16-bit Push/Pop instructions and double-moves

Version 0.1.0, 2025-01-29

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Licensing and Acknowledgements

This document is in the Development state.

Change should be expected

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Acknowledgements

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We express our gratitude to everyone that contributed to, reviewed or improved this specification through their comments and questions.

Versions

This specification documents version 0.1.0 of Xqccmp.

Version History

Version

0.1.0

State

development

Chapter 1. Conventions

Version requirements are specified as conditions using the following operators:

Operator	Meaning
`~> VERSION`	Accepts any version that is *compatible* with `VERSION`. By default, a version A is compatible with a version B if A's version number is greater than or equal to version B. If that default assumption is ever broken, it will be noted in the list of extension versions.
`= VERSION`	Accepts only version `VERSION`.
`>= VERSION`	Accepts any version greater than or equal to `VERSION`.
`<= VERSION`	Accepts any version less than or equal to `VERSION`.
`> VERSION`	Accepts any version greater than `VERSION`.
`< VERSION`	Accepts any version less than `VERSION`.

Chapter 2. Extension description

The Xqccmp extension is a set of instructions which may be executed as a series of existing 32-bit RISC-V instructions.

This extension reuses some encodings from *c.fsdsp*. Therefore it is *incompatible* with [Zcd], which is included when C and D extensions are both present.

Xqccmp is primarily targeted at embedded class CPUs due to implementation complexity. Additionally, it is not compatible with architecture class profiles.

The Xqccmp extension depends on the [Zca] extension.

The Xqccmp extension using same encodings as Zcmp extension for similar instructions, with 2 major differences:

- Order of load and store of registers is opposite to Zcmp order, but compliant with SW ABI
- Xqccmp on top of Zcmp instructions defines qc.cm.pushfp instruction to manage frame pointer

The PUSH/POP assembly syntax uses several variables, the meaning of which are:

- *reg_list* is a list containing 1 to 13 registers (ra and 0 to 12 s registers)
  - valid values: {ra}, {ra, s0}, {ra, s0-s1}, {ra, s0-s2}, ..., {ra, s0-s8}, {ra, s0-s9}, {ra, s0-s11}
  - note that {ra, s0-s10} is *not* valid, giving 12 lists not 13 for better encoding
- *stack_adj* is the total size of the stack frame.
  - valid values vary with register list length and the specific encoding, see the instruction pages for details.

RV32	RV64	Mnemonic	Instruction
yes	yes	qc.cm.push *{reg_list}, -stack_adj*	[insns-qc_cm_push]
yes	yes	qc.cm.pushfp *{reg_list}, -stack_adj*	[insns-qc_cm_pushfp]
yes	yes	qc.cm.pop *{reg_list}, stack_adj*	[insns-qc_cm_pop]
yes	yes	qc.cm.popret *{reg_list}, stack_adj*	[insns-qc_cm_popret]
yes	yes	qc.cm.popretz *{reg_list}, stack_adj*	[insns-qc_cm_popretz]
yes	yes	qc.cm.mva01s *rs1', rs2'*	[insns-qc_cm_mva01s]
yes	yes	qc.cm.mvsa01 *r1s', r2s'*	[insns-qc_cm_mvsa01]

Chapter 3. Instruction summary

The following 7 instructions are added by this extension:

RV32	RV64	Mnemonic	Instruction
✓	✓	`qc.cm.mva01s r1s, r2s`	Move two s0-s7 registers into a0-a1
✓	✓	`qc.cm.mvsa01 r1s, r2s`	Move a0-a1 into two registers of s0-s7
✓	✓	`qc.cm.pop reg_list, stack_adj`	Destroy function call stack frame
✓	✓	`qc.cm.popret reg_list, stack_adj`	Destroy function call stack frame and return to `ra`.
✓	✓	`qc.cm.popretz reg_list, stack_adj`	Destroy function call stack frame, move zero to `a0` and return to `ra`.
✓	✓	`qc.cm.push reg_list, -stack_adj`	Create function call stack frame
✓	✓	`qc.cm.pushfp reg_list, -stack_adj`	Create function call stack frame with frame pointer

Chapter 4. Instructions (in alphabetical order)

4.1. qc.cm.mva01s

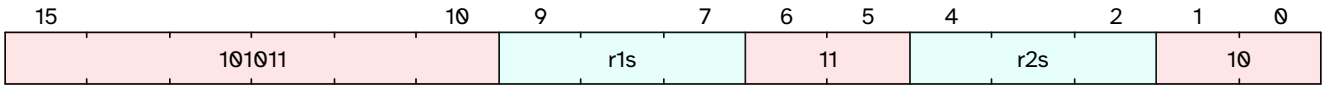
Synopsis

Move two s0-s7 registers into a0-a1

Mnemonic

```
qc.cm.mva01s r1s, r2s
```

Encoding



Description

This instruction moves r1s' into a0 and r2s' into a1. The execution is atomic, so it is not possible to observe state where only one of a0 or a1 have been updated. The encoding uses sreg number specifiers instead of xreg number specifiers to save encoding space. The mapping between them is specified in the pseudo-code below.

Decode Variables

```
Bits<3> r1s = $encoding[9:7];
Bits<3> r2s = $encoding[4:2];
```

Operation

```
if (implemented?(ExtensionName::Zcmp) && (CSR[misa].C == 1'b0)) {
  raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
}
XReg xreg1 = (r1s[2:1] > 0) ? {1, 0, r1s[2:0]} : {0, 1, r1s[2:0]};
XReg xreg2 = (r2s[2:1] > 0) ? {1, 0, r2s[2:0]} : {0, 1, r2s[2:0]};
X[10] = X[xreg1];
X[11] = X[xreg2];
```

Included in

Extension	Version
Xqccmp	~> 0.1.0

4.2. qc.cm.mvsa01

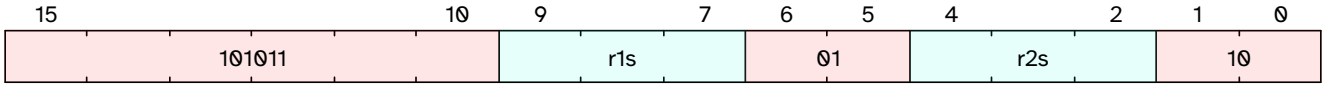
Synopsis

Move a0-a1 into two registers of s0-s7

Mnemonic

```
qc.cm.mvsa01 r1s, r2s
```

Encoding



Description

This instruction moves a0 into r1s' and a1 into r2s'. r1s' and r2s' must be different. The execution is atomic, so it is not possible to observe state where only one of r1s' or r2s' has been updated. The encoding uses sreg number specifiers instead of xreg number specifiers to save encoding space. The mapping between them is specified in the pseudo-code below.

Decode Variables

```
Bits<3> r1s = $encoding[9:7];
Bits<3> r2s = $encoding[4:2];
```

Operation

```
if (implemented?(ExtensionName::Zcmp) && (CSR[misa].C == 1'b0)) {
  raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
}
XReg xreg1 = (r1s[2:1] > 0) ? {1, 0, r1s[2:0]} : {0, 1, r1s[2:0]};
XReg xreg2 = (r2s[2:1] > 0) ? {1, 0, r2s[2:0]} : {0, 1, r2s[2:0]};
X[xreg1] = X[10];
X[xreg2] = X[11];
```

Included in

Extension	Version
Xqccmp	~> 0.1.0

4.3. qc.cm.pop

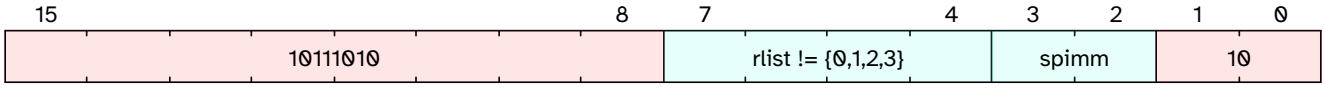
Synopsis

Destroy function call stack frame

Mnemonic

```
qc.cm.pop reg_list, stack_adj
```

Encoding



Description

Destroy stack frame: load ra and 0 to 12 saved registers from the stack frame, deallocate the stack frame. This instruction pops (loads) the registers in `reg_list` from stack memory, and then adjusts the stack pointer by `stack_adj`.

Restrictions on stack_adj:

- it must be enough to store all of the listed registers
- it must be a multiple of 16 (bytes):
  - for RV32 the allowed values are: 16, 32, 48, 64, 80, 96, 112
  - for RV64 the allowed values are: 16, 32, 48, 64, 80, 96, 112, 128, 144, 160

Decode Variables

```
Bits<4> rlist = $encoding[7:4];
Bits<2> spimm = $encoding[3:2];
```

Operation

```
if (implemented?(ExtensionName::Xqccmp) && (CSR[misa].C == 1'b0)) {
  raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
}
XReg size = xlen();
XReg nreg = (rlist == 15) ? 13 : (rlist - 3);
XReg stack_aligned_adj = (nreg * 4 + 15) & ~0xF;
XReg virtual_address_sp = X[2];
XReg virtual_address_new_sp = virtual_address_sp + stack_aligned_adj + spimm;
XReg virtual_address_base = virtual_address_new_sp - size;
X[1] = read_memory_xlen(virtual_address_base - 0 * size, $encoding);
if (nreg > 1) {
  X[8] = read_memory_xlen(virtual_address_base - 1 * size, $encoding);
}
if (nreg > 2) {
```

```
  X[9] = read_memory_xlen(virtual_address_base - 2 * size, $encoding);
}
if (nreg > 3) {
  X[18] = read_memory_xlen(virtual_address_base - 3 * size, $encoding);
}
if (nreg > 4) {
  X[19] = read_memory_xlen(virtual_address_base - 4 * size, $encoding);
}
if (nreg > 5) {
  X[20] = read_memory_xlen(virtual_address_base - 5 * size, $encoding);
}
if (nreg > 6) {
  X[21] = read_memory_xlen(virtual_address_base - 6 * size, $encoding);
}
if (nreg > 7) {
  X[22] = read_memory_xlen(virtual_address_base - 7 * size, $encoding);
}
if (nreg > 8) {
  X[23] = read_memory_xlen(virtual_address_base - 8 * size, $encoding);
}
if (nreg > 9) {
  X[24] = read_memory_xlen(virtual_address_base - 9 * size, $encoding);
}
if (nreg > 10) {
  X[25] = read_memory_xlen(virtual_address_base - 10 * size, $encoding);
}
if (nreg > 11) {
  X[26] = read_memory_xlen(virtual_address_base - 11 * size, $encoding);
  X[27] = read_memory_xlen(virtual_address_base - 12 * size, $encoding);
}
X[2] = virtual_address_new_sp;
```

Included in

Extension	Version
Xqccmp	~> 0.1.0

4.4. qc.cm.popret

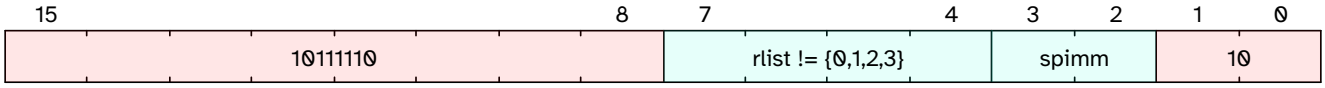
Synopsis

Destroy function call stack frame and return to `ra`.

Mnemonic

```
qc.cm.popret reg_list, stack_adj
```

Encoding



Description

Destroy stack frame: load ra and 0 to 12 saved registers from the stack frame, deallocate the stack frame, return to `ra`. This instruction pops (loads) the registers in `reg_list` from stack memory, and then adjusts the stack pointer by `stack_adj` and then return to ra.

Restrictions on stack_adj:

- it must be enough to store all of the listed registers
- it must be a multiple of 16 (bytes):
  - for RV32 the allowed values are: 16, 32, 48, 64, 80, 96, 112
  - for RV64 the allowed values are: 16, 32, 48, 64, 80, 96, 112, 128, 144, 160

Decode Variables

```
Bits<4> rlist = $encoding[7:4];
Bits<2> spimm = $encoding[3:2];
```

Operation

```
if (implemented?(ExtensionName::Xqccmp) && (CSR[misa].C == 1'b0)) {
  raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
}
XReg size = xlen();
XReg nreg = (rlist == 15) ? 13 : (rlist - 3);
XReg stack_aligned_adj = (nreg * 4 + 15) & ~0xF;
XReg virtual_address_sp = X[2];
XReg virtual_address_new_sp = virtual_address_sp + stack_aligned_adj + spimm;
XReg virtual_address_base = virtual_address_new_sp - size;
X[1] = read_memory_xlen(virtual_address_base - 0 * size, $encoding);
if (nreg > 1) {
  X[8] = read_memory_xlen(virtual_address_base - 1 * size, $encoding);
}
if (nreg > 2) {
```

```
  X[9] = read_memory_xlen(virtual_address_base - 2 * size, $encoding);
}
if (nreg > 3) {
  X[18] = read_memory_xlen(virtual_address_base - 3 * size, $encoding);
}
if (nreg > 4) {
  X[19] = read_memory_xlen(virtual_address_base - 4 * size, $encoding);
}
if (nreg > 5) {
  X[20] = read_memory_xlen(virtual_address_base - 5 * size, $encoding);
}
if (nreg > 6) {
  X[21] = read_memory_xlen(virtual_address_base - 6 * size, $encoding);
}
if (nreg > 7) {
  X[22] = read_memory_xlen(virtual_address_base - 7 * size, $encoding);
}
if (nreg > 8) {
  X[23] = read_memory_xlen(virtual_address_base - 8 * size, $encoding);
}
if (nreg > 9) {
  X[24] = read_memory_xlen(virtual_address_base - 9 * size, $encoding);
}
if (nreg > 10) {
  X[25] = read_memory_xlen(virtual_address_base - 10 * size, $encoding);
}
if (nreg > 11) {
  X[26] = read_memory_xlen(virtual_address_base - 11 * size, $encoding);
  X[27] = read_memory_xlen(virtual_address_base - 12 * size, $encoding);
}
X[2] = virtual_address_new_sp;
jump(X[1]);
```

Included in

Extension	Version
Xqccmp	~> 0.1.0

4.5. qc.cm.popretz

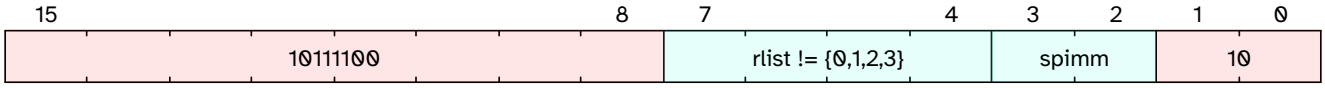
Synopsis

Destroy function call stack frame, move zero to `a0` and return to `ra`.

Mnemonic

```
qc.cm.popretz reg_list, stack_adj
```

Encoding



Description

Destroy stack frame: load `ra` and `0` to 12 saved registers from the stack frame, deallocate the stack frame, move zero to `a0`, return to `ra`. This instruction pops (loads) the registers in `reg_list` from stack memory, and then adjusts the stack pointer by `stack_adj`, move zero to `a0` and then return to `ra`.

Restrictions on stack_adj:

- it must be enough to store all of the listed registers
- it must be a multiple of 16 (bytes):
  - for RV32 the allowed values are: 16, 32, 48, 64, 80, 96, 112
  - for RV64 the allowed values are: 16, 32, 48, 64, 80, 96, 112, 128, 144, 160

Decode Variables

```
Bits<4> rlist = $encoding[7:4];
Bits<2> spimm = $encoding[3:2];
```

Operation

```
if (implemented?(ExtensionName::Xqccmp) && (CSR[misa].C == 1'b0)) {
  raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
}
XReg size = xlen();
XReg nreg = (rlist == 15) ? 13 : (rlist - 3);
XReg stack_aligned_adj = (nreg * 4 + 15) & ~0xF;
XReg virtual_address_sp = X[2];
XReg virtual_address_new_sp = virtual_address_sp + stack_aligned_adj + spimm;
XReg virtual_address_base = virtual_address_new_sp - size;
X[1] = read_memory_xlen(virtual_address_base - 0 * size, $encoding);
if (nreg > 1) {
  X[8] = read_memory_xlen(virtual_address_base - 1 * size, $encoding);
}
if (nreg > 2) {
```

```
  X[9] = read_memory_xlen(virtual_address_base - 2 * size, $encoding);
}
if (nreg > 3) {
  X[18] = read_memory_xlen(virtual_address_base - 3 * size, $encoding);
}
if (nreg > 4) {
  X[19] = read_memory_xlen(virtual_address_base - 4 * size, $encoding);
}
if (nreg > 5) {
  X[20] = read_memory_xlen(virtual_address_base - 5 * size, $encoding);
}
if (nreg > 6) {
  X[21] = read_memory_xlen(virtual_address_base - 6 * size, $encoding);
}
if (nreg > 7) {
  X[22] = read_memory_xlen(virtual_address_base - 7 * size, $encoding);
}
if (nreg > 8) {
  X[23] = read_memory_xlen(virtual_address_base - 8 * size, $encoding);
}
if (nreg > 9) {
  X[24] = read_memory_xlen(virtual_address_base - 9 * size, $encoding);
}
if (nreg > 10) {
  X[25] = read_memory_xlen(virtual_address_base - 10 * size, $encoding);
}
if (nreg > 11) {
  X[26] = read_memory_xlen(virtual_address_base - 11 * size, $encoding);
  X[27] = read_memory_xlen(virtual_address_base - 12 * size, $encoding);
}
X[2] = virtual_address_new_sp;
X[10] = 0;
jump(X[1]);
```

Included in

Extension	Version
Xqccmp	~> 0.1.0

4.6. qc.cm.push

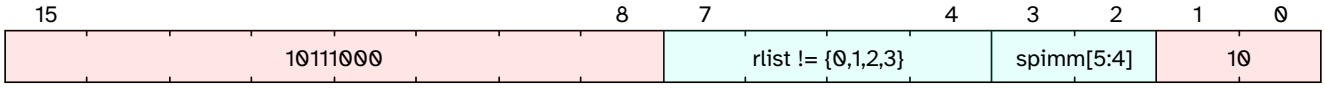
Synopsis

Create function call stack frame

Mnemonic

```
qc.cm.push reg_list, -stack_adj
```

Encoding



Description

Create stack frame: store `ra` and `0` to 12 saved registers to the stack frame, optionally allocate additional stack space. This instruction pushes (stores) the registers in rlist to the memory below the stack pointer, and then creates the stack frame by decrementing the stack pointer by stack_adj, including any additional stack space requested by the value of `spimm`.

Restrictions on stack_adj:

- it must be enough to store all of the listed registers
- it must be a multiple of 16 (bytes):
  - for RV32 the allowed values are: 16, 32, 48, 64, 80, 96, 112
  - for RV64 the allowed values are: 16, 32, 48, 64, 80, 96, 112, 128, 144, 160

Decode Variables

```
Bits<4> rlist = $encoding[7:4];
Bits<6> spimm = {$encoding[3:2], 4'd0};
```

Operation

```
if (implemented?(ExtensionName::Xqccmp) && (CSR[misa].C == 1'b0)) {
  raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
}
XReg size = xlen();
XReg nreg = (rlist == 15) ? 13 : (rlist - 3);
XReg stack_aligned_adj = (nreg * 4 + 15) & ~0xF;
XReg virtual_address_sp = X[2];
XReg virtual_address_new_sp = virtual_address_sp - stack_aligned_adj - spimm;
XReg virtual_address_base = virtual_address_sp - size;
write_memory_xlen(virtual_address_base - 0 * size, X[1], $encoding);
if (nreg > 1) {
  write_memory_xlen(virtual_address_base - 1 * size, X[8], $encoding);
}
```

```
if (nreg > 2) {
  write_memory_xlen(virtual_address_base - 2 * size, X[9], $encoding);
}
if (nreg > 3) {
  write_memory_xlen(virtual_address_base - 3 * size, X[18], $encoding);
}
if (nreg > 4) {
  write_memory_xlen(virtual_address_base - 4 * size, X[19], $encoding);
}
if (nreg > 5) {
  write_memory_xlen(virtual_address_base - 5 * size, X[20], $encoding);
}
if (nreg > 6) {
  write_memory_xlen(virtual_address_base - 6 * size, X[21], $encoding);
}
if (nreg > 7) {
  write_memory_xlen(virtual_address_base - 7 * size, X[22], $encoding);
}
if (nreg > 8) {
  write_memory_xlen(virtual_address_base - 8 * size, X[23], $encoding);
}
if (nreg > 9) {
  write_memory_xlen(virtual_address_base - 9 * size, X[24], $encoding);
}
if (nreg > 10) {
  write_memory_xlen(virtual_address_base - 10 * size, X[25], $encoding);
}
if (nreg > 11) {
  write_memory_xlen(virtual_address_base - 11 * size, X[26], $encoding);
  write_memory_xlen(virtual_address_base - 12 * size, X[27], $encoding);
}
X[2] = virtual_address_new_sp;
```

Included in

Extension	Version
Xqccmp	~> 0.1.0

4.7. qc.cm.pushfp

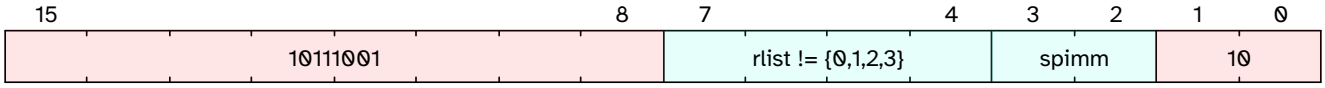
Synopsis

Create function call stack frame with frame pointer

Mnemonic

```
qc.cm.pushfp reg_list, -stack_adj
```

Encoding



Description

Create stack frame: store `ra` and `0` to 12 saved registers to the stack frame, optionally allocate additional stack space. As well, instruction initializes frame pointer (`fp`, aka `x8`) to the Canonical Frame Address (`sp` aka `x2`) on function entry. This instruction pushes (stores) the registers in rlist to the memory below the stack pointer, and then creates the stack frame by decrementing the stack pointer by stack_adj, including any additional stack space requested by the value of `spimm`.

Restrictions on stack_adj:

- it must be enough to store all of the listed registers
- it must be a multiple of 16 (bytes):
  - for RV32 the allowed values are: 16, 32, 48, 64, 80, 96, 112
  - for RV64 the allowed values are: 16, 32, 48, 64, 80, 96, 112, 128, 144, 160

Decode Variables

```
Bits<4> rlist = $encoding[7:4];
Bits<2> spimm = $encoding[3:2];
```

Operation

```
if (implemented?(ExtensionName::Xqccmp) && (CSR[misa].C == 1'b0)) {
  raise(ExceptionCode::IllegalInstruction, mode(), $encoding);
}
XReg size = xlen();
XReg nreg = (rlist == 15) ? 13 : (rlist - 3);
XReg stack_aligned_adj = (nreg * 4 + 15) & ~0xF;
XReg virtual_address_sp = X[2];
XReg virtual_address_new_sp = virtual_address_sp - stack_aligned_adj - spimm;
XReg virtual_address_base = virtual_address_sp - size;
write_memory_xlen(virtual_address_base - 0 * size, X[1], $encoding);
if (nreg > 1) {
  write_memory_xlen(virtual_address_base - 1 * size, X[8], $encoding);
```

```
}
if (nreg > 2) {
  write_memory_xlen(virtual_address_base - 2 * size, X[9], $encoding);
}
if (nreg > 3) {
  write_memory_xlen(virtual_address_base - 3 * size, X[18], $encoding);
}
if (nreg > 4) {
  write_memory_xlen(virtual_address_base - 4 * size, X[19], $encoding);
}
if (nreg > 5) {
  write_memory_xlen(virtual_address_base - 5 * size, X[20], $encoding);
}
if (nreg > 6) {
  write_memory_xlen(virtual_address_base - 6 * size, X[21], $encoding);
}
if (nreg > 7) {
  write_memory_xlen(virtual_address_base - 7 * size, X[22], $encoding);
}
if (nreg > 8) {
  write_memory_xlen(virtual_address_base - 8 * size, X[23], $encoding);
}
if (nreg > 9) {
  write_memory_xlen(virtual_address_base - 9 * size, X[24], $encoding);
}
if (nreg > 10) {
  write_memory_xlen(virtual_address_base - 10 * size, X[25], $encoding);
}
if (nreg > 11) {
  write_memory_xlen(virtual_address_base - 11 * size, X[26], $encoding);
  write_memory_xlen(virtual_address_base - 12 * size, X[27], $encoding);
}
X[8] = virtual_address_sp;
X[2] = virtual_address_new_sp;
```

Included in

Extension	Version
Xqccmp	~> 0.1.0

Chapter 5. IDL Functions