

RISC-V "V" Vector Extension

Version 0.7.0-draft-20190222

Table of Contents

1. Introduction
2. Implementation-defined Constant Parameters
3. Vector Extension Programmer's Model
 - 3.1. Vector Registers
 - 3.2. Vector Start Index CSR `vstart`
 - 3.3. Vector Fixed-Point Rounding Mode Register `vxrm`
 - 3.4. Vector Fixed-Point Saturation Flag `vxsat`
 - 3.5. Vector Fixed-Point Fields in `fcsr`
 - 3.6. Vector type register, `vtype`
 - 3.7. Vector Length Register `vl`
4. Mapping of Vector Elements to Vector Register State
 - 4.1. Mapping with `LMUL=1`
 - 4.2. Mapping with `LMUL > 1`
 - 4.3. Mapping across Mixed-Width Operations
 - 4.4. Mask Register Layout
5. Vector Instruction Formats
 - 5.1. Scalar operands
 - 5.2. Vector Operands
 - 5.3. Vector Masking
 - 5.4. Prestart, Active, Inactive, Body, and Tail Element Definitions
6. Configuration-Setting Instructions
 - 6.1. `vsetvli/vsetvl` instructions
 - 6.2. Constraints on Setting `vl`
 - 6.3. `vsetvl` Instruction
 - 6.4. Examples
7. Vector Loads and Stores
 - 7.1. Vector Load/Store Instruction Encoding
 - 7.2. Vector Load/Store Addressing Modes
 - 7.3. Vector Load/Store Width Encoding
 - 7.4. Vector Unit-Stride Instructions
 - 7.5. Vector Strided Instructions
 - 7.6. Vector Indexed Instructions
 - 7.7. Unit-stride Fault-Only-First Loads
 - 7.8. Vector Load/Store Segment Instructions (`Zvlssseg`)
8. Vector AMO Operations (`Zvamo`)
9. Vector Memory Alignment Constraints
10. Vector Memory Consistency Model
11. Vector Arithmetic Instruction Formats
 - 11.1. Vector Arithmetic Instruction encoding
 - 11.2. Widening Vector Arithmetic Instructions
 - 11.3. Narrowing Vector Arithmetic Instructions
12. Vector Integer Arithmetic Instructions
 - 12.1. Vector Single-Width Integer Add and Subtract

- 12.2. Vector Widening Integer Add/Subtract
- 12.3. Vector Integer Add-with-Carry / Subtract-with-Borrow Instructions
- 12.4. Vector Bitwise Logical Instructions
- 12.5. Vector Single-Width Bit Shift Instructions
- 12.6. Vector Narrowing Integer Right Shift Instructions
- 12.7. Vector Integer Comparison Instructions
- 12.8. Vector Integer Min/Max Instructions
- 12.9. Vector Single-Width Integer Multiply Instructions
- 12.10. Vector Widening Integer Multiply Instructions
- 12.11. Vector Single-Width Integer Multiply-Add Instructions
- 12.12. Vector Widening Integer Multiply-Add Instructions
- 12.13. Vector Integer Merge Instruction

13. Vector Fixed-Point Arithmetic Instructions

- 13.1. Vector Single-Width Saturating Add and Subtract
- 13.2. Vector Single-Width Averaging Add and Subtract
- 13.3. Vector Single-Width Fractional Multiply with Rounding and Saturation
- 13.4. Vector Widening Saturating Scaled Multiply-Add
- 13.5. Vector Single-Width Scaling Shift Instructions
- 13.6. Vector Narrowing Fixed-Point Clip Instructions

14. Vector Floating-Point Instructions

- 14.1. Vector Floating-Point Exception Flags
- 14.2. Vector Single-Width Floating-Point Add/Subtract Instructions
- 14.3. Vector Widening Floating-Point Add/Subtract Instructions
- 14.4. Vector Single-Width Floating-Point Multiply/Divide Instructions
- 14.5. Vector Widening Floating-Point Multiply
- 14.6. Vector Single-Width Floating-Point Fused Multiply-Add Instructions
- 14.7. Vector Widening Floating-Point Fused Multiply-Add Instructions
- 14.8. Vector Floating-Point Square-Root Instruction
- 14.9. Vector Floating-Point MIN/MAX Instructions
- 14.10. Vector Floating-Point Sign-Injection Instructions
- 14.11. Vector Floating-Point Compare Instructions
- 14.12. Vector Floating-Point Classify Instruction
- 14.13. Vector Floating-Point Merge Instruction
- 14.14. Single-Width Floating-Point/Integer Type-Convert Instructions
- 14.15. Widening Floating-Point/Integer Type-Convert Instructions
- 14.16. Narrowing Floating-Point/Integer Type-Convert Instructions

15. Vector Reduction Operations

- 15.1. Vector Single-Width Integer Reduction Instructions
- 15.2. Vector Widening Integer Reduction Instructions
- 15.3. Vector Single-Width Floating-Point Reduction Instructions
- 15.4. Vector Widening Floating-Point Reduction Instructions

16. Vector Mask Instructions

- 16.1. Vector Mask-Register Logical Instructions
- 16.2. Vector mask population count `vmppoc`
- 16.3. `vmfirst` find-first-set mask bit
- 16.4. `vmsbf.m` set-before-first mask bit
- 16.5. `vmsif.m` set-including-first mask bit

- 16.6. `vmsof .m` set-only-first mask bit
- 16.7. Example using vector mask instructions
- 16.8. Vector Iota Instruction
- 16.9. Vector Element Index Instruction

17. Vector Permutation Instructions

- 17.1. Integer Extract Instruction
- 17.2. Integer Scalar Move Instruction
- 17.3. Floating-Point Scalar Move Instructions
- 17.4. Vector Slide Instructions
- 17.5. Vector Register Gather Instruction
- 17.6. Vector Compress Instruction

18. Exception Handling

- 18.1. Precise vector traps
- 18.2. Imprecise vector traps
- 18.3. Selectable precise/imprecise traps
- 18.4. Swappable traps

19. Divided Element Extension ('Zvediv')

- 19.1. Instructions not affected by EDIV
- 19.2. Instructions Affected by EDIV
- 19.3. Vector Integer Dot-Product Instruction
- 19.4. Vector Floating-Point Dot Product Instruction

20. Vector Instruction Listing

Appendix A: Vector Assembly Code Examples

- A.1. Vector-vector add example
- A.2. Example with mixed-width mask and compute.
- A.3. Memcpy example
- A.4. Conditional example
- A.5. SAXPY example
- A.6. SGEMM example

Contributors include: Alon Amid, Krste Asanovic, Allen Baum, Alex Bradbury, Tony Brewer, Chris Celio, Silviu Chiricescu, Ken Dockser, Bob Dreyer, Roger Espasa, Sean Halle, John Hauser, David Horner, Bruce Houtt, Bill Huffman, Constantine Korikov, Ben Korpan, Robin Kruppe, Yunsup Lee, Guy Lemieux, Rich Newell, Albert Ou, David Patterson, Colin Schmidt, Alex Solomatnikov, Steve Wallach, Andrew Waterman, Jim Wilson.

Known issues with current version:

- encoding needs better formatting
- vector memory consistency model needs to be clarified
- interaction with privileged architectures

1. Introduction

This document describes the draft of the RISC-V base vector extension. The document describes all the individual features of the base vector extension.

This is a draft of a stable proposal for the vector specification to be used for implementation and evaluation. Once the draft label is removed, version 0.7 is intended to be stable enough to begin developing toolchains, functional simulators, and initial implementations, though will continue to evolve with minor changes and updates.

The term *base vector extension* is used informally to describe the standard set of vector ISA components. This draft spec is intended to capture how a certain vector function will be implemented as vector instructions, but to not yet determine what set of vector instructions are mandatory for a given platform.

Each actual platform profile will formally specify the mandatory components of any vector extension adopted by that platform. The base vector extension can be expected to be close to that which will eventually be used in the standard Unix platform profile that supports vectors. Other platforms, including embedded platforms, may choose to implement subsets of these extensions. The exact set of mandatory supported instructions for an implementation to be compliant with a given profile is subject to change until each profile spec is ratified.

The base vector extension is designed to act as a base for additional vector extensions in various domains, including cryptography and machine learning.

2. Implementation-defined Constant Parameters

Each hart supporting the vector extension defines three parameters:

1. The maximum size of a single vector element in bits, $ELEN$, which must be a power of 2.
2. The number of bits in a vector register, $VLEN \geq ELEN$, which must be a power of 2.
3. The striping distance in bits, $SLEN$, which must be $VLEN \geq SLEN \geq 32$, and which must be a power of 2.

Platform profiles may set further constraints on these parameters, for example, requiring that $ELEN \geq \max(XLEN, FLEN)$, or requiring a minimum $VLEN$ value, or setting an $SLEN$ value.

The ISA supports writing binary code that under certain constraints will execute portably on harts with different values for these parameters.

Code can be written that will expose differences in implementation parameters.

Thread contexts with active vector state cannot be migrated during execution between harts that have any difference in $VLEN$, $ELEN$, or $SLEN$ parameters.

3. Vector Extension Programmer's Model

The vector extension adds 32 vector registers, and five unprivileged CSRs (`vstart`, `vxsat`, `vxrm`, `vtype`, `v1`) to a base scalar RISC-V ISA. If the base scalar ISA does not include floating-point, then a `fcsr` register is also added to hold mirrors of the `vxsat` and `vxrm` CSRs as explained below.

New vector CSRs

Address	Privilege	Name	Description
0x008	URW	<code>vstart</code>	Vector start position
0x009	URW	<code>vxsat</code>	Fixed-Point Saturate Flag
0x00A	URW	<code>vxrm</code>	Fixed-Point Rounding Mode
0x00B	URW	<code>vtype</code>	Vector data type register
0xC20	URO	<code>v1</code>	Vector length

3.1. Vector Registers

The vector extension adds 32 architectural vector registers, `v0-v31` to the base scalar RISC-V ISA.

Each vector register has a fixed `VLEN` bits of state.

`Zfinx` ("F in X") is a new ISA option under consideration where floating-point instructions take their arguments from the integer register file. The 0.7 vector extension is also compatible with this option.

3.2. Vector Start Index CSR `vstart`

The `vstart` read-write CSR specifies the index of the first element to be executed by a vector instruction.

Normally, `vstart` is only written by hardware on a trap on a vector instruction, with the `vstart` value representing the element on which the trap was taken (either a synchronous exception or an asynchronous interrupt), and at which execution should resume after a resumable trap is handled.

All vector instructions are defined to begin execution with the element number given in the `vstart` CSR, leaving earlier elements in the destination vector undisturbed, and to reset the `vstart` CSR to zero at the end of execution.

If the value in the `vstart` register is greater than or equal to the vector length `v1` then no element operations are performed, though elements at the end of the destination vector past `v1` are zeroed, and the `vstart` register is reset to zero.

The `vstart` CSR is defined to have only enough writeable bits to hold the largest element index (one less than the maximum `VLMAX`) or $\lg_2(\text{VLEN})$ bits. The upper bits of the `vstart` CSR are hardwired to zero (reads zero, writes ignored).

The maximum vector length is obtained with the largest `LMUL` setting (8) and the smallest `SEW` setting (8), so $\text{VLMAX}_{\text{max}} = 8 \cdot \text{VLEN} / 8 = \text{VLEN}$. For example, for `VLEN=256`, `vstart` would have 8 bits to represent indices from 0 through 255.

The `vstart` CSR is writable by unprivileged code, but non-zero `vstart` values may cause vector instructions to run substantially slower on some implementations, so `vstart` should not be used by application programmers. A few vector instructions can not be executed with a non-zero `vstart` value and will raise an illegal instruction exception as defined below.

3.3. Vector Fixed-Point Rounding Mode Register `vxrm`

The vector fixed-point rounding-mode register holds a two-bit read-write rounding-mode field. The vector fixed-point rounding-mode is given a separate CSR address to allow independent access, but is also reflected as a field in the upper bits of `fcsr`. Systems without floating-point must add `fcsr` when adding the vector extension.

vxrm encoding

Bits	Abbreviation	Rounding Mode
[1:0]		
00	rnu	round-to-nearest-up (add +0.5 LSB)
01	rne	round-to-nearest-even
10	rdn	round-down (truncate)
11	rod	round-to-odd (OR bits into LSB, aka "jam")

Bits[XLEN-1:2] should be written as zeros.

| The rounding mode can be set with a single `cswi` instruction.

3.4. Vector Fixed-Point Saturation Flag `vxsat`

The `vxsat` CSR holds a single read-write bit that indicates if a fixed-point instruction has had to saturate an output value to fit into a destination format.

The `vxsat` bit is mirrored in the upper bits of `fcsr`.

3.5. Vector Fixed-Point Fields in `fcsr`

The `vxrm` and `vxsat` separate CSRs can also be accessed via fields in the floating-point CSR, `fcsr`. The `fcsr` register must be added to systems without floating-point that add a vector extension.

fcsr layout

Bits	Name	Description
10:9	vxrm	Fixed-point rounding mode
8	vxsat	Fixed-point accrued saturation flag
7:5	frm	Floating-point rounding mode
4:0	fflags	Floating-point accrued exception flags

| The fields are packed into `fcsr` to make context-save/restore faster.

3.6. Vector type register, `vtype`

The XLEN-wide *vector type* CSR, `vtype` provides the default type used to interpret the contents of the vector register file. The vector type also determines the organization of elements in each vector register, and how multiple vector registers are grouped.

In the base vector extension, the type register has two fields, `vsew[2:0]`, and `vlmul`.

vtype register layout

bits	contents
XLEN-1:7	Reserved (write 0)
6:5	vediv[1:0] # Used by EDIV extension
4:2	vsew[2:0]
1:0	vlmul[1:0]

The smallest base implementation has only four bits in vtype, two bits for vsew[1:0] and two bits for vlmul[1:0].

The vediv[1:0] field is used by the EDIV extension described below.

Further standard and custom extensions to the vector base will extend these fields to support a greater variety of data types.

An extended instruction encoding length would allow these fields to be specified in the instruction encoding, though vlmul might want to be varied with AVL.

3.6.1. Vector standard element width vsew

The value in vsew sets the dynamic *standard element width* (SEW). By default, a vector register is viewed as being divided into $VLEN / SEW$ standard-width elements. In the base vector extension, only SEW up to $\max(XLEN, FLEN)$ are required to be supported.

vsew[2:0] (standard element width) encoding

vsew[2:0]	SEW
---	----
000	8
001	16
010	32
011	64
100	128
101	256
110	512
111	1024

Example VLEN = 128 bits

SEW	Elements per vector register
64	2
32	4
16	8
8	16

3.6.2. Vector Register Grouping (vlmul)

Multiple vector registers can be grouped together to form a *vector register group*, so that a single vector instruction can operate on multiple vector registers. Vector register groups allow double-width or larger elements to be operated on with the same vector length as standard-width elements. Vector register groups also provide greater execution efficiency for longer application vectors.

The number of vector registers in a group, *LMUL*, is an integer power of two set by the vlmul field in vtype ($LMUL = 2^{vlmul[1:0]}$). The maximum vector length possible in a single vector instruction, *VLMAX*, is then increased by a factor of *LMUL*.

vlmul	LMUL	#groups	VLMAX	Grouped registers
00	1	32	VLEN/SEW	vn (no group)
01	2	16	2*VLEN/SEW	vn, vn+1
10	4	8	4*VLEN/SEW	vn, ..., vn+3
11	8	4	8*VLEN/SEW	vn, ..., vn+7

When `vlmul=01`, then vector operations on register `v n` also operate on vector register `v n+1`, giving twice the vector length in bits. Instructions specifying a vector operand with an odd-numbered vector register will raise an illegal instruction exception.

Similarly, when `vlmul=10`, vector instructions operate on four vector registers at a time, and instructions specifying vector operands using vector register numbers that are not multiples of four will raise an illegal instruction exception. When `vlmul=11`, operations operate on eight vector registers at a time, and instructions specifying vector operands using register numbers that are not multiples of eight will raise an illegal instruction exception.

This grouping pattern (LMUL=8 has groups `v0,v8,v16,v24`) was adopted in 0.6 initially to avoid issues with the floating-point calling convention when floating-point values were overlaid on the vector registers, whereas earlier versions kept the vector register group names contiguous (LMUL=8 has groups `v0, v1, v2, v3`). In v0.7, the floating-point registers are separate again.

Mask register instructions always operate on a single vector register, regardless of LMUL setting.

3.7. Vector Length Register `v1`

The *XLEN*-bit-wide read-only `v1` CSR can only be updated by the `vsetvli` and `vsetvl` instructions, and the *fault-only-first* vector load instruction variants.

The `v1` register holds an unsigned integer specifying the number of elements to be updated by a vector instruction. Elements in the destination vector with indices $\geq v1$ are zeroed during execution of a vector instruction. As a special case, when `v1=0`, no elements are updated in the destination vector.

The number of bits implemented in `v1` depends on the implementation's maximum vector length of the smallest supported type. The smallest vector implementation, RV32IV, would need at least six bits in `v1` to hold the values 0-32 (with `VLEN=32`, `LMUL=8` and `SEW=8` results in `VLMAX` of 32).

4. Mapping of Vector Elements to Vector Register State

The following diagrams illustrate how different width elements are packed into the bytes of a vector register depending on the current SEW and LMUL settings, as well as implementation ELEN and VLEN. Elements are packed into each vector register with the least-significant byte in the lowest-numbered bits.

Previous RISC-V vector proposals (< 0.6) hid this mapping from software, whereas this proposal has a specific mapping for all configurations, which reduces implementation flexibility but removes need for zeroing on config changes. Making the mapping explicit also has the advantage of simplifying oblivious context save-restore code, as the code can save the configuration in `v1` and `vtype`, then reset `vtype` to a convenient value (e.g., four vector groups of LMUL=8, SEW=ELEN) before saving all vector register bits without needing to parse the configuration. The reverse process will restore the state.

4.1. Mapping with LMUL=1

When LMUL=1, elements are simply packed in order from the least-significant to most-significant bits of the vector register.

To increase readability, vector register layouts are drawn with bytes ordered from right to left with increasing byte address. Bits within an element are numbered in a little-endian format with increasing bit index from right to left corresponding to increasing magnitude.

The element index is given in hexadecimal and is shown placed at the least-significant byte

VLEN=32b

Byte 3 2 1 0

SEW=8b 3 2 1 0

SEW=16b 1 0

SEW=32b 0

VLEN=64b

Byte 7 6 5 4 3 2 1 0

SEW=8b 7 6 5 4 3 2 1 0

SEW=16b 3 2 1 0

SEW=32b 1 0

SEW=64b 0

VLEN=128b

Byte F E D C B A 9 8 7 6 5 4 3 2 1 0

SEW=8b F E D C B A 9 8 7 6 5 4 3 2 1 0

SEW=16b 7 6 5 4 3 2 1 0

SEW=32b 3 2 1 0

SEW=64b 1 0

SEW=128b 0

VLEN=256b

Byte 1F1E1D1C1B1A19181716151413121110 F E D C B A 9 8 7 6 5 4 3 2 1 0

SEW=8b 1F1E1D1C1B1A19181716151413121110 F E D C B A 9 8 7 6 5 4 3 2 1 0

SEW=16b F E D C B A 9 8 7 6 5 4 3 2 1 0

SEW=32b 7 6 5 4 3 2 1 0

SEW=64b 3 2 1 0

SEW=128b 1 0

4.2. Mapping with LMUL > 1

When vector registers are grouped, the elements of the vector register group are striped across the constituent vector registers. The striping distance in bits, SLEN, sets how many bits are packed contiguously into one vector register before moving to the next in the group.

For example, when SLEN = 128, the striping pattern is repeated in multiples of 128 bits. The first 128/SEW elements are packed contiguously at the start of the first vector register in the group. The next 128/SEW elements are packed contiguously at the start of the next vector register in the group. After packing the first LMUL*128/SEW elements at the start of each of the LMUL vector registers in the group, the second LMUL*128/SEW group of elements are packed into the second 128b segment of each of the vector registers in the group, and so on.

Example 1: VLEN=32b, SEW=16b, LMUL=2

Byte	3	2	1	0
v2*n	1	0		
v2*n+1	3	2		

Example 2: VLEN=64b, SEW=32b, LMUL=2

Byte	7	6	5	4	3	2	1	0
v2*n			1					0
v2*n+1			3					2

Example 3: VLEN=128b, SEW=32b, LMUL=2

Byte	F	E	D	C	B	A	9	8	7	6	5	4	3	2	1	0
v2*n				3				2					1			0
v2*n+1				7				6					5			4

Example 4: VLEN=256b, SEW=32b, LMUL=2

Byte	1	F	1	E	1	D	1	C	1	B	1	A	1	9	1	8	1	7	1	6	1	5	1	4	1	3	1	2	1	1	1	0	F	E	D	C	B	A	9	8	7	6	5	4	3	2	1	0
v2*n					B					A				9				8								3				2															1			0
v2*n+1					F					E				D				C								7				6															5			4

If SEW > SLEN, the striping pattern places one element in each vector register in the group before moving to the next vector register in the group. So, when LMUL=2, the even-numbered vector register contains the even-numbered elements of the vector and the odd-numbered vector register contains the odd-numbered elements of the vector.

| In most implementations, the striping distance SLEN ≥ ELEN.

Example: VLEN=256b, SEW=256b, LMUL=2

Byte	1	F	1	E	1	D	1	C	1	B	1	A	1	9	1	8	1	7	1	6	1	5	1	4	1	3	1	2	1	1	1	0	F	E	D	C	B	A	9	8	7	6	5	4	3	2	1	0		
v2*n																																																		0
v2*n+1																																																		1

When LMUL = 4, four vector registers hold elements as shown:

Example 1: VLEN=32b, SLEN=32b, SEW=16b, LMUL=4,

Byte	3	2	1	0
v4*n	1	0		
v4*n+1	3	2		
v4*n+2	5	4		
v4*n+3	7	6		

Example 2: VLEN=64b, SLEN=64b, SEW=32b, LMUL=4

Byte	7	6	5	4	3	2	1	0
v4*n				1				0
v4*n+1				3				2
v4*n+2				5				4
v4*n+3				7				6

Example 3: VLEN=128b, SLEN=64b, SEW=32b, LMUL=4

Byte	F	E	D	C	B	A	9	8	7	6	5	4	3	2	1	0	
v4*n				9				8				1				0	32b elements
v4*n+1				B				A				3				2	
v4*n+2				D				C				5				4	
v4*n+3				F				E				7				6	

Example 3: VLEN=128b, SLEN=128b, SEW=32b, LMUL=4

Byte	F	E	D	C	B	A	9	8	7	6	5	4	3	2	1	0	
v4*n				3				2				1				0	32b elements
v4*n+1				7				6				5				4	
v4*n+2				B				A				9				8	
v4*n+3				F				E				D				C	

Example 4: VLEN=256b, SLEN=128b, SEW=32b, LMUL=4

Byte	1F	1E	1D	1C	1B	1A	19	18	17	16	15	14	13	12	11	10	F	E	D	C	B	A	9	8	7	6	5	4	3	2	1	0
v4*n				13				12				11				10		3				2						1			0	
v4*n+1				17				16				15				14		7				6						5			4	
v4*n+2				1B				1A				19				18		B				A						9			8	
v4*n+3				1F				1E				1D				1C		F				E						D			C	

Example 5: VLEN=256b, SLEN=128b, SEW=256b, LMUL=4

Byte	1F	1E	1D	1C	1B	1A	19	18	17	16	15	14	13	12	11	10	F	E	D	C	B	A	9	8	7	6	5	4	3	2	1	0
v4*n																															0	
v4*n+1																															1	
v4*n+2																															2	
v4*n+3																															3	

A similar pattern is followed for LMUL = 8.

Example: VLEN=256b, SLEN=128b, SEW=32b, LMUL=8

Byte	1	F	E	D	C	B	A	9	8	7	6	5	4	3	2	1	0
v8*n	23		22		21		20		3		2		1		0		
v8*n+1	27		26		25		24		7		6		5		4		
v8*n+2	2B		2A		29		28		B		A		9		8		
v8*n+3	2F		2E		2D		2C		F		E		D		C		
v8*n+4	33		32		31		30		13		12		11		10		
v8*n+5	37		36		35		34		17		16		15		14		
v8*n+6	3B		3A		39		38		1B		1A		19		18		
v8*n+7	3F		3E		3D		3C		1F		1E		1D		1C		

Different striping patterns are architecturally visible, but software can be written that produces the same results regardless of striping pattern. The primary constraint is to not change the LMUL used to access values held in a vector register group (i.e., do not read values with a different LMUL than used to write values to the group).

The striping length SLEN for an implementation is set to optimize the tradeoff between datapath wiring for mixed-width operations and buffering needed to corner-turn wide vector unit-stride memory accesses into parallel accesses for the vector register file.

The previous explicit configuration design allowed these tradeoffs to be managed at the microarchitectural level and optimized for each configuration.

4.3. Mapping across Mixed-Width Operations

The pattern used to map elements within a vector register group is designed to reduce datapath wiring when supporting operations across multiple element widths. The recommended software strategy in this case is to modify vtype dynamically to keep SEW/LMUL constant (and hence VLMAX constant).

The following example shows four different packed element widths (8b, 16b, 32b, 64b) in a VLEN=256b/SLEN=128b implementation. The vector register grouping factor (LMUL) is increased by the relative element size such that each group can hold the same number of vector elements (32 in this example) to simplify stripmining code. Any operation between elements with the same index only touches operand bits located within the same 128b portion of the datapath.

VLEN=256b, SLEN=128b

Byte 1F1E1D1C1B1A19181716151413121110 F E D C B A 9 8 7 6 5 4 3 2 1 0

SEW=8b, LMUL=1, VLMAX=32

v1 1F1E1D1C1B1A19181716151413121110 F E D C B A 9 8 7 6 5 4 3 2 1 0

SEW=16b, LMUL=2, VLMAX=32

v2*n 17 16 15 14 13 12 11 10 7 6 5 4 3 2 1 0
v2*n+1 1F 1E 1D 1C 1B 1A 19 18 F E D C B A 9 8

SEW=32b, LMUL=4, VLMAX=32

v4*n 13 12 11 10 3 2 1 0
v4*n+1 17 16 15 14 7 6 5 4
v4*n+2 1B 1A 19 18 B A 9 8
v4*n+3 1F 1E 1D 1C F E D C

SEW=64b, LMUL=8, VLMAX=32

v8*n 11 10 1 0
v8*n+1 13 12 3 2
v8*n+2 15 14 5 4
v8*n+3 17 16 7 6
v8*n+4 19 18 9 8
v8*n+5 1B 1A B A
v8*n+6 1D 1C D C
v8*n+7 1F 1E F E

Larger LMUL settings can also be used to simply increase vector length to reduce instruction fetch and dispatch overheads, in cases where fewer logical vector registers are required.

The following table shows each possible constant SEW/LMUL operating point for loops with mixed-width operations.

Numbers in columns are LMUL values, and each column represents constant SEW/LMUL operating point												
SEW/LMUL	1	2	4	8	16	32	64	128	256	512	1024	
SEW												
8	8	4	2	1								
16		8	4	2	1							
32			8	4	2	1						
64				8	4	2	1					
128					8	4	2	1				
256						8	4	2	1			
512							8	4	2	1		
1024								8	4	2	1	

Larger LMUL values can cause lower datapath utilization for short vectors if SLEN is less than the spatial datapath width. In the example above with VLEN=256b, SLEN=128b, and LMUL=8, if the implementation is purely spatial with a 256b-wide vector datapath, then for an application vector length less than 17, only half of the datapath will be active. The `vsetv1` instructions below could have a facility added to dynamically select an appropriate LMUL according to the required application vector length (AVL) and range of element widths.

Narrower machines will set SLEN to be at least as large as the datapath spatial width, so there is no need to reduce LMUL. Wider machines might set SLEN lower than the spatial datapath width to reduce wiring for mixed-width operations (e.g., width=1024, ELEN=32, SLEN=128), in which case optimizing LMUL will be important.

4.4. Mask Register Layout

A vector mask occupies only one vector register regardless of SEW and LMUL. The mask bits that are used for each vector operation depends on the current SEW and LMUL setting.

The maximum number of elements in a vector operand is:

$$VLMAX = LMUL * VLEN/SEW$$

A mask is allocated for each element by dividing the mask register into VLEN/VLMAX fields. The size of each mask element in bits, *MLEN*, is:

$$\begin{aligned} MLEN &= VLEN/VLMAX \\ &= VLEN/(LMUL * VLEN/SEW) \\ &= SEW/LMUL \end{aligned}$$

The size of MLEN varies from ELEN (SEW=ELEN, LMUL=1) down to 1 (SEW=8b, LMUL=8), and hence a single vector register can always hold the entire mask register.

The mask bits for element *i* are located in bits $[MLEN*i+(MLEN-1) : MLEN*i]$ of the mask register. When a mask element is written by a compare instruction, the low bit in the mask element is written with the compare result and the upper bits of the mask element are zeroed. When a value is read as a mask, only the least-significant bit of the mask element is used to control masking and the upper bits are ignored. Mask elements past the end of the current vector length are zeroed.

The pattern is such that for constant SEW/LMUL values, the effective predicate bits are located in the same bit of the mask vector register, which simplifies use of masking in loops with mixed-width elements.

VLEN=32b

Byte	3	2	1	0	
LMUL=1, SEW=8b					
	3	2	1	0	Element
	[24]	[16]	[08]	[00]	Mask bit position in decimal

LMUL=2, SEW=16b

1	0
[08]	[00]
3	2
[24]	[16]

LMUL=4, SEW=32b

0
[00]
1
[08]
2
[16]
3
[24]

LMUL=2, SEW=8b

3	2	1	0
[12]	[08]	[04]	[00]
7	6	5	4
[28]	[24]	[20]	[16]

LMUL=8, SEW=32b

0
[00]
1
[04]
2
[08]
3
[12]
4
[16]
5
[20]
6
[24]
7
[28]

LMUL=8, SEW=8b

3	2	1	0
[03]	[02]	[01]	[00]
7	6	5	4
[07]	[06]	[05]	[04]
B	A	9	8
[11]	[10]	[09]	[08]
F	E	D	C
[15]	[14]	[13]	[12]
13	12	11	10
[19]	[18]	[17]	[16]
17	16	15	14
[23]	[22]	[21]	[20]
1B	1A	19	18
[27]	[26]	[25]	[24]
1F	1E	1D	1C
[31]	[30]	[29]	[28]

VLEN=256b, SLEN=128b

Byte 1F1E1D1C1B1A19181716151413121110 F E D C B A 9 8 7 6 5 4 3 2 1 0

SEW=8b, LMUL=1, VLMAX=32

v1 1F1E1D1C1B1A19181716151413121110 F E D C B A 9 8 7 6 5 4 3 2 1 0
[248] ... [128] ... [96] ... [64] ... [32] ... [0] Mask bit positio

SEW=16b, LMUL=2, VLMAX=32

v2*n	17	16	15	14	13	12	11	10	7	6	5	4	3	2	1	0
	[184]							[128]				[32]				[0]
v2*n+1	1F	1E	1D	1C	1B	1A	19	18	F	E	D	C	B	A	9	8
	[248]							[196]				[96]				[64]

SEW=32b, LMUL=4, VLMAX=32

v4*n	13	12	11	10	3	2	1	0
	[152]			[128]	[24]			[0]
v4*n+1	17	16	15	14	7	6	5	4
	[184]			[160]	[56]			[32]
v4*n+2	1B	1A	19	18	B	A	9	8
	[116]			[192]	[88]			[64]
v4*n+3	1F	1E	1D	1C	F	E	D	C
	[248]			[224]	[120]			[96]

SEW=64b, LMUL=8, VLMAX=32

v8*n	11	10	1	0
	[136]	[128]	[8]	[0]
v8*n+1	13	12	3	2
	[152]	[144]	[24]	[16]
v8*n+2	15	14	5	4
	[168]	[160]	[40]	[32]
v8*n+3	17	16	7	6
	[184]	[176]	[56]	[48]
v8*n+4	19	18	9	8
	[200]	[192]	[72]	[64]
v8*n+5	1B	1A	B	A
	[216]	[208]	[88]	[80]
v8*n+6	1D	1C	D	C
	[232]	[224]	[104]	[96]
v8*n+7	1F	1E	F	E
	[248]	[240]	[120]	[112]

5. Vector Instruction Formats

The instructions in the vector extension fit under four existing major opcodes (LOAD-FP, STORE-FP, AMO) and one new major opcode (OP-V).

Vector loads and stores are encoding within the scalar floating-point load and store major opcodes (LOAD-FP/STORE-FP). The vector load and store encodings repurpose a portion of the standard scalar floating-point load/store 12-bit immediate field to provide further vector instruction encoding, with bit 25 holding the standard vector mask bit (see Mask Encoding).

Format for Vector Load Instructions under LOAD-FP major opcode

31	29	28	26	25	24	20	19	15	14	12	11	7	6	0
nf		mop		vm		lumop		rs1		width		vd	0000111	VL* unit-stride
nf		mop		vm		rs2		rs1		width		vd	0000111	VLS* strided
nf		mop		vm		vs2		rs1		width		vd	0000111	VLX* indexed
3		3		1		5		5		3		5		7

Format for Vector Store Instructions under STORE-FP major opcode

31	29	28	26	25	24	20	19	15	14	12	11	7	6	0
nf		mop		vm		sumop		rs1		width		vs3	0100111	VS* unit-stride
nf		mop		vm		rs2		rs1		width		vs3	0100111	VSS* strided
nf		mop		vm		vs2		rs1		width		vs3	0100111	VSX* indexed
3		3		1		5		5		3		5		7

Format for Vector AMO Instructions under AMO major opcode

31	27	26	25	24	20	19	15	14	12	11	7	6	0
amop		wd	vm		vs2		rs1		width		vs3/vd	0101111	VAMO*
5			1		1		5		3		5		7

Formats for Vector Arithmetic Instructions under OP-V major opcode

31	26	25	24	20	19	15	14	12	11	7	6	0
funct6		vm		vs2		vs1		0 0 0		vd	1010111	OP-V (OPIVV)
funct6		vm		vs2		vs1		0 0 1		vd	1010111	OP-V (OPFVV)
funct6		vm		vs2		vs1		0 1 0		vd/rd	1010111	OP-V (OPMVV)
funct6		vm		vs2		simm5		0 1 1		vd	1010111	OP-V (OPIVI)
funct6		vm		vs2		rs1		1 0 0		vd	1010111	OP-V (OPIVX)
funct6		vm		vs2		rs1		1 0 1		vd	1010111	OP-V (OPFVF)
funct6		vm		vs2		rs1		1 1 0		vd/rd	1010111	OP-V (OPMVX)
6		1		5		5		3		5		7

Formats for Vector Configuration Instructions under OP-V major opcode

31	30	25	24	20	19	15	14	12	11	7	6	0				
0		zimm[10:0]				rs1		1	1	1		rd	1010111	vsetvli		
1		000000				rs2		rs1		1	1	1		rd	1010111	vsetvl
1		6				5		5		3		5		7		

Vector instructions can have scalar or vector source operands and produce scalar or vector results, and most vector instructions can be performed either unconditionally or conditionally under a mask.

Vector loads and stores move bit patterns between vector register elements and memory. Vector arithmetic instructions operate on values held in vector register elements.

5.1. Scalar operands

Scalar operands can be immediates, or taken from the x registers, the f registers, or element 0 of a vector register. Scalar results are written to an x or f register or to element 0 of a vector register. Any vector register can be used to hold a scalar regardless of the current LMUL setting.

In a change from v0.6, the floating-point registers no longer overlay the vector registers and scalars can now come from the integer or floating-point registers. Not overlaying the f registers reduces vector register pressure, avoids interactions with the standard calling convention, simplifies high-performance scalar floating-point design, and provides compatibility with the Zfinx ISA option. Overlaying f with v would provide the advantage of lowering the number of state bits in some implementations, but complicates high-performance designs and would prevent compatibility with the Zfinx ISA option.

5.2. Vector Operands

Vector operands or results may occupy one or more vector registers depending on LMUL, but are always specified using the lowest-numbered vector register in the group. Using other than the lowest-numbered vector register to specify a vector register group will result in an illegal instruction exception.

Some vector instructions consume and produce wider-width elements and so operate on a larger vector register group than that specified in `vlmul`. The largest vector register group used by an instruction can not be greater than 8 vector registers, and if an vector instruction would require greater than 8 vector registers in a group, an illegal instruction exception is raised. For example, attempting a widening operation with LMUL=8 will raise an illegal instruction exception.

5.3. Vector Masking

Masking is supported on many vector instructions. Element operations that are masked off do not modify the destination vector register element and never generate exceptions.

In the base vector extension, the mask value used to control execution of a masked vector instruction is always supplied by vector register `v0`. Only the least-significant bit of each element of the mask vector is used to control execution.

Future vector extensions may provide longer instruction encodings with space for a full mask register specifier.

The destination vector register group for a masked vector instruction can only overlap the source mask register (`v0`) when LMUL=1. Otherwise, an illegal vector instruction exception is raised.

This constraint supports restart with a non-zero `vstart` value.

Other vector registers can be used to hold working mask values, and mask vector logical operations are provided to perform predicate calculations.

5.3.1. Mask Encoding

Where available, masking is encoded in a single-bit `vm` field in the instruction (`inst[25]`).

`vm`

0	vector result, only where <code>v0[i].LSB = 1</code>
1	unmasked

In earlier proposals, `vm` was a two-bit field `vm[1:0]` that provided both true and complement masking using `v0` as well as encoding scalar operations.

Vector masking is represented in assembler code as another vector operand, with `.t` indicating if operation occurs when `v0[i].LSB` is 1. If no masking operand is specified, unmasked vector execution (`vm=1`) is assumed.

<code>vop.v*</code>	<code>v1, v2, v3, v0.t</code>	# enabled where <code>v0[i].LSB=1</code> , <code>m=0</code>
<code>vop.v*</code>	<code>v1, v2, v3</code>	# unmasked vector operation, <code>m=1</code>

Even though the base only supports one vector mask register `v0` and only the true form of predication, the assembly syntax writes it out in full to be compatible with future extensions that might add a mask register specifier and supporting both true and complement masking. The `.t` suffix on the masking operand also helps to visually encode the use of a mask.

5.4. Prestart, Active, Inactive, Body, and Tail Element Definitions

The elements operated on during a vector instruction's execution can be divided into four disjoint subsets.

- The *prestart* elements are those whose element index is less than the initial value in the `vstart` register. The prestart elements do not raise exceptions and do not update the destination vector register.
- The *active* elements during a vector instruction's execution are the elements within the current vector length setting and where the current mask is enabled at that element position. The active elements can raise exceptions and update the destination vector register group.
- The *inactive* elements are the elements within the current vector length setting but where the current mask is disabled at that element position. The inactive elements do not raise exceptions and do not update the destination vector register.
- The *tail* elements during a vector instruction's execution are the elements past the current vector length setting. The tail elements do not raise exceptions, but do zero the results in the destination vector register group.
- In addition, another term, *body*, is used for the set of elements that are either active or inactive, i.e., after prestart but before the tail.

```

for element index x
prestart      = (0 <= x < vstart)
mask(x)       = unmasked || v0[x].LSB == 1
active(x)     = (vstart <= x < vl) && mask(x)
inactive(x)   = (vstart <= x < vl) && !mask(x)
body(x)       = active(x) || inactive(x)
tail(x)       = (vl <= x < VLMAX)

```

All regular vector instructions place zeros in the tail elements of the destination vector register group. Some vector arithmetic instructions are not maskable, so have no inactive elements, but still zero the tail elements.

The inactive and tail update rules were designed to provide an efficient compromise between requirements of implementations with and without vector register ECC and/or renaming.

Not zeroing past `vl` would penalize renamed implementations that would have to copy all elements past `VL` on every instruction execution, whereas it's a small penalty for non-renamed implementations to implement the tail zeroing. While a renamed machine could avoid copying for whole vector registers in a group by not renaming, operations on individual registers may be deep enough that requiring full occupancy for any vector length would be problematic. Zeroing values past `vl` does not impact most software, except for a small cost in some reduction cases.

For zeroing tail updates, implementations with temporally long vector registers, either with or without register renaming, will be motivated to add microarchitectural state to avoid actually writing zeros to all tail elements, but this is a relatively simple microarchitectural optimization. For example, one bit per element group or a quantized VL can be used to track the extent of zeroing. An element group is the set of elements comprising the smallest atomic unit of execution in the microarchitecture (often equivalent to the width of the physical datapath in the machine). The microarchitectural state for an element group indicates that zero should be returned for the element group on a read, and that zero should be substituted in for any masked-off elements in the group on the first write to that element group (after which the element group zero bit can be cleared).

Providing merging predication instead of zeroing inactive elements on a masked operation reduces code path length for many code blocks, and reduces register pressure by allowing different code paths to use disjoint sets of elements in the same vector register. Implementations with vector register ECC or renaming will have to perform read-update-write on the destination register value to preserve inactive elements on arithmetic instructions, so would appear to need an extra vector register read port. However, the arithmetic instructions are designed such that the largest read-port requirement is for fused multiply-add instructions that are destructive and overwrite one source, and hence do not need an extra read port to preserve inactive elements. Given that linear algebra is one of the more important applications for vector units, and that fused multiply-add is the dominant operation in linear algebra routines, microarchitectures will be optimized for fused multiply-add operations and so should be able to preserve inactive elements on other arithmetic operations without large additional cost. However, masked vector load instructions incur the cost of an additional read port on their destination register. The need to support resumable vector loads with non-zero `vstart` values also drives the need to preserve vector load destination register values. The AMOs have been defined to be destructive in their source operand to reduce the maximum read port requirement for the memory pipe. An option that was considered was to have loads behave differently from arithmetic instructions and to zero any masked-off elements. However, this would require additional instructions and increase register pressure, and vector loads must in any case still cope with non-zero `vstart` values through some mechanism.

6. Configuration-Setting Instructions

A set of instructions are provided to allow rapid configuration of the values in `vl` and `vtype` to match application needs.

6.1. vsetvli/vsetvl instructions

```
vsetvli rd, rs1, vtypei # rd = new v1, rs1 = AVL, vtypei = new vtype setting
                        # if rs1 = x0, then use maximum vector length
vsetvl  rd, rs1, rs2    # rd = new v1, rs1 = AVL, rs2 = new vtype value
                        # if rs1 = x0, then use maximum vector length
```

The `vsetvli` instruction sets the `vtype` and `v1` CSRs based on its arguments, and writes the new value of `v1` into `rd`.

The new `vtype` setting is encoded in the immediate fields of `vsetvli` and in the `rs2` register for `vsetvl`.

Formats for Vector Configuration Instructions under OP-V major opcode

31	30			25	24			20	19			15	14			12	11			7	6			0
0												rs1		1	1	1				rd		1010111		vsetvli
1			000000								rs2		rs1		1	1	1			rd		1010111		vsetvl
1			6						5			5			3			5			7			

```
vtype register layout
```

bits	contents
XLEN-1:7	Reserved (write 0)
6:5	vediv[1:0] # Used by EDIV extension
4:2	vsew[2:0]
1:0	vlmul[1:0]

Suggested assembler names used for vtypei setting

```
e8    #    8b elements
e16   #   16b elements
e32   #   32b elements
e64   #   64b elements
e128  #  128b elements

m1    # Vlmul x1, assumed if m setting absent
m2    # Vlmul x2
m4    # Vlmul x4
m8    # Vlmul x8

d1    # EDIV 1, assumed if d setting absent
d2    # EDIV 2
d4    # EDIV 4
d8    # EDIV 8
```

Examples:

```
vsetvli t0, a0, e8          # SEW= 8, LMUL=1, EDIV=1
vsetvli t0, a0, e8,m2       # SEW= 8, LMUL=2, EDIV=1
vsetvli t0, a0, e32,m2,d4   # SEW=32, LMUL=2, EDIV=4
```

The vtype setting must be supported by the implementation, and the vsetv1{i} instructions will raise an illegal instruction exception if the setting is not supported.

Specifying that vtype is WARL is problematic as that would hide errors. The current spec is problematic in that it requires a trap based on a data value in a CSR write. It would simplify pipelines if vtype value errors were flagged at use not write, but somehow need to catch errant code without requiring full XLEN bits in vtype when only a few bits are actually used. One alternative is to allow substitution of a fixed illegal value in vtype, e.g., all 1s, if an attempt is made to write an unsupported value. This would then cause a trap on use.

The requested application vector length (AVL) is passed in rs1 as an unsigned integer. Using x0 as the rs1 register specifier, encodes an infinite AVL, and so requests the maximum possible vector length.

A vsetv1 with AVL=x0 can be used to read current VLMAX, though this does overwrite v1.

6.2. Constraints on Setting v1

The resulting v1 setting must satisfy the following constraints:

1. $v1 = AVL$ if $AVL \leq VLMAX$
2. $v1 \geq \text{ceil}(AVL / 2)$ if $AVL < (2 * VLMAX)$
3. $v1 = VLMAX$ if $AVL \geq (2 * VLMAX)$
4. Deterministic on any given implementation for same input AVL and vtype values
5. These specific properties follow from the prior rules:
 - a. $v1 = 0$ if $AVL = 0$
 - b. $v1 > 0$ if $AVL > 0$
 - c. $v1 \leq VLMAX$
 - d. $v1 \leq AVL$

e. a value read from `v1` when used as AVL arg to `vsetv1{i}` results in same value in `v1`

The `v1` setting rules are designed to be sufficiently strict to preserve `v1` behavior across register spills and context swaps for $AVL \leq VLMAX$, yet flexible enough to enable implementations to improve vector lane utilization for $AVL > VLMAX$.

For example, this permits an implementation to set $v1 = \text{ceil}(AVL / 2)$ for $VLMAX < AVL < 2*VLMAX$ in order to evenly distribute work over the last two iterations of a stripmine loop. Requirement 2 ensures that the first stripmine iteration of reduction loops uses the largest vector length of all iterations, even in the case of $AVL < 2*VLMAX$. This allows software to avoid needing to explicitly calculate a running maximum of vector lengths observed during a stripmined loop.

6.3. `vsetv1` Instruction

The `vsetv1` variant operates similarly to `vsetvli` except that it takes a `vtype` value from `rs2` and can be used for context restore, and when the `vtypei` field is too small to hold the desired setting.

Several active complex types can be held in different `x` registers and swapped in as needed using `vsetv1`.

6.4. Examples

The SEW and LMUL settings can be changed dynamically to provide high throughput on mixed-width operations in a single loop.

Example: Load 16-bit values, widen multiply to 32b, shift 32b result
right by 3, store 32b values.

Loop using only widest elements:

loop:

```
vsetvli a3, a0, e32,m8    # Use only 32-bit elements
vlh.v v8, (a1)            # Sign-extend 16b load values to 32b elements
sll t1, a3, 1
add a1, a1, t1             # Bump pointer
vmul.vx v8, v8, x10       # 32b multiply result
vsrl.vi v8, v8, 3         # Shift elements
vsw.v v8, (a2)            # Store vector of 32b results
sll t1, a3, 2
add a2, a2, t1             # Bump pointer
sub a0, a0, a3            # Decrement count
bnez a0, loop             # Any more?
```

Alternative loop that switches element widths.

loop:

```
vsetvli a3, a0, e16,m4    # vtype = 16-bit integer vectors
vlh.v v4, (a1)            # Get 16b vector
slli t1, a3, 1
add a1, a1, t1            # Bump pointer
vwmul.vx v8, v4, x10      # 32b in <v8--v15>

vsetvli x0, a0, e32,m8    # Operate on 32b values
vsrl.vi v8, v8, 3
vsw.v v8, (a2)            # Store vector of 32b
slli t1, t1, 2
add a2, a2, t1            # Bump pointer
sub a0, a0, a3            # Decrement count
bnez a0, loop             # Any more?
```

The second loop is more complex but will have greater performance on machines where 16b widening multiplies are faster than 32b integer multiplies, and where 16b vector load can run faster due to the narrower writes to the vector regfile.

7. Vector Loads and Stores

Vector loads and stores move values between vector registers and memory. Vector loads and stores are masked and do not raise exceptions on inactive elements. Masked vector loads do not update inactive elements in the destination vector register group. Masked vector stores do not update inactive memory elements.

7.1. Vector Load/Store Instruction Encoding

Vector loads and stores are encoded within the scalar floating-point load and store major opcodes (LOAD-FP/STORE-FP). The vector load and store encodings repurpose a portion of the standard scalar floating-point load/store 12-bit immediate field to provide further vector instruction encoding, with bit 25 holding the standard vector mask bit (see Mask Encoding).

Format for Vector Load Instructions under LOAD-FP major opcode

31	29	28	26	25	24	20	19	15	14	12	11	7	6	0
nf		mop		vm		lumop		rs1		width		vd	0000111	VL* unit-stride
nf		mop		vm		rs2		rs1		width		vd	0000111	VLS* strided
nf		mop		vm		vs2		rs1		width		vd	0000111	VLX* indexed
3		3		1		5		5		3		5		7

Format for Vector Store Instructions under STORE-FP major opcode

31	29	28	26	25	24	20	19	15	14	12	11	7	6	0
nf		mop		vm		sumop		rs1		width		vs3	0100111	VS* unit-stride
nf		mop		vm		rs2		rs1		width		vs3	0100111	VSS* strided
nf		mop		vm		vs2		rs1		width		vs3	0100111	VSX* indexed
3		3		1		5		5		3		5		7

rs1[4:0] specifies x register holding base address

rs2[4:0] specifies x register holding stride

vs2[4:0] specifies v register holding address offsets

vs3[4:0] specifies v register holding store data

vd[4:0] specifies v register destination of load

vm specifies vector mask

width[2:0] specifies size of memory elements, and distinguishes from FP scalar

mop[2:0] specifies memory addressing mode

nf[2:0] specifies the number of fields in each segment, for segment load/stores

lumop[4:0]/sumop[4:0] are additional fields encoding variants of unit-stride instructions

7.2. Vector Load/Store Addressing Modes

The base vector extension supports unit-stride, strided, and indexed (scatter/gather) addressing modes. Vector load/store base registers and strides are taken from the GPR x registers.

The base effective address for all vector accesses is given by the contents of the x register named in rs1.

Vector unit-stride operations access elements stored contiguously in memory starting from the base effective address.

Vector strided operations access the first memory element at the base effective address, and then access subsequent elements at address increments given by the byte offset contained in the x register specified by

rs2.

Vector indexed operations add the contents of each element of the vector offset operand specified by vs2 to the base effective address to give the effective address of each element. The vector offset operand is treated as a vector of byte offsets. If the vector offset elements are narrower than XLEN, they are sign-extended to XLEN before adding to the base effective address. If the vector offset elements are wider than XLEN, the least-significant XLEN bits are used in the address calculation.

Current PoR for vector indexed instructions requires that vector byte offset (vs2) and vector read/write data (vs3/vd) are of same width. One question is whether and how to allow for two sizes of vector operand in a vector indexed instruction? For example, for scatter/gather of byte values in a 64-bit address space without requiring bytes use 64b of space in a vector register.

The vector addressing modes are encoded using the 3-bit mop[2:0] field.

mop [2:0] encoding for loads		
0 0 0	zero-extended unit-stride	VLxU, VLE
0 0 1	reserved	
0 1 0	zero-extended strided	VLSxU, VLSE
0 1 1	zero-extended indexed	VLXxU, VLXE
1 0 0	sign-extended unit-stride	VLx (x!=E)
1 0 1	reserved	
1 1 0	sign-extended strided	VLSx (x!=E)
1 1 1	sign-extended indexed	VLXx (x!=E)

mop [2:0] encoding for stores		
0 0 0	unit-stride	VSx
0 0 1	reserved	
0 1 0	strided	VSSx
0 1 1	indexed-ordered	VSXx
1 0 0	reserved	
1 0 1	reserved	
1 1 0	reserved	
1 1 1	indexed-unordered	VSUXx

The vector indexed memory operations have two forms, ordered and unordered. The indexed-unordered stores do not preserve element ordering on stores.

The indexed-unordered variant is provided as a potential implementation optimization. Implementations are free to ignore the optimization and implement indexed-unordered identically to indexed-ordered.

Additional unit-stride vector addressing modes are encoded using the 5-bit lumop and sumop fields in the unit-stride load and store instruction encodings respectively.

lumop[4:0]	
00000	unit-stride
0xxxx	reserved, x!=0
10000	unit-stride fault-only-first
1xxxx	reserved, x!=0

sumop[4:0]	
00000	unit-stride
0xxxx	reserved, x!=0
1xxxx	reserved

The nf[2:0] field encodes the number of fields in each segment. For regular vector loads and stores, nf=0, indicating that a single value is moved between a vector register group and memory at each element position.

Larger values in the `nf` field are used to access multiple contiguous fields within a segment as described below in Section Vector Load/Store Segment Instructions (`Zvlsseg`).

The `nf` field for segment load/stores has replaced the use of the same bits for an address offset field. The offset can be replaced with a single scalar integer calculation, while segment load/stores add more powerful primitives to move items to and from memory.

7.3. Vector Load/Store Width Encoding

The vector loads and stores are encoded using the width values that are not claimed by the standard scalar floating-point loads and stores. Three of the width types encode vector loads and stores that move fixed-size memory elements of 8 bits, 16 bits, or 32 bits, while the fourth encoding moves SEW-bit memory elements.

	Width [2:0]	Mem bits	Reg bits	Opcode
Standard scalar FP	001	16	FLEN	FLH/FSH
Standard scalar FP	010	32	FLEN	FLW/FSW
Standard scalar FP	011	64	FLEN	FLD/FSD
Standard scalar FP	100	128	FLEN	FLQ/FSQ
Vector byte	000	v1*8	v1*SEW	VxB
Vector halfword	101	v1*16	v1*SEW	VxH
Vector word	110	v1*32	v1*SEW	VxW
Vector element	111	v1*SEW	v1*SEW	VxE

Mem bits is the size of element accessed in memory
Reg bits is the size of element accessed in register

Fixed-sized vector loads can optionally sign or zero-extend their memory element into the destination register element if the register element is wider than the memory element. A fixed-size vector load raises an illegal instruction exception if the destination register element is narrower than the memory element. The variable-sized load is encoded as if a zero-extended load, with what would be the sign-extended encoding of a variable-sized load currently reserved.

Fixed-size vector stores take their operand from the least-significant bits of the register element if the register element is wider than the memory element. Fixed-sized vector stores raise an illegal instruction exception if the memory element is wider than the register element.

7.4. Vector Unit-Stride Instructions

Vector unit-stride loads and stores

vd destination, rs1 base address, vm is mask encoding (v0.t or <missing>)

vlb.v vd, (rs1), vm # 8b signed

vlh.v vd, (rs1), vm # 16b signed

vlw.v vd, (rs1), vm # 32b signed

vlbu.v vd, (rs1), vm # 8b unsigned

vlhu.v vd, (rs1), vm # 16b unsigned

vlwu.v vd, (rs1), vm # 32b unsigned

vle.v vd, (rs1), vm # SEW

vs3 store data, rs1 base address, vm is mask encoding (v0.t or <missing>)

vsb.v vs3, (rs1), vm # 8b store

vsh.v vs3, (rs1), vm # 16b store

vsw.v vs3, (rs1), vm # 32b store

vse.v vs3, (rs1), vm # SEW store

7.5. Vector Strided Instructions

Vector strided loads and stores

vd destination, rs1 base address, rs2 byte stride

vlsb.v vd, (rs1), rs2, vm # 8b

vlsh.v vd, (rs1), rs2, vm # 16b

vlsw.v vd, (rs1), rs2, vm # 32b

vlsbu.v vd, (rs1), rs2, vm # unsigned 8b

vlshu.v vd, (rs1), rs2, vm # unsigned 16b

vlswu.v vd, (rs1), rs2, vm # unsigned 32b

vlse.v vd, (rs1), rs2, vm # SEW

vs3 store data, rs1 base address, rs2 byte stride

vssb.v vs3, (rs1), rs2, vm # 8b

vssh.v vs3, (rs1), rs2, vm # 16b

vssw.v vs3, (rs1), rs2, vm # 32b

vsse.v vs3, (rs1), rs2, vm # SEW

7.6. Vector Indexed Instructions

```

# Vector indexed loads and stores

# vd destination, rs1 base address, vs2 indices
vldb.v  vd, (rs1), vs2, vm # 8b
vlxh.v  vd, (rs1), vs2, vm # 16b
vlxw.v  vd, (rs1), vs2, vm # 32b

vlxbu.v vd, (rs1), vs2, vm # 8b unsigned
vlxhu.v vd, (rs1), vs2, vm # 16b unsigned
vlxwu.v vd, (rs1), vs2, vm # 32b unsigned

vlxe.v  vd, (rs1), vs2, vm # SEW

# Vector ordered-indexed store instructions
# vs3 store data, rs1 base address, vs2 indices
vsxb.v  vs3, (rs1), vs2, vm # 8b
vsxh.v  vs3, (rs1), vs2, vm # 16b
vsxw.v  vs3, (rs1), vs2, vm # 32b
vsxe.v  vs3, (rs1), vs2, vm # SEW

# Vector unordered-indexed store instructions
vsuxb.v vs3, (rs1), vs2, vm # 8b
vsuxh.v vs3, (rs1), vs2, vm # 16b
vsuxw.v vs3, (rs1), vs2, vm # 32b
vsuxe.v vs3, (rs1), vs2, vm # SEW

```

7.7. Unit-stride Fault-Only-First Loads

The unit-stride fault-only-first load instructions are used to vectorize loops with data-dependent exit conditions (while loops). These instructions execute as a regular load except that they will only take a trap on element 0. If an element > 0 raises an exception, that element and all following elements in the destination vector register are not modified, and the vector length `v1` is reduced to the number of elements processed without a trap.

```

vlbff.v  vd, (rs1), vm # 8b
vlhff.v  vd, (rs1), vm # 16b
vlwff.v  vd, (rs1), vm # 32b

vlbuff.v vd, (rs1), vm # unsigned 8b
vlhuff.v vd, (rs1), vm # unsigned 16b
vlwuff.v vd, (rs1), vm # unsigned 32b

vleff.v  vd, (rs1), vm # SEW

```

strlen example using unit-stride fault-only-first instruction

```
# size_t strlen(const char *str)
# a0 holds *str

strlen:
    mv a3, a0          # Save start
loop:
    vsetvli a1, x0, e8 # Vector of bytes of maximum length
    vlbfv v1, (a3)      # Load bytes
    csrr a1, v1         # Get bytes read
    vseq.vi v0, v1, 0    # Set v0[i] where v1[i] = 0
    vmfirst.m a2, v0     # Find first set bit
    add a3, a3, a1       # Bump pointer
    bltz a2, loop       # Not found?

    add a0, a0, a1       # Sum start + bump
    add a3, a3, a2       # Add index
    sub a0, a3, a0       # Subtract start address+bump

    ret
```

Strided and scatter/gather fault-only-first instructions are not provided as they represent a large security hole, allowing software to check multiple random pages for accessibility without experiencing a trap. The unit-stride versions only allow probing a region immediately contiguous to a known region, and so do not appreciably impact security. It is possible that security mitigations can be implemented to allow fault-only-first variants of non-contiguous accesses in future vector extensions.

7.8. Vector Load/Store Segment Instructions (Zv1sseg)

This is being written as an extension but could be mandated in some profiles.

The vector load/store segment instructions move multiple contiguous fields in memory to and from consecutively numbered vector registers.

These operations support operations on "array-of-structures" datatypes by unpacking each field in a structure into separate vector registers.

As for regular vector loads and stores, the width encoding gives the size of the memory elements, which are homogeneous in size, while SEW encodes the size of the register elements.

The three-bit *nf* field in the vector instruction encoding is an unsigned integer that contains one less than the number of fields per segment, *NFIELDS*.

<i>nf</i> [2:0]	<i>NFIELDS</i>
000	1
001	2
010	3
011	4
100	5
101	6
110	7
111	8

LMUL must be set to 1 for a segment load or store (*NFIELDS* > 1), and each field will be held in successively numbered vector registers. If LMUL > 1, an illegal instruction exception will be raised.

The `v1` register gives the number of structures to move, which is equal to the number of elements transferred to each vector register.

If a trap is taken, `vstart` is in units of structures.

An earlier version imposed a vector register number constraint, but this decreased ability to make use of all registers when `NFIELDS` was not a power of 2.

7.8.1. Vector Unit-Stride Segment Loads and Stores

The vector unit-stride load and store segment instructions move packed contiguous segments ("array-of-structures") into multiple destination vector register groups.

For segments with heterogeneous-sized fields, software can later unpack fields using additional instructions after the segment load brings the values into the separate vector registers.

The assembler prefixes `vlseg/vsseg` are used for unit-stride segment loads and stores respectively.

```
# Format
vlseg<nf>{b,h,w}.v vd, (rs1), vm    # Unit-stride signed segment load template
vlseg<nf>e.v vd, (rs1), vm          # Unit-stride segment load template
vlseg<nf>{b,h,w}u.v vd, (rs1), vm    # Unit-stride unsigned segment load template
vsseg<nf>{b,h,w,e}.v vs3, (rs1), vm  # Unit-stride segment store template

# Examples
vlseg2b.v vd, (rs1), vm    # Load vector of signed 2*1-byte segments into vd, vd+1
vlseg3bu.v vd, (rs1), vm   # Load vector of unsigned 3*1-byte segments into vd, vd+1, vd+2
vlseg7w.v vd, (rs1), vm    # Load vector of 7*4-byte segments into vd, vd+1, ... vd+6
vlseg8e.v vd, (rs1), vm    # Load vector of 8*SEW-byte segments into vd, vd+1, .. vd+7

vsseg3b.v vs3, (rs1), vm   # Store packed vector of 3*1-byte segments from vs3,vs3+1,vs3+2
```

For loads, the `vd` register will hold the first field loaded from the segment. For stores, the `vs3` register is read to provide the first field to be stored in each segment.

```
# Example 1
# Memory structure holds packed RGB pixels (24-bit data structure, 8bpp)
vlseg3bu.v v8, (a0), vm
# v8 holds the red pixels
# v9 holds the green pixels
# v10 holds the blue pixels

# Example 2
# Memory structure holds complex values, 32b for real and 32b for imaginary
vlseg2w.v v8, (a0), vm
# v8 holds real
# v9 holds imaginary
```

There are also fault-only-first versions of the unit-stride instructions.

```
# Template for vector fault-only-first unit-stride segment loads and stores.
vlseg<nf>{b,h,w}ff.v vd, (rs1), vm    # Unit-stride signed fault-only-first segment loads
vlseg<nf>eff.v vd, (rs1), vm          # Unit-stride fault-only-first segment loads
vlseg<nf>{b,h,w}uff.v vd, (rs1), vm   # Unit-stride unsigned fault-only-first segment loads
```

7.8.2. Vector Strided Segment Loads and Stores

Vector strided segment loads and stores move contiguous segments where each segment is separated by the byte stride offset given in the rs2 GPR argument.

```
# Format
vlsseg<nf>{b,h,w}.v vd, (rs1), rs2, vm    # Strided signed segment loads
vlsseg<nf>e.v vd, (rs1), rs2, vm          # Strided segment loads
vlsseg<nf>{b,h,w}u.v vd, (rs1), rs2, vm    # Strided unsigned segment loads
vssseg<nf>{b,h,w,e}.v vs3, (rs1), rs2, vm  # Strided segment stores

# Examples
vlsseg3b.v v4, (x5), x6    # Load bytes at addresses x5+i*x6 into v4[i],
                           # and bytes at addresses x5+i*x6+1 into v5[i],
                           # and bytes at addresses x5+i*x6+2 into v6[i].

# Examples
vssseg2w.v v2, (x5), x6    # Store words from v2[i] to address x5+i*x6
                           # and words from v3[i] to address x5+i*x6+4
```

7.8.3. Vector Indexed Segment Loads and Stores

Vector indexed segment loads and stores move contiguous segments where each segment is located at an address given by adding the scalar base address in the rs1 field to byte offsets in vector register vs2.

```
# Format
vlxseg<nf>{b,h,w}.v vd, (rs1), vs2, vm    # Indexed signed segment loads
vlxseg<nf>e.v vd, (rs1), vs2, vm          # Indexed segment loads
vlxseg<nf>{b,h,w}u.v vd, (rs1), vs2, vm    # Indexed unsigned segment loads
vsxseg<nf>{b,h,w,e}.v vs3, (rs1), vs2, vm  # Indexed segment stores

# Examples
vlxseg3bu.v v4, (x5), v3    # Load bytes at addresses x5+v3[i] into v4[i],
                           # and bytes at addresses x5+v3[i]+1 into v5[i],
                           # and bytes at addresses x5+v3[i]+2 into v6[i].

# Examples
vsxseg2w.v v2, (x5), v5    # Store words from v2[i] to address x5+v5[i]
                           # and words from v3[i] to address x5+v5[i]+4
```

8. Vector AMO Operations (Zvamo)

Profiles will dictate whether vector AMO operations are supported. The expectation is that the Unix profile will require vector AMO operations.

If vector AMO instructions are supported, then the scalar Zaamo instructions (atomic operations from the standard A extension) must be present.

Vector AMO operations are encoded using the unused width encodings under the standard AMO major opcode. Each active element performs an atomic read-modify-write of a single memory location.

Format for Vector AMO Instructions under AMO major opcode															
31	27	26	25	24	20	19	15	14	12	11	7	6	0		
amooop		wd	vm	vs2		rs1	width		vs3/vd		01011111			VAMO*	
5		1	1	5		5	3		5		7				

vs2[4:0] specifies v register holding address
vs3/vd[4:0] specifies v register holding source operand and destination

vm specifies vector mask
width[2:0] specifies size of memory elements, and distinguishes from scalar AMO
amooop[4:0] specifies the AMO operation
wd specifies whether the original memory value is written to vd (1=yes, 0=no)

AMOs have the same addressing mode as indexed operations except with no immediate offset. A vector of byte offsets in register vs2 are added to the scalar base register in rs1 to give the addresses of the AMO operations.

The vs2 vector register supplies the byte offset of each element, while the vs3 vector register supplies the source data for the atomic memory operation.

If the wd bit is set, the vd register is written with the initial value of the memory element. If the wd bit is clear, the vd register is not written.

When wd is clear, the memory system does not need to return the original memory value, and the original values in vd will be preserved.
The AMOs were defined to overwrite source data partly to reduce total memory pipeline read port count for implementations with register renaming. Also, to support the same addressing mode as vector indexed operations, and because vector AMOs are less likely to need results given that the primary use is parallel in-memory reductions.

Vector AMOs operate as if aq and r1 bits were zero on each element with regard to ordering relative to other instructions in the same hart.

Vector AMOs provide no ordering guarantee between element operations in the same vector AMO instruction.

Vector AMO width encoding				
	Width [2:0]	Mem bits	Reg bits	Opcode
Standard scalar AMO	010	32	XLEN	AMO*.W
Standard scalar AMO	011	64	XLEN	AMO*.D
Standard scalar AMO	100	128	XLEN	AMO*.Q
Vector AMO	110	32	v1*SEW	VAMO*W.V
Vector AMO	111	64	v1*SEW	VAMO*D.V
Vector AMO	000	128	v1*SEW	VAMO*Q.V

Mem bits is the size of element accessed in memory
Reg bits is the size of element accessed in register

The vector AMO width encoding flips the high bit of the corresponding scalar AMO width encoding. SEW must be at least as wide as the AMO memory element size, otherwise an illegal instruction exception is raised. If the AMO memory element width is less than SEW, the value returned from memory is sign-extended to fill SEW.

If SEW is less than XLEN, then addresses in the vector vs2 are sign-extended to XLEN. If SEW is greater than XLEN, an illegal instruction exception is raised.

Note, the AMO instruction encoding does not support arbitrary SEW-bit memory elements, only the standard 32-bit, 64-bit, 128-bit sizes required by the standard scalar base architecture.

The vector amoop[4:0] field uses the same encoding as the scalar 5-bit AMO instruction field, except that LR and SC are not supported.

amoop	opcode
00001	vamoswap
00000	vamoadd
00100	vamoxor
01100	vamoand
01000	vamoor
10000	vamomin
10100	vamomax
11000	vamominu
11100	vamomaxu

9. Vector Memory Alignment Constraints

If the elements accessed by a vector memory instruction are not naturally aligned to the memory element size, either an address misaligned exception is raised on that element or the element is transferred successfully.

Vector memory accesses follow the same rules for atomicity as scalar memory accesses.

10. Vector Memory Consistency Model

Vector memory instructions appear to execute in program order on the local hart. Vector memory instructions follow RVWMO at the instruction level, and element operations are ordered within the instruction as if performed by an element-ordered sequence of syntactically independent scalar instructions. Vector indexed-ordered stores write elements to memory in element order. Vector indexed-unordered stores do not preserve element order for writes within a single vector store instruction.

| Need to flesh out details.

11. Vector Arithmetic Instruction Formats

The vector arithmetic instructions use a new major opcode (OP-V = 1010111₂) which neighbors OP-FP. The three-bit funct3 field is used to define sub-categories of vector instructions.

Formats for Vector Arithmetic Instructions under OP-V major opcode

31	26	25	24	20	19	15	14	12	11	7	6	0	
funct6	vm		vs2		vs1	0	0	0		vd	1010111	OP-V	(OPIVV)
funct6	vm		vs2		vs1	0	0	1		vd	1010111	OP-V	(OPFVV)
funct6	vm		vs2		vs1	0	1	0		vd/rd	1010111	OP-V	(OPMVV)
funct6	vm		vs2		simm5	0	1	1		vd	1010111	OP-V	(OPIVI)
funct6	vm		vs2		rs1	1	0	0		vd	1010111	OP-V	(OPIVX)
funct6	vm		vs2		rs1	1	0	1		vd	1010111	OP-V	(OPFVF)
funct6	vm		vs2		rs1	1	1	0		vd/rd	1010111	OP-V	(OPMVX)
6	1		5		5		3		5		7		

11.1. Vector Arithmetic Instruction encoding

The funct3 field encodes the operand type and source locations.

funct3[2:0]	Operands	Source of scalar(s)
0 0 0	OPIVV	vector-vector
0 0 1	OPFVV	vector-vector
0 1 0	OPMVV	vector-vector
0 1 1	OPIVI	vector-immediate imm[4:0]
1 0 0	OPIVX	vector-scalar GPR x register rs1
1 0 1	OPFVF	vector-scalar FP f register rs1
1 1 0	OPMVX	vector-scalar GPR x register rs1
1 1 1	OPCFG	scalars-imms GPR x register rs1 & rs2/imm

Integer operations are performed using unsigned or two's-complement signed integer arithmetic depending on the opcode.

All standard vector floating-point arithmetic operations follow the IEEE-754/2008 standard. All vector floating-point operations use the dynamic rounding mode in the frm register.

Vector-vector operations take two vectors of operands from vector register groups specified by vs2 and vs1 respectively.

Vector-scalar operations can have three possible forms, but in all cases take one vector of operands from a vector register group specified by vs2 and a second scalar source operand from one of three alternative sources.

1. For integer operations, the scalar can be a 5-bit immediate encoded in the rs1 field. The value is sign- or zero-extended to SEW bits.
2. For integer operations, the scalar can be taken from the scalar x register specified by rs1. If XLEN>SEW, the least-significant bits of the x register are used. If XLEN<SEW, the value from the x register is sign-extended to SEW bits.
3. For floating-point operation, the scalar can be taken from a scalar f register. If FLEN>SEW, the least-significant bits of the 'f' register are used. If FLEN<SEW, the value is NaN-boxed (one-extended) to SEW.

The proposed Zfinx variants will take the floating-point scalar argument from the x registers.

Vector arithmetic instructions are masked under control of the `vm` field.

Assembly syntax pattern for vector binary arithmetic instructions

Operations returning vector results, masked by `vm` (`v0.t`, `<nothing>`)

`vop.vv vd, vs2, vs1, vm` # integer vector-vector `vd[i] = vs2[i] op vs1[i]`

`vop.vx vd, vs2, rs1, vm` # integer vector-scalar `vd[i] = vs2[i] op x[rs1]`

`vop.vi vd, vs2, imm, vm` # integer vector-immediate `vd[i] = vs2[i] op imm`

`vfop.vv vd, vs2, vs1, vm` # FP vector-vector operation `vd[i] = vs2[i] fop vs1[i]`

`vfop.vf vd, vs2, rs1, vm` # FP vector-scalar operation `vd[i] = vs2[i] fop f[rs1]`

In the encoding, `vs2` is the first operand, while `rs1/simm5` is the second operand. This is the opposite to the standard scalar ordering. This arrangement retains the existing encoding conventions that instructions that read only one scalar register, read it from `rs1`, and that 5-bit immediates are sourced from the `rs1` field.

Assembly syntax pattern for vector ternary arithmetic instructions (multiply-add)

Integer operations overwriting third source

`vop.vv vd, vs1, vs2, vm` # `vd[i] = vs1[i]*vs2[i] + vd[i]`

`vop.vx vd, rs1, vs2, vm` # `vd[i] = x[rs1]*vs2[i] + vd[i]`

Integer operations overwriting first source

`vop.vv vd, vs1, vs2, vm` # `vd[i] = vd[i]*vs1[i] + vs2[i]`

`vop.vx vd, rs1, vs2, vm` # `vd[i] = vd[i]*x[rs1] + vs2[i]`

Floating-point operations overwriting third source

`vfop.vv vd, vs1, vs2, vm` # `vd[i] = vs1[i]*vs2[i] + vd[i]`

`vfop.vf vd, rs1, vs2, vm` # `vd[i] = f[rs1]*vs2[i] + vd[i]`

Floating-point operations overwriting first source

`vfop.vv vd, vs1, vs2, vm` # `vd[i] = vd[i]*vs1[i] + vs2[i]`

`vfop.vf vd, rs1, vs2, vm` # `vd[i] = vd[i]*f[rs1] + vs2[i]`

For ternary multiply-add operations, the assembler syntax always places the destination vector register first, followed by either `rs1` or `vs1`, then `vs2`. This ordering provides a more natural reading of the assembler for these ternary operations, as the multiply operands are always next to each other.

11.2. Widening Vector Arithmetic Instructions

A few vector arithmetic instructions are defined to be *widening* operations where the destination elements are $2 \times \text{SEW}$ wide and are stored in a vector register group with twice the number of vector registers.

The first operand can be either single or double-width. These are generally written with a `vw*` prefix on the opcode or `vfw*` for vector floating-point operations.

Originally, a `w` suffix was used on opcode, but this could be confused with the use of a `w` suffix to mean word-sized operations in doubleword integers, so the `w` was moved to prefix.

The floating-point widening operations were changed to `vfw*` from `vwf*` to be more consistent with any scalar widening floating-point operations that will be written as `fw*`.

For integer multiply-add, another possible widening option increases the size of the accumulator to $4 \times \text{SEW}$ (i.e., $4 \times \text{SEW} \neq \text{SEW} \times \text{SEW}$). These would be distinguished by a `vw4*` prefix on the opcode. These are not included at this time, but are a possible addition to spec.

The destination vector register group results are arranged as if both `SEW` and `LMUL` were at twice their current settings (i.e., the destination element width is $2 \times \text{SEW}$, and the destination vector register group `LMUL`

is $2 \times \text{LMUL}$).

For all widening instructions, the destination element width must be a supported element width and the destination LMUL value must also be a supported LMUL value (≤ 8 , i.e., current LMUL must be ≤ 4), otherwise an illegal instruction exception is raised.

The destination vector register group must be specified using a vector register number that is valid for the destination's LMUL value, otherwise an illegal instruction exception is raised.

The destination vector register group cannot overlap a source vector register group (including the mask register if masked), otherwise an illegal instruction exception is raised.

┆ This constraint is necessary to support restart with non-zero `vstart`.

Assembly syntax pattern for vector widening arithmetic instructions

Double-width result, two single-width sources: $2 \times \text{SEW} = \text{SEW}$ op SEW

`vwop.vv vd, vs2, vs1, vm` # integer vector-vector `vd[i] = vs2[i] op vs1[i]`

`vwop.vx vd, vs2, rs1, vm` # integer vector-scalar `vd[i] = vs2[i] op x[rs1]`

Double-width result, first source double-width, second source single-width: $2 \times \text{SEW} = 2 \times \text{SEW}$

`vwop.wv vd, vs2, vs1, vm` # integer vector-vector `vd[i] = vs2[i] op vs1[i]`

`vwop.wx vd, vs2, rs1, vm` # integer vector-scalar `vd[i] = vs2[i] op x[rs1]`

11.3. Narrowing Vector Arithmetic Instructions

A few instructions are provided to convert double-width source vectors into single-width destination vectors. These instructions convert a vector register group organized as if LMUL and SEW were twice the current settings, and convert to a vector register group with the current LMUL/SEW vectors/elements.

If $(2 \times \text{LMUL} > 8)$, or $(2 \times \text{SEW}) > \text{ELEN}$, an illegal instruction exception is raised.

┆ An alternative design decision would have been to treat LMUL as defining the size of the source vector register group. The choice here is motivated by the belief the chosen approach will require fewer LMUL changes.

The source and destination vector register groups have to be specified with a vector register number that is legal for the source and destination LMUL value respectively, otherwise an illegal instruction exception is raised.

Where there is a second source vector, this has the same (narrower) width as the result.

A `vn*` prefix on the opcode is used to distinguish these instructions in the assembler, or a `vfn*` prefix for narrowing floating-point opcodes.

┆ Comparison operations that set a mask register are also implicitly a narrowing operation.

12. Vector Integer Arithmetic Instructions

A set of vector integer arithmetic instructions are provided.

12.1. Vector Single-Width Integer Add and Subtract

Vector integer add and subtract are provided. Reverse-subtract instructions are also provided for the vector-scalar forms.

```
# Integer adds.
vadd.vv vd, vs2, vs1, vm    # Vector-vector
vadd.vx vd, vs2, rs1, vm    # vector-scalar
vadd.vi vd, vs2, imm, vm    # vector-immediate

# Integer subtract
vsub.vv vd, vs2, vs1, vm    # Vector-vector
vsub.vx vd, vs2, rs1, vm    # vector-scalar

# Integer reverse subtract
vrsb.vx vd, vs2, rs1, vm    # vd[i] = rs1 - vs2[i]
vrsb.vi vd, vs2, imm, vm    # vd[i] = imm - vs2[i]
```

12.2. Vector Widening Integer Add/Subtract

The widening add/subtract instructions are provided in both signed and unsigned variants, depending on whether the narrower source operands are first sign- or zero-extended before forming the double-width sum.

```
# Widening unsigned integer add/subtract, 2*SEW = SEW +/- SEW
vwaddu.vv vd, vs2, vs1, vm  # vector-vector
vwaddu.vx vd, vs2, rs1, vm  # vector-scalar
vwsubu.vv vd, vs2, vs1, vm  # vector-vector
vwsubu.vx vd, vs2, rs1, vm  # vector-scalar

# Widening signed integer add/subtract, 2*SEW = SEW +/- SEW
vwadd.vv vd, vs2, vs1, vm   # vector-vector
vwadd.vx vd, vs2, rs1, vm   # vector-scalar
vwsub.vv vd, vs2, vs1, vm   # vector-vector
vwsub.vx vd, vs2, rs1, vm   # vector-scalar

# Widening unsigned integer add/subtract, 2*SEW = 2*SEW +/- SEW
vwaddu.wv vd, vs2, vs1, vm  # vector-vector
vwaddu.wx vd, vs2, rs1, vm  # vector-scalar
vwsubu.wv vd, vs2, vs1, vm  # vector-vector
vwsubu.wx vd, vs2, rs1, vm  # vector-scalar

# Widening signed integer add/subtract, 2*SEW = 2*SEW +/- SEW
vwadd.wv vd, vs2, vs1, vm   # vector-vector
vwadd.wx vd, vs2, rs1, vm   # vector-scalar
vwsub.wv vd, vs2, vs1, vm   # vector-vector
vwsub.wx vd, vs2, rs1, vm   # vector-scalar
```

An integer value can be doubled in width using the widening add instructions with a scalar operand of `x0`. Can define assembly pseudoinstructions `vwcvtt.x.x.v vd,vs,vm = vwadd.vx vd,vs,x0,vm` and `vwcvttu.x.x.v vd,vs,vm = vwaddu.vx vd,vs,x0,vm`.

12.3. Vector Integer Add-with-Carry / Subtract-with-Borrow Instructions

To support multi-word arithmetic:

```
# vd[i] = vs1[i] + vs2[i] + v0[i].LSB
# v0[i] = carry(vs1[i] + vs2[i] + v0[i].LSB)

vadc.vv  vd, vs2, vs1 # Vector-vector
vadc.vx  vd, vs2, rs1 # Vector-scalar
vadc.vi  vd, vs2, imm # Vector-scalar
```

This instruction is encoded as an unmasked instruction ($vm=1$) and operates on all body elements. The instruction adds the two source operands and also adds in the LSB of the implicit mask register $v0$ as an implicit carry input. The sum is stored in the destination vector register group. The mask element in $v0$ is written with the carry result in the LSB and the upper bits of the mask element are set to 0.

The subtract with carry instruction $vsbc$ performs the equivalent function to support long word arithmetic for subtraction.

```
# vd[i] = vs1[i] - vs2[i] - v0[i].LSB
# v0[i] = carry(vs1[i] - vs2[i] - v0[i].LSB)

vsbc.vv  vd, vs2, vs1 # Vector-vector
vsbc.vx  vd, vs2, rs1 # Vector-scalar
```

The encodings corresponding to the masked versions ($vm=0$) of $vadc$ and $vsbc$ are reserved.

12.4. Vector Bitwise Logical Instructions

```
# Bitwise logical operations.
vand.vv vd, vs2, vs1, vm # Vector-vector
vand.vx vd, vs2, rs1, vm # vector-scalar
vand.vi vd, vs2, imm, vm # vector-immediate

vor.vv vd, vs2, vs1, vm # Vector-vector
vor.vx vd, vs2, rs1, vm # vector-scalar
vor.vi vd, vs2, imm, vm # vector-immediate

vxor.vv vd, vs2, vs1, vm # Vector-vector
vxor.vx vd, vs2, rs1, vm # vector-scalar
vxor.vi vd, vs2, imm, vm # vector-immediate
```

With an immediate of -1, scalar-immediate forms of the $vxor$ instruction provide a bitwise NOT operation. This can be provided as an assembler pseudoinstruction `vnot.v`.

12.5. Vector Single-Width Bit Shift Instructions

A full complement of vector shift instructions are provided, including logical shift left, and logical (zero-extending) and arithmetic (sign-extending) shift right.

```

# Bit shift operations
vsll.vv vd, vs2, vs1, vm    # Vector-vector
vsll.vx vd, vs2, rs1, vm    # vector-scalar
vsll.vi vd, vs2, imm, vm    # vector-immediate

vsrl.vv vd, vs2, vs1, vm    # Vector-vector
vsrl.vx vd, vs2, rs1, vm    # vector-scalar
vsrl.vi vd, vs2, imm, vm    # vector-immediate

vsra.vv vd, vs2, vs1, vm    # Vector-vector
vsra.vx vd, vs2, rs1, vm    # vector-scalar
vsra.vi vd, vs2, imm, vm    # vector-immediate

```

Only the low $\lg 2(\text{SEW})$ bits are read to obtain the shift amount.

The immediate is treated as an unsigned shift amount, with a maximum shift amount of 31.

12.6. Vector Narrowing Integer Right Shift Instructions

The narrowing right shifts extract a smaller field from a wider operand and have both zero-extending (srl) and sign-extending (sra) forms. The shift amount can come from a vector or a scalar x register or a 5-bit immediate. The low $\lg 2(2 * \text{SEW})$ bits of the vector or scalar shift amount value are used (e.g., the low 6 bits for a SEW=64-bit to SEW=32-bit narrowing operation). The immediate form supports shift amounts up to 31 only and is effectively zero-extended for SEW of > 32 .

```

# Narrowing shift right logical, SEW = (2*SEW) >> SEW
vnsrl.vv vd, vs2, vs1, vm    # vector-vector
vnsrl.vx vd, vs2, rs1, vm    # vector-scalar
vnsrl.vi vd, vs2, imm, vm    # vector-immediate

# Narrowing shift right arithmetic, SEW = (2*SEW) >> SEW
vnsra.vv vd, vs2, vs1, vm    # vector-vector
vnsra.vx vd, vs2, rs1, vm    # vector-scalar
vnsra.vi vd, vs2, imm, vm    # vector-immediate

```

It could be useful to add support for n4 variants, where the destination is 1/4 width of source.

12.7. Vector Integer Comparison Instructions

The following integer compare instructions write 1 to the destination mask register element if the comparison evaluates to true, and 0 otherwise. The destination mask vector is always held in a single vector register, with a layout of elements as described in Section Mask Register Layout.

```

# Set if equal
vseq.vv vd, vs2, vs1, vm    # Vector-vector
vseq.vx vd, vs2, rs1, vm    # vector-scalar
vseq.vi vd, vs2, imm, vm    # vector-immediate

# Set if not equal
vsne.vv vd, vs2, vs1, vm    # Vector-vector
vsne.vx vd, vs2, rs1, vm    # vector-scalar
vsne.vi vd, vs2, imm, vm    # vector-immediate

# Set if less than, unsigned
vsltu.vv vd, vs2, vs1, vm    # Vector-vector
vsltu.vx vd, vs2, rs1, vm    # Vector-scalar

# Set if less than, signed
vslt.vv vd, vs2, vs1, vm    # Vector-vector
vslt.vx vd, vs2, rs1, vm    # vector-scalar

# Set if less than or equal, unsigned
vsleu.vv vd, vs2, vs1, vm    # Vector-vector
vsleu.vx vd, vs2, rs1, vm    # vector-scalar
vsleu.vi vd, vs2, imm, vm    # Vector-immediate

# Set if less than or equal, signed
vsle.vv vd, vs2, vs1, vm    # Vector-vector
vsle.vx vd, vs2, rs1, vm    # vector-scalar
vsle.vi vd, vs2, imm, vm    # vector-immediate

# Set if greater than, unsigned
vsgtu.vx vd, vs2, rs1, vm    # Vector-scalar
vsgtu.vi vd, vs2, imm, vm    # Vector-immediate

# Set if greater than, signed
vsgt.vx vd, vs2, rs1, vm    # Vector-scalar
vsgt.vi vd, vs2, imm, vm    # Vector-immediate

# Following two instructions are not provided directly
# Set if greater than or equal, unsigned
# vsgeu.vx vd, vs2, rs1, vm    # Vector-scalar
# Set if greater than or equal, signed
# vsge.vx vd, vs2, rs1, vm    # Vector-scalar

```

The following table indicates how all comparisons are implemented in native machine code.

Comparison	Assembler Mapping	Assembler Pseudoinstruction
<code>va < vb</code>	<code>vslt{u}.vv vd, va, vb, vm</code>	
<code>va <= vb</code>	<code>vsle{u}.vv vd, va, vb, vm</code>	
<code>va > vb</code>	<code>vslt{u}.vv vd, vb, va, vm</code>	<code>vsgt{u}.vv vd, va, vb, vm</code>
<code>va >= vb</code>	<code>vsle{u}.vv vd, vb, va, vm</code>	<code>vsge{u}.vv vd, va, vb, vm</code>
<code>va < x</code>	<code>vslt{u}.vx vd, va, x, vm</code>	
<code>va <= x</code>	<code>vsle{u}.vx vd, va, x, vm</code>	
<code>va > x</code>	<code>vsgt{u}.vx vd, va, x, vm</code>	
<code>va >= x</code>	see below	
<code>va < i</code>	<code>vsle{u}.vi vd, va, i-1, vm</code>	<code>vslt{u}.vi vd, va, i, vm</code>
<code>va <= i</code>	<code>vsle{u}.vi vd, va, i, vm</code>	
<code>va > i</code>	<code>vsgt{u}.vi vd, va, i, vm</code>	
<code>va >= i</code>	<code>vsgt{u}.vi vd, va, i-1, vm</code>	<code>vsge{u}.vi vd, va, i, vm</code>
<code>va, vb</code> vector register groups		
<code>x</code> scalar integer register		
<code>i</code> immediate		

The immediate forms of `vslt{u}.vi` are not provided as the immediate value can be decreased by 1 and the `vsle{u}.vi` variants used instead. The `vsle.vi` range is -16 to 15, resulting in an effective `vslt.vi` range of -15 to 16. The `vsleu.vi` range is 0 to 15 (and $(\sim 0) - 15$ to ~ 0), giving an effective `vsltu.vi` range of 1 to 16 (Note, `vsltu.vi` with immediate 0 is not useful as it is always false). Similarly, `vsge{u}.vi` is not provided and the comparison is implemented using `vsgt{u}.vi` with the immediate decremented by one. The resulting effective `vsge.vi` range is -15 to 16, and the resulting effective `vsgeu.vi` range is 1 to 16 (Note, `vsgeu.vi` with immediate 0 is not useful as it is always true).

The `vsgt` forms for register scalar and immediates are provided to allow a single comparison instruction to provide the correct polarity of mask value without using additional mask logical instructions.

To reduce encoding space, the `vsge{u}.vx` form is not directly provided, and so the `va ≥ x` case requires special treatment.

The `vsge{u}.vx` could potentially be encoded in a non-orthogonal way under the unused OPIVI variant of `vslt{u}`. These would be the only instructions in OPIVI that use a scalar `x` register however. Alternatively, a further two funct6 encodings could be used, but these would have a different operand format (writes to mask register) than others in the same group of 8 funct6 encodings. The current PoR is to omit these instructions and to synthesize where needed as described below.

The `vsge{u}.vx` operation can be synthesized by reducing the value of `x` by 1 and using the `vsgt{u}.vx` instruction, when it is known that this will not underflow the representation in `x`.

Sequences to synthesize `vsge{u}.vx` instruction

`va >= x, x > minimum`

```
addi t0, x, -1; vsgt{u}.vx vd, va, t0, vm
```

The above sequence will usually be the most efficient implementation, but assembler pseudoinstructions can be provided for cases where the range of `x` is unknown.

unmasked `va >= x`

```
pseudoinstruction: vsge{u}.vx vd, va, x
expansion: vslt{u}.vx vd, va, x; vmnand.mm vd, vd, vd
```

masked `va >= x, vd != v0`

```
pseudoinstruction: vsge{u}.vx vd, va, x, v0.t
expansion: vslt{u}.vx vd, va, x, v0.t; vmxor.mm vd, vd, v0
```

masked `va >= x, any vd`

```
pseudoinstruction: vsge{u}.vx vd, va, x, v0.t, vt
expansion: vslt{u}.vx vt, va, x; vmmandnot.mm vd, vd, vt
```

The `vt` argument to the pseudoinstruction must name a temporary vector register that is not same as `vd` and which will be clobbered by the pseudoinstruction

Comparisons effectively AND in the mask, e.g,

```
# (a < b) && (b < c) in two instructions
vslt.vv    v0, va, vb          # All body elements written
vslt.vv    v0, vb, vc, v0.t    # Only update at set mask
```

12.8. Vector Integer Min/Max Instructions

Signed and unsigned integer minimum and maximum instructions are supported.

```
# Unsigned minimum
vminu.vv vd, vs2, vs1, vm    # Vector-vector
vminu.vx vd, vs2, rs1, vm    # vector-scalar

# Signed minimum
vmin.vv vd, vs2, vs1, vm    # Vector-vector
vmin.vx vd, vs2, rs1, vm    # vector-scalar

# Unsigned maximum
vmaxu.vv vd, vs2, vs1, vm    # Vector-vector
vmaxu.vx vd, vs2, rs1, vm    # vector-scalar

# Signed maximum
vmax.vv vd, vs2, vs1, vm    # Vector-vector
vmax.vx vd, vs2, rs1, vm    # vector-scalar
```

12.9. Vector Single-Width Integer Multiply Instructions

The single-width multiply instructions perform a SEW-bit*SEW-bit multiply and return an SEW-bit-wide result. The **mulh** versions write the high word of the product to the destination register.

```

# Signed multiply, returning low bits of product
vmul.vv vd, vs2, vs1, vm    # Vector-vector
vmul.vx vd, vs2, rs1, vm    # vector-scalar

# Signed multiply, returning high bits of product
vmulh.vv vd, vs2, vs1, vm    # Vector-vector
vmulh.vx vd, vs2, rs1, vm    # vector-scalar

# Unsigned multiply, returning high bits of product
vmulhu.vv vd, vs2, vs1, vm    # Vector-vector
vmulhu.vx vd, vs2, rs1, vm    # vector-scalar

# Signed(vs2)-Unsigned multiply, returning high bits of product
vmulhsu.vv vd, vs2, vs1, vm    # Vector-vector
vmulhsu.vx vd, vs2, rs1, vm    # vector-scalar

```

There is no vmulhus opcode to return high half of unsigned-vector * signed-scalar product.

The current vmulh* opcodes perform simple fractional multiplies, but with no option to scale, round, and/or saturate the result. Can consider changing definition of vmulh, vmulhu, vmulhsu to use vxrm rounding mode when discarding low half of product. There is no possibility of overflow in this case.

12.10. Vector Widening Integer Multiply Instructions

The widening integer multiply instructions return the full 2*SEW-bit product from an SEW-bit*SEW-bit multiply.

```

# Widening signed-integer multiply
vwmul.vv vd, vs2, vs1, vm    # vector-vector
vwmul.vx vd, vs2, rs1, vm    # vector-scalar

# Widening unsigned-integer multiply
vwmulu.vv vd, vs2, vs1, vm    # vector-vector
vwmulu.vx vd, vs2, rs1, vm    # vector-scalar

# Widening signed-unsigned integer multiply
vwmulsu.vv vd, vs2, vs1, vm    # vector-vector
vwmulsu.vx vd, vs2, rs1, vm    # vector-scalar

```

12.11. Vector Single-Width Integer Multiply-Add Instructions

The integer multiply-add instructions are destructive and are provided in two forms, one that overwrites the addend or minuend (vmacc,vmsac) and one that overwrites the first multiplicand (vmadd,vmsub).

The low half of the product is added or subtracted from the third operand.

"sac" is intended to be read as "subtract from accumulator".

```

# Integer multiply-add, overwrite addend
vmacc.vv vd, vs1, vs2, vm    # vd[i] = +(vs1[i] * vs2[i]) + vd[i]
vmacc.vx vd, rs1, vs2, vm    # vd[i] = +(x[rs1] * vs2[i]) + vd[i]

# Integer multiply-sub, overwrite minuend
vmsac.vv vd, vs1, vs2, vm    # vd[i] = -(vs1[i] * vs2[i]) + vd[i]
vmsac.vx vd, rs1, vs2, vm    # vd[i] = -(x[rs1] * vs2[i]) + vd[i]

# Integer multiply-add, overwrite multiplicand
vmadd.vv vd, vs1, vs2, vm    # vd[i] = (vd[i] * vs1[i]) + vs2[i]
vmadd.vx vd, rs1, vs2, vm    # vd[i] = (vd[i] * x[rs1]) + vs2[i]

# Integer multiply-sub, overwrite multiplicand
vmsub.vv vd, vs1, vs2, vm    # vd[i] = (vd[i] * vs1[i]) - vs2[i]
vmsub.vx vd, rs1, vs2, vm    # vd[i] = (vd[i] * x[rs1]) - vs2[i]

```

12.12. Vector Widening Integer Multiply-Add Instructions

The widening integer multiply-add instructions add (subtract) a SEW-bit*SEW-bit multiply result to (from) a 2*SEW-bit value and produce a 2*SEW-bit result.

```

# Widening unsigned-integer multiply-add, overwrite addend
vmaccu.vv vd, vs1, vs2, vm    # vd[i] = +(vs1[i] * vs2[i]) + vd[i]
vmaccu.vx vd, rs1, vs2, vm    # vd[i] = +(x[rs1] * vs2[i]) + vd[i]

# Widening signed-integer multiply-add, overwrite addend
vmacc.vv vd, vs1, vs2, vm    # vd[i] = +(vs1[i] * vs2[i]) + vd[i]
vmacc.vx vd, rs1, vs2, vm    # vd[i] = +(x[rs1] * vs2[i]) + vd[i]

# Widening unsigned-integer multiply-sub, overwrite minuend
vwmsacu.vv vd, vs1, vs2, vm    # vd[i] = -(vs1[i] * vs2[i]) + vd[i]
vwmsacu.vx vd, rs1, vs2, vm    # vd[i] = -(x[rs1] * vs2[i]) + vd[i]

# Widening signed-integer multiply-sub, overwrite minuend
vwmsac.vv vd, vs1, vs2, vm    # vd[i] = -(vs1[i] * vs2[i]) + vd[i]
vwmsac.vx vd, rs1, vs2, vm    # vd[i] = -(x[rs1] * vs2[i]) + vd[i]

```

There is no signed-unsigned widening multiply-add instruction.

12.12.1. Vector Integer Divide Instructions

The divide and remainder instructions are equivalent to the RISC-V standard scalar integer multiply/divides, with the same results for extreme inputs.

```

# Unsigned divide.
vdivu.vv vd, vs2, vs1, vm    # Vector-vector
vdivu.vx vd, vs2, rs1, vm    # vector-scalar

# Signed divide
vdiv.vv vd, vs2, vs1, vm    # Vector-vector
vdiv.vx vd, vs2, rs1, vm    # vector-scalar

# Unsigned remainder
vremu.vv vd, vs2, vs1, vm    # Vector-vector
vremu.vx vd, vs2, rs1, vm    # vector-scalar

# Signed remainder
vrem.vv vd, vs2, vs1, vm    # Vector-vector
vrem.vx vd, vs2, rs1, vm    # vector-scalar

```

The decision to include integer divide and remainder was contentious. The argument in favor is that without a standard instruction, software would have to pick some algorithm to perform the operation, which would likely perform poorly on some microarchitectures versus others.

There is no instruction to perform a "scalar divide by vector" operation.

12.13. Vector Integer Merge Instruction

The vector integer merge instruction combines two source operands based on the mask field. Unlike regular arithmetic instructions, the merge operates on all body elements (i.e., the set of elements from `vstart` up to the current vector length in `v1`).

When the operation is masked (`vm=0`), the instructions combine two sources as follows. At elements where the mask value is zero, the first operand is copied to the destination element, otherwise the second operand is copied to the destination element. The first operand is always a vector register group specified by `vs2`. The second operand is a vector register group specified by `vs1` or a scalar `x` register specified by `rs1` or a 5-bit sign-extended immediate.

```

# Masked operations, where vm=0
vmerge.vv vd, vs2, vs1, v0.t # vd[i] = v0[i].LSB ? vs1[i] : vs2[i]
vmerge.vx vd, vs2, rs1, v0.t # vd[i] = v0[i].LSB ? x[rs1] : vs2[i]
vmerge.vi vd, vs2, imm, v0.t # vd[i] = v0[i].LSB ? imm : vs2[i]

```

When the operation is unmasked (`vm=1`), the instructions copies the second operand to the first `v1` locations of the destination vector. The first operand specifier (`vs2`) in the instruction encoding must contain `v0`, and any other vector register number in `vs2` is *reserved*.

Microarchitectures can recognize this form to avoid unnecessary vector register file accesses from the first vector operand.

```

# Unmasked operations, where vm=1
vmerge.vv vd, v0, vs1 # vd[i] = vs1[i], pseudoinstruction vmv.v.v vd, vs1
vmerge.vx vd, v0, rs1 # vd[i] = x[rs1], pseudoinstruction vmv.v.x vd, rs1
vmerge.vi vd, v0, imm # vd[i] = imm, pseudoinstruction vmv.v.i vd, imm

```

An unmasked `vmerge.vv` instruction can be used to copy one vector register group to another. This is given a vector pseudoinstruction `vmv.v.v vdest, vsrc` (which expands to `vmerge.vv vdest, v0, vsrc`).

An unmasked `vmerge.vx` instruction can be used to *splat* a scalar `x` register value into all active elements of a vector. This is given a vector pseudoinstruction `vmv.v.x vd, rs1`, which expands to `vmerge.vx vd, v0, rs1`.

An unmasked `vmerge.vi` instruction can be used to initialize a vector register group with an immediate value. This is given a vector pseudoinstruction `vmv.v.i vd, imm`.

Mask values can be widened into SEW-width elements using a sequence `vmv.v.i vd, 0; vmerge.vi vd, vd, 1, v0.t`.

13. Vector Fixed-Point Arithmetic Instructions

A set of vector arithmetic instructions are provided to support fixed-point arithmetic.

An N-bit element can hold two's-complement signed integers in the range $-2^{N-1} \dots +2^{N-1}-1$, and unsigned integers in the range $0 \dots +2^N-1$. The fixed-point instructions help preserve precision in narrow operands by supporting scaling and rounding, and can handle overflow by saturating results into the destination format range.

| The widening integer operations described above can also be used to remove the possibility of overflow.

13.1. Vector Single-Width Saturating Add and Subtract

Saturating forms of integer add and subtract are provided, for both signed and unsigned integers. If the result would overflow the destination, the result is replaced with the closest representable value, and the vxsat bit is set.

```
# Saturating adds of unsigned integers.
vsaddu.vv vd, vs2, vs1, vm    # Vector-vector
vsaddu.vx vd, vs2, rs1, vm    # vector-scalar
vsaddu.vi vd, vs2, imm, vm    # vector-immediate

# Saturating adds of signed integers.
vsadd.vv vd, vs2, vs1, vm    # Vector-vector
vsadd.vx vd, vs2, rs1, vm    # vector-scalar
vsadd.vi vd, vs2, imm, vm    # vector-immediate

# Saturating subtract of unsigned integers.
vssubu.vv vd, vs2, vs1, vm    # Vector-vector
vssubu.vx vd, vs2, rs1, vm    # vector-scalar

# Saturating subtract of signed integers.
vssub.vv vd, vs2, vs1, vm    # Vector-vector
vssub.vx vd, vs2, rs1, vm    # vector-scalar
```

13.2. Vector Single-Width Averaging Add and Subtract

The averaging add and subtract instructions right shift the result by one bit and round off the result according to the setting in vxrm. There can be no overflow in the result.

```

# For vxrm=rnu, round = 1

# Averaging add
# result = (src1 + src2 + round) >> 1;

# Averaging adds of integers.
vaadd.vv vd, vs2, vs1, vm # Vector-vector
vaadd.vx vd, vs2, rs1, vm # vector-scalar
vaadd.vi vd, vs2, imm, vm # vector-immediate

# Averaging subtract
# result = (src1 - src2 + round) >> 1;

# Averaging subtract of integers.
vasub.vv vd, vs2, vs1, vm # Vector-vector
vasub.vx vd, vs2, rs1, vm # vector-scalar

```

13.3. Vector Single-Width Fractional Multiply with Rounding and Saturation

The signed fractional multiply instruction produces a $2 \times \text{SEW}$ product of the two SEW inputs, then shifts the result right by $\text{SEW}-1$ bits, rounding these bits according to vxrm , then saturates the result to fit into SEW bits. If the result causes saturation, the `vxsat` bit is set.

```

# Signed saturating and rounding fractional multiply
vsmul.vv vd, vs2, vs1, vm # vd[i] = clip((vs2[i]*vs1[i]+round)>>(SEW-1))
vsmul.vx vd, vs2, rs1, vm # vd[i] = clip((vs2[i]*x[rs1]+round)>>(SEW-1))

```

When multiplying two N -bit signed numbers, the largest magnitude is obtained for $-2^{N-1} * -2^{N-1}$ producing a result $+2^{2N-2}$, which has a single (zero) sign bit when held in $2N$ bits. All other products have two sign bits in $2N$ bits. To retain greater precision in N result bits, the product is shifted right by one bit less than N , saturating the largest magnitude result but increasing result precision by one bit for all other products.

Considering adding vxrm -controlled rounding to `vmulhu`, `vmulhsu`, and `vmulh` to further support fixed-point. These would not have saturation.

13.4. Vector Widening Saturating Scaled Multiply-Add

The widening saturating scaled multiply-add instructions perform an $\text{SEW-bit} * \text{SEW-bit}$ multiply to yield a $2 \times \text{SEW-bit}$ product. The product is then right-shifted by $\text{SEW}/2$ bits with the shifted bits rounded off according to vxrm , and the rounded product is added to a $2 \times \text{SEW-bit}$ destination accumulator, with saturation if the result would overflow the destination accumulator. The `vxsat` bit is set if any overflow occurs.

SEW	Product Width	Rounded Product	Accumulator	Guard Bits
8	16	12	16	4
16	32	24	32	8
32	64	48	64	16

```

# Widening unsigned-integer scaled multiply-accumulate
vwsmaccu.vv vd, vs1, vs2, vm # vd[i] = clipu((+(vs1[i]*vs2[i]+round)>>SEW/2)+vd[i])
vwsmaccu.vx vd, rs1, vs2, vm # vd[i] = clipu((+(x[rs1]*vs2[i]+round)>>SEW/2)+vd[i])

# Widening signed-integer scaled multiply-accumulate
vwsmacc.vv vd, vs1, vs2, vm # vd[i] = clipu((+(vs1[i]*vs2[i]+round)>>SEW/2)+vd[i])
vwsmacc.vx vd, rs1, vs2, vm # vd[i] = clipu((+(x[rs1]*vs2[i]+round)>>SEW/2)+vd[i])

# Widening unsigned-integer scaled multiply-subtract
vwmsacu.vv vd, vs1, vs2, vm # vd[i] = clipu(-(vs1[i]*vs2[i]+round)>>SEW/2)+vd[i])
vwmsacu.vx vd, rs1, vs2, vm # vd[i] = clipu(-(x[rs1]*vs2[i]+round)>>SEW/2)+vd[i])

# Widening signed-integer scaled multiply-subtract
vwmsac.vv vd, vs1, vs2, vm # vd[i] = clipu(-(vs1[i]*vs2[i]+round)>>SEW/2)+vd[i])
vwmsac.vx vd, rs1, vs2, vm # vd[i] = clipu(-(x[rs1]*vs2[i]+round)>>SEW/2)+vd[i])

# For vxrm=rnu, round = ( 1 << (SEW/2-1))

```

┆ An arbitrary scaling/shift amount would be more flexible but would require a fourth source operand.

13.5. Vector Single-Width Scaling Shift Instructions

These instructions shift the input value right, and round off the shifted out bits according to vxrm. The scaling right shifts have both zero-extending (vssrl) and sign-extending (vssra) forms. The shift amount can come from a vector or a scalar x register or a 5-bit immediate. The low lg2(2*SEW) bits of the vector or scalar shift amount value are used (e.g., the low 6 bits for a SEW=64-bit to SEW=32-bit narrowing operation). The immediate form supports shift amounts up to 31 only and is effectively zero-extended for SEW of > 32.

```

# For vxrm=rnu, round = 1 << (src2-1)
# Scaling shift right logical
vssrl.vv vd, vs2, vs1, vm # vd[i] = ((vs2[i] + round)>>vs1[i])
vssrl.vx vd, vs2, rs1, vm # vd[i] = ((vs2[i] + round)>>x[rs1])
vssrl.vi vd, vs2, imm, vm # vd[i] = ((vs2[i] + round)>>imm)

# Scaling shift right arithmetic
vssra.vv vd, vs2, vs1, vm # vd[i] = ((vs2[i] + round)>>vs1[i])
vssra.vx vd, vs2, rs1, vm # vd[i] = ((vs2[i] + round)>>x[rs1])
vssra.vi vd, vs2, imm, vm # vd[i] = ((vs2[i] + round)>>imm)

```

13.6. Vector Narrowing Fixed-Point Clip Instructions

The vnclip instructions are used to pack a fixed-point value into a narrower destination. The instructions support rounding, scaling, and saturation into the final destination format.

```

# Narrowing unsigned clip
vnclipu.vv vd, vs2, vs1, vm # vector-vector
vnclipu.vx vd, vs2, rs1, vm # vector-scalar
vnclipu.vi vd, vs2, imm, vm # vector-immediate

# Narrowing signed clip, vd[i] = clip(round(vs2[i] + rnd) >> vs1[i])
#                               SEW          2*SEW          SEW
vnclip.vv vd, vs2, vs1, vm # vector-vector
vnclip.vx vd, vs2, rs1, vm # vector-scalar
vnclip.vi vd, vs2, imm, vm # vector-immediate

```

For `vncclipu/vncclip`, the rounding mode is specified in the `vxrm` CSR. Rounding occurs around the least-significant bit of the destination and before saturation.

For `vncclipu`, the shifted rounded source value is treated as an unsigned integer and saturates if the result would overflow the destination viewed as an unsigned integer.

For `vncclip`, the shifted rounded source value is treated as a signed integer and saturates if the result would overflow the destination viewed as a signed integer.

If any destination element is saturated, the `vxsat` bit is set in the `vxsat` register.

14. Vector Floating-Point Instructions

The standard vector floating-point instructions treat 16-bit, 32-bit, 64-bit, and 128-bit elements as IEEE-754/2008-compatible values. If the current SEW does not correspond to a supported IEEE floating-point type, an illegal instruction exception is raised.

The floating-point element widths that are supported depend on the platform.

Platforms supporting 16-bit half-precision floating-point values will also have to implement scalar half-precision floating-point support in the f registers.

The vector floating-point instructions have the same behavior as the scalar floating-point instructions with regard to NaNs.

Scalar values for vector-scalar operations can be sourced from the standard scalar f registers.

Scalar floating-point values will be sourced from the integer x registers in the proposed Zfinx variant.

14.1. Vector Floating-Point Exception Flags

A vector floating-point exception at any active floating-point element sets the standard FP exception flags in the fflags register. Inactive elements do not set FP exception flags.

14.2. Vector Single-Width Floating-Point Add/Subtract Instructions

```
# Floating-point add
vfadd.vv vd, vs2, vs1, vm    # Vector-vector
vfadd.vf vd, vs2, rs1, vm    # vector-scalar

# Floating-point subtract
vfsub.vv vd, vs2, vs1, vm    # Vector-vector
vfsub.vf vd, vs2, rs1, vm    # vector-scalar
```

14.3. Vector Widening Floating-Point Add/Subtract Instructions

```
# Widening FP add/subtract, 2*SEW = SEW +/- SEW
vfwadd.vv vd, vs2, vs1, vm    # vector-vector
vfwadd.vf vd, vs2, rs1, vm    # vector-scalar
vfwsb.vv vd, vs2, vs1, vm    # vector-vector
vfwsb.vf vd, vs2, rs1, vm    # vector-scalar

# Widening FP add/subtract, 2*SEW = 2*SEW +/- SEW
vfwadd.wv vd, vs2, vs1, vm    # vector-vector
vfwadd.wf vd, vs2, rs1, vm    # vector-scalar
vfwsb.wv vd, vs2, vs1, vm    # vector-vector
vfwsb.wf vd, vs2, rs1, vm    # vector-scalar
```

14.4. Vector Single-Width Floating-Point Multiply/Divide Instructions

```

# Floating-point multiply
vfmul.vv vd, vs2, vs1, vm # Vector-vector
vfmul.vf vd, vs2, rs1, vm # vector-scalar

# Floating-point divide
vfdiv.vv vd, vs2, vs1, vm # Vector-vector
vfdiv.vf vd, vs2, rs1, vm # vector-scalar

# Reverse floating-point divide vector = scalar / vector
vfrdiv.vf vd, vs2, rs1, vm # scalar-vector, vd[i] = f[rs1]/vs2[i]

```

14.5. Vector Widening Floating-Point Multiply

```

# Widening floating-point multiply
vfwmul.vv vd, vs2, vs1, vm # vector-vector
vfwmul.vf vd, vs2, rs1, vm # vector-scalar

```

14.6. Vector Single-Width Floating-Point Fused Multiply-Add Instructions

All four varieties of fused multiply-add are provided, and in two destructive forms that overwrite one of the operands, either the addend or the first multiplicand.

```

# FP multiply-accumulate, overwrites addend
vfmac.vv vd, vs1, vs2, vm # vd[i] = +(vs1[i] * vs2[i]) + vd[i]
vfmac.vf vd, rs1, vs2, vm # vd[i] = +(f[rs1] * vs2[i]) + vd[i]

# FP negate-(multiply-accumulate), overwrites subtrahend
vfnmac.vv vd, vs1, vs2, vm # vd[i] = -(vs1[i] * vs2[i]) - vd[i]
vfnmac.vf vd, rs1, vs2, vm # vd[i] = -(f[rs1] * vs2[i]) - vd[i]

# FP multiply-subtract-accumulator, overwrites subtrahend
vfmsac.vv vd, vs1, vs2, vm # vd[i] = +(vs1[i] * vs2[i]) - vd[i]
vfmsac.vf vd, rs1, vs2, vm # vd[i] = +(f[rs1] * vs2[i]) - vd[i]

# FP negate-(multiply-subtract-accumulator), overwrites minuend
vfnmsac.vv vd, vs1, vs2, vm # vd[i] = -(vs1[i] * vs2[i]) + vd[i]
vfnmsac.vf vd, rs1, vs2, vm # vd[i] = -(f[rs1] * vs2[i]) + vd[i]

# FP multiply-add, overwrites multiplicand
vfmad.vv vd, vs1, vs2, vm # vd[i] = +(vd[i] * vs1[i]) + vs2[i]
vfmad.vf vd, rs1, vs2, vm # vd[i] = +(vd[i] * f[rs1]) + vs2[i]

# FP negate-(multiply-add), overwrites multiplicand
vfnmad.vv vd, vs1, vs2, vm # vd[i] = -(vd[i] * vs1[i]) - vs2[i]
vfnmad.vf vd, rs1, vs2, vm # vd[i] = -(vd[i] * f[rs1]) - vs2[i]

# FP multiply-sub, overwrites multiplicand
vfmsub.vv vd, vs1, vs2, vm # vd[i] = +(vd[i] * vs1[i]) - vs2[i]
vfmsub.vf vd, rs1, vs2, vm # vd[i] = +(vd[i] * f[rs1]) - vs2[i]

# FP negate-(multiply-sub), overwrites multiplicand
vfnmsub.vv vd, vs1, vs2, vm # vd[i] = -(vd[i] * vs1[i]) + vs2[i]
vfnmsub.vf vd, rs1, vs2, vm # vd[i] = -(vd[i] * f[rs1]) + vs2[i]

```

It would be possible to use the two unused rounding modes in the scalar FP FMA encoding to provide a few non-destructive FMAs. However, this would be the only maskable operation with three inputs and separate output.

14.7. Vector Widening Floating-Point Fused Multiply-Add Instructions

The widening floating-point fused multiply-add instructions all overwrite the wide addend with the result. The multiplier inputs are all SEW wide, while the addend and destination is 2*SEW bits wide.

```
# FP widening multiply-accumulate, overwrites addend
vfwmac.vv vd, vs1, vs2, vm    # vd[i] = +(vs1[i] * vs2[i]) + vd[i]
vfwmac.vf vd, rs1, vs2, vm    # vd[i] = +(f[rs1] * vs2[i]) + vd[i]

# FP widening negate-(multiply-accumulate), overwrites addend
vfwmac.vv vd, vs1, vs2, vm    # vd[i] = -(vs1[i] * vs2[i]) - vd[i]
vfwmac.vf vd, rs1, vs2, vm    # vd[i] = -(f[rs1] * vs2[i]) - vd[i]

# FP widening multiply-subtractor, overwrites addend
vfwmsac.vv vd, vs1, vs2, vm    # vd[i] = +(vs1[i] * vs2[i]) - vd[i]
vfwmsac.vf vd, rs1, vs2, vm    # vd[i] = +(f[rs1] * vs2[i]) - vd[i]

# FP widening negate-(multiply-subtractor), overwrites addend
vfwmsac.vv vd, vs1, vs2, vm    # vd[i] = -(vs1[i] * vs2[i]) + vd[i]
vfwmsac.vf vd, rs1, vs2, vm    # vd[i] = -(f[rs1] * vs2[i]) + vd[i]
```

14.8. Vector Floating-Point Square-Root Instruction

This is a unary vector-vector instruction.

```
# Floating-point square root
vfsqrt.v vd, vs2, vm    # Vector-vector square root
```

14.9. Vector Floating-Point MIN/MAX Instructions

The vector floating-point `vfmin` and `vfmax` instructions have the same behavior as the corresponding scalar floating-point instructions in version 2.2 of the RISC-V F/D/Q extension.

```
# Floating-point minimum
vfmin.vv vd, vs2, vs1, vm    # Vector-vector
vfmin.vf vd, vs2, rs1, vm    # vector-scalar

# Floating-point maximum
vfmax.vv vd, vs2, vs1, vm    # Vector-vector
vfmax.vf vd, vs2, rs1, vm    # vector-scalar
```

14.10. Vector Floating-Point Sign-Injection Instructions

Vector versions of the scalar sign-injection instructions. The result takes all bits except the sign bit from the vector `vs2` operands.

```
vfsgnj.vv vd, vs2, vs1, vm    # Vector-vector
vfsgnj.vf vd, vs2, rs1, vm    # vector-scalar

vfsgnjn.vv vd, vs2, vs1, vm    # Vector-vector
vfsgnjn.vf vd, vs2, rs1, vm    # vector-scalar

vfsgnjx.vv vd, vs2, vs1, vm    # Vector-vector
vfsgnjx.vf vd, vs2, rs1, vm    # vector-scalar
```

14.11. Vector Floating-Point Compare Instructions

These vector FP compare instructions compare two source operands and write the comparison result to a mask register. The destination mask vector is always held in a single vector register, with a layout of elements as described in Section Mask Register Layout.

The compare instructions follow the semantics of the scalar floating-point compare instructions.

```
# Compare equal
vfeq.vv vd, vs2, vs1, vm # Vector-vector
vfeq.vf vd, vs2, rs1, vm # vector-scalar

# Compare not equal
vfne.vv vd, vs2, vs1, vm # Vector-vector
vfne.vf vd, vs2, rs1, vm # vector-scalar

# Compare less than
vflt.vv vd, vs2, vs1, vm # Vector-vector
vflt.vf vd, vs2, rs1, vm # vector-scalar

# Compare less than or equal
vfle.vv vd, vs2, vs1, vm # Vector-vector
vfle.vf vd, vs2, rs1, vm # vector-scalar

# Compare greater than
vfgt.vf vd, vs2, rs1, vm # vector-scalar

# Compare greater than or equal
vfge.vf vd, vs2, rs1, vm # vector-scalar
```

Comparison	Assembler Mapping	Assembler pseudoinstruction
va < vb	vflt.vv vd, va, vb, vm	
va <= vb	vfle.vv vd, va, vb, vm	
va > vb	vflt.vv vd, vb, va, vm	vfgt.vv vd, va, vb, vm
va >= vb	vfle.vv vd, vb, va, vm	vfge.vv vd, va, vb, vm
va < f	vflt.vf vd, va, f, vm	
va <= f	vfle.vf vd, va, f, vm	
va > f	vfgt.vf vd, va, f, vm	
va >= f	vfge.vf vd, va, f, vm	

va, vb vector register groups
f scalar floating-point register

Providing all forms is necessary to correctly handle unordered comparisons for NaNs.

To help implement the C99 floating-point comparison functions, a vford instruction is added that sets a mask register if the arguments are ordered (i.e., neither argument is NaN).

```
# Are args ordered?
vford.vv vd, vs2, vs1, vm # Vector-vector
vford.vf vd, vs2, rs1, vm # Vector-scalar
```

```
# Example of implementing isgreater()
vford.vv v0, va, vb      # Only set where args are ordered,
vfgt.vv v0, va, vb, v0.t  # so only set flags on ordered values.
```

| Detailed NaN signaling conventions to be added.

14.12. Vector Floating-Point Classify Instruction

This is a unary vector-vector instruction that operates in the same way as the scalar classify instruction.

```
vfclass.v vd, vs2, vm    # Vector-vector
```

The 10-bit mask produced by this instruction is placed in the least-significant bits of the result elements. The instruction is only defined for SEW=16b and above, so the result will always fit in the destination elements.

14.13. Vector Floating-Point Merge Instruction

A vector-scalar floating-point merge instruction is provided, which operates on all body elements, from `vstart` up to the current vector length in `v1` regardless of mask value.

When the floating-point merge instruction is masked (`vm=0`), at elements where the mask value is zero, the first vector operand is copied to the destination element, otherwise a scalar floating-point register value is copied to the destination element.

```
vfmerge.vf vd, vs2, rs1, v0.t  # vd[i] = v0[i].LSB ? f[rs1] : vs2[i]
```

The unmasked form (`vm=1`) can be used to *splat* a scalar `f` register value into all active elements of a vector. The instruction must have the `vs2` field set to `v0`, with all other values for `vs2` reserved.

```
vfmerge.vf vd, v0, rs1  # vd[i] = f[rs1];
```

This is given a vector pseudoinstruction `vmv.v.f vd, rs1` which expands to `vfmerge.vf vd, v0, rs1`.

| In Zfinx systems, the instruction is identical to `vmerge.vx`.

14.14. Single-Width Floating-Point/Integer Type-Convert Instructions

Conversion operations are provided to convert to and from floating-point values and unsigned and signed integers, where both source and destination are SEW wide.

```
vfcv.t.xu.f.v vd, vs2, vm  # Convert float to unsigned integer.
vfcv.t.x.f.v  vd, vs2, vm  # Convert float to signed integer.

vfcv.t.f.xu.v vd, vs2, vm  # Convert unsigned integer to float.
vfcv.t.f.x.v  vd, vs2, vm  # Convert signed integer to float.
```

The conversions follow the same rules on exceptional conditions as the scalar conversion instructions. The conversions always use the dynamic rounding mode in `frm`.

14.15. Widening Floating-Point/Integer Type-Convert Instructions

A set of conversion instructions are provided to convert between narrower integer and floating-point datatypes to a type of twice the width.

<code>vfwcvt.xu.f.v</code>	<code>vd, vs2, vm</code>	# Convert float to double-width unsigned integer.
<code>vfwcvt.x.f.v</code>	<code>vd, vs2, vm</code>	# Convert float to double-width signed integer.
<code>vfwcvt.f.xu.v</code>	<code>vd, vs2, vm</code>	# Convert unsigned integer to double-width float.
<code>vfwcvt.f.x.v</code>	<code>vd, vs2, vm</code>	# Convert signed integer to double-width float.
<code>vfwcvt.f.f.v</code>	<code>vd, vs2, vm</code>	# Convert single-width float to double-width float.

| A double-width IEEE floating-point value can always represent a single-width integer exactly.

| A double-width IEEE floating-point value can always represent a single-width IEEE floating-point value exactly.

| A full set of floating-point widening conversions are not supported as single instructions, but any widening conversion can be implemented as several doubling steps with equivalent results and no additional exception flags raised.

14.16. Narrowing Floating-Point/Integer Type-Convert Instructions

A set of conversion instructions are provided to convert wider integer and floating-point datatypes to a type of half the width.

<code>vfncvt.xu.f.v</code>	<code>vd, vs2, vm</code>	# Convert double-width float to unsigned integer.
<code>vfncvt.x.f.v</code>	<code>vd, vs2, vm</code>	# Convert double-width float to signed integer.
<code>vfncvt.f.xu.v</code>	<code>vd, vs2, vm</code>	# Convert double-width unsigned integer to float.
<code>vfncvt.f.x.v</code>	<code>vd, vs2, vm</code>	# Convert double-width signed integer to float.
<code>vfncvt.f.f.v</code>	<code>vd, vs2, vm</code>	# Convert double-width float to single-width float.

| A full set of floating-point widening conversions are not supported as single instructions. Conversions can be implemented in several halving steps, with equivalently rounded results and with the same exception flags raised (possibly raised redundantly in multiple steps).

| An integer value can be halved in width using the narrowing integer shift instructions with a shift amount of 0.

15. Vector Reduction Operations

Vector reduction operations take a vector register group of elements and a scalar held in element 0 of a vector register, and perform a reduction using some binary operator, to produce a scalar result in element 0 of a vector register. The scalar input and output operands are held in element 0 of a single vector register, not a vector register group, so any vector register can be the scalar source or destination of a vector reduction regardless of LMUL setting.

Reductions read and write the scalar operand and result into element 0 of a vector register to avoid a loss of decoupling with the scalar processor, and to support future polymorphic use with future types not supported in the scalar unit.

Inactive elements are excluded from the reduction.

The other elements in the destination vector register ($0 < \text{index} < \text{VLEN}/\text{SEW}$) are zeroed.

If $v1=0$, no operation is performed and the destination register is not updated.

Traps on vector reduction instructions are always reported with a `vstart` of 0. Vector reduction operations raise an illegal instruction exception if `vstart` is non-zero.

The assembler syntax for a reduction operation is `vredop .vs`, where the `.vs` suffix denotes the first operand is a vector register group and the second operand is a scalar stored in element 0 of a vector register.

15.1. Vector Single-Width Integer Reduction Instructions

All operands and results of single-width reduction instructions have the same SEW width. Overflows wrap around on arithmetic sums.

```
# Simple reductions, where [*] denotes all active elements:
vredsum.vs  vd, vs2, vs1, vm  # vd[0] = sum( vs2[*] , vs1[0] )
vredmaxu.vs vd, vs2, vs1, vm  # vd[0] = maxu( vs2[*] , vs1[0] )
vredmax.vs  vd, vs2, vs1, vm  # vd[0] = max( vs2[*] , vs1[0] )
vredminu.vs vd, vs2, vs1, vm  # vd[0] = minu( vs2[*] , vs1[0] )
vredmin.vs  vd, vs2, vs1, vm  # vd[0] = min( vs2[*] , vs1[0] )
vredand.vs  vd, vs2, vs1, vm  # vd[0] = and( vs2[*] , vs1[0] )
vredor.vs   vd, vs2, vs1, vm  # vd[0] = or( vs2[*] , vs1[0] )
vredxor.vs  vd, vs2, vs1, vm  # vd[0] = xor( vs2[*] , vs1[0] )
```

15.2. Vector Widening Integer Reduction Instructions

The unsigned `vwredsumu.vs` instruction zero-extends the SEW-wide vector elements before summing them, then adds the $2*\text{SEW}$ -width scalar element, and stores the result in a $2*\text{SEW}$ -width scalar element.

The `vwredsum.vs` instruction sign-extends the SEW-wide vector elements before summing them.

```
# Unsigned sum reduction into double-width accumulator
vwredsumu.vs vd, vs2, vs1, vm  #  $2*\text{SEW} = \text{sum}(\text{SEW}) + 2*\text{SEW}$ 

# Signed sum reduction into double-width accumulator
vwredsum.vs  vd, vs2, vs1, vm  #  $2*\text{SEW} = \text{sum}(\text{SEW}) + 2*\text{SEW}$ 
```

15.3. Vector Single-Width Floating-Point Reduction Instructions

```
# Simple reductions.
vfredosum.vs vd, vs2, vs1, vm # Ordered sum
vfredsum.vs  vd, vs2, vs1, vm # Unordered sum
vfredmax.vs  vd, vs2, vs1, vm # Maximum value
vfredmin.vs  vd, vs2, vs1, vm # Minimum value
```

The `vfredosum` instruction must sum the floating-point values in element order, while the `vfredsum` is allowed to perform the reduction in any order, provided the final result corresponds to some sequential ordering of `v1-1` floating-point add operations.

- | The ordered reduction supports compiler autovectorization, while the unordered FP sum allows for faster implementations.
- | Floating-point max and min reductions should return the same final value and exception flags regardless of operation order.

15.4. Vector Widening Floating-Point Reduction Instructions

Widening forms of the sum reductions are provided that read and write a double-width reduction result.

```
# Simple reductions.
vfwredosum.vs vd, vs2, vs1, vm # Ordered reduce 2*SEW = sum(SEW) + 2*SEW
vfwredsum.vs  vd, vs2, vs1, vm # Unordered reduce 2*SEW = sum(SEW) + 2*SEW
```

The reduction of the SEW-width elements is performed as in the single-width reduction case, with the final SEW-width result promoted to 2*SEW bits before adding to the 2*SEW-width accumulator.

For the `vfwredsum.vs` instruction, implementations may optionally perform the reduction by first promoting elements to the wider (2*SEW) format.

- | The `vfwredosum.vs` instruction must round as if performed sequentially in the original format.

16. Vector Mask Instructions

Several instructions are provided to help operate on mask values held in a vector register.

16.1. Vector Mask-Register Logical Instructions

Vector mask-register logical operations operate on mask registers. The size of one element in a mask register is SEW/LMUL, so these instructions all operate on single vector registers regardless of the setting of the `vlmul` field in `vtype`. They do not change the value of `vlmul`.

As with other vector instructions, the elements with indices less than `vstart` are unchanged, and `vstart` is reset to zero after execution. Vector mask logical instructions are always unmasked so there are no inactive elements. Mask elements past `v1`, the tail elements, are zeroed.

<code>vmand.mm vd, vs2, vs1</code>	<code># vd = vs2 & vs1</code>
<code>vmnand.mm vd, vs2, vs1</code>	<code># vd = ~(vs2 & vs1)</code>
<code>vmandnot.mm vd, vs2, vs1</code>	<code># vd = vs2 & ~vs1</code>
<code>vmxor.mm vd, vs2, vs1</code>	<code># vd = vs2 ^ vs1</code>
<code>vmor.mm vd, vs2, vs1</code>	<code># vd = vs2 vs1</code>
<code>vmnor.mm vd, vs2, vs1</code>	<code># vd = ~(vs2 vs1)</code>
<code>vmornot.mm vd, vs2, vs1</code>	<code># vd = vs2 ~vs1</code>
<code>vmxnor.mm vd, vs2, vs1</code>	<code># vd = ~(vs2 ^ vs1)</code>

Several assembler pseudoinstructions are defined as shorthand for common uses of mask logical operations:

<code>vmmv.m vd, vs</code>	<code>=> vmand.mm vd, vs, vs</code>	<code># Move mask register</code>
<code>vmclr.m vd</code>	<code>=> vmxor.mm vd, vd, vd</code>	<code># Clear mask register</code>
<code>vmset.m vd</code>	<code>=> vmxnor.mm vd, vd, vd</code>	<code># Set mask register</code>
<code>vmnot.m vd, vs</code>	<code>=> vmnand.mm vd, vs, vs</code>	<code># Invert bits</code>

The set of eight mask logical instructions can generate any of the 16 possibly binary logical functions of the two input masks:

inputs		
0 0 1 1	<code>src1</code>	
0 1 0 1	<code>src2</code>	
output	instruction	pseudoinstruction
0 0 0 0	<code>vmxor.mm vd, vd, vd</code>	<code>vmclr.m vd</code>
1 0 0 0	<code>vmnor.mm vd, src1, src2</code>	
0 1 0 0	<code>vmandnot.mm vd, src2, src1</code>	
1 1 0 0	<code>vmnand.mm vd, src1, src1</code>	<code>vmnot.m vd, src1</code>
0 0 1 0	<code>vmandnot.mm vd, src1, src2</code>	
1 0 1 0	<code>vmnand.mm vd, src2, src2</code>	<code>vmnot.m vd, src2</code>
0 1 1 0	<code>vmxor.mm vd, src1, src2</code>	
1 1 1 0	<code>vmnand.mm vd, src1, src2</code>	
0 0 0 1	<code>vmand.mm vd, src1, src2</code>	
1 0 0 1	<code>vmxnor.mm vd, src1, src2</code>	
0 1 0 1	<code>vmand.mm vd, src2, src2</code>	<code>vmmv.m vd, src2</code>
1 1 0 1	<code>vmornot.mm vd, src2, src1</code>	
0 0 1 1	<code>vmand.mm vd, src1, src1</code>	<code>vmmv.m vd, src1</code>
1 0 1 1	<code>vmornot.mm vd, src1, src2</code>	
1 1 1 1	<code>vmxnor.mm vd, vd, vd</code>	<code>vmset.m vd</code>

The vector mask logical instructions are designed to be easily fused with a following masked vector operation to effectively expand the number of predicate registers by moving values into `v0` before use.

16.2. Vector mask population count `vmpopc`

```
vmpopc.m rd, vs2, vm
```

The source operand is a single vector register holding mask register values as described in Section Mask Register Layout.

The `vmpopc.m` instruction counts the number of mask elements of the active elements of the vector source mask register that have their least-significant bit set, and writes the result to a scalar x register.

The operation can be performed under a mask, in which case only the masked elements are counted.

```
vmpopc.m rd, vs2, v0.t # x[rd] = sum_i ( vs2[i].LSB && v0[i].LSB )
```

Traps on `vmpopc.m` are always reported with a `vstart` of 0. The `vmpopc` instruction will raise an illegal instruction exception if `vstart` is non-zero.

16.3. `vmfirst` find-first-set mask bit

```
vmfirst.m rd, vs2, vm
```

The `vmfirst` instruction finds the lowest-numbered active element of the source mask vector that has its LSB set and writes that element's index to a GPR. If no element has an LSB set, -1 is written to the GPR.

Software can assume that any negative value (highest bit set) corresponds to no element found, as vector lengths will never exceed 2^{31} on any implementation.

Traps on `vmfirst` are always reported with a `vstart` of 0. The `vmfirst` instruction will raise an illegal instruction exception if `vstart` is non-zero.

16.4. `msbf.m` set-before-first mask bit

vmsbf.m vd, vs2, vm

Example

7	6	5	4	3	2	1	0	Element number
1	0	0	1	0	1	0	0	v3 contents
vmsbf.m v2, v3								
0	0	0	0	0	0	1	1	v2 contents
1	0	0	1	0	1	0	1	v3 contents
vmsbf.m v2, v3								
0	0	0	0	0	0	0	0	v2
0	0	0	0	0	0	0	0	v3 contents
vmsbf.m v2, v3								
1	1	1	1	1	1	1	1	v2
1	1	0	0	0	0	1	1	v0 vcontents
1	0	0	1	0	1	0	0	v3 contents
vmsbf.m v2, v3, v0.t								
0	1	x	x	x	x	1	1	v2 contents

The vmsbf.m instruction takes a mask register as input and writes results to a mask register. The instruction writes a 1 to all active mask elements before the first source element that has a set LSB, then writes a zero to that element and all following active elements. If there is no set bit in the source vector, then all active elements in the destination are written with a 1.

The tail elements in the destination mask register are cleared.

16.5. vmsif.m set-including-first mask bit

The vector mask set-including-first instruction is similar to set-before-first, except it also includes the element with a set bit.

vmsif.m vd, vs2, vm

Example

7	6	5	4	3	2	1	0	Element number
1	0	0	1	0	1	0	0	v3 contents
vmsif.m v2, v3								
0	0	0	0	0	1	1	1	v2 contents
1	0	0	1	0	1	0	1	v3 contents
vmsif.m v2, v3								
0	0	0	0	0	0	0	1	v2
1	1	0	0	0	0	1	1	v0 vcontents
1	0	0	1	0	1	0	0	v3 contents
vmsif.m v2, v3, v0.t								
1	1	x	x	x	x	1	1	v2 contents

The tail elements in the destination mask register are cleared.

16.6. vmsof.m set-only-first mask bit

The vector mask set-only-first instruction is similar to set-before-first, except it only sets the first element with a bit set, if any.

vmsof.m vd, vs2, vm									
# Example									
7	6	5	4	3	2	1	0	Element number	
1	0	0	1	0	1	0	0	v3 contents	
								vmsof.m v2, v3	
0	0	0	0	0	1	0	0	v2 contents	
1	0	0	1	0	1	0	1	v3 contents	
								vmsof.m v2, v3	
0	0	0	0	0	0	0	1	v2	
1	1	0	0	0	0	1	1	v0 vcontents	
1	1	0	1	0	1	0	0	v3 contents	
								vmsof.m v2, v3, v0.t	
0	1	x	x	x	x	0	0	v2 contents	

The tail elements in the destination mask register are cleared.

16.7. Example using vector mask instructions

The following is an example of vectorizing a data-dependent exit loop.

```

# char* strcpy(char *dst, const char* src)
strcpy:
    mv a2, a0          # Copy dst
loop:
    vsetvli x0, x0, e8  # Max length vectors of bytes
    vlbuff.v v1, (a1)   # Get src bytes
    csrr t1, v1         # Get number of bytes fetched
    vseq.vi v0, v1, 0   # Flag zero bytes
    vmfirst.m a3, v0    # Zero found?
    add a1, a1, t1      # Bump pointer
    vmsif.m v0, v0      # Set mask up to and including zero byte.
    vsb.v v1, (a2), v0.t # Write out bytes
    add a2, a2, t1      # Bump pointer
    bltz a3, loop       # Zero byte not found, so loop

    ret

# char* strncpy(char *dst, const char* src, size_t n)
strncpy:
    mv a3, a0          # Copy dst
loop:
    vsetvli x0, a2, e8  # Vectors of bytes.
    vlbuff.v v1, (a1)   # Get src bytes
    vseq.vi v0, v1, 0   # Flag zero bytes
    vmfirst.m a4, v0    # Zero found?
    vmsif.m v0, v0      # Set mask up to and including zero byte.
    vsb.v v1, (a3), v0.t # Write out bytes
    bgez a4, exit       # Done
    csrr t1, v1         # Get number of bytes fetched
    add a1, a1, t1      # Bump pointer
    sub a2, a2, t1      # Decrement count.
    add a3, a3, t1      # Bump pointer
    bnez a2, loop       # Anymore?

exit:
    ret

```

16.8. Vector Iota Instruction

The `vmiota.m` instruction reads a source vector mask register and writes to each element of the destination vector register group the sum of all the least-significant bits of elements in the mask register whose index is less than the element, e.g., a parallel prefix sum of the mask values.

This instruction can be masked, in which case only the enabled elements contribute to the sum and only the enabled elements are written.

```
vmiota.m vd, vs2, vm
```

```
# Example
```

```
  7 6 5 4 3 2 1 0   Element number

  1 0 0 1 0 0 0 1   v2 contents
                    vmiota.m v4, v2 # Unmasked
  2 2 2 1 1 1 1 0   v4 result

  1 1 1 0 1 0 1 1   v0 contents
  1 0 0 1 0 0 0 1   v2 contents
  2 3 4 5 6 7 8 9   v4 contents
                    vmiota.m v4, v2, v0.t # Masked
  1 1 1 5 1 7 1 0   v4 results
```

The result value is zero-extended to fill the destination element if SEW is wider than the result. If the result value would overflow the destination SEW, the least-significant SEW bits are retained.

Traps on `vmiota.m` are always reported with a `vstart` of 0, and execution is always restarted from the beginning when resuming after a trap handler. An illegal instruction exception is raised if `vstart` is non-zero.

An illegal instruction exception is raised if the destination vector register group overlaps the source vector mask register. If the instruction is masked, an illegal instruction exception is issued if the destination vector register group overlaps `v0`.

These constraints exist for two reasons. First, to simplify avoidance of WAR hazards in implementations with temporally long vector registers and no vector register renaming. Second, to enable resuming execution after a trap simpler.

The `vmiota.m` instruction can be combined with memory scatter instructions (indexed stores) to perform vector compress functions.

```

# Compact non-zero elements from input memory array to output memory array
#
# size_t compact_non_zero(size_t n, const int* in, int* out)
# {
#     size_t i;
#     size_t count = 0;
#     int *p = out;
#
#     for (i=0; i<n; i++)
#     {
#         const int v = *in++;
#         if (v != 0)
#             *p++ = v;
#     }
#
#     return (size_t) (p - out);
# }
#
# a0 = n
# a1 = &in
# a2 = &out

```

```

compact_non_zero:
    li a6, 0                # Clear count of non-zero elements
loop:
    vsetvli a5, a0, e32,m8  # 32-bit integers
    vlw.v v8, (a1)          # Load input vector
    sub a0, a0, a5           # Decrement number done
    slli a5, a5, 2           # Multiply by four bytes
    vsne.vi v0, v8, 0       # Locate non-zero values
    add a1, a1, a5           # Bump input pointer
    vmpopc.m a5, v0          # Count number of elements set in v0
    vmiota.m v16, v0         # Get destination offsets of active elements
    add a6, a6, a5           # Accumulate number of elements
    vsll.vi v16, v16, 2, v0.t # Multiply offsets by four bytes
    slli a5, a5, 2           # Multiply number of non-zero elements by four bytes
    vsuxw.v v8, (a2), v16, v0.t # Scatter using scaled vmiota results under mask
    add a2, a2, a5           # Bump output pointer
    bnez a0, loop            # Any more?

    mv a0, a6                # Return count
    ret

```

16.9. Vector Element Index Instruction

The `vid.v` instruction writes each element's index to the destination vector register group, from 0 to `v1-1`.

```

vid.v vd, vm # Write element ID to destination.

```

The instruction can be masked.

An illegal instruction exception is generated if the destination vector register group overlaps the mask register and `LMUL > 1`.

┆ This constraint is to avoid WAR hazards in long vector implementations without register renaming, and to support restart.

┆ Microarchitectures can implement `vid.v` instruction using the same datapath as `vmiota.m` but with an implicit set mask source.

17. Vector Permutation Instructions

A range of permutation instructions are provided to move elements around within the vector registers.

17.1. Integer Extract Instruction

The integer extract operation transfers a single value between one element of a vector register and a GPR. This instruction ignores LMUL and vector register groups.

```
vext.x.v rd, vs2, rs1 # rd = vs2[rs1]
```

The integer extract operation, `vext.x.v` reads one SEW-width element from a vector register group at the element index and writes it to GPR destination register `rd`. The GPR `rs1` register gives the element index, treated as an unsigned integer. If the index is out of range (i.e., $x[rs1] \geq VLEN/SEW$), then zero is returned for the element value. If $SEW > XLEN$, the least-significant bits are copied to the destination and the upper $SEW - XLEN$ bits are ignored. If $SEW < XLEN$, the value is zero-extended to $XLEN$.

An assembler pseudoinstruction `vmv.x.s rd, vs2` expanding to `vext.x.v rd, vs2, x0` is provided as a complement to the `vmv.s.x` instruction below.

17.2. Integer Scalar Move Instruction

The integer scalar move instruction transfers a single value from a scalar `x` register to element 0 of a vector register. The instructions ignore LMUL and vector register groups.

In the base vector extension, this instruction can be used to initialize the input of a reduction instruction.

Using scalar move instructions to access element 0 of other than the base register in a vector register group can expose differences in element layout between different RISC-V vector extension implementations.

```
vmv.s.x vd, rs1 # vd[0] = rs1
```

The `vmv.s.x` instruction copies the scalar integer register to element 0 of the destination vector register. If $SEW < XLEN$, the least-significant bits are copied and the upper $XLEN - SEW$ bits are ignored. If $SEW > XLEN$, the value is zero-extended to SEW bits.

The other elements in the destination vector register ($0 < \text{index} < VLEN/SEW$) are zeroed.

If $v1=0$, no operation is performed and the destination register is not updated.

The complementary `vins.v.x` instruction, which allows a write to any element in a vector register, has been removed. This instruction would be the only instruction (apart from `vsetv1`) that requires two integer source operands, and also would be slow to execute in an implementation with vector register renaming, relegating its main use to debugger modifications to state. The alternative and more generally useful `vslide1up` and `vslide1down` instructions can be used to update vector register state in place over a debug link without accessing memory.

17.3. Floating-Point Scalar Move Instructions

The floating-point scalar read/write instructions transfer a single value between a scalar `f` register and element 0 of a vector register. The instructions ignore LMUL and vector register groups.

```
vfmv.f.s rd, vs2 # rd = vs2[0] (rs1=0)
vfmv.s.f vd, rs1 # vd[0] = rs1 (vs2=0)
```

The `vfmv.f.s` instruction copies a single SEW-wide element from index 0 of the source vector register to a destination scalar floating-point register. If $SEW > FLEN$, the least-significant FLEN bits are transferred and the upper SEW-FLEN bits are ignored. If $SEW < FLEN$, the value is NaN-boxed (1-extended) to FLEN bits.

The `vfmv.s.f` instruction copies the scalar register to element 0 of the destination vector register. If $SEW < FLEN$, the least-significant bits are copied and the upper XLEN-SEW bits are ignored. If $SEW > FLEN$, the value is NaN-boxed (1-extended) to SEW bits. The other elements in the destination vector register ($0 < \text{index} < FLEN/SEW$) are zeroed. If $v1=0$, no operation is performed and the destination register is not updated.

17.4. Vector Slide Instructions

The slide instructions move elements up and down a vector register group.

The slide operations can be implemented much more efficiently than using the arbitrary register gather instruction. Implementations may optimize certain OFFSET values for `vslideup` and `vslidedown`. In particular, power-of-2 offsets may operate substantially faster than other offsets.

For all of the `vslideup`, `vslidedown`, `vslide1up`, and `vslide1down` instructions, if $v1=0$, the instruction performs no operation and leaves the destination vector register unchanged.

17.4.1. Vector Slideup Instructions

```
vslideup.vx vd, vs2, rs1, vm      # vd[i+rs1] = vs2[i]
vslideup.vi vd, vs2, uimm[4:0], vm # vd[i+imm] = vs2[i]
```

For `vslideup`, the value in $v1$ specifies the number of destination elements that are written. The start index (*OFFSET*) for the destination can be either specified using an unsigned integer in the x register specified by $rs1$, or a 5-bit immediate treated as an unsigned 5-bit quantity.

`vslideup` behavior for destination elements

OFFSET is amount to slideup, either from x register or a 5-bit immediate

$0 < i < \max(vstart, OFFSET)$	Unchanged
$\max(vstart, OFFSET) \leq i < v1$	$vd[i] = vs2[i-OFFSET]$ if mask enabled, unchanged if not
$v1 \leq i < VLMAX$	Tail elements, $vd[i] = 0$

The destination vector register group for `vslideup` cannot overlap the vector register group of the source, and if operation is masked cannot overlap the vector mask register, otherwise an illegal instruction exception is raised.

The non-overlap constraints are to avoid WAR hazards on the input vectors during execution, and to enable restart with non-zero $vstart$.

17.4.2. Vector Slidedown Instructions

```
vslidedown.vx vd, vs2, rs1, vm    # vd[i] = vs2[i+rs1]
vslidedown.vi vd, vs2, uimm[4:0], vm # vd[i] = vs2[i+imm]
```

For `vslidedown`, the value in $v1$ specifies the number of destination elements that are written.

The start index (*OFFSET*) for the source can be either specified using an unsigned integer in the x register specified by $rs1$, or a 5-bit immediate treated as an unsigned 5-bit quantity.

vslidedown behavior for source elements for element i in slide	
$0 \leq i + \text{OFFSET} < \text{VLMAX}$	Read $\text{vs2}[i + \text{offset}]$
$\text{VLMAX} \leq i + \text{OFFSET}$	Read as 0
vslidedown behavior for destination element i in slide	
$0 < i < \text{vstart}$	Unchanged
$\text{vstart} \leq i < \text{vl}$	Updated if mask enabled, unchanged if not
$\text{vl} \leq i < \text{VLMAX}$	Zeroed

Microarchitectures can optimize zeros written to the end of a vector for large offsets by treating as effectively smaller vector length, and encoding using the same internal scheme as for regular vector instruction writes.

The destination vector register group for `vslidedown` cannot overlap the vector mask register if the instruction is masked, otherwise an illegal instruction exception is raised.

17.4.3. Vector Slide1up

Variants of slide are provided that only move by one element but which also allow a scalar integer value to be inserted at the vacated element position.

```
vslide1up.vx vd, vs2, rs1, vm      # vd[0]=x[rs1], vd[i+1] = vs2[i]
```

The `vslide1up` instruction places the `x` register argument at location 0 of the destination vector register group, provided that element 0 is active, otherwise the destination element is unchanged. If $\text{XLEN} < \text{SEW}$, the value is zero-extended to SEW bits. If $\text{XLEN} > \text{SEW}$, the least-significant bits are copied over and the high SEW-XLEN bits are ignored.

The remaining active $\text{vl}-1$ elements are copied over from index i in the source vector register group to index $i+1$ in the destination vector register group.

The `vl` register specifies how many of the destination vector register elements are written with source values, and all tail elements are zeroed.

vslide1up behavior	
$i < \text{vstart}$	unchanged
$0 = i = \text{vstart}$	$\text{vd}[i] = \text{x}[\text{rs1}]$ if mask enabled, unchanged if not
$\text{max}(\text{vstart}, 1) \leq i < \text{vl}$	$\text{vd}[i] = \text{vs2}[i-1]$ if mask enabled, unchanged if not
$\text{vl} \leq i < \text{VLMAX}$	tail elements, $\text{vd}[i] = 0$

The `vslide1up` instruction requires that the destination vector register group does not overlap the source vector register group and the mask register if masked. Otherwise, an illegal instruction exception is raised.

17.4.4. Vector Slide1down Instruction

The `vslide1down` instruction copies the first $\text{vl}-1$ active elements values from index $i+1$ in the source vector register group to index i in the destination vector register group.

The `vl` register specifies how many of the destination vector register elements are written with source values, and all tail elements are zeroed.

```
vslide1down.vx vd, vs2, rs1, vm    # vd[i] = vs2[i+1], vd[vl-1]=x[rs1]
```

The `vslide1down` instruction places the `x` register argument at location `v1-1` in the destination vector register, provided that element `v1-1` is active, otherwise the destination element is unchanged. If `XLEN < SEW`, the value is zero-extended to `SEW` bits. If `XLEN > SEW`, the least-significant bits are copied over and the high `SEW-XLEN` bits are ignored.

`vslide1down` behavior

	<code>i < vstart</code>	unchanged
<code>vstart <= i < v1-1</code>		<code>vd[i] = vs2[i+1]</code> if mask enabled, unchanged if not
<code>vstart <= i = v1-1</code>		<code>vd[v1-1] = x[rs1]</code> if mask enabled, unchanged if not
<code>v1 <= i < VLMAX</code>		tail elements, <code>vd[i] = 0</code>

The `vslide1down` instruction requires that the destination vector register group does not overlap the mask register if masked. Otherwise, an illegal instruction exception is raised.

The `vslide1down` instruction can be used to load values into a vector register without using memory and without disturbing other vector registers. This provides a path for debuggers to modify the contents of a vector register, albeit slowly, with multiple repeated `vslide1down` invocations.

17.5. Vector Register Gather Instruction

The vector register gather instruction reads elements from a first source vector register group at locations given by a second source vector register group. The index values in the second vector are treated as unsigned integers. The source vector can be read at any index `< VLMAX` regardless of `v1`. The number of elements to write to the destination register is given by `v1`, and elements past `v1` in the destination are zeroed. The operation can be masked.

```
vrgather.vv vd, vs2, vs1, vm # vd[i] = (vs1[i] >= VLMAX) ? 0 : vs2[vs1[i]];
```

If the element indices are out of range (`vs1[i] ≥ VLMAX`) then zero is returned for the element value.

Vector-scalar and vector-immediate forms of the register gather are also provided. These read one element from the source vector at the given index, and write this value to the `v1` elements at the start of the destination vector register.

These forms allow any vector element to be "splatted" to an entire vector.

```
vrgather.vx vd, vs2, rs1, vm # vd[i] = vs2[rs1]
vrgather.vi vd, vs2, imm, vm # vd[i] = vs2[imm]
```

For any `vrgather` instruction, the destination vector register group cannot overlap with the source vector register groups, including the mask register if the operation is masked, otherwise an illegal instruction exception is raised.

17.6. Vector Compress Instruction

The vector compress instruction allows elements selected by a vector mask register from a source vector register group to be packed into contiguous elements at the start of the destination vector register group.

```
vcompress.vm vd, vs2, vs1 # Compress into vd elements of vs2 where vs1 is enabled
```

The vector mask register specified by `vs1` indicates which of the first `v1` elements of vector register group `vs2` should be extracted and packed into contiguous elements at the beginning of vector register `vd`. Any

remaining elements of `vd` are zeroed.

Example use of `vcompress` instruction

1	1	0	1	0	0	1	0	1	<code>v0</code>
8	7	6	5	4	3	2	1	0	<code>v1</code>
<code>vcompress.vm v2, v1, v0</code>									
0	0	0	0	8	7	5	2	0	<code>v2</code>

The destination vector register group cannot overlap the source vector register group or the source vector mask register, otherwise an illegal instruction exception is raised.

A trap on a `vcompress` instruction is always reported with a `vstart` of 0. Executing a `vcompress` instruction with a non-zero `vstart` raises an illegal instruction exception.

Although possible, `vcompress` is one of the more difficult instructions to restart with a non-zero `vstart`, so assumption is implementations will choose not to do that but will instead restart from element 0. This does mean elements in destination register after `vstart` will already have been updated.

18. Exception Handling

On a trap during a vector instruction (caused by either a synchronous exception or an asynchronous interrupt), the existing `*epc` CSR is written with a pointer to the errant vector instruction, while the `vstart` CSR contains the element index that caused the trap to be taken.

We chose to add a `vstart` CSR to allow resumption of a partially executed vector instruction to reduce interrupt latencies and to simplify forward-progress guarantees. This is similar to the scheme in the IBM 3090 vector facility. To ensure forward progress without the `vstart` CSR, implementations would have to guarantee an entire vector instruction can always complete atomically without generating a trap. This is particularly difficult to ensure in the presence of strided or scatter/gather operations and demand-paged virtual memory.

18.1. Precise vector traps

Precise vector traps require that:

1. all instructions older than the trapping vector instruction have committed their results
2. no instructions newer than the trapping vector instruction have altered architectural state
3. any operations within the trapping vector instruction affecting result elements preceding the index in the `vstart` CSR have committed their results
4. no operations within the trapping vector instruction affecting elements at or following the `vstart` CSR have altered architectural state except if restarting and completing the affected vector instruction will recover the correct state.

We relax the last requirement to allow elements following `vstart` to have been updated at the time the trap is reported, provided that re-executing the instruction from the given `vstart` will correctly overwrite those elements.

We assume most supervisor-mode environments will require precise vector traps.

Except where noted above, vector instructions are allowed to overwrite their inputs, and so in most cases, the vector instruction restart must be from the `vstart` location. However, there are a number of cases where this overwrite is prohibited to enable execution of the the vector instructions to be idempotent and hence restartable from any location.

18.2. Imprecise vector traps

Imprecise vector traps are traps that are not precise. In particular, instructions newer than `*epc` may have committed results, and instructions older than `*epc` may have not completed execution. Imprecise traps are primarily intended to be used in situations where reporting an error and terminating execution is the appropriate response.

A platform might specify that interrupts are precise while other traps are imprecise. We assume many embedded platforms will only generate imprecise traps for vector instructions on fatal errors, so do not require resumable traps.

18.3. Selectable precise/imprecise traps

Some platforms may choose to provide a privileged mode bit to select between precise and imprecise vector traps. Imprecise mode would run at high-performance but possibly make it difficult to discern error causes, while precise mode would run more slowly, but support debugging of errors albeit with a possibility of not experiencing the same errors as in imprecise mode.

18.4. Swappable traps

Another trap mode can support swappable state in the vector unit, where on a trap, special instructions can save and restore the vector unit microarchitectural state, to allow execution to continue correctly around imprecise traps.

This mechanism is not defined in the base vector ISA.

19. Divided Element Extension ('Zvediv')

The divided element extension allows each element to be treated as a packed sub-vector of narrower elements. This provides efficient support for some forms of narrow-width and mixed-width arithmetic, and also to allow outer-loop vectorization of short vector and matrix operations. In addition to modifying the behavior of some existing instructions, a few new instructions are provided to operate on vectors when EDIV > 1.

| This is written as an extension for now, but could become part of mandatory base in Unix vector profile.

The divided element extension adds a two-bit field, `vediv[1:0]` to the `vtype` register.

`vtype` register layout

bits	contents
<code>XLEN-1:7</code>	Reserved (write 0)
<code>6:5</code>	<code>vediv[1:0]</code> # Used by EDIV extension
<code>4:2</code>	<code>vsew[2:0]</code>
<code>1:0</code>	<code>vlmul[1:0]</code>

The `vediv` field encodes the number of ways, *EDIV*, into which each SEW-bit element is subdivided into equal sub-elements. A vector register group is now considered to hold a vector of sub-vectors.

`vediv` Division

`[1:0]` EDIV

0 0	1	(undivided, as in base)
0 1	2	two equal sub-elements
1 0	4	four equal sub-elements
1 1	8	eight equal sub-elements

SEW	EDIV	Sub-element	Integer sum accumulator	Integer dot accumulator	FP sum/dot accumulator FLEN=32	FP sum/dot accumulator FLEN=64	FP sum/dot accumulator FLEN=128
8b	2	4b	8b	8b	-	-	-
8b	4	2b	8b	8b	-	-	-
8b	8	1b	8b	8b	-	-	-
16b	2	8b	16b	16b	-	-	-
16b	4	4b	8b	16b	-	-	-
16b	8	2b	8b	8b	-	-	-
32b	2	16b	32b	32b	32b	32b	32b
32b	4	8b	16b	32b	-	-	-
32b	8	4b	8b	16b	-	-	-
64b	2	32b	64b	64b	32b	64b	64b
64b	4	16b	32b	64b	32b	32b	32b
64b	8	8b	16b	32b	-	-	-
128b	2	64b	128b	128b	32b	64b	128b
128b	4	32b	64b	128b	32b	64b	64b
128b	8	16b	32b	64b	32b	32b	32b
256b	2	128b	256b	256b	32b	64b	128b
256b	4	64b	128b	256b	32b	64b	128b
256b	8	32b	64b	128b	32b	64b	64b

Each implementation defines a minimum size for a sub-element, *SELEN*, which must be at most 8 bits.

While *SELEN* is a fourth implementation-specific parameter, values smaller than 8 would be considered an additional extension.

19.1. Instructions not affected by EDIV

The vector start register `vstart` and exception reporting continue to work as before.

The vector length `vl` control and vector masking continue to operate at the element level.

Vector masking continues to operate at the element level, so sub-elements cannot be individually masked.

SEW can be changed dynamically to enabled per-element masking for sub-elements of 8 bits and greater.

Vector load/store and AMO instructions are unaffected by EDIV, and continue to move whole elements.

Vector mask logical operations are unchanged by EDIV setting, and continue to operate on vector registers containing element masks.

Vector mask population count (`vmpopc`), find-first and related instructions (`vmfirst`, `vmsbf`, `vmsif`, `vmsof`), `iota` (`vmiota`), and element index (`vid`) instructions are unaffected by EDIV.

Vector integer bit insert/extract, and integer and floating-point scalar move instruction are unaffected by EDIV.

Vector slide-up/slide-down are unaffected by EDIV.

Vector compress instructions are unaffected by EDIV.

19.2. Instructions Affected by EDIV

19.2.1. Regular Vector Arithmetic Instructions under EDIV

Most vector arithmetic operations are modified to operate on the individual sub-elements, so effective SEW is SEW/EDIV and effective vector length is $v1 * EDIV$. For example, a vector add of 32-bit elements with a $v1$ of 5 and EDIV of 4, operates identically to a vector add of 8-bit elements with a vector length of 20.

```
vsetvli t0, a0, e32,m1,d4 # Vectors of 32-bit elements, divided into byte sub-elements
vadd.vv v1,v2,v3          # Performs a vector of 4*v1 8-bit additions.
vsll.vx v1,v2,x1          # Performs a vector of 4*v1 8-bit shifts.
```

19.2.2. Vector Reduction Instructions under EDIV

Vector reduction instructions now operate independently on all elements in a vector, reducing sub-element values within an element to an element-wide result.

```
# Sum each sub-vector of four bytes into a 16-bit result.
vsetvli t0, a0, e32,d4 # Vectors of 32-bit elements, divided into byte sub-elements
vredsum.vv v1, v2, v3 # v1[i][15:0] = v2[i][31:24] + v2[i][23:16]
                      #               + v2[i][15:8] + v2[i][7:0] + v3[i][31:0]

vredmax.vv v5, v6, v7 # v5[i][31:0] = max(v6[i][31:24], v6[i][23:16],
                      #               v6[i][15:8], v6[i][7:0], v7[i][31:0])
```

Integer sub-element non-sum reductions produce a final result that is $\max(8, \text{SEW}/\text{EDIV})$ bits wide, sign- or zero-extended to full SEW if necessary.

Integer sub-element sum reductions produce a final result that is $\max(8, \min(\text{SEW}, 2 * \text{SEW}/\text{EDIV}))$ bits wide, sign- or zero-extended to full SEW if necessary.

Floating-point sub-element non-sum reductions produce a final result that is SEW/EDIV bits wide.

Floating-point sub-element sum reductions produce a final result that is $\min(2 * \text{SEW}/\text{EDIV}, \text{FLEN})$ bits wide, NaN-boxed to the full SEW width if necessary.

Widening vector reduction operations with non-zero EDIV are reserved. NOTE: While these could be defined, it is unclear they are needed and this reduces implementation complexity.

19.2.3. Vector Register Gather Instructions under EDIV

Vector register gather instructions under non-zero EDIV only gather sub-elements within the element. The source and index values are interpreted as relative to the enclosing element only. Index values $\geq \text{EDIV}$ write a zero value into the result sub-element.

					SEW = 32b, EDIV=4			
7	6	5	4	3	2	1	0	bytes
d	e	a	d	b	e	e	f	v1
0	1	9	2	0	2	3	2	v2
								vrgather.vv v3, v1, v2
d	a	0	e	f	e	b	e	v3
								vrgather.vi v4, v1, 1
a	a	a	a	e	e	e	e	v4

- Vector register gathers with scalar or immediate arguments can "splat" values across sub-elements within an element.
- Implementations can provide fast implementations of register gathers constrained within a single element width.

19.3. Vector Integer Dot-Product Instruction

The integer dot-product reduction `vdot.vv` performs an element-wise multiplication between the source sub-elements then accumulates the results into the destination vector element. Note the assembler syntax uses a `.vv` suffix since both inputs are vectors of elements.

Sub-element integer dot reductions produce a final result that is $\max(8, \min(\text{SEW}, 4 * \text{SEW} / \text{EDIV}))$ bits wide, sign- or zero-extended to full SEW if necessary.

```
# Unsigned dot-product
vdotu.vv vd, vs2, vs1, vm # Vector-vector

# Signed dot-product
vdot.vv vd, vs2, vs1, vm # Vector-vector
```

```
# Dot product, SEW=32, EDIV=1
vdot.vv vd, vs2, vs1, vm # vd[i][31:0] += vs2[i][31:0] * vs1[i][31:0]

# Dot product, SEW=32, EDIV=2
vdot.vv vd, vs2, vs1, vm # vd[i][31:0] += vs2[i][31:16] * vs1[i][31:16]
                           + vs2[i][15:0] * vs1[i][15:0]

# Dot product, SEW=32, EDIV=4
vdot.vv vd, vs2, vs1, vm # vd[i][31:0] += vs2[i][31:24] * vs1[i][31:24]
                           + vs2[i][23:16] * vs1[i][23:16]
                           + vs2[i][15:8] * vs1[i][15:8]
                           + vs2[i][7:0] * vs1[i][7:0]
```

19.4. Vector Floating-Point Dot Product Instruction

The floating-point dot-product reduction `vfdot.vv` performs an element-wise multiplication between the source sub-elements then accumulates the results into the destination vector element. Note the assembler syntax uses a `.vv` suffix since both inputs are vectors of elements.

```
# Signed dot-product
vfdot.vv vd, vs2, vs1, vm # Vector-vector
```

```

# Dot product. SEW=32, EDIV=2
vfdot.v vd, vs2, vs1, vm # vd[i][31:0] += vs2[i][31:16] * vs1[i][31:16]
                                + vs2[i][15:0] * vs1[i][15:0]

# Floating-point sub-vectors of two half-precision floats packed into 32-bit elements.
vsetvli t0, a0, e32,m1,d2 # Vectors of 32-bit elements, divided into 16b sub-elements
vfdot.vv v1, v2, v3 # v1[i][31:0] += v2[i][31:16]*v3[i][31:16] + v2[i][16:0]*v3[i][16:0]

# Floating-point sub-vectors of two half-precision floats packed into 32-bit elements.
vsetvli t0, a0, e32,m1,d2 # Vectors of 32-bit elements, divided into 16b sub-elements
vfdot.vv v1, v2, v3 # v1[i][31:0] += v2[i][31:16]*v3[i][31:16] + v2[i][16:0]*v3[i][16:0]

# Floating-point sub-vectors of four half-precision floats packed into 64-bit elements.
vsetvli t0, a0, e64,m1,d4 # Vectors of 64-bit elements, divided into 16b sub-elements
vfdot.vv v1, v2, v3
    # v1[i][31:0] += v2[i][31:16]*v3[i][31:16] + v2[i][16:0]*v3[i][16:0] +
    #                v2[i][63:48]*v3[i][63:48] + v2[i][47:32]*v3[i][47:32];
    # v1[i][63:32] = ~0 (NaN boxing)

```

20. Vector Instruction Listing

Integer		Integer		FP				
funct3		funct3		funct3				
OPIVV	V	OPMVV	V	OPFVV	V			
OPIVX	X	OPMVX	X	OPFVF	F			
OPIVI	I							
funct6		funct6		funct6				
000000	VXI	vadd	000000	V	vredsum	000000	VF	vfadd
000001			000001	V	vredand	000001	V	vfredsum
000010	VX	vsub	000010	V	vredor	000010	VF	vfsb
000011	XI	vrsb	000011	V	vredxor	000011	V	vfredosum
000100	VX	vminu	000100	V	vredminu	000100	VF	vfmin
000101	VX	vmin	000101	V	vredmin	000101	V	vfredmin
000110	VX	vmaxu	000110	V	vredmaxu	000110	VF	vfmax
000111	VX	vmax	000111	V	vredmax	000111	V	vfredmax
001000			001000			001000	VF	vfsgnj
001001	VXI	vand	001001			001001	VF	vfsgnn
001010	VXI	vor	001010			001010	VF	vfsgnx
001011	VXI	vxor	001011			001011		
001100	VXI	vrgather	001100	V	vext.x.v	001100	V	vfmv.f.s
001101			001101	X	vmv.s.x	001101	F	vfmv.s.f
001110	XI	vslideup	001110	X	vslide1up	001110		
001111	XI	vslidedown	001111	X	vslide1down	001111		
010000	VXI	vadc	010000			010000		
010001			010001			010001		
010010	VX	vsbc	010010			010010		
010011			010011			010011		
010100			010100	V	vmppc	010100		
010101			010101	V	vmfirst	010101		
010110			010110	V	VMUNARY0	010110		
010111	VXI	vmerge	010111	V	vcompress	010111	F	vfmerge.vf
011000	VXI	vseq	011000	V	vmandnot	011000	VF	vfeq
011001	VXI	vsne	011001	V	vmand	011001	VF	vfle
011010	VX	vsltu	011010	V	vmor	011010	VF	vford
011011	VX	vslt	011011	V	vmxor	011011	VF	vflt
011100	VXI	vsleu	011100	V	vmornot	011100	VF	vfne
011101	VXI	vsle	011101	V	vmnand	011101	F	vfgt
011110	XI	vsgtu	011110	V	vmnor	011110		
011111	XI	vsgt	011111	V	vmxnor	011111	F	vfge
100000	VXI	vsaddu	100000	VX	vdivu	100000	VF	vfdv
100001	VXI	vsadd	100001	VX	vdiv	100001	F	vfrdiv
100010	VX	vssubu	100010	VX	vremu	100010	V	VFUNARY0
100011	VX	vssub	100011	VX	vrem	100011	V	VFUNARY1
100100	VXI	vaadd	100100	VX	vmulhu	100100	VF	vfmul
100101	VXI	vsll	100101	VX	vmul	100101		
100110	VX	vasub	100110	VX	vmulhsu	100110		
100111	VX	vsmul	100111	VX	vmulh	100111		
101000	VXI	vsrl	101000			101000	VF	vfmadd
101001	VXI	vsra	101001	VX	vmadd	101001	VF	vfnmadd
101010	VXI	vssrl	101010			101010	VF	vfmsub
101011	VXI	vssra	101011	VX	vmsub	101011	VF	vfnmsub
101100	VXI	vnsrl	101100			101100	VF	vfmacc
101101	VXI	vnsra	101101	VX	vmacc	101101	VF	vfnmacc
101110	VXI	vnclipu	101110			101110	VF	vfmsac
101111	VXI	vnclip	101111	VX	vmsac	101111	VF	vfnmsac

110000 V	vwredsumu	110000 VX	vwaddu	110000 VF	vfwadd
110001 V	vwredsum	110001 VX	vwadd	110001 V	vfwredsum
110010		110010 VX	vwsubu	110010 VF	vfwsu
110011		110011 VX	vwsu	110011 V	vfwredosu
110100		110100 VX	vwaddu.w	110100 VF	vfwadd.w
110101		110101 VX	vwadd.w	110101	
110110		110110 VX	vwsubu.w	110110 VF	vfwsu.w
110111		110111 VX	vwsu.w	110111	
111000 V	vdotu	111000 VX	vwmulu	111000 VF	vfwmul
111001 V	vdot	111001		111001 V	vfdot
111010		111010 VX	vwmulsu	111010	
111011		111011 VX	vwmul	111011	
111100 VX	vwsmaccu	111100 VX	vwmaccu	111100 VF	vfwmac
111101 VX	vwsmac	111101 VX	vwmacc	111101 VF	vfwnmacc
111110 VX	vwsmsacu	111110 VX	vwsmsacu	111110 VF	vfwmsac
111111 VX	vwsmsac	111111 VX	vwsmsac	111111 VF	vfwnmsac

VFUNARY0 encoding space

vs1

single-width converts

00000 vfcvt.xu.f.v

00001 vfcvt.x.f.v

00010 vfcvt.f.xu.v

00011 vfcvt.f.x.v

widening converts

01000 vfwcvt.xu.f.v

01001 vfwcvt.x.f.v

01010 vfwcvt.f.xu.v

01011 vfwcvt.f.x.v

01100 vfwcvt.f.f.v

narrowing converts

10000 vfncvt.xu.f.v

10001 vfncvt.x.f.v

10010 vfncvt.f.xu.v

10011 vfncvt.f.x.v

10100 vfncvt.f.f.v

VFUNARY1 encoding space

vs1

00000 vfsqrt.v

10000 vfclass.v

VMUNARY0 encoding space

vs1

00001 vmsbf

00010 vmsof

00011 vmsif

10000 vmiota

10001 vid

Appendix A: Vector Assembly Code Examples

The following are provided as non-normative text to help explain the vector ISA.

A.1. Vector-vector add example

```
# vector-vector add routine of 32-bit integers
# void vvaddint32(size_t n, const int*x, const int*y, int*z)
# { for (size_t i=0; i<n; i++) { z[i]=x[i]+y[i]; } }
#
# a0 = n, a1 = x, a2 = y, a3 = z
# Non-vector instructions are indented
vvaddint32:
    vsetvli t0, a0, e32 # Set vector length based on 32-bit vectors
    vlw.v v0, (a1)      # Get first vector
    sub a0, a0, t0      # Decrement number done
    slli t0, t0, 2      # Multiply number done by 4 bytes
    add a1, a1, t0      # Bump pointer
    vlw.v v1, (a2)      # Get second vector
    add a2, a2, t0      # Bump pointer
    vadd.vv v2, v0, v1   # Sum vectors
    vsw.v v2, (a3)      # Store result
    add a3, a3, t0      # Bump pointer
    bnez a0, vvaddint32 # Loop back
    ret                # Finished
```

A.2. Example with mixed-width mask and compute.

```
# Code using one width for predicate and different width for masked
# compute.
# int8_t a[]; int32_t b[], c[];
# for (i=0; i<n; i++) { b[i] = (a[i] < 5) ? c[i] : 1; }
#
# Mixed-width code that keeps SEW/LMUL=8
loop:
    vsetvli a4, a0, e8,m1 # Byte vector for predicate calc
    vlb.v v1, (a1)        # Load a[i]
    add a1, a1, a4         # Bump pointer.
    vslt.vi v0, v1, 5      # a[i] < 5?

    vsetvli x0, a0, e32,m4 # Vector of 32-bit values.
    sub a0, a0, a4         # Decrement count
    vmv.v.i v4, 1          # Splat immediate to destination
    vlw.v v4, (a3), v0.t    # Load requested elements of C.
    sll t1, a4, 2          # Bump pointer.
    add a3, a3, t1
    vsw.v v4, (a2)         # Store b[i].
    add a2, a2, t1         # Bump pointer.
    bnez a0, loop          # Any more?
```

A.3. Malloc example

```

# void *memcpy(void* dest, const void* src, size_t n)
# a0=dest, a1=src, a2=n
#
memcpy:
    mv a3, a0 # Copy destination
loop:
    vsetvli t0, a2, e8,m8 # Vectors of 8b
    vlb.v v0, (a1)         # Load bytes
    add a1, a1, t0         # Bump pointer
    sub a2, a2, t0         # Decrement count
    vsb.v v0, (a3)         # Store bytes
    add a3, a3, t0         # Bump pointer
    bnez a2, loop          # Any more?
    ret                   # Return

```

A.4. Conditional example

```

# (int16) z[i] = ((int8) x[i] < 5) ? (int16) a[i] : (int16) b[i];
#
# Fixed 16b SEW:
loop:
    vsetvli t0, a0, e16 # Use 16b elements.
    vlb.v v0, (a1)      # Get x[i], sign-extended to 16b
    sub a0, a0, t0      # Decrement element count
    add a1, a1, t0      # x[i] Bump pointer
    vslt.vi v0, v0, 5   # Set mask in v0
    slli t0, t0, 1      # Multiply by 2 bytes
    vlh.v v1, (a2), v0.t # z[i] = a[i] case
    vmnot.m v0, v0      # Invert v0
    add a2, a2, t0      # a[i] bump pointer
    vlh.v v1, (a3), v0.t # z[i] = b[i] case
    add a3, a3, t0      # b[i] bump pointer
    vsh.v v1, (a4)      # Store z
    add a4, a4, t0      # b[i] bump pointer
    bnez a0, loop

```

A.5. SAXPY example

```
# void
# saxpy(size_t n, const float a, const float *x, float *y)
# {
#     size_t i;
#     for (i=0; i<n; i++)
#         y[i] = a * x[i] + y[i];
# }
#
# register arguments:
#     a0      n
#     fa0     a
#     a1      x
#     a2      y
```

```
saxpy:
    vsetvli a4, a0, e32, m8
    vlw.v v0, (a1)
    sub a0, a0, a4
    slli a4, a4, 2
    add a1, a1, a4
    vlw.v v8, (a2)
    vfmaccc.vf v8, fa0, v0
    vsw.v v8, (a2)
    add a2, a2, a4
    bnez a0, saxpy
    ret
```

A.6. SGEMM example

```

# RV64IDV system
#
# void
# sgemm_nn(size_t n,
#          size_t m,
#          size_t k,
#          const float*a,    // m * k matrix
#          size_t lda,
#          const float*b,    // k * n matrix
#          size_t ldb,
#          float*c,          // m * n matrix
#          size_t ldc)
#
# c += a*b (alpha=1, no transpose on input matrices)
# matrices stored in C row-major order

#define n a0
#define m a1
#define k a2
#define ap a3
#define astride a4
#define bp a5
#define bstride a6
#define cp a7
#define cstride t0
#define kt t1
#define nt t2
#define bnp t3
#define cnp t4
#define akp t5
#define bkp s0
#define nvl s1
#define ccp s2
#define amp s3

# Use args as additional temporaries
#define ft12 fa0
#define ft13 fa1
#define ft14 fa2
#define ft15 fa3

# This version holds a 16*VLMAX block of C matrix in vector registers
# in inner loop, but otherwise does not cache or TLB tiling.

sgemm_nn:
    addi sp, sp, -FRAMESIZE
    sd s0, OFFSET(sp)
    sd s1, OFFSET(sp)
    sd s2, OFFSET(sp)

    # Check for zero size matrices
    beqz n, exit
    beqz m, exit
    beqz k, exit

    # Convert elements strides to byte strides.
    ld cstride, OFFSET(sp)    # Get arg from stack frame
    slli astride, astride, 2

```

```

slli bstride, bstride, 2
slli cstride, cstride, 2

slti t6, m, 16
bnez t6, end_rows

c_row_loop: # Loop across rows of C blocks

    mv nt, n # Initialize n counter for next row of C blocks

    mv bnp, bp # Initialize B n-loop pointer to start
    mv cnp, cp # Initialize C n-loop pointer

c_col_loop: # Loop across one row of C blocks
    vsetvli nv1, nt, e32 # 32-bit vectors, LMUL=1

    mv akp, ap # reset pointer into A to beginning
    mv bkp, bnp # step to next column in B matrix

    # Initialize current C submatrix block from memory.
    vlw.v v0, (cnp); add ccp, cnp, cstride;
    vlw.v v1, (ccp); add ccp, ccp, cstride;
    vlw.v v2, (ccp); add ccp, ccp, cstride;
    vlw.v v3, (ccp); add ccp, ccp, cstride;
    vlw.v v4, (ccp); add ccp, ccp, cstride;
    vlw.v v5, (ccp); add ccp, ccp, cstride;
    vlw.v v6, (ccp); add ccp, ccp, cstride;
    vlw.v v7, (ccp); add ccp, ccp, cstride;
    vlw.v v8, (ccp); add ccp, ccp, cstride;
    vlw.v v9, (ccp); add ccp, ccp, cstride;
    vlw.v v10, (ccp); add ccp, ccp, cstride;
    vlw.v v11, (ccp); add ccp, ccp, cstride;
    vlw.v v12, (ccp); add ccp, ccp, cstride;
    vlw.v v13, (ccp); add ccp, ccp, cstride;
    vlw.v v14, (ccp); add ccp, ccp, cstride;
    vlw.v v15, (ccp)

    mv kt, k # Initialize inner loop counter

    # Inner loop scheduled assuming 4-clock occupancy of vfmacc instruction and single-issue
    # Software pipeline loads
    flw ft0, (akp); add amp, akp, astride;
    flw ft1, (amp); add amp, amp, astride;
    flw ft2, (amp); add amp, amp, astride;
    flw ft3, (amp); add amp, amp, astride;
    # Get vector from B matrix
    vlw.v v16, (bkp)

    # Loop on inner dimension for current C block
k_loop:
    vfmacc.vf v0, ft0, v16
    add bkp, bkp, bstride
    flw ft4, (amp)
    add amp, amp, astride
    vfmacc.vf v1, ft1, v16
    addi kt, kt, -1 # Decrement k counter
    flw ft5, (amp)

```

```

add amp, amp, astride
vmacc.vf v2, ft2, v16
flw ft6, (amp)
add amp, amp, astride
flw ft7, (amp)
vmacc.vf v3, ft3, v16
add amp, amp, astride
flw ft8, (amp)
add amp, amp, astride
vmacc.vf v4, ft4, v16
flw ft9, (amp)
add amp, amp, astride
vmacc.vf v5, ft5, v16
flw ft10, (amp)
add amp, amp, astride
vmacc.vf v6, ft6, v16
flw ft11, (amp)
add amp, amp, astride
vmacc.vf v7, ft7, v16
flw ft12, (amp)
add amp, amp, astride
vmacc.vf v8, ft8, v16
flw ft13, (amp)
add amp, amp, astride
vmacc.vf v9, ft9, v16
flw ft14, (amp)
add amp, amp, astride
vmacc.vf v10, ft10, v16
flw ft15, (amp)
add amp, amp, astride
addi akp, akp, 4          # Move to next column of a
vmacc.vf v11, ft11, v16
beqz kt, 1f              # Don't load past end of matrix
flw ft0, (akp)
add amp, akp, astride
1: vmacc.vf v12, ft12, v16
beqz kt, 1f
flw ft1, (amp)
add amp, amp, astride
1: vmacc.vf v13, ft13, v16
beqz kt, 1f
flw ft2, (amp)
add amp, amp, astride
1: vmacc.vf v14, ft14, v16
beqz kt, 1f              # Exit out of loop
flw ft3, (amp)
add amp, amp, astride
vmacc.vf v15, ft15, v16
vlw.v v16, (bkp)          # Get next vector from B matrix, overlap loads with jump sta
j k_loop

1: vmacc.vf v15, ft15, v16

# Save C matrix block back to memory
vsw.v v0, (cnp); add ccp, cnp, cstride;
vsw.v v1, (ccp); add ccp, ccp, cstride;
vsw.v v2, (ccp); add ccp, ccp, cstride;
vsw.v v3, (ccp); add ccp, ccp, cstride;

```

```

vsw.v v4, (ccp); add ccp, ccp, cstride;
vsw.v v5, (ccp); add ccp, ccp, cstride;
vsw.v v6, (ccp); add ccp, ccp, cstride;
vsw.v v7, (ccp); add ccp, ccp, cstride;
vsw.v v8, (ccp); add ccp, ccp, cstride;
vsw.v v9, (ccp); add ccp, ccp, cstride;
vsw.v v10, (ccp); add ccp, ccp, cstride;
vsw.v v11, (ccp); add ccp, ccp, cstride;
vsw.v v12, (ccp); add ccp, ccp, cstride;
vsw.v v13, (ccp); add ccp, ccp, cstride;
vsw.v v14, (ccp); add ccp, ccp, cstride;
vsw.v v15, (ccp)

```

```

# Following tail instructions should be scheduled earlier in free slots during C block s
# Leaving here for clarity.

```

```

# Bump pointers for loop across blocks in one row

```

```

slli t6, nv1, 2
add cnp, cnp, t6           # Move C block pointer over
add bnp, bnp, t6           # Move B block pointer over
sub nt, nt, nv1            # Decrement element count in n dimension
bnez nt, c_col_loop        # Any more to do?

```

```

# Move to next set of rows

```

```

addi m, m, -16 # Did 16 rows above
slli t6, astride, 4 # Multiply astride by 16
add ap, ap, t6      # Move A matrix pointer down 16 rows
slli t6, cstride, 4 # Multiply cstride by 16
add cp, cp, t6      # Move C matrix pointer down 16 rows

```

```

slti t6, m, 16
beqz t6, c_row_loop

```

```

# Handle end of matrix with fewer than 16 rows.

```

```

# Can use smaller versions of above decreasing in powers-of-2 depending on code-size cor
end_rows:
# Not done.

```

```

exit:

```

```

ld s0, OFFSET(sp)
ld s1, OFFSET(sp)
ld s2, OFFSET(sp)
addi sp, sp, FRAMESIZE
ret

```
