



## OVP Guide to Using Processor Models

### Model specific information for SiFive\_U74MC

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## Model Release Status

This model is released as part of OVP releases and is included in OVPworld packages. Please visit [OVPworld.org](http://OVPworld.org).

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# Chapter 1

## Overview

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

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

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

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

### 1.1 Description

RISC-V U74MC 64-bit processor model

### 1.2 Licensing

This Model is released under the Open Source Apache 2.0

### 1.3 Extensions

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

misa bit 0: extension A (atomic instructions)

misa bit 2: extension C (compressed instructions)

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

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

misa bit 8: RV32I/64I/128I base ISA

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

misa bit 18: extension S (Supervisor mode)

misa bit 20: extension U (User mode)

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.

Legacy parameter “misa\_Extensions\_mask” can also be used. This Uns32-valued parameter specifies all writable bits in the misa Extensions field, replacing any value 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.

### 1.3.1 Available (But Not Enabled) Extensions

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

misa bit 1: extension B (bit manipulation extension) (NOT ENABLED)

misa bit 4: RV32E base ISA (NOT ENABLED)

misa bit 13: extension N (user-level interrupts) (NOT ENABLED)

misa bit 21: extension V (vector extension) (NOT ENABLED)

misa bit 23: extension X (non-standard extensions present) (NOT ENABLED)

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

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

## 1.4 General Features

This is a multicore variant with 4 cores by default. The number of cores may be overridden with the “numHarts” parameter.

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 0x3fffffff. 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 64.

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

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

On reset, the model will restart at address 0x0. A different reset address may be specified using parameter “reset\_address” if required.

On an NMI, the model will restart at address 0x0. A different NMI address may be specified using parameter “nmi\_address” if required.

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

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

The “time” CSR is not implemented in this variant and reads of it will require emulation in Machine mode. Set parameter “time\_undefined” to False to instead specify that “time” is implemented.

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

A 0-bit ASID is implemented. Use parameter “ASID\_bits” to specify a different implemented ASID size if required.

This variant supports address translation modes 0 and 8. Use parameter “Sv\_modes” to specify a bit mask of different modes if required.

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

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

8 PMP entries are implemented by this variant. Use parameter “PMP\_registers” to specify a different number of PMP entries; set the parameter to 0 to disable the PMP unit. The PMP grain size (G) is 0, meaning that PMP regions as small as 4 bytes are implemented. Use parameter “PMP\_grain” to specify a different grain size if required.

LR/SC instructions are implemented with a 64-byte reservation granule. A different granule size may be specified using parameter “lr\_sc\_grain”.

## 1.5 Floating Point Features

The D extension is enabled in this variant only if the F extension is also enabled. Set parameter “d\_requires\_f” to “F” to allow D and F to be independently enabled.

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

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

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

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

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

In this variant, “mstatus\_fs\_mode” is set to “always\_dirty”.

## 1.6 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 (see references). When “CLICLEVELS” is non-zero, further parameters are made available to configure other aspects of the CLIC, as described below.

The model can be configured either to use an internal CLIC model (if parameter “externalCLIC” is False) or to present a net interface to allow the CLIC to be implemented externally in a platform component (if parameter “externalCLIC” is True). When the CLIC is implemented internally, net ports for standard interrupts and additional local interrupts are available. When the CLIC is implemented externally, a net port interface allowing the highest-priority pending interrupt to be delivered is instead present. This is described below.

### 1.6.1 CLIC Common Parameters

This section describes parameters applicable whether the CLIC is implemented internally or externally. These are:



“CLICANDBASIC”: this Boolean parameter indicates whether both CLIC and basic interrupt controller are present (if True) or whether only the CLIC is present (if False).

“CLICXNXTI”: this Boolean parameter indicates whether xnxti CSRs are implemented (if True) or unimplemented (if False).

“CLICXCSW”: this Boolean parameter indicates whether xscratchcsw and xscratchcswl CSRs registers are implemented (if True) or unimplemented (if False).

“mclibase”: this parameter specifies the CLIC base address in physical memory.

“tvt\_undefined”: this Boolean parameter indicates whether xtvt CSRs registers are implemented (if True) or unimplemented (if False). If the registers are unimplemented then the model will use basic mode vectored interrupt semantics based on the xtvec CSRs instead of Selective Hardware Vectoring semantics described in the specification.

“intthresh\_undefined”: this Boolean parameter indicates whether xintthresh CSRs registers are implemented (if True) or unimplemented (if False).

“mclibase\_undefined”: this Boolean parameter indicates whether the mclibase CSR register is implemented (if True) or unimplemented (if False).

### 1.6.2 CLIC Internal-Implementation Parameters

This section describes parameters applicable only when the CLIC is implemented internally. These are:

“CLICCFGMBITS”: this Uns32 parameter indicates the number of bits implemented in clic-cfg.nmbits, and also indirectly defines CLICPRIVMODES. For cores which implement only Machine mode, or which implement Machine and User modes but not the N extension, the parameter is absent (“CLICCFGMBITS” must be zero in these cases).

“CLICCFGLBITS”: this Uns32 parameter indicates the number of bits implemented in clic-cfg.nlbits.

“CLICSELHVEC”: this Boolean parameter indicates whether Selective Hardware Vectoring is supported (if True) or unsupported (if False).

### 1.6.3 CLIC External-Implementation Net Port Interface

When the CLIC is externally implemented, net ports are present allowing the external CLIC model to supply the highest-priority pending interrupt and to be notified when interrupts are handled. These are:

“irq\_id\_i”: this input should be written with the id of the highest-priority pending interrupt.

“irq\_lev\_i”: this input should be written with the highest-priority interrupt level.

“irq\_sec\_i”: this 2-bit input should be written with the highest-priority interrupt security state (00:User, 01:Supervisor, 11:Machine).

“irq\_shv\_i”: this input port should be written to indicate whether the highest-priority interrupt should be direct (0) or vectored (1). If the “tvt\_undefined parameter” is False, vectored interrupts

will use selective hardware vectoring, as described in the CLIC specification. If “`tvf_undefined`” is True, vectored interrupts will behave like basic mode vectored interrupts.

“`irq_id_i`”: this input should be written with the id of the highest-priority pending interrupt.

“`irq_i`”: this input should be written with 1 to indicate that the external CLIC is presenting an interrupt, or 0 if no interrupt is being presented.

“`irq_ack_o`”: this output is written by the model on entry to the interrupt handler (i.e. when the interrupt is taken). It will be written as an instantaneous pulse (i.e. written to 1, then immediately 0).

“`irq_id_o`”: this output is written by the model with the id of the interrupt currently being handled. It is valid during the instantaneous `irq_ack_o` pulse.

“`sec_lvl_o`”: this output signal indicates the current secure status of the processor, as a 2-bit value (00=User, 01:Supervisor, 11=Machine).

## 1.7 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.

## 1.8 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

## 1.9 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 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 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.

## 1.10 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 (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.

### 1.10.1 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`);
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.

### 1.10.2 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.

### 1.10.3 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.

### 1.10.4 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.

### 1.10.5 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.

### 1.10.6 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).

## 1.11 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.

## 1.12 Integration Support

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

### 1.12.1 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.

### 1.12.2 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.

## 1.13 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.

The processor fully supports the architecturally-specified floating-point instructions.

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

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

## 1.14 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 Foundations 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.

## 1.15 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 Core-Local Interrupt Controller (CLIC) Version 0.9-draft-20191208

RISC-V External Debug Support Version 0.14.0-DRAFT

SiFive U74 Manual v19.05

SiFive Custom Extensions



## Chapter 2

# SiFive-Specific Extensions

SiFive processors can add various custom extensions to the basic RISC-V architecture. This model implements the following:

### 2.1 SiFive-Specific CSRs

This section describes SiFive-specific CSRs implemented by this variant. Refer to SiFive reference documentation for more information.

#### 2.1.1 featureDisable (csr num 0x7c1)

Reading and writing the SiFive custom M-Mode Feature Disable CSR is supported. Since this register controls only micro-architectural behavior, which is not modeled, the setting of this register has no effect, and all fields are hardwired to 0.

### 2.2 SiFive-Specific Instructions

This section describes SiFive-specific instructions implemented by this variant. Refer to SiFive reference documentation for more information.

#### 2.2.1 CFLUSH.D.L1

31	20	19	15	14	12	11	7	6	0
111111000000		Rs1		000		00000		1110011	(System)

Instruction to flush the DCACHE L1 line for the address in Rs1. This instruction will generate exceptions for attempts to flush addresses that are not writable, but since caches are not modeled will otherwise have no effect.

# Chapter 3

## Configuration

### 3.1 Location

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

The model source is usually at:

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

The model binary is usually at:

`$IMPERAS_HOME/lib/$IMPERAS_ARCH/ImperasLib/sifive.ovpworld.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.ovpworld.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

<b>Variant</b>	Description
E20	
E21	
E24	
E31	
E34	
E76	
E76MC	
E51	
S21	
S51	
S54	
S76	
S76MC	
U54	
U54MC	
U74	
U74MC	(described in this document)

Table 4.1: All Variants in this model

## Chapter 5

# Bus Master Ports

This model has these bus master ports.

<b>Name</b>	min	max	Connect?	Description
INSTRUCTION	32	64	mandatory	Instruction bus
DATA	32	64	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
hart0_reset	input	optional	Reset
hart0_nmi	input	optional	NMI
hart0_SSWInterrupt	input	optional	Supervisor software interrupt
hart0_MSWSInterrupt	input	optional	Machine software interrupt
hart0_STimerInterrupt	input	optional	Supervisor timer interrupt
hart0_MTimerInterrupt	input	optional	Machine timer interrupt
hart0_SExternalInterrupt	input	optional	Supervisor external interrupt
hart0_MExternalInterrupt	input	optional	Machine external interrupt
hart0_LocalInterrupt0	input	optional	Local Interrupt 0
hart0_LocalInterrupt1	input	optional	Local Interrupt 1
hart0_LocalInterrupt2	input	optional	Local Interrupt 2
hart0_LocalInterrupt3	input	optional	Local Interrupt 3
hart0_LocalInterrupt4	input	optional	Local Interrupt 4
hart0_LocalInterrupt5	input	optional	Local Interrupt 5
hart0_LocalInterrupt6	input	optional	Local Interrupt 6
hart0_LocalInterrupt7	input	optional	Local Interrupt 7
hart0_LocalInterrupt8	input	optional	Local Interrupt 8
hart0_LocalInterrupt9	input	optional	Local Interrupt 9
hart0_LocalInterrupt10	input	optional	Local Interrupt 10
hart0_LocalInterrupt11	input	optional	Local Interrupt 11
hart0_LocalInterrupt12	input	optional	Local Interrupt 12
hart0_LocalInterrupt13	input	optional	Local Interrupt 13
hart0_LocalInterrupt14	input	optional	Local Interrupt 14
hart0_LocalInterrupt15	input	optional	Local Interrupt 15
hart0_LocalInterrupt16	input	optional	Local Interrupt 16
hart0_LocalInterrupt17	input	optional	Local Interrupt 17
hart0_LocalInterrupt18	input	optional	Local Interrupt 18
hart0_LocalInterrupt19	input	optional	Local Interrupt 19
hart0_LocalInterrupt20	input	optional	Local Interrupt 20
hart0_LocalInterrupt21	input	optional	Local Interrupt 21
hart0_LocalInterrupt22	input	optional	Local Interrupt 22

hart0_LocalInterrupt23	input	optional	Local Interrupt 23
hart0_LocalInterrupt24	input	optional	Local Interrupt 24
hart0_LocalInterrupt25	input	optional	Local Interrupt 25
hart0_LocalInterrupt26	input	optional	Local Interrupt 26
hart0_LocalInterrupt27	input	optional	Local Interrupt 27
hart0_LocalInterrupt28	input	optional	Local Interrupt 28
hart0_LocalInterrupt29	input	optional	Local Interrupt 29
hart0_LocalInterrupt30	input	optional	Local Interrupt 30
hart0_LocalInterrupt31	input	optional	Local Interrupt 31
hart0_LocalInterrupt32	input	optional	Local Interrupt 32
hart0_LocalInterrupt33	input	optional	Local Interrupt 33
hart0_LocalInterrupt34	input	optional	Local Interrupt 34
hart0_LocalInterrupt35	input	optional	Local Interrupt 35
hart0_LocalInterrupt36	input	optional	Local Interrupt 36
hart0_LocalInterrupt37	input	optional	Local Interrupt 37
hart0_LocalInterrupt38	input	optional	Local Interrupt 38
hart0_LocalInterrupt39	input	optional	Local Interrupt 39
hart0_LocalInterrupt40	input	optional	Local Interrupt 40
hart0_LocalInterrupt41	input	optional	Local Interrupt 41
hart0_LocalInterrupt42	input	optional	Local Interrupt 42
hart0_LocalInterrupt43	input	optional	Local Interrupt 43
hart0_LocalInterrupt44	input	optional	Local Interrupt 44
hart0_LocalInterrupt45	input	optional	Local Interrupt 45
hart0_LocalInterrupt46	input	optional	Local Interrupt 46
hart0_LocalInterrupt47	input	optional	Local Interrupt 47
hart0_irq_ack_o	output	optional	interrupt acknowledge (pulse)
hart0_irq_id_o	output	optional	acknowledged interrupt id (valid during irq_ack_o pulse)
hart0_sec_lvl_o	output	optional	current privilege level
hart0_LR_address	output	optional	Port written with effective address for LR instruction
hart0_SC_address	output	optional	Port written with effective address for SC instruction
hart0_SC_valid	input	optional	SC.address valid input signal
hart0_AMO_active	output	optional	Port written with code indicating active AMO
hart0_deferint	input	optional	Artifact signal causing interrupts to be held off when high
hart1_reset	input	optional	Reset
hart1_nmi	input	optional	NMI
hart1_SSWInterrupt	input	optional	Supervisor software interrupt
hart1_MSWSInterrupt	input	optional	Machine software interrupt
hart1_STimerInterrupt	input	optional	Supervisor timer interrupt
hart1_MTimerInterrupt	input	optional	Machine timer interrupt
hart1_SExternalInterrupt	input	optional	Supervisor external interrupt

hart1_MExternalInterrupt	input	optional	Machine external interrupt
hart1_LocalInterrupt0	input	optional	Local Interrupt 0
hart1_LocalInterrupt1	input	optional	Local Interrupt 1
hart1_LocalInterrupt2	input	optional	Local Interrupt 2
hart1_LocalInterrupt3	input	optional	Local Interrupt 3
hart1_LocalInterrupt4	input	optional	Local Interrupt 4
hart1_LocalInterrupt5	input	optional	Local Interrupt 5
hart1_LocalInterrupt6	input	optional	Local Interrupt 6
hart1_LocalInterrupt7	input	optional	Local Interrupt 7
hart1_LocalInterrupt8	input	optional	Local Interrupt 8
hart1_LocalInterrupt9	input	optional	Local Interrupt 9
hart1_LocalInterrupt10	input	optional	Local Interrupt 10
hart1_LocalInterrupt11	input	optional	Local Interrupt 11
hart1_LocalInterrupt12	input	optional	Local Interrupt 12
hart1_LocalInterrupt13	input	optional	Local Interrupt 13
hart1_LocalInterrupt14	input	optional	Local Interrupt 14
hart1_LocalInterrupt15	input	optional	Local Interrupt 15
hart1_LocalInterrupt16	input	optional	Local Interrupt 16
hart1_LocalInterrupt17	input	optional	Local Interrupt 17
hart1_LocalInterrupt18	input	optional	Local Interrupt 18
hart1_LocalInterrupt19	input	optional	Local Interrupt 19
hart1_LocalInterrupt20	input	optional	Local Interrupt 20
hart1_LocalInterrupt21	input	optional	Local Interrupt 21
hart1_LocalInterrupt22	input	optional	Local Interrupt 22
hart1_LocalInterrupt23	input	optional	Local Interrupt 23
hart1_LocalInterrupt24	input	optional	Local Interrupt 24
hart1_LocalInterrupt25	input	optional	Local Interrupt 25
hart1_LocalInterrupt26	input	optional	Local Interrupt 26
hart1_LocalInterrupt27	input	optional	Local Interrupt 27
hart1_LocalInterrupt28	input	optional	Local Interrupt 28
hart1_LocalInterrupt29	input	optional	Local Interrupt 29
hart1_LocalInterrupt30	input	optional	Local Interrupt 30
hart1_LocalInterrupt31	input	optional	Local Interrupt 31
hart1_LocalInterrupt32	input	optional	Local Interrupt 32
hart1_LocalInterrupt33	input	optional	Local Interrupt 33
hart1_LocalInterrupt34	input	optional	Local Interrupt 34
hart1_LocalInterrupt35	input	optional	Local Interrupt 35
hart1_LocalInterrupt36	input	optional	Local Interrupt 36
hart1_LocalInterrupt37	input	optional	Local Interrupt 37
hart1_LocalInterrupt38	input	optional	Local Interrupt 38
hart1_LocalInterrupt39	input	optional	Local Interrupt 39
hart1_LocalInterrupt40	input	optional	Local Interrupt 40
hart1_LocalInterrupt41	input	optional	Local Interrupt 41
hart1_LocalInterrupt42	input	optional	Local Interrupt 42
hart1_LocalInterrupt43	input	optional	Local Interrupt 43



hart1_LocalInterrupt44	input	optional	Local Interrupt 44
hart1_LocalInterrupt45	input	optional	Local Interrupt 45
hart1_LocalInterrupt46	input	optional	Local Interrupt 46
hart1_LocalInterrupt47	input	optional	Local Interrupt 47
hart1_irq_ack_o	output	optional	interrupt acknowledge (pulse)
hart1_irq_id_o	output	optional	acknowledged interrupt id (valid during irq_ack_o pulse)
hart1_sec_lvl_o	output	optional	current privilege level
hart1_LR_address	output	optional	Port written with effective address for LR instruction
hart1_SC_address	output	optional	Port written with effective address for SC instruction
hart1_SC_valid	input	optional	SC_address valid input signal
hart1_AMO_active	output	optional	Port written with code indicating active AMO
hart1_deferint	input	optional	Artifact signal causing interrupts to be held off when high
hart2_reset	input	optional	Reset
hart2_nmi	input	optional	NMI
hart2_SSWInterrupt	input	optional	Supervisor software interrupt
hart2_MSInterrupt	input	optional	Machine software interrupt
hart2_STimerInterrupt	input	optional	Supervisor timer interrupt
hart2_MTimerInterrupt	input	optional	Machine timer interrupt
hart2_SExternalInterrupt	input	optional	Supervisor external interrupt
hart2_MExternalInterrupt	input	optional	Machine external interrupt
hart2_LocalInterrupt0	input	optional	Local Interrupt 0
hart2_LocalInterrupt1	input	optional	Local Interrupt 1
hart2_LocalInterrupt2	input	optional	Local Interrupt 2
hart2_LocalInterrupt3	input	optional	Local Interrupt 3
hart2_LocalInterrupt4	input	optional	Local Interrupt 4
hart2_LocalInterrupt5	input	optional	Local Interrupt 5
hart2_LocalInterrupt6	input	optional	Local Interrupt 6
hart2_LocalInterrupt7	input	optional	Local Interrupt 7
hart2_LocalInterrupt8	input	optional	Local Interrupt 8
hart2_LocalInterrupt9	input	optional	Local Interrupt 9
hart2_LocalInterrupt10	input	optional	Local Interrupt 10
hart2_LocalInterrupt11	input	optional	Local Interrupt 11
hart2_LocalInterrupt12	input	optional	Local Interrupt 12
hart2_LocalInterrupt13	input	optional	Local Interrupt 13
hart2_LocalInterrupt14	input	optional	Local Interrupt 14
hart2_LocalInterrupt15	input	optional	Local Interrupt 15
hart2_LocalInterrupt16	input	optional	Local Interrupt 16
hart2_LocalInterrupt17	input	optional	Local Interrupt 17
hart2_LocalInterrupt18	input	optional	Local Interrupt 18
hart2_LocalInterrupt19	input	optional	Local Interrupt 19

hart2_LocalInterrupt20	input	optional	Local Interrupt 20
hart2_LocalInterrupt21	input	optional	Local Interrupt 21
hart2_LocalInterrupt22	input	optional	Local Interrupt 22
hart2_LocalInterrupt23	input	optional	Local Interrupt 23
hart2_LocalInterrupt24	input	optional	Local Interrupt 24
hart2_LocalInterrupt25	input	optional	Local Interrupt 25
hart2_LocalInterrupt26	input	optional	Local Interrupt 26
hart2_LocalInterrupt27	input	optional	Local Interrupt 27
hart2_LocalInterrupt28	input	optional	Local Interrupt 28
hart2_LocalInterrupt29	input	optional	Local Interrupt 29
hart2_LocalInterrupt30	input	optional	Local Interrupt 30
hart2_LocalInterrupt31	input	optional	Local Interrupt 31
hart2_LocalInterrupt32	input	optional	Local Interrupt 32
hart2_LocalInterrupt33	input	optional	Local Interrupt 33
hart2_LocalInterrupt34	input	optional	Local Interrupt 34
hart2_LocalInterrupt35	input	optional	Local Interrupt 35
hart2_LocalInterrupt36	input	optional	Local Interrupt 36
hart2_LocalInterrupt37	input	optional	Local Interrupt 37
hart2_LocalInterrupt38	input	optional	Local Interrupt 38
hart2_LocalInterrupt39	input	optional	Local Interrupt 39
hart2_LocalInterrupt40	input	optional	Local Interrupt 40
hart2_LocalInterrupt41	input	optional	Local Interrupt 41
hart2_LocalInterrupt42	input	optional	Local Interrupt 42
hart2_LocalInterrupt43	input	optional	Local Interrupt 43
hart2_LocalInterrupt44	input	optional	Local Interrupt 44
hart2_LocalInterrupt45	input	optional	Local Interrupt 45
hart2_LocalInterrupt46	input	optional	Local Interrupt 46
hart2_LocalInterrupt47	input	optional	Local Interrupt 47
hart2_irq_ack_o	output	optional	interrupt acknowledge (pulse)
hart2_irq_id_o	output	optional	acknowledged interrupt id (valid during irq_ack_o pulse)
hart2_sec_lvl_o	output	optional	current privilege level
hart2_LR_address	output	optional	Port written with effective address for LR instruction
hart2_SC_address	output	optional	Port written with effective address for SC instruction
hart2_SC_valid	input	optional	SC.address valid input signal
hart2_AMO_active	output	optional	Port written with code indicating active AMO
hart2_deferint	input	optional	Artifact signal causing interrupts to be held off when high
hart3_reset	input	optional	Reset
hart3_nmi	input	optional	NMI
hart3_SSWInterrupt	input	optional	Supervisor software interrupt
hart3_MSWSWInterrupt	input	optional	Machine software interrupt

hart3_STimerInterrupt	input	optional	Supervisor timer interrupt
hart3_MTimerInterrupt	input	optional	Machine timer interrupt
hart3_SExternalInterrupt	input	optional	Supervisor external interrupt
hart3_MExternalInterrupt	input	optional	Machine external interrupt
hart3_LocalInterrupt0	input	optional	Local Interrupt 0
hart3_LocalInterrupt1	input	optional	Local Interrupt 1
hart3_LocalInterrupt2	input	optional	Local Interrupt 2
hart3_LocalInterrupt3	input	optional	Local Interrupt 3
hart3_LocalInterrupt4	input	optional	Local Interrupt 4
hart3_LocalInterrupt5	input	optional	Local Interrupt 5
hart3_LocalInterrupt6	input	optional	Local Interrupt 6
hart3_LocalInterrupt7	input	optional	Local Interrupt 7
hart3_LocalInterrupt8	input	optional	Local Interrupt 8
hart3_LocalInterrupt9	input	optional	Local Interrupt 9
hart3_LocalInterrupt10	input	optional	Local Interrupt 10
hart3_LocalInterrupt11	input	optional	Local Interrupt 11
hart3_LocalInterrupt12	input	optional	Local Interrupt 12
hart3_LocalInterrupt13	input	optional	Local Interrupt 13
hart3_LocalInterrupt14	input	optional	Local Interrupt 14
hart3_LocalInterrupt15	input	optional	Local Interrupt 15
hart3_LocalInterrupt16	input	optional	Local Interrupt 16
hart3_LocalInterrupt17	input	optional	Local Interrupt 17
hart3_LocalInterrupt18	input	optional	Local Interrupt 18
hart3_LocalInterrupt19	input	optional	Local Interrupt 19
hart3_LocalInterrupt20	input	optional	Local Interrupt 20
hart3_LocalInterrupt21	input	optional	Local Interrupt 21
hart3_LocalInterrupt22	input	optional	Local Interrupt 22
hart3_LocalInterrupt23	input	optional	Local Interrupt 23
hart3_LocalInterrupt24	input	optional	Local Interrupt 24
hart3_LocalInterrupt25	input	optional	Local Interrupt 25
hart3_LocalInterrupt26	input	optional	Local Interrupt 26
hart3_LocalInterrupt27	input	optional	Local Interrupt 27
hart3_LocalInterrupt28	input	optional	Local Interrupt 28
hart3_LocalInterrupt29	input	optional	Local Interrupt 29
hart3_LocalInterrupt30	input	optional	Local Interrupt 30
hart3_LocalInterrupt31	input	optional	Local Interrupt 31
hart3_LocalInterrupt32	input	optional	Local Interrupt 32
hart3_LocalInterrupt33	input	optional	Local Interrupt 33
hart3_LocalInterrupt34	input	optional	Local Interrupt 34
hart3_LocalInterrupt35	input	optional	Local Interrupt 35
hart3_LocalInterrupt36	input	optional	Local Interrupt 36
hart3_LocalInterrupt37	input	optional	Local Interrupt 37
hart3_LocalInterrupt38	input	optional	Local Interrupt 38
hart3_LocalInterrupt39	input	optional	Local Interrupt 39
hart3_LocalInterrupt40	input	optional	Local Interrupt 40

hart3_LocalInterrupt41	input	optional	Local Interrupt 41
hart3_LocalInterrupt42	input	optional	Local Interrupt 42
hart3_LocalInterrupt43	input	optional	Local Interrupt 43
hart3_LocalInterrupt44	input	optional	Local Interrupt 44
hart3_LocalInterrupt45	input	optional	Local Interrupt 45
hart3_LocalInterrupt46	input	optional	Local Interrupt 46
hart3_LocalInterrupt47	input	optional	Local Interrupt 47
hart3_irq_ack_o	output	optional	interrupt acknowledge (pulse)
hart3_irq_id_o	output	optional	acknowledged interrupt id (valid during irq_ack_o pulse)
hart3_sec_lvl_o	output	optional	current privilege level
hart3_LR_address	output	optional	Port written with effective address for LR instruction
hart3_SC_address	output	optional	Port written with effective address for SC instruction
hart3_SC_valid	input	optional	SC_address valid input signal
hart3_AMO_active	output	optional	Port written with code indicating active AMO
hart3_deferint	input	optional	Artifact signal causing interrupts to be held off when high

Table 7.1: Net Ports

## Chapter 8

# FIFO Ports

This model has no FIFO ports.

# Chapter 9

## Formal Parameters

Name	Type	Description
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)
mstatus_fs_mode	Enumeration	Specify conditions causing update of mstatus.FS to dirty (write_1, write_any or always_dirty)
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
verbose	Boolean	Specify verbose output messages
numHarts	Uns32	Specify the number of hart contexts in a multiprocessor
updatePTEA	Boolean	Specify whether hardware update of PTE A bit is supported
updatePTED	Boolean	Specify whether hardware update of PTE D bit is supported
unaligned	Boolean	Specify whether the processor supports unaligned memory accesses
unalignedAMO	Boolean	Specify whether the processor supports unaligned memory accesses for AMO instructions
wfi_is_nop	Boolean	Specify whether WFI should be treated as a NOP (if not, halt while waiting for interrupts)
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
counteren_mask	Uns32	Specify hardware-enforced mask of writable bits in mcounteren/scounteren registers
mtvec_mask	Uns64	Specify hardware-enforced mask of writable bits in mtvec register
stvec_mask	Uns64	Specify hardware-enforced mask of writable bits in stvec register
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_ii_code	Boolean	Specify whether mtval/stval contain faulting instruction bits on illegal instruction exception
cycle_undefined	Boolean	Specify that the cycle CSR is undefined (reads to it are emulated by a Machine mode trap)
time_undefined	Boolean	Specify that the time CSR is undefined (reads to it are emulated by a Machine mode trap)
instret_undefined	Boolean	Specify that the instret CSR is undefined (reads to it are emulated by a Machine mode trap)
enable_CSR_bus	Boolean	Add artifact CSR bus port, allowing CSR registers to be externally implemented
d_requires_f	Boolean	If D and F extensions are separately enabled in the misa CSR, whether D is enabled only if F is enabled

xret_preserves_lr	Boolean	Whether an xRET instruction preserves the value of LR
ASID_bits	Uns32	Specify the number of implemented ASID bits
lr_sc_grain	Uns32	Specify byte granularity of ll/sc lock region (constrained to a power of two)
reset_address	Uns64	Override reset vector address
nmi_address	Uns64	Override NMI vector address
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
Sv_modes	Uns32	Specify bit mask of implemented Sv modes (e.g. 1<<8 is Sv39)
local_int_num	Uns32	Specify number of supplemental local interrupts
unimp_int_mask	Uns64	Specify mask of unimplemented interrupts (e.g. 1<<9 indicates Supervisor external interrupt unimplemented)
force_mideleg	Uns64	Specify mask of interrupts always delegated to lower-priority execution level from Machine execution level
force_sideleg	Uns64	Specify mask of interrupts always delegated to User execution level from Supervisor execution level
no_ideleg	Uns64	Specify mask of interrupts that cannot be delegated to lower-priority execution levels
no_eideleg	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
endian	Endian	Model endian
misa_MXL	Uns32	Override default value of misa.MXL
misa_MXL_mask	Uns32	Override mask of writable bits in misa.MXL
misa_Extensions	Uns32	Override default value of misa.Extensions
add_Extensions	String	Add extensions specified by letters to misa.Extensions (for example, specify “VD” to add V and D features)
misa_Extensions_mask	Uns32	Override mask of writable bits in misa.Extensions
add_Extensions_mask	String	Add extensions specified by letters to mask of writable bits in misa.Extensions (for example, specify “VD” to add V and D features)
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
mstatus_FS	Uns32	Override default value of mstatus.FS (initial state of floating point unit)
CLICLEVELS	Uns32	Specify number of interrupt levels implemented by CLIC, or 0 if CLIC absent

Table 9.1: Parameters that can be set in: SMP

## 9.1 Parameters with enumerated types

### 9.1.1 Parameter user\_version

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

Table 9.2: Values for Parameter user\_version

### 9.1.2 Parameter priv\_version

Set to this value	Description
-------------------	-------------

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

Table 9.3: Values for Parameter `priv_version`

### 9.1.3 Parameter `mstatus_fs_mode`

Set to this value	Description
<code>write_1</code>	Any non-zero flag result sets <code>mstatus.fs</code> dirty
<code>write_any</code>	Any write of flags sets <code>mstatus.fs</code> dirty
<code>always_dirty</code>	<code>mstatus.fs</code> is either off or dirty

Table 9.4: Values for Parameter `mstatus_fs_mode`

### 9.1.4 Parameter `debug_mode`

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

Table 9.5: Values for Parameter `debug_mode`



## Chapter 10

# Execution Modes

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

Table 10.1: Modes implemented in: SMP

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

Table 10.2: 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
EnvironmentCallFromUMode	8	ECALL instruction executed in User mode
EnvironmentCallFromSMode	9	ECALL instruction executed in Supervisor mode
EnvironmentCallFromMMode	11	ECALL instruction executed in Machine mode
InstructionPageFault	12	Page fault at fetch address
LoadPageFault	13	Page fault at load address
StoreAMOPageFault	15	Page fault at store/atomic memory operation address
SSWInterrupt	65	Supervisor software interrupt
MSWInterrupt	67	Machine software interrupt
STimerInterrupt	69	Supervisor timer interrupt
MTimerInterrupt	71	Machine timer interrupt
SExternalInterrupt	73	Supervisor external interrupt
MExternalInterrupt	75	Machine external interrupt
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
LocalInterrupt16	96	Local interrupt 16
LocalInterrupt17	97	Local interrupt 17
LocalInterrupt18	98	Local interrupt 18
LocalInterrupt19	99	Local interrupt 19
LocalInterrupt20	100	Local interrupt 20
LocalInterrupt21	101	Local interrupt 21
LocalInterrupt22	102	Local interrupt 22
LocalInterrupt23	103	Local interrupt 23
LocalInterrupt24	104	Local interrupt 24
LocalInterrupt25	105	Local interrupt 25
LocalInterrupt26	106	Local interrupt 26
LocalInterrupt27	107	Local interrupt 27
LocalInterrupt28	108	Local interrupt 28
LocalInterrupt29	109	Local interrupt 29
LocalInterrupt30	110	Local interrupt 30
LocalInterrupt31	111	Local interrupt 31
LocalInterrupt32	112	Local interrupt 32
LocalInterrupt33	113	Local interrupt 33
LocalInterrupt34	114	Local interrupt 34
LocalInterrupt35	115	Local interrupt 35
LocalInterrupt36	116	Local interrupt 36
LocalInterrupt37	117	Local interrupt 37
LocalInterrupt38	118	Local interrupt 38
LocalInterrupt39	119	Local interrupt 39
LocalInterrupt40	120	Local interrupt 40
LocalInterrupt41	121	Local interrupt 41
LocalInterrupt42	122	Local interrupt 42
LocalInterrupt43	123	Local interrupt 43
LocalInterrupt44	124	Local interrupt 44
LocalInterrupt45	125	Local interrupt 45
LocalInterrupt46	126	Local interrupt 46
LocalInterrupt47	127	Local interrupt 47

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: SMP

This level in the model hierarchy has 2 commands.

This level in the model hierarchy has no register groups.

This level in the model hierarchy has 4 children:

hart0, hart1, hart2 and hart3.

### 12.2 Level 2: Hart

This level in the model hierarchy has 3 commands.

This level in the model hierarchy has 6 register groups:

Group name	Registers
Core	33
Floating_point	32
User_Control_and_Status	35
Supervisor_Control_and_Status	10
Machine_Control_and_Status	100
Integration_support	2

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: SMP

#### 13.1.1 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 13.1: isync command arguments

#### 13.1.2 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 13.2: itrace command arguments

## 13.2 Level 2: Hart

### 13.2.1 dumpTLB

#### 13.2.1.1 Argument description

show TLB contents

### 13.2.2 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 13.3: isync command arguments

### 13.2.3 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 13.4: itrace command arguments

# Chapter 14

## Registers

### 14.1 Level 1: SMP

No registers.

### 14.2 Level 2: Hart

#### 14.2.1 Core

Registers at level:2, type:Hart group:Core

Name	Bits	Initial-Hex	RW	Description
zero	64	0	r-	
ra	64	0	rw	
sp	64	0	rw	stack pointer
gp	64	0	rw	
tp	64	0	rw	
t0	64	0	rw	
t1	64	0	rw	
t2	64	0	rw	
s0	64	0	rw	
s1	64	0	rw	
a0	64	0	rw	
a1	64	0	rw	
a2	64	0	rw	
a3	64	0	rw	
a4	64	0	rw	
a5	64	0	rw	
a6	64	0	rw	
a7	64	0	rw	
s2	64	0	rw	
s3	64	0	rw	
s4	64	0	rw	
s5	64	0	rw	
s6	64	0	rw	
s7	64	0	rw	
s8	64	0	rw	
s9	64	0	rw	
s10	64	0	rw	
s11	64	0	rw	

t3	64	0	rw	
t4	64	0	rw	
t5	64	0	rw	
t6	64	0	rw	
pc	64	0	rw	program counter

Table 14.1: Registers at level 2, type:Hart group:Core

### 14.2.2 Floating\_point

Registers at level:2, type:Hart group:Floating\_point

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

Table 14.2: Registers at level 2, type:Hart group:Floating\_point

### 14.2.3 User\_Control\_and\_Status

Registers at level:2, type:Hart group:User\_Control\_and\_Status

Name	Bits	Initial-Hex	RW	Description
fflags	64	0	rw	Floating-Point Flags
frm	64	0	rw	Floating-Point Rounding Mode



fcsr	64	0	rw	Floating-Point Control and Status
cycle	64	0	r-	Cycle Counter
time	64	0	r-	Timer
instret	64	0	r-	Instructions Retired
hpmcounter3	64	0	r-	Performance Monitor Counter 3
hpmcounter4	64	0	r-	Performance Monitor Counter 4
hpmcounter5	64	0	r-	Performance Monitor Counter 5
hpmcounter6	64	0	r-	Performance Monitor Counter 6
hpmcounter7	64	0	r-	Performance Monitor Counter 7
hpmcounter8	64	0	r-	Performance Monitor Counter 8
hpmcounter9	64	0	r-	Performance Monitor Counter 9
hpmcounter10	64	0	r-	Performance Monitor Counter 10
hpmcounter11	64	0	r-	Performance Monitor Counter 11
hpmcounter12	64	0	r-	Performance Monitor Counter 12
hpmcounter13	64	0	r-	Performance Monitor Counter 13
hpmcounter14	64	0	r-	Performance Monitor Counter 14
hpmcounter15	64	0	r-	Performance Monitor Counter 15
hpmcounter16	64	0	r-	Performance Monitor Counter 16
hpmcounter17	64	0	r-	Performance Monitor Counter 17
hpmcounter18	64	0	r-	Performance Monitor Counter 18
hpmcounter19	64	0	r-	Performance Monitor Counter 19
hpmcounter20	64	0	r-	Performance Monitor Counter 20
hpmcounter21	64	0	r-	Performance Monitor Counter 21
hpmcounter22	64	0	r-	Performance Monitor Counter 22
hpmcounter23	64	0	r-	Performance Monitor Counter 23
hpmcounter24	64	0	r-	Performance Monitor Counter 24
hpmcounter25	64	0	r-	Performance Monitor Counter 25
hpmcounter26	64	0	r-	Performance Monitor Counter 26
hpmcounter27	64	0	r-	Performance Monitor Counter 27
hpmcounter28	64	0	r-	Performance Monitor Counter 28
hpmcounter29	64	0	r-	Performance Monitor Counter 29
hpmcounter30	64	0	r-	Performance Monitor Counter 30
hpmcounter31	64	0	r-	Performance Monitor Counter 31

Table 14.3: Registers at level 2, type:Hart group:User\_Control\_and\_Status

#### 14.2.4 Supervisor\_Control\_and\_Status

Registers at level:2, type:Hart group:Supervisor\_Control\_and\_Status

Name	Bits	Initial-Hex	RW	Description
sstatus	64	2 00000000	rw	Supervisor Status
sie	64	0	rw	Supervisor Interrupt Enable
stvec	64	0	rw	Supervisor Trap-Vector Base-Address
scounteren	64	0	rw	Supervisor Counter Enable
sscratch	64	0	rw	Supervisor Scratch
sepc	64	0	rw	Supervisor Exception Program Counter
scause	64	0	rw	Supervisor Cause
stval	64	0	rw	Supervisor Trap Value
sip	64	0	rw	Supervisor Interrupt Pending
satp	64	0	rw	Supervisor Address Translation and Protection

Table 14.4: Registers at level 2, type:Hart group:Supervisor\_Control\_and\_Status

## 14.2.5 Machine\_Control\_and\_Status

Registers at level:2, type:Hart group:Machine\_Control\_and\_Status

Name	Bits	Initial-Hex	RW	Description
mstatus	64	a 00000000	rw	Machine Status
misa	64	80000000 0014112d	rw	ISA and Extensions
medeleg	64	0	rw	Machine Exception Delegation
mideleg	64	0	rw	Machine Interrupt Delegation
mie	64	0	rw	Machine Interrupt Enable
mtvec	64	0	rw	Machine Trap-Vector Base-Address
mcounteren	64	0	rw	Machine Counter Enable
mcountinhibit	64	0	rw	Machine Counter Inhibit
mhpmevent3	64	0	rw	Machine Performance Monitor Event Select 3
mhpmevent4	64	0	rw	Machine Performance Monitor Event Select 4
mhpmevent5	64	0	rw	Machine Performance Monitor Event Select 5
mhpmevent6	64	0	rw	Machine Performance Monitor Event Select 6
mhpmevent7	64	0	rw	Machine Performance Monitor Event Select 7
mhpmevent8	64	0	rw	Machine Performance Monitor Event Select 8
mhpmevent9	64	0	rw	Machine Performance Monitor Event Select 9
mhpmevent10	64	0	rw	Machine Performance Monitor Event Select 10
mhpmevent11	64	0	rw	Machine Performance Monitor Event Select 11
mhpmevent12	64	0	rw	Machine Performance Monitor Event Select 12
mhpmevent13	64	0	rw	Machine Performance Monitor Event Select 13
mhpmevent14	64	0	rw	Machine Performance Monitor Event Select 14
mhpmevent15	64	0	rw	Machine Performance Monitor Event Select 15
mhpmevent16	64	0	rw	Machine Performance Monitor Event Select 16
mhpmevent17	64	0	rw	Machine Performance Monitor Event Select 17
mhpmevent18	64	0	rw	Machine Performance Monitor Event Select 18
mhpmevent19	64	0	rw	Machine Performance Monitor Event Select 19
mhpmevent20	64	0	rw	Machine Performance Monitor Event Select 20
mhpmevent21	64	0	rw	Machine Performance Monitor Event Select 21
mhpmevent22	64	0	rw	Machine Performance Monitor Event Select 22
mhpmevent23	64	0	rw	Machine Performance Monitor Event Select 23
mhpmevent24	64	0	rw	Machine Performance Monitor Event Select 24
mhpmevent25	64	0	rw	Machine Performance Monitor Event Select 25
mhpmevent26	64	0	rw	Machine Performance Monitor Event Select 26
mhpmevent27	64	0	rw	Machine Performance Monitor Event Select 27
mhpmevent28	64	0	rw	Machine Performance Monitor Event Select 28
mhpmevent29	64	0	rw	Machine Performance Monitor Event Select 29
mhpmevent30	64	0	rw	Machine Performance Monitor Event Select 30
mhpmevent31	64	0	rw	Machine Performance Monitor Event Select 31
mscratch	64	0	rw	Machine Scratch
mepc	64	0	rw	Machine Exception Program Counter
mcause	64	0	rw	Machine Cause
mtval	64	0	rw	Machine Trap Value
mip	64	0	rw	Machine Interrupt Pending
pmpcfg0	64	0	rw	Physical Memory Protection Configuration 0
pmpcfg2	64	0	rw	Physical Memory Protection Configuration 2
pmpaddr0	64	0	rw	Physical Memory Protection Address 0
pmpaddr1	64	0	rw	Physical Memory Protection Address 1
pmpaddr2	64	0	rw	Physical Memory Protection Address 2
pmpaddr3	64	0	rw	Physical Memory Protection Address 3
pmpaddr4	64	0	rw	Physical Memory Protection Address 4
pmpaddr5	64	0	rw	Physical Memory Protection Address 5
pmpaddr6	64	0	rw	Physical Memory Protection Address 6

pmpaddr7	64	0	rw	Physical Memory Protection Address 7
pmpaddr8	64	0	rw	Physical Memory Protection Address 8
pmpaddr9	64	0	rw	Physical Memory Protection Address 9
pmpaddr10	64	0	rw	Physical Memory Protection Address 10
pmpaddr11	64	0	rw	Physical Memory Protection Address 11
pmpaddr12	64	0	rw	Physical Memory Protection Address 12
pmpaddr13	64	0	rw	Physical Memory Protection Address 13
pmpaddr14	64	0	rw	Physical Memory Protection Address 14
pmpaddr15	64	0	rw	Physical Memory Protection Address 15
tselect	64	-	rw	Debug/Trace Trigger Register Select (not implemented)
tdata1	64	-	rw	Debug/Trace Trigger Data 1 (not implemented)
tdata2	64	-	rw	Debug/Trace Trigger Data 2 (not implemented)
tdata3	64	-	rw	Debug/Trace Trigger Data 3 (not implemented)
featureDisable*	64	0	rw	SiFive FeatureDisable
mcycle	64	0	rw	Machine Cycle Counter
minstret	64	0	rw	Machine Instructions Retired
mhpmcounter3	64	0	rw	Machine Performance Monitor Counter 3
mhpmcounter4	64	0	rw	Machine Performance Monitor Counter 4
mhpmcounter5	64	0	rw	Machine Performance Monitor Counter 5
mhpmcounter6	64	0	rw	Machine Performance Monitor Counter 6
mhpmcounter7	64	0	rw	Machine Performance Monitor Counter 7
mhpmcounter8	64	0	rw	Machine Performance Monitor Counter 8
mhpmcounter9	64	0	rw	Machine Performance Monitor Counter 9
mhpmcounter10	64	0	rw	Machine Performance Monitor Counter 10
mhpmcounter11	64	0	rw	Machine Performance Monitor Counter 11
mhpmcounter12	64	0	rw	Machine Performance Monitor Counter 12
mhpmcounter13	64	0	rw	Machine Performance Monitor Counter 13
mhpmcounter14	64	0	rw	Machine Performance Monitor Counter 14
mhpmcounter15	64	0	rw	Machine Performance Monitor Counter 15
mhpmcounter16	64	0	rw	Machine Performance Monitor Counter 16
mhpmcounter17	64	0	rw	Machine Performance Monitor Counter 17
mhpmcounter18	64	0	rw	Machine Performance Monitor Counter 18
mhpmcounter19	64	0	rw	Machine Performance Monitor Counter 19
mhpmcounter20	64	0	rw	Machine Performance Monitor Counter 20
mhpmcounter21	64	0	rw	Machine Performance Monitor Counter 21
mhpmcounter22	64	0	rw	Machine Performance Monitor Counter 22
mhpmcounter23	64	0	rw	Machine Performance Monitor Counter 23
mhpmcounter24	64	0	rw	Machine Performance Monitor Counter 24
mhpmcounter25	64	0	rw	Machine Performance Monitor Counter 25
mhpmcounter26	64	0	rw	Machine Performance Monitor Counter 26
mhpmcounter27	64	0	rw	Machine Performance Monitor Counter 27
mhpmcounter28	64	0	rw	Machine Performance Monitor Counter 28
mhpmcounter29	64	0	rw	Machine Performance Monitor Counter 29
mhpmcounter30	64	0	rw	Machine Performance Monitor Counter 30
mhpmcounter31	64	0	rw	Machine Performance Monitor Counter 31
mvendorid	64	0	r-	Vendor ID
marchid	64	0	r-	Architecture ID
mimpid	64	0	r-	Implementation ID
mhartid	64	0	r-	Hardware Thread ID

Table 14.5: Registers at level 2, type:Hart group:Machine\_Control\_and\_Status

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

### 14.2.6 Integration\_support

Registers at level:2, type:Hart group:Integration\_support

Name	Bits	Initial-Hex	RW	Description
LRSCAddress	64	ffffff fffffff	rw	LR/SC active lock address
commercial	8	0	r-	Commercial feature in use

Table 14.6: Registers at level 2, type:Hart group:Integration\_support