



OVP Guide to Using Processor Models

Model specific information for OpenHwGroup_CV32E40X

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| Author | Imperas Software Limited |
| Version | 99999999 |
| Filename | OVP_Model_Specific_Informationopenhwgroup_riscv_CV32E40X.pdf |
| Created | 23 June 2022 |
| Status | OVP Standard Release |

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Contents

| | | |
|----------|---------------------------------------|----------|
| 1 | Overview | 1 |
| 1.1 | Description | 1 |
| 1.2 | Licensing | 1 |
| 1.3 | Extensions | 2 |
| 1.3.1 | Extensions Enabled by Default | 2 |
| 1.3.2 | Enabling Other Extensions | 2 |
| 1.3.3 | Disabling Extensions | 3 |
| 1.4 | General Features | 3 |
| 1.4.1 | mtvec CSR | 3 |
| 1.4.2 | Reset | 3 |
| 1.4.3 | NMI | 3 |
| 1.4.4 | WFI | 4 |
| 1.4.5 | cycle CSR | 4 |
| 1.4.6 | time CSR | 4 |
| 1.4.7 | instret CSR | 4 |
| 1.4.8 | hpmcounter CSRs | 4 |
| 1.4.9 | Unaligned Accesses | 4 |
| 1.4.10 | PMP | 5 |
| 1.5 | Compressed Extension | 5 |
| 1.6 | Privileged Architecture | 5 |
| 1.6.1 | Legacy Version 1.10 | 5 |
| 1.6.2 | Version 20190608 | 6 |
| 1.6.3 | Version 20211203 | 6 |
| 1.6.4 | Version 1.12 | 6 |
| 1.6.5 | Version master | 6 |
| 1.7 | Unprivileged Architecture | 6 |
| 1.7.1 | Legacy Version 2.2 | 6 |
| 1.7.2 | Version 20191213 | 7 |
| 1.8 | Bit-Manipulation Extension | 7 |
| 1.8.1 | Bit-Manipulation Extension Parameters | 7 |
| 1.8.2 | Bit-Manipulation Extension Versions | 8 |
| 1.8.3 | Version 0.90 | 8 |
| 1.8.4 | Version 0.91 | 8 |
| 1.8.5 | Version 0.92 | 8 |
| 1.8.6 | Version 0.93-draft | 8 |
| 1.8.7 | Version 0.93 | 8 |
| 1.8.8 | Version 0.94 | 9 |

| | | |
|----------|--|-----------|
| 1.8.9 | Version 1.0.0 | 9 |
| 1.8.10 | Version master | 9 |
| 1.9 | Other Extensions | 10 |
| 1.9.1 | Zmmul | 10 |
| 1.9.2 | Zicsr | 10 |
| 1.9.3 | Zifencei | 10 |
| 1.9.4 | Zicbom | 10 |
| 1.9.5 | Zicbop | 10 |
| 1.9.6 | Zicboz | 10 |
| 1.9.7 | Smstateen | 11 |
| 1.10 | CLIC | 11 |
| 1.11 | Interrupts | 11 |
| 1.12 | Debug Mode | 12 |
| 1.12.1 | Debug State Entry | 12 |
| 1.12.2 | Debug State Exit | 13 |
| 1.12.3 | Debug Registers | 13 |
| 1.12.4 | Debug Mode Execution | 13 |
| 1.12.5 | Debug Single Step | 13 |
| 1.12.6 | Debug Event Priorities | 14 |
| 1.12.7 | Debug Ports | 14 |
| 1.13 | Trigger Module | 14 |
| 1.13.1 | Trigger Module Restrictions | 14 |
| 1.13.2 | Trigger Module Parameters | 14 |
| 1.14 | Debug Mask | 15 |
| 1.15 | Integration Support | 15 |
| 1.15.1 | CSR Register External Implementation | 15 |
| 1.16 | Limitations | 16 |
| 1.17 | Verification | 16 |
| 1.18 | References | 16 |
| 2 | Openhwgroup-Specific Extensions | 18 |
| 2.1 | Parameter: extensions/PULP_XPULP | 18 |
| 2.2 | Parameter: extensions/PMA_NUM_REGIONS | 18 |
| 2.3 | PULP_XPULP Extension Status | 19 |
| 2.3.1 | PULP_XPULP Features: | 19 |
| 2.3.2 | PULP_XPULP Limitations: | 19 |
| 2.3.3 | PULP_XPULP References: | 19 |
| 2.4 | PMA Extension Status | 19 |
| 2.5 | Custom Bus Fault Extension Status | 19 |
| 2.6 | Secure Exceptions Status | 20 |
| 3 | Configuration | 21 |
| 3.1 | Location | 21 |
| 3.2 | GDB Path | 21 |
| 3.3 | Semi-Host Library | 21 |
| 3.4 | Processor Endian-ness | 21 |
| 3.5 | QuantumLeap Support | 21 |
| 3.6 | Processor ELF code | 21 |

| | | |
|-----------|--|-----------|
| 4 | All Variants in this model | 22 |
| 5 | Bus Master Ports | 23 |
| 6 | Bus Slave Ports | 24 |
| 7 | Net Ports | 25 |
| 8 | FIFO Ports | 27 |
| 9 | Formal Parameters | 28 |
| 9.1 | Extension Parameters | 31 |
| 9.2 | Parameters with enumerated types | 33 |
| 9.2.1 | Parameter user_version | 33 |
| 9.2.2 | Parameter priv_version | 33 |
| 9.2.3 | Parameter bitmanip_version | 33 |
| 9.2.4 | Parameter compress_version | 34 |
| 9.2.5 | Parameter debug_version | 34 |
| 9.2.6 | Parameter rnmi_version | 34 |
| 9.2.7 | Parameter Smepmp_version | 34 |
| 9.2.8 | Parameter debug_mode | 34 |
| 9.2.9 | Parameter debug_eret_mode | 34 |
| 9.2.10 | Parameter debug_priority | 35 |
| 9.3 | Parameter values | 35 |
| 10 | Execution Modes | 41 |
| 11 | Exceptions | 42 |
| 12 | Hierarchy of the model | 44 |
| 12.1 | Level 1: Hart | 44 |
| 13 | Model Commands | 45 |
| 13.1 | Level 1: Hart | 45 |
| 13.1.1 | debugflags | 45 |
| 13.1.2 | getCSRIndex | 45 |
| 13.1.3 | isync | 45 |
| 13.1.4 | itrace | 46 |
| 13.1.5 | listCSRs | 46 |
| 13.1.5.1 | Argument description | 46 |
| 14 | Registers | 47 |
| 14.1 | Level 1: Hart | 47 |
| 14.1.1 | Core | 47 |
| 14.1.2 | Machine_Control_and_Status | 48 |
| 14.1.3 | Integration_support | 51 |

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 CV32E40X 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 corresponding bits in the misa CSR Extensions field will be set upon reset:

misa bit 2: extension C (compressed instructions)

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

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

In addition, the model has the following architectural extensions implicitly enabled (not shown in the misa CSR Extensions field):

misa bit 1: extension B (bit manipulation 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. Parameter “sub_Extensions_mask” can be used to disable dynamic update of features in the same way.

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 Enabling Other Extensions

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

misa bit 0: extension A (atomic instructions)

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

To add features from this list to the visible set in the misa register, use parameter “add_Extensions”. This is a string containing identification letters of features to enable; 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.

To add features from this list to the implicitly-enabled set (not visible in the misa register), use parameter “add_implicit_Extensions”. This is a string parameter in the same format as the “add_Extensions” parameter described above.

1.3.3 Disabling Extensions

The following extensions are enabled by default in the model and can be disabled:

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

To disable features that are enabled by default, use parameter “sub_Extensions”. This is a string containing identification letters of features to disable; for example, value “DF” indicates that double-precision and single-precision floating point extensions should be disabled, if they are enabled by default on this variant.

To remove features from this list from the implicitly-enabled set (not visible in the misa register), use parameter “sub_implicit_Extensions”. This is a string parameter in the same format as the “sub_Extensions” parameter described above.

1.4 General Features

1.4.1 mtvec CSR

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 0xfffff81. 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.

If parameter “mtvec_sext” is True, values written to “mtvec” are sign-extended from the most-significant writable bit. In this variant, “mtvec_sext” is False, indicating that “mtvec” is not sign-extended.

The initial value of “mtvec” is 0x1. A different value may be specified using parameter “mtvec” if required.

1.4.2 Reset

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.

1.4.3 NMI

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. The cause reported on an NMI is 0x0 by default; a different cause may be specified using parameter “ecode_nmi” or applied using optional input port “nmi_cause” if required.

If parameter “rnmi_version” is not “none”, resumable NMIs are supported, managed by additional CSRs “mnscratch”, “mnepc”, “mncause” and “mnstatus”, following the indicated version of the

Resumable NMI extension proposal. In this variant, “`rnmi_version`” is “none”.

The NMI input is latched on the rising edge of the NMI signal. To instead specify that NMI input is level-sensitive, set parameter “`nmi_is_latched`” to False.

1.4.4 WFI

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`).

1.4.5 cycle CSR

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 cause Illegal Instruction traps.

1.4.6 time CSR

The “time” CSR is not implemented in this variant and reads of it will cause Illegal Instruction traps. Set parameter “`time_undefined`” to False to instead specify that “time” is implemented.

1.4.7 instret CSR

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 cause Illegal Instruction traps.

1.4.8 hpmcounter CSRs

“hpmcounter” CSRs are implemented in this variant. Set parameter “`hpmcounter_undefined`” to True to instead specify that “hpmcounter” CSRs are unimplemented and reads of them should cause Illegal Instruction traps.

1.4.9 Unaligned Accesses

Unaligned memory accesses are supported by this variant. Set parameter “`unaligned`” to “F” to disable such accesses.

Address misaligned exceptions are higher priority than page fault or access fault exceptions on this variant. Set parameter “`unaligned_low_pri`” to “T” to specify that they are lower priority instead.

1.4.10 PMP

A PMP unit is not implemented by this variant. Set parameter “PMP_registers” to indicate that the unit should be implemented with that number of PMP entries.

Accesses to unimplemented PMP registers cause Illegal Instruction exceptions on this variant. Set parameter “PMP_undefined” to False to indicate that these registers are hard-wired to zero instead.

1.5 Compressed Extension

This variant implements the compressed extension with version specified in the References section of this document. Note that parameter “compress_version” can be used to select the required architecture version.

Parameter Zca is used to specify that basic C extension instructions are present. By default, Zca is set to 1 in this variant. Updates to this parameter require a commercial product license.

Parameter Zcf is used to specify that floating point load/store instructions are present. By default, Zcf is set to 1 in this variant. Updates to this parameter require a commercial product license.

Parameter Zcb is used to specify that additional simple operation instructions are present. By default, Zcb is set to 0 in this variant. Updates to this parameter require a commercial product license.

Parameter Zcmb is used to specify that load/store byte/half instructions are present. By default, Zcmb is set to 0 in this variant. Updates to this parameter require a commercial product license.

Parameter Zcmp is used to specify that push/pop and double move instructions are present. By default, Zcmp is set to 0 in this variant. Updates to this parameter require a commercial product license.

Parameter Zcmpe is used to specify that E-extension push/pop instructions are present. By default, Zcmpe is set to 0 in this variant. Updates to this parameter require a commercial product license.

Parameter Zcmt is used to specify that table jump instructions are present. By default, Zcmt is set to 0 in this variant. Updates to this parameter require a commercial product license.

1.6 Privileged Architecture

This variant implements the Privileged Architecture with version specified in the References section of this document. Note that parameter “priv_version” can be used to select the required architecture version; see the following sections for detailed information about differences between each supported version.

1.6.1 Legacy Version 1.10

1.10 version of May 7 2017.

1.6.2 Version 20190608

Stable 1.11 version of June 8 2019, with these changes compared to version 1.10:

- mcountinhibit CSR defined;
- pages are never executable in Supervisor mode if page table entry U bit is 1;
- mstatus.TW is writable if any lower-level privilege mode is implemented (previously, it was just if Supervisor mode was implemented);

1.6.3 Version 20211203

1.12 draft version of December 3 2021, with these changes compared to version 20190608:

- mstatush, mseccfg, mseccfgh, menvcfg, menvcfgh, senvcfg, henvcfg, henvcfgh and mconfigptr CSRs defined;
- xret instructions clear mstatus.MPRV when leaving Machine mode if new mode is less privileged than M-mode;
- maximum number of PMP registers increased to 64;
- data endian is now configurable.

1.6.4 Version 1.12

Official 1.12 version, identical to 20211203.

1.6.5 Version master

Unstable master version, currently identical to 1.12.

1.7 Unprivileged Architecture

This variant implements the Unprivileged Architecture with version specified in the References section of this document. Note that parameter “user_version” can be used to select the required architecture version; see the following sections for detailed information about differences between each supported version.

1.7.1 Legacy Version 2.2

2.2 version of May 7 2017.

1.7.2 Version 20191213

Stable 20191213-Base-Ratified version of December 13 2019, with these changes compared to version 2.2:

- floating point fmin/fmax instruction behavior modified to comply with IEEE 754-201x.
- numerous other optional behaviors can be separately enabled using Z-prefixed parameters.

1.8 Bit-Manipulation Extension

This variant implements the Bit-Manipulation extension with version specified in the References section of this document. Note that parameter “bitmanip_version” can be used to select the required version of this extension. See section “Bit-Manipulation Extension Versions” for detailed information about differences between each supported version.

1.8.1 Bit-Manipulation Extension Parameters

Parameter Zbb is used to specify that the base instructions are present. By default, Zbb is set to 1 in this variant. Updates to this parameter require a commercial product license.

Parameter Zba is used to specify that address calculation instructions are present. By default, Zba is set to 1 in this variant. Updates to this parameter require a commercial product license.

Parameter Zbc is used to specify that carryless operation instructions are present. By default, Zbc is set to 1 in this variant. Updates to this parameter require a commercial product license.

Parameter Zbe is used to specify that bit deposit/extract instructions are present. By default, Zbe is set to 0 in this variant. Updates to this parameter require a commercial product license. This parameter is ignored for version 1.0.0, which does not implement that subset.

Parameter Zbf is used to specify that bit field place instructions are present. By default, Zbf is set to 0 in this variant. Updates to this parameter require a commercial product license. This parameter is ignored for version 1.0.0, which does not implement that subset.

Parameter Zbm is used to specify that bit matrix operation instructions are present. By default, Zbm is set to 0 in this variant. Updates to this parameter require a commercial product license. This parameter is ignored for version 1.0.0, which does not implement that subset.

Parameter Zbp is used to specify that permutation instructions are present. By default, Zbp is set to 0 in this variant. Updates to this parameter require a commercial product license. This parameter is ignored for version 1.0.0, which does not implement that subset.

Parameter Zbr is used to specify that CRC32 instructions are present. By default, Zbr is set to 0 in this variant. Updates to this parameter require a commercial product license. This parameter is ignored for version 1.0.0, which does not implement that subset.

Parameter Zbs is used to specify that single bit instructions are present. By default, Zbs is set to 1 in this variant. Updates to this parameter require a commercial product license.

Parameter Zbt is used to specify that ternary instructions are present. By default, Zbt is set to 0

in this variant. Updates to this parameter require a commercial product license. This parameter is ignored for version 1.0.0, which does not implement that subset.

1.8.2 Bit-Manipulation Extension Versions

The Bit-Manipulation 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.

1.8.3 Version 0.90

Stable 0.90 version of June 10 2019.

1.8.4 Version 0.91

Stable 0.91 version of August 29 2019, with these changes compared to version 0.90:

- change encodings of bmatxor, grev, grevw, grevi and greviw;
- add gorc, gorcw, gorci, gorciw, bfp and bfpw instructions.

1.8.5 Version 0.92

Stable 0.92 version of November 8 2019, with these changes compared to version 0.91:

- add packh, packu and packuw instructions;
- add sext.b and sext.h instructions;
- change encoding and behavior of bfp and bfpw instructions;
- change encoding of bdep and bdepw instructions.

1.8.6 Version 0.93-draft

Draft 0.93 version of January 29 2020, with these changes compared to version 0.92:

- add sh1add, sh2add, sh3add, sh1addu, sh2addu and sh3addu instructions;
- move slo, sloi, sro and sroi to Zbp subset;
- add orc16 to Zbb subset.

1.8.7 Version 0.93

Stable 0.93 version of January 10 2021, with these changes compared to version 0.93-draft:

- assignments of instructions to Z extension groups changed;
- exchange encodings of max and minu instructions;
- add xperm.[nbhw] instructions;
- instructions named *u.w renamed to *.uw;
- instruction add.uw zero-extends argument rs1, not rs2;
- instructions named sb* renamed to b*;
- instructions named pcnt* renamed to cpop*;
- instructions subu.w, addiwu, addwu, subwu, clmulw, clmulrw and clmulhw removed;
- instructions slo, sro, sloi, sroi, slow, srow, sloiw and sroiw removed from all Z extension groups and are therefore never implemented;
- instructions bext/bdep renamed to bcompress/bdecompress (this change is documented under the draft 0.94 version but is required to resolve an instruction name conflict introduced by instruction renames above);

1.8.8 Version 0.94

Stable 0.94 version of January 20 2021, with these changes compared to version 0.93:

- instructions bset[i]w, bclr[i]w, binv[i]w and bextw removed.

1.8.9 Version 1.0.0

Stable 1.0.0 version of June 6 2021, with these changes compared to version 0.94:

- instructions with immediate shift operands now follow base architecture semantics to determine operand legality instead of masking to XLEN-1;
- only subsets Zba, Zbb, Zbc and Zbs may be enabled;
- if the B extension is present, it is implicitly always enabled and not subject to control by misa.B, which is zero.

1.8.10 Version master

Unstable master version, with these changes compared to version 1.0.0:

- any subset may be enabled;
- xperm.n, xperm.b, xperm.h and xperm.w instructions renamed xperm4, xperm8, xperm16 and xperm32.

1.9 Other Extensions

Other extensions that can be configured are described in this section.

1.9.1 Zmmul

Parameter “Zmmul” is 0 on this variant, meaning that all multiply and divide instructions are implemented. if “Zmmul” is set to 1 then multiply instructions are implemented but divide and remainder instructions are not implemented.

1.9.2 Zicsr

Parameter “Zicsr” is 1 on this variant, meaning that standard CSRs and CSR access instructions are implemented. if “Zicsr” is set to 0 then standard CSRs and CSR access instructions are not implemented and an alternative scheme must be provided as a processor extension.

1.9.3 Zifencei

Parameter “Zifencei” is 1 on this variant, meaning that the fence.i instruction is implemented (but treated as a NOP by the model). if “Zifencei” is set to 0 then the fence.i instruction is not implemented.

1.9.4 Zicbom

Parameter “Zicbom” is 0 on this variant, meaning that code block management instructions are undefined. if “Zicbom” is set to 1 then code block management instructions cbo.clean, cbo.flush and cbo.inval are defined.

If Zicbom is present, the cache block size is given by parameter “cmomp_bytes”. The instructions may cause traps if used illegally but otherwise are NOPs in this model.

1.9.5 Zicbop

Parameter “Zicbop” is 0 on this variant, meaning that prefetch instructions are undefined. if “Zicbop” is set to 1 then prefetch instructions prefetch.i, prefetch.r and prefetch.w are defined (but behave as NOPs in this model).

1.9.6 Zicboz

Parameter “Zicboz” is 0 on this variant, meaning that the cbo.zero instruction is undefined. if “Zicboz” is set to 1 then the cbo.zero instruction is defined.

If Zicboz is present, the cache block size is given by parameter “cmoz_bytes”.

1.9.7 Smstateen

Parameter “Smstateen” is 0 on this variant, meaning that state enable CSRs are undefined. if “Smstateen” is set to 1 then state enable CSRs are defined.

Within the state enable CSRs, only bit 1 (for Zfinx), bit 57 (for xcontext CSR access), bit 62 (for xenvcfg CSR access) and bit 63 (for lower-level state enable CSR access) are currently implemented.

1.10 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.

1.11 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.

1.12 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.

1.12.1 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.

1.12.2 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.

1.12.3 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.

1.12.4 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.

1.12.5 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.

1.12.6 Debug Event Priorities

The model supports two different models for determining which debug exception occurs when multiple debug events are pending:

- 1: original mode (when parameter “debug_priority”=“original”);
- 2: modified mode, as described in Debug Specification pull request 693 (when parameter “debug_priority”=“PR693”). This mode resolves some anomalous behavior of the original specification.

1.12.7 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).

1.13 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).

1.13.1 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.

1.13.2 Trigger Module Parameters

Parameter “trigger_num” is used to specify the number of implemented triggers. In this variant, “trigger_num” is 1.

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 0x04.

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 1.

Parameter “mcontext_bits” is used to specify the number of writable bits in the “mcontext” register. In this variant, “mcontext_bits” is 0.

Parameter “mvalue_bits” is used to specify the number of writable bits in the “mvalue” field in “extra32”/“extra64” registers; if zero, the “mselect” field is tied to zero. In this variant, “mvalue_bits” is 0.

Parameter “mcontrol_maskmax” is used to specify the value of field “maskmax” in the “mcontrol” register. In this variant, “mcontrol_maskmax” is 0.

1.14 Debug Mask

It is possible to enable model debug messages in various categories. This can be done statically using the “debugflags” 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.

1.15 Integration Support

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

1.15.1 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.

1.16 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.

THIS IS A STARTING POINT AS THE SPECS DEVELOP More detail to be added once confirmed Awaiting information for: PMA (bespoke model requiring specification), Zce, Bus Error, ISA_B (exists in other models, to be added when ratified), ISA_P (exists in other models, to be added when ratified).

1.17 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.

1.18 References

The Model details are based upon the following specifications:

RISC-V Instruction Set Manual, Volume I: User-Level ISA (User Architecture Version 20191213)

RISC-V Instruction Set Manual, Volume II: Privileged Architecture (Privileged Architecture Version 1.12, equivalent to 20211203)

RISC-V “C” Compressed Extension (Compressed Architecture Version 0.70.1)

RISC-V “B” Bit Manipulation Extension (Bit Manipulation Architecture Version 1.0.0)

RISC-V External Debug Support (RISC-V External Debug Support Version 1.0.0-STABLE)

Chapter 2

Openhwgroup-Specific Extensions

Open HW Group processors add various custom extensions to the basic RISC-V architecture. This model supports the following CORE-V Instruction Set Extensions:

- PULP_XPULP Features
- Static 16 entry PMA
- Custom bus fault extensions
- Secure exceptions

The PULP_CLUSTER and PULP_ZFINX CORE-V Instruction Set Extensions are not supported, although the standard Risc-V Zfinx extension is supported in the base model.

In addition to the base model RISC-V parameters, this model implements parameters allowing openhwgroup-specific model features to be controlled. These parameters are documented below.

2.1 Parameter: extensions/PULP_XPULP

The PULP_XPULP CORE-V Instruction Set Extensions may be enabled on RV32 cores by setting the parameter extension/PULP_XPULP to True.

Note that currently the XPULP instructions use the non-conforming encodings that are in the process of being updated (see <https://github.com/openhwgroup/cv32e40p/issues/452> for details.) Until the new encodings have been defined and implemented, the parameter extension/PULP_V1 must also be set to True to enable the extensions.

2.2 Parameter: extensions/PMA_NUM_REGIONS

TBD

2.3 PULP_XPULP Extension Status

The XPULP extension is not enabled on this variant. Use parameter extension/PULP_XPULP to enable it.

2.3.1 PULP_XPULP Features:

The following features are enabled by the PULP_XPULP parameter:

- Post-Incrementing Load & Store Instructions and Register-Register Load & Store Instructions
- Hardware Loops and the lpcount0/1, lpstart0/1 and lpend0/1 CSRs
- ALU Instructions
- Multiply-Accumulate Instructions
- SIMD Instructions
- uhartid and privlv custom CSRs

2.3.2 PULP_XPULP Limitations:

Valid behaviour of the hardware loops is fully modeled, however the exception behaviour for hardware loops is not yet modeled, so code that would cause illegal instruction exceptions on the hardware will have undefined behaviour in the model.

2.3.3 PULP_XPULP References:

The cv32e40p documentation was used as the reference documentation for the PULP_XPULP extension, and may be found here:

- <https://cv32e40p.readthedocs.io/en/latest/>

The specific commit used was:

- <https://github.com/openhwgroup/cv32e40p/commit/dffc7adaf44c0ccc8dfa07ab79fbb34358056175>

2.4 PMA Extension Status

The PMA extension is not enabled on this variant. Use parameter extension/PMA_NUM_REGIONS to enable it.

2.5 Custom Bus Fault Extension Status

The Custom Bus Fault extension is enabled on this variant.

2.6 Secure Exceptions Status

Secure Exceptions are not supported on this variant.

Chapter 3

Configuration

3.1 Location

This model's VLVN is openhwgroup.org/processor/riscv/1.0.

The model source is usually at:

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

The model binary is usually at:

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

3.2 GDB Path

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

3.3 Semi-Host Library

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

3.4 Processor Endian-ness

This is a LITTLE endian model.

3.5 QuantumLeap Support

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

3.6 Processor ELF code

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

Chapter 4

All Variants in this model

This model has these variants

| Variant | Description |
|----------------|------------------------------|
| CV32E20 | |
| CV32E40P | |
| CV32E41P | |
| CV32E40S | |
| CV32E40X | (described in this document) |
| CV32E40X_DEV | |
| CV32A6 | |
| CV64A6 | |

Table 4.1: All Variants in this model

Chapter 5

Bus Master Ports

This model has these bus master ports.

| Name | min | max | Connect? | Description |
|-------------|-----|-----|-----------|-----------------|
| INSTRUCTION | 32 | 34 | mandatory | Instruction bus |
| DATA | 32 | 34 | optional | Data bus |

Table 5.1: Bus Master Ports

Chapter 6

Bus Slave Ports

This model has no bus slave ports.

Chapter 7

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_cause | input | optional | externally-applied NMI cause |
| nmi_addr | input | optional | externally-applied NMI address |
| MSWInterrupt | input | optional | Machine software interrupt |
| MTimerInterrupt | input | optional | Machine timer interrupt |
| MExternalInterrupt | input | optional | Machine external interrupt |
| LocalInterrupt0 | input | optional | Local interrupt 0 |
| LocalInterrupt1 | input | optional | Local interrupt 1 |
| LocalInterrupt2 | input | optional | Local interrupt 2 |
| LocalInterrupt3 | input | optional | Local interrupt 3 |
| LocalInterrupt4 | input | optional | Local interrupt 4 |
| LocalInterrupt5 | input | optional | Local interrupt 5 |
| LocalInterrupt6 | input | optional | Local interrupt 6 |
| LocalInterrupt7 | input | optional | Local interrupt 7 |
| LocalInterrupt8 | input | optional | Local interrupt 8 |
| LocalInterrupt9 | input | optional | Local interrupt 9 |
| LocalInterrupt10 | input | optional | Local interrupt 10 |
| LocalInterrupt11 | input | optional | Local interrupt 11 |
| LocalInterrupt12 | input | optional | Local interrupt 12 |
| LocalInterrupt13 | input | optional | Local interrupt 13 |
| LocalInterrupt14 | input | optional | Local interrupt 14 |
| LocalInterrupt15 | input | optional | Local interrupt 15 |
| 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 |
| DM | output | optional | Debug state indication |
| haltreq | input | optional | haltreq (Debug halt request) |

| | | | |
|---------------------|-------|----------|---|
| resethaltreq | input | optional | resethaltreq (Debug halt request after reset) |
| deferint | input | optional | Artifact signal causing interrupts to be held off when high |
| IllegalInstruction | input | optional | Illegal Instruction Exception |
| InstructionBusFault | input | optional | Instruction Bus Fault Exception |

Table 7.1: Net Ports

Chapter 8

FIFO Ports

This model has no FIFO ports.

Chapter 9

Formal Parameters

| Name | Type | Description |
|-----------------------------------|-------------|---|
| Fundamental | | |
| variant | Enumeration | Selects variant (either a generic UISA or a specific model) |
| user_version | Enumeration | Specify required User Architecture version (2.2, 2.3, 20190305 or 20191213) |
| priv_version | Enumeration | Specify required Privileged Architecture version (1.10, 1.11, 20190405, 20190608, 20211203, 1.12 or master) |
| Smepmp_version | Enumeration | Specify required Smepmp Architecture version (none, 0.9.5 or 1.0) |
| endian | Endian | Model endian |
| enable_expanded | Boolean | Specify that 48-bit and 64-bit expanded instructions are supported |
| 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) |
| sub_Extensions | String | Remove extensions specified by letters from misa.Extensions (for example, specify “VD” to remove 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) |
| sub_Extensions_mask | String | Remove extensions specified by letters from mask of writable bits in misa.Extensions (for example, specify “VD” to remove V and D features) |
| add_implicit_Extensions | String | Add extensions specified by letters to implicitly-present extensions not visible in misa.Extensions |
| sub_implicit_Extensions | String | Remove extensions specified by letters from implicitly-present extensions not visible in misa.Extensions |
| Bit_Manipulation_Extension | | |
| bitmanip_version | Enumeration | Specify required Bit Manipulation Architecture version (0.90, 0.91, 0.92, 0.93-draft, 0.93, 0.94, 1.0.0 or master) |
| Zba | Boolean | Specify that Zba is implemented |
| Zbb | Boolean | Specify that Zbb is implemented |
| Zbc | Boolean | Specify that Zbc is implemented |
| Zbe | Boolean | Specify that Zbe is implemented (ignored if version 1.0.0) |
| Zbf | Boolean | Specify that Zbf is implemented (ignored if version 1.0.0) |
| Zbm | Boolean | Specify that Zbm is implemented (ignored if version 1.0.0) |
| Zbp | Boolean | Specify that Zbp is implemented (ignored if version 1.0.0) |
| Zbr | Boolean | Specify that Zbr is implemented (ignored if version 1.0.0) |
| Zbs | Boolean | Specify that Zbs is implemented |
| Zbt | Boolean | Specify that Zbt is implemented (ignored if version 1.0.0) |
| Compressed_Extension | | |

| | | |
|------------------------------|-------------|---|
| compress_version | Enumeration | Specify required Compressed Architecture version (legacy or 0.70.1) |
| Zca | Boolean | Specify that Zca is implemented |
| Zcb | Boolean | Specify that Zcb is implemented |
| Zcf | Boolean | Specify that Zcf is implemented |
| Zcmb | Boolean | Specify that Zcmb is implemented |
| Zcmp | Boolean | Specify that Zcmp is implemented |
| Zcmpe | Boolean | Specify that Zcmpe is implemented |
| Zcmt | Boolean | Specify that Zcmt is implemented |
| Debug Extension | | |
| debug_version | Enumeration | Specify required Debug Architecture version (0.13.2-DRAFT, 0.14.0-DRAFT or 1.0.0-STABLE) |
| debug_mode | Enumeration | Specify how Debug mode is implemented (none, vector, interrupt or halt) |
| debug_address | Uns64 | Specify address to which to jump to enter debug in vectored mode |
| dexc_address | Uns64 | Specify address to which to jump on debug exception in vectored mode |
| debug_eret_mode | Enumeration | Specify behavior for MRET, SRET or URET in Debug mode (nop, jump to dexc.address or trap to dexc.address) (nop, jump_to_dexc_address or trap_to_dexc_address) |
| debug_priority | Enumeration | Specify relative priorities of simultaneous debug events (original or PR693) |
| dcsr_ebreak_mask | Uns32 | Specify mask of dcsr.ebreak fields that reset to 1 (ebreak instructions enter Debug mode) |
| Interrupts Exceptions | | |
| rnmi_version | Enumeration | Specify required RNMI Architecture version (none or 0.2.1) |
| 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 |
| nmi_is_latched | Boolean | Specify whether NMI input is latched on rising edge (if False, it is level-sensitive) |
| 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 |
| reset_address | Uns64 | Override reset vector address |
| nmi_address | Uns64 | Override NMI vector address |
| CLINT_address | Uns64 | Specify base address of internal CLINT model (or 0 for no CLINT) |
| 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 |
| 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 |
| Simulation Artifact | | |
| use_hw_reg_names | Boolean | Specify whether to use hardware register names x0-x31 and f0-f31 instead of ABI register names |
| no_pseudo_inst | Boolean | Specify whether pseudo-instructions should not be reported in trace and disassembly |
| verbose | Boolean | Specify verbose output messages |
| traceVolatile | Boolean | Specify whether volatile registers (e.g. minstret) should be shown in change trace |
| 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> |
| Memory | | |
| unaligned_low_pri | Boolean | Specify whether address misaligned exceptions are lower priority than page or access fault exceptions |
| unaligned | Boolean | Specify whether the processor supports unaligned memory accesses |
| Instruction_CSR_Behavior | | |
| 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 |
| time_undefined | Boolean | Specify that the time CSR is undefined |
| instret_undefined | Boolean | Specify that the instret CSR is undefined |
| hpmcounter_undefined | Boolean | Specify that the hpmcounter CSRs are undefined |
| CSR_Masks | | |
| mtvec_mask | Uns64 | Specify hardware-enforced mask of writable bits in mtvec register |
| tdata1_mask | Uns64 | Specify hardware-enforced mask of writable bits in Trigger Module tdata1 register |
| mip_mask | Uns64 | Specify hardware-enforced mask of writable bits in mip register |
| envcfg_mask | Uns64 | Specify hardware-enforced mask of writable bits in envcfg registers |
| mtvec_sext | Boolean | Specify whether mtvec is sign-extended from most-significant bit |
| Trigger | | |
| 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 |
| 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 |
| mvalue_bits | Uns32 | Specify the number of implemented bits in textra.mvalue (if zero, textra.mselect is tied to zero) |
| mcontrol_maskmax | Uns32 | Specify mcontrol.maskmax value |
| PMP Configuration | | |
| 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 |
| PMP_undefined | Boolean | Whether accesses to unimplemented PMP registers are undefined (if True) or write ignored and zero (if False) |
| PMP_maskparams | Boolean | Enable parameters to change the read-only masks for PMP CSRs |
| PMP_initialparams | Boolean | Enable parameters to change the reset values for PMP CSRs |
| Other Extensions | | |
| Smstateen | Boolean | Specify that Smstateen is implemented |
| Zicr | Boolean | Specify that Zicr is implemented |
| Zifencei | Boolean | Specify that Zifencei is implemented |
| Zicbom | Boolean | Specify that Zicbom is implemented |
| Zicbop | Boolean | Specify that Zicbop is implemented |

| | | |
|-----------------------|---------|--|
| Zicboz | Boolean | Specify that Zicboz is implemented |
| Zmmul | Boolean | Specify that Zmmul is implemented |
| CSR Defaults | | |
| 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) |
| mconfigptr | Uns64 | Override mconfigptr register |
| mtvec | Uns64 | Override mtvec register |
| mseccfg | Uns64 | Override mseccfg register |
| Fast Interrupt | | |
| CLICLEVELS | Uns32 | Specify number of interrupt levels implemented by CLIC, or 0 if CLIC absent |

Table 9.1: Parameters that can be set in: Hart

9.1 Extension Parameters

| Name | Type | Description |
|---------------------|---------|------------------------------|
| debug | Boolean | debug flags |
| mcountinhibit_reset | Uns32 | reset value of mcountinhibit |
| PMA_NUM_REGIONS | Uns32 | number of PMA regions |
| word_addr_low0 | Uns32 | PMA region 0 low bound |
| word_addr_high0 | Uns32 | PMA region 0 high bound |
| main0 | Boolean | PMA region 0 main |
| bufferable0 | Boolean | PMA region 0 bufferable |
| cacheable0 | Boolean | PMA region 0 cacheable |
| atomic0 | Boolean | PMA region 0 atomic |
| word_addr_low1 | Uns32 | PMA region 1 low bound |
| word_addr_high1 | Uns32 | PMA region 1 high bound |
| main1 | Boolean | PMA region 1 main |
| bufferable1 | Boolean | PMA region 1 bufferable |
| cacheable1 | Boolean | PMA region 1 cacheable |
| atomic1 | Boolean | PMA region 1 atomic |
| word_addr_low2 | Uns32 | PMA region 2 low bound |
| word_addr_high2 | Uns32 | PMA region 2 high bound |
| main2 | Boolean | PMA region 2 main |
| bufferable2 | Boolean | PMA region 2 bufferable |
| cacheable2 | Boolean | PMA region 2 cacheable |
| atomic2 | Boolean | PMA region 2 atomic |
| word_addr_low3 | Uns32 | PMA region 3 low bound |
| word_addr_high3 | Uns32 | PMA region 3 high bound |
| main3 | Boolean | PMA region 3 main |
| bufferable3 | Boolean | PMA region 3 bufferable |
| cacheable3 | Boolean | PMA region 3 cacheable |
| atomic3 | Boolean | PMA region 3 atomic |
| word_addr_low4 | Uns32 | PMA region 4 low bound |
| word_addr_high4 | Uns32 | PMA region 4 high bound |
| main4 | Boolean | PMA region 4 main |
| bufferable4 | Boolean | PMA region 4 bufferable |
| cacheable4 | Boolean | PMA region 4 cacheable |
| atomic4 | Boolean | PMA region 4 atomic |
| word_addr_low5 | Uns32 | PMA region 5 low bound |
| word_addr_high5 | Uns32 | PMA region 5 high bound |

| | | |
|------------------|---------|--------------------------|
| main5 | Boolean | PMA region 5 main |
| bufferable5 | Boolean | PMA region 5 bufferable |
| cacheable5 | Boolean | PMA region 5 cacheable |
| atomic5 | Boolean | PMA region 5 atomic |
| word_addr_low6 | Uns32 | PMA region 6 low bound |
| word_addr_high6 | Uns32 | PMA region 6 high bound |
| main6 | Boolean | PMA region 6 main |
| bufferable6 | Boolean | PMA region 6 bufferable |
| cacheable6 | Boolean | PMA region 6 cacheable |
| atomic6 | Boolean | PMA region 6 atomic |
| word_addr_low7 | Uns32 | PMA region 7 low bound |
| word_addr_high7 | Uns32 | PMA region 7 high bound |
| main7 | Boolean | PMA region 7 main |
| bufferable7 | Boolean | PMA region 7 bufferable |
| cacheable7 | Boolean | PMA region 7 cacheable |
| atomic7 | Boolean | PMA region 7 atomic |
| word_addr_low8 | Uns32 | PMA region 8 low bound |
| word_addr_high8 | Uns32 | PMA region 8 high bound |
| main8 | Boolean | PMA region 8 main |
| bufferable8 | Boolean | PMA region 8 bufferable |
| cacheable8 | Boolean | PMA region 8 cacheable |
| atomic8 | Boolean | PMA region 8 atomic |
| word_addr_low9 | Uns32 | PMA region 9 low bound |
| word_addr_high9 | Uns32 | PMA region 9 high bound |
| main9 | Boolean | PMA region 9 main |
| bufferable9 | Boolean | PMA region 9 bufferable |
| cacheable9 | Boolean | PMA region 9 cacheable |
| atomic9 | Boolean | PMA region 9 atomic |
| word_addr_low10 | Uns32 | PMA region 10 low bound |
| word_addr_high10 | Uns32 | PMA region 10 high bound |
| main10 | Boolean | PMA region 10 main |
| bufferable10 | Boolean | PMA region 10 bufferable |
| cacheable10 | Boolean | PMA region 10 cacheable |
| atomic10 | Boolean | PMA region 10 atomic |
| word_addr_low11 | Uns32 | PMA region 11 low bound |
| word_addr_high11 | Uns32 | PMA region 11 high bound |
| main11 | Boolean | PMA region 11 main |
| bufferable11 | Boolean | PMA region 11 bufferable |
| cacheable11 | Boolean | PMA region 11 cacheable |
| atomic11 | Boolean | PMA region 11 atomic |
| word_addr_low12 | Uns32 | PMA region 12 low bound |
| word_addr_high12 | Uns32 | PMA region 12 high bound |
| main12 | Boolean | PMA region 12 main |
| bufferable12 | Boolean | PMA region 12 bufferable |
| cacheable12 | Boolean | PMA region 12 cacheable |
| atomic12 | Boolean | PMA region 12 atomic |
| word_addr_low13 | Uns32 | PMA region 13 low bound |
| word_addr_high13 | Uns32 | PMA region 13 high bound |
| main13 | Boolean | PMA region 13 main |
| bufferable13 | Boolean | PMA region 13 bufferable |
| cacheable13 | Boolean | PMA region 13 cacheable |
| atomic13 | Boolean | PMA region 13 atomic |
| word_addr_low14 | Uns32 | PMA region 14 low bound |
| word_addr_high14 | Uns32 | PMA region 14 high bound |
| main14 | Boolean | PMA region 14 main |
| bufferable14 | Boolean | PMA region 14 bufferable |

| | | |
|------------------|---------|--|
| cacheable14 | Boolean | PMA region 14 cacheable |
| atomic14 | Boolean | PMA region 14 atomic |
| word_addr_low15 | Uns32 | PMA region 15 low bound |
| word_addr_high15 | Uns32 | PMA region 15 high bound |
| main15 | Boolean | PMA region 15 main |
| bufferable15 | Boolean | PMA region 15 bufferable |
| cacheable15 | Boolean | PMA region 15 cacheable |
| atomic15 | Boolean | PMA region 15 atomic |
| PULP_XPULP | Boolean | Enable XPULP features (CORE-V Extensions, excluding cv.elw |
| PULP_V1 | Boolean | Enable obsolete V1 encodings for PULP opcodes |

Table 9.2: Parameters for extension

9.2 Parameters with enumerated types

9.2.1 Parameter user_version

| Set to this value | Description |
|-------------------|---------------------------------------|
| 2.2 | User Architecture Version 2.2 |
| 2.3 | Deprecated and equivalent to 20191213 |
| 20190305 | Deprecated and equivalent to 20191213 |
| 20191213 | User Architecture Version 20191213 |

Table 9.3: Values for Parameter user_version

9.2.2 Parameter priv_version

| Set to this value | Description |
|-------------------|--|
| 1.10 | Privileged Architecture Version 1.10 |
| 1.11 | Privileged Architecture Version 1.11, equivalent to 20190608 |
| 20190405 | Deprecated and equivalent to 20190608 |
| 20190608 | Privileged Architecture Version Ratified-IMFDQC-and-Priv-v1.11 |
| 20211203 | Privileged Architecture Version 20211203 |
| 1.12 | Privileged Architecture Version 1.12, equivalent to 20211203 |
| master | Privileged Architecture Master Branch as of commit 6bdeb58 (this is subject to change) |

Table 9.4: Values for Parameter priv_version

9.2.3 Parameter bitmanip_version

| Set to this value | Description |
|-------------------|---|
| 0.90 | Bit Manipulation Architecture Version v0.90-20190610 |
| 0.91 | Bit Manipulation Architecture Version v0.91-20190829 |
| 0.92 | Bit Manipulation Architecture Version v0.92-20191108 |
| 0.93-draft | Bit Manipulation Architecture Version 0.93-draft-20200129 |
| 0.93 | Bit Manipulation Architecture Version v0.93-20210110 |
| 0.94 | Bit Manipulation Architecture Version v0.94-20210120 |
| 1.0.0 | Bit Manipulation Architecture Version 1.0.0 |
| master | Bit Manipulation Master Branch as of commit 1f56afe (this is subject to change) |

Table 9.5: Values for Parameter bitmanip_version

9.2.4 Parameter compress_version

| Set to this value | Description |
|-------------------|--|
| legacy | Compressed Architecture absent or legacy version |
| 0.70.1 | Compressed Architecture Version 0.70.1 |

Table 9.6: Values for Parameter compress_version

9.2.5 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 |
| 1.0.0-STABLE | RISC-V External Debug Support Version 1.0.0-STABLE |

Table 9.7: Values for Parameter debug_version

9.2.6 Parameter rnmi_version

| Set to this value | Description |
|-------------------|----------------------|
| none | RNMI not implemented |
| 0.2.1 | RNMI version 0.2.1 |

Table 9.8: Values for Parameter rnmi_version

9.2.7 Parameter Smepmp_version

| Set to this value | Description |
|-------------------|--|
| none | Smepmp not implemented |
| 0.9.5 | Smepmp version 0.9.5 (deprecated and identical to 1.0) |
| 1.0 | Smepmp version 1.0 |

Table 9.9: Values for Parameter Smepmp_version

9.2.8 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 9.10: Values for Parameter debug_mode

9.2.9 Parameter debug_eret_mode

| Set to this value | Description |
|----------------------|--|
| nop | MRET, SRET or URET in Debug mode is a nop |
| jump_to_dexc_address | MRET, SRET or URET in Debug mode jumps to dexc_address |
| trap_to_dexc_address | MRET, SRET or URET in Debug mode traps to dexc_address |

Table 9.11: Values for Parameter debug_eret_mode

9.2.10 Parameter debug_priority

| Set to this value | Description |
|-------------------|---|
| original | original debug priorities |
| PR693 | priorities described specification PR 693 |

Table 9.12: Values for Parameter debug_priority

9.3 Parameter values

These are the current parameter values.

| Name | Value |
|-----------------------------------|----------|
| Fundamental | |
| variant | CV32E40X |
| user_version | 20191213 |
| priv_version | 1.12 |
| Smepmp_version | none |
| endian | none |
| enable_expanded | F |
| endianFixed | F |
| misa_MXL | 1 |
| misa_Extensions | 0x1106 |
| add_Extensions | |
| sub_Extensions | |
| misa_Extensions_mask | 0 |
| add_Extensions_mask | |
| sub_Extensions_mask | |
| add_implicit_Extensions | |
| sub_implicit_Extensions | |
| Bit Manipulation Extension | |
| bitmanip_version | 1.0.0 |
| Zba | T |
| Zbb | T |
| Zbc | T |
| Zbe | T |
| Zbf | T |
| Zbm | T |
| Zbp | T |
| Zbr | T |
| Zbs | T |
| Zbt | T |
| Compressed Extension | |
| compress_version | 0.70.1 |
| Zca | T |
| Zcb | F |
| Zcf | T |

| | |
|---------------------------------|----------------------|
| Zcmb | F |
| Zcmp | F |
| Zcmpe | F |
| Zcmt | F |
| Debug_Extension | |
| debug_version | 1.0.0-STABLE |
| debug_mode | vector |
| debug_address | 0x1a110800 |
| dexc_address | 0x1a111000 |
| debug_eret_mode | trap_to_dexc_address |
| debug_priority | original |
| dcsr_ebreak_mask | 0 |
| Interrupts_Exceptions | |
| rnmi_version | none |
| mtvec_is_ro | F |
| tvec_align | 0 |
| ecode_mask | 0x7ff |
| ecode_nmi | 0 |
| nmi_is_latched | T |
| tval_zero | T |
| tval_zero_ebreak | F |
| tval_ii_code | F |
| reset_address | 0 |
| nmi_address | 0 |
| CLINT_address | 0 |
| local_int_num | 16 |
| unimp_int_mask | 0 |
| force_mideleg | 0 |
| no_ideleg | 0 |
| no_e deleg | 0 |
| external_int_id | F |
| Simulation Artifact | |
| use_hw_reg_names | F |
| no_pseudo_inst | F |
| verbose | F |
| traceVolatile | F |
| enable_CSR_bus | F |
| CSR_remap | |
| Memory | |
| unaligned_low_pri | F |
| unaligned | T |
| Instruction_CSR_Behavior | |
| wfi_is_nop | F |
| counteren_mask | 0xffffffff |
| noinhibit_mask | 0 |

| | |
|--------------------------|--------------------|
| cycle_undefined | F |
| time_undefined | T |
| instret_undefined | F |
| hpmcounter_undefined | F |
| CSR Masks | |
| mtvec_mask | 0xfffff81 |
| tdata1_mask | 4 |
| mip_mask | 0x337 |
| envcfg_mask | 0x8000000000000001 |
| mtvec_sext | F |
| Trigger | |
| tinfo_undefined | F |
| tcontrol_undefined | F |
| mcontext_undefined | F |
| scontext_undefined | F |
| mscontext_undefined | F |
| amo_trigger | F |
| no_hit | T |
| trigger_num | 1 |
| tinfo | 4 |
| mcontext_bits | 0 |
| mvalue_bits | 0 |
| mcontrol_maskmax | 0 |
| PMP Configuration | |
| PMP_grain | 0 |
| PMP_registers | 0 |
| PMP_max_page | 0 |
| PMP_decompose | F |
| PMP_undefined | T |
| PMP_maskparams | F |
| PMP_initialparams | F |
| Other Extensions | |
| Smstateen | F |
| Zicsr | T |
| Zifencei | T |
| Zicbom | F |
| Zicbop | F |
| Zicboz | F |
| Zmmul | F |
| CSR Defaults | |
| mvendorid | 0x602 |
| marchid | 20 |
| mimpid | 0 |
| mhartid | 0 |
| mconfigptr | 0 |

| | |
|-----------------------|----|
| mtvec | 1 |
| mseccfg | 0 |
| Fast Interrupt | |
| CLICLEVELS | 0 |
| extension | |
| debug* | F |
| mcountinhibit_reset* | 13 |
| PMA_NUM_REGIONS* | 0 |
| word_addr_low0* | 0 |
| word_addr_high0* | 0 |
| main0* | F |
| bufferable0* | F |
| cacheable0* | F |
| atomic0* | F |
| word_addr_low1* | 0 |
| word_addr_high1* | 0 |
| main1* | F |
| bufferable1* | F |
| cacheable1* | F |
| atomic1* | F |
| word_addr_low2* | 0 |
| word_addr_high2* | 0 |
| main2* | F |
| bufferable2* | F |
| cacheable2* | F |
| atomic2* | F |
| word_addr_low3* | 0 |
| word_addr_high3* | 0 |
| main3* | F |
| bufferable3* | F |
| cacheable3* | F |
| atomic3* | F |
| word_addr_low4* | 0 |
| word_addr_high4* | 0 |
| main4* | F |
| bufferable4* | F |
| cacheable4* | F |
| atomic4* | F |
| word_addr_low5* | 0 |
| word_addr_high5* | 0 |
| main5* | F |
| bufferable5* | F |
| cacheable5* | F |
| atomic5* | F |
| word_addr_low6* | 0 |

| | |
|-------------------|---|
| word_addr_high6* | 0 |
| main6* | F |
| bufferable6* | F |
| cacheable6* | F |
| atomic6* | F |
| word_addr_low7* | 0 |
| word_addr_high7* | 0 |
| main7* | F |
| bufferable7* | F |
| cacheable7* | F |
| atomic7* | F |
| word_addr_low8* | 0 |
| word_addr_high8* | 0 |
| main8* | F |
| bufferable8* | F |
| cacheable8* | F |
| atomic8* | F |
| word_addr_low9* | 0 |
| word_addr_high9* | 0 |
| main9* | F |
| bufferable9* | F |
| cacheable9* | F |
| atomic9* | F |
| word_addr_low10* | 0 |
| word_addr_high10* | 0 |
| main10* | F |
| bufferable10* | F |
| cacheable10* | F |
| atomic10* | F |
| word_addr_low11* | 0 |
| word_addr_high11* | 0 |
| main11* | F |
| bufferable11* | F |
| cacheable11* | F |
| atomic11* | F |
| word_addr_low12* | 0 |
| word_addr_high12* | 0 |
| main12* | F |
| bufferable12* | F |
| cacheable12* | F |
| atomic12* | F |
| word_addr_low13* | 0 |
| word_addr_high13* | 0 |
| main13* | F |
| bufferable13* | F |

| | |
|-------------------|---|
| cacheable13* | F |
| atomic13* | F |
| word_addr_low14* | 0 |
| word_addr_high14* | 0 |
| main14* | F |
| bufferable14* | F |
| cacheable14* | F |
| atomic14* | F |
| word_addr_low15* | 0 |
| word_addr_high15* | 0 |
| main15* | F |
| bufferable15* | F |
| cacheable15* | F |
| atomic15* | F |
| PULP_XPULP* | F |
| PULP_V1* | F |

Table 9.13: Parameter values

* Parameters marked with an asterisk are part of the processor extension library.

Chapter 10

Execution Modes

| Mode | Code | Description |
|---------|------|--------------|
| Machine | 3 | Machine mode |
| Debug | 6 | Debug mode |

Table 10.1: Modes implemented in: Hart

Chapter 11

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 |
| 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 |
| InstructionBusFault | 48 | Instruction Bus Fault |
| MSWInterrupt | 67 | Machine software interrupt |
| MTimerInterrupt | 71 | Machine timer interrupt |
| MExternalInterrupt | 75 | Machine external interrupt |
| LocalInterrupt0 | 80 | Local interrupt 0 |
| LocalInterrupt1 | 81 | Local interrupt 1 |
| LocalInterrupt2 | 82 | Local interrupt 2 |
| LocalInterrupt3 | 83 | Local interrupt 3 |
| LocalInterrupt4 | 84 | Local interrupt 4 |
| LocalInterrupt5 | 85 | Local interrupt 5 |
| LocalInterrupt6 | 86 | Local interrupt 6 |
| LocalInterrupt7 | 87 | Local interrupt 7 |
| LocalInterrupt8 | 88 | Local interrupt 8 |
| LocalInterrupt9 | 89 | Local interrupt 9 |
| LocalInterrupt10 | 90 | Local interrupt 10 |
| LocalInterrupt11 | 91 | Local interrupt 11 |

| | | |
|------------------|------------|--------------------|
| LocalInterrupt12 | 92 | Local interrupt 12 |
| LocalInterrupt13 | 93 | Local interrupt 13 |
| LocalInterrupt14 | 94 | Local interrupt 14 |
| LocalInterrupt15 | 95 | Local interrupt 15 |
| GenericNMI | 4294967295 | Generic NMI |

Table 11.1: Exceptions implemented in: Hart

Chapter 12

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.

12.1 Level 1: Hart

This level in the model hierarchy has 5 commands.

This level in the model hierarchy has 3 register groups:

| Group name | Registers |
|----------------------------|-----------|
| Core | 33 |
| Machine_Control_and_Status | 182 |
| Integration_support | 3 |

Table 12.1: Register groups

This level in the model hierarchy has no children.

Chapter 13

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.

13.1 Level 1: Hart

13.1.1 debugflags

show or modify the processor debug flags

| Argument | Type | Description |
|----------|---------|---|
| -get | Boolean | print current processor flags value |
| -mask | Boolean | print valid debug flag bits |
| -set | Int32 | new processor flags (only flags 0x00000006 can be modified) |

Table 13.1: debugflags command arguments

13.1.2 getCSRIndex

Return index for a named CSR (or -1 if no matching CSR)

| Argument | Type | Description |
|----------|--------|-------------|
| -name | String | CSR name |

Table 13.2: getCSRIndex command arguments

13.1.3 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 13.3: isync command arguments

13.1.4 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 |
| -memory | String | show memory accesses by this instruction. Argument can be any combination of X (execute), A (load or store access) and S (system) |
| -mode | Boolean | show processor mode changes |
| -off | Boolean | disable instruction tracing |
| -on | Boolean | enable instruction tracing |
| -processorname | Boolean | Include processor name in all trace lines |
| -registerchange | Boolean | show registers changed by this instruction |
| -registers | Boolean | show registers after each trace |

Table 13.4: itrace command arguments

13.1.5 listCSRs

13.1.5.1 Argument description

List all CSRs in index order

Chapter 14

Registers

14.1 Level 1: Hart

14.1.1 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 14.1: Registers at level 1, type:Hart group:Core

14.1.2 Machine_Control_and_Status

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

| Name | Bits | Initial-Hex | RW | Description |
|---------------|------|-------------|----|---|
| mstatus | 32 | 1800 | rw | Machine Status |
| misa | 32 | 40001104 | rw | ISA and Extensions |
| mie | 32 | 0 | rw | Machine Interrupt Enable |
| mtvec | 32 | 1 | rw | Machine Trap-Vector Base-Address |
| mstatush | 32 | 0 | rw | Machine Status High |
| mcountinhibit | 32 | d | 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 |
| scontext | 32 | 0 | rw | Trigger Supervisor Context |
| tselect | 32 | 0 | rw | Trigger Register Select |
| tdata1 | 32 | 28001040 | rw | Trigger Data 1 |
| tdata2 | 32 | 0 | rw | Trigger Data 2 |
| tdata3 | 32 | 0 | rw | Trigger Data 3 |
| tinfo | 32 | 4 | rw | Trigger Info |
| tcontrol* | 32 | 0 | rw | tcontrol zero |
| mcontext | 32 | 0 | rw | Trigger Machine Context |

| | | | | |
|----------------|----|----------|----|---|
| mscontext | 32 | 0 | rw | Trigger Machine Context Alias |
| dcsr | 32 | 40000003 | rw | Debug Control and Status |
| dpc | 32 | 0 | rw | Debug PC |
| dscratch0 | 32 | 0 | rw | Debug Scratch 0 |
| dscratch1 | 32 | 0 | rw | Debug Scratch 1 |
| 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 |
| cycle | 32 | 0 | r- | Cycle Counter |
| 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 |
| cycleh | 32 | 0 | r- | Cycle Counter 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 |
| mvendorid | 32 | 602 | r- | Vendor ID |
| marchid | 32 | 14 | r- | Architecture ID |
| mimpid | 32 | 0 | r- | Implementation ID |
| mhartid | 32 | 0 | r- | Hardware Thread ID |
| mconfigptr | 32 | 0 | r- | Configuration Data Structure |

Table 14.2: Registers at level 1, type:Hart group:Machine_Control_and_Status

* Registers marked with an asterisk are part of the processor extension library.

14.1.3 Integration_support

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

| Name | Bits | Initial-Hex | RW | Description |
|------------|------|-------------|----|--------------------------------------|
| DM | 8 | 0 | rw | Debug mode active |
| commercial | 8 | 0 | r- | Commercial feature in use |
| ASYNCPPE | 8 | 0 | r- | Asynchronous Event Pending & Enabled |

Table 14.3: Registers at level 1, type:Hart group:Integration_support