



# RISC-V S-mode Physical Memory Protection (SPMP)

Editor - Dong Du, Bicheng Yang, RISC-V SPMP Task Group

Version 1.0.0-rc1, 7/2025: This document is in development. Assume everything can change. See <http://riscv.org/spec-state> for details.

# Table of Contents

<b>Preamble</b>	<b>1</b>
<b>Copyright and license information</b>	<b>2</b>
<b>Contributors</b>	<b>3</b>
<b>1. Introduction</b>	<b>4</b>
<b>2. Machine Mode Modification</b>	<b>5</b>
2.1. Resource Sharing between PMP and SPMP	5
<b>3. S-mode Physical Memory Protection (SPMP)</b>	<b>7</b>
3.1. Requirements	7
3.2. S-mode Physical Memory Protection CSRs	7
3.3. Encoding of Permissions	9
3.4. Address Matching	10
3.5. Matching Logic	11
3.6. Access Method of SPMP CSRs	11
3.7. Access Method of PMP_Entry	12
3.8. SPMP and Paging	12
3.9. Exceptions	13
3.10. Context Switching Optimization	13
<b>4. Summary of Hardware Changes</b>	<b>15</b>
<b>5. Recommended Programming Guidelines</b>	<b>16</b>
5.1. Static Configuration	16
5.2. Dynamic Reconfiguration	16
5.3. Entry Configuration Recommendations	17
5.4. Re-configuration Non-preemption and Synchronization	18
<b>6. Interaction with other proposals</b>	<b>19</b>

## Preamble



*This document is in the [Development state](#)*

*Assume everything can change. This draft specification will change before being accepted as standard, so implementations made to this draft specification will likely not conform to the future standard.*

## Copyright and license information

This specification is licensed under the Creative Commons Attribution 4.0 International License (CC-BY 4.0). The full license text is available at [creativecommons.org/licenses/by/4.0/](https://creativecommons.org/licenses/by/4.0/).

Copyright 2023 by RISC-V International.

## Contributors

The proposed SPMP specifications (non-ratified, under discussion) has been contributed to directly or indirectly by:

- Dong Du, Editor <[dd\\_nirvana@sjtu.edu.cn](mailto:dd_nirvana@sjtu.edu.cn)>
- Bicheng Yang, Editor <[bichengyang@sjtu.edu.cn](mailto:bichengyang@sjtu.edu.cn)>
- José Martins
- Thomas Roecker
- Sandro Pinto
- Manuel Rodriguez
- Luís Cunha
- Rongchuan Liu
- Nick Kossifidis
- Andy Dellow
- Manuel Offenberger
- Allen Baum
- Bill Huffman
- Xu Lu
- Wenhao Li
- Yubin Xia
- Joe Xie
- Paul Ku
- Jonathan Behrens
- Robin Zheng
- Zeyu Mi
- Fabrice Marinnet
- Nouredine Ait Said
- Xi Zhao

## Chapter 1. Introduction

This document describes the RISC-V S-mode Physical Memory Protection (SPMP) proposal to provide isolation when virtual memory (via an MMU) is unavailable or disabled. RISC-V based processors recently stimulated great interest in the emerging markets of internet of things (IoT) and automotive devices. However, use of virtual memory is usually undesirable for these markets in order to meet resource and latency constraints. Without the use of an MMU, it is difficult on such devices to isolate the S-mode operating systems (e.g., RTOS) and user-mode applications from each other. The SPMP extension provides mechanisms for an S-mode OS to support secure processing and fault isolation of U-mode software via limiting the physical addresses accessible by U-mode software running on a hart.

## Chapter 2. Machine Mode Modification

Given that the PMP and SPMP registers have a similar layout of address/config registers and the same address matching logic, reusing registers and comparators between PMP and SPMP may be beneficial (in some cases) to save hardware resources. This chapter introduces the resource sharing mechanism that can support dynamic reallocation of hardware resources between PMP and SPMP.

### 2.1. Resource Sharing between PMP and SPMP

Implementations should consider PMP/SPMP entries as a pool of entities, each of which is called a PMP\_Entry. Specifically, each PMP\_Entry consists of an address CSR, a configuration CSR, and associated microarchitecture state. A new M-mode CSR called `mpmpdeleg` is introduced to control the sharing of PMP\_Entry entities between PMP and SPMP.

In the following description, we will refer to the PMP/SPMP entity from the hardware perspective as PMP\_Entries, and the PMP/SPMP from the software perspective as M-level PMP entries and S-level PMP entries (Referred to as PMP and SPMP entries for short).

The 32-bit `mpmpdeleg` CSRs shown in [\[mpmpdeleg\\_format\]](#) has one `pmpnum` field:

- 1. `pmpnum` is 7-bit, allowing a value of 0–64 to specify the number of PMP\_Entry entities. With RV32, the values of `pmpnum`, can only be a multiple of 4 (the lowest 2 bits are read-only 0); with RV64, it can only be a multiple of 8 (the lowest 3 bits are read-only 0). This design avoids sharing the same configuration CSR between S-level and M-level.
- 2. Any PMP\_Entry entity with an index greater than or equal to the `pmpnum` is delegated to S-level (SPMP). The lower numbered PMP\_Entry entities are left for M-level (PMP).
- 3. If M-mode sets the `pmpnum` to a value larger than the max number of PMP entries, the largest allowed value is returned.
- 4. M-mode could set `pmpnum=0` to delegate all PMP\_Entry entities to SPMP.
- 5. For implementations that do not hardwire the `pmpnum`, the reset value of `pmpnum` is `0b100_0000` (no delegation).
- 6. The `pmpnum` is locked when `mseccfg.MML` is set. (Please refer to the `Smpmp` extension specification for details on `mseccfg.MML`.)
- 7. If the SPMP entry with lowest CSR number is configured with TOR address-matching mode (i.e., `spmp[0]cfg.A == TOR`), zero is used for the lower bound.

An S-mode read-only shadow of `mpmpdeleg` CSR, called `spmpdeleg`, is provided to S-mode software to obtain the `pmpnum` value without invoking an SBI call.

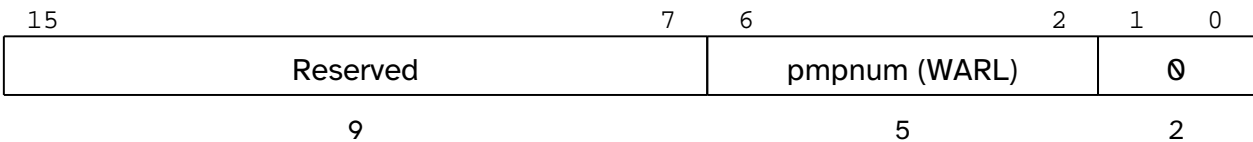
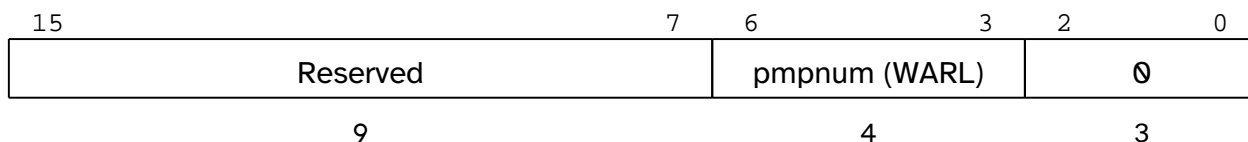


Figure 1. `mpmpdeleg` CSR format, RV32.

Figure 2. *mpmpdeleg* CSR format, RV64.

The *mpmpdeleg* CSR is WARL, and allows an implementation to hardwire the PMP/SPMP split if desired.

### Addressing:

Both PMP and SPMP entries will be supported contiguously. The PMP entries begin with the lowest CSR number, while the SPMP entries begin with *pmpnum*. For instance, given an implementation with a total of 64 *PMP\_Entry* entities, if *pmpnum* is set to 16 during runtime, *PMP\_Entry*[0] to *PMP\_Entry*[15] would map to PMP[0] to PMP[15]. The remaining entities, *PMP\_Entry*[16] to *PMP\_Entry*[63], would be mapped as SPMP[16] to SPMP[63]. A read of an out-of-index *PMP\_Entry* (e.g., PMP[16] or SPMP[15]) will return 0, and a write to such a *PMP\_Entry* will be ignored.



Software that uses SPMP should start with SPMP[*pmpnum*].

### Re-configuration:

1. M-mode software can re-configure the allocation of entries for PMP vs. SPMP by modifying the *mpmpdeleg* CSR.
2. The behavior that attempts to modify *mpmpdeleg*, which delegates a locked PMP entry to an SPMP entry, is **UNDEFINED**.



## Chapter 3. S-mode Physical Memory Protection (SPMP)

The RISC-V S-mode Physical Memory Protection (SPMP) extension provides per-hart supervisor-mode control registers to allow physical memory access privileges (read, write, execute) to be specified for each physical memory region.

Memory accesses succeed only if both PMP/ePMP and SPMP permission checks pass. The implementation can perform SPMP checks in parallel with the PMA and PMP checks. The SPMP exception has higher priority than PMP or PMA exceptions (i.e., if the access violates both SPMP and PMP/PMA, the SPMP exception will be reported).

SPMP checks will be applied to all accesses whose effective privilege mode is S or U, including instruction fetches and data accesses in S and U mode, and data accesses in M-mode when the MPRV bit in `mstatus` is set and the MPP field in `mstatus` contains S or U.

SPMP can grant permissions to U-mode, which has none by default. SPMP can also revoke permissions from S-mode.

### 3.1. Requirements

1. S-mode must be implemented.
2. The `Smepp` extension must be implemented.
3. The `Sscsrind` extension must be implemented to support indirect CSR access.
4. The `sstatus.SUM` (permit Supervisor User Memory access) bit must be **writable**, which is a change from the Privileged Architecture.



*The Privileged Architecture specification states the following*

*SUM has no effect when page-based virtual memory is not in effect, nor when executing in U-mode. SUM is read-only 0 if `satp.MODE` is read-only 0.*

*In SPMP, this bit modifies the privilege with which S-mode loads and stores access to physical memory, hence the need to make it writable.*

5. The `sstatus.MXR` (Make eXecutable Readable) bit must be **writable**, which is also a change from the Privileged Architecture.



*The Privileged Architecture specification states that*

*MXR has no effect when page-based virtual memory is not in effect.*

*In SPMP, the MXR bit modifies the privilege with which loads access physical memory. Its semantics are consistent with those of the Machine Mode ISA.*

*In SPMP, this bit is made writable to support M-mode emulation handlers where instructions are read with `MXR=1` and `MPRV=1`.*

## 3.2. S-mode Physical Memory Protection CSRs

SPMP entries are described by an 16-bit configuration register and one XLEN-bit address register. Some SPMP settings additionally use the address register associated with the preceding SPMP entry. Up to 64 SPMP entries are supported.



An SPMP entry denotes a pair of `smppcfg[i]` / `smppaddr[i]` registers.

An SPMP rule is described by the contents of an `smppcfg` register and its associated `smppaddr` register(s) that together encode a valid protected physical memory region and its restrictions, where `smppcfg[i].A != OFF`, and if `smppcfg[i].A == TOR` then `smppaddr[i-1] < smppaddr[i]`.

The SPMP address registers are CSRs named `smppaddr0-smppaddr63`, and has the same layout as the PMP architecture. For RV32, each SPMP address register encodes bits 33-2 of 34-bit physical address, as shown in Figure 3. For RV64, each SPMP address encodes bits 55-2 of a 56-bit physical address, as shown in Figure 4. Fewer address bits may be implemented for specific reasons, e.g., systems with smaller physical address space. The number of address bits should be the same for all **writable SPMP entries**. Implemented address bits must extend to the LSB format, except as otherwise permitted by granularity rules. See the Privileged Architecture specification, Section 3.7: Physical Memory Protection, Address Matching.

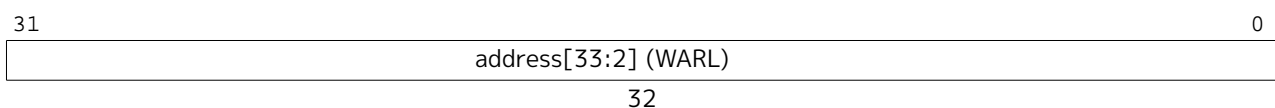


Figure 3. SPMP address register format, RV32.

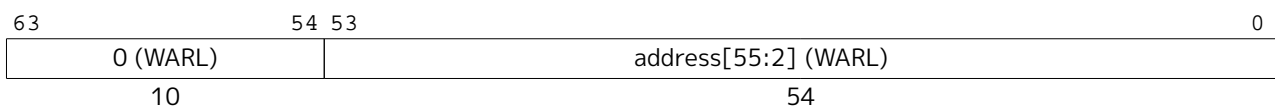


Figure 4. SPMP address register format, RV64.

The layout within each SPMP configuration register is shown in Figure 5. The register is WARL. The rules and encodings for permission are explained in Section 3.3.

1. The R/W/X bits control read, write, and instruction execution permissions.
2. The A field will be described in Section 3.4.
3. Bits 5 and 6 are used for memory types if `Smpmpmt` is implemented, else reserved (please refer to the specification of `Smpmpmt` for more details).
4. The L bit marks an entry as locked, i.e., writes to the configuration register and associated address registers via **S-mode CSRs** are ignored. It can only be reset via **M-mode CSRs** (see Section 3.7).
5. For a rule that is not Shared-Region, the U bit marks it as **U-mode-only** when set and **S-mode-only** when unset (details in Section 3.3).
6. The SHARED bit marks a **Shared-Region** rules.



Figure 5. SPMP configuration register format.



The `smppcfg[i]` is 16-bit. The low 8 bits of the SPMP configuration register alias to

the 8 bits of the corresponding PMP configuration register field. The additional bits are recommended to be held in an internal state array.

An implementation can hardwire the L bit to 0 if the lock functionality is not required.

Setting the L bit locks the SPMP entry even when the A field is set to OFF.

Writes to locked `spmpcfg[i]` and `spmpaddr[i]` will succeed only if the effective privilege mode is M via the `miselect` CSR.

Writes to locked `spmpcfg[i]` and `spmpaddr[i]` are ignored from both effective privilege mode (M and S) via the `siselect` CSR. Additionally, if `spmpcfg[i].A` of the locked entry is set to TOR, writes to `spmpaddr[i-1]` via `siselect` are ignored.

The L bit can be used by M-mode to contain software running in S-mode by setting and locking highest-priority SPMP entries with `spmpcfg[i].U == 1`. This can be useful to prevent privilege escalation attacks that would reprogram SPMP entries used to limit S-mode accesses.

Although this could arguably be achieved by using PMP/ePMP entries, the resulting configuration would not be equivalent as they do not differentiate between S and U modes. Furthermore, in cases resource sharing is statically defined (i.e., `mpmpdeleg.pmpnum` is hardwired - see [Section 2.1](#)) there may be insufficient PMP/ePMP entries available to implement the desired isolation.

### 3.3. Encoding of Permissions

SPMP has three kinds of rules: **S-mode-only**, **U-mode-only** and **Shared-Region** rules.

1. An **S-mode-only** rule is **enforced** on Supervisor mode and **denied** on User mode.
2. A **U-mode-only** rule is **enforced** on User modes and is either **denied** or **enforced** on Supervisor mode depending on the value of `sstatus.SUM` bit:
  - If `sstatus.SUM` is set, a U-mode-only rule is enforced on Supervisor mode, but denies executable permission by S-mode (denoted as **EnforceNoX** in [Figure 6](#)). This ensures the Supervisor Memory Execution Prevention (SMEP) guarantee.
  - If `sstatus.SUM` is unset, a U-mode-only rule is denied on Supervisor mode. This ensures the Supervisor Memory Access Prevention (SMAP) guarantee.
3. A **Shared-Region** rule is **enforced** on both Supervisor and User modes, with the restriction that read and write permissions are mutually exclusive in User mode.
4. When `spmpcfg.SHARED == 1`, the U and SUM bits are ignored.
5. The encoding `spmpcfg.XWR=010` and `spmpcfg.XWR=110` are reserved.

The encoding and results are shown in [Figure 6](#):

Shared Rules	smpcfg.SHARED =0						smpcfg.SHARED =1	
U/S Rules	smpcfg.U =1 (U-mode rules)			smpcfg.U =0 (S-mode rules)			smpcfg.U is ignored	
Effective Privilege Mode	U mode Access	S mode Access		U mode Access	S mode Access		U mode Access	S mode Access
Supervisor User Memory Access	sstatus.SUM is ignored	sstatus.SUM =0	sstatus.SUM =1	sstatus.SUM is ignored	sstatus.SUM =0	sstatus.SUM =1	sstatus.SUM is ignored	
RWX= 000	Enforce	Deny	EnforceNoX	Deny	Enforce	Enforce	Enforce	Enforce
RWX =100	Enforce	Deny	EnforceNoX	Deny	Enforce	Enforce	Enforce	Enforce
RWX =110	Enforce	Deny	EnforceNoX	Deny	Enforce	Enforce	Read-only	Enforce
RWX =001	Enforce	Deny	EnforceNoX	Deny	Enforce	Enforce	Enforce	Enforce
RWX = 101	Enforce	Deny	EnforceNoX	Deny	Enforce	Enforce	Enforce	Enforce
RWX = 111	Enforce	Deny	EnforceNoX	Deny	Enforce	Enforce	Exec-only	Enforce
RWX =010	A shadow stack region if Zicfiss is enabled, else reserved						Reserved	
RWX =011	Reserved						Reserved	

Figure 6. SPMP Encoding Table

**Deny:** Access fails.

**Enforce:** The R/W/X permissions specified in smpcfg are enforced on accesses.

**EnforceNoX:** The R/W permissions specified in smpcfg are enforced on accesses, while execute permission is revoked.

**Reserved:** It is reserved for future use.

**SUM bit:** The SPMP uses the sstatus.SUM (permit Supervisor User Memory access) bit to modify the privilege with which S-mode loads and stores access physical memory. The semantics of sstatus.SUM in SPMP are consistent with those of the Machine-Level ISA (please refer to the "Memory Privilege in mstatus Register" subsection in the "RISC-V Privileged Architecture" for detailed information).

### 3.4. Address Matching

The A field in an SPMP entry's configuration register encodes the address-matching mode of the associated SPMP address register. The encoding of this field is shown in the following table:

smpcfg[i].A	Name	Description
0	OFF	Null region (disabled)
1	TOR	Top of range
2	NA4	Naturally aligned four-byte region
3	NAPOT	Naturally aligned power-of-two region, ≥8 bytes

It aligns with PMP/ePMP. Please refer to the "Address Matching" subsection of PMP in the "RISC-V Privileged Architecture" for detailed information.



Software may determine the SPMP granularity by writing zero to smpcfg[i], then writing all ones to smpaddr[i], then reading back smpaddr[i]. If G is the index of the least-significant bit set, the SPMP granularity is  $2^{G+2}$

*Software may also determine the size of physical address by setting `spmpcfg[i].A == 0b11`, then writing all ones to `spmpaddr[i]` and reading back. (Please refer to the "NAPOT range encoding in PMP address and configuration registers" table in the "RISC-V Privileged Architecture" for detailed information.)*

*The `spmpcfg[i].A` is WARL, so an implementation can hardwire the address matching method to a specific one it desires.*

### 3.5. Matching Logic

- SPMP entries are statically prioritized.
- The lowest-numbered SPMP entry that matches any byte of an access (indicated by an address and the accessed length) determines whether that access is allowed or denied.
- This matching SPMP entry must match **all** bytes of the access, or the access fails and an instruction, load, or store page-fault exception is generated (see [Section 3.9](#)).
- This matching is done irrespective of the SHARED, U, R, W, and X bits.

On some implementations, misaligned loads, stores, and instruction fetches may also be decomposed into multiple accesses, some of which may succeed before an exception occurs. In particular, a portion of a misaligned store that passes the SPMP check may become visible, even if another portion fails the SPMP check. The same behavior may manifest for stores wider than XLEN bits (e.g., the FSD instruction in RV32D), even when the store address is naturally aligned.

1. If the effective privilege mode of the access is M, the access is allowed.
2. If the effective privilege mode of the access is S/U and no SPMP entry matches, but at least one SPMP entry is delegated, the access is denied.
3. Otherwise, each access is checked according to the permission bits in the matching SPMP entry. That access is allowed if it satisfies the permission checking with the encoding corresponding to the access type.

*The SPMP rules are checked for all implicit and explicit accesses in all S-mode and lesser-privileged modes.*



*The execution environment should configure SPMP entry(s) to grant the most permissive access to S-mode. S-mode software can then further refine SPMP entries as desired.*

### 3.6. Access Method of SPMP CSRs

**Indirect CSR access:** The SPMP CSRs are accessed indirectly. This indirect CSR access avoids the potential cost in pipeline flushes due to the switch statement or series of if statements that would otherwise be required.

Each combination of `siselect` and `sireg` represents an access to the corresponding SPMP CSR. There is no ordering guarantee between writes to different SPMP CSRs, except when explicitly executing an SFENCE.VMA instruction with `rs1=x0` and `rs2=x0`.

S-mode can set `spmpcfg[i].L` to lock an SPMP entry. When `spmpcfg[i].L` is set, SPMP writes via `siselect` are ignored, regardless of the effective privilege mode. Only M-mode access via `miselect` can

reset `spmpcfg[i].L` (see [Section 3.7](#)).

Given an implementation with 64 PMP\_Entries, where 48 entries are delegated to S-level. S-mode can only access SPMP[16..63] via `siselect#16..63`. Otherwise, the reads of out-of-index SPMP entries will return zero, and writes will be ignored.

siselect number	indirect CSR access of sireg
siselect#0	sireg → <code>spmpaddr[0]</code> , <code>sireg2</code> → <code>spmpcfg[0]</code>
siselect#1	sireg → <code>spmpaddr[1]</code> , <code>sireg2</code> → <code>spmpcfg[1]</code>
...	...
siselect#63	sireg → <code>spmpaddr[63]</code> , <code>sireg2</code> → <code>spmpcfg[63]</code>



*The rationale for the fact that M-mode cannot reset `spmpcfg[i].L` via `siselect` is to separate this permission by the CSR address space rather than only by privileged mode.*

*The rationale for SPMP to only assign one entry per `siselect` value is due to a performance consideration. If multiple SPMP entries are assigned to each `siselect`, a jump table or additional calculations would be needed to determine which `sireg` to access.*

*Please refer to the `Sscsrind` extension specification in the "RISC-V Privileged Architecture" for details on indirect CSR accesses.*

### 3.7. Access Method of PMP\_Entry

**Indirect CSR access:** PMP\_Entry CSRs can be accessed indirectly from M-mode. Each combination of `miselect` and `mireg` represents an access to the corresponding PMP\_Entry CSR.

There is no ordering guarantee between writes to different PMP\_Entry CSRs via indirect access, except when explicitly executing an `SFENCE.VMA` instruction with `rs1=x0` and `rs2=x0`.

The `spmpcfg[i].L` bit can only be reset when accessing in M-mode via `miselect`.

The `miselect` has the same view of `siselect`. For example, given an implementation with 64 PMP\_Entries, where 48 entries are delegated to S-level. S-mode can access SPMP[16..63] via `siselect#16..63`. M-mode can access SPMP[16..63] via `siselect#16..63` or `miselect#16..63`. In such a case, both privileged mode attempts to access SPMP[i], where  $i < \text{mpmpdeleg.pmpnum}$ , will read zero. Writes to such SPMP entries will be ignored.

miselect number	indirect CSR access of mireg
miselect#0	mireg → <code>spmpaddr[0]</code> , <code>mireg2</code> → <code>spmpcfg[0]</code>
miselect#1	mireg → <code>spmpaddr[1]</code> , <code>mireg2</code> → <code>spmpcfg[1]</code>
...	...
miselect#63	mireg → <code>spmpaddr[63]</code> , <code>mireg2</code> → <code>spmpcfg[63]</code>

### 3.8. SPMP and Paging

The table below shows which mechanism to use. (Assume both paged virtual memory and SPMP are implemented.)

satp	Isolation mechanism
satp.mode == Bare	SPMP only
satp.mode != Bare	Paged Virtual Memory only

SPMP and paged virtual memory cannot be active simultaneously for two reasons:

1. An additional permission check layer would be introduced for each memory access.
2. Sufficient protection is provided by paged virtual memory.

That means SPMP is always enabled when `satp.mode==Bare` and SPMP is implemented.



Please refer to Table "Encoding of satp MODE field" in the "RISC-V Privileged Architecture" for detailed information on the `satp.MODE` field.

### 3.9. Exceptions

When an access fails, SPMP generates an exception based on the access type (i.e., load accesses, store/AMO accesses, and instruction fetches). Each exception has a different code.

The SPMP extension reuses page fault exception codes for SPMP faults since page faults are typically delegated to S-mode. S-mode software (i.e., an OS) can distinguish between SPMP-generated exceptions and page faults by checking `satp.mode`, since SPMP and paged virtual memory cannot be active simultaneously (as described in [Section 3.8](#)).

Note that a single instruction may generate multiple accesses, which may not be mutually atomic.

Table of exception codes:

Interrupt	Exception Code	Description
0	12	Instruction page fault
0	13	Load page fault
0	15	Store/AMO page fault



Please refer to Table "Supervisor cause register (scause) values after trap" in the "RISC-V Privileged Architecture" for detailed information on exception codes.

**Delegation:** Unlike PMP, which uses access faults for violations, SPMP uses page faults for violations. The benefit of using page faults is that the violations caused by SPMP can be delegated to S-mode, while the access violations caused by PMP may remain undelegated and thus still be handled by machine mode.

### 3.10. Context Switching Optimization

Context switching with SPMP requires updating up to 64 address and 8 configuration registers (RV64). This **optional** optimization reduces such overhead.



- In RV32: two XLEN-bit read/write CSRs called `spmpswitch` and `spmpswitchh` are added, as depicted in [Figure 7](#).
- In RV64: one XLEN-bit read/write CSR called `spmpswitch` is added, as depicted in [Figure 8](#).
- If the context switching optimization is not implemented, the `spmpswitch` CSR should be hardwired to zero. Software can discover the context switching optimization by writing to and reading back the `spmpswitch` CSR.

Each bit controls the activation of its corresponding SPMP entry. An entry is active only when both its `spmpswitch[i]` bit and `spmpcfg[i].A` field are set, i.e., `spmpswitch[i] & spmpcfg[i].A != 0`.

If an entry `i` is locked (i.e., `spmpcfg[i].L == 1`), then `spmpswitch[i]` is **read-only** using **S-mode CSRs**.

The `spmpswitch` registers must be cleared on reset.

Please refer to [Chapter 5](#) for how software can use the optimization to reduce context switch overhead.



Figure 7. SPMP domain switch registers (`spmpswitch` and `spmpswitchh`), RV32.



Figure 8. SPMP domain switch register (`spmpswitch`), RV64.

Accessing `spmpswitch` CSR should follow the rule specified in [Section 3.6](#). Specifically, given an implementation with 64 PMP\_Entries, where 48 entries are delegated to S-level. The `spmpswitch[16..63]` are used to control the activation of SPMP entries `[16..63]`. Writes to `spmpswitch[0..15]` are ignored.

When `spmpswitch` is implemented and `spmpcfg[i].A == TOR`, an entry matches any address `y` where:

1.  $\text{spmpaddr}[i-1] \leq y < \text{spmpaddr}[i]$
2. This matching occurs regardless of `spmpcfg[i-1]` and `spmpswitch[i-1]` values



*Utilizing `spmpswitch` for optimizing context switches can be beneficial in several scenarios, including (but not limited to):*

1. *When the number of available SPMP entries is sufficient to accommodate all tasks executing on a given hart, each task's memory regions can be permanently mapped to a fixed subset of SPMP entries. In this model, switching SPMP contexts reduces to a single write to `spmpswitch` (or two writes in RV32 systems: `spmpswitch` and `spmpswitchh`) to deactivate the outgoing task and enable the entries associated with the incoming task.*
2. *A subset of SPMP entries may be reserved for timing-critical or latency-sensitive tasks, such as interrupt handlers. This ensures minimal overhead when switching into these contexts, avoiding the need for dynamic reconfiguration of SPMP entries.*



## Chapter 4. Summary of Hardware Changes

### Machine Mode Changes:

Item	Changes
mpmpdeleg: A CSR for resource sharing	1 new CSR
Indirect access to PMP_Resource	64 new miselect values

### Supervisor Mode Changes:

Item	Changes
smpmpdeleg: A read-only shadow of mpmpdeleg	1 new CSR
smpswitch: CSRs for domain switch	2 new CSRs for RV32 and 1 for RV64
Indirect access to delegated PMP_Resource	64 new siselect values

## Chapter 5. Recommended Programming Guidelines

When configuring SPMP to isolate user-mode tasks from each other and from the operating system (OS) executing in supervisor mode, two primary usage models arise, depending on whether the available SPMP entries can simultaneously accommodate all required memory ranges for both the user tasks and the OS:

- **Static Configuration:** all SPMP entries are programmed during system initialization. This model assumes that the number of available entries is sufficient to cover the complete set of memory regions assigned to user tasks and the OS without further modification.
- **Dynamic Configuration:** SPMP entries are reprogrammed on each context switch. This model is employed when the number of available SPMP entries is insufficient to simultaneously represent all relevant memory regions, requiring dynamic updates to enforce memory isolation between tasks.

### 5.1. Static Configuration

In the static configuration model, the number of available SPMP entries is sufficient to accommodate all required memory ranges for user-mode tasks and the OS. In this case, SPMP entries are programmed once during system initialization and remain unchanged at runtime. Only the `spmswitch` register(s) need to be updated during context switches between user-mode tasks.

The M-mode software is responsible for allocating SPMP entries and configuring them with the appropriate address ranges and permissions for S-mode software during boot.

The OS begins by allocating SPMP entries and populating the `spmaddr[i]` and `spmpcfg[i]` CSRs with the appropriate address ranges and permissions for each user-mode task.

If the OS itself is to be protected using SPMP, additional entries must be allocated and configured with the OS memory ranges, with the U bit (User bit) unset in `spmpcfg[i]`. After initializing the entries, the OS must also set the corresponding bits in the `spmswitch` register to activate these entries for itself.

Prior to launching the first user task, the OS sets the bits in `spmswitch` corresponding to the SPMP entries assigned to that task. During a context switch, the OS clears the current task's entry bits and sets those of the newly scheduled task using the `csrc` and `csrs` instructions, respectively. On RV32 systems, both `spmswitch` and `spmswitchh` must be managed as a continuous pair.

### 5.2. Dynamic Reconfiguration

In this configuration model, the available SPMP entries are insufficient to simultaneously represent the memory ranges required for all user-mode tasks and the supervisor. As a result, the OS must dynamically reconfigure SPMP entries for user tasks on every context switch. Notably, for any given hart, the number of SPMP entries must still be sufficient to hold both the supervisor entries and the entries for the currently executing user-mode task.

The following sequence is recommended for dynamic reconfiguration:

1. **Disable Entries for the Outgoing Task.** Use the `csrc` instruction to clear the `spmswitch` bits corresponding to the SPMP entries of the outgoing task. A bitmask representing active entries (typically stored in the task's control block) should be passed as an argument.

2. **Update SPMP Address Registers.** Write the `spmpaddr[i]` CSRs with the address ranges corresponding to the memory regions of the incoming task.
3. **Update SPMP Configuration Registers.** For each corresponding `spmpcfg[i]` field:
  - Clear the existing configuration bits using the `csrc` instruction with an appropriate mask;
  - Set the desired configuration using the `csrs` instruction.
4. **Enable Entries for the Incoming Task.** Use the `csrs` instruction to write to `spmpswitch`, passing a bitmask that enables the SPMP entries allocated to the incoming task.



*It is recommended that SPMP entries configured to protect the supervisor (i.e., entries with `spmpcfg[i].U == 0`) remain resident and are not reprogrammed during the context-switch process. Maintaining these entries as persistent minimizes reconfiguration overhead and ensures consistent enforcement of memory protection for the supervisor across task switches.*

### 5.3. Entry Configuration Recommendations

When programming SPMP entries, a trade-off exists between using exclusively Naturally Aligned Power-Of-Two (NAPOT) or Top-Of-Range (TOR) address-matching modes (see [Section 3.4](#)).

While NAPOT allows compact encoding for power-of-two-aligned regions using a single entry, it may lead to internal fragmentation if the region size exceeds the actual requirement, resulting in memory waste. On the other hand, TOR mode (particularly in its generic form) requires two SPMP entries per protected region (base and top), which may exhaust available entries more quickly. However, for regions that are naturally power-of-two aligned, TOR may still be encoded with fewer entries.

This trade-off becomes especially relevant in Microcontroller Unit (MCU) environments, where local memories are often sparsely mapped to fixed address ranges associated with specific core functions. In such cases, exclusive use of NAPOT or naively pairing TOR entries may be inefficient or lead to undesirable gaps in protection. Additionally, while it is possible to define multiple contiguous regions with different access permissions using overlapping or consecutive TOR entries, this technique can introduce subtle dependencies. Sharing a top address between two address spaces (e.g., supervisor and user) can lead to unintended interactions: reducing the supervisor region may inadvertently expand the adjacent user region. Similarly, replacing a shared top address during context switches could expose previously protected memory.

Given these risks, the following configuration model is recommended:

- Use TOR mode exclusively, treating each pair of `spmpaddr[i]` registers (even/odd indexed) as a base/top pair defining a single memory region;
- Conceptually, view SPMP entries as organized into pairs: (0/1), (2/3), ..., (62/63). Only the odd-indexed entries are enabled via the corresponding bits in `spmpswitch`, as each odd entry finalizes the definition of a region;
- Allocate and populate SPMP entries in descending index order (i.e., from lower priority to higher priority), starting from the highest index downward. This allocation strategy allows the OS to define temporary subregions by configuring unused lower-index entries without needing to reconfigure existing higher-index (priority) ones.

This disciplined use of TOR-mode SPMP entries ensures clearer isolation boundaries, reduces the likelihood of configuration errors, and improves runtime flexibility for memory protection schemes.

## 5.4. Re-configuration Non-preemption and Synchronization

To preserve the integrity of SPMP state, the reconfiguration process during a context switch must be executed as a non-preemptible critical section. This requirement stems from the need to update multiple control and configuration CSRs, and any interruption or concurrent modification during this process can result in transient inconsistencies or unintended access permissions.

In the **dynamic reconfiguration model**, the critical section must be enforced across updates to the following CSRs: `smpaddr[i]`, `smpcfg[i]`, and `smpswitch`. In the **static configuration model**, this concern is relevant only for RV32 systems with more than 32 SPMP entries, where both `smpswitch` and `smpswitchh` must be updated in coordination.

To prevent asynchronous S-mode interrupts during reconfiguration, the supervisor must clear the SIE (Supervisor Interrupt Enable) bit in the `sstatus` CSR. Furthermore, synchronisation mechanisms (e.g., mutexes or spinlocks) must be employed to serialise access to SPMP CSRs in multi-threaded or multi-core systems, ensuring that concurrent modifications do not result in conflicting or corrupted configurations.

By enforcing non-preemption and proper synchronisation, software ensures that SPMP protections remain deterministic, secure, and verifiable across context switches.

## Chapter 6. Interaction with other proposals

This section discusses how SPMP interacts with other proposals.

**J-extension pointer masking proposal:** When both PM and SPMP are used, SPMP checking should be performed using the actual addresses generated by PM (pointer masking).

**Hypervisor extension:** Virtualization support for the SPMP extension will be an independent proposal.

**Smstateen extension:** SPMP adds readable and writable states in S-mode, which can be abused as a covert channel if the OS/hypervisor is not aware of SPMP (thus the states won't be context-switched). It is desired that SPMP occupies a bit in the `mstateen` register of Smstateen extension, which can control supervisor access to SPMP states.