



## OVP Guide to Using Processor Models

### Model specific information for RISC-V\_RV32GCV

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# Chapter 1

## Overview

This document provides the details of an OVP Fast Processor Model variant.

OVP Fast Processor Models are written in C and provide a C API for use in C based platforms. The models also provide a native interface for use in SystemC TLM2 platforms.

The models are written using the OVP VMI API that provides a Virtual Machine Interface that defines the behavior of the processor. The VMI API makes a clear line between model and simulator allowing very good optimization and world class high speed performance. Most models are provided as a binary shared object and also as source. This allows the download and use of the model binary or the use of the source to explore and modify the model.

The models are run through an extensive QA and regression testing process and most model families are validated using technology provided by the processor IP owners. There is a companion document (OVP Guide to Using Processor Models) which explains the general concepts of OVP Fast Processor Models and their use. It is downloadable from the OVPworld website documentation pages.

### 1.1 Description

RISC-V RV32GCV 32-bit processor model

### 1.2 Licensing

This Model is released under the Open Source Apache 2.0

## 1.3 Extensions

### 1.3.1 Extensions Enabled by Default

The model has the following architectural extensions enabled, and the following bits in the `misa` CSR Extensions field will be set upon reset:

`misa` bit 0: extension A (atomic instructions)

`misa` bit 2: extension C (compressed instructions)

`misa` bit 3: extension D (double-precision floating point)

`misa` bit 5: extension F (single-precision floating point)

`misa` bit 8: RV32I/RV64I/RV128I base integer instruction set

`misa` bit 12: extension M (integer multiply/divide instructions)

`misa` bit 18: extension S (Supervisor mode)

`misa` bit 20: extension U (User mode)

`misa` bit 21: extension V (vector extension)

To specify features that can be dynamically enabled or disabled by writes to the `misa` register in addition to those listed above, use parameter “`add_Extensions_mask`”. This is a string parameter containing the feature letters to add; for example, value “DV” indicates that double-precision floating point and the Vector Extension can be enabled or disabled by writes to the `misa` register, if supported on this variant.

Legacy parameter “`misa_Extensions_mask`” can also be used. This `Uns32`-valued parameter specifies all writable bits in the `misa` Extensions field, replacing any permitted bits defined in the base variant.

Note that any features that are indicated as present in the `misa` mask but absent in the `misa` will be ignored. See the next section.

### 1.3.2 Available Extensions Not Enabled by Default

The following extensions are supported by the model, but not enabled by default in this variant:

`misa` bit 1: extension B (bit manipulation extension)

`misa` bit 4: RV32E base integer instruction set (embedded)

`misa` bit 7: extension H (hypervisor)

`misa` bit 10: extension K (cryptographic)

`misa` bit 13: extension N (user-level interrupts)

`misa` bit 23: extension X (non-standard extensions present)

To add features from this list to the base variant, use parameter “`add_Extensions`”. This is a string parameter containing the feature letters to add; for example, value “DV” indicates that double-precision floating point and the Vector Extension should be enabled, if they are currently absent

and are available on this variant.

Legacy parameter “`misa_Extensions`” can also be used. This `Uns32`-valued parameter specifies the reset value for the `misa` CSR Extensions field, replacing any permitted bits defined in the base variant.

## 1.4 General Features

On this variant, the Machine trap-vector base-address register (`mtvec`) is writable. It can instead be configured as read-only using parameter “`mtvec_is_ro`”.

Values written to “`mtvec`” are masked using the value `0xffffffd`. A different mask of writable bits may be specified using parameter “`mtvec_mask`” if required. In addition, when Vectored interrupt mode is enabled, parameter “`tvec_align`” may be used to specify additional hardware-enforced base address alignment. In this variant, “`tvec_align`” defaults to 0, implying no alignment constraint.

The initial value of “`mtvec`” is `0x0`. A different value may be specified using parameter “`mtvec`” if required.

Values written to “`stvec`” are masked using the value `0xffffffd`. A different mask of writable bits may be specified using parameter “`stvec_mask`” if required. parameter “`tvec_align`” may be used to specify additional hardware-enforced base address alignment in the same manner as for the “`mtvec`” register, described above.

On reset, the model will restart at address `0x0`. A different reset address may be specified using parameter “`reset_address`” or applied using optional input port “`reset_addr`” if required.

On an NMI, the model will restart at address `0x0`. A different NMI address may be specified using parameter “`nmi_address`” or applied using optional input port “`nmi_addr`” if required.

WFI will halt the processor until an interrupt occurs. It can instead be configured as a NOP using parameter “`wfi_is_nop`”. WFI timeout wait is implemented with a time limit of 0 (i.e. WFI causes an Illegal Instruction trap in Supervisor mode when `mstatus.TW=1`).

The “`cycle`” CSR is implemented in this variant. Set parameter “`cycle_undefined`” to `True` to instead specify that “`cycle`” is unimplemented and reads of it should trap to Machine mode.

The “`time`” CSR is implemented in this variant. Set parameter “`time_undefined`” to `True` to instead specify that “`time`” is unimplemented and reads of it should trap to Machine mode. Usually, the value of the “`time`” CSR should be provided by the platform - see notes below about the artifact “`CSR`” bus for information about how this is done.

The “`instret`” CSR is implemented in this variant. Set parameter “`instret_undefined`” to `True` to instead specify that “`instret`” is unimplemented and reads of it should trap to Machine mode.

A 9-bit ASID is implemented. Use parameter “`ASID_bits`” to specify a different implemented ASID size if required.

This variant supports address translation modes 0 and 1. Use parameter “`Sv_modes`” to specify a bit mask of different modes if required.

TLB behavior is controlled by parameter “`ASIDCacheSize`”. If this parameter is 0, then an unlimited number of TLB entries will be maintained concurrently. If this parameter is non-zero,



then only TLB entries for up to “ASIDCacheSize” different ASIDs will be maintained concurrently initially; as new ASIDs are used, TLB entries for less-recently used ASIDs are deleted, which improves model performance in some cases. If the model detects that the TLB entry cache is too small (entry ejections are very frequent), it will increase the cache size automatically. In this variant, “ASIDCacheSize” is 8

Unaligned memory accesses are not supported by this variant. Set parameter “unaligned” to “T” to enable such accesses.

Unaligned memory accesses are not supported for AMO instructions by this variant. Set parameter “unalignedAMO” to “T” to enable such accesses.

16 PMP entries are implemented by this variant. Use parameter “PMP\_registers” to specify a different number of PMP entries; set the parameter to 0 to disable the PMP unit. The PMP grain size (G) is 0, meaning that PMP regions as small as 4 bytes are implemented. Use parameter “PMP\_grain” to specify a different grain size if required. Unaligned PMP accesses are not decomposed into separate aligned accesses; use parameter “PMP\_decompose” to modify this behavior if required.

LR/SC instructions are implemented with a 1-byte reservation granule. A different granule size may be specified using parameter “lr\_sc\_grain”.

## 1.5 Floating Point Features

The D extension is enabled in this variant independently of the F extension. Set parameter “d\_requires\_f” to “T” to specify that the D extension requires the F extension to be enabled.

Half precision floating point is not implemented. Use parameter “Zfh” to enable this if required.

By default, the processor starts with floating-point instructions disabled (mstatus.FS=0). Use parameter “mstatus\_FS” to force mstatus.FS to a non-zero value for floating-point to be enabled from the start.

The specification is imprecise regarding the conditions under which mstatus.FS is set to Dirty state (3). Parameter “mstatus\_fs\_mode” can be used to specify the required behavior in this model, as described below.

If “mstatus\_fs\_mode” is set to “always\_dirty” then the model implements a simplified floating point status view in which mstatus.FS holds values 0 (Off) and 3 (Dirty) only; any write of values 1 (Initial) or 2 (Clean) from privileged code behave as if value 3 was written.

If “mstatus\_fs\_mode” is set to “write\_1” then mstatus.FS will be set to 3 (Dirty) by any explicit write to the fflags, frm or fcsr control registers, or by any executed instruction that writes an FPR, or by any executed floating point compare or conversion to integer/unsigned that signals a floating point exception. Floating point compare or conversion to integer/unsigned instructions that do not signal an exception will not set mstatus.FS.

If “mstatus\_fs\_mode” is set to “write\_any” then mstatus.FS will be set to 3 (Dirty) by any explicit write to the fflags, frm or fcsr control registers, or by any executed instruction that writes an FPR, or by any executed floating point compare or conversion even if those instructions do not signal a floating point exception.

In this variant, “mstatus\_fs\_mode” is set to “write\_1”.

## 1.6 Vector Extension

This variant implements the RISC-V base vector extension with version specified in the References section of this document. Note that parameter “vector\_version” can be used to select the required version, including the unstable “master” version corresponding to the active specification. See section “Vector Extension Versions” for detailed information about differences between each supported version.

### 1.6.1 Vector Extension Parameters

Parameter ELEN is used to specify the maximum size of a single vector element in bits (32 or 64). By default, ELEN is set to 64 in this variant.

Parameter VLEN is used to specify the number of bits in a vector register (a power of two in the range 32 to 65536). By default, VLEN is set to 512 in this variant.

Parameter SLEN is used to specify the striping distance (a power of two in the range 32 to 65536). By default, SLEN is set to 512 in this variant.

Parameter SEW\_min is used to specify the minimum supported SEW (a power of two in the range 8 to ELEN). By default, SEW\_min is set to 8 in this variant.

Parameter Zvlsseg is used to specify whether the Zvlsseg extension is implemented. By default, Zvlsseg is set to 1 in this variant.

Parameter Zvamo is used to specify whether the Zvamo extension is implemented. By default, Zvamo is set to 1 in this variant.

Parameter Zvediv will be used to specify whether the Zvediv extension is implemented. This is not currently supported.

Parameter Zvqmac is used to specify whether the Zvqmac extension is implemented (from version 0.8-draft-20191117 only). By default, Zvqmac is set to 1 in this variant.

Parameter require\_vstart0 is used to specify whether non-interruptible vector instructions require vstart=0. By default, require\_vstart0 is set to 0 in this variant.

Parameter align\_whole is used to specify whether whole-register load and store instructions require alignment to the encoded EEW. By default, align\_whole is set to 0 in this variant.

Parameter vill\_trap is used to specify whether attempts to write illegal values to vtype cause an Illegal Instruction trap. By default, vill\_trap is set to 0 in this variant.

### 1.6.2 Vector Extension Features

The model implements the base vector extension with a maximum ELEN of 64. Striping, masking and polymorphism are all fully supported. Zvlsseg and Zvamo extensions are fully supported. The Zvediv extension specification is subject to change and therefore not yet supported.

Single precision and double precision floating point types are supported if those types are also supported in the base architecture (i.e. the corresponding D and F features must be present and enabled). Vector floating point operations may only be executed if the base floating point unit is also enabled (i.e. `mstatus.FS` must be non-zero). Attempting to execute vector floating point instructions when `mstatus.FS` is 0 will cause an Illegal Instruction exception.

The model assumes that all vector memory operations must be aligned to the memory element size. Unaligned accesses will cause a Load/Store Address Alignment exception.

By default, the processor starts with vector extension disabled (`mstatus.VS=0`). Use parameter “`mstatus_VS`” to force `mstatus.VS` to a non-zero value for the vector extension to be enabled from the start.

### 1.6.3 Vector Extension Versions

The Vector Extension specification has been under active development. To enable simulation of hardware that may be based on an older version of the specification, the model implements behavior for a number of previous versions of the specification. The differing features of these are listed below, in chronological order.

#### 1.6.4 Version 0.7.1-draft-20190605

Stable 0.7.1 version of June 10 2019.

#### 1.6.5 Version 0.7.1-draft-20190605+

Version 0.7.1, with some 0.8 and custom features. Not intended for general use.

#### 1.6.6 Version 0.8-draft-20190906

Stable 0.8 draft of September 6 2019, with these changes compared to version 0.7.1-draft-20190605:

- tail vector and scalar elements preserved, not zeroed;
- `vext.s.v`, `vmford.vv` and `vmford.vf` instructions removed;
- encodings for `vfmv.f.s`, `vfmv.s.f`, `vmv.s.x`, `vpopc.m`, `vfirst.m`, `vmsbf.m`, `vmsif.m`, `vmsof.m`, `viota.m` and `vid.v` instructions changed;
- overlap constraints for `slideup` and `slidedown` instructions relaxed to allow overlap of destination and mask when `SEW=1`;
- 64-bit vector AMO operations replaced with SEW-width vector AMO operations;
- `vsetvl` and `vsetvli` instructions when `rs1 = x0` preserve the current `vl` instead of selecting the maximum possible `vl`;
- instruction `vfnvvt.rod.ff.w` added (to allow narrowing floating point conversions with jamming semantics);

- instructions that transfer values between vector registers and general purpose registers (`vmv.s.x` and `vmv.x.s`) sign-extend the source if required (previously, it was zero-extended).

### 1.6.7 Version 0.8-draft-20191004

Stable 0.8 draft of October 4 2019, with these changes compared to version 0.8-draft-20190906:

- `vwmaccsu` and `vwmaccus` instruction encodings exchanged;
- `vwsmacsu` and `vwsmacus` instruction encodings exchanged.

### 1.6.8 Version 0.8-draft-20191117

Stable 0.8 draft of November 17 2019, with these changes compared to version 0.8-draft-20191004:

- indexed load/store instructions zero-extend offsets (previously, they were sign-extended);
- `vslide1up/vslide1down` instructions sign-extend `XLEN` values to `SEW` length (previously, they were zero-extended);
- `vadc/vsbc` instruction encodings require `vm=0` (previously, they required `vm=1`);
- `vmadc/vmsbc` instruction encodings allow both `vm=0`, implying carry input is used, and `vm=1`, implying carry input is zero (previously, only `vm=1` was permitted, implying carry input is used);
- `vaaddu.vv`, `vaaddu.vx`, `vasubu.vv` and `vasubu.vx` instructions added;
- `vaadd.vv` and `vaadd.vx`, instruction encodings changed;
- `vaadd.vi` instruction removed;
- all widening saturating scaled multiply-add instructions removed;
- `vqmaccu.vv`, `vqmaccu.vx`, `vqmacc.vv`, `vqmacc.vx`, `vqmacc.vx`, `vqmaccsu.vx` and `vqmaccus.vx` instructions added;
- CSR `vlenb` added (vector register length in bytes);
- load/store whole register instructions added;
- whole register move instructions added.

### 1.6.9 Version 0.8-draft-20191118

Stable 0.8 draft of November 18 2019, with these changes compared to version 0.8-draft-20191117:

- `vsetvl/vsetvli` with `rd!=zero` and `rs1=zero` sets `vl` to the maximum vector length.

### 1.6.10 Version 0.8

Stable 0.8 official release (commit 9a65519), with these changes compared to version 0.8-draft-20191118:

- vector context status in mstatus register is now implemented;
- whole register load and store operations have been restricted to a single register only;
- whole register move operations have been restricted to aligned groups of 1, 2, 4 or 8 registers only.

### 1.6.11 Version 0.9

Stable 0.9 official release (commit cb7d225), with these significant changes compared to version 0.8:

- mstatus.VS and sstatus.VS fields moved to bits 10:9;
- new CSR vcsr added and fields VXSAT and VXRM relocated there from CSR fcsr;
- vfslide1up.vf, vfslide1down.vf, vfcvt.rtz.xu.f.v, vfcvt.rtz.x.f.v, vfwcvt.rtz.xu.f.v, vfwcvt.rtz.x.f.v, vfnvcvt.rtz.xu.f.v, vfnvcvt.rtz.x.f.v, vzext.vf2, vsxt.vf2, vzext.vf4, vsxt.vf4, vzext.vf8 and vsxt.vf8 instructions added;
- fractional LMUL support added, controlled by an extended vtype.vlmul CSR field;
- vector tail agnostic and vector mask agnostic fields added to the vtype CSR;
- all vector load/store instructions replaced with new instructions that explicitly encode EEW of data or index;
- whole register load and store operation encodings changed;
- VFUNARY0 and VFUNARY1 encodings changed;
- MLEN is always 1;
- for implementations with SLEN != VLEN, striping is applied horizontally rather than the previous vertical striping;
- vmsbf.m, vmsif.m and vmsof.m no longer allow overlap of destination with source or mask registers.

### 1.6.12 Version 1.0-draft-20210130

Stable 1.0-draft-20210130 official release (commit 8e768b0), with these changes compared to version 0.9:

- SLEN=VLEN register layout is mandatory;
- ELEN>VLEN is now supported for LMUL>1;
- whole register moves and load/stores now have element size hints;
- whole register load and store operations now permit use of aligned groups of 1, 2, 4 or 8 registers.
- overlap constraints for different source/destination EEW changed;
- instructions vfrsqrt7.v, vfrec7.v and vrgatherei16.vv added;
- CSR vtype format changed to make vlmul bits contiguous.

- vsetvli x0, x0, imm instruction is reserved if it would cause vl to change;
- ordered/unordered indexed vector memory instructions added;
- instructions vle1.v, vse1.v and vsetivli added.

### 1.6.13 Version master

Unstable master version as of 19 March 2021 (commit 4ab6506), with these changes compared to version 1.0-draft-20210130:

- instructions vle1.v/vse1.v renamed vlm.v/vsm.v.

## 1.7 CLIC

The model can be configured to implement a Core Local Interrupt Controller (CLIC) using parameter “CLICLEVELS”; when non-zero, the CLIC is present with the specified number of interrupt levels (2-256), as described in the RISC-V Core-Local Interrupt Controller specification, and further parameters are made available to configure other aspects of the CLIC. “CLICLEVELS” is zero in this variant, indicating that a CLIC is not implemented.

## 1.8 Load-Reserved/Store-Conditional Locking

By default, LR/SC locking is implemented automatically by the model and simulator, with a reservation granule defined by the “lr\_sc\_grain” parameter. It is also possible to implement locking externally to the model in a platform component, using the “LR\_address”, “SC\_address” and “SC\_valid” net ports, as described below.

The “LR\_address” output net port is written by the model with the address used by a load-reserved instruction as it executes. This port should be connected as an input to the external lock management component, which should record the address, and also that an LR/SC transaction is active.

The “SC\_address” output net port is written by the model with the address used by a store-conditional instruction as it executes. This should be connected as an input to the external lock management component, which should compare the address with the previously-recorded load-reserved address, and determine from this (and other implementation-specific constraints) whether the store should succeed. It should then immediately write the Boolean success/fail code to the “SC\_valid” input net port of the model. Finally, it should update state to indicate that an LR/SC transaction is no longer active.

It is also possible to write zero to the “SC\_valid” input net port at any time outside the context of a store-conditional instruction, which will mark any active LR/SC transaction as invalid.

Irrespective of whether LR/SC locking is implemented internally or externally, taking any exception or interrupt or executing exception-return instructions (e.g. MRET) will always mark any active LR/SC transaction as invalid.

## 1.9 Active Atomic Operation Indication

The “AMO\_active” output net port is written by the model with a code indicating any current atomic memory operation while the instruction is active. The written codes are:

0: no atomic instruction active

1: AMOMIN active

2: AMOMAX active

3: AMOMINU active

4: AMOMAXU active

5: AMOADD active

6: AMOXOR active

7: AMOOR active

8: AMOAND active

9: AMOSWAP active

10: LR active

11: SC active

## 1.10 Interrupts

The “reset” port is an active-high reset input. The processor is halted when “reset” goes high and resumes execution from the reset address specified using the “reset\_address” parameter or “reset\_addr” port when the signal goes low. The “mcause” register is cleared to zero.

The “nmi” port is an active-high NMI input. The processor resumes execution from the address specified using the “nmi\_address” parameter or “nmi\_addr” port when the NMI signal goes high. The “mcause” register is cleared to zero.

All other interrupt ports are active high. For each implemented privileged execution level, there are by default input ports for software interrupt, timer interrupt and external interrupt; for example, for Machine mode, these are called “MSWInterrupt”, “MTimerInterrupt” and “MExternalInterrupt”, respectively. When the N extension is implemented, ports are also present for User mode. Parameter “unimp\_int\_mask” allows the default behavior to be changed to exclude certain interrupt ports. The parameter value is a mask in the same format as the “mip” CSR; any interrupt corresponding to a non-zero bit in this mask will be removed from the processor and read as zero in “mip”, “mie” and “mideleg” CSRs (and Supervisor and User mode equivalents if implemented).

Parameter “external\_int\_id” can be used to enable extra interrupt ID input ports on each hart. If the parameter is True then when an external interrupt is applied the value on the ID port is sampled and used to fill the Exception Code field in the “mcause” CSR (or the equivalent CSR for other execution levels). For Machine mode, the extra interrupt ID port is called “MExternalInterruptID”.

The “deferint” port is an active-high artifact input that, when written to 1, prevents any pending-

and-enabled interrupt being taken (normally, such an interrupt would be taken on the next instruction after it becomes pending-and-enabled). The purpose of this signal is to enable alignment with hardware models in step-and-compare usage.

## 1.11 Debug Mode

The model can be configured to implement Debug mode using parameter “debug\_mode”. This implements features described in Chapter 4 of the RISC-V External Debug Support specification with version specified by parameter “debug\_version” (see References). Some aspects of this mode are not defined in the specification because they are implementation-specific; the model provides infrastructure to allow implementation of a Debug Module using a custom harness. Features added are described below.

Parameter “debug\_mode” can be used to specify three different behaviors, as follows:

1. If set to value “vector”, then operations that would cause entry to Debug mode result in the processor jumping to the address specified by the “debug\_address” parameter. It will execute at this address, in Debug mode, until a “dret” instruction causes return to non-Debug mode. Any exception generated during this execution will cause a jump to the address specified by the “dexc\_address” parameter.
2. If set to value “interrupt”, then operations that would cause entry to Debug mode result in the processor simulation call (e.g. `opProcessorSimulate`) returning, with a stop reason of `OP_SR_INTERRUPT`. In this usage scenario, the Debug Module is implemented in the simulation harness.
3. If set to value “halt”, then operations that would cause entry to Debug mode result in the processor halting. Depending on the simulation environment, this might cause a return from the simulation call with a stop reason of `OP_SR_HALT`, or debug mode might be implemented by another platform component which then restarts the debugged processor again.

### 1.11.1 Debug State Entry

The specification does not define how Debug mode is implemented. In this model, Debug mode is enabled by a Boolean pseudo-register, “DM”. When “DM” is True, the processor is in Debug mode. When “DM” is False, mode is defined by “mstatus” in the usual way.

Entry to Debug mode can be performed in any of these ways:

1. By writing True to register “DM” (e.g. using `opProcessorRegWrite`) followed by simulation of at least one cycle (e.g. using `opProcessorSimulate`), `dcsr.cause` will be reported as trigger;
2. By writing a 1 then 0 to net “haltreq” (using `opNetWrite`) followed by simulation of at least one cycle (e.g. using `opProcessorSimulate`);
3. By writing a 1 to net “resethaltreq” (using `opNetWrite`) while the “reset” signal undergoes a negedge transition, followed by simulation of at least one cycle (e.g. using `opProcessorSimulate`);
4. By executing an “ebreak” instruction when Debug mode entry for the current processor mode is enabled by `dcsr.ebreakm`, `dcsr.ebreaks` or `dcsr.ebreaku`.



In all cases, the processor will save required state in “dpc” and “dcsr” and then perform actions described above, depending in the value of the “debug\_mode” parameter.

### 1.11.2 Debug State Exit

Exit from Debug mode can be performed in any of these ways:

1. By writing False to register “DM” (e.g. using `opProcessorRegWrite`) followed by simulation of at least one cycle (e.g. using `opProcessorSimulate`);
2. By executing an “dret” instruction when Debug mode.

In both cases, the processor will perform the steps described in section 4.6 (Resume) of the Debug specification.

### 1.11.3 Debug Registers

When Debug mode is enabled, registers “dcsr”, “dpc”, “dscratch0” and “dscratch1” are implemented as described in the specification. These may be manipulated externally by a Debug Module using `opProcessorRegRead` or `opProcessorRegWrite`; for example, the Debug Module could write “dcsr” to enable “ebreak” instruction behavior as described above, or read and write “dpc” to emulate stepping over an “ebreak” instruction prior to resumption from Debug mode.

### 1.11.4 Debug Mode Execution

The specification allows execution of code fragments in Debug mode. A Debug Module implementation can cause execution in Debug mode by the following steps:

1. Write the address of a Program Buffer to the program counter using `opProcessorPCSet`;
2. If “debug\_mode” is set to “halt”, write 0 to pseudo-register “DMStall” (to leave halted state);
3. If entry to Debug mode was handled by exiting the simulation callback, call `opProcessorSimulate` or `opRootModuleSimulate` to resume simulation.

Debug mode will be re-entered in these cases:

1. By execution of an “ebreak” instruction; or:
2. By execution of an instruction that causes an exception.

In both cases, the processor will either jump to the debug exception address, or return control immediately to the harness, with `stopReason` of `OP_SR_INTERRUPT`, or perform a halt, depending on the value of the “debug\_mode” parameter.

### 1.11.5 Debug Single Step

When in Debug mode, the processor or harness can cause a single instruction to be executed on return from that mode by setting `dcsr.step`. After one non-Debug-mode instruction has been

executed, control will be returned to the harness. The processor will remain in single-step mode until `dcsr.step` is cleared.

### 1.11.6 Debug Ports

Port “DM” is an output signal that indicates whether the processor is in Debug mode

Port “haltreq” is a rising-edge-triggered signal that triggers entry to Debug mode (see above).

Port “resethaltreq” is a level-sensitive signal that triggers entry to Debug mode after reset (see above).

## 1.12 Trigger Module

This model is configured with a trigger module, implementing a subset of the behavior described in Chapter 5 of the RISC-V External Debug Support specification with version specified by parameter “`debug_version`” (see References).

### 1.12.1 Trigger Module Restrictions

The model currently supports `tdata1` of type 0, type 2 (`mcontrol`), type 3 (`icount`), type 4 (`itrigger`), type 5 (`etrigger`) and type 6 (`mcontrol6`). `icount` triggers are implemented for a single instruction only, with count hard-wired to 1 and automatic zeroing of mode bits when the trigger fires.

### 1.12.2 Trigger Module Parameters

Parameter “`trigger_num`” is used to specify the number of implemented triggers. In this variant, “`trigger_num`” is 4.

Parameter “`tinfo`” is used to specify the value of the read-only “`tinfo`” register, which indicates the trigger types supported. In this variant, “`tinfo`” is 0x7d.

Parameter “`tinfo_undefined`” is used to specify whether the “`tinfo`” register is undefined, in which case reads of it trap to Machine mode. In this variant, “`tinfo_undefined`” is 0.

Parameter “`tcontrol_undefined`” is used to specify whether the “`tcontrol`” register is undefined, in which case accesses to it trap to Machine mode. In this variant, “`tcontrol_undefined`” is 0.

Parameter “`mcontext_undefined`” is used to specify whether the “`mcontext`” register is undefined, in which case accesses to it trap to Machine mode. In this variant, “`mcontext_undefined`” is 0.

Parameter “`scontext_undefined`” is used to specify whether the “`scontext`” register is undefined, in which case accesses to it trap to Machine mode. In this variant, “`scontext_undefined`” is 0.

Parameter “`mscontext_undefined`” is used to specify whether the “`mscontext`” register is undefined, in which case accesses to it trap to Machine mode. In this variant, “`mscontext_undefined`” is 0.

Parameter “`amo_trigger`” is used to specify whether load/store triggers are activated for AMO instructions. In this variant, “`amo_trigger`” is 0.

Parameter “no\_hit” is used to specify whether the “hit” bit in tdata1 is unimplemented. In this variant, “no\_hit” is 0.

Parameter “no\_sselect\_2” is used to specify whether the “sselect” field in “textra32”/“textra64” registers is unable to hold value 2 (indicating match by ASID is not allowed). In this variant, “no\_sselect\_2” is 0.

Parameter “mcontext\_bits” is used to specify the number of writable bits in the “mcontext” register. In this variant, “mcontext\_bits” is 6.

Parameter “scontext\_bits” is used to specify the number of writable bits in the “scontext” register. In this variant, “scontext\_bits” is 16.

Parameter “mvalue\_bits” is used to specify the number of writable bits in the “mvalue” field in “textra32”/“textra64” registers; if zero, the “mselect” field is tied to zero. In this variant, “mvalue\_bits” is 6.

Parameter “svalue\_bits” is used to specify the number of writable bits in the “svalue” field in “textra32”/“textra64” registers; if zero, the “sselect” is tied to zero. In this variant, “svalue\_bits” is 16.

Parameter “mcontrol\_maskmax” is used to specify the value of field “maskmax” in the “mcontrol” register. In this variant, “mcontrol\_maskmax” is 63.

## 1.13 Debug Mask

It is possible to enable model debug messages in various categories. This can be done statically using the “override\_debugMask” parameter, or dynamically using the “debugflags” command. Enabled messages are specified using a bitmask value, as follows:

Value 0x002: enable debugging of PMP and virtual memory state;

Value 0x004: enable debugging of interrupt state.

All other bits in the debug bitmask are reserved and must not be set to non-zero values.

## 1.14 Integration Support

This model implements a number of non-architectural pseudo-registers and other features to facilitate integration.

### 1.14.1 CSR Register External Implementation

If parameter “enable\_CSR\_bus” is True, an artifact 16-bit bus “CSR” is enabled. Slave callbacks installed on this bus can be used to implement modified CSR behavior (use opBusSlaveNew or icmMapExternalMemory, depending on the client API). A CSR with index 0xABC is mapped on the bus at address 0xABC0; as a concrete example, implementing CSR “time” (number 0xC01) externally requires installation of callbacks at address 0xC010 on the CSR bus.

### 1.14.2 LR/SC Active Address

Artifact register “LRSCAddress” shows the active LR/SC lock address. The register holds all-ones if there is no LR/SC operation active or if LR/SC locking is implemented externally as described above.

## 1.15 Limitations

Instruction pipelines are not modeled in any way. All instructions are assumed to complete immediately. This means that instruction barrier instructions (e.g. fence.i) are treated as NOPs, with the exception of any Illegal Instruction behavior, which is modeled.

Caches and write buffers are not modeled in any way. All loads, fetches and stores complete immediately and in order, and are fully synchronous. Data barrier instructions (e.g. fence) are treated as NOPs, with the exception of any Illegal Instruction behavior, which is modeled.

Real-world timing effects are not modeled: all instructions are assumed to complete in a single cycle.

Hardware Performance Monitor registers are not implemented and hardwired to zero.

The TLB is architecturally-accurate but not device accurate. This means that all TLB maintenance and address translation operations are fully implemented but the cache is larger than in the real device.

## 1.16 Verification

All instructions have been extensively tested by Imperas, using tests generated specifically for this model and also reference tests from <https://github.com/riscv/riscv-tests>.

Also reference tests have been used from various sources including:

<https://github.com/riscv/riscv-tests>

<https://github.com/ucb-bar/riscv-torture>

The Imperas OVPsim RISC-V models are used in the RISC-V Foundation Compliance Framework as a functional Golden Reference:

<https://github.com/riscv/riscv-compliance>

where the simulated model is used to provide the reference signatures for compliance testing. The Imperas OVPsim RISC-V models are used as reference in both open source and commercial instruction stream test generators for hardware design verification, for example:

<http://valtrix.in/sting> from Valtrix

<https://github.com/google/riscv-dv> from Google

The Imperas OVPsim RISC-V models are also used by commercial and open source RISC-V Core RTL developers as a reference to ensure correct functionality of their IP.

## 1.17 References

The Model details are based upon the following specifications:

RISC-V Instruction Set Manual, Volume I: User-Level ISA (User Architecture Version 20190305-Base-Ratification)

RISC-V Instruction Set Manual, Volume II: Privileged Architecture (Privileged Architecture Version 20190405-Priv-MSU-Ratification)

RISC-V “V” Vector Extension (Vector Architecture Version 1.0-draft-20210130)

## Chapter 2

# Configuration

### 2.1 Location

This model's VLNv is `riscv.ovpworld.org/processor/riscv/1.0`.

The model source is usually at:

`$IMPERAS_HOME/ImperasLib/source/riscv.ovpworld.org/processor/riscv/1.0`

The model binary is usually at:

`$IMPERAS_HOME/lib/$IMPERAS_ARCH/ImperasLib/riscv.ovpworld.org/processor/riscv/1.0`

### 2.2 GDB Path

The default GDB for this model is: `$IMPERAS_HOME/lib/$IMPERAS_ARCH/gdb/riscv-none-embed-gdb`.

### 2.3 Semi-Host Library

The default semi-host library file is `riscv.ovpworld.org/semihosting/pk/1.0`

### 2.4 Processor Endian-ness

This is a LITTLE endian model.

### 2.5 QuantumLeap Support

This processor is qualified to run in a QuantumLeap enabled simulator.

### 2.6 Processor ELF code

The ELF code supported by this model is: `0xf3`.

## Chapter 3

# All Variants in this model

This model has these variants

Variant	Description
RV32I	
RV32IM	
RV32IMC	
RV32IMAC	
RV32G	
RV32GC	
RV32GCZ <sub>finx</sub>	
RV32GCB	
RV32GCH	
RV32GCK	
RV32GCN	
RV32GCV	(described in this document)
RV32E	
RV32EC	
RV64I	
RV64IM	
RV64IMC	
RV64IMAC	
RV64G	
RV64GC	
RV64GCZ <sub>finx</sub>	
RV64GCB	
RV64GCH	
RV64GCK	
RV64GCN	
RV64GCV	
RVB32I	
RVB32E	
RVB64I	

Table 3.1: All Variants in this model

## Chapter 4

# Bus Master Ports

This model has these bus master ports.

<b>Name</b>	min	max	Connect?	Description
INSTRUCTION	32	34	mandatory	Instruction bus
DATA	32	34	optional	Data bus

Table 4.1: Bus Master Ports



## Chapter 5

# Bus Slave Ports

This model has no bus slave ports.

## Chapter 6

# Net Ports

This model has these net ports.

Name	Type	Connect?	Description
reset	input	optional	Reset
reset_addr	input	optional	externally-applied reset address
nmi	input	optional	NMI
nmi_addr	input	optional	externally-applied NMI address
SSWInterrupt	input	optional	Supervisor software interrupt
MSWInterrupt	input	optional	Machine software interrupt
STimerInterrupt	input	optional	Supervisor timer interrupt
MTimerInterrupt	input	optional	Machine timer interrupt
SExternalInterrupt	input	optional	Supervisor external interrupt
MExternalInterrupt	input	optional	Machine external interrupt
irq_ack_o	output	optional	interrupt acknowledge (pulse)
irq_id_o	output	optional	acknowledged interrupt id (valid during irq_ack_o pulse)
sec_lvl_o	output	optional	current privilege level
LR_address	output	optional	Port written with effective address for LR instruction
SC_address	output	optional	Port written with effective address for SC instruction
SC_valid	input	optional	SC_address valid input signal
AMO_active	output	optional	Port written with code indicating active AMO
deferint	input	optional	Artifact signal causing interrupts to be held off when high

Table 6.1: Net Ports

## Chapter 7

# FIFO Ports

This model has no FIFO ports.

# Chapter 8

## Formal Parameters

Name	Type	Description
<b>Fundamental</b>		
variant	Enumeration	Selects variant (either a generic UISA or a specific model)
user_version	Enumeration	Specify required User Architecture version (2.2, 2.3 or 20190305)
priv_version	Enumeration	Specify required Privileged Architecture version (1.10, 1.11, 20190405 or master)
numHarts	Uns32	Specify the number of hart contexts in a multiprocessor
endian	Endian	Model endian
endianFixed	Boolean	Specify that data endianness is fixed (mstatus.{MBE,SBE,UBE} fields are read-only)
misa_MXL	Uns32	Override default value of misa.MXL
misa_Extensions	Uns32	Override default value of misa.Extensions
add_Extensions	String	Add extensions specified by letters to misa.Extensions (for example, specify “VD” to add V and D features)
misa_Extensions_mask	Uns32	Override mask of writable bits in misa.Extensions
add_Extensions_mask	String	Add extensions specified by letters to mask of writable bits in misa.Extensions (for example, specify “VD” to add V and D features)
<b>Vector</b>		
vector_version	Enumeration	Specify required Vector Architecture version (0.7.1-draft-20190605, 0.7.1-draft-20190605+, 0.8-draft-20190906, 0.8-draft-20191004, 0.8-draft-20191117, 0.8-draft-20191118, 0.8, 0.9, 1.0-draft-20210130 or master)
fp16_version	Enumeration	Specify required 16-bit floating point format (none, IEEE754 or BFLOAT16)
require_vstart0	Boolean	Whether CSR vstart must be 0 for non-interruptible vector instructions
align_whole	Boolean	Whether whole-register load addresses must be aligned using the encoded EEW
vill_trap	Boolean	Whether illegal vtype values cause trap instead of setting vtype.vill
mstatus_VS	Uns32	Override default value of mstatus.VS (initial state of vector unit)
ELEN	Uns32	Override ELEN (vector extension)
SLEN	Uns32	Override SLEN (vector extension before version 1.0 only)
VLEN	Uns32	Override VLEN (vector extension)
SEW_min	Uns32	Override minimum supported SEW (vector extension)
Zvlsseg	Boolean	Specify that Zvlsseg is implemented (vector extension)
Zvamo	Boolean	Specify that Zvamo is implemented (vector extension)
Zvediv	Boolean	Specify that Zvediv is implemented (vector extension)
Zvqmac	Boolean	Specify that Zvqmac is implemented (vector extension)
<b>Debug</b>		
debug_version	Enumeration	Specify required Debug Architecture version (0.13.2-DRAFT or 0.14.0-DRAFT)
debug_mode	Enumeration	Specify how Debug mode is implemented (none, vector, interrupt or halt)
<b>Floating_Point</b>		

mstatus_fs_mode	Enumeration	Specify conditions causing update of mstatus.FS to dirty (write_1, write_any or always_dirty)
d_requires_f	Boolean	If D and F extensions are separately enabled in the misa CSR, whether D is enabled only if F is enabled
mstatus_FS	Uns32	Override default value of mstatus.FS (initial state of floating point unit)
Zfh	Boolean	Specify that Zfh is implemented (IEEE half-precision floating point is supported)
Zfinx_version	Enumeration	Specify that Zfinx is implemented (use integer register file for floating point instructions) (none or 0.4)
<b>Simulation Artifact</b>		
ABId	Boolean	Specify whether D registers are used for parameters (ABI SemiHosting)
verbose	Boolean	Specify verbose output messages
enable_CSR_bus	Boolean	Add artifact CSR bus port, allowing CSR registers to be externally implemented
CSR_remap	String	Comma-separated list of CSR number mappings, each of the form <csr-Name>=<number>
ASID_cache_size	Uns32	Specifies the number of different ASIDs for which TLB entries are cached; a value of 0 implies no limit
<b>Memory</b>		
updatePTEA	Boolean	Specify whether hardware update of PTE A bit is supported
updatePTED	Boolean	Specify whether hardware update of PTE D bit is supported
unaligned	Boolean	Specify whether the processor supports unaligned memory accesses
unalignedAMO	Boolean	Specify whether the processor supports unaligned memory accesses for AMO instructions
ASID_bits	Uns32	Specify the number of implemented ASID bits
lr_sc_grain	Uns32	Specify byte granularity of ll/sc lock region (constrained to a power of two)
PMP_grain	Uns32	Specify PMP region granularity, G (0 =>4 bytes, 1 =>8 bytes, etc)
PMP_registers	Uns32	Specify the number of implemented PMP address registers
PMP_max_page	Uns32	Specify the maximum size of PMP region to map if non-zero (may improve performance; constrained to a power of two)
PMP_decompose	Boolean	Whether unaligned PMP accesses are decomposed into separate aligned accesses
Sv_modes	Uns32	Specify bit mask of implemented Sv modes (e.g. 1<<8 is Sv39)
<b>Instruction_CSR_Behavior</b>		
wfi_is_nop	Boolean	Specify whether WFI should be treated as a NOP (if not, halt while waiting for interrupts)
counteren_mask	Uns32	Specify hardware-enforced mask of writable bits in mcounteren/scounteren registers
noinhibit_mask	Uns32	Specify hardware-enforced mask of always-zero bits in mcountinhibit register
cycle_undefined	Boolean	Specify that the cycle CSR is undefined (reads to it are emulated by a Machine mode trap)
time_undefined	Boolean	Specify that the time CSR is undefined (reads to it are emulated by a Machine mode trap)
instret_undefined	Boolean	Specify that the instret CSR is undefined (reads to it are emulated by a Machine mode trap)
<b>Interrupts_Exceptions</b>		
mtvec_is_ro	Boolean	Specify whether mtvec CSR is read-only
tvec_align	Uns32	Specify hardware-enforced alignment of mtvec/stvec/utvec when Vectored interrupt mode enabled
ecode_mask	Uns64	Specify hardware-enforced mask of writable bits in xcause.ExceptionCode
ecode_nmi	Uns64	Specify xcause.ExceptionCode for NMI
tval_zero	Boolean	Specify whether mtval/stval/utval are hard wired to zero
tval_zero_ebreak	Boolean	Specify whether mtval/stval/utval are set to zero by an ebreak
tval_ii_code	Boolean	Specify whether mtval/stval contain faulting instruction bits on illegal instruction exception
xret_preserves_lr	Boolean	Whether an xRET instruction preserves the value of LR

reset_address	Uns64	Override reset vector address
nmi_address	Uns64	Override NMI vector address
local_int_num	Uns32	Specify number of supplemental local interrupts
unimp_int_mask	Uns64	Specify mask of unimplemented interrupts (e.g. 1<<9 indicates Supervisor external interrupt unimplemented)
force_mideleg	Uns64	Specify mask of interrupts always delegated to lower-priority execution level from Machine execution level
force_sideleg	Uns64	Specify mask of interrupts always delegated to User execution level from Supervisor execution level
no_ideleg	Uns64	Specify mask of interrupts that cannot be delegated to lower-priority execution levels
no_e deleg	Uns64	Specify mask of exceptions that cannot be delegated to lower-priority execution levels
external_int_id	Boolean	Whether to add nets allowing External Interrupt ID codes to be forced
<b>CSR_Masks</b>		
mtvec_mask	Uns64	Specify hardware-enforced mask of writable bits in mtvec register
stvec_mask	Uns64	Specify hardware-enforced mask of writable bits in stvec register
<b>Trigger</b>		
tinfo_undefined	Boolean	Specify that the tinfo CSR is undefined
tcontrol_undefined	Boolean	Specify that the tcontrol CSR is undefined
mcontext_undefined	Boolean	Specify that the mcontext CSR is undefined
scontext_undefined	Boolean	Specify that the scontext CSR is undefined
mscontext_undefined	Boolean	Specify that the mscontext CSR is undefined (Debug Version 0.14.0 and later)
amo_trigger	Boolean	Specify whether AMO load/store operations activate triggers
no_hit	Boolean	Specify that tdata1.hit is unimplemented
no_sselect_2	Boolean	Specify that textra.sselect=2 is not supported (no trigger match by ASID)
trigger_num	Uns32	Specify the number of implemented hardware triggers
tinfo	Uns32	Override tinfo register (for all triggers)
mcontext_bits	Uns32	Specify the number of implemented bits in mcontext
scontext_bits	Uns32	Specify the number of implemented bits in scontext
mvalue_bits	Uns32	Specify the number of implemented bits in textra.mvalue (if zero, textra.mselect is tied to zero)
svalue_bits	Uns32	Specify the number of implemented bits in textra.svalue (if zero, textra.sselect is tied to zero)
mcontrol_maskmax	Uns32	Specify mcontrol.maskmax value
<b>CSR_Defaults</b>		
mvendorid	Uns64	Override mvendorid register
marchid	Uns64	Override marchid register
mimpid	Uns64	Override mimpid register
mhartid	Uns64	Override mhartid register (or first mhartid of an incrementing sequence if this is an SMP variant)
mtvec	Uns64	Override mtvec register
<b>Fast Interrupt</b>		
CLICLEVELS	Uns32	Specify number of interrupt levels implemented by CLIC, or 0 if CLIC absent

Table 8.1: Parameters that can be set in: Hart

## 8.1 Parameters with enumerated types

### 8.1.1 Parameter user\_version

Set to this value	Description
2.2	User Architecture Version 2.2
2.3	Deprecated and equivalent to 20190305

20190305	User Architecture Version 20190305-Base-Ratification
----------	--

Table 8.2: Values for Parameter user\_version

### 8.1.2 Parameter priv\_version

Set to this value	Description
1.10	Privileged Architecture Version 1.10
1.11	Deprecated and equivalent to 20190405
20190405	Privileged Architecture Version 20190405-Priv-MSU-Ratification
master	Privileged Architecture Master Branch (1.12 draft)

Table 8.3: Values for Parameter priv\_version

### 8.1.3 Parameter vector\_version

Set to this value	Description
0.7.1-draft-20190605	Vector Architecture Version 0.7.1-draft-20190605
0.7.1-draft-20190605+	Vector Architecture Version 0.7.1-draft-20190605 with custom features (not for general use)
0.8-draft-20190906	Vector Architecture Version 0.8-draft-20190906
0.8-draft-20191004	Vector Architecture Version 0.8-draft-20191004
0.8-draft-20191117	Vector Architecture Version 0.8-draft-20191117
0.8-draft-20191118	Vector Architecture Version 0.8-draft-20191118
0.8	Vector Architecture Version 0.8
0.9	Vector Architecture Version 0.9
1.0-draft-20210130	Vector Architecture Version 1.0-draft-20210130
master	Vector Architecture Master Branch as of commit 4ab6506 (this is subject to change)

Table 8.4: Values for Parameter vector\_version

### 8.1.4 Parameter debug\_version

Set to this value	Description
0.13.2-DRAFT	RISC-V External Debug Support Version 0.13.2-DRAFT
0.14.0-DRAFT	RISC-V External Debug Support Version 0.14.0-DRAFT

Table 8.5: Values for Parameter debug\_version

### 8.1.5 Parameter fp16\_version

Set to this value	Description
none	No 16-bit floating point implemented
IEEE754	IEEE 754 half precision implemented
BFLOAT16	BFLOAT16 implemented

Table 8.6: Values for Parameter fp16\_version

### 8.1.6 Parameter mstatus\_fs\_mode

Set to this value	Description
write_1	Any non-zero flag result sets mstatus.fs dirty

write_any	Any write of flags sets mstatus.fs dirty
always_dirty	mstatus.fs is either off or dirty

Table 8.7: Values for Parameter mstatus\_fs\_mode

### 8.1.7 Parameter debug\_mode

Set to this value	Description
none	Debug mode not implemented
vector	Debug mode implemented by execution at vector
interrupt	Debug mode implemented by interrupt
halt	Debug mode implemented by halt

Table 8.8: Values for Parameter debug\_mode

### 8.1.8 Parameter Zfinx\_version

Set to this value	Description
none	Zfinx not implemented
0.4	Zfinx version 0.4

Table 8.9: Values for Parameter Zfinx\_version



## Chapter 9

# Execution Modes

<b>Mode</b>	Code	Description
User	0	User mode
Supervisor	1	Supervisor mode
Machine	3	Machine mode

Table 9.1: Modes implemented in: Hart

# Chapter 10

## Exceptions

Exception	Code	Description
InstructionAddressMisaligned	0	Fetch from unaligned address
InstructionAccessFault	1	No access permission for fetch
IllegalInstruction	2	Undecoded, unimplemented or disabled instruction
Breakpoint	3	EBREAK instruction executed
LoadAddressMisaligned	4	Load from unaligned address
LoadAccessFault	5	No access permission for load
StoreAMOAddressMisaligned	6	Store/atomic memory operation at unaligned address
StoreAMOAccessFault	7	No access permission for store/atomic memory operation
EnvironmentCallFromUMode	8	ECALL instruction executed in User mode
EnvironmentCallFromSMode	9	ECALL instruction executed in Supervisor mode
EnvironmentCallFromMMode	11	ECALL instruction executed in Machine mode
InstructionPageFault	12	Page fault at fetch address
LoadPageFault	13	Page fault at load address
StoreAMOPageFault	15	Page fault at store/atomic memory operation address
SSWInterrupt	65	Supervisor software interrupt
MSWInterrupt	67	Machine software interrupt
STimerInterrupt	69	Supervisor timer interrupt
MTimerInterrupt	71	Machine timer interrupt
SExternalInterrupt	73	Supervisor external interrupt
MExternalInterrupt	75	Machine external interrupt

Table 10.1: Exceptions implemented in: Hart

# Chapter 11

## Hierarchy of the model

A CPU core may be configured to instance many processors of a Symmetrical Multi Processor (SMP). A CPU core may also have sub elements within a processor, for example hardware threading blocks.

OVP processor models can be written to include SMP blocks and to have many levels of hierarchy. Some OVP CPU models may have a fixed hierarchy, and some may be configured by settings in a configuration register. Please see the register definitions of this model.

This model documentation shows the settings and hierarchy of the default settings for this model variant.

### 11.1 Level 1: Hart

This level in the model hierarchy has 3 commands.

This level in the model hierarchy has 7 register groups:

Group name	Registers
Core	33
Floating_point	32
Vector	32
User_Control_and_Status	74
Supervisor_Control_and_Status	12
Machine_Control_and_Status	135
Integration_support	2

Table 11.1: Register groups

This level in the model hierarchy has no children.

# Chapter 12

## Model Commands

A Processor model can implement one or more **Model Commands** available to be invoked from the simulator command line, from the OP API or from the Imperas Multiprocessor Debugger.

### 12.1 Level 1: Hart

#### 12.1.1 dumpTLB

##### 12.1.1.1 Argument description

show TLB contents

#### 12.1.2 isync

specify instruction address range for synchronous execution

Argument	Type	Description
-addresshi	Uns64	end address of synchronous execution range
-addresslo	Uns64	start address of synchronous execution range

Table 12.1: isync command arguments

#### 12.1.3 itrace

enable or disable instruction tracing

Argument	Type	Description
-after	Uns64	apply after this many instructions
-enable	Boolean	enable instruction tracing
-instructioncount	Boolean	include the instruction number in each trace
-off	Boolean	disable instruction tracing
-on	Boolean	enable instruction tracing
-registerchange	Boolean	show registers changed by this instruction
-registers	Boolean	show registers after each trace

Table 12.2: itrace command arguments

# Chapter 13

## Registers

### 13.1 Level 1: Hart

#### 13.1.1 Core

Registers at level:1, type:Hart group:Core

Name	Bits	Initial-Hex	RW	Description
zero	32	0	r-	
ra	32	0	rw	
sp	32	0	rw	stack pointer
gp	32	0	rw	
tp	32	0	rw	
t0	32	0	rw	
t1	32	0	rw	
t2	32	0	rw	
s0	32	0	rw	
s1	32	0	rw	
a0	32	0	rw	
a1	32	0	rw	
a2	32	0	rw	
a3	32	0	rw	
a4	32	0	rw	
a5	32	0	rw	
a6	32	0	rw	
a7	32	0	rw	
s2	32	0	rw	
s3	32	0	rw	
s4	32	0	rw	
s5	32	0	rw	
s6	32	0	rw	
s7	32	0	rw	
s8	32	0	rw	
s9	32	0	rw	
s10	32	0	rw	
s11	32	0	rw	
t3	32	0	rw	
t4	32	0	rw	
t5	32	0	rw	
t6	32	0	rw	
pc	32	0	rw	program counter

Table 13.1: Registers at level 1, type:Hart group:Core

### 13.1.2 Floating\_point

Registers at level:1, type:Hart group:Floating\_point

Name	Bits	Initial-Hex	RW	Description
ft0	64	0	rw	
ft1	64	0	rw	
ft2	64	0	rw	
ft3	64	0	rw	
ft4	64	0	rw	
ft5	64	0	rw	
ft6	64	0	rw	
ft7	64	0	rw	
fs0	64	0	rw	
fs1	64	0	rw	
fa0	64	0	rw	
fa1	64	0	rw	
fa2	64	0	rw	
fa3	64	0	rw	
fa4	64	0	rw	
fa5	64	0	rw	
fa6	64	0	rw	
fa7	64	0	rw	
fs2	64	0	rw	
fs3	64	0	rw	
fs4	64	0	rw	
fs5	64	0	rw	
fs6	64	0	rw	
fs7	64	0	rw	
fs8	64	0	rw	
fs9	64	0	rw	
fs10	64	0	rw	
fs11	64	0	rw	
ft8	64	0	rw	
ft9	64	0	rw	
ft10	64	0	rw	
ft11	64	0	rw	

Table 13.2: Registers at level 1, type:Hart group:Floating\_point

### 13.1.3 Vector

Registers at level:1, type:Hart group:Vector

Name	Bits	Initial-Hex	RW	Description
v0	512	-	rw	
v1	512	-	rw	
v2	512	-	rw	
v3	512	-	rw	
v4	512	-	rw	
v5	512	-	rw	
v6	512	-	rw	

v7	512	-	rw	
v8	512	-	rw	
v9	512	-	rw	
v10	512	-	rw	
v11	512	-	rw	
v12	512	-	rw	
v13	512	-	rw	
v14	512	-	rw	
v15	512	-	rw	
v16	512	-	rw	
v17	512	-	rw	
v18	512	-	rw	
v19	512	-	rw	
v20	512	-	rw	
v21	512	-	rw	
v22	512	-	rw	
v23	512	-	rw	
v24	512	-	rw	
v25	512	-	rw	
v26	512	-	rw	
v27	512	-	rw	
v28	512	-	rw	
v29	512	-	rw	
v30	512	-	rw	
v31	512	-	rw	

Table 13.3: Registers at level 1, type:Hart group:Vector

### 13.1.4 User\_Control\_and\_Status

Registers at level:1, type:Hart group:User\_Control\_and\_Status

Name	Bits	Initial-Hex	RW	Description
fflags	32	0	rw	Floating-Point Flags
frm	32	0	rw	Floating-Point Rounding Mode
fcsr	32	0	rw	Floating-Point Control and Status
vstart	32	0	rw	Vector Start Index
vxsat	32	0	rw	Fixed-Point Saturate Flag
vxrm	32	0	rw	Fixed-Point Rounding Mode
vcsr	32	0	rw	Vector Control and Status
cycle	32	0	r-	Cycle Counter
time	32	0	r-	Timer
instret	32	0	r-	Instructions Retired
hpmcounter3	32	0	r-	Performance Monitor Counter 3
hpmcounter4	32	0	r-	Performance Monitor Counter 4
hpmcounter5	32	0	r-	Performance Monitor Counter 5
hpmcounter6	32	0	r-	Performance Monitor Counter 6
hpmcounter7	32	0	r-	Performance Monitor Counter 7
hpmcounter8	32	0	r-	Performance Monitor Counter 8
hpmcounter9	32	0	r-	Performance Monitor Counter 9
hpmcounter10	32	0	r-	Performance Monitor Counter 10
hpmcounter11	32	0	r-	Performance Monitor Counter 11
hpmcounter12	32	0	r-	Performance Monitor Counter 12
hpmcounter13	32	0	r-	Performance Monitor Counter 13
hpmcounter14	32	0	r-	Performance Monitor Counter 14
hpmcounter15	32	0	r-	Performance Monitor Counter 15

hpmcounter16	32	0	r-	Performance Monitor Counter 16
hpmcounter17	32	0	r-	Performance Monitor Counter 17
hpmcounter18	32	0	r-	Performance Monitor Counter 18
hpmcounter19	32	0	r-	Performance Monitor Counter 19
hpmcounter20	32	0	r-	Performance Monitor Counter 20
hpmcounter21	32	0	r-	Performance Monitor Counter 21
hpmcounter22	32	0	r-	Performance Monitor Counter 22
hpmcounter23	32	0	r-	Performance Monitor Counter 23
hpmcounter24	32	0	r-	Performance Monitor Counter 24
hpmcounter25	32	0	r-	Performance Monitor Counter 25
hpmcounter26	32	0	r-	Performance Monitor Counter 26
hpmcounter27	32	0	r-	Performance Monitor Counter 27
hpmcounter28	32	0	r-	Performance Monitor Counter 28
hpmcounter29	32	0	r-	Performance Monitor Counter 29
hpmcounter30	32	0	r-	Performance Monitor Counter 30
hpmcounter31	32	0	r-	Performance Monitor Counter 31
vl	32	0	r-	Vector Length
vtype	32	0	r-	Vector Type
vlenb	32	40	r-	Vector Length in Bytes
cycleh	32	0	r-	Cycle Counter High
timeh	32	0	r-	Timer High
instreth	32	0	r-	Instructions Retired High
hpmcounterh3	32	0	r-	Performance Monitor High 3
hpmcounterh4	32	0	r-	Performance Monitor High 4
hpmcounterh5	32	0	r-	Performance Monitor High 5
hpmcounterh6	32	0	r-	Performance Monitor High 6
hpmcounterh7	32	0	r-	Performance Monitor High 7
hpmcounterh8	32	0	r-	Performance Monitor High 8
hpmcounterh9	32	0	r-	Performance Monitor High 9
hpmcounterh10	32	0	r-	Performance Monitor High 10
hpmcounterh11	32	0	r-	Performance Monitor High 11
hpmcounterh12	32	0	r-	Performance Monitor High 12
hpmcounterh13	32	0	r-	Performance Monitor High 13
hpmcounterh14	32	0	r-	Performance Monitor High 14
hpmcounterh15	32	0	r-	Performance Monitor High 15
hpmcounterh16	32	0	r-	Performance Monitor High 16
hpmcounterh17	32	0	r-	Performance Monitor High 17
hpmcounterh18	32	0	r-	Performance Monitor High 18
hpmcounterh19	32	0	r-	Performance Monitor High 19
hpmcounterh20	32	0	r-	Performance Monitor High 20
hpmcounterh21	32	0	r-	Performance Monitor High 21
hpmcounterh22	32	0	r-	Performance Monitor High 22
hpmcounterh23	32	0	r-	Performance Monitor High 23
hpmcounterh24	32	0	r-	Performance Monitor High 24
hpmcounterh25	32	0	r-	Performance Monitor High 25
hpmcounterh26	32	0	r-	Performance Monitor High 26
hpmcounterh27	32	0	r-	Performance Monitor High 27
hpmcounterh28	32	0	r-	Performance Monitor High 28
hpmcounterh29	32	0	r-	Performance Monitor High 29
hpmcounterh30	32	0	r-	Performance Monitor High 30
hpmcounterh31	32	0	r-	Performance Monitor High 31

Table 13.4: Registers at level 1, type:Hart group:User\_Control\_and\_Status



### 13.1.5 Supervisor\_Control\_and\_Status

Registers at level:1, type:Hart group:Supervisor\_Control\_and\_Status

Name	Bits	Initial-Hex	RW	Description
sstatus	32	0	rw	Supervisor Status
sie	32	0	rw	Supervisor Interrupt Enable
stvec	32	0	rw	Supervisor Trap-Vector Base-Address
scounteren	32	0	rw	Supervisor Counter Enable
sscratch	32	0	rw	Supervisor Scratch
sepc	32	0	rw	Supervisor Exception Program Counter
scause	32	0	rw	Supervisor Cause
stval	32	0	rw	Supervisor Trap Value
sip	32	0	rw	Supervisor Interrupt Pending
satp	32	0	rw	Supervisor Address Translation and Protection
scontext	32	0	rw	Trigger Supervisor Context
mscontext	32	0	rw	Trigger Machine Context Alias

Table 13.5: Registers at level 1, type:Hart group:Supervisor\_Control\_and\_Status

### 13.1.6 Machine\_Control\_and\_Status

Registers at level:1, type:Hart group:Machine\_Control\_and\_Status

Name	Bits	Initial-Hex	RW	Description
mstatus	32	0	rw	Machine Status
misa	32	4034112d	rw	ISA and Extensions
medeleg	32	0	rw	Machine Exception Delegation
mideleg	32	0	rw	Machine Interrupt Delegation
mie	32	0	rw	Machine Interrupt Enable
mtvec	32	0	rw	Machine Trap-Vector Base-Address
mcounteren	32	0	rw	Machine Counter Enable
mcountinhibit	32	0	rw	Machine Counter Inhibit
mhpmevent3	32	0	rw	Machine Performance Monitor Event Select 3
mhpmevent4	32	0	rw	Machine Performance Monitor Event Select 4
mhpmevent5	32	0	rw	Machine Performance Monitor Event Select 5
mhpmevent6	32	0	rw	Machine Performance Monitor Event Select 6
mhpmevent7	32	0	rw	Machine Performance Monitor Event Select 7
mhpmevent8	32	0	rw	Machine Performance Monitor Event Select 8
mhpmevent9	32	0	rw	Machine Performance Monitor Event Select 9
mhpmevent10	32	0	rw	Machine Performance Monitor Event Select 10
mhpmevent11	32	0	rw	Machine Performance Monitor Event Select 11
mhpmevent12	32	0	rw	Machine Performance Monitor Event Select 12
mhpmevent13	32	0	rw	Machine Performance Monitor Event Select 13
mhpmevent14	32	0	rw	Machine Performance Monitor Event Select 14
mhpmevent15	32	0	rw	Machine Performance Monitor Event Select 15
mhpmevent16	32	0	rw	Machine Performance Monitor Event Select 16
mhpmevent17	32	0	rw	Machine Performance Monitor Event Select 17
mhpmevent18	32	0	rw	Machine Performance Monitor Event Select 18
mhpmevent19	32	0	rw	Machine Performance Monitor Event Select 19
mhpmevent20	32	0	rw	Machine Performance Monitor Event Select 20
mhpmevent21	32	0	rw	Machine Performance Monitor Event Select 21
mhpmevent22	32	0	rw	Machine Performance Monitor Event Select 22
mhpmevent23	32	0	rw	Machine Performance Monitor Event Select 23
mhpmevent24	32	0	rw	Machine Performance Monitor Event Select 24
mhpmevent25	32	0	rw	Machine Performance Monitor Event Select 25

mhpmevent26	32	0	rw	Machine Performance Monitor Event Select 26
mhpmevent27	32	0	rw	Machine Performance Monitor Event Select 27
mhpmevent28	32	0	rw	Machine Performance Monitor Event Select 28
mhpmevent29	32	0	rw	Machine Performance Monitor Event Select 29
mhpmevent30	32	0	rw	Machine Performance Monitor Event Select 30
mhpmevent31	32	0	rw	Machine Performance Monitor Event Select 31
mscratch	32	0	rw	Machine Scratch
mepc	32	0	rw	Machine Exception Program Counter
mcause	32	0	rw	Machine Cause
mtval	32	0	rw	Machine Trap Value
mip	32	0	rw	Machine Interrupt Pending
pmpcfg0	32	0	rw	Physical Memory Protection Configuration 0
pmpcfg1	32	0	rw	Physical Memory Protection Configuration 1
pmpcfg2	32	0	rw	Physical Memory Protection Configuration 2
pmpcfg3	32	0	rw	Physical Memory Protection Configuration 3
pmpaddr0	32	0	rw	Physical Memory Protection Address 0
pmpaddr1	32	0	rw	Physical Memory Protection Address 1
pmpaddr2	32	0	rw	Physical Memory Protection Address 2
pmpaddr3	32	0	rw	Physical Memory Protection Address 3
pmpaddr4	32	0	rw	Physical Memory Protection Address 4
pmpaddr5	32	0	rw	Physical Memory Protection Address 5
pmpaddr6	32	0	rw	Physical Memory Protection Address 6
pmpaddr7	32	0	rw	Physical Memory Protection Address 7
pmpaddr8	32	0	rw	Physical Memory Protection Address 8
pmpaddr9	32	0	rw	Physical Memory Protection Address 9
pmpaddr10	32	0	rw	Physical Memory Protection Address 10
pmpaddr11	32	0	rw	Physical Memory Protection Address 11
pmpaddr12	32	0	rw	Physical Memory Protection Address 12
pmpaddr13	32	0	rw	Physical Memory Protection Address 13
pmpaddr14	32	0	rw	Physical Memory Protection Address 14
pmpaddr15	32	0	rw	Physical Memory Protection Address 15
tselect	32	0	rw	Trigger Register Select
tdata1	32	0	rw	Trigger Data 1
tdata2	32	0	rw	Trigger Data 2
tdata3	32	0	rw	Trigger Data 3
tinfo	32	7d	rw	Trigger Info
tcontrol	32	0	rw	Trigger Control
mcontext	32	0	rw	Trigger Machine Context
mcycle	32	0	rw	Machine Cycle Counter
minstret	32	0	rw	Machine Instructions Retired
mhpmcounter3	32	0	rw	Machine Performance Monitor Counter 3
mhpmcounter4	32	0	rw	Machine Performance Monitor Counter 4
mhpmcounter5	32	0	rw	Machine Performance Monitor Counter 5
mhpmcounter6	32	0	rw	Machine Performance Monitor Counter 6
mhpmcounter7	32	0	rw	Machine Performance Monitor Counter 7
mhpmcounter8	32	0	rw	Machine Performance Monitor Counter 8
mhpmcounter9	32	0	rw	Machine Performance Monitor Counter 9
mhpmcounter10	32	0	rw	Machine Performance Monitor Counter 10
mhpmcounter11	32	0	rw	Machine Performance Monitor Counter 11
mhpmcounter12	32	0	rw	Machine Performance Monitor Counter 12
mhpmcounter13	32	0	rw	Machine Performance Monitor Counter 13
mhpmcounter14	32	0	rw	Machine Performance Monitor Counter 14
mhpmcounter15	32	0	rw	Machine Performance Monitor Counter 15
mhpmcounter16	32	0	rw	Machine Performance Monitor Counter 16
mhpmcounter17	32	0	rw	Machine Performance Monitor Counter 17
mhpmcounter18	32	0	rw	Machine Performance Monitor Counter 18

mhpmcounter19	32	0	rw	Machine Performance Monitor Counter 19
mhpmcounter20	32	0	rw	Machine Performance Monitor Counter 20
mhpmcounter21	32	0	rw	Machine Performance Monitor Counter 21
mhpmcounter22	32	0	rw	Machine Performance Monitor Counter 22
mhpmcounter23	32	0	rw	Machine Performance Monitor Counter 23
mhpmcounter24	32	0	rw	Machine Performance Monitor Counter 24
mhpmcounter25	32	0	rw	Machine Performance Monitor Counter 25
mhpmcounter26	32	0	rw	Machine Performance Monitor Counter 26
mhpmcounter27	32	0	rw	Machine Performance Monitor Counter 27
mhpmcounter28	32	0	rw	Machine Performance Monitor Counter 28
mhpmcounter29	32	0	rw	Machine Performance Monitor Counter 29
mhpmcounter30	32	0	rw	Machine Performance Monitor Counter 30
mhpmcounter31	32	0	rw	Machine Performance Monitor Counter 31
mcycleh	32	0	rw	Machine Cycle Counter High
minstreth	32	0	rw	Machine Instructions Retired High
mhpmcounterh3	32	0	rw	Machine Performance Monitor Counter High 3
mhpmcounterh4	32	0	rw	Machine Performance Monitor Counter High 4
mhpmcounterh5	32	0	rw	Machine Performance Monitor Counter High 5
mhpmcounterh6	32	0	rw	Machine Performance Monitor Counter High 6
mhpmcounterh7	32	0	rw	Machine Performance Monitor Counter High 7
mhpmcounterh8	32	0	rw	Machine Performance Monitor Counter High 8
mhpmcounterh9	32	0	rw	Machine Performance Monitor Counter High 9
mhpmcounterh10	32	0	rw	Machine Performance Monitor Counter High 10
mhpmcounterh11	32	0	rw	Machine Performance Monitor Counter High 11
mhpmcounterh12	32	0	rw	Machine Performance Monitor Counter High 12
mhpmcounterh13	32	0	rw	Machine Performance Monitor Counter High 13
mhpmcounterh14	32	0	rw	Machine Performance Monitor Counter High 14
mhpmcounterh15	32	0	rw	Machine Performance Monitor Counter High 15
mhpmcounterh16	32	0	rw	Machine Performance Monitor Counter High 16
mhpmcounterh17	32	0	rw	Machine Performance Monitor Counter High 17
mhpmcounterh18	32	0	rw	Machine Performance Monitor Counter High 18
mhpmcounterh19	32	0	rw	Machine Performance Monitor Counter High 19
mhpmcounterh20	32	0	rw	Machine Performance Monitor Counter High 20
mhpmcounterh21	32	0	rw	Machine Performance Monitor Counter High 21
mhpmcounterh22	32	0	rw	Machine Performance Monitor Counter High 22
mhpmcounterh23	32	0	rw	Machine Performance Monitor Counter High 23
mhpmcounterh24	32	0	rw	Machine Performance Monitor Counter High 24
mhpmcounterh25	32	0	rw	Machine Performance Monitor Counter High 25
mhpmcounterh26	32	0	rw	Machine Performance Monitor Counter High 26
mhpmcounterh27	32	0	rw	Machine Performance Monitor Counter High 27
mhpmcounterh28	32	0	rw	Machine Performance Monitor Counter High 28
mhpmcounterh29	32	0	rw	Machine Performance Monitor Counter High 29
mhpmcounterh30	32	0	rw	Machine Performance Monitor Counter High 30
mhpmcounterh31	32	0	rw	Machine Performance Monitor Counter High 31
mvendorid	32	0	r-	Vendor ID
marchid	32	0	r-	Architecture ID
mimpid	32	0	r-	Implementation ID
mhartid	32	0	r-	Hardware Thread ID

Table 13.6: Registers at level 1, type:Hart group:Machine\_Control\_and\_Status

### 13.1.7 Integration support

Registers at level:1, type:Hart group:Integration\_support

Name	Bits	Initial-Hex	RW	Description
------	------	-------------	----	-------------

LRSCAddress	32	ffffff	rw	LR/SC active lock address
commercial	8	0	r-	Commercial feature in use

Table 13.7: Registers at level 1, type:Hart group:Integration.support