t   | vint8mf8x8_t   | $(VLEN / 8)$         | 1                 |
| __rvv_vuint8mf8x8_t  | vuint8mf8x8_t  | $(VLEN / 8)$         | 1                 |

| Internal Name        | Type           | Size (Bytes)        | Alignment (Bytes) |
|----------------------|----------------|---------------------|-------------------|
| __rvv_vfloat8mf8x8_t | vfloat8mf8x8_t | $(VLEN / 8)$        | 1                 |
| __rvv_vint8mf4x2_t   | vint8mf4x2_t   | $(VLEN / 8) / 2$    | 1                 |
| __rvv_vuint8mf4x2_t  | vuint8mf4x2_t  | $(VLEN / 8) / 2$    | 1                 |
| __rvv_vfloat8mf4x2_t | vfloat8mf4x2_t | $(VLEN / 8) / 2$    | 1                 |
| __rvv_vint8mf4x3_t   | vint8mf4x3_t   | $(VLEN / 8) * 0.75$ | 1                 |
| __rvv_vuint8mf4x3_t  | vuint8mf4x3_t  | $(VLEN / 8) * 0.75$ | 1                 |
| __rvv_vfloat8mf4x3_t | vfloat8mf4x3_t | $(VLEN / 8) * 0.75$ | 1                 |
| __rvv_vint8mf4x4_t   | vint8mf4x4_t   | $(VLEN / 8)$        | 1                 |
| __rvv_vuint8mf4x4_t  | vuint8mf4x4_t  | $(VLEN / 8)$        | 1                 |
| __rvv_vfloat8mf4x4_t | vfloat8mf4x4_t | $(VLEN / 8)$        | 1                 |
| __rvv_vint8mf4x5_t   | vint8mf4x5_t   | $(VLEN / 8) * 1.25$ | 1                 |
| __rvv_vuint8mf4x5_t  | vuint8mf4x5_t  | $(VLEN / 8) * 1.25$ | 1                 |
| __rvv_vfloat8mf4x5_t | vfloat8mf4x5_t | $(VLEN / 8) * 1.25$ | 1                 |
| __rvv_vint8mf4x6_t   | vint8mf4x6_t   | $(VLEN / 8) * 1.5$  | 1                 |
| __rvv_vuint8mf4x6_t  | vuint8mf4x6_t  | $(VLEN / 8) * 1.5$  | 1                 |
| __rvv_vfloat8mf4x6_t | vfloat8mf4x6_t | $(VLEN / 8) * 1.5$  | 1                 |
| __rvv_vint8mf4x7_t   | vint8mf4x7_t   | $(VLEN / 8) * 1.75$ | 1                 |
| __rvv_vuint8mf4x7_t  | vuint8mf4x7_t  | $(VLEN / 8) * 1.75$ | 1                 |
| __rvv_vfloat8mf4x7_t | vfloat8mf4x7_t | $(VLEN / 8) * 1.75$ | 1                 |
| __rvv_vint8mf4x8_t   | vint8mf4x8_t   | $(VLEN / 8) * 2$    | 1                 |
| __rvv_vuint8mf4x8_t  | vuint8mf4x8_t  | $(VLEN / 8) * 2$    | 1                 |
| __rvv_vfloat8mf4x8_t | vfloat8mf4x8_t | $(VLEN / 8) * 2$    | 1                 |
| __rvv_vint8mf2x2_t   | vint8mf2x2_t   | $(VLEN / 8)$        | 1                 |
| __rvv_vuint8mf2x2_t  | vuint8mf2x2_t  | $(VLEN / 8)$        | 1                 |
| __rvv_vfloat8mf2x2_t | vfloat8mf2x2_t | $(VLEN / 8)$        | 1                 |
| __rvv_vint8mf2x3_t   | vint8mf2x3_t   | $(VLEN / 8) * 1.5$  | 1                 |
| __rvv_vuint8mf2x3_t  | vuint8mf2x3_t  | $(VLEN / 8) * 1.5$  | 1                 |
| __rvv_vfloat8mf2x3_t | vfloat8mf2x3_t | $(VLEN / 8) * 1.5$  | 1                 |
| __rvv_vint8mf2x4_t   | vint8mf2x4_t   | $(VLEN / 8) * 2$    | 1                 |
| __rvv_vuint8mf2x4_t  | vuint8mf2x4_t  | $(VLEN / 8) * 2$    | 1                 |
| __rvv_vfloat8mf2x4_t | vfloat8mf2x4_t | $(VLEN / 8) * 2$    | 1                 |
| __rvv_vint8mf2x5_t   | vint8mf2x5_t   | $(VLEN / 8) * 2.5$  | 1                 |
| __rvv_vuint8mf2x5_t  | vuint8mf2x5_t  | $(VLEN / 8) * 2.5$  | 1                 |

| Internal Name        | Type           | Size (Bytes)       | Alignment (Bytes) |
|----------------------|----------------|--------------------|-------------------|
| __rvv_vfloat8mf2x5_t | vfloat8mf2x5_t | $(VLEN / 8) * 2.5$ | 1                 |
| __rvv_vint8mf2x6_t   | vint8mf2x6_t   | $(VLEN / 8) * 3$   | 1                 |
| __rvv_vuint8mf2x6_t  | vuint8mf2x6_t  | $(VLEN / 8) * 3$   | 1                 |
| __rvv_vfloat8mf2x6_t | vfloat8mf2x6_t | $(VLEN / 8) * 3$   | 1                 |
| __rvv_vint8mf2x7_t   | vint8mf2x7_t   | $(VLEN / 8) * 3.5$ | 1                 |
| __rvv_vuint8mf2x7_t  | vuint8mf2x7_t  | $(VLEN / 8) * 3.5$ | 1                 |
| __rvv_vfloat8mf2x7_t | vfloat8mf2x7_t | $(VLEN / 8) * 3.5$ | 1                 |
| __rvv_vint8mf2x8_t   | vint8mf2x8_t   | $(VLEN / 8) * 4$   | 1                 |
| __rvv_vuint8mf2x8_t  | vuint8mf2x8_t  | $(VLEN / 8) * 4$   | 1                 |
| __rvv_vfloat8mf2x8_t | vfloat8mf2x8_t | $(VLEN / 8) * 4$   | 1                 |
| __rvv_vint8m1x2_t    | vint8m1x2_t    | $(VLEN / 8) * 2$   | 1                 |
| __rvv_vuint8m1x2_t   | vuint8m1x2_t   | $(VLEN / 8) * 2$   | 1                 |
| __rvv_vfloat8m1x2_t  | vfloat8m1x2_t  | $(VLEN / 8) * 2$   | 1                 |
| __rvv_vint8m1x3_t    | vint8m1x3_t    | $(VLEN / 8) * 3$   | 1                 |
| __rvv_vuint8m1x3_t   | vuint8m1x3_t   | $(VLEN / 8) * 3$   | 1                 |
| __rvv_vfloat8m1x3_t  | vfloat8m1x3_t  | $(VLEN / 8) * 3$   | 1                 |
| __rvv_vint8m1x4_t    | vint8m1x4_t    | $(VLEN / 8) * 4$   | 1                 |
| __rvv_vuint8m1x4_t   | vuint8m1x4_t   | $(VLEN / 8) * 4$   | 1                 |
| __rvv_vfloat8m1x4_t  | vfloat8m1x4_t  | $(VLEN / 8) * 4$   | 1                 |
| __rvv_vint8m1x5_t    | vint8m1x5_t    | $(VLEN / 8) * 5$   | 1                 |
| __rvv_vuint8m1x5_t   | vuint8m1x5_t   | $(VLEN / 8) * 5$   | 1                 |
| __rvv_vfloat8m1x5_t  | vfloat8m1x5_t  | $(VLEN / 8) * 5$   | 1                 |
| __rvv_vint8m1x6_t    | vint8m1x6_t    | $(VLEN / 8) * 6$   | 1                 |
| __rvv_vuint8m1x6_t   | vuint8m1x6_t   | $(VLEN / 8) * 6$   | 1                 |
| __rvv_vfloat8m1x6_t  | vfloat8m1x6_t  | $(VLEN / 8) * 6$   | 1                 |
| __rvv_vint8m1x7_t    | vint8m1x7_t    | $(VLEN / 8) * 7$   | 1                 |
| __rvv_vuint8m1x7_t   | vuint8m1x7_t   | $(VLEN / 8) * 7$   | 1                 |
| __rvv_vfloat8m1x7_t  | vfloat8m1x7_t  | $(VLEN / 8) * 7$   | 1                 |
| __rvv_vint8m1x8_t    | vint8m1x8_t    | $(VLEN / 8) * 8$   | 1                 |
| __rvv_vuint8m1x8_t   | vuint8m1x8_t   | $(VLEN / 8) * 8$   | 1                 |
| __rvv_vfloat8m1x8_t  | vfloat8m1x8_t  | $(VLEN / 8) * 8$   | 1                 |
| __rvv_vint8m2x2_t    | vint8m2x2_t    | $(VLEN / 8) * 4$   | 1                 |
| __rvv_vuint8m2x2_t   | vuint8m2x2_t   | $(VLEN / 8) * 4$   | 1                 |

| Internal Name          | Type             | Size (Bytes)         | Alignment (Bytes) |
|------------------------|------------------|----------------------|-------------------|
| __rvv_vfloat8m2x2_t    | vfloat8m2x2_t    | $(VLEN / 8) * 4$     | 1                 |
| __rvv_vint8m2x3_t      | vint8m2x3_t      | $(VLEN / 8) * 6$     | 1                 |
| __rvv_vuint8m2x3_t     | vuint8m2x3_t     | $(VLEN / 8) * 6$     | 1                 |
| __rvv_vfloat8m2x3_t    | vfloat8m2x3_t    | $(VLEN / 8) * 6$     | 1                 |
| __rvv_vint8m2x4_t      | vint8m2x4_t      | $(VLEN / 8) * 8$     | 1                 |
| __rvv_vuint8m2x4_t     | vuint8m2x4_t     | $(VLEN / 8) * 8$     | 1                 |
| __rvv_vfloat8m2x4_t    | vfloat8m2x4_t    | $(VLEN / 8) * 8$     | 1                 |
| __rvv_vint8m4x2_t      | vint8m4x2_t      | $(VLEN / 8) * 8$     | 1                 |
| __rvv_vuint8m4x2_t     | vuint8m4x2_t     | $(VLEN / 8) * 8$     | 1                 |
| __rvv_vfloat8m4x2_t    | vfloat8m4x2_t    | $(VLEN / 8) * 8$     | 1                 |
| __rvv_vint16mf8x2_t    | vint16mf8x2_t    | $(VLEN / 8) / 4$     | 2                 |
| __rvv_vuint16mf8x2_t   | vuint16mf8x2_t   | $(VLEN / 8) / 4$     | 2                 |
| __rvv_vbfloat16mf8x2_t | vbfloat16mf8x2_t | $(VLEN / 8) / 4$     | 2                 |
| __rvv_vint16mf8x3_t    | vint16mf8x3_t    | $(VLEN / 8) * 0.375$ | 2                 |
| __rvv_vuint16mf8x3_t   | vuint16mf8x3_t   | $(VLEN / 8) * 0.375$ | 2                 |
| __rvv_vbfloat16mf8x3_t | vbfloat16mf8x3_t | $(VLEN / 8) * 0.375$ | 2                 |
| __rvv_vint16mf8x4_t    | vint16mf8x4_t    | $(VLEN / 8) / 2$     | 2                 |
| __rvv_vuint16mf8x4_t   | vuint16mf8x4_t   | $(VLEN / 8) / 2$     | 2                 |
| __rvv_vbfloat16mf8x4_t | vbfloat16mf8x4_t | $(VLEN / 8) / 2$     | 2                 |
| __rvv_vint16mf8x5_t    | vint16mf8x5_t    | $(VLEN / 8) * 0.625$ | 2                 |
| __rvv_vuint16mf8x5_t   | vuint16mf8x5_t   | $(VLEN / 8) * 0.625$ | 2                 |
| __rvv_vbfloat16mf8x5_t | vbfloat16mf8x5_t | $(VLEN / 8) * 0.625$ | 2                 |
| __rvv_vint16mf8x6_t    | vint16mf8x6_t    | $(VLEN / 8) * 0.75$  | 2                 |
| __rvv_vuint16mf8x6_t   | vuint16mf8x6_t   | $(VLEN / 8) * 0.75$  | 2                 |
| __rvv_vbfloat16mf8x6_t | vbfloat16mf8x6_t | $(VLEN / 8) * 0.75$  | 2                 |
| __rvv_vint16mf8x7_t    | vint16mf8x7_t    | $(VLEN / 8) * 0.875$ | 2                 |
| __rvv_vuint16mf8x7_t   | vuint16mf8x7_t   | $(VLEN / 8) * 0.875$ | 2                 |
| __rvv_vbfloat16mf8x7_t | vbfloat16mf8x7_t | $(VLEN / 8) * 0.875$ | 2                 |
| __rvv_vint16mf8x8_t    | vint16mf8x8_t    | $(VLEN / 8)$         | 2                 |
| __rvv_vuint16mf8x8_t   | vuint16mf8x8_t   | $(VLEN / 8)$         | 2                 |
| __rvv_vbfloat16mf8x8_t | vbfloat16mf8x8_t | $(VLEN / 8)$         | 2                 |
| __rvv_vint16mf4x2_t    | vint16mf4x2_t    | $(VLEN / 8) / 2$     | 2                 |
| __rvv_vuint16mf4x2_t   | vuint16mf4x2_t   | $(VLEN / 8) / 2$     | 2                 |



| Internal Name          | Type             | Size (Bytes)        | Alignment (Bytes) |
|------------------------|------------------|---------------------|-------------------|
| __rvv_vbfloat16mf4x2_t | vbfloat16mf4x2_t | $(VLEN / 8) / 2$    | 2                 |
| __rvv_vint16mf4x3_t    | vint16mf4x3_t    | $(VLEN / 8) * 0.75$ | 2                 |
| __rvv_vuint16mf4x3_t   | vuint16mf4x3_t   | $(VLEN / 8) * 0.75$ | 2                 |
| __rvv_vbfloat16mf4x3_t | vbfloat16mf4x3_t | $(VLEN / 8) * 0.75$ | 2                 |
| __rvv_vint16mf4x4_t    | vint16mf4x4_t    | $(VLEN / 8)$        | 2                 |
| __rvv_vuint16mf4x4_t   | vuint16mf4x4_t   | $(VLEN / 8)$        | 2                 |
| __rvv_vbfloat16mf4x4_t | vbfloat16mf4x4_t | $(VLEN / 8)$        | 2                 |
| __rvv_vint16mf4x5_t    | vint16mf4x5_t    | $(VLEN / 8) * 1.25$ | 2                 |
| __rvv_vuint16mf4x5_t   | vuint16mf4x5_t   | $(VLEN / 8) * 1.25$ | 2                 |
| __rvv_vbfloat16mf4x5_t | vbfloat16mf4x5_t | $(VLEN / 8) * 1.25$ | 2                 |
| __rvv_vint16mf4x6_t    | vint16mf4x6_t    | $(VLEN / 8) * 1.5$  | 2                 |
| __rvv_vuint16mf4x6_t   | vuint16mf4x6_t   | $(VLEN / 8) * 1.5$  | 2                 |
| __rvv_vbfloat16mf4x6_t | vbfloat16mf4x6_t | $(VLEN / 8) * 1.5$  | 2                 |
| __rvv_vint16mf4x7_t    | vint16mf4x7_t    | $(VLEN / 8) * 1.75$ | 2                 |
| __rvv_vuint16mf4x7_t   | vuint16mf4x7_t   | $(VLEN / 8) * 1.75$ | 2                 |
| __rvv_vbfloat16mf4x7_t | vbfloat16mf4x7_t | $(VLEN / 8) * 1.75$ | 2                 |
| __rvv_vint16mf4x8_t    | vint16mf4x8_t    | $(VLEN / 8) * 2$    | 2                 |
| __rvv_vuint16mf4x8_t   | vuint16mf4x8_t   | $(VLEN / 8) * 2$    | 2                 |
| __rvv_vbfloat16mf4x8_t | vbfloat16mf4x8_t | $(VLEN / 8) * 2$    | 2                 |
| __rvv_vint16mf2x2_t    | vint16mf2x2_t    | $(VLEN / 8)$        | 2                 |
| __rvv_vuint16mf2x2_t   | vuint16mf2x2_t   | $(VLEN / 8)$        | 2                 |
| __rvv_vbfloat16mf2x2_t | vbfloat16mf2x2_t | $(VLEN / 8)$        | 2                 |
| __rvv_vint16mf2x3_t    | vint16mf2x3_t    | $(VLEN / 8) * 1.5$  | 2                 |
| __rvv_vuint16mf2x3_t   | vuint16mf2x3_t   | $(VLEN / 8) * 1.5$  | 2                 |
| __rvv_vbfloat16mf2x3_t | vbfloat16mf2x3_t | $(VLEN / 8) * 1.5$  | 2                 |
| __rvv_vint16mf2x4_t    | vint16mf2x4_t    | $(VLEN / 8) * 2$    | 2                 |
| __rvv_vuint16mf2x4_t   | vuint16mf2x4_t   | $(VLEN / 8) * 2$    | 2                 |
| __rvv_vbfloat16mf2x4_t | vbfloat16mf2x4_t | $(VLEN / 8) * 2$    | 2                 |
| __rvv_vint16mf2x5_t    | vint16mf2x5_t    | $(VLEN / 8) * 2.5$  | 2                 |
| __rvv_vuint16mf2x5_t   | vuint16mf2x5_t   | $(VLEN / 8) * 2.5$  | 2                 |
| __rvv_vbfloat16mf2x5_t | vbfloat16mf2x5_t | $(VLEN / 8) * 2.5$  | 2                 |
| __rvv_vint16mf2x6_t    | vint16mf2x6_t    | $(VLEN / 8) * 3$    | 2                 |
| __rvv_vuint16mf2x6_t   | vuint16mf2x6_t   | $(VLEN / 8) * 3$    | 2                 |

| Internal Name          | Type             | Size (Bytes)       | Alignment (Bytes) |
|------------------------|------------------|--------------------|-------------------|
| __rvv_vbfloat16mf2x6_t | vbfloat16mf2x6_t | $(VLEN / 8) * 3$   | 2                 |
| __rvv_vint16mf2x7_t    | vint16mf2x7_t    | $(VLEN / 8) * 3.5$ | 2                 |
| __rvv_vuint16mf2x7_t   | vuint16mf2x7_t   | $(VLEN / 8) * 3.5$ | 2                 |
| __rvv_vbfloat16mf2x7_t | vbfloat16mf2x7_t | $(VLEN / 8) * 3.5$ | 2                 |
| __rvv_vint16mf2x8_t    | vint16mf2x8_t    | $(VLEN / 8) * 4$   | 2                 |
| __rvv_vuint16mf2x8_t   | vuint16mf2x8_t   | $(VLEN / 8) * 4$   | 2                 |
| __rvv_vbfloat16mf2x8_t | vbfloat16mf2x8_t | $(VLEN / 8) * 4$   | 2                 |
| __rvv_vint16m1x2_t     | vint16m1x2_t     | $(VLEN / 8) * 2$   | 2                 |
| __rvv_vuint16m1x2_t    | vuint16m1x2_t    | $(VLEN / 8) * 2$   | 2                 |
| __rvv_vbfloat16m1x2_t  | vbfloat16m1x2_t  | $(VLEN / 8) * 2$   | 2                 |
| __rvv_vint16m1x3_t     | vint16m1x3_t     | $(VLEN / 8) * 3$   | 2                 |
| __rvv_vuint16m1x3_t    | vuint16m1x3_t    | $(VLEN / 8) * 3$   | 2                 |
| __rvv_vbfloat16m1x3_t  | vbfloat16m1x3_t  | $(VLEN / 8) * 3$   | 2                 |
| __rvv_vint16m1x4_t     | vint16m1x4_t     | $(VLEN / 8) * 4$   | 2                 |
| __rvv_vuint16m1x4_t    | vuint16m1x4_t    | $(VLEN / 8) * 4$   | 2                 |
| __rvv_vbfloat16m1x4_t  | vbfloat16m1x4_t  | $(VLEN / 8) * 4$   | 2                 |
| __rvv_vint16m1x5_t     | vint16m1x5_t     | $(VLEN / 8) * 5$   | 2                 |
| __rvv_vuint16m1x5_t    | vuint16m1x5_t    | $(VLEN / 8) * 5$   | 2                 |
| __rvv_vbfloat16m1x5_t  | vbfloat16m1x5_t  | $(VLEN / 8) * 5$   | 2                 |
| __rvv_vint16m1x6_t     | vint16m1x6_t     | $(VLEN / 8) * 6$   | 2                 |
| __rvv_vuint16m1x6_t    | vuint16m1x6_t    | $(VLEN / 8) * 6$   | 2                 |
| __rvv_vbfloat16m1x6_t  | vbfloat16m1x6_t  | $(VLEN / 8) * 6$   | 2                 |
| __rvv_vint16m1x7_t     | vint16m1x7_t     | $(VLEN / 8) * 7$   | 2                 |
| __rvv_vuint16m1x7_t    | vuint16m1x7_t    | $(VLEN / 8) * 7$   | 2                 |
| __rvv_vbfloat16m1x7_t  | vbfloat16m1x7_t  | $(VLEN / 8) * 7$   | 2                 |
| __rvv_vint16m1x8_t     | vint16m1x8_t     | $(VLEN / 8) * 8$   | 2                 |
| __rvv_vuint16m1x8_t    | vuint16m1x8_t    | $(VLEN / 8) * 8$   | 2                 |
| __rvv_vbfloat16m1x8_t  | vbfloat16m1x8_t  | $(VLEN / 8) * 8$   | 2                 |
| __rvv_vint16m2x2_t     | vint16m2x2_t     | $(VLEN / 8) * 4$   | 2                 |
| __rvv_vuint16m2x2_t    | vuint16m2x2_t    | $(VLEN / 8) * 4$   | 2                 |
| __rvv_vbfloat16m2x2_t  | vbfloat16m2x2_t  | $(VLEN / 8) * 4$   | 2                 |
| __rvv_vint16m2x3_t     | vint16m2x3_t     | $(VLEN / 8) * 6$   | 2                 |
| __rvv_vuint16m2x3_t    | vuint16m2x3_t    | $(VLEN / 8) * 6$   | 2                 |

| Internal Name         | Type            | Size (Bytes)         | Alignment (Bytes) |
|-----------------------|-----------------|----------------------|-------------------|
| __rvv_vbfloat16m2x3_t | vbfloat16m2x3_t | $(VLEN / 8) * 6$     | 2                 |
| __rvv_vint16m2x4_t    | vint16m2x4_t    | $(VLEN / 8) * 8$     | 2                 |
| __rvv_vuint16m2x4_t   | vuint16m2x4_t   | $(VLEN / 8) * 8$     | 2                 |
| __rvv_vbfloat16m2x4_t | vbfloat16m2x4_t | $(VLEN / 8) * 8$     | 2                 |
| __rvv_vint16m4x2_t    | vint16m4x2_t    | $(VLEN / 8) * 8$     | 2                 |
| __rvv_vuint16m4x2_t   | vuint16m4x2_t   | $(VLEN / 8) * 8$     | 2                 |
| __rvv_vbfloat16m4x2_t | vbfloat16m4x2_t | $(VLEN / 8) * 8$     | 2                 |
| __rvv_vint32mf8x2_t   | vint32mf8x2_t   | $(VLEN / 8) / 4$     | 4                 |
| __rvv_vuint32mf8x2_t  | vuint32mf8x2_t  | $(VLEN / 8) / 4$     | 4                 |
| __rvv_vfloat32mf8x2_t | vfloat32mf8x2_t | $(VLEN / 8) / 4$     | 4                 |
| __rvv_vint32mf8x3_t   | vint32mf8x3_t   | $(VLEN / 8) * 0.375$ | 4                 |
| __rvv_vuint32mf8x3_t  | vuint32mf8x3_t  | $(VLEN / 8) * 0.375$ | 4                 |
| __rvv_vfloat32mf8x3_t | vfloat32mf8x3_t | $(VLEN / 8) * 0.375$ | 4                 |
| __rvv_vint32mf8x4_t   | vint32mf8x4_t   | $(VLEN / 8) / 2$     | 4                 |
| __rvv_vuint32mf8x4_t  | vuint32mf8x4_t  | $(VLEN / 8) / 2$     | 4                 |
| __rvv_vfloat32mf8x4_t | vfloat32mf8x4_t | $(VLEN / 8) / 2$     | 4                 |
| __rvv_vint32mf8x5_t   | vint32mf8x5_t   | $(VLEN / 8) * 0.625$ | 4                 |
| __rvv_vuint32mf8x5_t  | vuint32mf8x5_t  | $(VLEN / 8) * 0.625$ | 4                 |
| __rvv_vfloat32mf8x5_t | vfloat32mf8x5_t | $(VLEN / 8) * 0.625$ | 4                 |
| __rvv_vint32mf8x6_t   | vint32mf8x6_t   | $(VLEN / 8) * 0.75$  | 4                 |
| __rvv_vuint32mf8x6_t  | vuint32mf8x6_t  | $(VLEN / 8) * 0.75$  | 4                 |
| __rvv_vfloat32mf8x6_t | vfloat32mf8x6_t | $(VLEN / 8) * 0.75$  | 4                 |
| __rvv_vint32mf8x7_t   | vint32mf8x7_t   | $(VLEN / 8) * 0.875$ | 4                 |
| __rvv_vuint32mf8x7_t  | vuint32mf8x7_t  | $(VLEN / 8) * 0.875$ | 4                 |
| __rvv_vfloat32mf8x7_t | vfloat32mf8x7_t | $(VLEN / 8) * 0.875$ | 4                 |
| __rvv_vint32mf8x8_t   | vint32mf8x8_t   | $(VLEN / 8)$         | 4                 |
| __rvv_vuint32mf8x8_t  | vuint32mf8x8_t  | $(VLEN / 8)$         | 4                 |
| __rvv_vfloat32mf8x8_t | vfloat32mf8x8_t | $(VLEN / 8)$         | 4                 |
| __rvv_vint32mf4x2_t   | vint32mf4x2_t   | $(VLEN / 8) / 2$     | 4                 |
| __rvv_vuint32mf4x2_t  | vuint32mf4x2_t  | $(VLEN / 8) / 2$     | 4                 |
| __rvv_vfloat32mf4x2_t | vfloat32mf4x2_t | $(VLEN / 8) / 2$     | 4                 |
| __rvv_vint32mf4x3_t   | vint32mf4x3_t   | $(VLEN / 8) * 0.75$  | 4                 |
| __rvv_vuint32mf4x3_t  | vuint32mf4x3_t  | $(VLEN / 8) * 0.75$  | 4                 |

| Internal Name         | Type            | Size (Bytes)        | Alignment (Bytes) |
|-----------------------|-----------------|---------------------|-------------------|
| __rvv_vfloat32mf4x3_t | vfloat32mf4x3_t | $(VLEN / 8) * 0.75$ | 4                 |
| __rvv_vint32mf4x4_t   | vint32mf4x4_t   | $(VLEN / 8)$        | 4                 |
| __rvv_vuint32mf4x4_t  | vuint32mf4x4_t  | $(VLEN / 8)$        | 4                 |
| __rvv_vfloat32mf4x4_t | vfloat32mf4x4_t | $(VLEN / 8)$        | 4                 |
| __rvv_vint32mf4x5_t   | vint32mf4x5_t   | $(VLEN / 8) * 1.25$ | 4                 |
| __rvv_vuint32mf4x5_t  | vuint32mf4x5_t  | $(VLEN / 8) * 1.25$ | 4                 |
| __rvv_vfloat32mf4x5_t | vfloat32mf4x5_t | $(VLEN / 8) * 1.25$ | 4                 |
| __rvv_vint32mf4x6_t   | vint32mf4x6_t   | $(VLEN / 8) * 1.5$  | 4                 |
| __rvv_vuint32mf4x6_t  | vuint32mf4x6_t  | $(VLEN / 8) * 1.5$  | 4                 |
| __rvv_vfloat32mf4x6_t | vfloat32mf4x6_t | $(VLEN / 8) * 1.5$  | 4                 |
| __rvv_vint32mf4x7_t   | vint32mf4x7_t   | $(VLEN / 8) * 1.75$ | 4                 |
| __rvv_vuint32mf4x7_t  | vuint32mf4x7_t  | $(VLEN / 8) * 1.75$ | 4                 |
| __rvv_vfloat32mf4x7_t | vfloat32mf4x7_t | $(VLEN / 8) * 1.75$ | 4                 |
| __rvv_vint32mf4x8_t   | vint32mf4x8_t   | $(VLEN / 8) * 2$    | 4                 |
| __rvv_vuint32mf4x8_t  | vuint32mf4x8_t  | $(VLEN / 8) * 2$    | 4                 |
| __rvv_vfloat32mf4x8_t | vfloat32mf4x8_t | $(VLEN / 8) * 2$    | 4                 |
| __rvv_vint32mf2x2_t   | vint32mf2x2_t   | $(VLEN / 8)$        | 4                 |
| __rvv_vuint32mf2x2_t  | vuint32mf2x2_t  | $(VLEN / 8)$        | 4                 |
| __rvv_vfloat32mf2x2_t | vfloat32mf2x2_t | $(VLEN / 8)$        | 4                 |
| __rvv_vint32mf2x3_t   | vint32mf2x3_t   | $(VLEN / 8) * 1.5$  | 4                 |
| __rvv_vuint32mf2x3_t  | vuint32mf2x3_t  | $(VLEN / 8) * 1.5$  | 4                 |
| __rvv_vfloat32mf2x3_t | vfloat32mf2x3_t | $(VLEN / 8) * 1.5$  | 4                 |
| __rvv_vint32mf2x4_t   | vint32mf2x4_t   | $(VLEN / 8) * 2$    | 4                 |
| __rvv_vuint32mf2x4_t  | vuint32mf2x4_t  | $(VLEN / 8) * 2$    | 4                 |
| __rvv_vfloat32mf2x4_t | vfloat32mf2x4_t | $(VLEN / 8) * 2$    | 4                 |
| __rvv_vint32mf2x5_t   | vint32mf2x5_t   | $(VLEN / 8) * 2.5$  | 4                 |
| __rvv_vuint32mf2x5_t  | vuint32mf2x5_t  | $(VLEN / 8) * 2.5$  | 4                 |
| __rvv_vfloat32mf2x5_t | vfloat32mf2x5_t | $(VLEN / 8) * 2.5$  | 4                 |
| __rvv_vint32mf2x6_t   | vint32mf2x6_t   | $(VLEN / 8) * 3$    | 4                 |
| __rvv_vuint32mf2x6_t  | vuint32mf2x6_t  | $(VLEN / 8) * 3$    | 4                 |
| __rvv_vfloat32mf2x6_t | vfloat32mf2x6_t | $(VLEN / 8) * 3$    | 4                 |
| __rvv_vint32mf2x7_t   | vint32mf2x7_t   | $(VLEN / 8) * 3.5$  | 4                 |
| __rvv_vuint32mf2x7_t  | vuint32mf2x7_t  | $(VLEN / 8) * 3.5$  | 4                 |

| Internal Name         | Type            | Size (Bytes)       | Alignment (Bytes) |
|-----------------------|-----------------|--------------------|-------------------|
| __rvv_vfloat32mf2x7_t | vfloat32mf2x7_t | $(VLEN / 8) * 3.5$ | 4                 |
| __rvv_vint32mf2x8_t   | vint32mf2x8_t   | $(VLEN / 8) * 4$   | 4                 |
| __rvv_vuint32mf2x8_t  | vuint32mf2x8_t  | $(VLEN / 8) * 4$   | 4                 |
| __rvv_vfloat32mf2x8_t | vfloat32mf2x8_t | $(VLEN / 8) * 4$   | 4                 |
| __rvv_vint32m1x2_t    | vint32m1x2_t    | $(VLEN / 8) * 2$   | 4                 |
| __rvv_vuint32m1x2_t   | vuint32m1x2_t   | $(VLEN / 8) * 2$   | 4                 |
| __rvv_vfloat32m1x2_t  | vfloat32m1x2_t  | $(VLEN / 8) * 2$   | 4                 |
| __rvv_vint32m1x3_t    | vint32m1x3_t    | $(VLEN / 8) * 3$   | 4                 |
| __rvv_vuint32m1x3_t   | vuint32m1x3_t   | $(VLEN / 8) * 3$   | 4                 |
| __rvv_vfloat32m1x3_t  | vfloat32m1x3_t  | $(VLEN / 8) * 3$   | 4                 |
| __rvv_vint32m1x4_t    | vint32m1x4_t    | $(VLEN / 8) * 4$   | 4                 |
| __rvv_vuint32m1x4_t   | vuint32m1x4_t   | $(VLEN / 8) * 4$   | 4                 |
| __rvv_vfloat32m1x4_t  | vfloat32m1x4_t  | $(VLEN / 8) * 4$   | 4                 |
| __rvv_vint32m1x5_t    | vint32m1x5_t    | $(VLEN / 8) * 5$   | 4                 |
| __rvv_vuint32m1x5_t   | vuint32m1x5_t   | $(VLEN / 8) * 5$   | 4                 |
| __rvv_vfloat32m1x5_t  | vfloat32m1x5_t  | $(VLEN / 8) * 5$   | 4                 |
| __rvv_vint32m1x6_t    | vint32m1x6_t    | $(VLEN / 8) * 6$   | 4                 |
| __rvv_vuint32m1x6_t   | vuint32m1x6_t   | $(VLEN / 8) * 6$   | 4                 |
| __rvv_vfloat32m1x6_t  | vfloat32m1x6_t  | $(VLEN / 8) * 6$   | 4                 |
| __rvv_vint32m1x7_t    | vint32m1x7_t    | $(VLEN / 8) * 7$   | 4                 |
| __rvv_vuint32m1x7_t   | vuint32m1x7_t   | $(VLEN / 8) * 7$   | 4                 |
| __rvv_vfloat32m1x7_t  | vfloat32m1x7_t  | $(VLEN / 8) * 7$   | 4                 |
| __rvv_vint32m1x8_t    | vint32m1x8_t    | $(VLEN / 8) * 8$   | 4                 |
| __rvv_vuint32m1x8_t   | vuint32m1x8_t   | $(VLEN / 8) * 8$   | 4                 |
| __rvv_vfloat32m1x8_t  | vfloat32m1x8_t  | $(VLEN / 8) * 8$   | 4                 |
| __rvv_vint32m2x2_t    | vint32m2x2_t    | $(VLEN / 8) * 4$   | 4                 |
| __rvv_vuint32m2x2_t   | vuint32m2x2_t   | $(VLEN / 8) * 4$   | 4                 |
| __rvv_vfloat32m2x2_t  | vfloat32m2x2_t  | $(VLEN / 8) * 4$   | 4                 |
| __rvv_vint32m2x3_t    | vint32m2x3_t    | $(VLEN / 8) * 6$   | 4                 |
| __rvv_vuint32m2x3_t   | vuint32m2x3_t   | $(VLEN / 8) * 6$   | 4                 |
| __rvv_vfloat32m2x3_t  | vfloat32m2x3_t  | $(VLEN / 8) * 6$   | 4                 |
| __rvv_vint32m2x4_t    | vint32m2x4_t    | $(VLEN / 8) * 8$   | 4                 |
| __rvv_vuint32m2x4_t   | vuint32m2x4_t   | $(VLEN / 8) * 8$   | 4                 |

| Internal Name         | Type            | Size (Bytes)         | Alignment (Bytes) |
|-----------------------|-----------------|----------------------|-------------------|
| __rvv_vfloat32m2x4_t  | vfloat32m2x4_t  | $(VLEN / 8) * 8$     | 4                 |
| __rvv_vint32m4x2_t    | vint32m4x2_t    | $(VLEN / 8) * 8$     | 4                 |
| __rvv_vuint32m4x2_t   | vuint32m4x2_t   | $(VLEN / 8) * 8$     | 4                 |
| __rvv_vfloat32m4x2_t  | vfloat32m4x2_t  | $(VLEN / 8) * 8$     | 4                 |
| __rvv_vint64mf8x2_t   | vint64mf8x2_t   | $(VLEN / 8) / 4$     | 8                 |
| __rvv_vuint64mf8x2_t  | vuint64mf8x2_t  | $(VLEN / 8) / 4$     | 8                 |
| __rvv_vfloat64mf8x2_t | vfloat64mf8x2_t | $(VLEN / 8) / 4$     | 8                 |
| __rvv_vint64mf8x3_t   | vint64mf8x3_t   | $(VLEN / 8) * 0.375$ | 8                 |
| __rvv_vuint64mf8x3_t  | vuint64mf8x3_t  | $(VLEN / 8) * 0.375$ | 8                 |
| __rvv_vfloat64mf8x3_t | vfloat64mf8x3_t | $(VLEN / 8) * 0.375$ | 8                 |
| __rvv_vint64mf8x4_t   | vint64mf8x4_t   | $(VLEN / 8) / 2$     | 8                 |
| __rvv_vuint64mf8x4_t  | vuint64mf8x4_t  | $(VLEN / 8) / 2$     | 8                 |
| __rvv_vfloat64mf8x4_t | vfloat64mf8x4_t | $(VLEN / 8) / 2$     | 8                 |
| __rvv_vint64mf8x5_t   | vint64mf8x5_t   | $(VLEN / 8) * 0.625$ | 8                 |
| __rvv_vuint64mf8x5_t  | vuint64mf8x5_t  | $(VLEN / 8) * 0.625$ | 8                 |
| __rvv_vfloat64mf8x5_t | vfloat64mf8x5_t | $(VLEN / 8) * 0.625$ | 8                 |
| __rvv_vint64mf8x6_t   | vint64mf8x6_t   | $(VLEN / 8) * 0.75$  | 8                 |
| __rvv_vuint64mf8x6_t  | vuint64mf8x6_t  | $(VLEN / 8) * 0.75$  | 8                 |
| __rvv_vfloat64mf8x6_t | vfloat64mf8x6_t | $(VLEN / 8) * 0.75$  | 8                 |
| __rvv_vint64mf8x7_t   | vint64mf8x7_t   | $(VLEN / 8) * 0.875$ | 8                 |
| __rvv_vuint64mf8x7_t  | vuint64mf8x7_t  | $(VLEN / 8) * 0.875$ | 8                 |
| __rvv_vfloat64mf8x7_t | vfloat64mf8x7_t | $(VLEN / 8) * 0.875$ | 8                 |
| __rvv_vint64mf8x8_t   | vint64mf8x8_t   | $(VLEN / 8)$         | 8                 |
| __rvv_vuint64mf8x8_t  | vuint64mf8x8_t  | $(VLEN / 8)$         | 8                 |
| __rvv_vfloat64mf8x8_t | vfloat64mf8x8_t | $(VLEN / 8)$         | 8                 |
| __rvv_vint64mf4x2_t   | vint64mf4x2_t   | $(VLEN / 8) / 2$     | 8                 |
| __rvv_vuint64mf4x2_t  | vuint64mf4x2_t  | $(VLEN / 8) / 2$     | 8                 |
| __rvv_vfloat64mf4x2_t | vfloat64mf4x2_t | $(VLEN / 8) / 2$     | 8                 |
| __rvv_vint64mf4x3_t   | vint64mf4x3_t   | $(VLEN / 8) * 0.75$  | 8                 |
| __rvv_vuint64mf4x3_t  | vuint64mf4x3_t  | $(VLEN / 8) * 0.75$  | 8                 |
| __rvv_vfloat64mf4x3_t | vfloat64mf4x3_t | $(VLEN / 8) * 0.75$  | 8                 |
| __rvv_vint64mf4x4_t   | vint64mf4x4_t   | $(VLEN / 8)$         | 8                 |
| __rvv_vuint64mf4x4_t  | vuint64mf4x4_t  | $(VLEN / 8)$         | 8                 |

| Internal Name         | Type            | Size (Bytes)      | Alignment (Bytes) |
|-----------------------|-----------------|-------------------|-------------------|
| __rvv_vfloat64mf4x4_t | vfloat64mf4x4_t | (VLEN / 8)        | 8                 |
| __rvv_vint64mf4x5_t   | vint64mf4x5_t   | (VLEN / 8) * 1.25 | 8                 |
| __rvv_vuint64mf4x5_t  | vuint64mf4x5_t  | (VLEN / 8) * 1.25 | 8                 |
| __rvv_vfloat64mf4x5_t | vfloat64mf4x5_t | (VLEN / 8) * 1.25 | 8                 |
| __rvv_vint64mf4x6_t   | vint64mf4x6_t   | (VLEN / 8) * 1.5  | 8                 |
| __rvv_vuint64mf4x6_t  | vuint64mf4x6_t  | (VLEN / 8) * 1.5  | 8                 |
| __rvv_vfloat64mf4x6_t | vfloat64mf4x6_t | (VLEN / 8) * 1.5  | 8                 |
| __rvv_vint64mf4x7_t   | vint64mf4x7_t   | (VLEN / 8) * 1.75 | 8                 |
| __rvv_vuint64mf4x7_t  | vuint64mf4x7_t  | (VLEN / 8) * 1.75 | 8                 |
| __rvv_vfloat64mf4x7_t | vfloat64mf4x7_t | (VLEN / 8) * 1.75 | 8                 |
| __rvv_vint64mf4x8_t   | vint64mf4x8_t   | (VLEN / 8) * 2    | 8                 |
| __rvv_vuint64mf4x8_t  | vuint64mf4x8_t  | (VLEN / 8) * 2    | 8                 |
| __rvv_vfloat64mf4x8_t | vfloat64mf4x8_t | (VLEN / 8) * 2    | 8                 |
| __rvv_vint64mf2x2_t   | vint64mf2x2_t   | (VLEN / 8)        | 8                 |
| __rvv_vuint64mf2x2_t  | vuint64mf2x2_t  | (VLEN / 8)        | 8                 |
| __rvv_vfloat64mf2x2_t | vfloat64mf2x2_t | (VLEN / 8)        | 8                 |
| __rvv_vint64mf2x3_t   | vint64mf2x3_t   | (VLEN / 8) * 1.5  | 8                 |
| __rvv_vuint64mf2x3_t  | vuint64mf2x3_t  | (VLEN / 8) * 1.5  | 8                 |
| __rvv_vfloat64mf2x3_t | vfloat64mf2x3_t | (VLEN / 8) * 1.5  | 8                 |
| __rvv_vint64mf2x4_t   | vint64mf2x4_t   | (VLEN / 8) * 2    | 8                 |
| __rvv_vuint64mf2x4_t  | vuint64mf2x4_t  | (VLEN / 8) * 2    | 8                 |
| __rvv_vfloat64mf2x4_t | vfloat64mf2x4_t | (VLEN / 8) * 2    | 8                 |
| __rvv_vint64mf2x5_t   | vint64mf2x5_t   | (VLEN / 8) * 2.5  | 8                 |
| __rvv_vuint64mf2x5_t  | vuint64mf2x5_t  | (VLEN / 8) * 2.5  | 8                 |
| __rvv_vfloat64mf2x5_t | vfloat64mf2x5_t | (VLEN / 8) * 2.5  | 8                 |
| __rvv_vint64mf2x6_t   | vint64mf2x6_t   | (VLEN / 8) * 3    | 8                 |
| __rvv_vuint64mf2x6_t  | vuint64mf2x6_t  | (VLEN / 8) * 3    | 8                 |
| __rvv_vfloat64mf2x6_t | vfloat64mf2x6_t | (VLEN / 8) * 3    | 8                 |
| __rvv_vint64mf2x7_t   | vint64mf2x7_t   | (VLEN / 8) * 3.5  | 8                 |
| __rvv_vuint64mf2x7_t  | vuint64mf2x7_t  | (VLEN / 8) * 3.5  | 8                 |
| __rvv_vfloat64mf2x7_t | vfloat64mf2x7_t | (VLEN / 8) * 3.5  | 8                 |
| __rvv_vint64mf2x8_t   | vint64mf2x8_t   | (VLEN / 8) * 4    | 8                 |
| __rvv_vuint64mf2x8_t  | vuint64mf2x8_t  | (VLEN / 8) * 4    | 8                 |

| Internal Name         | Type            | Size (Bytes)     | Alignment (Bytes) |
|-----------------------|-----------------|------------------|-------------------|
| __rvv_vfloat64mf2x8_t | vfloat64mf2x8_t | $(VLEN / 8) * 4$ | 8                 |
| __rvv_vint64m1x2_t    | vint64m1x2_t    | $(VLEN / 8) * 2$ | 8                 |
| __rvv_vuint64m1x2_t   | vuint64m1x2_t   | $(VLEN / 8) * 2$ | 8                 |
| __rvv_vfloat64m1x2_t  | vfloat64m1x2_t  | $(VLEN / 8) * 2$ | 8                 |
| __rvv_vint64m1x3_t    | vint64m1x3_t    | $(VLEN / 8) * 3$ | 8                 |
| __rvv_vuint64m1x3_t   | vuint64m1x3_t   | $(VLEN / 8) * 3$ | 8                 |
| __rvv_vfloat64m1x3_t  | vfloat64m1x3_t  | $(VLEN / 8) * 3$ | 8                 |
| __rvv_vint64m1x4_t    | vint64m1x4_t    | $(VLEN / 8) * 4$ | 8                 |
| __rvv_vuint64m1x4_t   | vuint64m1x4_t   | $(VLEN / 8) * 4$ | 8                 |
| __rvv_vfloat64m1x4_t  | vfloat64m1x4_t  | $(VLEN / 8) * 4$ | 8                 |
| __rvv_vint64m1x5_t    | vint64m1x5_t    | $(VLEN / 8) * 5$ | 8                 |
| __rvv_vuint64m1x5_t   | vuint64m1x5_t   | $(VLEN / 8) * 5$ | 8                 |
| __rvv_vfloat64m1x5_t  | vfloat64m1x5_t  | $(VLEN / 8) * 5$ | 8                 |
| __rvv_vint64m1x6_t    | vint64m1x6_t    | $(VLEN / 8) * 6$ | 8                 |
| __rvv_vuint64m1x6_t   | vuint64m1x6_t   | $(VLEN / 8) * 6$ | 8                 |
| __rvv_vfloat64m1x6_t  | vfloat64m1x6_t  | $(VLEN / 8) * 6$ | 8                 |
| __rvv_vint64m1x7_t    | vint64m1x7_t    | $(VLEN / 8) * 7$ | 8                 |
| __rvv_vuint64m1x7_t   | vuint64m1x7_t   | $(VLEN / 8) * 7$ | 8                 |
| __rvv_vfloat64m1x7_t  | vfloat64m1x7_t  | $(VLEN / 8) * 7$ | 8                 |
| __rvv_vint64m1x8_t    | vint64m1x8_t    | $(VLEN / 8) * 8$ | 8                 |
| __rvv_vuint64m1x8_t   | vuint64m1x8_t   | $(VLEN / 8) * 8$ | 8                 |
| __rvv_vfloat64m1x8_t  | vfloat64m1x8_t  | $(VLEN / 8) * 8$ | 8                 |
| __rvv_vint64m2x2_t    | vint64m2x2_t    | $(VLEN / 8) * 4$ | 8                 |
| __rvv_vuint64m2x2_t   | vuint64m2x2_t   | $(VLEN / 8) * 4$ | 8                 |
| __rvv_vfloat64m2x2_t  | vfloat64m2x2_t  | $(VLEN / 8) * 4$ | 8                 |
| __rvv_vint64m2x3_t    | vint64m2x3_t    | $(VLEN / 8) * 6$ | 8                 |
| __rvv_vuint64m2x3_t   | vuint64m2x3_t   | $(VLEN / 8) * 6$ | 8                 |
| __rvv_vfloat64m2x3_t  | vfloat64m2x3_t  | $(VLEN / 8) * 6$ | 8                 |
| __rvv_vint64m2x4_t    | vint64m2x4_t    | $(VLEN / 8) * 8$ | 8                 |
| __rvv_vuint64m2x4_t   | vuint64m2x4_t   | $(VLEN / 8) * 8$ | 8                 |
| __rvv_vfloat64m2x4_t  | vfloat64m2x4_t  | $(VLEN / 8) * 8$ | 8                 |
| __rvv_vint64m4x2_t    | vint64m4x2_t    | $(VLEN / 8) * 8$ | 8                 |
| __rvv_vuint64m4x2_t   | vuint64m4x2_t   | $(VLEN / 8) * 8$ | 8                 |



| Internal Name        | Type           | Size (Bytes)     | Alignment (Bytes) |
|----------------------|----------------|------------------|-------------------|
| __rvv_vfloat64m4x2_t | vfloat64m4x2_t | $(VLEN / 8) * 8$ | 8                 |



The vector mask types utilize a portion of the space, while the remaining content may be undefined, both in the register and in memory.



Size must be a positive integer.

# Appendix A: Linux-Specific ABI



This section of the RISC-V calling convention specification only applies to Linux-based systems.

In order to ensure compatibility between different implementations of the C library for Linux, we provide some extra definitions which only apply on those systems. These are noted in this section.

## A.1. Linux-Specific C Type Sizes and Alignments

The following definitions apply for all ABIs defined in this document. Here there is no differentiation between ILP32 and LP64 ABIs.

Table 10. Linux-specific C type sizes and alignments

| Type    | Size (Bytes) | Alignment (Bytes) |
|---------|--------------|-------------------|
| wchar_t | 4            | 4                 |
| wint_t  | 4            | 4                 |

## A.2. Linux-Specific C Type Representations

The following definitions apply for all ABIs defined in this document. Here there is no differentiation between ILP32 and LP64 ABIs.

`wchar_t` is signed. `wint_t` is unsigned.

# References

- [\[riscv-v-extension\]](#) "RISC-V V vector extension specification" [github.com/riscv/riscv-v-spec](https://github.com/riscv/riscv-v-spec)
- [\[rvv-intrinsic-doc\]](#) "RISC-V Vector Extension Intrinsic Document" [github.com/riscv-non-isa/rvv-intrinsic-doc](https://github.com/riscv-non-isa/rvv-intrinsic-doc)

# RISC-V ELF Specification

# Chapter 5. Code Models

The RISC-V architecture constrains the addressing of positions in the address space. There is no single instruction that can refer to an arbitrary memory position using a literal as its argument. Rather, instructions exist that, when combined together, can then be used to refer to a memory position via its literal. And, when not, other data structures are used to help the code to address the memory space. The coding conventions governing their use are known as code models.

However, some code models can't access the whole address space. The linker may raise an error if it cannot adjust the instructions to access the target address in the current code model.

## 5.1. Medium Low Code Model

The medium low code model, or **medlow**, allows the code to address the whole RV32 address space or the lower 2 GiB and highest 2 GiB of the RV64 address space (**0xFFFFFFFF7FFF800** ~ **0xFFFFFFFFFFFFFFFF** and **0x0** ~ **0x000000007FFFF7FF**). By using the **lui** and load / store instructions, when referring to an object, or **addi**, when calculating an address literal, for example, a 32-bit address literal can be produced.

The following instructions show how to load a value, store a value, or calculate an address in the **medlow** code model.

```
# Load value from a symbol
lui a0, %hi(symbol)
lw a0, %lo(symbol)(a0)

# Store value to a symbol
lui a0, %hi(symbol)
sw a1, %lo(symbol)(a0)

# Calculate address
lui a0, %hi(symbol)
addi a0, a0, %lo(symbol)
```



The ranges on RV64 are not **0x0** ~ **0x000000007FFFFFFF** and **0xFFFFFFFF80000000** ~ **0xFFFFFFFFFFFFFFFF** due to RISC-V's sign-extension of immediates; the following code fragments show where the ranges come from:

```
# Largest positive number:
lui a0, 0x7ffff # a0 = 0x7ffff000
addi a0, 0x7ff # a0 = a0 + 2047 = 0x000000007FFFF7FF

# Smallest negative number:
lui a0, 0x80000 # a0 = 0xffffffff80000000
addi a0, a0, -0x800 # a0 = a0 + -2048 = 0xFFFFFFFF7FFFF800
```

## 5.2. Medium Any Code Model

The medium any code model, or **medany**, allows the code to address the range between -2 GiB and +2 GiB from its position. By using **auipc** and load / store instructions, when referring to an object, or **addi**, when calculating an address literal, for example, a signed 32-bit offset, relative to the value of the **pc** register, can be produced.

As a special edge-case, undefined weak symbols must still be supported, whose addresses will be 0 and may be out of range depending on the address at which the code is linked. Any references to possibly-undefined weak symbols should be made indirectly through the GOT as is used for position-independent code. Not doing so is deprecated and a future version of this specification will require using the GOT, not just advise.



This is not yet a requirement as existing toolchains predating this part of the specification do not adhere to this, and without improvements to linker relaxation support doing so would regress performance and code size.

The following instructions show how to load a value, store a value, or calculate an address in the medany code model.

```
# Load value from a symbol
.Ltmp0: auipc a0, %pcrel_hi(symbol)
        lw    a0, %pcrel_lo(.Ltmp0)(a0)

# Store value to a symbol
.Ltmp1: auipc a0, %pcrel_hi(symbol)
        sw    a1, %pcrel_lo(.Ltmp1)(a0)

# Calculate address
.Ltmp2: auipc a0, %pcrel_hi(symbol)
        addi  a0, a0, %pcrel_lo(.Ltmp2)
```



Although the generated code is technically position independent, it's not suitable for ELF shared libraries due to differing symbol interposition rules; for that, please use the medium position independent code model below.



The address space of RV64ILP32\* ABIs is not continuous in the middle.

## 5.3. Medium Position Independent Code Model

This model is similar to the medium any code model, but uses the **global offset table** (GOT) for non-local symbol addresses.

```
# Load value from a local symbol
.Ltmp0: auipc a0, %pcrel_hi(symbol)
        lw    a0, %pcrel_lo(.Ltmp0)(a0)
```

```

        # Store value to a local symbol
.Ltmp1: auipc a0, %pcrel_hi(symbol)
        sw    a1, %pcrel_lo(.Ltmp1)(a0)

        # Calculate address of a local symbol
.Ltmp2: auipc a0, %pcrel_hi(symbol)
        addi  a0, a0, %pcrel_lo(.Ltmp2)

        # Calculate address of non-local symbol
.Ltmp3: auipc  a0, %got_pcrel_hi(symbol)
        l[w|d] a0, %pcrel_lo(.Ltmp3)(a0)

```

## 5.4. Large Code Model

The **large** code model allows the code to address the whole RV64 address space. Thus, this model is only available for RV64. By putting object addresses into literal pools, a 64-bit address literal can be loaded from the pool.



Because calculating the pool entry address must use **auipc** and **addi** or **ld**, each pool entry has to be located within the range between -2GiB and +2GiB from its access instructions. In general, the pool is appended in `.text` section or put into `.rodata` section.

```

        # Get address of a symbol
        # Literal pool
.LCPI0:
        .8byte symbol
        ...
.Ltmp0: auipc  a0, %pcrel_hi(.LCPI0)
        ld     a0, %pcrel_lo(.Ltmp0)(a0)

```

This model also changes the function call patterns. An external function address must be loaded from a literal pool entry, and use **jalr** to jump to the target function.



Same as getting address of symbol, each pool entry has to be located within the range between -2GiB and +2GiB from its access instructions. The function call can reach the whole 64-bit address space.



The code generation of function call may be changed after the range extension thunk is implemented. The compiler can emit **call** directly, and leave the model variation to the linker which could decide to jump via the literal pool or not.

```

        # Function call
        # Literal pool
.LCPI1:

```

```
.8byte function
...
.Ltmp1: auipc    a0, %pcrel_hi(.LCPI1)
        ld      a0, %pcrel_lo(.Ltmp1)(a0)
        jalr    a0
```



Large code model is disallowed to be used with PIC code model.



There will be more different code generation strategies for different usage purposes in the future.



# Chapter 6. Dynamic Linking

Any functions that use registers in a way that is incompatible with the calling convention of the ABI in use must be annotated with `STO_RISCV_VARIANT_CC`, as defined in [Section 8.3](#).



Vector registers have a variable size depending on the hardware implementation and can be quite large. Saving/restoring all these vector arguments in a run-time linker's lazy resolver would use a large amount of stack space and hurt performance. `STO_RISCV_VARIANT_CC` attribute will require the run-time linker to resolve the symbol directly to prevent saving/restoring any vector registers.

# Chapter 7. C++ Name Mangling

C++ name mangling for RISC-V follows the *Itanium C++ ABI* [\[itanium-cxx-abi\]](#); plus mangling for RISC-V vector data types and vector mask types, which are defined in the following section.

See the "Type encodings" section in *Itanium C++ ABI* for more detail on how to mangle types. Note that `__bf16` is mangled in the same way as `std::bfloat16_t`.

## 7.1. Name Mangling for Vector Data Types, Vector Mask Types and Vector Tuple Types.

The vector data types and vector mask types, as defined in the section [Section 4.6](#), are treated as vendor-extended types in the *Itanium C++ ABI* [\[itanium-cxx-abi\]](#). These mangled name for these types is `"u"<len>"rvv_"<type-name>`. Specifically, prefixing the type name with `rvv_`, which is prefixed by a decimal string indicating its length, which is prefixed by `"u"`.

For example:

```
void foo(vint8m1_t x);
```

is mangled as

```
_Z3foou15__rvv_vint8m1_t
```

```
mangled-name = "u" len "__rvv_" type-name
```

```
len = nonzero *DIGIT
```

```
nonzero = "1" / "2" / "3" / "4" / "5" / "6" / "7" / "8" / "9"
```

```
type-name = identifier-nondigit *identifier-char
```

```
identifier-nondigit = ALPHA / "_"
```

```
identifier-char = identifier-nondigit / "_"
```

# Chapter 8. ELF Object Files

The ELF object file format for RISC-V follows the *Generic System V Application Binary Interface* [gabi] ("gABI"); this specification only describes RISC-V-specific definitions.

## 8.1. File Header

The section below lists the defined RISC-V-specific values for several ELF header fields; any fields not listed in this section have no RISC-V-specific values.

### e\_ident

#### EI\_CLASS

Specifies the ABIs, either ILP32\*, LP64\* or RV64ILP32\*. Linking different ABIs' code together is not supported.

**ELFCLASS64**      ELF-64 Object File

**ELFCLASS32**      ELF-32 Object File

#### EI\_DATA

Specifies the endianness; either big-endian or little-endian. Linking big-endian and little-endian code together is not supported.

**ELFDATA2LSB**      Little-endian Object File

**ELFDATA2MSB**      Big-endian Object File

### e\_machine

Identifies the machine this ELF file targets. Always contains EM\_RISCV (243) for RISC-V ELF files.

### e\_flags

Describes the format of this ELF file. These flags are used by the linker to disallow linking ELF files with incompatible ABIs together, [Table 11](#) shows the layout of e\_flags, and flag details are listed below.

Table 11. Layout of e\_flags

| Bit<br>0 | Bits 1 - 2 | Bit<br>3 | Bit<br>4 | Bit<br>5          | Bits 6 - 23 | Bits 24 - 31            |
|----------|------------|----------|----------|-------------------|-------------|-------------------------|
| RVC      | Float ABI  | RVE      | TSO      | RV6<br>4ILP<br>32 | Reserved    | Non-standard extensions |

#### EF\_RISCV\_RVC (0x0001)

This bit is set when the binary targets the C ABI, which allows instructions to be aligned to 16-bit boundaries (the base RV32 and RV64 ISAs only allow 32-bit instruction alignment). When linking objects which specify EF\_RISCV\_RVC, the linker is permitted to use RVC instructions such as C.JAL in the linker relaxation process.

## EF\_RISCV\_FLOAT\_ABI\_SOFT (0x0000)

## EF\_RISCV\_FLOAT\_ABI\_SINGLE (0x0002)

## EF\_RISCV\_FLOAT\_ABI\_DOUBLE (0x0004)

## EF\_RISCV\_FLOAT\_ABI\_QUAD (0x0006)

These flags identify the floating point ABI in use for this ELF file. They store the largest floating-point type that ends up in registers as part of the ABI (but do not control if code generation is allowed to use floating-point internally). The rule is that if you have a floating-point type in a register, then you also have all smaller floating-point types in registers. For example `_DOUBLE` would store "float" and "double" values in F registers, but would not store "long double" values in F registers. If none of the float ABI flags are set, the object is taken to use the soft-float ABI.

## EF\_RISCV\_FLOAT\_ABI (0x0006)

This macro is used as a mask to test for one of the above floating-point ABIs, e.g., `(e_flags & EF_RISCV_FLOAT_ABI) == EF_RISCV_FLOAT_ABI_DOUBLE`.

## EF\_RISCV\_RVE (0x0008)

This bit is set when the binary targets the E ABI.

## EF\_RISCV\_TSO (0x0010)

This bit is set when the binary requires the RVTSO memory consistency model.

## EF\_RISCV\_RV64ILP32 (0x0020)

This bit is set when the binary requires the RV64ILP32\* ABIs on RV64\* ISAs.



RV64ILP32\* ABIs are experimental.

Until such a time that the **Reserved** bits (0x00ffffe0) are allocated by future versions of this specification, they shall not be set by standard software. Non-standard extensions are free to use bits 24-31 for any purpose. This may conflict with other non-standard extensions.



There is no provision for compatibility between conflicting uses of the `e_flags` bits reserved for non-standard extensions, and many standard RISC-V tools will ignore them. Do not use them unless you control both the toolchain and the operating system, and the ABI differences are so significant they cannot be done with a `.RISCV.attributes` tag nor an ELF note, such as using a different syscall ABI.

## ==== Policy for Merge Objects with Different File Headers

This section describe the behavior when the inputs files come with different file headers.

`e_ident` and `e_machine` should have exact same value otherwise linker should raise an error.

`e_flags` has different different policy for different fields:

## RVC

Input file could have different values for the RVC field; the linker should set this field into EF\_RISCV\_RVC if any of the input objects has been set.

## Float ABI

Linker should report errors if object files of different value for float ABI field.

## RVE

Linker should report errors if object files of different value for RVE field.

## TSO

Input files can have different values for the TSO field; the linker should set this field if any of the input objects have the TSO field set.

## RV64ILP32

Linker should report errors if object files of different value for RV64ILP32 field.



The static linker may ignore the compatibility checks if all fields in the `e_flags` are zero and all sections in the input file are non-executable sections.

# 8.2. String Tables

There are no RISC-V specific definitions relating to ELF string tables.

# 8.3. Symbol Table

## st\_other

The lower 2 bits are used to specify a symbol's visibility. The remaining 6 bits have no defined meaning in the ELF gABI. We use the highest bit to mark functions that do not follow the standard calling convention for the ABI in use.

The defined processor-specific `st_other` flags are listed in [Table 12](#).

Table 12. RISC-V-specific `st_other` flags

| Name                 | Mask |
|----------------------|------|
| STO_RISCV_VARIANT_CC | 0x80 |

See [Chapter 6](#) for the meaning of `STO_RISCV_VARIANT_CC`.

`__global_pointer$` must be exported in the dynamic symbol table of dynamically-linked executables if there are any GP-relative accesses present in the executable.

# 8.4. Relocations

RISC-V is a classical RISC architecture that has densely packed non-word sized instruction immediate values. While the linker can make relocations on arbitrary memory locations, many of

the RISC-V relocations are designed for use with specific instructions or instruction sequences. RISC-V has several instruction specific encodings for PC-Relative address loading, jumps, branches and the RVC compressed instruction set.

The purpose of this section is to describe the RISC-V specific instruction sequences with their associated relocations in addition to the general purpose machine word sized relocations that are used for symbol addresses in the Global Offset Table or DWARF meta data.

[Table 13](#) provides details of the RISC-V ELF relocations; the meaning of each column is given below:

#### Enum

The number of the relocation, encoded in the `r_info` field

#### ELF Reloc Type

The name of the relocation, omitting the prefix of `R_RISCV_`.

#### Type

Whether the relocation is a static or dynamic relocation:

- A static relocation relocates a location in a relocatable file, processed by a static linker.
- A dynamic relocation relocates a location in an executable or shared object, processed by a run-time linker.
- **Both**: Some relocation types are used by both static relocations and dynamic relocations.

#### Field

Describes the set of bits affected by this relocation; see [Section 8.4.3](#) for the definitions of the individual types

#### Calculation

Formula for how to resolve the relocation value; definitions of the symbols can be found in [Section 8.4.2](#)

#### Description

Additional information about the relocation

*Table 13. Relocation types*

| Enum | ELF Reloc Type | Type    | Field / Calculation         | Description   |
|------|----------------|---------|-----------------------------|---|
| 0    | NONE           | None    |                             |   |
| 1    | 32             | Both    | <i>word32</i><br>$S + A$    | 32-bit relocation                                     |
| 2    | 64             | Both    | <i>word64</i><br>$S + A$    | 64-bit relocation                                     |
| 3    | RELATIVE       | Dynamic | <i>wordclass</i><br>$B + A$ | Adjust a link address (A) to its load address (B + A) |

| Enum | ELF Reloc Type | Type    | Field / Calculation               | Description   |
|------|----------------|---------|-----------------------------------|---|
| 4    | COPY           | Dynamic |                                   | Must be in executable; not allowed in shared library  |
|      |                |         |                                   |   |
| 5    | JUMP_SLOT      | Dynamic | <i>wordclass</i>                  | Indicates the symbol associated with a PLT entry  |
|      |                |         | S                                 |   |
| 6    | TLS_DTPMOD32   | Dynamic | <i>word32</i>                     |   |
|      |                |         | TLSMODULE                         |   |
| 7    | TLS_DTPMOD64   | Dynamic | <i>word64</i>                     |   |
|      |                |         | TLSMODULE                         |   |
| 8    | TLS_DTPREL32   | Dynamic | <i>word32</i>                     |   |
|      |                |         | S + A - TLS_DTV_OFFSET            |   |
| 9    | TLS_DTPREL64   | Dynamic | <i>word64</i>                     |   |
|      |                |         | S + A - TLS_DTV_OFFSET            |   |
| 10   | TLS_TPREL32    | Dynamic | <i>word32</i>                     |   |
|      |                |         | S + A + TLSOFFSET                 |   |
| 11   | TLS_TPREL64    | Dynamic | <i>word64</i>                     |   |
|      |                |         | S + A + TLSOFFSET                 |   |
| 12   | TLSDESC        | Dynamic | See <a href="#">Section 8.5.4</a> |   |
|      |                |         | TLSDESC(S+A)                      |   |
| 16   | BRANCH         | Static  | <i>B-Type</i>                     | 12-bit PC-relative branch offset  |
|      |                |         | S + A - P                         |   |
| 17   | JAL            | Static  | <i>J-Type</i>                     | 20-bit PC-relative jump offset  |
|      |                |         | S + A - P                         |   |
| 18   | CALL           | Static  | <i>U+I-Type</i>                   | <b>Deprecated, please use CALL_PLT instead</b> 32-bit PC-relative function call, macros <code>call</code> , <code>tail</code> |
|      |                |         | S + A - P                         |   |
| 19   | CALL_PLT       | Static  | <i>U+I-Type</i>                   | 32-bit PC-relative function call, macros <code>call</code> , <code>tail</code> (PIC)  |
|      |                |         | S + A - P                         |   |
| 20   | GOT_HI20       | Static  | <i>U-Type</i>                     | High 20 bits of 32-bit PC-relative GOT access, <code>%got_pcrel_hi(symbol)</code>   |
|      |                |         | G + GOT + A - P                   |   |
| 21   | TLS_GOT_HI20   | Static  | <i>U-Type</i>                     | High 20 bits of 32-bit PC-relative TLS IE GOT access, macro <code>la.tls.ie</code>  |
|      |                |         |                                   |   |

| Enum | ELF Reloc Type | Type   | Field / Calculation          | Description  |
|------|----------------|--------|------------------------------|--|
| 22   | TLS_GD_HI20    | Static | <i>U-Type</i>                | High 20 bits of 32-bit PC-relative TLS GD GOT reference, macro <code>la.tls.gd</code>                    |
| 23   | PCREL_HI20     | Static | <i>U-Type</i><br>$S + A - P$ | High 20 bits of 32-bit PC-relative reference, <code>%pcrel_hi(symbol)</code>                             |
| 24   | PCREL_LO12_I   | Static | <i>I-type</i><br>$S - P$     | Low 12 bits of a 32-bit PC-relative, <code>%pcrel_lo(address of %pcrel_hi)</code> , the addend must be 0 |
| 25   | PCREL_LO12_S   | Static | <i>S-Type</i><br>$S - P$     | Low 12 bits of a 32-bit PC-relative, <code>%pcrel_lo(address of %pcrel_hi)</code> , the addend must be 0 |
| 26   | HI20           | Static | <i>U-Type</i><br>$S + A$     | High 20 bits of 32-bit absolute address, <code>%hi(symbol)</code>  |
| 27   | LO12_I         | Static | <i>I-Type</i><br>$S + A$     | Low 12 bits of 32-bit absolute address, <code>%lo(symbol)</code>   |
| 28   | LO12_S         | Static | <i>S-Type</i><br>$S + A$     | Low 12 bits of 32-bit absolute address, <code>%lo(symbol)</code>   |
| 29   | TPREL_HI20     | Static | <i>U-Type</i>                | High 20 bits of TLS LE thread pointer offset, <code>%tprel_hi(symbol)</code>                             |
| 30   | TPREL_LO12_I   | Static | <i>I-Type</i>                | Low 12 bits of TLS LE thread pointer offset, <code>%tprel_lo(symbol)</code>                              |
| 31   | TPREL_LO12_S   | Static | <i>S-Type</i>                | Low 12 bits of TLS LE thread pointer offset, <code>%tprel_lo(symbol)</code>                              |
| 32   | TPREL_ADD      | Static |                              | TLS LE thread pointer usage, <code>%tprel_add(symbol)</code>   |
| 33   | ADD8           | Static | <i>word8</i><br>$V + S + A$  | 8-bit label addition   |
| 34   | ADD16          | Static | <i>word16</i><br>$V + S + A$ | 16-bit label addition  |
| 35   | ADD32          | Static | <i>word32</i><br>$V + S + A$ | 32-bit label addition  |
| 36   | ADD64          | Static | <i>word64</i><br>$V + S + A$ | 64-bit label addition  |
| 37   | SUB8           | Static | <i>word8</i><br>$V - S - A$  | 8-bit label subtraction  |



| Enum  | ELF Reloc Type  | Type   | Field / Calculation | Description  |
|-------|-----------------|--------|---------------------|--|
| 38    | SUB16           | Static | <i>word16</i>       | 16-bit label subtraction   |
|       |                 |        | V - S - A           |  |
| 39    | SUB32           | Static | <i>word32</i>       | 32-bit label subtraction   |
|       |                 |        | V - S - A           |  |
| 40    | SUB64           | Static | <i>word64</i>       | 64-bit label subtraction   |
|       |                 |        | V - S - A           |  |
| 41    | GOT32_PCREL     | Static | <i>word32</i>       | 32-bit difference between the GOT entry for a symbol and the current location  |
|       |                 |        | G + GOT + A - P     |  |
| 42    | <b>Reserved</b> | -      |                     | Reserved for future standard use   |
| 43    | ALIGN           | Static |                     | Alignment statement. The addend indicates the number of bytes occupied by <b>nop</b> instructions at the relocation offset. The alignment boundary is specified by the addend rounded up to the next power of two. |
|       |                 |        |                     |  |
| 44    | RVC_BRANCH      | Static | <i>CB-Type</i>      | 8-bit PC-relative branch offset  |
|       |                 |        | S + A - P           |  |
| 45    | RVC_JUMP        | Static | <i>CJ-Type</i>      | 11-bit PC-relative jump offset   |
|       |                 |        | S + A - P           |  |
| 46-50 | <b>Reserved</b> | -      |                     | Reserved for future standard use   |
| 51    | RELAX           | Static |                     | Instruction can be relaxed, paired with a normal relocation at the same address  |
|       |                 |        |                     |  |
| 52    | SUB6            | Static | <i>word6</i>        | Local label subtraction  |
|       |                 |        | V - S - A           |  |
| 53    | SET6            | Static | <i>word6</i>        | Local label assignment   |
|       |                 |        | S + A               |  |
| 54    | SET8            | Static | <i>word8</i>        | Local label assignment   |
|       |                 |        | S + A               |  |
| 55    | SET16           | Static | <i>word16</i>       | Local label assignment   |
|       |                 |        | S + A               |  |
| 56    | SET32           | Static | <i>word32</i>       | Local label assignment   |
|       |                 |        | S + A               |  |

| Enum    | ELF Reloc Type    | Type    | Field / Calculation                              | Description  |
|---------|-------------------|---------|--|--|
| 57      | 32_PCREL          | Static  | <i>word32</i><br>S + A - P                       | 32-bit PC relative   |
| 58      | IRELATIVE         | Dynamic | <i>wordclass</i><br><i>ifunc_resolver(B + A)</i> | Relocation against a non-preemptible ifunc symbol  |
| 59      | PLT32             | Static  | <i>word32</i><br>S + A - P                       | 32-bit relative offset to a function or its PLT entry  |
| 60      | SET_ULEB128       | Static  | <i>ULEB128</i><br>S + A                          | Must be placed immediately before a SUB_ULEB128 with the same offset. Local label assignment <i>*note</i>                                      |
| 61      | SUB_ULEB128       | Static  | <i>ULEB128</i><br>V - S - A                      | Must be placed immediately after a SET_ULEB128 with the same offset. Local label subtraction <i>*note</i>                                      |
| 62      | TLSDESC_HI20      | Static  | <i>U-Type</i><br>S + A - P                       | High 20 bits of a 32-bit PC-relative offset into a TLS descriptor entry, <i>%tlsdesc_hi(symbol)</i>  |
| 63      | TLSDESC_LOAD_LO12 | Static  | <i>I-Type</i><br>S - P                           | Low 12 bits of a 32-bit PC-relative offset into a TLS descriptor entry, <i>%tlsdesc_load_lo(address of %tlsdesc_hi)</i> , the addend must be 0 |
| 64      | TLSDESC_ADD_LO12  | Static  | <i>I-Type</i><br>S - P                           | Low 12 bits of a 32-bit PC-relative offset into a TLS descriptor entry, <i>%tlsdesc_add_lo(address of %tlsdesc_hi)</i> , the addend must be 0  |
| 65      | TLSDESC_CALL      | Static  |  | Annotate call to TLS descriptor resolver function, <i>%tlsdesc_call(address of %tlsdesc_hi)</i> , for relaxation purposes only                 |
| 66-190  | <b>Reserved</b>   | -       |  | Reserved for future standard use   |
| 191     | VENDOR            | Static  |  | Paired with a vendor-specific relocation and must be placed immediately before it, indicates which vendor owns the relocation.                 |
| 192-255 | <b>Reserved</b>   | -       |  | Reserved for nonstandard ABI extensions  |

This section and later ones contain fragments written in assembler. The precise assembler syntax, including that of the relocations, is described in the *RISC-V Assembly Programmer's Manual* [rv-asm].



The assembler must allocate sufficient space to accommodate the final value for the `R_RISCV_SET_ULEB128` and `R_RISCV_SUB_ULEB128` relocation pair and fill the space with a single ULEB128-encoded value. This is achieved by prepending the redundant `0x80` byte as necessary. The linker must not alter the length of the ULEB128-encoded value.

### 8.4.1. Nonstandard Relocations (a.k.a. Vendor-Specific Relocations)

Nonstandard extensions are free to use relocation numbers 192-255 for any purpose. These vendor-specific relocations must be preceded by a `R_RISCV_VENDOR` relocation against a vendor identifier symbol. The preceding `R_RISCV_VENDOR` relocation is used by the linker to choose the correct implementation for the associated nonstandard relocation.

The vendor identifier symbol should be a defined symbol and should set the type to `STT_NOTYPE`, binding to `STB_LOCAL`, and the size of symbol to zero.

Vendor identifiers must be unique amongst all vendors providing custom relocations. Vendor identifiers may be suffixed with a tag to provide extra relocations for a given vendor.



Please refer to the *RISC-V Toolchain Conventions* [\[rv-toolchain-conventions\]](#) for the full list of vendor identifiers.

Where possible, tools should present relocation as their vendor-specific relocation types, otherwise a generic name of `R_RISCV_CUSTOM<enum value>` must be shown.

### 8.4.2. Calculation Symbols

[Table 14](#) provides details on the variables used in relocation calculation:

*Table 14. Variables used in relocation calculation*

| Variable  | Description   |
|-----------|---|
| A         | Addend field in the relocation entry associated with the symbol                             |
| B         | Base address of a shared object loaded into memory  |
| G         | Offset of the symbol into the GOT (Global Offset Table)                                     |
| GOT       | Address of the GOT (Global Offset Table)  |
| P         | Position of the relocation  |
| S         | Value of the symbol in the symbol table   |
| V         | Value at the position of the relocation   |
| GP        | Value of <code>__global_pointer\$</code> symbol   |
| TLSMODULE | TLS module index for the object containing the symbol                                       |
| TLSOFFSET | TLS static block offset (relative to <code>tp</code> ) for the object containing the symbol |

**Global Pointer:** It is assumed that program startup code will load the value of the `__global_pointer$` symbol into register `gp` (aka `x3`).

### 8.4.3. Field Symbols

Table 15 provides details on the variables used in relocation fields:

Table 15. Variables used in relocation fields

| Variable         | Description   |
|------------------|---|
| <i>word6</i>     | Specifies the 6 least significant bits of a <i>word8</i> field                    |
| <i>word8</i>     | Specifies an 8-bit word   |
| <i>word16</i>    | Specifies a 16-bit word   |
| <i>word32</i>    | Specifies a 32-bit word   |
| <i>word64</i>    | Specifies a 64-bit word   |
| <i>ULEB128</i>   | Specifies a variable-length data encoded in ULEB128 format.                       |
| <i>wordclass</i> | Specifies a <i>word32</i> field for ILP32 or a <i>word64</i> field for LP64       |
| <i>B-Type</i>    | Specifies a field as the immediate field in a B-type instruction                  |
| <i>CB-Type</i>   | Specifies a field as the immediate field in a CB-type instruction                 |
| <i>CI-Type</i>   | Specifies a field as the immediate field in a CI-type instruction                 |
| <i>CJ-Type</i>   | Specifies a field as the immediate field in a CJ-type instruction                 |
| <i>I-Type</i>    | Specifies a field as the immediate field in an I-type instruction                 |
| <i>S-Type</i>    | Specifies a field as the immediate field in an S-type instruction                 |
| <i>U-Type</i>    | Specifies a field as the immediate field in an U-type instruction                 |
| <i>J-Type</i>    | Specifies a field as the immediate field in a J-type instruction                  |
| <i>U+I-Type</i>  | Specifies a field as the immediate fields in a U-type and I-type instruction pair |

### 8.4.4. Constants

Table 16 provides details on the constants used in relocation fields:

Table 16. Constants used in relocation fields

| Name           | Value |
|----------------|-------|
| TLS_DTV_OFFSET | 0x800 |

### 8.4.5. Absolute Addresses

32-bit absolute addresses in position dependent code are loaded with a pair of instructions which have an associated pair of relocations: **R\_RISCV\_HI20** plus **R\_RISCV\_L012\_I** or **R\_RISCV\_L012\_S**.

The **R\_RISCV\_HI20** refers to an **LUI** instruction containing the high 20-bits to be relocated to an absolute symbol address. The **LUI** instruction is used in conjunction with one or more I-Type instructions (add immediate or load) with **R\_RISCV\_L012\_I** relocations or S-Type instructions (store) with **R\_RISCV\_L012\_S** relocations. The addresses for pair of relocations are calculated like this:

**HI20**     `(symbol_address + 0x800) >> 12`

**LO12**     `symbol_address`

The following assembly and relocations show loading an absolute address:

```
lui a0, %hi(symbol)    # R_RISCV_HI20 (symbol)
addi a0, a0, %lo(symbol) # R_RISCV_LO12_I (symbol)
```

A symbol can be loaded in multiple fragments using different addends, where multiple instructions associated with `R_RISCV_LO12_I/R_RISCV_LO12_S` share a single `R_RISCV_HI20`. The HI20 values for the multiple fragments must be identical, a condition met when the symbol is sufficiently aligned.

```
lui a0, 0              # R_RISCV_HI20 (symbol)
lw a1, 0(a0)           # R_RISCV_LO12_I (symbol)
lw a2, 0(a0)           # R_RISCV_LO12_I (symbol+4)
lw a3, 0(a0)           # R_RISCV_LO12_I (symbol+8)
lw a0, 0(a0)           # R_RISCV_LO12_I (symbol+12)
```

### 8.4.6. Global Offset Table

For position independent code in dynamically linked objects, each shared object contains a GOT (Global Offset Table), which contains addresses of global symbols (objects and functions) referred to by the dynamically linked shared object. The GOT in each shared library is filled in by the dynamic linker during program loading, or on the first call to extern functions.

To avoid dynamic relocations within the text segment of position independent code the GOT is used for indirection. Instead of code loading virtual addresses directly, as can be done in static code, addresses are loaded from the GOT. This allows runtime binding to external objects and functions at the expense of a slightly higher runtime overhead for access to extern objects and functions.

### 8.4.7. Procedure Linkage Table

The PLT (Procedure Linkage Table) exists to allow function calls between dynamically linked shared objects. Each dynamic object has its own GOT (Global Offset Table) and PLT (Procedure Linkage Table).

The first entry of a shared object PLT is a special entry that calls `_dl_runtime_resolve` to resolve the GOT offset for the called function. The `_dl_runtime_resolve` function in the dynamic loader resolves the GOT offsets lazily on the first call to any function, except when `LD_BIND_NOW` is set in which case the GOT entries are populated by the dynamic linker before the executable is started. Lazy resolution of GOT entries is intended to speed up program loading by deferring symbol resolution to the first time the function is called. The first entry in the PLT occupies two 16 byte entries:

```
1: auipc t2, %pcrel_hi(.got.plt)
   sub t1, t1, t3              # shifted .got.plt offset + hdr size + 12
   lw[d] t3, %pcrel_lo(1b)(t2) # _dl_runtime_resolve
```

```

addi    t1, t1, -(hdr size + 12) # shifted .got.plt offset
addi    t0, t2, %pcrel_lo(1b)    # &.got.plt
srli    t1, t1, log2(16/PTRSIZE) # .got.plt offset
l[w|d]  t0, PTRSIZE(t0)          # link map
jr      t3

```

Subsequent function entry stubs in the PLT take up 16 bytes and load a function pointer from the GOT. On the first call to a function, the entry redirects to the first PLT entry which calls `_dl_runtime_resolve` and fills in the GOT entry for subsequent calls to the function:

```

1: auipc  t3, %pcrel_hi(function@.got.plt)
   l[w|d] t3, %pcrel_lo(1b)(t3)
   jalr   t1, t3
   nop

```

### 8.4.8. Procedure Calls

`R_RISCV_CALL` and `R_RISCV_CALL_PLT` relocations are associated with pairs of instructions (`AUIPC+JALR`) generated by the `CALL` or `TAIL` pseudoinstructions. Originally, these relocations had slightly different behavior, but that has turned out to be unnecessary, and they are now interchangeable, `R_RISCV_CALL` is deprecated, suggest using `R_RISCV_CALL_PLT` instead.

With linker relaxation enabled, the `AUIPC` instruction in the `AUIPC+JALR` pair has both a `R_RISCV_CALL` or `R_RISCV_CALL_PLT` relocation and an `R_RISCV_RELAX` relocation indicating the instruction sequence can be relaxed during linking.

Procedure call linker relaxation allows the `AUIPC+JALR` pair to be relaxed to the `JAL` instruction when the procedure or PLT entry is within (-1MiB to +1MiB-2) of the instruction pair.

The pseudoinstruction:

```

call symbol
call symbol@plt

```

expands to the following assembly and relocation:

```

auipc ra, 0          # R_RISCV_CALL (symbol), R_RISCV_RELAX (symbol)
jalr  ra, ra, 0

```

and when symbol has an `@plt` suffix it expands to:

```

auipc ra, 0          # R_RISCV_CALL_PLT (symbol), R_RISCV_RELAX (symbol)
jalr  ra, ra, 0

```

### 8.4.9. PC-Relative Jumps and Branches

Unconditional jump (J-Type) instructions have a `R_RISCV_JAL` relocation that can represent an even signed 21-bit offset (-1MiB to +1MiB-2).

Branch (SB-Type) instructions have a `R_RISCV_BRANCH` relocation that can represent an even signed 13-bit offset (-4096 to +4094).

### 8.4.10. PC-Relative Symbol Addresses

32-bit PC-relative relocations for symbol addresses on sequences of instructions such as the `AUIPC+ADDI` instruction pair expanded from the `la` pseudoinstruction, in position independent code typically have an associated pair of relocations: `R_RISCV_PCREL_HI20` plus `R_RISCV_PCREL_LO12_I` or `R_RISCV_PCREL_LO12_S`.

The `R_RISCV_PCREL_HI20` relocation refers to an `AUIPC` instruction containing the high 20-bits to be relocated to a symbol relative to the program counter address of the `AUIPC` instruction. The `AUIPC` instruction is used in conjunction with one or more I-Type instructions (add immediate or load) with `R_RISCV_PCREL_LO12_I` relocations or S-Type instructions (store) with `R_RISCV_PCREL_LO12_S` relocations.

The `R_RISCV_PCREL_LO12_I` or `R_RISCV_PCREL_LO12_S` relocations contain a label pointing to an instruction in the same section with an `R_RISCV_PCREL_HI20` relocation entry that points to the target symbol:

- At label: `R_RISCV_PCREL_HI20` relocation entry → symbol
- `R_RISCV_PCREL_LO12_I` relocation entry → label

To get the symbol address to perform the calculation to fill the 12-bit immediate on the add, load or store instruction the linker finds the `R_RISCV_PCREL_HI20` relocation entry associated with the `AUIPC` instruction. The addresses for pair of relocations are calculated like this:

**HI20**     `(symbol_address - hi20_reloc_offset + 0x800) >> 12`

**LO12**     `symbol_address - hi20_reloc_offset`

The successive instruction has a signed 12-bit immediate so the value of the preceding high 20-bit relocation may have 1 added to it.

Note the compiler emitted instructions for PC-relative symbol addresses are not necessarily sequential or in pairs. There is a constraint is that the instruction with the `R_RISCV_PCREL_LO12_I` or `R_RISCV_PCREL_LO12_S` relocation label points to a valid HI20 PC-relative relocation pointing to the symbol.

Here is example assembler showing the relocation types:

```
label:
    auipc t0, %pcrel_hi(symbol)    # R_RISCV_PCREL_HI20 (symbol)
    lui t1, 1
    lw t2, t0, %pcrel_lo(label)    # R_RISCV_PCREL_LO12_I (label)
```

```
add t2, t2, t1
sw t2, t0, %pcrel_lo(label)    # R_RISCV_PCREL_L012_S (label)
```

### 8.4.11. Relocation for Alignment

The relocation type `R_RISCV_ALIGN` marks a location that must be aligned to `N`-bytes, where `N` is the smallest power of two that is greater than the value of the addend field, e.g. `R_RISCV_ALIGN` with addend value 2 means align to 4 bytes, `R_RISCV_ALIGN` with addend value 4 means align to 8 bytes; this relocation is only required if the containing section has any `R_RISCV_RELAX` relocations, `R_RISCV_ALIGN` points to the beginning of the padding bytes, and the instruction that actually needs to be aligned is located at the point of `R_RISCV_ALIGN` plus its addend.

To ensure the linker can always satisfy the required alignment solely by deleting bytes, the compiler or assembler must emit a `R_RISCV_ALIGN` relocation and then insert `N - [IALIGN]` padding bytes before the location where we need to align, it could be mark by an alignment directive like `.align`, `.p2align` or `.balign` or emit by compiler directly, the addend value of that relocation is the number of padding bytes.

The compiler and assembler must ensure padding bytes are valid instructions without any side-effect like `nop` or `c.nop`, and make sure those instructions are aligned to `IALIGN` if possible.

The linker may remove part of the padding bytes at the linking process to meet the alignment requirement, and must make sure those padding bytes still are valid instructions and each instruction is aligned to at least `IALIGN` byte.

Here is example to showing how `R_RISCV_ALIGN` is used:

```
0x0    c.nop          # R_RISCV_ALIGN with addend 2
0x2    add t1, t2, t3 # This instruction must align to 4 byte.
```



`R_RISCV_ALIGN` relocation is needed because linker relaxation can shrink preceding code during the linking process, which may cause an aligned location to become mis-aligned.



`IALIGN` means the instruction-address alignment constraint. `IALIGN` is 4 bytes in the base ISA, but some ISA extensions, including the compressed ISA extension, relax `IALIGN` to 2 bytes. `IALIGN` may not take on any value other than 4 or 2. This term is also defined in [The RISC-V Instruction Set Manual](#) with a similar meaning, the only difference being it is specified in terms of the number of bits instead of the number of bytes.



Here is pseudocode to decide the alignment of `R_RISCV_ALIGN` relocation:

```
# input:
#   addend: addend value of relocation with R_RISCV_ALIGN type.
# output:
```



```
# Alignment of this relocation.
```

```
def align(addend):  
    ALIGN = 1  
    while addend >= ALIGN:  
        ALIGN *= 2  
    return ALIGN
```

## 8.5. Thread Local Storage

RISC-V adopts the ELF Thread Local Storage Model in which ELF objects define `.tbss` and `.tdata` sections and `PT_TLS` program headers that contain the TLS "initialization images" for new threads. The `.tbss` and `.tdata` sections are not referenced directly like regular segments, rather they are copied or allocated to the thread local storage space of newly created threads. See *ELF Handling For Thread-Local Storage* [tls].

In The ELF Thread Local Storage Model, TLS offsets are used instead of pointers. The ELF TLS sections are initialization images for the thread local variables of each new thread. A TLS offset defines an offset into the dynamic thread vector which is pointed to by the TCB (Thread Control Block). RISC-V uses Variant I as described by the ELF TLS specification, with `tp` containing the address one past the end of the TCB.

There are various thread local storage models for statically allocated or dynamically allocated thread local storage. Table 17 lists the thread local storage models:

Table 17. TLS models

| Mnemonic | Model          |
|----------|----------------|
| TLS LE   | Local Exec     |
| TLS IE   | Initial Exec   |
| TLS LD   | Local Dynamic  |
| TLS GD   | Global Dynamic |

The program linker in the case of static TLS or the dynamic linker in the case of dynamic TLS allocate TLS offsets for storage of thread local variables.



Global Dynamic model is also known as General Dynamic model.

### 8.5.1. Local Exec

Local exec is a form of static thread local storage. This model is used when static linking as the TLS offsets are resolved during program linking.

#### Variable attribute

```
__thread int i __attribute__((tls_model("local-exec")));
```

Example assembler load and store of a thread local variable `i` using the `%tprel_hi`, `%tprel_add` and

`%tprel_lo` assembler functions. The emitted relocations are in comments.

```
lui  a5,%tprel_hi(i)      # R_RISCV_TPREL_HI20 (symbol)
add  a5,a5,tp,%tprel_add(i) # R_RISCV_TPREL_ADD (symbol)
lw   t0,%tprel_lo(i)(a5)  # R_RISCV_TPREL_L012_I (symbol)
addi t0,t0,1
sw   t0,%tprel_lo(i)(a5)  # R_RISCV_TPREL_L012_S (symbol)
```

The `%tprel_add` assembler function does not return a value and is used purely to associate the `R_RISCV_TPREL_ADD` relocation with the `add` instruction.

### 8.5.2. Initial Exec

Initial exec is a form of static thread local storage that can be used in shared libraries that use thread local storage. TLS relocations are performed at load time. `dlopen` calls to libraries that use thread local storage may fail when using the initial exec thread local storage model as TLS offsets must all be resolved at load time. This model uses the GOT to resolve TLS offsets.

#### Variable attribute

```
__thread int i __attribute__((tls_model("initial-exec")));
```

#### ELF flags

```
DF_STATIC_TLS
```

Example assembler load and store of a thread local variable `i` using the `la.tls.ie` pseudoinstruction, with the emitted TLS relocations in comments:

```
la.tls.ie a5,i
add  a5,a5,tp
lw   t0,0(a5)
addi t0,t0,1
sw   t0,0(a5)
```

The assembler pseudoinstruction:

```
la.tls.ie a5,symbol
```

expands to the following assembly instructions and relocations:

```
label:
    auipc a5, 0          # R_RISCV_TLS_GOT_HI20 (symbol)
    {ld,lw} a5, 0(a5)    # R_RISCV_PCREL_L012_I (label)
```

### 8.5.3. Global Dynamic

RISC-V local dynamic and global dynamic TLS models generate equivalent object code. The Global dynamic thread local storage model is used for PIC Shared libraries and handles the case where more than one library uses thread local variables, and additionally allows libraries to be loaded and unloaded at runtime using `dlopen`. In the global dynamic model, application code calls the dynamic linker function `__tls_get_addr` to locate TLS offsets into the dynamic thread vector at runtime.

#### Variable attribute

```
__thread int i __attribute__((tls_model("global-dynamic")));
```

Example assembler load and store of a thread local variable `i` using the `la.tls.gd` pseudoinstruction, with the emitted TLS relocations in comments:

```
la.tls.gd a0,i
call __tls_get_addr@plt
mv a5,a0
lw t0,0(a5)
addi t0,t0,1
sw t0,0(a5)
```

The assembler pseudoinstruction:

```
la.tls.gd a0,symbol
```

expands to the following assembly instructions and relocations:

```
label:
    auipc a0,0                # R_RISCV_TLS_GD_HI20 (symbol)
    addi a0,a0,0              # R_RISCV_PCREL_L012_I (label)
```

In the Global Dynamic model, the runtime library provides the `__tls_get_addr` function:

```
extern void *__tls_get_addr (tls_index *ti);
```

where the type `tls_index` is defined as:

```
typedef struct
{
    unsigned long int ti_module;
    unsigned long int ti_offset;
} tls_index;
```

### 8.5.4. TLS Descriptors

TLS Descriptors (TLSDESC) are an alternative implementation of the Global Dynamic model that allows the dynamic linker to achieve performance close to that of Initial Exec when the library was not loaded dynamically with `dlopen`.

The linker reserves a consecutive pair of pointer-sized entry in the GOT for each `TLSDESC` relocation. At runtime, the dynamic linker fills in the TLS descriptor entry as defined below:

```
typedef struct
{
    unsigned long (*entry)(tls_descriptor *);
    unsigned long arg;
} tls_descriptor;
```

Upon accessing the thread local variable, the `entry` function is called with the address of `tls_descriptor` containing it, returning `<address of thread local variable> - tp`.

The TLS descriptor `entry` is called with a special calling convention, specified as follows:

- `a0` is used to pass the argument and return value.
- `t0` is used as the link register.
- Any other registers are callee-saved. This includes any vector registers when the vector extension is supported.

Example assembler load and store of a thread local variable `i` using the `%tlsdesc_hi`, `%tlsdesc_load_lo`, `%tlsdesc_add_lo` and `%tlsdesc_call` assembler functions. The emitted relocations are in the comments.

```
label:
    auipc tX, %tlsdesc_hi(symbol)          // R_RISCV_TLSDESC_HI20 (symbol)
    lw    tY, tX, %tlsdesc_load_lo(label) // R_RISCV_TLSDESC_LOAD_LO12 (label)
    addi  a0, tX, %tlsdesc_add_lo(label)   // R_RISCV_TLSDESC_ADD_LO12 (label)
    jalr  t0, tY, %tlsdesc_call(label)     // R_RISCV_TLSDESC_CALL (label)
```

`tX` and `tY` in the example may be replaced with any combination of two general purpose registers.

The `%tlsdesc_call` assembler function does not return a value and is used purely to associate the `R_RISCV_TLSDESC_CALL` relocation with the `jalr` instruction.

The linker can use the relocations to recognize the sequence and to perform relaxations. To ensure correctness, only the following changes to the sequence are allowed:

- Instructions outside the sequence that do not clobber the registers used within the sequence may be inserted in-between the instructions of the sequence (known as instruction scheduling).
- Instructions in the sequence with no data dependency may be reordered. In the preceding example, the only instructions that can be reordered are `lw` and `addi`.

## 8.6. Sections

### 8.6.1. Section Types

The defined processor-specific section types are listed in [Table 18](#).

Table 18. RISC-V-specific section types

| Name                 | Value      | Attributes |
|----------------------|------------|------------|
| SHT_RISCV_ATTRIBUTES | 0x70000003 | none       |

### 8.6.2. Special Sections

[Table 19](#) lists the special sections defined by this ABI.

Table 19. RISC-V-specific sections

| Name               | Type                 | Attributes                |
|--------------------|----------------------|---------------------------|
| .riscv.attributes  | SHT_RISCV_ATTRIBUTES | none                      |
| .riscv.jvt         | SHT_PROGBITS         | SHF_ALLOC + SHF_EXECINSTR |
| .note.gnu.property | SHT_NOTE             | SHF_ALLOC                 |

.riscv.attributes names a section that contains RISC-V ELF attributes.

.riscv.jvt is a linker-created section to store table jump target addresses. The minimum alignment of this section is 64 bytes.

.note.gnu.property names a section that contains a program property note.

## 8.7. Program Header Table

The defined processor-specific segment types are listed in [Table 20](#).

Table 20. RISC-V-specific segment types

| Name                | Value      | Meaning                       |
|---------------------|------------|-------------------------------|
| PT_RISCV_ATTRIBUTES | 0x70000003 | RISC-V ELF attribute section. |

**PT\_RISCV\_ATTRIBUTES** describes the location of RISC-V ELF attribute section.



**PT\_RISCV\_ATTRIBUTES** is deprecated. The build attributes section does not contain the **SHF\_ALLOC** flag. Dynamic loaders cannot assume that the region described by **PT\_RISCV\_ATTRIBUTES** is present.

## 8.8. Note Sections

There are no RISC-V specific definitions relating to ELF note sections.

## 8.9. Dynamic Section

The defined processor-specific dynamic array tags are listed in [Table 21](#).

Table 21. RISC-V-specific dynamic array tags

| Name                | Value      | d_un  | Executable        | Shared Object     |
|---------------------|------------|-------|-------------------|-------------------|
| DT_RISCV_VARIANT_CC | 0x70000001 | d_val | Platform specific | Platform specific |

An object must have the dynamic tag `DT_RISCV_VARIANT_CC` if it has one or more `R_RISCV_JUMP_SLOT` relocations against symbols with the `STO_RISCV_VARIANT_CC` attribute.

`DT_INIT` and `DT_FINI` are not required to be supported and should be avoided in favour of `DT_PREINIT_ARRAY`, `DT_INIT_ARRAY` and `DT_FINI_ARRAY`.

## 8.10. Hash Table

There are no RISC-V specific definitions relating to ELF hash tables.

## 8.11. Attributes

Attributes are used to record information about an object file/binary that a linker or runtime loader needs to check compatibility.

Attributes are encoded in a vendor-specific section of type `SHT_RISCV_ATTRIBUTES` and name `.riscv.attributes`. The value of an attribute can hold an integer encoded in the uleb128 format or a null-terminated byte string (NTBS). The tag number is also encoded as uleb128.

In order to improve the compatibility of the tool, the attribute follows below rules:

- RISC-V attributes have a string value if the tag number is odd and an integer value if the tag number is even.
- The tag is mandatory; If the tool does not recognize this attribute and the tag number modulo 128 is less than 64 ( $(N \% 128) < 64$ ), errors should be reported.
- The tag is optional; If the tool does not recognize this attribute and the tag number modulo 128 is greater than or equal to 64 ( $(N \% 128) \geq 64$ ), the tag can be ignored.

### 8.11.1. Layout of .riscv.attributes Section

The attributes section start with a format-version (uint8 = 'A') followed by vendor specific sub-section(s). A sub-section starts with sub-section length (uint32), vendor name (NTBS) and one or more sub-sub-section(s).

A sub-sub-section consists of a tag (uleb128), sub-sub-section length (uint32) followed by actual

attribute tag,value pair(s) as specified above. Sub-sub-section Tag Tag\_file (value 1) specifies that contained attributes relate to whole file.

A sub-section with name "riscv\0" is mandatory. Vendor specific sub-sections are allowed in future. Vendor names starting with "[Aa]non" are reserved for non-standard ABI extensions.

### 8.11.2. List of Attributes

Table 22. RISC-V attributes

| Tag                                 | Value    | Parameter type | Description   |
|-------------------------------------|----------|----------------|---|
| Tag_RISCV_stack_align               | 4        | uleb128        | Indicates the stack alignment requirement in bytes.                                 |
| Tag_RISCV_arch                      | 5        | NTBS           | Indicates the target architecture of this object.                                   |
| Tag_RISCV_unaligned_access          | 6        | uleb128        | Indicates whether to impose unaligned memory accesses in code generation.           |
| Tag_RISCV_priv_spec                 | 8        | uleb128        | <b>Deprecated</b> , indicates the major version of the privileged specification.    |
| Tag_RISCV_priv_spec_minor           | 10       | uleb128        | <b>Deprecated</b> , indicates the minor version of the privileged specification.    |
| Tag_RISCV_priv_spec_revision        | 12       | uleb128        | <b>Deprecated</b> , indicates the revision version of the privileged specification. |
| Tag_RISCV_atomic_abi                | 14       | uleb128        | Indicates which version of the atomics ABI is being used.                           |
| Tag_RISCV_x3_reg_usage              | 16       | uleb128        | Indicates the usage definition of the X3 register.                                  |
| Reserved for non-standard attribute | >= 32768 | -              | -   |

### 8.11.3. Detailed Attribute Description

**How does this specification describe public attributes?**

Each attribute is described in the following structure: <Tag name>, <Value>, <Parameter type 1>=<Parameter name 1>[, <Parameter type 2>=<Parameter name 2>]

**Tag\_RISCV\_stack\_align, 4, uleb128=value**

Tag\_RISCV\_stack\_align records the N-byte stack alignment for this object. The default value is 16 for RV32I or RV64I, and 4 for RV32E.

## Merge Policy

The linker should report errors if link object files with different `Tag_RISCV_stack_align` values.

### Tag\_RISCV\_arch, 5, NTBS=subarch

`Tag_RISCV_arch` contains a string for the target architecture taken from the option `-march`. Different architectures will be integrated into a superset when object files are merged.

`Tag_RISCV_arch` should be recorded in lowercase, and all extensions should be separated by `underline()`.

Note that the version information for target architecture must be presented explicitly in the attribute and abbreviations must be expanded. The version information, if not given by `-march`, must agree with the default specified by the tool. For example, the architecture `rv32i` has to be recorded in the attribute as `rv32i2p1` in which `2p1` stands for the default version of its based ISA. On the other hand, the architecture `rv32g` has to be presented as `rv32i2p1_m2p0_a2p1_f2p2_d2p2_zicsr2p0_zifencei2p0` in which the abbreviation `g` is expanded to the `imafd_zicsr_zifencei` combination with default versions of the standard extensions.

The toolchain should normalize the architecture string by expanding all required extensions and placing them in canonical order which is defined in *The RISC-V Instruction Set Manual, Volume I: User-Level ISA, Document [riscv-unpriv]*. Shorthand extensions should be expanded into the architecture string if all expanded extensions are included in the architecture string.



A shorthand extension is an extension that does not define any actual instructions, registers or behavior, but requires other extensions, such as the `zks` cryptography extension. `zks` extension is shorthand for `zbbk`, `zbbc`, `zbbx`, `zksed` and `zksh`, so the toolchain should normalize `rv32i_zbbk_zbbc_zbbx_zksed_zksh` to `rv32i_zbbk_zbbc_zbbx_zks_zksed_zksh`; `g` is an exception and does not follow this rule.

## Merge Policy

The linker should merge the different architectures into a superset when object files are merged, and should report errors if the merge result contains conflict extensions.

This specification does not mandate rules on how to merge ISA strings that refer to different versions of the same ISA extension. The suggested merge rules are as follows:

- Merge versions into the latest version of all input versions that are ratified without warning or error.
- The linker should emit a warning or error if input versions have different versions and any extension versions are not ratified.
- The linker may report a warning or error if it detects incompatible versions, even if it's ratified.



Example of conflicting merge result: `RV32IF` and `RV32IZfinx` will be merged into `RV32IFZfinx`, which is an invalid architecture since `F` and `Zfinx` conflict.



### Tag\_RISCV\_unaligned\_access, 6, uleb128=value

Tag\_RISCV\_unaligned\_access denotes the code generation policy for this object file. Its values are defined as follows:

- 0 This object does not perform any unaligned memory accesses.
- 1 This object may perform unaligned memory accesses.

#### Merge policy

Input file could have different values for the Tag\_RISCV\_unaligned\_access; the linker should set this field into 1 if any of the input objects has been set.

### Tag\_RISCV\_priv\_spec, 8, uleb128=version

### Tag\_RISCV\_priv\_spec\_minor, 10, uleb128=version

### Tag\_RISCV\_priv\_spec\_revision, 12, uleb128=version



Those three attributes are deprecated since RISC-V using extensions with version rather than a single privileged specification version scheme for privileged ISA.

Tag\_RISCV\_priv\_spec contains the major/minor/revision version information of the privileged specification.

#### Merge policy

The linker should report errors if object files of different privileged specification versions are merged.

### Tag\_RISCV\_atomic\_abi, 14, uleb128=version

Tag\_RISCV\_atomic\_abi denotes the atomic ABI used within this object file. Its values are defined as follows:

| Value | Symbolic Name | Description   |
|-------|---------------|---|
| 0     | UNKNOWN       | This object uses unknown atomic ABI.  |
| 1     | A6C           | This object uses the A6 classical atomic ABI, which is defined in table A.6 in <a href="#">[riscv-unpriv-20191213]</a> .  |
| 2     | A6S           | This object uses the strengthened A6 ABI, which uses the atomic mapping defined by <a href="#">Table 24</a> and does not rely on any note 3 annotated mappings. |
| 3     | A7            | This object uses the A7 atomic ABI, which uses the atomic mapping defined by <a href="#">Table 24</a> and may rely on note 3 annotated mappings.                |

#### Merge policy

The linker should report errors if object files with incompatible atomics ABIs are merged; the compatibility rules for atomic ABIs can be found in the compatibility column in the following

table.

| Input Values    | Compatible? | Ouput Value |
|-----------------|-------------|-------------|
| UNKNOWN and A6C | Yes         | A6C         |
| UNKNOWN and A6S | Yes         | A6S         |
| UNKNOWN and A7  | Yes         | A7          |
| A6C and A6S     | Yes         | A6C         |
| A6C and A7      | No          | -           |
| A6S and A7      | Yes         | A7          |



Merging object files with the same ABI will result in the same ABI.



Programs that implement atomic operations without relying on the A-extension are classified as UNKNOWN for now. A new value for those may be defined in the future.

### Tag\_RISCV\_x3\_reg\_usage, 16, uleb128=value

Tag\_RISCV\_x3\_reg\_usage indicates the usage of **x3/gp** register. **x3/gp** could be used for global pointer relaxation, as a reserved platform register, or as a temporary register.

- 0** This object uses **x3** as a fixed register with unknown purpose.
- 1** This object uses **x3** as the global pointer, for relaxation purposes.
- 2** This object uses **x3** as the shadow stack pointer.
- 3** This object uses **X3** as a temporary register.
- 4~1023** Reserved for future standard defined platform register.
- 1024~2047** Reserved for nonstandard defined platform register.

### Merge policy

The linker should issue errors when object files with differing **gp** usage are combined. However, an exception exists: the value **0** can merge with **1** or **2** value. After the merge, the resulting value will be the non-zero one.

## 8.12. Program Property

Program properties are used to record information about an object file or binary that a linker or runtime loader needs to check for compatibility.

The linker should ignore and discard unknown bits in program properties, and issue warnings or errors.

## 8.13. Mapping Symbol

The section can have a mixture of code and data or code with different ISAs. A number of symbols, named mapping symbols, describe the boundaries.

| Symbol Name    | Meaning   |
|----------------|---|
| \$d            | Start of a sequence of data.                              |
| \$d.<any>      |   |
| \$x            | Start of a sequence of instructions.                      |
| \$x.<any>      |   |
| \$x<ISA>       | Start of a sequence of instructions with <ISA> extension. |
| \$x<ISA>.<any> |   |

The mapping symbol should set the type to `STT_NOTYPE`, binding to `STB_LOCAL`, and the size of symbol to zero.

The mapping symbol for data(`$d`) indicates the start of a sequence of data bytes.

The mapping symbol for instruction(`$x`) indicates the start of a sequence of instructions. It has an optional ISA string that indicates the following code regions are using ISA which is different from the ISA recorded in the arch attribute. The optional ISA information, when present, will be used until the next instruction mapping symbol. An instruction mapping symbol without ISA string means using ISA configuration from ELF attribute. The format and rules of the optional ISA string are same as `Tag_RISCV_arch` and must have explicit version. For more detailed rules, please refer to [Section 8.11](#).

The mapping symbol can be followed by an optional uniquifier, which is prefixed with a dot (`.`).



The use case for mapping symbol for instruction(`$x`) with ISA information is used with `IFUNC`. Consider a scenario where C library is built with `rv64gc` but few functions like `memcpy` may provide two versions, one built with `rv64gc` and another built with `rv64gcv`, and the `IFUNC` mechanism selects one version of those at run-time. However, the arch attribute is recorded for the minimal execution environment requirements, so the ISA information from arch attribute is not enough for the disassembler to disassemble the `rv64gcv` version correctly. Specifying ISA string appropriately with the two `memcpy` instruction mapping symbols helps the disassembler to disassemble instructions correctly.

# Chapter 9. Linker Relaxation

At link time, when all the memory objects have been resolved, the code sequence used to refer to them may be simplified and optimized by the linker by relaxing some assumptions about the memory layout made at compile time.

Some relocation types, in certain situations, indicate to the linker where this can happen. Additionally, some relocation types indicate to the linker the associated parts of a code sequence that can be thusly simplified, rather than to instruct the linker how to apply a relocation.

The linker should only perform such relaxations when a `R_RISCV_RELAX` relocation is at the same position as a candidate relocation.

As this transformation may delete bytes (and thus invalidate references that are commonly resolved at compile-time, such as intra-function jumps), code generators must in general ensure that relocations are always emitted when relaxation is enabled.

Linkers should adjust relocations that refer to symbols whose addresses have been updated.

ULEB128 value with relocation must be padding to the same length even if the data can be encoded with a shorter byte sequence after linker relaxation. The linker should report errors if the length of ULEB128 byte sequence is more extended than the current byte sequence.

## 9.1. Linker Relaxation Types

The purpose of this section is to describe all types of linker relaxation, the linker may implement a part of linker relaxation type, and can be skipped the relaxation type is unsupported.

Each candidate relocation might fit more than one relaxation type, the linker should only apply one relaxation type.

In the linker relaxation optimization, we introduce a concept called relocation group; a relocation group consists of 1) relocations associated with the same target symbol and can be applied with the same relaxation, or 2) relocations with the linkage relationship (e.g. `R_RISCV_PCREL_L012_S` linked with a `R_RISCV_PCREL_HI20`); all relocations in a single group must be present in the same section, otherwise will split into another relocation group.

Every relocation group must apply the same relaxation type, and the linker should not apply linker relaxation to only part of the relocation group.



Applying relaxation on the part of the relocation group might result in a wrong execution result; for example, a relocation group consists of `lui t0, 0 # R_RISCV_HI20 (foo)`, `lw t1, 0(t0) # R_RISCV_L012_I (foo)`, and we only apply [global pointer relaxation](#) on first instruction, then remove that instruction, and didn't apply relaxation on the second instruction, which made the load instruction reference to an unspecified address.

### 9.1.1. Function Call Relaxation

#### Target Relocation

R\_RISCV\_CALL, R\_RISCV\_CALL\_PLT.

#### Description

This relaxation type can relax **AUIPC+JALR** into **JAL**.

#### Condition

The offset between the location of relocation and target symbol or the PLT stub of the target symbol is within +-1MiB.

#### Relaxation

- Instruction sequence associated with **R\_RISCV\_CALL** or **R\_RISCV\_CALL\_PLT** can be rewritten to a single **JAL** instruction with the offset between the location of relocation and target symbol.

#### Example

Relaxation candidate:

```
auipc ra, 0          # R_RISCV_CALL_PLT (symbol), R_RISCV_RELAX
jalr  ra, ra, 0
```

Relaxation result:

```
jal  ra, 0          # R_RISCV_JAL (symbol)
```



Using address of PLT stubs of the target symbol or address target symbol directly will resolve by linker according to the visibility of the target symbol.

### 9.1.2. Compressed Function Call Relaxation

#### Target Relocation

R\_RISCV\_CALL, R\_RISCV\_CALL\_PLT.

#### Description

This relaxation type can relax **AUIPC+JALR** into **C.JAL** instruction sequence.

#### Condition

The offset between the location of relocation and target symbol or the PLT stub of the target symbol is within +-2KiB and rd operand of second instruction in the instruction sequence is **X1/RA** and if it is RV32.

#### Relaxation

- Instruction sequence associated with **R\_RISCV\_CALL** or **R\_RISCV\_CALL\_PLT** can be rewritten to a single **C.JAL** instruction with the offset between the location of relocation and target

symbol.

### Example

Relaxation candidate:

```
auipc ra, 0          # R_RISCV_CALL_PLT (symbol), R_RISCV_RELAX
jalr  ra, ra, 0
```

Relaxation result:

```
c.jal  ra, <offset-between-pc-and-symbol>
```

## 9.1.3. Compressed Tail Call Relaxation

### Target Relocation

R\_RISCV\_CALL, R\_RISCV\_CALL\_PLT.

### Description

This relaxation type can relax **AUIPC+JALR** into **C.J** instruction sequence.

### Condition

The offset between the location of relocation and target symbol or the PLT stub of the target symbol is within +2KiB and rd operand of second instruction in the instruction sequence is **X0**.

### Relaxation

- Instruction sequence associated with **R\_RISCV\_CALL** or **R\_RISCV\_CALL\_PLT** can be rewritten to a single **C.J** instruction with the offset between the location of relocation and target symbol.

### Example

Relaxation candidate:

```
auipc ra, 0          # R_RISCV_CALL_PLT (symbol), R_RISCV_RELAX
jalr  x0, ra, 0
```

Relaxation result:

```
c.j   ra, <offset-between-pc-and-symbol>
```

## 9.1.4. Global-Pointer Relaxation

### Target Relocation

R\_RISCV\_HI20, R\_RISCV\_LO12\_I, R\_RISCV\_LO12\_S, R\_RISCV\_PCREL\_HI20,  
R\_RISCV\_PCREL\_LO12\_I, R\_RISCV\_PCREL\_LO12\_S

## Description

This relaxation type can relax a sequence of the load address of a symbol or load/store with a symbol reference into global-pointer-relative instruction.

## Condition

Global-pointer relaxation requires that `Tag_RISCV_x3_reg_usage` must be 0 or 1, and offset between global-pointer and symbol is within +2KiB, `R_RISCV_PCREL_L012_I` and `R_RISCV_PCREL_L012_S` resolved as indirect relocation pointer. It will always point to another `R_RISCV_PCREL_HI20` relocation, the symbol pointed by `R_RISCV_PCREL_HI20` will be used in the offset calculation.

## Relaxation

- Instruction associated with `R_RISCV_HI20` or `R_RISCV_PCREL_HI20` can be removed.
- Instruction associated with `R_RISCV_L012_I`, `R_RISCV_L012_S`, `R_RISCV_PCREL_L012_I` or `R_RISCV_PCREL_L012_S` can be replaced with a global-pointer-relative access instruction.

## Example

Relaxation candidate (`tX` and `tY` can be any combination of two general purpose registers):

```
lui tX, 0      # R_RISCV_HI20 (symbol), R_RISCV_RELAX
lw tY, 0(tX)   # R_RISCV_L012_I (symbol), R_RISCV_RELAX
```

Relaxation result:

```
lw tY, <gp-offset-for-symbol>(gp)
```

A symbol can be loaded in multiple fragments using different addends, where multiple instructions associated with `R_RISCV_L012_I/R_RISCV_L012_S` share a single `R_RISCV_HI20`. The `HI20` values for the multiple fragments must be identical and all the relaxed global-pointer offsets must be in range.

Relaxation candidate:

```
lui tX, 0      # R_RISCV_HI20 (symbol), R_RISCV_RELAX
lw tY, 0(tX)   # R_RISCV_L012_I (symbol), R_RISCV_RELAX
lw tZ, 0(tX+4) # R_RISCV_L012_I (symbol+4), R_RISCV_RELAX
lw tW, 0(tX+8) # R_RISCV_L012_I (symbol+8), R_RISCV_RELAX
lw tX, 0(tX+12) # R_RISCV_L012_I (symbol+12), R_RISCV_RELAX
```

Relaxation result:

```
lw tY, <gp-offset-for-symbol>(gp)
lw tZ, <gp-offset-for-symbol+4>(gp)
lw tW, <gp-offset-for-symbol+8>(gp)
lw tX, <gp-offset-for-symbol+12>(gp)
```



The global-pointer refers to the address of the `__global_pointer$` symbol, which is the content of `gp` register.



This relaxation requires the program to initialize the `gp` register with the address of `__global_pointer$` symbol before accessing any symbol address, strongly recommended initialize `gp` at the beginning of the program entry function like `_start`, and code fragments of initialization must disable linker relaxation to prevent initialization instruction relaxed into a NOP-like instruction (e.g. `mv gp, gp`).

```
# Recommended way to initialize the gp register.
.option push
.option norelax
1: auipc gp, %pcrel_hi(__global_pointer$)
   addi gp, gp, %pcrel_lo(1b)
.option pop
```



The global pointer is referred to as the global offset table pointer in many other targets, however, RISC-V uses PC-relative addressing rather than access GOT via the global pointer register (`gp`), so we use `gp` register to optimize code size and performance of the symbol accessing.



`Tag_RISCV_x3_reg_usage` is treated as 0 if it is not present.

### 9.1.5. GOT Load Relaxation

#### Target Relocation

`R_RISCV_GOT_HI20`, `R_RISCV_PCREL_LO12_I`

#### Description

This relaxation can relax a GOT indirection into load immediate or PC-relative addressing. This relaxation is intended to optimize the `lga` assembly pseudo-instruction (and thus `la` for PIC objects), which loads a symbol's address from a GOT entry with an `auipc + l[w|d]` instruction pair.

#### Condition

- Both `R_RISCV_GOT_HI20` and `R_RISCV_PCREL_LO12_I` are marked with `R_RISCV_RELAX`.
- The symbol pointed to by `R_RISCV_PCREL_LO12_I` is at the location to which `R_RISCV_GOT_HI20` refers.
- If the symbol is absolute, its address is within `0x0 ~ 0x7ff` or `0xffffffffffff800 ~ 0xfffffffffffff` for RV64 and `0xffff800 ~ 0xfffff` for RV32. Note that an undefined weak symbol satisfies this condition because such a symbol is handled as if it were an absolute symbol at address 0.
- If the symbol is relative, it's bound at link time to be within the object. It should not be of the



GNU ifunc type. Additionally, the offset between the location to which `R_RISCV_GOT_HI20` refers and the target symbol should be within a range of  $\pm 2\text{GiB}$ .

## Relaxation

- The `auipc` instruction associated with `R_RISCV_GOT_HI20` can be removed if the symbol is absolute.
- The instruction or instructions associated with `R_RISCV_PCREL_LO12_I` can be rewritten to either `c.li` or `addi` to materialize the symbol's address directly in a register.
- If this relaxation eliminates all references to the symbol's GOT slot, the linker may opt not to create a GOT slot for that symbol.

## Example

Relaxation candidate:

```
label:
    auipc    tX, 0        # R_RISCV_GOT_HI20 (symbol), R_RISCV_RELAX
    l[w|d]   tY, 0(tX)    # R_RISCV_PCREL_LO12_I (label), R_RISCV_RELAX
```

Relaxation result (absolute symbol whose address can be represented as a 6-bit signed integer and if the RVC instruction is permitted):

```
c.li    tY, <symbol-value>
```

Relaxation result (absolute symbol and did not meet the above condition to use `c.li`):

```
addi    tY, zero, <symbol-value>
```

Relaxation result (relative symbol):

```
auipc    tX, <hi>
addi     tY, tX, <lo>
```

## 9.1.6. Zero-Page Relaxation

### Target Relocation

`R_RISCV_HI20`, `R_RISCV_LO12_I`, `R_RISCV_LO12_S`

### Description

This relaxation type can relax a sequence of the load address of a symbol or load/store with a symbol reference into shorter instruction sequence if possible.

### Condition

The symbol address located within `0x0 ~ 0x7ff` or `0xffffffffffff800 ~ 0xffffffffffffffff` for RV64 and `0xffff800 ~ 0xffffffff` for RV32.

## Relaxation

- Instruction associated with **R\_RISCV\_HI20** can be removed if the symbol address satisfies the x0-relative access.
- Instruction associated with **R\_RISCV\_LO12\_I** or **R\_RISCV\_LO12\_S** can be relaxed into x0-relative access.

## Example

Relaxation candidate:

```
lui t0, 0      # R_RISCV_HI20 (symbol), R_RISCV_RELAX
lw t1, 0(t0)   # R_RISCV_LO12_I (symbol), R_RISCV_RELAX
```

Relaxation result:

```
lw t1, <address-of-symbol>(x0)
```

## 9.1.7. Compressed LUI Relaxation

### Target Relocation

R\_RISCV\_HI20, R\_RISCV\_LO12\_I, R\_RISCV\_LO12\_S

### Description

This relaxation type can relax a sequence of the load address of a symbol or load/store with a symbol reference into shorter instruction sequence if possible.

### Condition

The symbol address can be presented by a **C.LUI** plus an **ADDI** or load / store instruction.

### Relaxation

- Instruction associated with **R\_RISCV\_HI20** can be replaced with **C.LUI**.
- Instruction associated with **R\_RISCV\_LO12\_I** or **R\_RISCV\_LO12\_S** should keep unchanged.

## Example

Relaxation candidate:

```
lui t0, 0      # R_RISCV_HI20 (symbol), R_RISCV_RELAX
lw t1, 0(t0)   # R_RISCV_LO12_I (symbol), R_RISCV_RELAX
```

Relaxation result:

```
c.lui t0, <non-zero> # RVC_LUI (symbol), R_RISCV_RELAX
lw t1, 0(t0)         # R_RISCV_LO12_I (symbol), R_RISCV_RELAX
```

## 9.1.8. Thread-Pointer Relaxation

### Target Relocation

R\_RISCV\_TPREL\_HI20, R\_RISCV\_TPREL\_ADD, R\_RISCV\_TPREL\_LO12\_I, R\_RISCV\_TPREL\_LO12\_S.

### Description

This relaxation type can relax a sequence of the load address of a symbol or load/store with a thread-local symbol reference into a thread-pointer-relative instruction.

### Condition

Offset between thread-pointer and thread-local symbol is within +-2KiB.

### Relaxation

- Instruction associated with **R\_RISCV\_TPREL\_HI20** or **R\_RISCV\_TPREL\_ADD** can be removed.
- Instruction associated with **R\_RISCV\_TPREL\_LO12\_I** or **R\_RISCV\_TPREL\_LO12\_S** can be replaced with a thread-pointer-relative access instruction.

### Example

Relaxation candidate:

```
lui t0, 0      # R_RISCV_TPREL_HI20 (symbol), R_RISCV_RELAX
add t0, t0, tp  # R_RISCV_TPREL_ADD (symbol), R_RISCV_RELAX
lw t1, 0(t0)   # R_RISCV_TPREL_LO12_I (symbol), R_RISCV_RELAX
```

Relaxation result:

```
lw t1, <tp-offset-for-symbol>(tp)
```

## 9.1.9. TLS Descriptors → Initial Exec Relaxation

### Target Relocation

R\_RISCV\_TLSDESC\_HI20, R\_RISCV\_TLSDESC\_LOAD\_LO12, R\_RISCV\_TLSDESC\_ADD\_LO12,  
R\_RISCV\_TLSDESC\_CALL

### Description

This relaxation can relax a sequence loading the address of a thread-local symbol reference into a GOT load instruction.

### Condition

- Linker output is an executable.

### Relaxation

- Instruction associated with **R\_RISCV\_TLSDESC\_HI20** or **R\_RISCV\_TLSDESC\_LOAD\_LO12** can be removed.
- Instruction associated with **R\_RISCV\_TLSDESC\_ADD\_LO12** can be replaced with load of the high half of the symbol's GOT address.

- Instruction associated with `R_RISCV_TLSDESC_CALL` can be replaced with load of the low half of the symbol's GOT address.

### Example

Relaxation candidate (`tX` and `tY` can be any combination of two general purpose registers):

```
label:
    auipc tX, <hi>      // R_RISCV_TLSDESC_HI20 (symbol), R_RISCV_RELAX
    lw    tY, tX, <lo>  // R_RISCV_TLSDESC_LOAD_LO12 (label)
    addi  a0, tX, <lo>  // R_RISCV_TLSDESC_ADD_LO12 (label)
    jalr  t0, tY        // R_RISCV_TLSDESC_CALL (label)
```

Relaxation result:

```
auipc  a0, <pcrel-got-offset-for-symbol-hi>
{ld,lw} a0, <pcrel-got-offset-for-symbol-lo>(a0)
```

## 9.1.10. TLS Descriptors → Local Exec Relaxation

### Target Relocation

`R_RISCV_TLSDESC_HI20`, `R_RISCV_TLSDESC_LOAD_LO12`, `R_RISCV_TLSDESC_ADD_LO12`,  
`R_RISCV_TLSDESC_CALL`

### Description

This relaxation can relax a sequence loading the address of a thread-local symbol reference into a thread-pointer-relative instruction sequence.

### Condition

- Short form only: Offset between thread-pointer and thread-local symbol is within  $\pm 2\text{KiB}$ .
- Linker output is an executable.
- Target symbol is non-preemptible.

### Relaxation

- Instruction associated with `R_RISCV_TLSDESC_HI20` or `R_RISCV_TLSDESC_LOAD_LO12` can be removed.
- Instruction associated with `R_RISCV_TLSDESC_ADD_LO12` can be replaced with the high TP-relative offset of symbol (long form) or be removed (short form).
- Instruction associated with `R_RISCV_TLSDESC_CALL` can be replaced with the low TP-relative offset of symbol.

### Example

Relaxation candidate (`tX` and `tY` can be any combination of two general purpose registers):

```
label:
    auipc tX, <hi>      // R_RISCV_TLSDESC_HI20 (symbol), R_RISCV_RELAX
    lw    tY, tX, <lo>  // R_RISCV_TLSDESC_LOAD_LO12 (label)
```

```
addi a0, tX, <lo> // R_RISCV_TLSDESC_ADD_L012 (label)
jalr t0, tY       // R_RISCV_TLSDESC_CALL (label)
```

Relaxation result (long form):

```
lui a0, <tp-offset-for-symbol-hi>
addi a0, a0, <tp-offset-for-symbol-lo>
```

Relaxation result (short form):

```
addi a0, zero, <tp-offset-for-symbol>
```

### 9.1.11. Table Jump Relaxation

#### Target Relocation

R\_RISCV\_CALL, R\_RISCV\_CALL\_PLT, R\_RISCV\_JAL.

#### Description

This relaxation type can relax a function call or jump instruction into a single table jump instruction with the index of the target address in table jump section ([Table 19](#)). Before relaxation, the linker scans all relocations and calculates whether additional gains can be obtained by using table jump instructions, where expected size saving from function-call-related relaxations and the size of jump table will be taken into account. If there is no additional gain, then table jump relaxation is ignored. Otherwise, this relaxation is switched on. [Compressed Tail Call Relaxation](#) and [Compressed Function Call Relaxation](#) are always preferred during relaxation, since table jump relaxation has no extra size saving over these two relaxations and might bring a performance overhead.

#### Condition

The **zcm**t extension is required, the linker output is not position-independent and the rd operand of a function call or jump instruction is **X0** or **RA**.

#### Relaxation

- Instruction sequence associated with **R\_RISCV\_CALL** or **R\_RISCV\_CALL\_PLT** can be rewritten to a table jump instruction.
- Instruction associated with **R\_RISCV\_JAL** can be rewritten to a table jump instruction.

#### Example

Relaxation candidate:

```
auipc ra, 0           # R_RISCV_CALL (symbol), R_RISCV_RELAX (symbol)
jalr  ra, ra, 0

auipc ra, 0           # R_RISCV_CALL_PLT (symbol), R_RISCV_RELAX (symbol)
jalr  x0, ra, 0
```

```
jal ra, 0          # R_RISCV_JAL (symbol), R_RISCV_RELAX (symbol)
jal x0, 0          # R_RISCV_JAL (symbol), R_RISCV_RELAX (symbol)
```

Relaxation result:

```
cm.jalt <index-for-symbol>
cm.jt   <index-for-symbol>
cm.jalt <index-for-symbol>
```



The **zcmt** extension cannot be used in position-independent binaries.



Jump or call instructions with the rd operand **RA** will be relaxed into **cm.jalt** and instructions with the rd operand **X0** will be relaxed into **cm.jt**. The table jump section holds target addresses for these two instructions separately. More details are available in the *ZC\* extension specification* [\[riscv-zc-extension-group\]](#).



This relaxation requires programs to initialize the **jvt** CSR with the address of the **\_\_jvt\_base\$** symbol before executing table jump instructions. It is recommended to initialize **jvt** CSR immediately after [global pointer initialization](#).

```
# Recommended way to initialize the jvt CSR.
1: auipc a0, %pcrel_hi(__jvt_base$)
   addi a0, a0, %pcrel_lo(1b)
   csrw jvt, a0
```

# References

- [\[gabi\]](#) "Generic System V Application Binary Interface" [www.sco.com/developers/gabi/latest/contents.html](http://www.sco.com/developers/gabi/latest/contents.html)
- [\[itanium-cxx-abi\]](#) "Itanium C++ ABI" [itanium-cxx-abi.github.io/cxx-abi/](http://itanium-cxx-abi.github.io/cxx-abi/)
- [\[rv-asm\]](#) "RISC-V Assembly Programmer's Manual" [github.com/riscv-non-isa/riscv-asm-manual](https://github.com/riscv-non-isa/riscv-asm-manual)
- [\[tls\]](#) "ELF Handling For Thread-Local Storage" [www.akkadia.org/drepper/tls.pdf](http://www.akkadia.org/drepper/tls.pdf), Ulrich Drepper
- [\[riscv-unpriv\]](#) "The RISC-V Instruction Set Manual, Volume I: User-Level ISA, Document", Editors Andrew Waterman and Krste Asanović, RISC-V International.
- [\[riscv-unpriv-20191213\]](#) "The RISC-V Instruction Set Manual, Volume I: User-Level ISA, Document release 20191213", Editors Andrew Waterman and Krste Asanović, RISC-V International.
- [\[riscv-zc-extension-group\]](#) "ZC\* extension specification" [github.com/riscv/riscv-code-size-reduction](https://github.com/riscv/riscv-code-size-reduction)
- [\[rv-toolchain-conventions\]](#) "RISC-V Toolchain Conventions" [github.com/riscv-non-isa/riscv-toolchain-conventions](https://github.com/riscv-non-isa/riscv-toolchain-conventions)

# RISC-V DWARF Specification



# Chapter 10. DWARF Debugging Format

The DWARF debugging format for RISC-V follows the [standard DWARF specification](#); this specification only describes RISC-V-specific definitions.

# Chapter 11. DWARF Register Numbers

The table below lists the mapping from DWARF register numbers to machine registers.

*Table 23. DWARF register number encodings*

| DWARF Number | Register Name | Description                             |
|--------------|---------------|---|
| 0 - 31       | x0 - x31      | Integer Registers                       |
| 32 - 63      | f0 - f31      | Floating-point Registers                |
| 64           |               | Alternate Frame Return Column           |
| 65 - 95      |               | Reserved for future standard extensions |
| 96 - 127     | v0 - v31      | Vector Registers                        |
| 128 - 3071   |               | Reserved for future standard extensions |
| 3072 - 4095  |               | Reserved for custom extensions          |
| 4096 - 8191  |               | CSRs                                    |

The alternate frame return column is meant to be used when unwinding from signal handlers, and stores the address where the signal handler will return to.

The RISC-V specification defines a total of 4096 CSRs (see [\[riscv-priv\]](#)). Each CSR is assigned a DWARF register number corresponding to its specified CSR number plus 4096.

# References

- [\[riscv-priv\]](#) "The RISC-V Instruction Set Manual, Volume II: Privileged Architecture, Document", Editors Andrew Waterman, Krste Asanović, and John Hauser, RISC-V International.

# RISC-V Run-Time ABI Specification

# Chapter 12. Run-Time ABI

This document defines the run-time helper function ABI for RISC-V, which includes compiler helper functions, but does not cover the language standard library functions.

# RISC-V Atomics ABI Specification

# Chapter 13. RISC-V Atomics Mappings

This specifies mappings of C and C++ atomic operations to RISC-V machine instructions. Other languages, for example Java, provide similar facilities that should be implemented in a consistent manner, usually by applying the mapping for the corresponding C++ primitive.



Because different programming languages may be used within the same process, these mappings must be compatible across programming languages. For example, Java programmers expect memory ordering guarantees to be enforced even if some of the actual memory accesses are performed by a library written in C.



Though many mappings are possible, not all of them will interoperate correctly. In particular, many mapping combinations will not correctly enforce ordering between a C++ `memory_order_seq_cst` store and a subsequent `memory_order_seq_cst` load.



These mappings are very similar to those that originally appeared in the appendix of the RISC-V "unprivileged" architecture specification as "Mappings from C/C++ primitives to RISC-V Primitives", which we will refer to by their 2019 historical label of "Table A.6". That mapping may be used, *except* that `atomic_store(memory_order_seq_cst)` must have an an extra trailing fence for compatibility with the "Hypothetical mappings ..." table in the same section, which we similarly refer to as "Table A.7". As a result, we allow the "Table A.7" mappings as well.



Our primary design goal is to maximize performance of the "Table A.7" mappings. These require additional load-acquire and store-release instructions, and are this not immediately usable. By requiring the extra store fence. or equivalent, we avoid an ABI break when moving to the "Table A.7" mappings in the future, in return for a small performance penalty in the short term.

For each construct, we provide a mapping that assumes only the A extension. In some cases, we provide additional mappings that assume a future load-acquire and store-release extension, as denoted by note 1 in the table.

All mappings interoperate correctly, and with the original "Table A.6" mappings, *except* that mappings marked with note 3 do not interoperate with the original "Table A.6" mappings.

We present the mappings as a table in 3 sections. The first deals with translations for loads, stores, and fences. The next two sections address mappings for read-modify-write operations like `fetch_add`, and `exchange`. The second section deals with operations that have direct `amo` instruction equivalents in the RISC-V A extension. The final section deals with other read-modify-write operations that require the `lr` and `sc` instructions.

Table 24. Mappings from C/C++ primitives to RISC-V primitives

| C/C++ Construct  | RVWMO Mapping                                     | Notes |
|--|---|-------|
| Non-atomic load  | <code>l{b h w d}</code>                           |       |
| <code>atomic_load(memory_order_relaxed)</code>         | <code>l{b h w d}</code>                           |       |
| <code>atomic_load(memory_order_acquire)</code>         | <code>l{b h w d}; fence r,rw</code>               |       |
| <code>atomic_load(memory_order_acquire)</code>         | <code>&lt;RCsc atomic load-acquire&gt;</code>     | 1, 2  |
| <code>atomic_load(memory_order_seq_cst)</code>         | <code>fence rw,rw; l{b h w d}; fence r,rw</code>  |       |
| <code>atomic_load(memory_order_seq_cst)</code>         | <code>&lt;RCsc atomic load-acquire&gt;</code>     | 1, 3  |
| Non-atomic store                                       | <code>s{b h w d}</code>                           |       |
| <code>atomic_store(memory_order_relaxed)</code>        | <code>s{b h w d}</code>                           |       |
| <code>atomic_store(memory_order_release)</code>        | <code>fence rw,w; s{b h w d}</code>               |       |
| <code>atomic_store(memory_order_release)</code>        | <code>&lt;RCsc atomic store-release&gt;</code>    | 1, 2  |
| <code>atomic_store(memory_order_seq_cst)</code>        | <code>fence rw,w; s{b h w d}; fence rw,rw;</code> |       |
| <code>atomic_store(memory_order_seq_cst)</code>        | <code>amoswap.rl{w d};</code>                     | 4     |
| <code>atomic_store(memory_order_seq_cst)</code>        | <code>&lt;RCsc atomic store-release&gt;</code>    | 1     |
| <code>atomic_thread_fence(memory_order_acquire)</code> | <code>fence r,rw</code>                           |       |
| <code>atomic_thread_fence(memory_order_release)</code> | <code>fence rw,w</code>                           |       |
| <code>atomic_thread_fence(memory_order_acq_rel)</code> | <code>fence.tso</code>                            |       |
| <code>atomic_thread_fence(memory_order_seq_cst)</code> | <code>fence rw,rw</code>                          |       |

| C/C++ Construct                                      | RVWMO AMO Mapping                     | Notes |
|--|---------------------------------------|-------|
| <code>atomic_&lt;op&gt;(memory_order_relaxed)</code> | <code>amo&lt;op&gt;.{w d}</code>      | 4     |
| <code>atomic_&lt;op&gt;(memory_order_acquire)</code> | <code>amo&lt;op&gt;.{w d}.aq</code>   | 4     |
| <code>atomic_&lt;op&gt;(memory_order_release)</code> | <code>amo&lt;op&gt;.{w d}.rl</code>   | 4     |
| <code>atomic_&lt;op&gt;(memory_order_acq_rel)</code> | <code>amo&lt;op&gt;.{w d}.aqr1</code> | 4     |
| <code>atomic_&lt;op&gt;(memory_order_seq_cst)</code> | <code>amo&lt;op&gt;.{w d}.aqr1</code> | 4, 5  |

| C/C++ Construct                                      | RVWMO LR/SC Mapping   | Notes |
|--|---|-------|
| <code>atomic_&lt;op&gt;(memory_order_relaxed)</code> | <code>loop:lr.{w d}; &lt;op&gt;; sc.{w d}; bnez loop</code>         | 4     |
| <code>atomic_&lt;op&gt;(memory_order_acquire)</code> | <code>loop:lr.{w d}.aq; &lt;op&gt;; sc.{w d}; bnez loop</code>      | 4     |
| <code>atomic_&lt;op&gt;(memory_order_release)</code> | <code>loop:lr.{w d}; &lt;op&gt;; sc.{w d}.rl; bnez loop</code>      | 4     |
| <code>atomic_&lt;op&gt;(memory_order_acq_rel)</code> | <code>loop:lr.{w d}.aq; &lt;op&gt;; sc.{w d}.rl; bnez loop</code>   | 4     |
| <code>atomic_&lt;op&gt;(memory_order_seq_cst)</code> | <code>loop:lr.{w d}.aqr1; &lt;op&gt;; sc.{w d}.rl; bnez loop</code> | 4     |
| <code>atomic_&lt;op&gt;(memory_order_seq_cst)</code> | <code>loop:lr.{w d}.aq; &lt;op&gt;; sc.{w d}.rl; bnez loop</code>   | 3, 4  |

## Meaning of Notes in Table

1) Depends on a load instruction with an RCsc acquire annotation, or a store instruction with an RCsc release annotation. These are currently under discussion, but the specification has not yet



been approved.

2) An RCpc load or store would also suffice, if it were to be introduced in the future.

3) Incompatible with the original "Table A.6" mapping. Do not combine these mappings with code generated by a compiler using those older mappings. (This was mostly used by the initial LLVM implementations for RISC-V.)

4) Currently only directly possible for 32- and 64-bit operands.

5) `atomic_compare_exchange` operations with a `memory_order_seq_cst` failure ordering are considered to have a note 3 annotation. To remove the note 3 annotation the amocas operation must be prepended with a leading fence (`fence rw,rw; amocas.{w|d}.aqrl`).

# Chapter 14. Ztso Atomics Mappings

This specifies additional mappings of C and C++ atomic operations to RISC-V machine instructions.

For each construct, we provide a mapping that assumes only the A and Ztso extension.

All mappings interoperate correctly with the RVWMO mappings, and with the original "Table A.6" mappings, *except* that mappings marked with note 3 do not interoperate with the original "Table A.6" mappings.

We present the mappings as a table in 3 sections, as above.

Table 25. Mappings with Ztso extension from C/C++ primitives to RISC-V primitives

| C/C++ Construct  | Ztso Mapping                          | Notes |
|--|---------------------------------------|-------|
| <code>atomic_load(memory_order_acquire)</code>         | <code>l{b h w d}</code>               | 6     |
| <code>atomic_load(memory_order_seq_cst)</code>         | <code>fence rw,rw; l{b h w d}</code>  | 6     |
| <code>atomic_store(memory_order_release)</code>        | <code>s{b h w d}</code>               | 6     |
| <code>atomic_store(memory_order_seq_cst)</code>        | <code>s{b h w d}; fence rw, rw</code> | 6     |
| <code>atomic_thread_fence(memory_order_acquire)</code> | <code>nop</code>                      | 6     |
| <code>atomic_thread_fence(memory_order_release)</code> | <code>nop</code>                      | 6     |
| <code>atomic_thread_fence(memory_order_acq_rel)</code> | <code>nop</code>                      | 6     |

| C/C++ Construct                                      | Ztso AMO Mapping                 | Notes   |
|--|----------------------------------|---------|
| <code>atomic_&lt;op&gt;(memory_order_acquire)</code> | <code>amo&lt;op&gt;.{w d}</code> | 4, 6    |
| <code>atomic_&lt;op&gt;(memory_order_release)</code> | <code>amo&lt;op&gt;.{w d}</code> | 4, 6    |
| <code>atomic_&lt;op&gt;(memory_order_acq_rel)</code> | <code>amo&lt;op&gt;.{w d}</code> | 4, 6    |
| <code>atomic_&lt;op&gt;(memory_order_seq_cst)</code> | <code>amo&lt;op&gt;.{w d}</code> | 4, 5, 6 |

| C/C++ Construct                                      | Ztso LR/SC Mapping  | Notes |
|--|---|-------|
| <code>atomic_&lt;op&gt;(memory_order_acquire)</code> | <code>loop:lr.{w d}; &lt;op&gt;; sc.{w d}; bnez loop</code> | 4, 6  |
| <code>atomic_&lt;op&gt;(memory_order_release)</code> | <code>loop:lr.{w d}; &lt;op&gt;; sc.{w d}; bnez loop</code> | 4, 6  |
| <code>atomic_&lt;op&gt;(memory_order_acq_rel)</code> | <code>loop:lr.{w d}; &lt;op&gt;; sc.{w d}; bnez loop</code> | 4, 6  |

## Meaning of Notes in Table

3) Incompatible with the original "Table A.6" mapping. Do not combine these mappings with code generated by a compiler using those older mappings. (This was mostly used by the initial LLVM implementations for RISC-V.)

4) Currently only directly possible for 32- and 64-bit operands.

5) `atomic_compare_exchange` operations with a `memory_order_seq_cst` failure ordering are

considered to have a note 3 annotation. To remove the note 3 annotation the amocas operation must be prepended with a leading fence (`fence rw,rw; amocas.{w\|d}`).

6) Requires the Ztso extension.

# Chapter 15. Other Conventions

It is expected that the RVWMO and Ztso AMO Mappings will be used for atomic read-modify-write operations that are directly supported by corresponding AMO instructions, and that LR/SC mappings will be used for the remainder, currently including compare-exchange operations. Compare-exchange LR/SC sequences on the containing 32-bit word should be used for shorter operands. Thus, a `fetch_add` operation on a 16-bit quantity would use a 32-bit LR/SC sequence.

It is acceptable, but usually undesirable for performance reasons, to use LR/SC mappings where an AMO mapping would suffice.

Atomics do not imply any ordering for IO operations. IO operations should include sufficient fences to prevent them from being visibly reordered with atomic operations.

Float and double atomic loads and stores should be implemented using the integer sequences.

Float and double read-modify-write instructions should consist of a loop performing an initial plain load of the value, followed by the floating point computation, followed by an integer compare-and-swap sequence to try to store back the updated value. This avoids floating point instructions between LR and SC instructions. Depending on language requirements, it may be necessary to save and restore floating-point exception flags in the case of an operation that is later redone due to a failed SC operation.



The "Eventual Success of Store-Conditional Instructions" section in the ISA specification provides that essential progress guarantee only if there are no floating point instructions between the LR and matching SC instruction. By compiling such sequences with an "extra" ordinary load, and performing the floating point computation before the LR, we preserve the guarantee.