

4.6 Memory protection unit

The *Memory Protection Unit* (MPU) divides the memory map into a number of regions, and defines the location, size, access permissions, and memory attributes of each region. It supports:

- Independent attribute settings for each region.
- Overlapping regions.
- Export of memory attributes to the system.

The memory attributes affect the behavior of memory accesses to the region. The Cortex[®]-M7 MPU defines:

- 8 or 16 separate memory regions, 0-7 or 0-15.
- A background region.

When memory regions overlap, a memory access is affected by the attributes of the region with the highest number. For example, the attributes for region 7 take precedence over the attributes of any region that overlaps region 7.

The background region has the same memory access attributes as the default memory map, but is accessible from privileged software only.

The Cortex[®]-M7 MPU memory map is unified. This means instruction accesses and data accesses have same region settings.

If a program accesses a memory location that is prohibited by the MPU, the processor generates a MemManage fault. This causes a fault exception, and might cause termination of the process in an OS environment. In an OS environment, the kernel can update the MPU region setting dynamically based on the process to be executed. Typically, an embedded OS uses the MPU for memory protection.

The configuration of MPU regions is based on memory types, see [Memory regions, types and attributes on page 33](#).

[Table 83](#) shows the possible MPU region attributes. These include Shareability and cache behavior attributes that are generally only relevant when the processor is configured with caches.

Table 83. Memory attributes summary

Memory type	Shareability	Other attributes	Description
Strongly-ordered	-	-	All accesses to Strongly-ordered memory occur in program order. All Strongly-ordered regions are assumed to be shared.
Device	Shared	-	Memory-mapped peripherals that several processors share.
-	Non-shared	-	Memory-mapped peripherals that only a single processor uses.

Table 83. Memory attributes summary (continued)

Memory type	Shareability	Other attributes	Description
Normal	Shared	Non-cacheable Write-through Cacheable Write-back Cacheable	Normal memory that is shared between several processors.
-	Non-shared	Non-cacheable Write-through Cacheable Write-back Cacheable	Normal memory that only a single processor uses.

Use the MPU registers to define the MPU regions and their attributes. The MPU registers are:

Table 84. MPU registers summary

Address	Name	Type	Required privilege	Reset value	Description
0xE000ED90	MPU_TYPE	RO	Privileged	0x00000800	MPU type register on page 223
0xE000ED94	MPU_CTRL	RW	Privileged	0x00000000	MPU control register on page 223
0xE000ED98	MPU_RNR	RW	Privileged	Unknown	MPU region number register on page 225
0xE000ED9C	MPU_RBAR	RW	Privileged	Unknown	MPU region base address register on page 225
0xE000EDA0	MPU_RASR	RW	Privileged	_(1)	MPU region attribute and size register on page 226
0xE000EDA4	MPU_RBAR_A1	RW	Privileged	Unknown	Alias of RBAR, see MPU region base address register on page 225
0xE000EDA8	MPU_RASR_A1	RW	Privileged	_(1)	Alias of RASR, see MPU region attribute and size register on page 226
0xE000EDAC	MPU_RBAR_A2	RW	Privileged	Unknown	Alias of RBAR, see MPU region base address register on page 225
0xE000EDB0	MPU_RASR_A2	RW	Privileged	_(1)	Alias of RASR, see MPU region attribute and size register on page 226
0xE000EDB4	MPU_RBAR_A3	RW	Privileged	Unknown	Alias of RBAR, see MPU region base address register on page 225
0xE000EDB8	MPU_RASR_A3	RW	Privileged	_(1)	Alias of RASR, see MPU region attribute and size register on page 226

1. Unknown apart from the ENABLE field, which is reset to 0.

4.6.1 MPU type register

The MPU_TYPE register indicates whether the MPU is present, and if so, how many regions it supports. If the MPU is not present the MPU_TYPE register is RAZ. See the register summary in [Table 84](#) for its attributes. The bit assignments are:

Figure 48. TYPE bit assignments

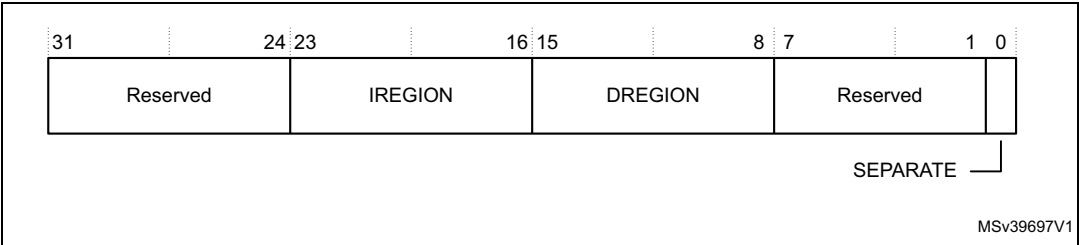


Table 85. TYPE bit assignments

Bits	Name	Function
[31:24]	-	Reserved.
[23:16]	IREGION	Indicates the number of supported MPU instruction regions. Always contains 0x00. The MPU memory map is unified and is described by the DREGION field.
[15:8]	DREGION	Indicates the number of supported MPU data regions: 0x08: 8 MPU regions. 0x10: 16 MPU regions.
[7:1]	-	Reserved.
[0]	SEPARATE	Indicates support for unified or separate instruction and data memory maps: 0: Unified.

4.6.2 MPU control register

The MPU_CTRL register:

- Enables the MPU.
- Enables the default memory map background region.
- Enables use of the MPU when in the hard fault, *Non Maskable Interrupt* (NMI), and FAULTMASK escalated handlers.

See the register summary in [Table 84 on page 222](#) for the MPU_CTRL attributes. The bit assignments are:

Figure 49. MPU_CTRL bit assignments

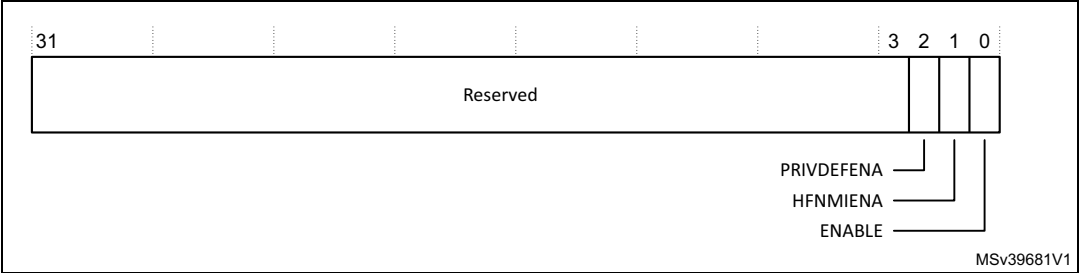


Table 86. MPU_CTRL bit assignments

Bits	Name	Function
[31:3]	-	Reserved.
[2]	PRIVDEFENA	<p>Enables privileged software access to the default memory map:</p> <p>0: If the MPU is enabled, disables use of the default memory map. Any memory access to a location not covered by any enabled region causes a fault.</p> <p>1: If the MPU is enabled, enables use of the default memory map as a background region for privileged software accesses.</p> <p>When enabled, the background region acts as if it is region number -1. Any region that is defined and enabled has priority over this default map.</p> <p>If the MPU is disabled, the processor ignores this bit.</p>
[1]	HFNMENA	<p>Enables the operation of MPU during hard fault, NMI, and FAULTMASK handlers.</p> <p>When the MPU is enabled:</p> <p>0: MPU is disabled during hard fault, NMI, and FAULTMASK handlers, regardless of the value of the ENABLE bit.</p> <p>1: The MPU is enabled during hard fault, NMI, and FAULTMASK handlers.</p> <p>When the MPU is disabled, if this bit is set to 1 the behavior is Unpredictable.</p>
[0]	ENABLE	<p>Enables the MPU:</p> <p>0: MPU disabled.</p> <p>1: MPU enabled.</p>

When ENABLE and PRIVDEFENA are both set to 1:

- For privileged accesses, the *default memory map* is as described in [Cortex®-M7 configurations on page 30](#). Any access by privileged software that does not address an enabled memory region behaves as defined by the default memory map.
- Any access by unprivileged software that does not address an enabled memory region causes a MemManage fault.

XN and Strongly-ordered rules always apply to the System Control Space regardless of the value of the ENABLE bit.

When the ENABLE bit is set to 1, at least one region of the memory map must be enabled for the system to function unless the PRIVDEFENA bit is set to 1. If the PRIVDEFENA bit is set to 1 and no regions are enabled, then only privileged software can operate.

When the ENABLE bit is set to 0, the system uses the default memory map. This has the same memory attributes as if the MPU is not implemented, see [Table 77 on page 217](#). The default memory map applies to accesses from both privileged and unprivileged software.

When the MPU is enabled, accesses to the System Control Space and vector table are always permitted. Other areas are accessible based on regions and whether PRIVDEFENA is set to 1.

Unless HFNMENA is set to 1, the MPU is not enabled when the processor is executing the handler for an exception with priority -1 or -2. These priorities are only possible when handling a hard fault or NMI exception, or when FAULTMASK is enabled. Setting the HFNMENA bit to 1 enables the MPU when operating with these two priorities.

4.6.3 MPU region number register

The MPU_RNR selects which memory region is referenced by the MPU_RBAR and MPU_RASR registers. See the register summary in [Table 77 on page 217](#) for its attributes. The bit assignments are:

Figure 50. MPU_RNR bit assignments

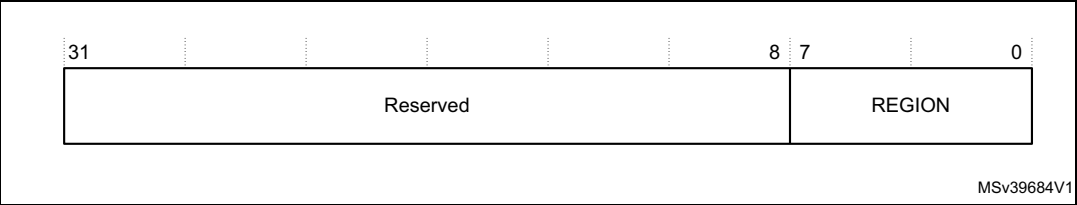


Table 87. MPU_RNR bit assignments

Bits	Name	Function
[31:8]	-	Reserved.
[7:0]	REGION	Indicates the MPU region referenced by the MPU_RBAR and MPU_RASR registers. The MPU supports 8 or 16 memory regions, so the permitted values of this field are 0-7 or 0-15.

Normally, the user writes the required region number to this register before accessing the MPU_RBAR or MPU_RASR. However the region number can be changed by writing to the MPU_RBAR with the VALID bit set to 1, see [MPU region base address register](#). This write updates the value of the REGION field.

4.6.4 MPU region base address register

The MPU_RBAR defines the base address of the MPU region selected by the MPU_RNR, and can update the value of the MPU_RNR. See the register summary in [Table 84 on page 222](#) for its attributes.

Write MPU_RBAR with the VALID bit set to 1 to change the current region number and update the MPU_RNR. See the register summary in [Table 84 on page 222](#) for its attributes. The bit assignments are

Figure 51. MPU_RBAR bit assignments:

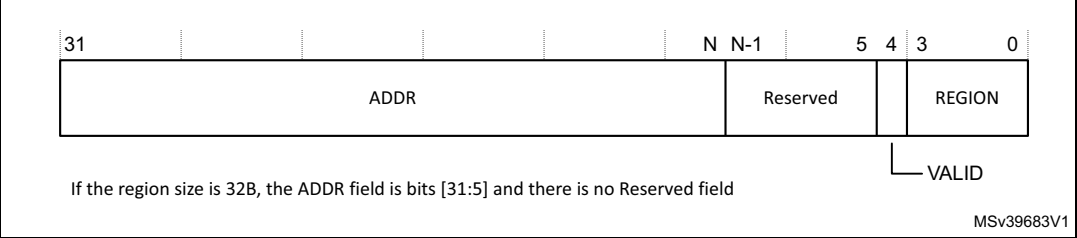


Table 88. MPU_RBAR bit assignments

Bits	Name	Function
[31:N]	ADDR	Region base address field. The value of N depends on the region size. For more information see The ADDR field .
[(N-1):5]	-	Reserved.
[4]	VALID	MPU Region Number valid bit: Write: 0: MPU_RNR not changed, and the processor: Updates the base address for the region specified in the MPU_RNR Ignores the value of the REGION field 1: The processor: Updates the value of the MPU_RNR to the value of the REGION field Updates the base address for the region specified in the REGION field. Always reads as zero.
[3:0]	REGION	MPU region field: For the behavior on writes, see the description of the VALID field. On reads, returns the current region number, as specified by the RNR.

The ADDR field

The ADDR field is bits[31:N] of the MPU_RBAR. The region size, as specified by the SIZE field in the MPU_RASR, defines the value of N:

$$N = \text{Log}_2(\text{Region size in bytes}),$$

If the region size is configured to 4 Gbytes, in the MPU_RASR, there is no valid ADDR field. In this case, the region occupies the complete memory map, and the base address is 0x00000000.

The base address is aligned to the size of the region. For example, a 64KB region must be aligned on a multiple of 64KB, for example, at 0x00010000 or 0x00020000.

4.6.5 MPU region attribute and size register

The MPU_RASR defines the region size and memory attributes of the MPU region specified by the MPU_RNR, and enables that region and any subregions. See the register summary in [Table 84 on page 222](#) for its attributes.

MPU_RASR is accessible using word accesses:

- The most significant halfword holds the region attributes.
- The least significant halfword holds the region size and the region and subregion enable bits.

The bit assignments are:

Figure 52. MPU_RASR bit assignments

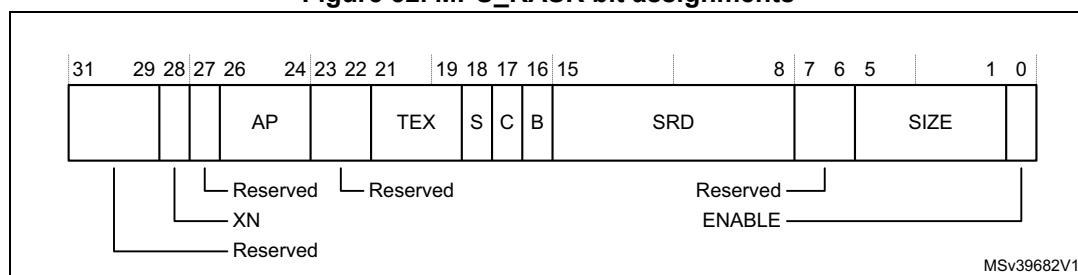


Table 89. MPU_RASR bit assignments

Bits	Name	Function
[31:29]	-	Reserved.
[28]	XN	Instruction access disable bit: 0: Instruction fetches enabled. 1: Instruction fetches disabled.
[27]	-	Reserved.
[26:24]	AP	Access permission field, see Table 93 on page 229 .
[23:22]	-	Reserved.
[21:19, 17, 16]	TEX, C, B	Memory access attributes, see Table 91 on page 228 .
[18]	S	Shareable bit, see Table 91 on page 228 .
[15:8]	SRD	Subregion disable bits. For each bit in this field: 0: Corresponding sub-region is enabled. 1: Corresponding sub-region is disabled. See Subregions on page 231 for more information. Region sizes of 128 bytes and less do not support subregions. When writing the attributes for such a region, write the SRD field as 0x00.
[7:6]	-	Reserved.
[5:1]	SIZE	Specifies the size of the MPU protection region. The minimum permitted value is 4 (0b00100), see SIZE field values for more information.
[0]	ENABLE	Region enable bit.

For information about access permission, see [MPU access permission attributes on page 228](#).

SIZE field values

The SIZE field defines the size of the MPU memory region specified by the RNR. as follows:

$$(\text{Region size in bytes}) = 2^{(\text{SIZE}+1)}$$

The smallest permitted region size is 32B, corresponding to a SIZE value of 4. [Table 90](#) gives example SIZE values, with the corresponding region size and value of N in the MPU_RBAR.

Table 90. Example SIZE field values

SIZE value	Region size	Value of N ⁽¹⁾	Note
0b00100 (4)	32 Bytes	5	Minimum permitted size
0b01001 (9)	1 Kbyte	10	-
0b10011 (19)	1 Mbyte	20	-
0b11101 (29)	1 Gbyte	30	-
0b11111 (31)	4 Gbytes	32	Maximum possible size

1. In the MPU_RBAR, see [MPU region base address register on page 225](#).

4.6.6 MPU access permission attributes

This section describes the MPU access permission attributes. The access permission bits, TEX, C, B, S, AP, and XN, of the RASR, control access to the corresponding memory region. If an access is made to an area of memory without the required permissions, then the MPU generates a permission fault. [Table 91](#) shows encodings for the TEX, C, B, and S access permission bits.

Table 91. TEX, C, B, and S encoding

TEX	C	B	S	Memory type	Shareability	Other attributes
0b000	0	0	x ⁽¹⁾	Strongly-ordered	Shareable	-
		1	x ⁽¹⁾	Device	Shareable	-
	1	0	0	Normal	Not shareable	Outer and inner write-through. No write allocate.
			1		Shareable	
		1	0	Normal	Not shareable	Outer and inner write-back. No write allocate.
			1		Shareable	
0b001	0	0	0	Normal	Not shareable	Outer and inner noncacheable.
			1		Shareable	
		1	x ⁽¹⁾	Reserved encoding		-
	1	0	x ⁽¹⁾	Implementation defined attributes.		-
		1	0	Normal	Not shareable	Outer and inner write-back. Write and read allocate.
			1		Shareable	
0b010	0	0	x ⁽¹⁾	Device	Not shareable	Nonshared Device.
		1	x ⁽¹⁾	Reserved encoding		-
	1	x ⁽¹⁾	x ⁽¹⁾	Reserved encoding		-

Table 91. TEX, C, B, and S encoding (continued)

TEX	C	B	S	Memory type	Shareability	Other attributes
0b1BB	A	A	0	Normal	Not shareable	Cached memory, BB = outer policy, AA = inner policy. See Table 92 on page 229 for the encoding of the AA and BB bits.
			1		Shareable	

1. The MPU ignores the value of this bit.

[Table 92](#) shows the cache policy for memory attribute encodings with a TEX value is in the range 4-7.

Table 92. Cache policy for memory attribute encoding

Encoding, AA or BB	Corresponding cache policy
00	Non-cacheable
01	Write back, write and read allocate
10	Write through, no write allocate
11	Write back, no write allocate

[Table 93](#) shows the AP encodings that define the access permissions for privileged and unprivileged software.

Table 93. AP encoding

AP[2:0]	Privileged permissions	Unprivileged permissions	Description
000	No access	No access	All accesses generate a permission fault
001	RW	No access	Access from privileged software only
010	RW	RO	Writes by unprivileged software generate a permission fault
011	RW	RW	Full access
100	Unpredictable	Unpredictable	Reserved
101	RO	No access	Reads by privileged software only
110	RO	RO	Read only, by privileged or unprivileged software
111	RO	RO	Read only, by privileged or unprivileged software

4.6.7 MPU mismatch

When an access violates the MPU permissions, the processor generates a MemManage fault, see [Exceptions and interrupts on page 28](#). The MMFSR indicates the cause of the fault. See [MemManage fault status register on page 206](#) for more information.

4.6.8 Updating an MPU region

To update the attributes for an MPU region, update the MPU_RNR, MPU_RBAR and MPU_RASR registers. It is possible to program each register separately, or use a multiple-word write to program all of these registers. The MPU_RBAR and MPU_RASR aliases can be used to program up to four regions simultaneously using an STM instruction.

Updating an MPU region using separate words

Simple code to configure one region:

```
; R1 = region number
; R2 = size/enable
; R3 = attributes
; R4 = address
LDR R0,=MPU_RNR          ; 0xE000ED98, MPU region number register
STR R1, [R0, #0x0]        ; Region Number
STR R4, [R0, #0x4]        ; Region Base Address
STRH R2, [R0, #0x8]       ; Region Size and Enable
STRH R3, [R0, #0xA]       ; Region Attribute
```

Disable a region before writing new region settings to the MPU if the region being changed, has been previously enabled. For example:

```
; R1 = region number
; R2 = size/enable
; R3 = attributes
; R4 = address
LDR R0,=MPU_RNR          ; 0xE000ED98, MPU region number register
STR R1, [R0, #0x0]        ; Region Number
BIC R2, R2, #1            ; Disable
STRH R2, [R0, #0x8]       ; Region Size and Enable
STR R4, [R0, #0x4]        ; Region Base Address
STRH R3, [R0, #0xA]       ; Region Attribute
ORR R2, #1                ; Enable
STRH R2, [R0, #0x8]       ; Region Size and Enable
```

The software must use memory barrier instructions:

- Before MPU setup if there might be outstanding memory transfers, such as buffered writes, that might be affected by the change in MPU settings.
- After MPU setup if it includes memory transfers that must use the new MPU settings.

The software does not require any memory barrier instructions during MPU setup, because it accesses the MPU through the PPB, which is a Strongly-ordered memory region.

For example, if it is required that all of the memory access behavior to take effect immediately after the programming sequence, use a DSB instruction and an ISB instruction. A DSB is required after changing MPU settings, such as at the end of context switch. An ISB is required if the code that programs the MPU region or regions is entered using a branch or call. If the programming sequence is entered by taking an exception and the programming sequence is exited by using a return from exception then an ISB instruction is not required.

Updating an MPU region using multi-word writes

The user can program directly using multi-word writes, depending on how the information is divided. Consider the following reprogramming:

```
; R1 = region number
; R2 = address
; R3 = size, attributes in one
LDR R0, =MPU_RNR      ; 0xE000ED98, MPU region number register
STR R1, [R0, #0x0]    ; Region Number
STR R2, [R0, #0x4]    ; Region Base Address
STR R3, [R0, #0x8]    ; Region Attribute, Size and Enable
```

Use an STM instruction to optimize this:

```
; R1 = region number
; R2 = address
; R3 = size, attributes in one
LDR R0, =MPU_RNR      ; 0xE000ED98, MPU region number register
STM R0, {R1-R3}       ; Region Number, address, attribute, size and enable
```

The user can do this in two words for pre-packed information. This means that the MPU_RBAR contains the required region number and had the VALID bit set to 1, see [MPU region base address register on page 225](#). Use this when the data is statically packed, for example in a boot loader:

```
; R1 = address and region number in one
; R2 = size and attributes in one
LDR R0, =MPU_RBAR     ; 0xE000ED9C, MPU Region Base register.
STR R1, [R0, #0x0]    ; Region base address and region number combined
                        ; with VALID (bit 4) set to 1.
STR R2, [R0, #0x4]    ; Region Attribute, Size and Enable.
```

Subregions

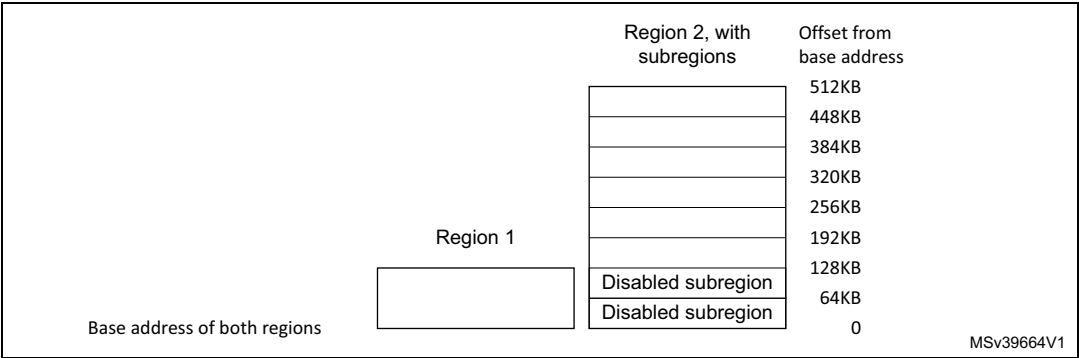
Regions of 256 bytes or more are divided into eight equal-sized subregions. Set the corresponding bit in the SRD field of the MPU_RASR to disable a subregion, see [MPU region attribute and size register on page 226](#). The least significant bit of SRD controls the first subregion, and the most significant bit controls the last subregion. Disabling a subregion means another region overlapping the disabled range matches instead. If no other enabled region overlaps the disabled subregion, and the access is unprivileged or the background region is disabled, the MPU issues a fault.

Regions of 32, 64, and 128 bytes do not support subregions. With regions of these sizes, The user must set the SRD field to 0x00, otherwise the MPU behavior is Unpredictable.

Example of SRD use

Two regions with the same base address overlap. Region one is 128 KB, and region two is 512 KB. To ensure the attributes from region one apply to the first 128 KB region, set the SRD field for region two to 0b00000011 to disable the first two subregions, as the figure shows.

Figure 53. Example of disabling subregion



4.6.9 MPU design hints and tips

To avoid an unexpected behavior, disable the interrupts before updating the attributes of a region that the interrupt handlers might access.

The processor does not support unaligned accesses to MPU registers.

The MPU registers support aligned word accesses only. The byte and halfword accesses are unpredictable.

When setting up the MPU, and if the MPU has previously been programmed, disable the unused regions to prevent any previous region settings from affecting the new MPU setup.