OVP Guide to Using Processor Models

Model specific information for OpenHwGroup_CV32E40X

Imperas Software Limited
Imperas Buildings, North Weston
Thame, Oxfordshire, OX9 2HA, U.K.
docs@imperas.com

Author	Imperas Software Limited
Version	99999999
Filename	OVP_Model_Specific_Information_openhwgroup_riscv_CV32E40X.pdf
Created	23 September 2021
Status	OVP Standard Release

Copyright Notice

Right to Copy Documentation

Destination Control Statement

Disclaimer

Model Release Status

This model is released as part of OVP releases and is included in OVPworld packages. Please visit OVPworld.org.

Contents

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 0: extension A (atomic instructions)

misa bit 1: extension B (bit manipulation extension)

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)

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

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 Disabling Extensions

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

misa bit 0: extension A (atomic instructions)

misa bit 1: extension B (bit manipulation extension)

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

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.

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 0xffffff01. 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".

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.

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

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.

1.4.11 LR/SC Granule

LR/SC instructions are implemented with a 1-byte reservation granule. A different granule size may be specified using parameter "lr_sc_grain".

1.4.12 Zicsr

Parameter "Zicsr" is 1 on this variant, meaning that standard CSRs and CSR access instructions are implemented. If CSRs are not implemented, an alternative scheme must be provided as a processor extension.

1.4.13 Zifencei

Parameter "Zifencei" is 1 on this variant, meaning that the fence.i instruction is implemented. If implemented, this instruction is treated as a NOP by the model.

1.5 Compressed Extension

Standard compressed instructions are present in this variant.

Parameter Zcea_version is used to specify the version of Zcea instructions present. By default, Zcea_version is set to "none" in this variant. Updates to this parameter require a commercial product license.

Parameter Zceb_version is used to specify the version of Zceb instructions present. By default, Zceb_version is set to "none" in this variant. Updates to this parameter require a commercial product license.

Parameter Zcee_version is used to specify the version of Zcee instructions present. By default, Zcee_version is set to "none" in this variant. Updates to this parameter require a commercial product license.

1.6 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.

1.6.1 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 1 in this variant. Updates to this parameter require a commercial product license.

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

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

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

Parameter Zbr is used to specify that CRC32 instructions are present. By default, Zbr is set to 1 in this variant. Updates to this parameter require a commercial product license.

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 1 in this variant. Updates to this parameter require a commercial product license.

1.6.2 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.

1.6.3 Version 0.90

Stable 0.90 version of June 10 2019.

1.6.4 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.

1.6.5 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.

1.6.6 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.

1.6.7 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;

- 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);

1.6.8 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.

1.6.9 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.

1.6.10 Version master

Unstable master version, currently identical to 1.0.0, except that any subset may be enabled.

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 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 1.

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 "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 "textra32"/"textra64" 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.

1.13 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.

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).

1.16 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 “B” Bit Manipulation Extension (Bit Manipulation Architecture Version v0.90-20190610)

RISC-V External Debug Support (RISC-V External Debug Support Version 0.13.2-DRAFT)

Chapter 2

Configuration

2.1 Location

This model's VLNV is openhwgroup.ovpworld.org/processor/riscv/1.0.
The model source is usually at:
$IMPERAS_HOME/ImperasLib/source/openhwgroup.ovpworld.org/processor/riscv/1.0
The model binary is usually at:
$IMPERAS_HOME/lib/$IMPERAS_ARCH/ImperasLib/openhwgroup.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
CV32E20	
CV32E40P	
CV32E41P	
CV32E40Pv2	
CV32E40S	
CV32E40X	(described in this document)
CV32A6	
CV64A6	

Table 3.1: All Variants in this model

Chapter 4

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 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_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)
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
IllegalInstruction	input	optional	Illegal Instruction Exception
LoadBusFaultNMI	input	optional	Load Bus Fault Interrupt
StoreBusFaultNMI	input	optional	Store Bus Fault Interrupt
InstructionBusFault	input	optional	Instruction Bus Fault Exception

Table 6.1: Net Ports

Chapter 7

FIFO Ports

This model has no FIFO ports.

Chapter 8

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 or 20190305)
priv_version	Enumeration	Specify required Privileged Architecture version (1.10, 1.11, 20190405 or master)
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)
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)
Zicsr	Boolean	Specify that Zicsr is implemented
Zifencei	Boolean	Specify that Zifencei is implemented
Bit_Manipulation		
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 (bit manipulation extension)
Zbb	Boolean	Specify that Zbb is implemented (bit manipulation extension)
Zbc	Boolean	Specify that Zbc is implemented (bit manipulation extension)
Zbe	Boolean	Specify that Zbe is implemented (bit manipulation extension)
Zbf	Boolean	Specify that Zbf is implemented (bit manipulation extension)
Zbm	Boolean	Specify that Zbm is implemented (bit manipulation extension)
Zbp	Boolean	Specify that Zbp is implemented (bit manipulation extension)
Zbr	Boolean	Specify that Zbr is implemented (bit manipulation extension)
Zbs	Boolean	Specify that Zbs is implemented (bit manipulation extension)
Zbt	Boolean	Specify that Zbt is implemented (bit manipulation extension)
Debug		
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)
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
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
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_edeleg	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		
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 <csrName>=<number>
Memory		
unaligned	Boolean	Specify whether the processor supports unaligned memory accesses
unalignedAMO	Boolean	Specify whether the processor supports unaligned memory accesses for AMO instructions
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
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
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
CSR_Defauts		
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
Compressed		
Zcea_version	Enumeration	Specify version of Zcea implemented (code-size reduction extension) (none or 0.50.1)
Zceb_version	Enumeration	Specify version of Zceb implemented (code-size reduction extension) (none or 0.50.1)
Zcee_version	Enumeration	Specify version of Zcee implemented (code-size reduction extension) (none or 1.0.0-rc)
Fast_Interrupt		
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 Extension Parameters

Name	Type	Description
debug	Boolean	debug flags
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

Table 8.2: Parameters for extension

8.2 Parameters with enumerated types

8.2.1 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 8.3: Values for Parameter user_version

8.2.2 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 8.4: Values for Parameter priv_version

8.2.3 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 c1bd8ee (this is subject to change)

Table 8.5: Values for Parameter bitmanip_version

8.2.4 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
1.0.0-STABLE	RISC-V External Debug Support Version 1.0.0-STABLE

Table 8.6: Values for Parameter debug_version

8.2.5 Parameter rnmi_version

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

Table 8.7: Values for Parameter rnmi_version

8.2.6 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

8.2.7 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 8.9: Values for Parameter debug_eret_mode

8.2.8 Parameter Zcea_version

Set to this value	Description
none	Zcea not implemented
0.50.1	Zcea version 0.50.1

Table 8.10: Values for Parameter Zcea_version

8.2.9 Parameter Zceb_version

Set to this value	Description
none	Zceb not implemented
0.50.1	Zceb version 0.50.1

Table 8.11: Values for Parameter Zceb_version

8.2.10 Parameter Zcee_version

Set to this value	Description
none	Zcee not implemented
1.0.0-rc	Zcee version 1.0.0-rc

Table 8.12: Values for Parameter Zcee_version

Chapter 9

Execution Modes

Mode	Code	Description
Machine	3	Machine mode
Debug	6	Debug 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
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
LoadBusFault	192	Load Bus Fault NMI
StoreBusFault	193	Store Bus Fault NMI

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 4 commands.
This level in the model hierarchy has 3 register groups:

Group name	Registers
Core	33
Machine_Control_and_Status	178
Integration_support	3

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 getCSRIndex

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

Argument	Type	Description
-name	String	CSR name

Table 12.1: getCSRIndex command arguments

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 12.2: 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 12.3: itrace command arguments

12.1.4 listCSRs

12.1.4.1 Argument description

List all CSRs in index order

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 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	40801107	rw	ISA and Extensions
mie	32	0	rw	Machine Interrupt Enable
mtvec	32	1	rw	Machine Trap-Vector Base-Address
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	-	rw	Machine Trap Value
mip	32	0	rw	Machine Interrupt Pending
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
mcontext	32	0	rw	Trigger Machine Context
scontext	32	0	rw	Trigger Supervisor Context
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

Table 13.2: Registers at level 1, type:Hart group:Machine_Control_and_Status

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

13.1.3 Integration_support

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

Name	Bits	Initial-Hex	RW	Description
LRSCAddress	32	ffffffff	rw	LR/SC active lock address
DM	8	0	rw	Debug mode active
commercial	8	0	r-	Commercial feature in use

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