PM0223
Programming manual

Cortex®-M0+ programming manual for STM32L0, STM32G0, STM32WL and STM32WB Series

Introduction

This programming manual provides information for application and system-level software developers. It gives a full description of the programming model, instruction set, and core peripherals of the Cortex®-M0+ processor used on the STM32L0, STM32G0, STM32WL and STM32WB Series MCUs.

Cortex®-M0+ is a high performance 32-bit processor designed for integration in microcontrollers. It offers significant benefits to developers, including:

- Outstanding processing performance combined with fast interrupt handling
- Enhanced system debug with extensive breakpoint options
- Efficient processor core, system and memories
- Ultra-low power consumption with integrated sleep modes
- Platform security

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1 About this document

This document provides the information required for application and system-level software development. It does not provide information on debug components, features, or operation.

This material is for microcontroller software and hardware engineers, including those who have no experience of Arm®(a) products.

1.1 Typographical conventions

The typographical conventions used in this document are:

italic	Highlights important notes, introduces special terminology, denotes internal cross-references, and citations.
bold	Highlights interface elements, such as menu names. Denotes signal names. Also used for terms in descriptive lists, where appropriate.
`monospace`	Denotes text that you can enter at the keyboard, such as commands, file and program names, and source code.
`monospace`	Denotes a permitted abbreviation for a command or option. You can enter the underlined text instead of the full command or option name.
`monospace italic`	Denotes arguments to monospace text where the argument is to be replaced by a specific value.
`monospace bold`	Denotes language keywords when used outside example code.
< and >	Enclose replaceable terms for assembler syntax where they appear in code or code fragments. For example: LDRSB<cond> <Rt>, [<Rn>, #<offset>]

1.2 List of abbreviations for registers

The following abbreviations are used in register descriptions:

read/write (rw)	Software can read and write to these bits.
read-only (r)	Software can only read these bits.
write-only (w)	Software can only write to this bit. Reading the bit returns the reset value.
read/clear (rc_w)	Software can read as well as clear this bit by writing any value.

a. Arm is a registered trademark of Arm Limited (or its subsidiaries) in the US and/or elsewhere.

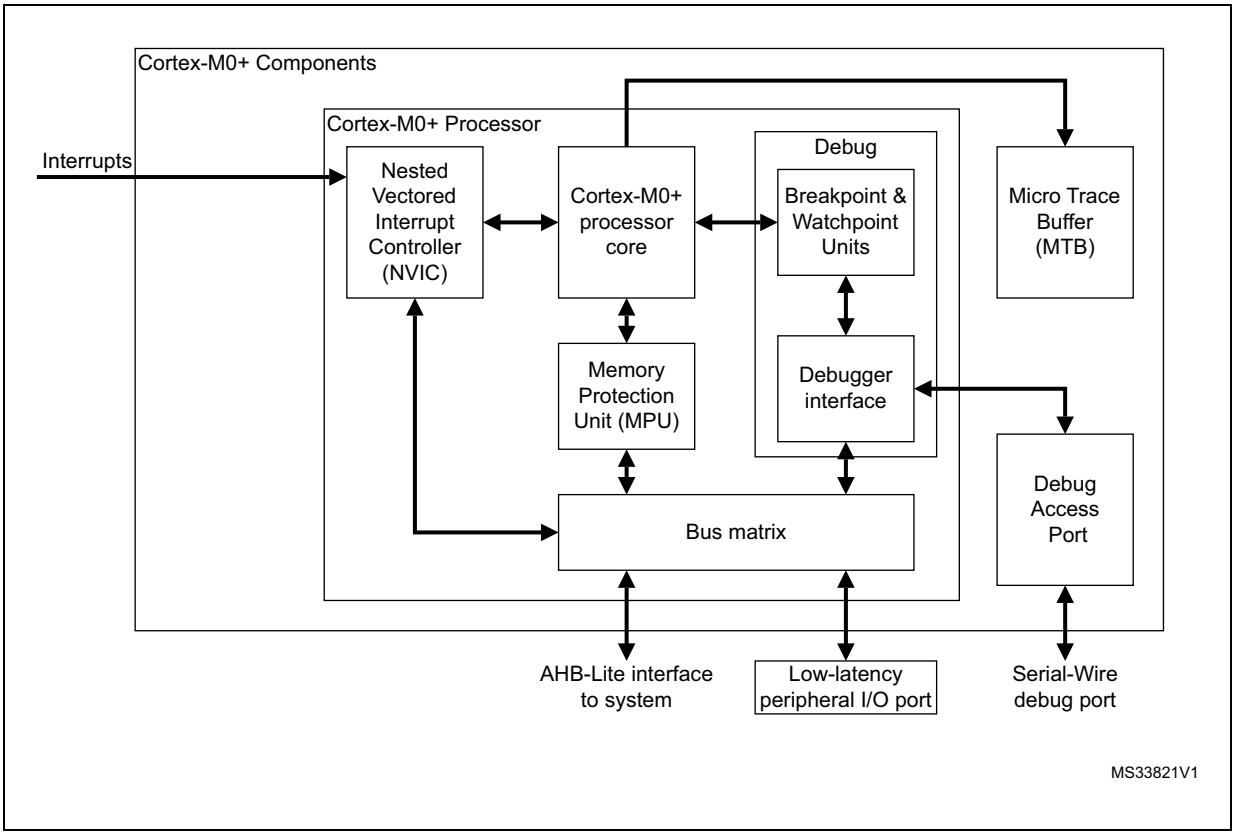
read/clear (rc_w1)	Software can read as well as clear this bit by writing 1. Writing ‘0’ has no effect on the bit value.
read/clear (rc_w0)	Software can read as well as clear this bit by writing 0. Writing ‘1’ has no effect on the bit value.
toggle (t)	Software can only toggle this bit by writing ‘1’. Writing ‘0’ has no effect.
Reserved (Res.)	Reserved bit, must be kept at reset value.

1.3 About the Cortex-M0+ processor and core peripherals

The Cortex-M0+ processor is an entry-level 32-bit Arm® Cortex processor designed for a broad range of embedded applications. It offers significant benefits to developers, including:

- A simple architecture that is easy to learn and program.
- Ultra-low power, energy-efficient operation.
- Excellent code density.
- Deterministic, high-performance interrupt handling.
- Upward compatibility with Cortex-M processor family.
- Platform security robustness, with optional integrated Memory Protection Unit (MPU).

Figure 1. Cortex-M0+ implementation



The Cortex-M0+ processor is built on a highly area and power optimized 32-bit processor core, with a 2-stage pipeline Von Neumann architecture. The processor delivers exceptional

energy efficiency through a small but powerful instruction set and extensively optimized design, providing high-end processing hardware including a single-cycle multiplier.

The Cortex-M0+ processor implements the ARMv6-M architecture, which is based on the 16-bit Thumb® instruction set and includes Thumb-2 technology. This provides the exceptional performance expected of a modern 32-bit architecture, with a higher code density than other 8-bit and 16-bit microcontrollers.

The Cortex-M0+ processor closely integrates a configurable *Nested vectored interrupt controller (NVIC)*, to deliver industry-leading interrupt performance. The NVIC:

- Includes a *Non-Maskable* Interrupt (NMI).
- Provides zero jitter interrupt option.
- Provides four interrupt priority levels.

The tight integration of the processor core and NVIC provides fast execution of *Interrupt Service Routines (ISRs*), dramatically reducing the interrupt latency. This is achieved through the hardware stacking of registers, and the ability to abandon and restart load-multiple and store-multiple operations. Interrupt handlers do not require any assembler wrapper code, removing any code overhead from the ISRs. Tail-chaining optimization also significantly reduces the overhead when switching from one ISR to another.

To optimize low-power designs, the NVIC integrates with the sleep modes, that include a deep sleep function that enables the entire device to be rapidly powered down.

1.3.1 System-level interface

The Cortex-M0+ processor provides a single system-level interface using AMBA® technology to provide high speed, low latency memory accesses.

The Cortex-M0+ processor has an optional Memory Protection Unit (MPU) that provides fine grain memory control, enabling applications to use multiple privilege levels, separating and protecting code, data and stack on a task-by-task basis. Such requirements are becoming critical in many embedded applications such as automotive systems.

1.3.2 Integrated configurable debug

The Cortex-M0+ processor implements a complete hardware debug solution, with extensive hardware breakpoint and watchpoint options. This provides high system visibility of the processor, memory and peripherals through a <2-pin *Serial Wire Debug* (SWD) port> that is ideal for microcontrollers and other small package devices.

1.3.3 Cortex-M0+ processor feature summary

- Thumb instruction set with Thumb-2 Technology.
- High code density with 32-bit performance.
- User and Privileged mode execution.
- Tools and binary upwards compatible with Cortex-M processor family.
- Integrated ultra low-power sleep modes.
- Efficient code execution enabling slower processor clock or increased sleep time.
- Single-cycle 32-bit hardware multiplier.
- Zero jitter interrupt handling.
- Memory Protection Unit (MPU) for safety-critical applications.
- Low latency, high-speed peripheral I/O port.
- A Vector Table Offset Register.
- Extensive debug capabilities.

1.3.4 Cortex-M0+ core peripherals

These are:

Nested vectored interrupt controller (NVIC)

The NVIC is an embedded interrupt controller that supports low latency interrupt processing.

System Control Block

The *System Control Block (SCB)* is the programmers model interface to the processor. It provides system implementation information and system control, including configuration, control, and reporting of system exceptions.

System timer

The system timer, SysTick, is a 24-bit count-down timer. Use this as a *Real Time Operating System* (RTOS) tick timer or as a simple counter.

Memory Protection Unit

The *Memory Protection Unit (MPU)* improves system reliability by defining the memory attributes for different memory regions. It provides up to eight different regions, and an optional predefined background region.

I/O port

The I/O port provides single-cycle loads and stores to tightly-coupled peripherals.

2 Cortex-M0+ processor

2.1 Programmers model

This section describes the Cortex-M0+ programmers model. In addition to the individual core register descriptions, it contains information about the processor modes, privilege levels for software execution, and stacks.

2.1.1 Processor modes and privilege levels for software execution

The processor *modes* are:

Thread mode — Executes application software. The processor enters Thread mode when it comes out of reset.

Handler mode — Handles exceptions. The processor returns to Thread mode when it has finished all exception processing.

The *privilege levels* for software execution are:

Unprivileged — The software:

- Has limited access to system registers using the `MSR` and `MRS` instructions, and cannot use the `CPS` instruction to mask interrupts.
- Cannot access the system timer, NVIC, or system control block.
- Might have restricted access to memory or peripherals.

Unprivileged software executes at the unprivileged level.

Privileged — The software can use all the instructions and has access to all resources.

Privileged software executes at the privileged level.

In Thread mode, the CONTROL register controls whether software execution is privileged or unprivileged, see *CONTROL register on page 18*. In Handler mode, software execution is always privileged.

Only privileged software can write to the CONTROL register to change the privilege level for software execution in Thread mode. Unprivileged software can use the `SVC` instruction to make a Supervisor Call to transfer control to privileged software.

2.1.2 Stacks

The processor uses a full descending stack. This means the stack pointer indicates the last stacked item on the stack memory. When the processor pushes a new item onto the stack, it decrements the stack pointer and then writes the item to the new memory location. The processor implements two stacks, the *main stack* and the *process stack*, with independent copies of the stack pointer, see *Stack Pointer on page 14*.

In Thread mode, the CONTROL register controls whether the processor uses the main stack or the process stack, see *CONTROL register on page 18*. In Handler mode, the processor always uses the main stack. The options for processor operations are:

Table 1. Summary of processor mode, execution privilege level, and stack use options

Processor mode	Used to execute	Privilege level for software execution	Stack used
Thread	Applications	Privileged or unprivileged(1)	Main stack or process stack(1)
Handler	Exception handlers	Always privileged	Main stack

1. See *CONTROL register on page 18*

2.1.3 Core registers

The processor core register are:

Figure 2. Processor core registers

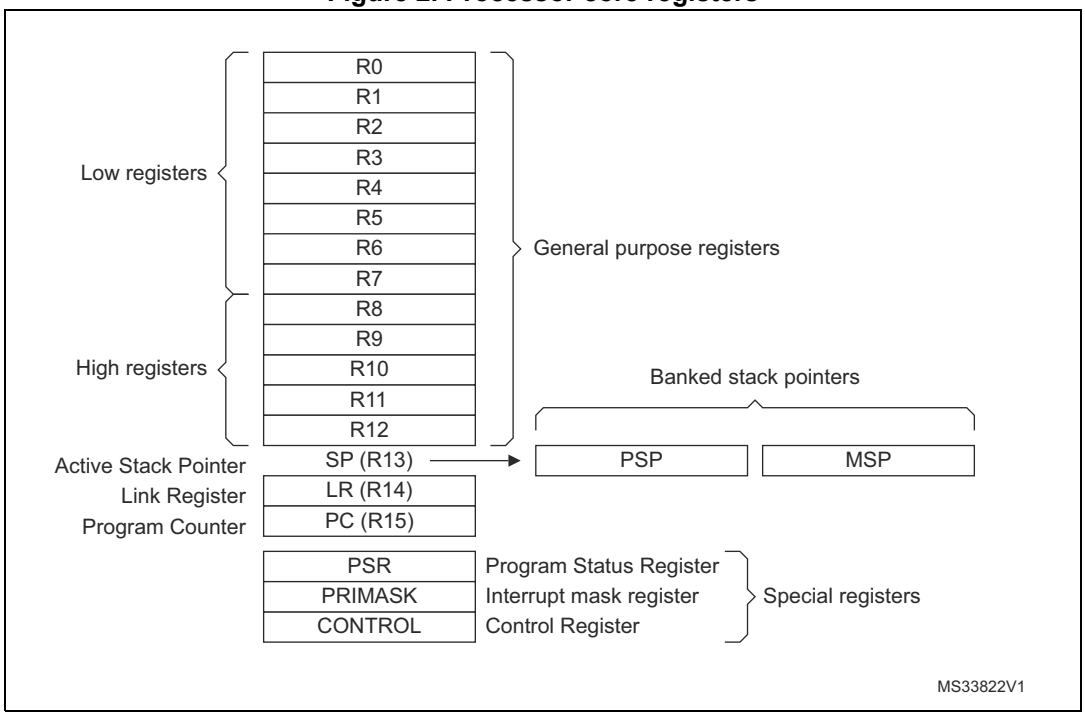


Table 2. Core register set summary

Name	Type(1)	Reset value	Description
R0-R12	RW	Unknown	*General purpose registers on page 14*.
MSP	RW	See description	*Stack Pointer on page 14*.
PSP	RW	Unknown	*Stack Pointer on page 14*
LR	RW	Unknown	*Link Register on page 14*
PC	RW	See description	*Program Counter on page 14*
PSR	RW	Unknown(2)	*Program Status Register on page 14*

Table 2. Core register set summary (continued)

APSR	RW	Unknown	*Application Program Status Register on page 15*
IPSR	RO	0x00000000	*Interrupt Program Status Register on page 16*
EPSR	RO	Unknown	*Execution Program Status Register on page 16*
PRIMASK	RW	0x00000000	*Priority Mask Register on page 17*
CONTROL	RW	0x00000000	*CONTROL register on page 18*

1. Describes access type during program execution in Thread mode and Handler mode. Debug access can differ.
2. Bit[24] is the T-bit and is loaded from bit[0] of the reset vector.

General purpose registers

R0-R12 are 32-bit general purpose registers for data operations.

Stack Pointer

The *Stack Pointer* (SP) is register R13. In Thread mode, bit[1] of the CONTROL register indicates the stack pointer to use:

- 0 = *Main Stack Pointer* (MSP). This is the reset value.
- 1 = *Process Stack Pointer* (PSP).

On reset, the processor loads the MSP with the value from address `0x00000000`.

Link Register

The *Link Register* (LR) is register R14. It stores the return information for subroutines, function calls, and exceptions. On reset, the LR value is Unknown.

Program Counter

The *Program Counter* (PC) is register R15. It contains the current program address. On reset, the processor loads the PC with the value of the reset vector, which is at address `0x00000004`. Bit[0] of the value is loaded into the EPSR T-bit at reset and must be 1.

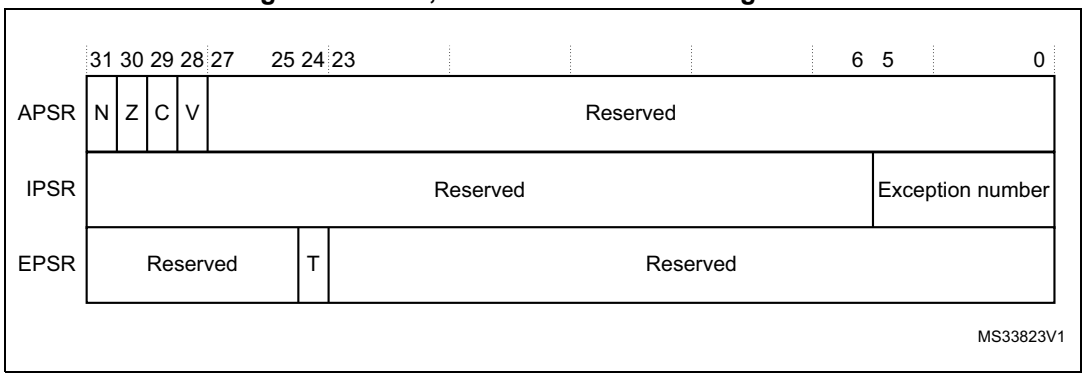
Program Status Register

The *Program Status Register* (PSR) combines:

- *Application Program Status Register* (APSR).
- *Interrupt Program Status Register* (IPSR).
- *Execution Program Status Register* (EPSR).

These registers are allocated as mutually exclusive bitfields within the 32-bit PSR. The PSR bit assignments are:

Figure 3. APSR, IPSR and EPSR bit assignments



Access these registers individually or as a combination of any two or all three registers, using the register name as an argument to the `MSR` or `MRS` instructions. For example:

- Read all of the registers using PSR with the MRS instruction.
- Write to the APSR using `APSR` with the `MSR` instruction.

The PSR combinations and attributes are:

Table 3. PSR register combinations

Register	Type	Combination
PSR	RW(1),(2)	APSR, EPSR, and IPSR.
IEPSR	RO	EPSR and IPSR.
IAPSR	RW(1)	APSR and IPSR.
EAPSR	RW(2)	APSR and EPSR.

1. The processor ignores writes to the IPSR bits.
2. Reads of the EPSR bits return zero, and the processor ignores writes to these bits.

See the instruction descriptions *MRS on page 74* and *MSR on page 75* for more information about how to access the program status registers.

Application Program Status Register

The APSR contains the current state of the condition flags, from previous instruction executions. See the register summary in *Table 2 on page 13* for its attributes. The bit assignments are:

Table 4. APSR bit assignment

Bits	Name	Description
[31]	N	Negative flag.
[30]	Z	Zero flag.
[29]	C	Carry or borrow flag.

Table 4. APSR bit assignment (continued)

Bits	Name	Description
[28]	V	Overflow flag.
[27:0]	-	Reserved.

See *The condition flags on page 43* for more information about the APSR negative, zero, carry or borrow, and overflow flags.

Interrupt Program Status Register

The IPSR contains the exception number of the current *Interrupt Service Routine* (ISR). See the register summary in *Table 2 on page 13* for its attributes. The bit assignments are:

Table 5. IPSR bit assignments

Bits	Name	Function
[31:6]	-	Reserved
[5:0]	Exception number	This is the number of the current exception: 0 = Thread mode. 1 = Reserved. 2 = NMI. 3 = HardFault. 4-10 = Reserved. 11 = SVCall. 12, 13 = Reserved. 14 = PendSV. 15 = SysTick | Reserved. 16 = IRQ0. . . 47 = IRQ31. 48-63 = Reserved. see *Exception types on page 26* for more information.

Execution Program Status Register

The EPSR contains the Thumb state bit.

See the register summary in *Table 2 on page 13* for the EPSR attributes. The bit assignments are:

Table 6. EPSR bit assignments

Bits	Name	Function
[31:25]	-	Reserved.
[24]	T	Thumb state bit.
[23:0]	-	Reserved.

Attempts by application software to read the EPSR directly using the `MRS` instruction always return zero. Attempts to write the EPSR using the `MRS` instruction are ignored. Fault handlers can examine the EPSR value in the stacked PSR to determine the cause of the fault. See *Exception entry and return on page 30*. The following can clear the T bit to 0:

- Instructions `BLX`, `BX` and `POP{PC}`.
- Restoration from the stacked xPSR value on an exception return.
- Bit[0] of the vector value on an exception entry.

Attempting to execute instructions when the T bit is 0 results in a HardFault or Lockup. See *2.4.1: Lockup on page 33* for more information.

Interruptible-restartable instructions

The interruptible-restartable instructions are `LDM` and `STM`, `PUSH`, `POP`, and `MULS`. When an interrupt occurs during the execution of one of these instructions, the processor abandons execution of the instruction. After servicing the interrupt, the processor restarts execution of the instruction from the beginning.

Exception mask register

The exception mask register disables the handling of exceptions by the processor. Disable exceptions where they might impact on timing critical tasks or code sequences requiring atomicity.

To disable or re-enable exceptions, use the `MSR` and `MRS` instructions, or the `CPS` instruction, to change the value of PRIMASK. *3.7.6: MRS on page 74*, *3.7.7: MSR on page 75*, and *3.7.2: CPS on page 70* for more information.

Priority Mask Register

The PRIMASK register prevents activation of all exceptions with configurable priority. See the register summary in *Table 2 on page 13* for its attributes. The bit assignments are:

Table 7. PRIMASK register bit assignments

Bits	Name	Function
[31:1]	-	Reserved.
[0]	PM	Prioritizable interrupt mask: 0 = No effect. 1 = Prevents the activation of all exceptions with configurable priority.

CONTROL register

The CONTROL register controls the stack used, and the privilege level for software execution, when the processor is in Thread mode. See the register summary in *Table 2 on page 13* for its attributes. The bit assignments are:

Figure 4. Control bit assignment

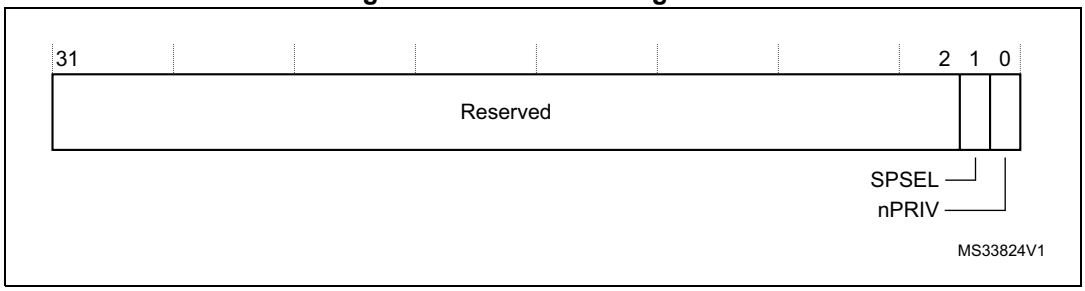


Table 8. Control register bit assignments

Bits	Name	Function
[31:2]	-	Reserved.
[1]	SPSEL	Defines the current stack: 0 = MSP is the current stack pointer. 1 = PSP is the current stack pointer. In Handler mode this bit reads as zero and ignores writes.
[0]	nPRIV	Defines the Thread mode privilege level: 0 = Privileged. 1 = Unprivileged.

Handler mode always uses the MSP, so the processor ignores explicit writes to the active stack pointer bit of the CONTROL register when in Handler mode. The exception entry and return mechanisms automatically update the CONTROL register.

In an OS environment, it is recommended that threads running in Thread mode use the process stack and the kernel and exception handlers use the main stack.

By default, Thread mode uses the MSP. To switch the stack pointer used in Thread mode to the PSP, use the `MSR` instruction to set the active stack pointer bit to 1, *3.7.6: MRS on page 74*

Note: When changing the stack pointer, software must use an ISB instruction immediately after the MSR instruction. This ensures that instructions after the ISB execute using the new stack pointer. See 3.7.5: ISB on page 73.

2.1.4 Exceptions and interrupts

The Cortex-M0+ processor supports interrupts and system exceptions. The processor and the *Nested vectored interrupt controller* (NVIC) prioritize and handle all exceptions. An interrupt or exception changes the normal flow of software control. The processor uses

Handler mode to handle all exceptions except for reset. See *Exception entry on page 31* and *Exception return on page 32* for more information.

The NVIC registers control interrupt handling. See *4.2: Nested vectored interrupt controller on page 82* for more information.

2.1.5 Data types

The processor:

- Supports the following data types:
  - 32-bit words.
  - 16-bit halfwords.
  - 8-bit bytes.
- Manages all data memory accesses as little-endian or big-endian. Instruction memory and *Private Peripheral Bus* (PPB) accesses are always little-endian. See *2.2.1: Memory regions, types and attributes on page 21* for more information.

2.1.6 The Cortex Microcontroller Software Interface Standard

Arm® provides the *Cortex Microcontroller Software Interface Standard* (CMSIS) for programming Cortex-M0+ microcontrollers. The CMSIS is an integrated part of the device driver library. For a Cortex-M0+ microcontroller system, CMSIS defines:

- A common way to:
  - Access peripheral registers.
  - Define exception vectors.
- The names of:
  - The registers of the core peripherals.
  - The core exception vectors.
- A device-independent interface for RTOS kernels.

The CMSIS includes address definitions and data structures for the core peripherals in the Cortex-M0+ processor. It also includes optional interfaces for middleware components comprising a TCP/IP stack and a Flash file system.

The CMSIS simplifies software development by enabling the reuse of template code, and the combination of CMSIS-compliant software components from various middleware vendors. Software vendors can expand the CMSIS to include their peripheral definitions and access functions for those peripherals.

This document includes the register names defined by the CMSIS, and gives short descriptions of the CMSIS functions that address the processor core and the core peripherals.

Note: This document uses the register short names defined by the CMSIS. In a few cases these differ from the architectural short names that might be used in other documents.

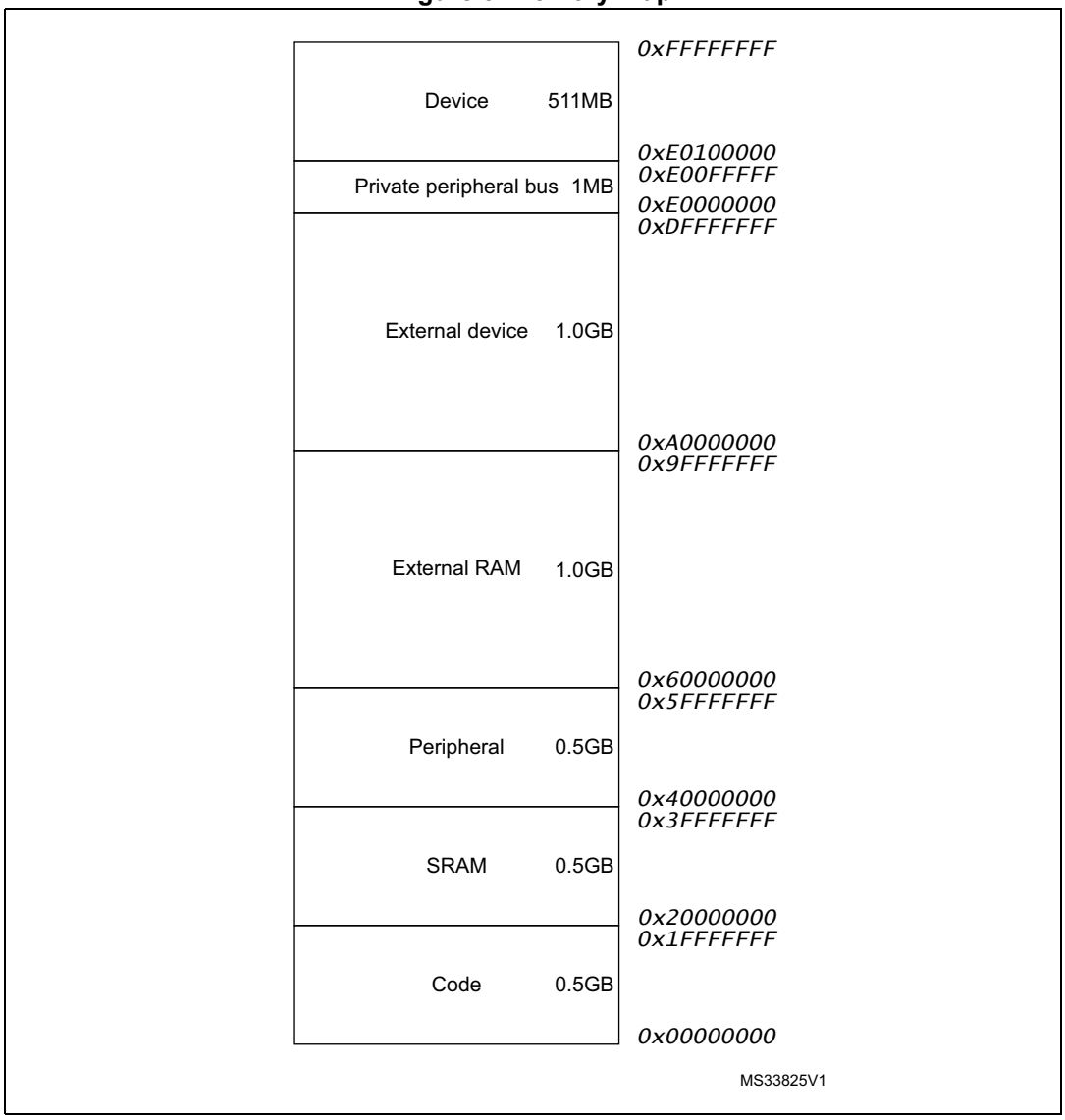
The following sections give more information about the CMSIS:

- *2.5.4: Power management programming hints on page 35*
- *3.2: Intrinsic functions on page 39*
- *4.2.1: Accessing the Cortex-M0+ NVIC registers using CMSIS on page 82*
- *NVIC programming hints on page 87*

2.2 Memory model

This section describes the processor memory map and the behavior of memory accesses. The processor has a fixed memory map that provides up to 4GB of addressable memory. The memory map is:

Figure 5. Memory map



The processor reserves regions of the *Private Peripheral Bus* (PPB) address range for core peripheral registers, see *1.3: About the Cortex-M0+ processor and core peripherals on page 9*.

2.2.1 Memory regions, types and attributes

The memory map and the programming of the MPU splits into regions. Each region has a defined memory type, and some regions have additional memory attributes. The memory type and attributes determine the behavior of accesses to the region.

The memory types are:

Normal	The processor can re-order transactions for efficiency, or perform speculative reads.
Device	The processor preserves transaction order relative to other transactions to Device or Strongly-ordered memory.
Strongly-ordered	The processor preserves transaction order relative to all other transactions.

The different ordering requirements for Device and Strongly-ordered memory mean that the memory system can buffer a write to Device memory, but must not buffer a write to Strongly-ordered memory.

The additional memory attributes include.

Shareable	For a shareable memory region, the memory system provides data synchronization between bus masters in a system with multiple bus masters, for example, a processor with a DMA controller. Strongly-ordered memory is always shareable. If multiple bus masters can access a non-shareable memory region, software must ensure data coherency between the bus masters. <This description is required only if the device is likely to be used in systems where memory is shared between multiple processors.>
Execute Never (XN)	Means the processor prevents instruction accesses. A HardFault exception is generated on executing an instruction fetched from an XN region of memory.

2.2.2 Memory system ordering of memory accesses

For most memory accesses caused by explicit memory access instructions, the memory system does not guarantee that the order in which the accesses complete matches the program order of the instructions, providing any re-ordering does not affect the behavior of the instruction sequence. Normally, if correct program execution depends on two memory accesses completing in program order, software must insert a memory barrier instruction between the memory access instructions, see *2.2.2: Memory system ordering of memory accesses on page 21*.

However, the memory system does guarantee some ordering of accesses to Device and Strongly-ordered memory. For two memory access instructions A1 and A2, if A1 occurs before A2 in program order, the ordering of the memory accesses caused by two instructions is:

Table 9. Ordering of memory accesses(1)

A1 \ A2	Normal access	Device access		Strongly-ordered access
		Non-shareable	Shareable	
Normal access	-	-	-	-
Device access, non-shareable	-	<	-	<
Device access, shareable	-	-	<	<
Strongly-ordered access	-	<	<	<

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1. - Means that the memory system does not guarantee the ordering of the accesses

   < Means that accesses are observed in program order, that is A1 is always observed before A2.

2.2.3 Behavior of memory accesses

The behavior of accesses to each region in the memory map is:

Table 10. Memory access behavior(1)

Address range	Memory region	Memory type	XN	Description
0x00000000-0x1FFFFFFF	Code	Normal	-	Executable region for program code. You can also put data here.
0x20000000-0x3FFFFFFF	SRAM	Normal	-	Executable region for data. You can also put code here.
0x40000000-0x5FFFFFFF	Peripheral	Device	XN	External device memory.
0x60000000-0x9FFFFFFF	External RAM	Normal	-	Executable region for data.
0xA0000000-0xDFFFFFFF	External device	Device	XN	External device memory.
0xE0000000-0xE00FFFFF	Private Peripheral Bus	Strongly- ordered	XN	This region includes the NVIC, System timer, and System Control Block. Only word accesses can be used in this region.

1. See *Memory regions, types and attributes on page 21* for more information.

The Code, SRAM, and external RAM regions can hold programs.

The MPU can override the default memory access behavior described in this section. For more information, see *4.5: Memory Protection Unit on page 98*.

2.2.4 Additional memory access constraints for caches and shared memory

When a system includes caches or shared memory, some memory regions have additional access constraints, and some regions are subdivided, as *Table 11* shows:

Table 11. Memory region shareability and cache policies

Address range	Memory region	Memory type(1)	Shareability(1)	Cache policy(2)
0x00000000-0x1FFFFFFF	Code	Normal	-	WT
0x20000000-0x3FFFFFFF	SRAM	Normal	-	WBWA
0x40000000-0x5FFFFFFF	Peripheral	Device	-	-
0x60000000-0x7FFFFFFF	External RAM	Normal	-	WBWA
0x80000000-0x9FFFFFFF				WT
0xA0000000-0xBFFFFFFF	External device	Device	Shareable	-
0xC0000000-0xDFFFFFFF			Non-shareable	
0xE0000000-0xE00FFFFF	Private Peripheral Bus	Strongly- ordered	Shareable	-
0xE0100000-0xFFFFFFFF	Device	Device	-	-

1. See *2.2.1: Memory regions, types and attributes on page 21* for more information.
2. WT = Write through, no write allocate. WBWA = Write back, write allocate.

2.2.5 Software ordering of memory accesses

The order of instructions in the program flow does not always guarantee the order of the corresponding memory transactions. This is because:

- The processor can reorder some memory accesses to improve efficiency, providing this does not affect the behavior of the instruction sequence.
- Memory or devices in the memory map might have different wait states.
- Some memory accesses are buffered or speculative.

Memory system ordering of memory accesses on page 21 describes the cases where the memory system guarantees the order of memory accesses. Otherwise, if the order of memory accesses is critical, software must include memory barrier instructions to force that ordering. The processor provides the following memory barrier instructions:

DMB — The Data Memory Barrier (DMB) instruction ensures that outstanding memory transactions complete before subsequent memory transactions. See *DMB on page 71*.

DSB — The Data Synchronization Barrier (DSB) instruction ensures that outstanding memory transactions complete before subsequent instructions execute. See *DSB on page 72*.

ISB — The Instruction Synchronization Barrier (ISB) ensures that the effect of all completed memory transactions is recognizable by subsequent instructions. See *ISB on page 73*.

The following are examples of using memory barrier instructions:

Vector table — If the program changes an entry in the vector table, and then enables the corresponding exception, use a DMB instruction between the operations. This ensures that if the exception is taken immediately after being enabled the processor uses the new exception vector.

Self-modifying code — If a program contains self-modifying code, use an ISB instruction immediately after the code modification in the program. This ensures subsequent instruction execution uses the updated program.

Memory map switching — If the system contains a memory map switching mechanism, use a DSB instruction after switching the memory map. This ensures subsequent instruction execution uses the updated memory map

MPU programming — Use a DSB followed by an ISB instruction or exception return to ensure that the new MPU configuration is used by subsequent instructions.

VTOR programming — If the program updates the value of the VTOR, use a DMB instruction to ensure that the new vector table is used for subsequent exceptions.

Memory accesses to Strongly-ordered memory, such as the System Control Block, do not require the use of `DMB` instructions.

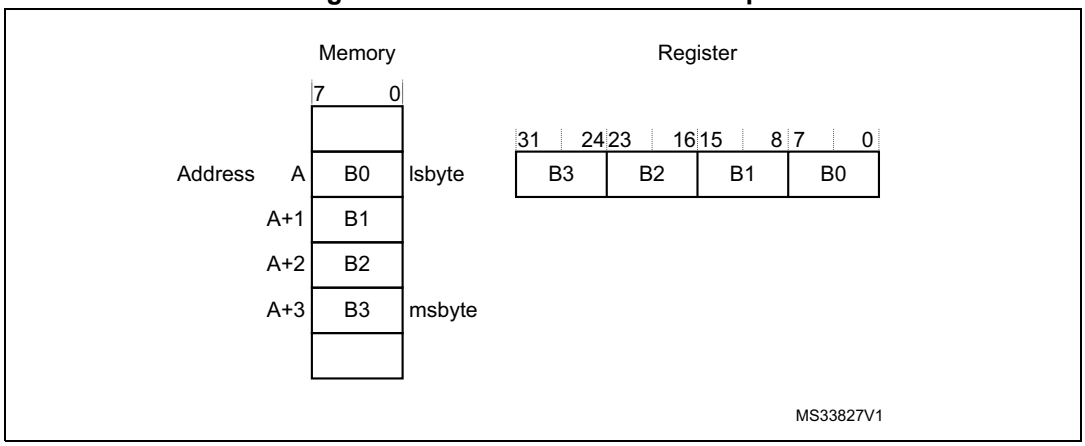
2.2.6 Memory endianness

The processor views memory as a linear collection of bytes numbered in ascending order from zero. For example, bytes 0-3 hold the first stored word, and bytes 4-7 hold the second stored word. *Little-endian format* describes how words of data are stored in memory.

Little-endian format

In little-endian format, the processor stores the least significant byte (lsbyte) of a word at the lowest-numbered byte, and the most significant byte (msbyte) at the highest-numbered byte. For example:

Figure 6. Little-endian format example



2.3 Exception model

This section describes the exception model.

2.3.1 Exception states

Each exception is in one of the following states:

Inactive The exception is not active and not pending.

Pending The exception is waiting to be serviced by the processor.

An interrupt request from a peripheral or from software can change the state of the corresponding interrupt to pending.

Active An exception that is being serviced by the processor but has not completed.

Note: An exception handler can interrupt the execution of another exception handler. In this case both exceptions are in the active state.

Active and pending The exception is being serviced by the processor and there is a pending exception from the same source.

2.3.2 Exception types

The exception types are:

Reset Reset is invoked on power up or a warm reset. The exception model treats reset as a special form of exception. When reset is asserted, the operation of the processor stops, potentially at any point in an instruction. When reset is deasserted, execution restarts from the address provided by the reset entry in the vector table. Execution restarts as privileged execution in Thread mode.

NMI A *NonMaskable Interrupt* (NMI) can be signalled by a peripheral or triggered by software. This is the highest priority exception other than reset. It is permanently enabled and has a fixed priority of -2. NMIs cannot be:

- Masked or prevented from activation by any other exception.
- Preempted by any exception other than Reset.

HardFault A HardFault is an exception that occurs because of an error during normal or exception processing. HardFaults have a fixed priority of -1, meaning they have higher priority than any exception with configurable priority.

SVCall A *Supervisor Call* (SVC) is an exception that is triggered by the `SVC` instruction. In an OS environment, applications can use `SVC` instructions to access OS kernel functions and device drivers.

PendSV PendSV is an interrupt-driven request for system-level service. In an OS environment, use PendSV for context switching when no other exception is active.

SysTick A SysTick exception is an exception the system timer generates when it reaches zero. Software can also generate a SysTick exception. In an OS environment, the processor can use this exception as system tick.

Interrupt (IRQ) An interrupt, or IRQ, is an exception signalled by a peripheral, or generated by a software request. All interrupts are asynchronous to instruction execution. In the system, peripherals use interrupts to communicate with the processor.

Table 12. Properties of the different exception types

Exception number(1)	IRQ number(1)	Exception type	Priority	Vector address(2)	Activation
1	-	Reset	-3, the highest	0x00000004	Asynchronous
2	-14	NMI	-2	0x00000008	Asynchronous
3	-13	HardFault	-1	0x0000000C	Synchronous
4-10	-	Reserved	-	-	-
11	-5	SVCall	Configurable(3)	0x0000002C	Synchronous
12-13	-	Reserved	-	-	-
14	-2	PendSV	Configurable(3)	0x00000038	Asynchronous
15	-1	SysTick	Configurable(3)	0x0000003C	Asynchronous
15	-	Reserved	-	-	-
16 and above	0 and above	Interrupt (IRQ)	Configurable(3)	0x00000040 and above(4)	Asynchronous

1. To simplify the software layer, the CMSIS only uses IRQ numbers. It uses negative values for exceptions other than interrupts. The IPSR returns the Exception number, see *Interrupt Program Status Register on page 16*
2. See *Figure 7.: Vector table on page 29* for more information.
3. See *4.2.6: Interrupt Priority Registers on page 85*
4. Increasing in steps of 4.

For an asynchronous exception, other than reset, the processor can execute additional instructions between when the exception is triggered and when the processor enters the exception handler.

Privileged software can disable the exceptions that *Table 12 on page 27* shows as having configurable priority, see *4.2.3: Interrupt Clear-enable Register on page 83*.

For more information about HardFaults, see *2.4: Fault handling on page 33*

2.3.3 Exception handlers

The processor handles exceptions using:

Interrupt Service Routines (ISRs) Interrupts IRQ0 to IRQ31 are the exceptions handled by ISRs

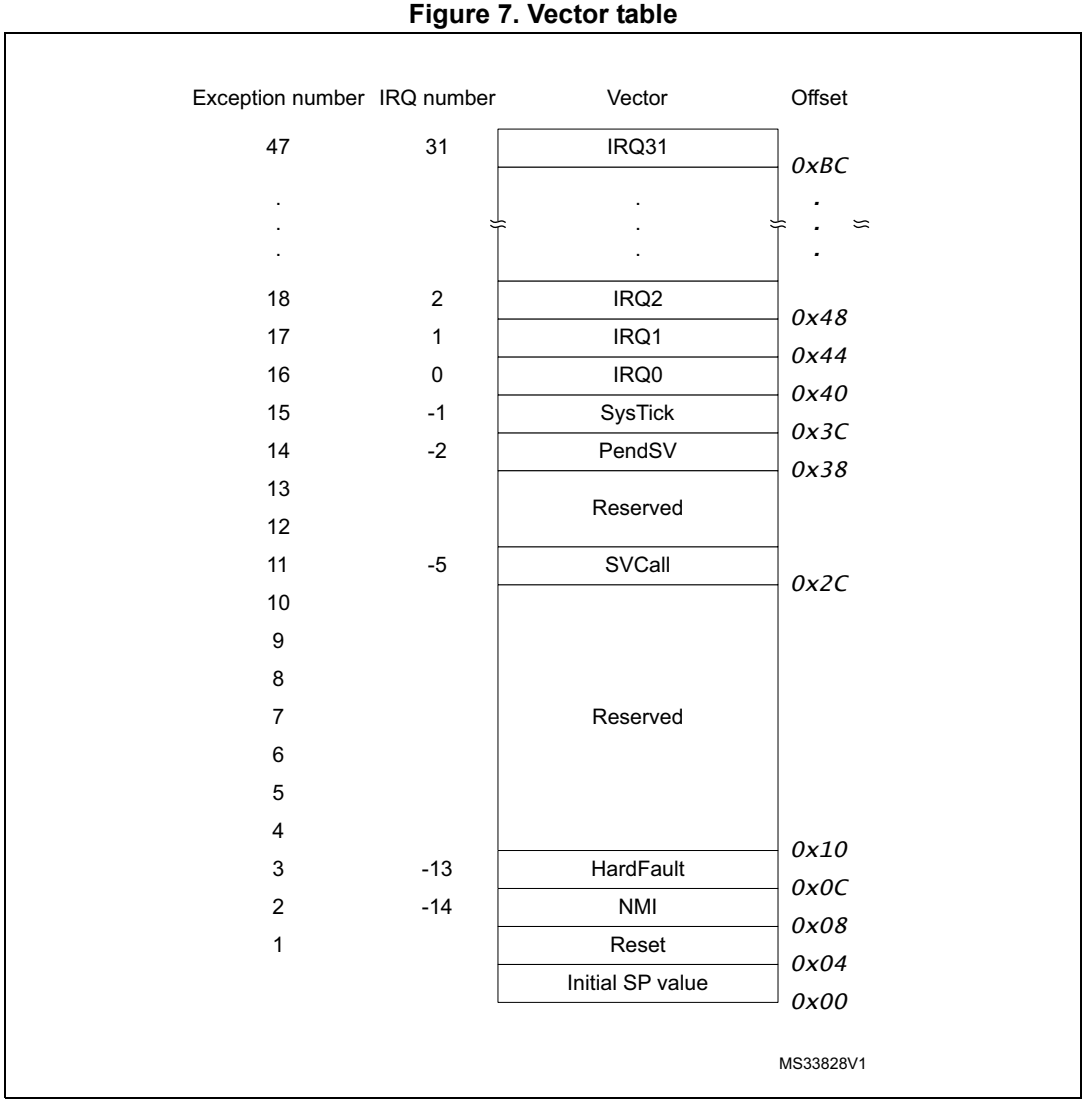
Fault handler HardFault is the only exception handled by the fault handler.

System handlers NMI, PendSV, SVCall SysTick, and HardFault are all system exceptions handled by system handlers.

2.3.4 Vector table

The vector table contains the reset value of the stack pointer, and the start addresses, also called exception vectors, for all exception handlers. *Figure 7 on page 29* shows the order of the exception vectors in the vector table. The least-significant bit of each vector must be 1, indicating that the exception handler is written in Thumb code.

Figure 7. Vector table



On system reset, the vector table is fixed at address `0x00000000`. Privileged software can write to the VTOR to relocate the vector table start address to a different memory location with the respect to vector table size and granularity of TBLOFF settings (see *Section 4.3.4: Vector Table Offset Register*).

2.3.5 Exception priorities

As *Table 12 on page 27* shows, all exceptions have an associated priority, with:

- A lower priority value indicating a higher priority.
- Configurable priorities for all exceptions except Reset, HardFault, and NMI.

If software does not configure any priorities, then all exceptions with a configurable priority have a priority of 0. For information about configuring exception priorities see

- *4.3.8: System Handler Priority Registers on page 94*
- *I4.2.6: Interrupt Priority Registers on page 85*.

Note: Configurable priority values are in the range 0-192, in steps of 64. The Reset, HardFault, and NMI exceptions, with fixed negative priority values, always have higher priority than any other exception.

Assigning a higher priority value to IRQ[0] and a lower priority value to IRQ[1] means that IRQ[1] has higher priority than IRQ[0]. If both IRQ[1] and IRQ[0] are asserted, IRQ[1] is processed before IRQ[0].

If multiple pending exceptions have the same priority, the pending exception with the lowest exception number takes precedence. For example, if both IRQ[0] and IRQ[1] are pending and have the same priority, then IRQ[0] is processed before IRQ[1].

When the processor is executing an exception handler, the exception handler is preempted if a higher priority exception occurs. If an exception occurs with the same priority as the exception being handled, the handler is not preempted, irrespective of the exception number. However, the status of the new interrupt changes to pending.

2.3.6 Exception entry and return

Descriptions of exception handling use the following terms:

Preemption When the processor is executing an exception handler, an exception can preempt the exception handler if its priority is higher than the priority of the exception being handled.

When one exception preempts another, the exceptions are called nested exceptions. See *Exception entry on page 31* for more information.

Return This occurs when the exception handler is completed, and:

- There is no pending exception with sufficient priority to be serviced.
- The completed exception handler was not handling a late-arriving exception.

The processor pops the stack and restores the processor state to the state it had before the interrupt occurred. See *Exception return on page 32* for more information.

Tail-chaining This mechanism speeds up exception servicing. On completion of an exception handler, if there is a pending exception that meets the requirements for exception entry, the stack pop is skipped and control transfers to the new exception handler.

Late-arriving This mechanism speeds up preemption. If a higher priority exception occurs during state saving for a previous exception, the processor switches to handle the higher priority exception and initiates the vector fetch for that exception. State saving is not affected by late arrival because the state saved would be the same for both exceptions. On return from the exception handler of the late-arriving exception, the normal tail-chaining rules apply.

Exception entry

Exception entry occurs when there is a pending exception with sufficient priority and either:

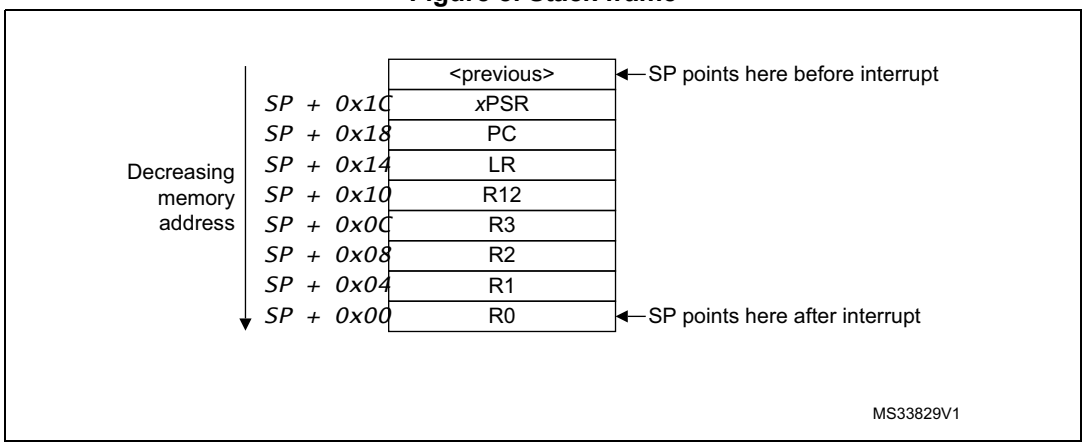
- The processor is in Thread mode.
- The new exception is of higher priority than the exception being handled, in which case the new exception preempts the exception being handled.

When one exception preempts another, the exceptions are nested.

Sufficient priority means the exception has greater priority than any limit set by the mask register, see *Exception mask register on page 17*. An exception with less priority than this is pending but is not handled by the processor.

When the processor takes an exception, unless the exception is a tail-chained or a late-arriving exception, the processor pushes information onto the current stack. This operation is referred to as *stacking* and the structure of eight data words is referred to as a *stack frame*. The stack frame contains the following information:

Figure 8. Stack frame



Immediately after stacking, the stack pointer indicates the lowest address in the stack frame. The stack frame is aligned to a double-word address.

The stack frame includes the return address. This is the address of the next instruction in the interrupted program. This value is restored to the PC at exception return so that the interrupted program resumes.

The processor performs a vector fetch that reads the exception handler start address from the vector table. When stacking is complete, the processor starts executing the exception

handler. At the same time, the processor writes an EXC_RETURN value to the LR. This indicates which stack pointer corresponds to the stack frame and what operation mode the processor was in before the entry occurred.

If no higher priority exception occurs during exception entry, the processor starts executing the exception handler and automatically changes the status of the corresponding pending interrupt to active.

If another higher priority exception occurs during exception entry, the processor starts executing the exception handler for this exception and does not change the pending status of the earlier exception. This is the late arrival case.

Exception return

Exception return occurs when the processor is in Handler mode and execution of one of the following instructions attempts to set the PC to an EXC_RETURN value:

- A `POP` instruction that loads the PC.
- B `PBX` instruction using any register.

The processor saves an EXC_RETURN value to the LR on exception entry. The exception mechanism relies on this value to detect when the processor has completed an exception handler. Bits[31:4] of an EXC_RETURN value are `0xFFFFFFF`. When the processor loads a value matching this pattern to the PC it detects that the operation is a not a normal branch operation and, instead, that the exception is complete. As a result, it starts the exception return sequence. Bits[3:0] of the EXC_RETURN value indicate the required return stack and processor mode, as *Table 13 on page 32* shows.

Table 13. Exception return behavior

EXC_RETURN	Description
`0xFFFFFF1`	Return to Handler mode. Exception return gets state from the main stack. Execution uses MSP after return.
`0xFFFFFF9`	Return to Thread mode. Exception return gets state from MSP. Execution uses MSP after return.
`0xFFFFFFD`	Return to Thread mode. Exception return gets state from PSP. Execution uses PSP after return.
All other values	Reserved.

2.4 Fault handling

Faults are a subset of exceptions, see *2.3: Exception model on page 26*. All faults result in the HardFault exception being taken or cause Lockup if they occur in the NMI or HardFault handler. The faults are:

- Execution of an `SVC` instruction at a priority equal or higher than SVCall.
- Execution of a `BKPT` instruction without a debugger attached.
- A system-generated bus error on a load or store.
- Execution of an instruction from an XN memory address.
- Execution of an instruction from a location for which the system generates a bus fault.
- A system-generated bus error on a vector fetch.
- Execution of an Undefined instruction.
- Execution of an instruction when not in Thumb state as a result of the T-bit being previously cleared to 0.
- An attempted load or store to an unaligned address.
- An MPU fault because of a privilege violation or an attempt to access an unmanaged region.

Note: Only Reset and NMI can preempt the fixed priority HardFault handler. A HardFault can preempt any exception other than Reset, NMI, or another HardFault.

2.4.1 Lockup

The processor enters a Lockup state if a fault occurs when executing the NMI or HardFault handlers, or if the system generates a bus error when unstacking the PSR on an exception return using the MSP. When the processor is in Lockup state it does not execute any instructions. The processor remains in Lockup state until one of the following occurs:

- It is reset.
- A debugger halts it.
- An NMI occurs and the current Lockup is in the HardFault handler.

Note: If Lockup state occurs in the NMI handler a subsequent NMI does not cause the processor to leave Lockup state.

2.5 Power management

The Cortex-M0+ processor sleep modes reduce power consumption:

- A sleep mode, that stops the processor clock.
- A deep sleep mode, that enters ultra low-power modes.

The SLEEPDEEP bit of the SCR selects which sleep mode is used, see *4.3.6: System Control Register on page 92*. When entering the deep sleep mode, the PDSS bit in

PWR_CR register will select entry in Stop or Standby mode, see the reference manual chapter "low-power modes" for details.

This section describes the mechanisms for entering sleep mode, and the conditions for waking up from sleep mode.

2.5.1 Entering sleep mode

This section describes the mechanisms software can use to put the processor into sleep mode.

The system can generate spurious wakeup events, for example a debug operation wakes up the processor. For this reason, software must be able to put the processor back into sleep mode after such an event. A program might have an idle loop to put the processor back in to sleep mode.

Wait for interrupt

The Wait For Interrupt instruction, `WFI`, causes immediate entry to sleep mode. When the processor executes a `WFI` instruction it stops executing instructions and enters sleep mode. See *3.7.12: WFI on page 80* for more information.

Wait for event

The Wait For Event instruction, `WFE`, causes entry to sleep mode conditional on the value of a one-bit event register. When the processor executes a `WFE` instruction, it checks the value of the event register:

0 The processor stops executing instructions and enters sleep mode.

1 The processor sets the register to zero and continues executing instructions without entering sleep mode.

See *3.7.11: WFE on page 79* for more information.

If the event register is 1, this indicates that the processor must not enter sleep mode on execution of a `WFE` instruction. Typically, this is because of the assertion of an external event, or because another processor in the system has executed a `SEV` instruction, see *3.7.9: SEV on page 77*. Software cannot access this register directly.

Sleep-on-exit

If the SLEEPONEXIT bit of the SCR is set to 1, when the processor completes the execution of an exception handler and returns to Thread mode it immediately enters sleep mode. Use this mechanism in applications that only require the processor to run when an interrupt occurs.

2.5.2 Wakeup from sleep mode

The conditions for the processor to wakeup depend on the mechanism that caused it to enter sleep mode.

Wakeup from WFI or sleep-on-exit

Normally, the processor wakes up only when it detects an exception with sufficient priority to cause exception entry.

Some embedded systems might have to execute system restore tasks after the processor wakes up, and before it executes an interrupt handler. To achieve this set the PRIMASK.PM bit to 1. If an interrupt arrives that is enabled and has a higher priority than current exception priority, the processor wakes up but does not execute the interrupt handler until the processor sets PRIMASK.PM to zero. For more information about PRIMASK, see *Exception mask register on page 17*.

Wakeup from WFE

The processor wakes up if:

- It detects an exception with sufficient priority to cause exception entry.
- It detects an external event signal, see *2.5.3: The external event input on page 35*.
- In a multiprocessor system, another processor in the system executes a `SEV` instruction.

In addition, if the SEVONPEND bit in the SCR is set to 1, any new pending interrupt triggers an event and wakes up the processor, even if the interrupt is disabled or has insufficient priority to cause exception entry. For more information about the SCR, see *4.3.6: System Control Register on page 92*.

2.5.3 The external event input

The processor provides an external event input signal. This signal can be generated by peripherals. Tie this signal LOW if it is not used.

This signal can wakeup the processor from WFE, or set the internal WFE event register to one to indicate that the processor must not enter sleep mode on a later `WFE` instruction, see *Wait for event on page 34*.

2.5.4 Power management programming hints

ISO/IEC C cannot directly generate the `WFI`, `WFE`, and `SEV` instructions. The CMSIS provides the following intrinsic functions for these instructions:

```
void __WFE(void) // Wait for Event
void __WFI(void) // Wait for Interrupt
void __SEV(void) // Send Event
```

3 Cortex-M0+ instruction set

3.1 Instruction set summary

The processor implements a version of the Thumb instruction set. *Table 14* lists the supported instructions.

In *Table 14*

- Angle brackets, <>, enclose alternative forms of the operand.
- Braces, {}, enclose optional operands and mnemonic parts.
- The Operands column is not exhaustive.

For more information on the instructions and operands, see the instruction descriptions.

Table 14. Cortex-M0+ instructions

Mnemonic	Operands	Brief description	Flags	Section
ADCS	`{Rd,} Rn, Rm`	Add with Carry	N,Z,C,V	*3.5.1 on page 54*.
ADD{S}	`{Rd,} Rn, <Rm|#imm>`	Add	N,Z,C,V	*3.5.1 on page 54*.
ADR	`Rd, label`	PC-relative Address to Register	-	*3.4.1 on page 46*.
ANDS	`{Rd,} Rn, Rm`	Bitwise AND	N,Z	*3.5.2 on page 56*.
ASRS	`{Rd,} Rm, <Rs|#imm>`	Arithmetic Shift Right	N,Z,C	*3.5.3 on page 57*.
B{cc}	`label`	Branch {conditionally}	-	*3.6.1 on page 66*.
BICS	`{Rd,} Rn, Rm`	Bit Clear	N,Z	*3.5.2 on page 56*.
BKPT	`#imm`	Breakpoint	-	*3.7.1 on page 69*.
BL	`label`	Branch with Link	-	*3.6.1 on page 66*.
BLX	`Rm`	Branch indirect with Link	-	*3.6.1 on page 66*.
BX	`Rm`	Branch indirect	-	*3.6.1 on page 66*.
CMN	`Rn, Rm`	Compare Negative	N,Z,C,V	*3.5.4 on page 59*.
CMP	`Rn, <Rm|#imm>`	Compare	N,Z,C,V	*3.5.4 on page 59*.
CPSID	`i`	Change Processor State, Disable Interrupts	-	*3.7.2 on page 70*.
CPSIE	`i`	Change Processor State, Enable Interrupts	-	*3.7.2 on page 70*.
DMB	-	Data Memory Barrier	-	*3.7.3 on page 71*.
DSB	-	Data Synchronization Barrier	-	*3.7.4 on page 72*.
EORS	`{Rd,} Rn, Rm`	Exclusive OR	N,Z	*3.5.2 on page 56*.

Table 14. Cortex-M0+ instructions (continued)

Mnemonic	Operands	Brief description	Flags	Section
ISB	–	Instruction Synchronization Barrier	-	3.7.5 on page 73.
LDM	`Rn{!}, reglist`	Load Multiple registers, increment after	-	3.4.5 on page 50.
LDR	`Rt, label`	Load Register from PC-relative address	-	3.4.2 on page 47.
LDR	`Rt, [Rn, <Rm|#imm>]`	Load Register with word	-	3.4.2 on page 47.
LDRB	`Rt, [Rn, <Rm|#imm>]`	Load Register with byte	-	3.4.2 on page 47.
LDRH	`Rt, [Rn, <Rm|#imm>]`	Load Register with halfword	-	3.4.2 on page 47.
LDRSB	`Rt, [Rn, <Rm|#imm>]`	Load Register with signed byte	-	3.4.2 on page 47.
LDRSH	`Rt, [Rn, <Rm|#imm>]`	Load Register with signed halfword	-	3.4.2 on page 47.
LSLS	`{Rd,} Rn, <Rs|#imm>`	Logical Shift Left	N,Z,C	3.5.3 on page 57.
LSRS	`{Rd,} Rn, <Rs|#imm>`	Logical Shift Right	N,Z,C	3.5.3 on page 57.
MOV{S}	`Rd, Rm`	Move	N,Z	3.5.5 on page 60.
MRS	`Rd, spec_reg`	Move to general register from special register	-	3.7.6 on page 74.
MSR	`spec_reg, Rm`	Move to special register from general register	N,Z,C,V	3.7.7 on page 75.
MULS	`Rd, Rn, Rm`	Multiply, 32-bit result	N,Z	3.5.6 on page 61.
MVNS	`Rd, Rm`	Bitwise NOT	N,Z	3.5.5 on page 60.
NOP	–	No Operation	-	3.7.8 on page 76.
ORRS	`{Rd,} Rn, Rm`	Logical OR	N,Z	3.5.2 on page 56.
POP	`reglist`	Pop registers from stack	-	3.4.6 on page 52.
PUSH	`reglist`	Push registers onto stack	-	3.4.6 on page 52.
REV	`Rd, Rm`	Byte-Reverse word	-	3.5.7 on page 62.
REV16	`Rd, Rm`	Byte-Reverse packed halfwords	-	3.5.7 on page 62.
REVSH	`Rd, Rm`	Byte-Reverse signed halfword	-	3.5.7 on page 62.
RORS	`{Rd,} Rn, Rs`	Rotate Right	N,Z,C	3.5.3 on page 57.

Table 14. Cortex-M0+ instructions (continued)

Mnemonic	Operands	Brief description	Flags	Section
RSBS	*{Rd,} Rn, #0*	Reverse Subtract	N,Z,C,V	*3.5.1 on page 54*.
SBCS	*{Rd,} Rn, Rm*	Subtract with Carry	N,Z,C,V	*3.5.1 on page 54*.
SEV	-	Send Event	-	*3.7.9 on page 77*.
STM	*Rn!, reglist*	Store Multiple registers, increment after	-	*3.4.5 on page 50*.
STR	*Rt, [Rn, <Rm|#imm>]*	Store Register as word	-	*3.4.2 on page 47*.
STRB	*Rt, [Rn, <Rm|#imm>]*	Store Register as byte	-	*3.4.2 on page 47*.
STRH	*Rt, [Rn, <Rm|#imm>]*	Store Register as halfword	-	*3.4.2 on page 47*.
SUB{S}	*{Rd,} Rn, <Rm|#imm>*	Subtract	N,Z,C,V	*3.5.1 on page 54*.
SVC	*#imm*	Supervisor Call	-	*3.7.10 on page 78*.
SXTB	*Rd, Rm*	Sign extend byte	-	*3.5.8 on page 63*.
SXTH	*Rd, Rm*	Sign extend halfword	-	*3.5.8 on page 63*.
TST	*Rn, Rm*	Logical AND based test	N,Z	*3.5.9 on page 64*.
UXTB	*Rd, Rm*	Zero extend a byte	-	*3.5.8 on page 63*.
UXTH	*Rd, Rm*	Zero extend a halfword	-	*3.5.8 on page 63*.
WFE	-	Wait For Event	-	*3.7.11 on page 79*.
WFI	-	Wait For Interrupt	-	*3.7.12 on page 80*.

3.2 Intrinsic functions

ISO/IEC C code cannot directly access some Cortex-M0+ instructions. This section describes intrinsic functions that can generate these instructions, provided by the CMSIS and that might be provided by a C compiler. If a C compiler does not support an appropriate intrinsic function, you might have to use inline assembler to access the relevant instruction.

The CMSIS provides the following intrinsic functions to generate instructions that ISO/IEC C code cannot directly access:

Table 15. CMSIS intrinsic functions to generate some Cortex-M0+ instructions

Instruction	CMSIS intrinsic function
`CPSIE i`	`void __enable_irq(void)`
`CPSID i`	`void __disable_irq(void)`
`ISB`	`void __ISB(void)`
`DSB`	`void __DSB(void)`
`DMB`	`void __DMB(void)`
`NOP`	`void __NOP(void)`
`REV`	`uint32_t __REV(uint32_t int value)`
`REV16`	`uint32_t __REV16(uint32_t int value)`
`REVSH`	`uint32_t __REVSH(uint32_t int value)`
`SEV`	`void __SEV(void)`
`WFE`	`void __WFE(void)`
`WFI`	`void __WFI(void)`

The CMSIS also provides a number of functions for accessing the special registers using `MRS` and `MSR` instructions

Table 16. CMSIS intrinsic functions to access the special registers

Special register	Access	CMSIS function
PRIMASK	Read	`uint32_t __get_PRIMASK (void)`
	Write	`void __set_PRIMASK (uint32_t value)`
CONTROL	Read	`uint32_t __get_CONTROL (void)`
	Write	`void __set_CONTROL (uint32_t value)`
MSP	Read	`uint32_t __get_MSP (void)`
	Write	`void __set_MSP (uint32_t TopOfMainStack)`
PSP	Read	`uint32_t __get_PSP (void)`
	Write	`void __set_PSP (uint32_t TopOfProcStack)`

3.3 About the instruction descriptions

The following sections give more information about using the instructions:

- *Operands*.
- *Restrictions when using PC or SP*.
- *Shift operations*.
- *Address alignment*.
- *PC-relative expressions*.
- *Conditional execution*.

3.3.1 Operands

An instruction operand can be an Arm® register, a constant, or another instruction-specific parameter. Instructions act on the operands and often store the result in a destination register. When there is a destination register in the instruction, it is usually specified before the other operands.

3.3.2 Restrictions when using PC or SP

Many instructions are unable to use, or have restrictions on whether you can use, the *Program Counter* (PC) or *Stack Pointer* (SP) for the operands or destination register. See instruction descriptions for more information.

Note: When you update the PC with a `BX`*,* `BLX`*, or* `POP` *instruction, bit[0] of any address must be 1 for correct execution. This is because this bit indicates the destination instruction set, and the Cortex-M0+ processor only supports Thumb instructions. When a* `BL` *or* `BLX` *instruction writes the value of bit[0] into the LR it is automatically assigned the value 1.*

3.3.3 Shift operations

Register shift operations move the bits in a register left or right by a specified number of bits, the *shift length*. Register shift can be performed directly by the instructions `ASR`, `LSR`, `LSL`, and `ROR` and the result is written to a destination register.

The permitted shift lengths depend on the shift type and the instruction, see the individual instruction description. If the shift length is 0, no shift occurs. Register shift operations update the carry flag except when the specified shift length is 0. The following sub-sections describe the various shift operations and how they affect the carry flag. In these descriptions, *Rm* is the register containing the value to be shifted, and *n* is the shift length.

ASR

Arithmetic shift right by *n* bits moves the left-hand *32-n* bits of the register *Rm*, to the right by *n* places, into the right-hand *32-n* bits of the result, and it copies the original bit[31] of the register into the left-hand *n* bits of the result. See *Figure 9 on page 41*.

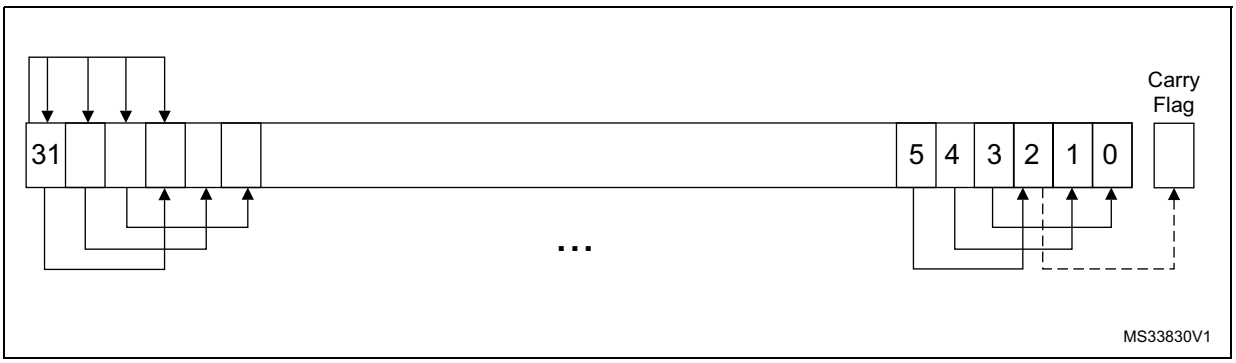
You can use the *ASR* operation to divide the signed value in the register *Rm* by 2^n, with the result being rounded towards negative-infinity.

When the instruction is *ASRS* the carry flag is updated to the last bit shifted out, bit[*n-1*], of the register *Rm*

Note: If n is 32 or more, then all the bits in the result are cleared to 0.

If n is 33 or more and the carry flag is updated, it is updated to 0.

Figure 9. ASR#3



LSR

Logical shift right by n bits moves the left-hand *32-n* bits of the register *Rm*, to the right by n places, into the right-hand *32-n* bits of the result, and it sets the left-hand n bits of the result to 0. See *Figure 10 on page 41*.

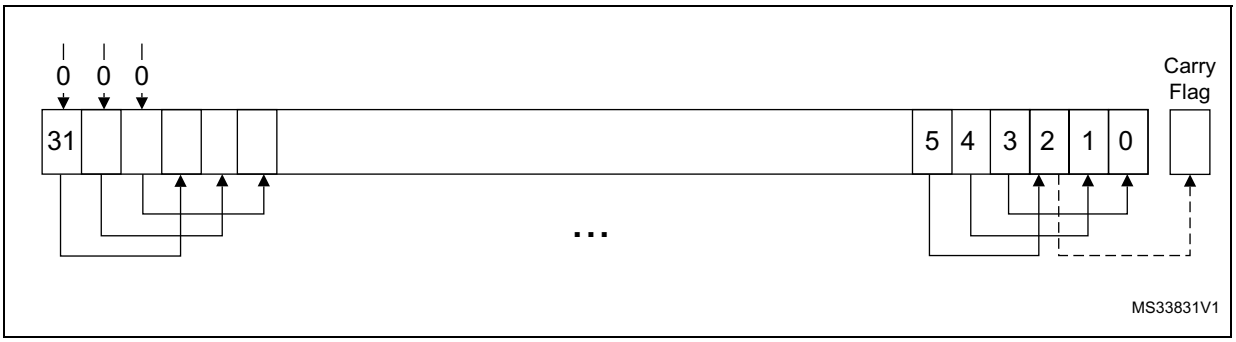
You can use the LSR operation to divide the value in the register *Rm* by 2^n, if the value is regarded as an unsigned integer.

When the instruction is LSRS, the carry flag is updated to the last bit shifted out, bit[n-1], of the register *Rm*.

Note: If n is 32 or more, then all the bits in the result are cleared to 0.

If n is 33 or more and the carry flag is updated, it is updated to 0.

Figure 10. LSR#3



LSL

Logical shift left by *n* bits moves the right-hand *32-n* bits of the register *Rm*, to the left by n places, into the left-hand *32-n* bits of the result, and it sets the right-hand n bits of the result to 0. See *Figure 11 on page 42*.

You can use the LSL operation to multiply the value in the register *Rm* by 2^n, if the value is regarded as an unsigned integer or a two's complement signed integer. Overflow can occur without warning.

When the instruction is LSLS the carry flag is updated to the last bit shifted out, bit[*32-n*], of the register *Rm*. These instructions do not affect the carry flag when used with *LSL#0*.

Note: If n is 32 or more, then all the bits in the result are cleared to 0.

If n is 33 or more and the carry flag is updated, it is updated to 0.

Figure 11. LSL #3

ROR

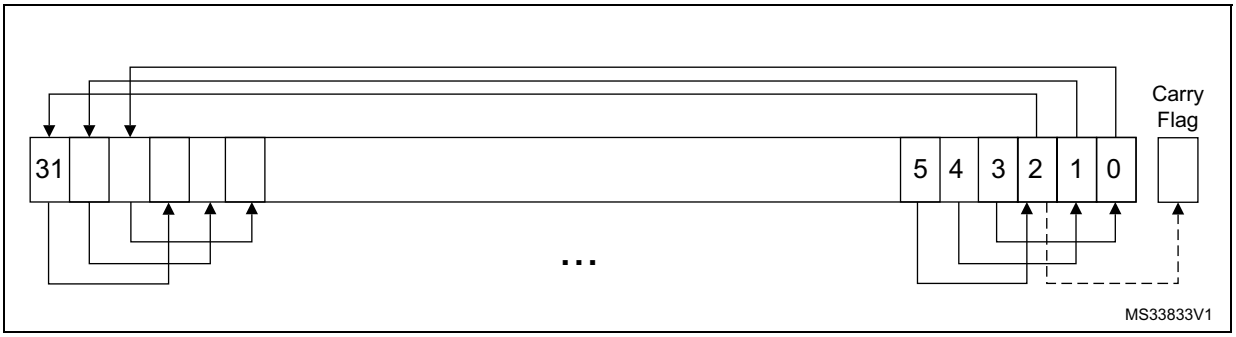
Rotate right by *n* bits moves the left-hand *32−n*bits of the register *Rm*, to the right by *n* places, into the right-hand *32−n* bits of the result, and it moves the right-hand *n* bits of the register into the left-hand *n* bits of the result. See *Figure 12 on page 42*.

When the instruction is RORS the carry flag is updated to the last bit rotation, bit[*n*-1], of the register *Rm*.

Note: If n is 32, then the value of the result is same as the value in Rm, and if the carry flag is updated, it is updated to bit[31] of Rm.

If ROR with shift length, n, greater than 32 is the same as ROR with shift length n-32

Figure 12. ROR #3



3.3.4 Address alignment

An aligned access is an operation where a word-aligned address is used for a word, or multiple word access, or where a halfword-aligned address is used for a halfword access. Byte accesses are always aligned.

There is no support for unaligned accesses on the Cortex-M0+ processor. Any attempt to perform an unaligned memory access operation results in a HardFault exception.

3.3.5 PC-relative expressions

A PC-relative expression or *label* is a symbol that represents the address of an instruction or literal data. It is represented in the instruction as the PC value plus or minus a numeric offset. The assembler calculates the required offset from the label and the address of the current instruction. If the offset is too big, the assembler produces an error.

Note: For most instructions, the value of the PC is the address of the current instruction plus 4 bytes.

Your assembler might permit other syntaxes for PC-relative expressions, such as a label plus or minus a number, or an expression of the form `[PC,#imm]`.

3.3.6 Conditional execution

Most data processing instructions update the condition flags in the *Application Program Status Register* (APSR) according to the result of the operation, see *Application Program Status Register on page 15*. Some instructions update all flags, and some only update a subset. If a flag is not updated, the original value is preserved. See the instruction descriptions for the flags they affect.

You can execute a conditional branch instruction, based on the condition flags set in another instruction, either:

- Immediately after the instruction that updated the flags.
- After any number of intervening instructions that have not updated the flags.

On the Cortex-M0+ processor, conditional execution is available by using conditional branches.

This section describes:

- *The condition flags on page 43*.
- *Condition code suffixes on page 44*.

The condition flags

The APSR contains the following condition flags:

N	Set to 1 when the result of the operation was negative, cleared to 0 otherwise
Z	Set to 1 when the result of the operation was zero, cleared to 0 otherwise.
C	Set to 1 when the operation resulted in a carry, cleared to 0 otherwise.
V	Set to 1 when the operation caused overflow, cleared to 0 otherwise.

For more information about the APSR see *Program Status Register on page 14*.

A carry occurs:

- If the result of an addition is greater than or equal to 2^{32}.
- If the result of a subtraction is positive or zero.
- As the result of a shift or rotate instruction.

Overflow occurs when the sign of the result, in bit[31], does not match the sign of the result had the operation been performed at infinite precision, for example:

- If adding two negative values results in a positive value.
- If adding two positive values results in a negative value.
- If subtracting a positive value from a negative value generates a positive value.
- If subtracting a negative value from a positive value generates a negative value.

The Compare operations are identical to subtracting, for `CMP`, or adding, for `CMN`, except that the result is discarded. See the instruction descriptions for more information.

Condition code suffixes

Conditional branch is shown in syntax descriptions as `B{cond}`. A branch instruction with a condition code is only taken if the condition code flags in the APSR meet the specified condition, otherwise the branch instruction is ignored. *Table 17* shows the condition codes to use.

Table 17 also shows the relationship between condition code suffixes and the N, Z, C, and V flags

Table 17. Condition code suffixes

Suffix	Flags	Meaning
`EQ`	Z = 1	Equal, last flag setting result was zero.
`NE`	Z = 0	Not equal, last flag setting result was non-zero.
`CS or HS`	C = 1	Higher or same, unsigned.
`CC or LO`	C = 0	Lower, unsigned.
`MI`	N = 1	Negative.
`PL`	N = 0	Positive or zero.
`VS`	V = 1	Overflow.
`VC`	V = 0	No overflow.
`HI`	C = 1 and Z = 0	Higher, unsigned.
`LS`	C = 0 or Z = 1	Lower or same, unsigned.
`GE`	N = V	Greater than or equal, signed.
`LT`	N != V	Less than, signed.
`GT`	Z = 0 and N = V	Greater than, signed.
`LE`	Z = 1 or N != V	Less than or equal, signed.
`AL`	Can have any value	Always. This is the default when no suffix is specified.

3.4 Memory access instructions

Table 18 shows the memory access instructions

Table 18. Memory access instructions

Mnemonic	Brief description	See
ADR	Generate PC-relative address	*3.4.1: ADR on page 46*.
LDM	Load Multiple registers	*3.4.5: LDM and STM on page 50*.
LDR{type}	Load Register using immediate offset	*3.4.2: LDR and STR, immediate offset on page 47*.
LDR{type}	Load Register using register offset	*3.4.3: LDR and STR, register offset on page 48*.
LDR	Load Register from PC-relative address	*3.4.4: LDR, PC-relative on page 49*.
POP	Pop registers from stack	*3.4.6: PUSH and POP on page 52*.
PUSH	Push registers onto stack	*3.4.6: PUSH and POP on page 52*.
STM	Store Multiple registers	*3.4.5: LDM and STM on page 50*.
STR{type}	Store Register using immediate offset	*3.4.2: LDR and STR, immediate offset on page 47*.
STR{type}	Store Register using register offset	*3.4.3: LDR and STR, register offset on page 48*.

3.4.1 ADR

Generates a PC-relative address.

Syntax

`ADR Rd, label`

where:

`Rd` Is the destination register.

`label` Is a PC-relative expression. See *3.3.5: PC-relative expressions on page 43*.

Operation

`ADR` generates an address by adding an immediate value to the PC, and writes the result to the destination register.

`ADR` facilitates the generation of position-independent code, because the address is PC-relative.

If you use `ADR` to generate a target address for a `BX` or `BLX` instruction, you must ensure that bit[0] of the address you generate is set to 1 for correct execution.

Restrictions

In this instruction *Rd* must specify R0-R7. The data-value addressed must be word aligned and within 1020 bytes of the current PC.

Condition flags

This instruction does not change the flags.

Examples

```
ADR R1, TextMessage ; Write address value of a location labelled as;
TextMessage to R1
ADR R3, [PC,#996]   ; Set R3 to value of PC + 996.
```

3.4.2 LDR and STR, immediate offset

Load and Store with immediate offset.

Syntax

```
LDR Rt, [<Rn | SP> {, #imm}]
LDR<B|H> Rt, [Rn {, #imm}]
STR Rt, [<Rn | SP>, {,#imm}]
STR<B|H> Rt, [Rn {,#imm}]
```

where:

Rt	Is the register to load or store.
Rn	Is the register on which the memory address is based
imm	Is an offset from *Rn*. If *imm* is omitted, it is assumed to be zero.

Operation

LDR, LDRB and LDRH instructions load the register specified by *Rt* with either a word, byte or halfword data value from memory. Sizes less than word are zero extended to 32-bits before being written to the register specified by *Rt*.

STR, STRB and STRH instructions store the word, least-significant byte or lower halfword contained in the single register specified by *Rt* in to memory. The memory address to load from or store to is the sum of the value in the register specified by either *Rn* or SP and the immediate value *imm*.

Restrictions

In these instructions:

- *Rt* and *Rn* must only specify R0-R7.
- *imm* must be between:
  - 0 and 1020 and an integer multiple of four for LDR and STR using SP as the base register.
  - 0 and 124 and an integer multiple of four for LDR and STR using R0-R7 as the base register.
  - 0 and 62 and an integer multiple of two for LDRH and STRH.
  - 0 and 31 for LDRB and STRB.
- The computed address must be divisible by the number of bytes in the transaction, see *3.3.4: Address alignment on page 42*.

Condition flags

These instructions do not change the flags.

Examples

```
   LDR R4, [R7 ; Loads R4 from the address in R7.
STR R2,[R0,#const-struc] ; const-struc is an expression evaluating
     ; to a constant in the range 0-1020.
```

3.4.3 LDR and STR, register offset

Load and Store with register offset.

Syntax

```
LDR Rt, [Rn, Rm]
LDR<B|H> Rt, [Rn, Rm]
LDR<SB|SH> Rt, [Rn, Rm]
STR Rt, [Rn, Rm]
STR<B|H> Rt, [Rn, Rm]
```

where:

Rt	Is the register to load or store.
Rn	Is the register on which the memory address is based
Rm	s a register containing a value to be used as the offset

Operation

`LDR, LDRB, LDRH, LDRSB and LDRSH` load the register specified by *Rt* with either a word, zero extended byte, zero extended halfword, sign extended byte or sign extended halfword value from memory.

`STR, STRB and STRH` store the word, least-significant byte or lower halfword contained in the single register specified by *Rt* into memory.

The memory address to load from or store to is the sum of the values in the registers specified by *Rn* and *Rm*.

Restrictions

In these instructions:

- *Rt*, *Rn*, and *Rm* must only specify R0-R7.
- The computed memory address must be divisible by the number of bytes in the load or store, see *3.3.4: Address alignment on page 42*.

Condition flags

These instructions do not change the flags.

Examples

```
STR R0, [R5, R1]          ; Store value of R0 into an address equal to
                          ; sum of R5 and R1
LDRSH  R1, [R2, R3]       ; Load a halfword from the memory address
                          ; specified by (R2 + R3), sign extend to 32-bits
                          ; and write to R1.
```

3.4.4 LDR, PC-relative

Load register (literal) from memory.

Syntax

`LDR Rt, label`

where:

Rt Is the register to load

label Is a PC-relative expression. See *3.3.5: PC-relative expressions on page 43*.

Operation

Loads the register specified by *Rt* from the word in memory specified by *label*.

Restrictions

In these instructions, *label* must be within 1020 bytes of the current PC and word aligned.

Condition flags

These instructions do not change the flags.

Examples

```
LDR   R0, LookUpTable   ; Load R0 with a word of data from an address
                        ; labelled as LookUpTable.
LDR   R3, [PC, #100]    ; Load R3 with memory word at (PC + 100).
```

3.4.5 LDM and STM

Load and Store Multiple registers.

Syntax

`LDM Rn{!}, reglist`

`STM Rn!, reglist`

where:

`Rn` Is the register on which the memory addresses are based.

`!` Writeback suffix.

`reglist` Is a list of one or more registers to be loaded or stored, enclosed in braces. It can contain register ranges. It must be comma separated if it contains more than one register or register range, see *Examples on page 51*.

`LDMIA` and `LDMFD` are synonyms for `LDM`. `LDMIA` refers to the base register being Incremented After each access. LDMFD refers to its use for popping data from Full Descending stacks.

`STMIA` and `STMEA` are synonyms for `STM`. `STMIA` refers to the base register being Incremented After each access. `STMEA` refers to its use for pushing data onto Empty Ascending stacks.

Operation

`LDM` instructions load the registers in *`reglist`* with word values from memory addresses based on `Rn`.

`STM` instructions store the word values in the registers in *`reglist`* to memory addresses based on *`Rn`*.

The memory addresses used for the accesses are at 4-byte intervals ranging from the value in the register specified by *`Rn`* to the value in the register specified by *`Rn`* + 4 * (*n*-1), where *n* is the number of registers in *`reglist`*. The accesses happens in order of increasing register numbers, with the lowest numbered register using the lowest memory address and the highest number register using the highest memory address. If the writeback suffix is specified, the value in the register specified by *`Rn`* + 4 **n* is written back to the register specified by *`Rn`*.

Restrictions

In these instructions:

- *`reglist`* and *`Rn`* are limited to R0-R7.
- The writeback suffix must always be used unless the instruction is an `LDM` where reglist also contains *`Rn`*, in which case the writeback suffix must not be used.
- The value in the register specified by *`Rn`* must be word aligned. See *3.3.4: Address alignment on page 42* for more information.
- For `STM`, if *`Rn`* appears in *`reglist`*, then it must be the first register in the list.

Condition flags

These instructions do not change the flags.

Examples

```
LDM     R0,{R0,R3,R4}       ; LDMIA is a synonym for LDM
STMIA   R1!,{R2-R4,R6}
```

Incorrect examples

```
STM     R5!,{R4,R5,R6} ;Value stored for R5 is unpredictable
LDM     R2,{}          ;There must be at least one register in the list
```

3.4.6 PUSH and POP

Push registers onto, and pop registers off a full-descending stack.

Syntax

`PUSH` *`reglist`*

`POP` *`reglist`*

where:

`reglist` Is a non-empty list of registers, enclosed in braces. It can contain register ranges. It must be comma separated if it contains more than one register or register range.

Operation

`PUSH` stores registers on the stack, with the lowest numbered register using the lowest memory address and the highest numbered register using the highest memory address.

`POP` loads registers from the stack, with the lowest numbered register using the lowest memory address and the highest numbered register using the highest memory address.

`PUSH` uses the value in the SP register minus four as the highest memory address, POP uses the value in the SP register as the lowest memory address, implementing a full-descending stack. On completion, `PUSH` updates the SP register to point to the location of the lowest store value, `POP` updates the SP register to point to the location above the highest location loaded.

If a `POP` instruction includes PC in its `reglist`, a branch to this location is performed when the `POP` instruction has completed. Bit[0] of the value read for the PC is used to update the APSR T-bit. This bit must be 1 to ensure correct operation.

Restrictions

In these instructions:

- `reglist` must use only R0-R7.
- The exception is LR for a `PUSH` and PC for a `POP`.

Condition flags

These instructions do not change the flags.

Examples

```
PUSH    {R0,R4-R7}      ; Push R0,R4,R5,R6,R7 onto the stack
PUSH    {R2,LR}         ; Push R2 and the link-register onto the stack
POP     {R0,R6,PC}      ; Pop r0,r6 and PC from the stack, then branch to
                        ; the new PC.
```

3.5 General data processing instructions

Table 19 shows the data processing instructions:

Table 19. Data processing instructions

Mnemonic	Brief description	See
ADCS	Add with Carry	*3.5.1: ADC, ADD, RSB, SBC, and SUB on page 54*.
ADD{S}	Add	*3.5.1: ADC, ADD, RSB, SBC, and SUB on page 54*.
ANDS	Logical AND	*3.5.2: AND, ORR, EOR, and BIC on page 56*.
ASRS	Arithmetic Shift Right	*3.5.3: ASR, LSL, LSR, and ROR on page 57*.
BICS	Bit Clear	*3.5.2: AND, ORR, EOR, and BIC on page 56*.
CMN	Compare Negative	*3.5.4: CMP and CMN on page 59*.
CMP	Compare	*3.5.4: CMP and CMN on page 59*.
EORS	Exclusive OR	*3.5.2: AND, ORR, EOR, and BIC on page 56*.
LSLS	Logical Shift Left	*3.5.3: ASR, LSL, LSR, and ROR on page 57*.
LSRS	Logical Shift Right	*3.5.3: ASR, LSL, LSR, and ROR on page 57*.
MOV{S}	Move	*3.5.5: MOV and MVN on page 60*.
MULS	Multiply	*3.5.6: MULS on page 61*.
MVNS	Move NOT	*3.5.5: MOV and MVN on page 60*.
ORRS	Logical OR	*3.5.2: AND, ORR, EOR, and BIC on page 56*.
REV	Reverse byte order in a word	*3.5.7: REV, REV16, and REVSH on page 62*.
REV16	Reverse byte order in each halfword	*3.5.7: REV, REV16, and REVSH on page 62*.
REVSH	Reverse byte order in bottom halfword and sign extend	*3.5.7: REV, REV16, and REVSH on page 62*.
RORS	Rotate Right	*3.5.3: ASR, LSL, LSR, and ROR on page 57*.
RSBS	Reverse Subtract	*3.5.1: ADC, ADD, RSB, SBC, and SUB on page 54*.
SBCS	Subtract with Carry	*3.5.1: ADC, ADD, RSB, SBC, and SUB on page 54*.
SUBS	Subtract	*3.5.1: ADC, ADD, RSB, SBC, and SUB on page 54*.
SXTB	Sign extend a byte	*3.5.8: SXT and UXT on page 63*.
SXTH	Sign extend a halfword	*3.5.8: SXT and UXT on page 63*.
UXTB	Zero extend a byte	*3.5.8: SXT and UXT on page 63*.
UXTH	Zero extend a halfword	*3.5.8: SXT and UXT on page 63*.
TST	Test	*3.5.9: TST on page 64*.

3.5.1 ADC, ADD, RSB, SBC, and SUB

Add with carry, Add, Reverse Subtract, Subtract with carry, and Subtract.

Syntax

```
ADCS    {Rd,} Rn, Rm
ADD{S}  {Rd,} Rn, <Rm|#imm>
RSBS    {Rd,} Rn, Rm, #0
SBCS    {Rd,} Rn, Rm
SUB{S}  {Rd,} Rn, <Rm|#imm>
```

Where:

`S` Causes an `ADD` or `SUB` instruction to update flags.

`Rd` Specifies the result register.

`reglist` Specifies the first source register.

`Imm` Specifies a constant immediate value.

When the optional `Rd` register specifier is omitted, it is assumed to take the same value as *Rn*, for example ADDS R1,R2 is identical to ADDS R1,R1,R2.

Operation

The `ADCS` instruction adds the value in `Rn` to the value in `Rm`, adding another one if the carry flag is set, places the result in the register specified by `Rd` and updates the N, Z, C, and V flags.

The `ADD` instruction adds the value in *Rn* to the value in *Rm* or an immediate value specified by *imm* and places the result in the register specified by `Rd`.

The `ADDS` instruction performs the same operation as ADD and also updates the N, Z, C and V flags.

The `RSBS` instruction subtracts the value in *Rn* from zero, producing the arithmetic negative of the value, and places the result in the register specified by `Rd` and updates the N, Z, C and V flags.

The `SBCS` instruction subtracts the value of *Rm* from the value in *Rn,* if the carry flag is clear, the result is reduced by one. It places the result in the register specified by Rd and updates the N, Z, C and V flags.

The `SUB` instruction subtracts the value in *Rm* or the immediate specified by *imm*. It places the result in the register specified by `Rd`.

The `SUBS` instruction performs the same operation as SUB and also updates the N, Z, C and V flags.

Use `ADC` and `SBC` to synthesize multiword arithmetic, see *Examples on page 55*.

See also *3.4.1: ADR on page 46*.

Restrictions

Table 20 lists the legal combinations of register specifiers and immediate values that can be used with each instruction.

Table 20. ADC, ADD, RSB, SBC and SUB operand restrictions

Instruction	Rd	Rn	Rm	imm	Restrictions
ADCS	R0-R7	R0-R7	R0-R7	-	Rd and Rn must specify the same register.
ADD	R0-R15	R0-R15	R0-PC	-	Rd and Rn must specify the same register. Rn and Rm must not both specify PC.
	R0-R7	SP or PC	-	0-1020	Immediate value must be an integer multiple of four.
	SP	SP	-	0-508	Immediate value must be an integer multiple of four.
ADDS	R0-R7	R0-R7	-	0-7	-
	R0-R7	R0-R7	-	0-255	Rd and Rn must specify the same register.
	R0-R7	R0-R7	R0-R7	-	-
RSBS	R0-R7	R0-R7	-	-	-
SBCS	R0-R7	R0-R7	R0-R7	-	Rd and Rn must specify the same register.
SUB	SP	SP	-	0-508	Immediate value must be an integer multiple of four.
SUBS	R0-R7	R0-R7	-	0-7	-
	R0-R7	R0-R7	-	0-255	Rd and Rn must specify the same register.
	R0-R7	R0-R7	R0-R7	-	-

Examples

Example 1 shows two instructions that add a 64-bit integer contained in R0 and R1 to another 64-bit integer contained in R2 and R3, and place the result in R0 and R1.

Example 164-bit addition

```
ADDS    R0, R0, R2    ; add the least significant words
ADCS    R1, R1, R3    ; add the most significant words with carry
```

Multiword values do not have to use consecutive registers. *Example 2* shows instructions that subtract a 96-bit integer contained in R1, R2, and R3 from another contained in R4, R5, and R6. The example stores the result in R4, R5, and R6.

Example 296-bit subtraction

```
SUBS    R4, R4, R1    ; subtract the least significant words
SBCS    R5, R5, R2    ; subtract the middle words with carry
SBCS    R6, R6, R3    ; subtract the most significant words with carry
```

Example 3 shows the RSBS instruction used to perform a 1's complement of a single register.

Example 3Arithmetic negation

```
RSBS    R7, R7, #0    ; subtract R7 from zero
```

3.5.2 AND, ORR, EOR, and BIC

Logical AND, OR, Exclusive OR, and Bit Clear.

Syntax

```
ANDS {Rd,} Rn, Rm
ORRS {Rd,} Rn, Rm
EORS {Rd,} Rn, Rm
BICS {Rd,} Rn, Rm
```

where:

`Rd`	Is the destination register.
`Rn`	Is the register holding the first operand and is the same as the destination register.
`Rm`	Second register

Operation

The `AND, EOR, and ORR` instructions perform bitwise AND, exclusive OR, and inclusive OR operations on the values in *Rn* and *Rm*.

The BIC instruction performs an AND operation on the bits in *Rn* with the logical negation of the corresponding bits in the value of *Rm*.

The condition code flags are updated on the result of the operation, see *Condition flags on page 47*.

Restrictions

In these instructions, *Rd*, *Rn*, and *Rm* must only specify R0-R7.

Condition flags

These instructions:

Update the N and Z flags according to the result.

Do not affect the C or V flag.

Examples

```
ANDS    R2, R2, R1
ORRS    R2, R2, R5
ANDS    R5, R5, R8
EORS    R7, R7, R6
BICS    R0, R0, R1
```

3.5.3 ASR, LSL, LSR, and ROR

Arithmetic Shift Right, Logical Shift Left, Logical Shift Right, and Rotate Right.

Syntax

```
ASRS {Rd,} Rm, Rs
ASRS {Rd,} Rm, #imm
LSLS {Rd,} Rm, Rs
LSLS {Rd,} Rm, #imm
LSRS {Rd,} Rm, Rs
LSRS {Rd,} Rm, #imm
RORS {Rd,} Rm, Rs
```

where:

- `Rd` Is the destination register. If *Rd* is omitted, it is assumed to take the same value as *Rm*.
- `Rm` Is the register holding the value to be shifted.
- `Rs` Is the register holding the shift length to apply to the value in *Rm*
- `Imm` Is the shift length. The range of shift length depends on the instruction:
  - ASR shift length from 1 to 32
  - LSL shift length from 0 to 31
  - LSR shift length from 1 to 32.

Note: MOVS Rd, Rm is a pseudonym for `LSLS Rd, Rm, #0`.

Operation

ASR, `LSL, LSR, and ROR` perform an arithmetic-shift-left, logical-shift-left, logical-shift-right or a right-rotation of the bits in the register *Rm* by the number of places specified by the immediate *imm* or the value in the least-significant byte of the register specified by *Rs*.

For details on what result is generated by the different instructions, see *3.3.3: Shift operations on page 40*.

Restrictions

In these instructions, *Rd*, *Rm*, and *Rs* must only specify R0-R7. For non-immediate instructions, *Rd* and *Rm* must specify the same register.

Condition flags

These instructions update the N and Z flags according to the result.

The C flag is updated to the last bit shifted out, except when the shift length is 0, see *3.3.3: Shift operations on page 40*. The V flag is left unmodified.

Examples

```
ASRS    R7, R5, #9  ; Arithmetic shift right by 9 bits
LSLS    R1, R2, #3  ; Logical shift left by 3 bits with flag update
LSRS    R4, R5, #6  ; Logical shift right by 6 bits
RORS    R4, R4, R6  ; Rotate right by the value in the bottom byte of R6.
```

3.5.4 CMP and CMN

Compare and Compare Negative.

Syntax

```
CMN Rn, Rm
CMP Rn, #imm
CMP Rn, Rm
```

where:

Rn	Is the register holding the first operand.
Rm	Is the register to compare with.
Imm	Is the immediate value to compare with.

Operation

These instructions compare the value in a register with either the value in another register or an immediate value. They update the condition flags on the result, but do not write the result to a register.

The `CMP` instruction subtracts either the value in the register specified by *Rm*, or the immediate *imm* from the value in *Rn* and updates the flags. This is the same as a SUBS instruction, except that the result is discarded.

The `CMN` instruction adds the value of *Rm* to the value in *Rn* and updates the flags. This is the same as an `ADDS` instruction, except that the result is discarded.

Restrictions

For the:

- `CMN` instruction *Rn*, and *Rm* must only specify R0-R7.
- `CMP` instruction:
  - *Rn* and *Rm* can specify R0-R14.
  - Immediate must be in the range 0-255.

Condition flags

These instructions update the N, Z, C and V flags according to the result.

Examples

```
CMP     R2, R9
CMN     R0, R2
```

3.5.5 MOV and MVN

Move and Move NOT.

Syntax

```
MOV{S} Rd, Rm
MOVS Rd, #imm
MVNS Rd, Rm
```

where:

S	Is an optional suffix. If S is specified, the condition code flags are updated on the result of the operation, see *3.3.6: Conditional execution on page 43*.
Rd	Is the destination register.
Rm	Is a register.
Imm	Is any value in the range 0-255.

Operation

The MOV instruction copies the value of *Rm* into *Rd*.

The MOVS instruction performs the same operation as the MOV instruction, but also updates the N and Z flags.

The MVSN instruction takes the value of *Rm*, performs a bitwise logical negate operation on the value, and places the result into *Rd*.

Restrictions

In these instructions, *Rd*, and *Rm* must only specify R0-R7.

When Rd is the PC in a MOV instruction:

- Bit[0] of the result is discarded.
- A branch occurs to the address created by forcing bit[0] of the result to 0. The T-bit remains unmodified.

Note: Though it is possible to use MOV *as a branch instruction,* Arm® *strongly recommends the use of a* BX *or* BLX *instruction to branch for software portability.*

Condition flags

If S is specified, these instructions:

- update the N and Z flags according to the result
- do not affect the C or V flags.

Example

```
MOVS  R0, #0x000B    ; Write value of 0x000B to R0, flags get updated
MOVS  R1, #0x0       ; Write value of zero to R1, flags are updated
MOV   R10, R12       ; Write value in R12 to R10, flags are not updated
MOVS  R3, #23        ; Write value of 23 to R3
MOV   R8, SP         ; Write value of stack pointer to R8
MVNS  R2, R0         ; Write inverse of R0 to the R2 and update flags
```

3.5.6 MULS

Multiply using 32-bit operands, and producing a 32-bit result.

Syntax

MULS Rd, Rn, Rm

where:

Rd Is the destination register.

Rn, Rm Ire registers holding the values to be multiplied.

Operation

The `MUL` instruction multiplies the values in the registers specified by `Rn` and `Rm`, and places the least significant 32 bits of the result in `Rd`. The condition code flags are updated on the result of the operation, see *3.3.6: Conditional execution on page 43*.

The results of this instruction does not depend on whether the operands are signed or unsigned.

Restrictions

In this instruction:

- `Rd`, `Rn`, and `Rm` must only specify R0-R7.
- `Rd` must be the same as `Rm`.

Condition flags

This instruction:

- Updates the N and Z flags according to the result.
- Does not affect the C or V flags.

Examples

```
MULS    R0, R2, R0      ; Multiply with flag update, R0 = R0 x R2
```

3.5.7 REV, REV16, and REVSH

Reverse bytes.

Syntax

```
REV Rd, Rn
REV16 Rd, Rn
REVSH Rd, Rn
```

where:

Rd Is the destination register.

Rn Is the source register.

Operation

Use these instructions to change endianness of data:

RER

`REV` Converts 32-bit big-endian data into little-endian data or 32-bit little-endian data into big-endian data.

`REV16` Converts two packed 16-bit big-endian data into little-endian data or two packed 16-bit little-endian data into big-endian data.

`REVSH` Converts 16-bit signed big-endian data into 32-bit signed little-endian data or 16-bit signed little-endian data into 32-bit signed big-endian data.

Restrictions

In these instructions, `Rd`, and `Rn` must only specify R0-R7.

Condition flags

These instructions do not change the flags.

Examples

```
REV    R3, R7  ; Reverse byte order of value in R7 and write it to R3
REV16  R0, R0  ; Reverse byte order of each 16-bit halfword in R0
REVSH  R0, R5  ; Reverse signed halfword
```

3.5.8 SXT and UXT

Sign extend and Zero extend.

Syntax

```
SXTB Rd, Rm
SXTH Rd, Rm
UXTB Rd, Rm
UXTH Rd, Rm
```

where:

Rd Is the destination register.

Rm Is the register holding the value to be extended.

Operation

- These instructions extract bits from the resulting value:
- `SXTB` extracts bits[7:0] and sign extends to 32 bits.
- `UXTB` extracts bits[7:0] and zero extends to 32 bits.
- `SXTH` extracts bits[15:0] and sign extends to 32 bits.
- `UXTH` extracts bits[15:0] and zero extends to 32 bits.

Restrictions

In these instructions, *Rd* and *Rm* must only specify R0-R7.

Condition flags

These instructions do not affect the flags.

Examples

```
SXTH  R4, R6          ; Obtain the lower halfword of the
                      ; value in R6 and then sign extend to
                      ; 32 bits and write the result to R4.
UXTB  R3, R1          ; Extract lowest byte of the value in R10 and zero
                      ; extend it, and write the result to R3
```

3.5.9 TST

Test bits.

Syntax

```
TST Rn, Rm
```

where:

Rn Is the register holding the first operand.

Rm The register to test against.

Operation

This instruction tests the value in a register against another register. It updates the condition flags based on the result, but does not write the result to a register.

The `TST` instruction performs a bitwise AND operation on the value in *Rn* and the value in *Rm*. This is the same as the `ANDS` instruction, except that it discards the result.

To test whether a bit of *Rn* is 0 or 1, use the `TST` instruction with a register that has that bit set to 1 and all other bits cleared to 0.

Restrictions

In these instructions, *Rn* and *Rm* must only specify R0-R7.

Condition flags

This instruction:

- updates the N and Z flags according to the result
- does not affect the C or V flags.

Examples

```
TST   R0, R1 ; Perform bitwise AND of R0 value and R1 value,
             ; condition code flags are updated but result is discarded
```

3.6 Branch and control instructions

Table 21 shows the branch and control instructions:

Table 21. Branch and control instructions

Mnemonic	Brief description	See
`B{cc}`	Branch {conditionally}	*3.6.1: B, BL, BX, and BLX on page 66*.
`BL`	Branch with Link	*3.6.1: B, BL, BX, and BLX on page 66*.
`BLX`	Branch indirect with Link	*3.6.1: B, BL, BX, and BLX on page 66*.
`BX`	Branch indirect	*3.6.1: B, BL, BX, and BLX on page 66*.

3.6.1 B, BL, BX, and BLX

Branch instructions.

Syntax

```
B{cond} label
BL label
BX Rm
BLX Rm
```

where:

Cond Is an optional condition code, see *3.3.6: Conditional execution on page 43*.

label Is a PC-relative expression. See *3.3.5: PC-relative expressions on page 43*.

Rm Is a register providing the address to branch to.

Operation

All these instructions cause a branch to the address indicated by *label* or contained in the register specified by *Rm*. In addition:

- the BL and BLX instructions write the address of the next instruction to LR, the link register R14.
- the BX and BLX instructions result in a HardFault exception if bit[0] of *Rm* is 0.

BL and BLX instructions also set bit[0] of the LR to 1. This ensures that the value is suitable for use by a subsequent POP {PC} or BX instruction to perform a successful return branch.

Table 22 shows the ranges for the various branch instructions

Table 22. Branch ranges

Instruction	Branch range
B *label*	−2 KB to +2 KB.
B*cond* *label*	−256 bytes to +254 bytes.
BL *label*	−16 MB to +16 MB.
BX *Rm*	Any value in register.
BLX *Rm*	Any value in register.

Restrictions

In these instructions:

- Do not use SP or PC in the BX or BLX instruction.
- For BX and BLX, bit[0] of *Rm* must be 1 for correct execution. Bit[0] is used to update the EPSR T-bit and is discarded from the target address.

Note: B*cond* *is the only conditional instruction on the Cortex-M0+ processor.*

Condition flags

These instructions do not change the flags.

Examples

```
B       loopA ; Branch to loopA
BL      funC  ; Branch with link (Call) to function funC, return address
              ; stored in LR
BX      LR    ; Return from function call
BLX     R0    ; Branch with link and exchange (Call) to a address stored
              ; in R0
BEQ     labelD ; Conditionally branch to labelD if last flag setting
              ; instruction set the Z flag, else do not branch.
```

3.7 Miscellaneous instructions

Table 23 shows the remaining Cortex-M0+ instructions

Table 23. Miscellaneous instructions

Mnemonic	Brief description	See
BKPT	Breakpoint	*3.7.1: BKPT on page 69*.
CPSID	Change Processor State, Disable Interrupts	*3.7.2: CPS on page 70*.
CPSIE	Change Processor State, Enable Interrupts	*3.7.2: CPS on page 70*.
DMB	Data Memory Barrier	*3.7.3: DMB on page 71*.
DSB	Data Synchronization Barrier	*3.7.4: DSB on page 72*.
ISB	Instruction Synchronization Barrier	*3.7.5: ISB on page 73*.
MRS	Move from special register to register	*3.7.6: MRS on page 74*.
MSR	Move from register to special register	*3.7.7: MSR on page 75*.
NOP	No Operation	*3.7.7: MSR on page 75*.
SEV	Send Event	*3.7.9: SEV on page 77*.
SVC	Supervisor Call	*3.7.10: SVC on page 78*.
WFE	Wait For Event	*3.7.11: WFE on page 79*.
WFI	Wait For Interrupt	*3.7.12: WFI on page 80*.

3.7.1 BKPT

Breakpoint.

Syntax

```
BKPT #imm
```

where:

Imm Is an integer in the range 0-255.

Operation

The `BKPT` instruction causes the processor to enter Debug state. Debug tools can use this to investigate system state when the instruction at a particular address is reached.

Imm is ignored by the processor. If required, a debugger can use it to store additional information about the breakpoint.

The processor might also produce a HardFault or go in to Lockup if a debugger is not attached when a `BKPT` instruction is executed. See *2.4.1: Lockup on page 33* for more information.

Restrictions

There are no restrictions.

Condition flags

This instruction does not change the flags.

Examples

```
BKPT #0     ; Breakpoint with immediate value set to 0x0.
```

3.7.2 CPS

Change Processor State.

Syntax

```
CPSID i
CPSIE i
```

Operation

`CPS` changes the PRIMASK special register values. `CPSID` causes interrupts to be disabled by setting PRIMASK. CPSIE cause interrupts to be enabled by clearing PRIMASK. See *Exception mask register on page 17* for more information about these registers.

Restrictions

If the current mode of execution is not privileged, then this instruction behaves as a `NOP` and does not change the current state of PRIMASK.

Condition flags

This instruction does not change the condition flags.

Examples

```
CPSID i ; Disable all interrupts except NMI (set PRIMASK.PM)
CPSIE i ; Enable interrupts (clear PRIMASK.PM)
```

3.7.3 DMB

Data Memory Barrier.

Syntax

`DMB`

Operation

`DMB` acts as a data memory barrier. It ensures that all explicit memory accesses that appear in program order before the `DMB` instruction are observed before any explicit memory accesses that appear in program order after the `DMB` instruction. `DMB` does not affect the ordering of instructions that do not access memory.

Restrictions

There are no restrictions.

Condition flags

This instruction does not change the flags.

Examples

```
DMB  ; Data Memory Barrier
```

3.7.4 DSB

Data Synchronization Barrier.

Syntax

`DSB`

Operation

`DSB` acts as a special data synchronization memory barrier. Instructions that come after the `DSB`, in program order, do not execute until the `DSB` instruction completes. The `DSB` instruction completes when all explicit memory accesses before it complete.

Restrictions

There are no restrictions.

Condition flags

This instruction does not change the flags.

Examples

```
DSB ; Data Synchronisation Barrier
```

3.7.5 ISB

Instruction Synchronization Barrier.

Syntax

`ISB`

Operation

`ISB` acts as an instruction synchronization barrier. It flushes the pipeline of the processor, so that all instructions following the `ISB` are fetched from cache or memory again, after the `ISB` instruction has been completed.

Restrictions

There are no restrictions.

Condition flags

This instruction does not change the flags.

Examples

```
ISB  ; Instruction Synchronisation Barrier
```

3.7.6 MRS

Move the contents of a special register to a general-purpose register.

Syntax

`MRS Rd, spec_reg`

where:

Rd Is the general purpose destination register.

spec_reg Is one of the special purpose registers: `APSR, IPSR, EPSR, IEPSR, IAPSR, EAPSR, PSR, MSP, PSP, PRIMASK, or CONTROL.`

Operation

`MSR` stores the contents of a special-purpose register to a general purpose register. The `MSR` instruction can be combined with the `MSR` instruction to produce read-modify-write sequences, which are suitable for modifying a specific flag in the PSR.

See *3.7.7: MSR on page 75*.

Restrictions

In this instruction, *Rd* must not be SP or PC.

If the current mode of execution is not privileged, then the values of all registers other than the APSR read as zero.

Condition flags

This instruction does not change the flags.

Examples

```
MRS  R0, PRIMASK ; Read PRIMASK value and write it to R0
```

3.7.7 MSR

Move the contents of a general-purpose register into the specified special register.

Syntax

`MSR spec_reg, Rn`

where:

Rn Is the general-purpose source register.

spec_reg Is the special-purpose destination register: `APSR, IPSR, EPSR, IEPSR, IAPSR, EAPSR, PSR, MSP, PSP, PRIMASK, or CONTROL.`

Operation

`MSR` updates one of the special registers with the value from the register specified by *Rn*.

See *3.7.6: MRS on page 74*.

Restrictions

In this instruction, *Rn* must not be SP and must not be PC.

If the current mode of execution is not privileged, then all attempts to modify any register other than the APSR are ignored.

Condition flags

This instruction updates the flags explicitly based on the value in *Rn*.

Examples

```
MSR  CONTROL, R1 ; Read R1 value and write it to the CONTROL register
```

3.7.8 NOP

No Operation.

Syntax

`NOP`

Operation

`NOP` performs no operation and is not guaranteed to be time consuming. The processor might remove it from the pipeline before it reaches the execution stage.

Restrictions

There are no restrictions.

Condition flags

This instruction does not change the flags.

Examples

```
NOP  ; No operation
```

3.7.9 SEV

Send Event.

Syntax

`SEV`

Operation

`SEV` causes an event to be signaled to all processors within a multiprocessor system. It also sets the local event register, see*2.5: Power management on page 33*.

See also *3.7.11: WFE on page 79*.

Restrictions

There are no restrictions.

Condition flags

This instruction does not change the flags.

Examples

```
SEV ; Send Event
```

3.7.10 SVC

Supervisor Call.

Syntax

`SVC #imm`

where:

Imm Is an integer in the range 0-255.

Operation

The `SVC` instruction causes the `SVC` exception.

Imm is ignored by the processor. If required, it can be retrieved by the exception handler to determine what service is being requested.

Restrictions

Executing the `SVC` instruction, while the current execution priority level is greater than or equal to that of the SVCall handler, results in a fault being generated.

Condition flags

This instruction does not change the flags.

Examples

```
    SVC  #0x32 ; Supervisor Call (SVC handler can extract the immediate
value
               ; by locating it through the stacked PC)
```

3.7.11 WFE

Wait For Event.

Syntax

`WFE`

Operation

If the event register is 0, `WFE` suspends execution until one of the following events occurs:

- An exception, unless masked by the exception mask registers or the current priority level.
- An exception enters the Pending state, if `SEVONPEND` in the System Control Register is set.
- A Debug Entry request, if debug is enabled.
- An event signaled by a peripheral or another processor in a multiprocessor system using the `SEV` instruction.

If the event register is 1, `WFE` clears it to 0 and completes immediately.

For more information see *2.5: Power management on page 33*.

Note: `WFE` is intended for power saving only. When writing software assume that `WFE` might behave as `NOP`.

Restrictions

There are no restrictions.

Condition flags

This instruction does not change the flags.

Examples

```
WFE  ; Wait for event
```

3.7.12 WFI

Wait for Interrupt.

Syntax

`WFI`

Operation

`WFI` suspends execution until one of the following events occurs:

- An exception.
- An interrupt becomes pending which would preempt if PRIMASK.PM was clear.
- A Debug Entry request, regardless of whether debug is enabled.

Note: `WFI` is intended for power saving only. When writing software assume that `WFI` might behave as a `NOP` operation.

Restrictions

There are no restrictions.

Condition flags

This instruction does not change the flags.

Examples

```
WFI ; Wait for interrupt
```

4 Cortex-M0+ core peripherals

4.1 About the Cortex-M0+ core peripherals

The address map of the *Private Peripheral Bus* (PPB) is:

Table 24. Core peripheral register regions

Address	Core peripheral	Description
0xE000E008-0xE000E00F	System Control Block	*Table 29 on page 88*.
0xE000E010-0xE000E01F	Reserved	-
0xE000E010-0xE000E01F	System timer	*Table 32 on page 95*.
0xE000E100-0xE000E4EF	Nested vectored interrupt controller	*Table 25 on page 82*.
0xE000ED00-0xE000ED3F	System Control Block	*Table 29 on page 88*.
0xE000ED90-0xE000EDB8	Memory Protection Unit(1)	*Table 34 on page 99*.
0xE000EF00-0xE000EF03	Nested vectored interrupt controller	*Table 25 on page 82*.

1. Software can read the MPU Type Register at 0xE000ED90 to test for the presence of a Memory Protection Unit (MPU).

In register descriptions:

the register *type* is described as follows:

RW Read and write.

RO Read-only.

WO Write-only.

- the *required privilege* gives the privilege level required to access the register, as follows:

Privileged

Only privileged software can access the register.

Unprivileged

Both unprivileged and privileged software can access the register.

4.2 Nested vectored interrupt controller

This section describes the *Nested vectored interrupt controller* (NVIC) and the registers it uses. The NVIC supports:

- 32 interrupts.
- A programmable priority level of 0-192 in steps of 64 for each interrupt. A higher level corresponds to a lower priority, so level 0 is the highest interrupt priority.
- Level and pulse detection of interrupt signals.
- Interrupt tail-chaining.
- An external *Non-Maskable Interrupt* (NMI).

The processor automatically stacks its state on exception entry and unstacks this state on exception exit, with no instruction overhead. This provides low latency exception handling. The hardware implementation of the NVIC registers is

Table 25. NVIC register summary

Address	Name	Type	Reset value	Description
0xE000E100	NVIC_ISER	RW	0x00000000	*Interrupt Set-enable Register on page 83*.
0xE000E180	NVIC_ICER	RW	0x00000000	*Interrupt Clear-enable Register on page 83*.
0xE000E200	NVIC_ISPR	RW	0x00000000	*Interrupt Set-pending Register on page 84*.
0xE000E280	NVIC_ICPR	RW	0x00000000	*Interrupt Clear-pending Register on page 84*.
0xE000E400-0xE000E4EF	NVIC_IPR0-7	RW	0x00000000	*Interrupt Priority Registers on page 85*.

4.2.1 Accessing the Cortex-M0+ NVIC registers using CMSIS

CMSIS functions enable software portability between different Cortex-M profile processors.

To access the NVIC registers when using CMSIS, use the following functions:

Table 26. CMSIS access NVIC functions

CMSIS function	Description
`void NVIC_EnableIRQ(IRQn_Type IRQn)`(1)	Enables an interrupt or exception.
`void NVIC_DisableIRQ(IRQn_Type IRQn)`(1)	Disables an interrupt or exception.
`void NVIC_SetPendingIRQ(IRQn_Type IRQn)`(1)	Sets the pending status of interrupt or exception to 1.
`void NVIC_ClearPendingIRQ(IRQn_Type IRQn)`(1)	Clears the pending status of interrupt or exception to 0.
`uint32_t NVIC_GetPendingIRQ(IRQn_Type IRQn)`(1)	Reads the pending status of interrupt or exception. This function returns non-zero value if the pending status is set to 1.

Table 26. CMSIS access NVIC functions (continued)

CMSIS function	Description
void NVIC_SetPriority(IRQn_Type IRQn, uint32_t priority)(1)	Sets the priority of an interrupt or exception with configurable priority level to 1.
uint32_t NVIC_GetPriority(IRQn_Type IRQn)(1)	Reads the priority of an interrupt or exception with configurable priority level. This function return the current priority level.

1. The input parameter IRQn is the IRQ number, see *Table 12 on page 27* for more information.

4.2.2 Interrupt Set-enable Register

The NVIC_ISER enables interrupts, and shows which interrupts are enabled. See the register summary in *Table 25 on page 82* for the register attributes.

The bit assignments are:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SETPENA[31:16]															
rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SETPENA[15:0]															
rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs

Bits 31:0 **SETENA**: Interrupt set-enable bits

Write:

0: No effect

1: Enable interrupt

Read:

0: Interrupt disabled

1: Interrupt enabled

If a pending interrupt is enabled, the NVIC activates the interrupt based on its priority. If an interrupt is not enabled, asserting its interrupt signal changes the interrupt state to pending, but the NVIC never activates the interrupt, regardless of its priority.

4.2.3 Interrupt Clear-enable Register

The NVIC_ICER disables interrupts, and show which interrupts are enabled. See the register summary in *Table 25 on page 82* for the register attributes.

The bit assignments are:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CLRENA[31:16]															
rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CLRENA[15:0]															
rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1

Bits 31:0 **CLRENA**: Interrupt clear-enable bits

Write:

0: No effect

1: Disable interrupt

Read:

0: Interrupt disabled

1: Interrupt enabled

4.2.4 Interrupt Set-pending Register

The NVIC_ISPR forces interrupts into the pending state, and shows which interrupts are pending. See the register summary in *Table 25 on page 82* for the register attributes.

The bit assignments are:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SETPEND[31:16]															
rs	rs	rs	rs	rs	rs	rs	rs	rs	rs7	rs	rs	rs	rs	rs	rs
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SETPEND[15:0]															
rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs	rs

Bits 31:0 **SETPEND**: Interrupt set-pending bits

Write:

0: No effect

1: Change interrupt state to pending

Read:

0: Interrupt is not pending

1: Interrupt is pending

Note: Writing 1 to the NVIC_ISPR bit corresponding to:

- An interrupt that is pending has no effect.
- A disabled interrupt sets the state of that interrupt to pending.

4.2.5 Interrupt Clear-pending Register

The NVIC_ICPR removes the pending state from interrupts, and shows which interrupts are pending. See the register summary in *Table 25 on page 82* for the register attributes.

The bit assignments are:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
CLRPEND[31:16]															
rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CLRPEND[15:0]															
rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1	rc_w1

Bits 31:0 **CLRPEND**: Interrupt clear-pending bits

Write:

0: No effect

1: Removes pending state and interrupt.

Read:

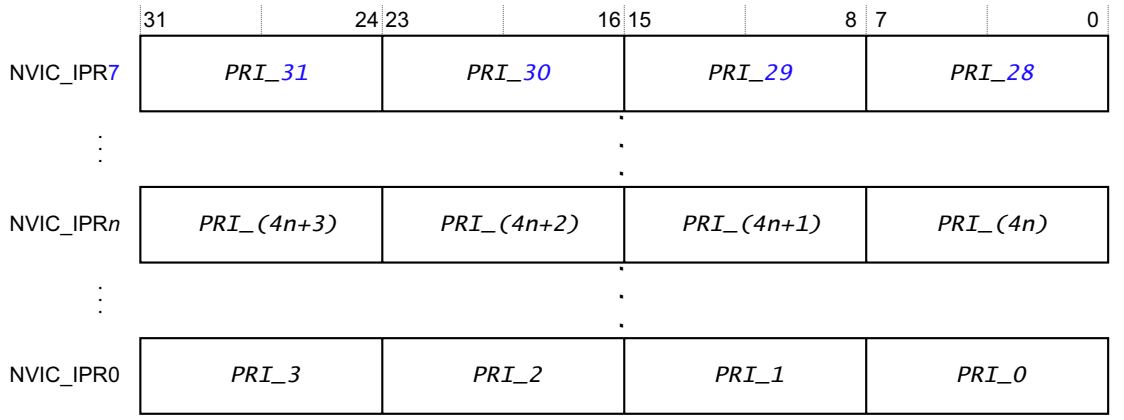
0: Interrupt is not pending

1: Interrupt is pending

Note: Writing 1 to an NVIC_ICPR bit does not affect the active state of the corresponding interrupt.

4.2.6 Interrupt Priority Registers

The NVIC_IPR0-NVIC_IPR7 registers provide an 8-bit priority field for each interrupt. These registers are only word-accessible. See the register summary in *Table 25 on page 82* for their attributes. Each register holds four priority fields as shown:



MS33834V1

Table 27. NVIC_IPRx bit assignments

Bits	Name	Function
[31:24]	Priority, byte offset 3	Each priority field holds a priority value, 0-192. The lower the value, the greater the priority of the corresponding interrupt. The processor implements only bits[7:6] of each field, bits [5:0] read as zero and ignore writes. This means writing 255 to a priority register saves value 192 to the register.
[23:16]	Priority, byte offset 2	
[15:8]	Priority, byte offset 1	
[7:0]	Priority, byte offset 0	

See *4.2.1: Accessing the Cortex-M0+ NVIC registers using CMSIS on page 82* for more information about the access to the interrupt priority array, which provides the software view of the interrupt priorities.

Find the NVIC_IPR number and byte offset for interrupt *M* as follows:

- The corresponding NVIC_IPR number, *N*, is given by *N* = *N* DIV 4.
- The byte offset of the required Priority field in this register is *M* MOD 4, where:
  - Byte offset 0 refers to register bits[7:0].
  - Byte offset 1 refers to register bits[15:8].
  - Byte offset 2 refers to register bits[23:16].
  - Byte offset 3 refers to register bits[31:24].

4.2.7 Level-sensitive and pulse interrupts

Cortex-M0+ interrupts are both level-sensitive and pulse-sensitive. Pulse interrupts are also described as edge-triggered interrupts.

A level-sensitive interrupt is held asserted until the peripheral deasserts the interrupt signal. Typically this happens because the ISR accesses the peripheral, causing it to clear the interrupt request. A pulse interrupt is an interrupt signal sampled synchronously on the rising edge of the processor clock. To ensure the NVIC detects the interrupt, the peripheral must assert the interrupt signal for at least one clock cycle, during which the NVIC detects the pulse and latches the interrupt.

When the processor enters the ISR, it automatically removes the pending state from the interrupt, see *Hardware and software control of interrupts on page 86*. For a level-sensitive interrupt, if the signal is not deasserted before the processor returns from the ISR, the interrupt becomes pending again, and the processor must execute its ISR again. This means that the peripheral can hold the interrupt signal asserted until it no longer requires servicing.

Hardware and software control of interrupts

The Cortex-M0+ processor latches all interrupts. A peripheral interrupt becomes pending for one of the following reasons:

- The NVIC detects that the interrupt signal is active and the corresponding interrupt is not active.
- The NVIC detects a rising edge on the interrupt signal.
- Software writes to the corresponding interrupt set-pending register bit, see *4.2.4: Interrupt Set-pending Register on page 84*.

A pending interrupt remains pending until one of the following:

- The processor enters the ISR for the interrupt. This changes the state of the interrupt from pending to active. Then:
  - For a level-sensitive interrupt, when the processor returns from the ISR, the NVIC samples the interrupt signal. If the signal is asserted, the state of the interrupt changes to pending, which might cause the processor to immediately re-enter the ISR. Otherwise, the state of the interrupt changes to inactive.
  - For a pulse interrupt, the NVIC continues to monitor the interrupt signal, and if this is pulsed the state of the interrupt changes to pending and active. In this case, when the processor returns from the ISR the state of the interrupt changes to pending, which might cause the processor to immediately re-enter the ISR. If the interrupt signal is not pulsed while the processor is in the ISR, when the processor returns from the ISR the state of the interrupt changes to inactive.
- Software writes to the corresponding interrupt clear-pending register bit.

For a level-sensitive interrupt, if the interrupt signal is still asserted, the state of the interrupt does not change. Otherwise, the state of the interrupt changes to inactive.

For a pulse interrupt, state of the interrupt changes to:

– Inactive, if the state was pending.
– Active, if the state was active and pending.

4.2.8 NVIC usage hints and tips

Ensure software uses correctly aligned register accesses. The processor does not support unaligned accesses to NVIC registers.

An interrupt can enter pending state even if it is disabled. Disabling an interrupt only prevents the processor from taking that interrupt.

Before programming VTOR to relocate the vector table, ensure the vector table entries of the new vector table are set up for fault handlers, NMI and all enabled exception like interrupts. For more information, see *4.3.4: Vector Table Offset Register on page 91*.

NVIC programming hints

Software uses the `CPSIEi` and `CPSIDi` instructions to enable and disable interrupts. The CMSIS provides the following intrinsic functions for these instructions:

```
void __disable_irq(void) // Disable Interrupts
void __enable_irq(void)  // Enable Interrupts
```

In addition, the CMSIS provides a number of functions for NVIC control, including:

Table 28. CMSIS functions for NVIC control

CMSIS interrupt control function	Description
`void NVIC_EnableIRQ(IRQn_t IRQn)`	Enable IRQn.
`void NVIC_DisableIRQ(IRQn_t IRQn)`	Disable IRQn
`uint32_t NVIC_GetPendingIRQ (IRQn_t IRQn)`	Return true (1) if IRQn is pending.
`void NVIC_SetPendingIRQ (IRQn_t IRQn)`	Set IRQn pending.
`void NVIC_ClearPendingIRQ (IRQn_t IRQn)`	Clear IRQn pending status.
`void NVIC_SetPriority (IRQn_t IRQn, uint32_t priority)`	Set priority for IRQn.
`uint32_t NVIC_GetPriority (IRQn_t IRQn)`	Read priority of IRQn.
`void NVIC_SystemReset (void)`	Reset the system.

The input parameter `IRQn` is the IRQ number, see *Table 12 on page 27* for more information. For more information about these functions, see the CMSIS documentation.

4.3 System Control Block

The *System Control Block* (SCB) provides system implementation information, and system control. This includes configuration, control, and reporting of the system exceptions. The SCB registers are:

Table 29. Summary of the SCB registers

Address	Name	Type	Reset value	Description
0xE000ED00	CPUID	RO	0x410CC601	*4.3.2: CPUID Register on page 88*.
0xE000ED04	ICSR	RW(1)	0x00000000	*4.3.3: Interrupt Control and State Register (ICSR) on page 89*.
0xE000ED08	VTOR	RW	0x00000000	*4.3.4: Vector Table Offset Register on page 91*.
0xE000ED0C	AIRCR	RW(1)	0xFA050000	*4.3.5: Application Interrupt and Reset Control Register on page 91*.
0xE000ED10	SCR	RW	0x00000000	*4.3.6: System Control Register on page 92*.
0xE000ED14	CCR	RO	0x00000204	*4.3.7: Configuration and Control Register on page 93*.
0xE000ED1C	SHPR 2	RW	0x00000000	*System Handler Priority Register 2 on page 94*.
0xE000ED20	SHPR 3	RW	0x00000000	*System Handler Priority Register 3 on page 95*.

1. See the register description for more information.

4.3.1 The CMSIS mapping of the Cortex-M0+ SCB registers

To improve software efficiency, the CMSIS simplifies the SCB register presentation. In the CMSIS, the array `SHP[1]` corresponds to the registers SHPR2-SHPR3.

4.3.2 CPUID Register

The CPUID register contains the processor part number, version, and implementation information. See the register summary in *Table 29 on page 88* for its attributes. The bit assignments are:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
IMPLEMENTER								VARIANT				Architecture			
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PART No												REVISION			
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bits 31:24 **Implementer**: Implementer code
`0x41`: ARM

Bits 23:20 **Variant**: Major revision number *n* in the rnp*m* revision status:
`0x0`: Revision 0

Bits 19:16 **Architecture:** Constant that defines the architecture of the processor:
`0xC`: ARMv6-M architecture

Bits 15:4 **PartNo**: Part number of the processor
`0xC60`: = Cortex-M0+

Bits 3:0 **Revision**: Minor revision number *m* in the rnp*m* revision status:
`0x1`: patch 1

4.3.3 Interrupt Control and State Register (ICSR)

The ICSR:

- Provides:
  - A set-pending bit for the *Non-Maskable Interrupt* (NMI) exception.
  - Set-pending and clear-pending bits for the PendSV and SysTick exceptions.
- Indicates:
  - The exception number of the highest priority pending exception.

See the register summary in *Table 29 on page 88* for the ICSR attributes. The bit assignments are

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
NMIPENDSET	Reserved		PENDSVSET	PENDSVCLR	PENDSTSET	PENDSTCLR	Reserved		ISRPENDING	Reserved			VECTPENDING[6:4]		
rw			rw	w	rw	w			r				r	r	r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
VECTPENDING[3:0]				RETOBASE	Reserved		VECTACTIVE[8:0]								
r	r	r	r	r			rw	rw	rw	rw	rw	rw	rw	rw	rw

Table 30. ICSR bit assignments

Bits	Name	Type	Function
[31]	NMIPENDSET	rw	NMI set-pending bit. Write: 0 = No effect. 1 = Changes NMI exception state to pending. Read: 0 = NMI exception is not pending. 1 = NMI exception is pending. Because NMI is the highest-priority exception, normally the processor enters the NMI exception handler as soon as it detects a write of 1 to this bit. Entering the handler then clears this bit to 0. This means a read of this bit by the NMI exception handler returns 1 only if the NMI signal is reasserted while the processor is executing that handler.
[30:29]	-	-	Reserved.
[28]	PENDSVSET	rw	PendSV set-pending bit. Write: 0 = No effect. 1 = Changes PendSV exception state to pending. Read: 0 = PendSV exception is not pending. 1 = PendSV exception is pending. Writing 1 to this bit is the only way to set the PendSV exception state to pending.
[27]	PENDSVCLR	w	PendSV clear-pending bit. Write: 0 = No effect. 1 = Removes the pending state from the PendSV exception.
[26]	PENDSTSET	rw	SysTick exception set-pending bit. Write: 0 = No effect. 1 = Changes SysTick exception state to pending. Read: 0 = SysTick exception is not pending. 1 = SysTick exception is pending.
[25]	PENDSTCLR	w	SysTick exception clear-pending bit. Write: 0 = No effect. 1 = Removes the pending state from the SysTick exception. This bit is WO. On a register read its value is Unknown.
[24:18]	-	-	Reserved.

Table 30. ICSR bit assignments (continued)

Bits	Name	Type	Function
[17:12]	VECTPENDING	r	Indicates the exception number of the highest priority pending enabled exception: 0 = No pending exceptions. Nonzero = the exception number of the highest priority pending enabled exception. Subtract 16 from this value to obtain the CMSIS IRQ number that identifies the corresponding bit in the Interrupt Clear-Enable, Set-Enable, Clear-Pending, Set-pending, and Priority Register, see *Table 5 on page 16*.
[11:0]	-	-	Reserved.

When you write to the ICSR, the effect is Unpredictable if you:

- write 1 to the PENDSVSET bit and write 1 to the PENDSVCLR bit
- write 1 to the PENDSTSET bit and write 1 to the PENDSTCLR bit.

4.3.4 Vector Table Offset Register

The VTOR indicates the offset of the vector table base address from memory address `0x00000000`. See the register summary for its attributes.

The bit assignments are:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TBLOFF[31:16]															
rw		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TBLOFF[15:7]									Reserved						
rw	rw	rw	rw	rw	rw	rw	rw	rw							

Bits 31:7 TBLOFF Vector table base offset field.
It contains bits[31:7] of the offset of the table base from the bottom of the memory map.

Bits 6:0 Reserved

4.3.5 Application Interrupt and Reset Control Register

The AIRCR provides endian status for data accesses and reset control of the system. To write to this register, you must write `0x05FA` to the VECTKEY field, otherwise the processor ignores the write.

The bit assignments are:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
VECTKEYSTAT															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ENDIANESS	Reserved												SYSRESETREQ	VECTCLRACTIVE	Reserved
r													w	w	

Bits 31:16 VECTKEY Register key

Register key:

Reads as Unknown

On writes, write 0x05FA to VECTKEY, otherwise the write is ignored.

Bit 15 ENDIANESS Data endianness bit

Reads as 0.

0: Little-endian

Bits 14:3 Reserved

Bit 2 SYSRESETREQ System reset request:

0: No effect

1: Requests a system level reset.

This bit reads as 0.

Bit 1 VECTCLRACTIVE

Reserved for Debug use. This bit reads as 0. When writing to the register you must write 0 to this bit, otherwise behavior is unpredictable.

Bit 0 Reserved

4.3.6 System Control Register

The SCR controls features of entry to and exit from low power state. See the register summary in *Table 29 on page 88* for its attributes. The bit assignments are

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved											SEVONPEND	Res.	SLEEPDEEP	SLEEPONEXIT	Res.
											rw		rw	rw	

Bits 31:5 Reserved

Bit 4 **SEVEONPEND** Send Event on Pending bit

0 : Only enabled interrupts or events can wakeup the processor, disabled interrupts are excluded.

1 = Enabled events and all interrupts, including disabled interrupts, can wakeup the processor.

When an event or interrupt becomes pending, the event signal wakes up the processor from WFE. If the processor is not waiting for an event, the event is registered and affects the next WFE.

The processor also wakes up on execution of an SEV instruction or an external event.

Bit 3 **Reserved**, must be kept cleared

Bit 2 **SLEEPDEEP**

Controls whether the processor uses sleep or deep sleep as its low power mode:

0: Sleep

1: Deep sleep.

Bit 1 **SLEEPONEXIT**

Indicates sleep-on-exit when returning from Handler mode to Thread mode. Setting this bit to 1 enables an interrupt-driven application to avoid returning to an empty main application.

0: Do not sleep when returning to Thread mode.

1: Enter sleep, or deep sleep, on return from an ISR to Thread mode.

Bit 0 **Reserved**, must be kept cleared

4.3.7 Configuration and Control Register

The CCR is a read-only register and indicates some aspects of the behavior of the Cortex-M0+ processor. See the register summary in *Table 29 on page 88* for the CCR attributes.

The bit assignments are

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved						STK ALIGN	BFHF NMIGN	Reserved			DIV_0_ TRP	UN ALIGN_ TRP	Res.	USER SET MPEND	NON BASE THRD ENA
						rw	rw				rw	rw		rw	rw

Bits 31:10 **Reserved**, must be kept cleared

Bit 9 STKALIGN

Always reads as one, indicates 8-byte stack alignment on exception entry.

On exception entry, the processor uses bit[9] of the stacked PSR to indicate the stack alignment. On return from the exception it uses this stacked bit to restore the correct stack alignment.

Bits 8:4 **Reserved**, must be kept cleared

Bit 3 **UNALIGN_ TRP**

Always reads as one, indicates that all unaligned accesses generate a HardFault.

Bit 2:0 Reserved, must be kept cleared

4.3.8 System Handler Priority Registers

The SHPR2-SHPR3 registers set the priority level, 0 to 192, of the system exception handlers that have configurable priority.

SHPR2-SHPR3 are word accessible. See the register summary in for their attributes.

To access the system exception priority level using CMSIS, use the following CMSIS functions:

- `uint32_t NVIC_GetPriority(IRQn_Type IRQn)`
- `void NVIC_SetPriority(IRQn_Type IRQn, uint32_t priority)`

The input parameter `IRQn` is the IRQ number, see *Table 12 on page 27* for more information.

The system handlers, and the priority field and register for each handler are:

Table 31. System fault handler priority fields

Handler	Field	Register description
SVCall	PRI_11	*System Handler Priority Register 2 on page 94*.
PendSV	PRI_14	*System Handler Priority Register 3 on page 95*.
SysTick	PRI_15	

Each PRI_N field is 8 bits wide, but the processor implements only bits[7:6] of each field, and bits[5:0] read as zero and ignore writes.

System Handler Priority Register 2

The bit assignments are:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved								PRI_6[7:4]				PRI_6[3:0]			
								rw	rw	rw	rw	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PRI_5[7:4]				PRI_5[3:0]				PRI_4[7:4]				PRI_4[7:4]			
rw	rw	rw	rw	r	r	r	r	rw	rw	rw	rw	r	r	r	r

Bits 31:24 **PRI_11**: Priority of system handler 11, SVCall.

Bits 23:0 Reserved, must be kept cleared

System Handler Priority Register 3

The bit assignments are

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
PRI_15								PRI_14							
rw	rw	rw	rw	r	r	r	r	rw	rw	rw	rw	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved															

Bits 31:24 **PRI_15:** Priority of system handler 15, SysTick exception(1)

Bits 23:16 **PRI_14:** Priority of system handler 14, PendSV

Bits 15:0 Reserved, must be kept cleared

1. This is Reserved when the SysTick timer is not implemented.

4.3.9 SCB usage hints and tips

Ensure software uses aligned 32-bit word size transactions to access all the SCB registers.

4.4 SysTick timer (STK)

When enabled, the timer counts down from the reload value to zero, reloads (wraps to) the value in the SYST_RVR on the next clock cycle, then decrements on subsequent clock cycles. Writing a value of zero to the SYST_RVR disables the counter on the next wrap. When the counter transitions to zero, the COUNTFLAG status bit is set to 1. Reading SYST_CSR clears the COUNTFLAG bit to 0.Writing to the SYST_CVR clears the register and the COUNTFLAG status bit to 0. The write does not trigger the SysTick exception logic. Reading the register returns its value at the time it is accessed.

Note: When the processor is halted for debugging the counter does not decrement.

The system timer registers are:

Table 32. System timer registers summary

Address	Name	Type	Required privilege	Reset value	Description
0xE000E010	STK_CSR	RW	Privileged	0x00000000	*4.4.1: SysTick Control and Status Register (STK_CSR) on page 96*.
0xE000E014	STK_RVR	RW	Privileged	Unknown	*4.4.2: SysTick Reload Value Register (STK_RVR) on page 96*.
0xE000E018	STK_CVR	RW	Privileged	Unknown	*4.4.3: SysTick Current Value Register (STK_CVR) on page 97*.
0xE000E01C	STK_CALIB	RO	Privileged	0xC0000000(1)	*4.4.4: SysTick Calibration Value Register (STK_CALIB) on page 97*.

1. SysTick calibration value.

4.4.1 SysTick Control and Status Register (STK_CSR)

The SYST_CSR enables the SysTick features. See the register summary in *Table 32 on page 95* for its attributes. The bit assignments are:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
															rc_r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved															
													rw	rw	rw

Bits31:17 Reserved, must be kept cleared.

Bit 16 **COUNTFLAG** Returns 1 if timer counted to 0 since the last read of this register.

Bits 15:3 Reserved, must be kept cleared.

Bit 2 **CLKSOURCE** Selects the SysTick timer clock source:
0 = External reference clock.
1 = Processor clock.

Bit 1 **TICKINT** Enables SysTick exception request:
0 = Counting down to zero does not assert the SysTick exception request.
1 = Counting down to zero to asserts the SysTick exception request.

Bit 0 **ENABLE** Enables the counter:
0 = Counter disabled.
1 = Counter enabled.

4.4.2 SysTick Reload Value Register (STK_RVR)

The STK_RVR specifies the start value to load into the SYST_CVR. See the register summary in *Table 32 on page 95* for its attributes. The bit assignments are:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved								RELOAD							
								rw	rw	rw	rw	rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RELOAD															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits31:24 Reserved, must be kept cleared.

Bits 23:0 **RELOAD** Value to load into the STK_CVR when the counter is enabled and when it reaches 0, see *Calculating the RELOAD value on page 96*.

Calculating the RELOAD value

The RELOAD value can be any value in the range `0x00000001-0x00FFFFFF`. You can program a value of 0, but this has no effect because the SysTick exception request and COUNTFLAG are activated when counting from 1 to 0.

To generate a multi-shot timer with a period of N processor clock cycles, use a RELOAD value of N-1. For example, if the SysTick interrupt is required every 100 clock pulses, set RELOAD to 99.

4.4.3 SysTick Current Value Register (STK_CVR)

The STK_CVR contains the current value of the SysTick counter. See the register summary in *Table 32 on page 95* for its attributes. The bit assignments are:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved								CURRENT							
								rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CURRENT															
rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w	rc_w

Bits31:24 Reserved, must be kept cleared.

Bits 23:0 **CURRENT** Reads return the current value of the SysTick counter.
A write of any value clears the field to 0, and also clears the SYST_CSR.COUNTFLAG bit to 0.

4.4.4 SysTick Calibration Value Register (STK_CALIB)

The STK_CALIB register indicates the SysTick calibration properties. See the register summary in *Table 32 on page 95* for its attributes. The bit assignments are:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
NO REF	SKEW	Reserved						TENMS[23:16]							
r	r							r	r	r	r	r	r	r	r
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TENMS[15:0]															
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

Bit 31 **NOREF:** Reads as zero. Indicates that separate reference clock is provided. The frequency of this clock is HCLK/8.

Bit 30 **SKEW:** Reads as one. Calibration value for the 1ms inexact timing is not known because TENMS is not known. This can affect the suitability of SysTick as a software real time clock.

Bits 29:24 Reserved, must be kept cleared.

Bits 23:0 **TENMS[23:0]:**
Indicates the calibration value when the SysTick counter runs on HCLK max/8 as external clock. The value is product dependent, please refer to the Product Reference Manual, SysTick Calibration Value section. When HCLK is programmed at the maximum frequency, the SysTick period is 1ms.

If calibration information is not known, calculate the calibration value required from the frequency of the processor clock or external clock.

4.4.5 SysTick usage hints and tips

The interrupt controller clock updates the SysTick counter. If this clock signal is stopped for low power mode, the SysTick counter stops.

Ensure software uses word accesses to access the SysTick registers.

If the SysTick counter reload and current value are undefined at reset, the correct initialization sequence for the SysTick counter is:

1. Program reload value.
2. Clear current value.
3. Program Control and Status register.

4.5 Memory Protection Unit

This section describes the *Memory Protection Unit* (MPU).

The MPU can divide 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-M0+ MPU defines:

- Eight separate memory regions, 0-7.
- 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-M0+ 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 HardFault exception.

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.

Configuration of MPU regions is based on memory types, see *2.2.1: Memory regions, types and attributes on page 20*.

Table 33 on page 99 shows the possible MPU region attributes. These include Shareability and cache behavior attributes that are not relevant to most microcontroller implementations. See *MPU configuration for a microcontroller on page 107* for guidelines for programming such an implementation.

Table 33. 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.
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. *Table 34 on page 99* shows the MPU registers

Table 34. MPU registers summary

Address	Name	Type	Reset value	Description
0xE000ED90	MPU_TYPE	RO	0x00000000 or 0x00000800(1)	*4.5.1: MPU Type Register on page 99*.
0xE000ED94	MPU_CTRL	RW	0x00000000	*4.5.2: MPU Control Register on page 100*.
0xE000ED98	MPU_RNR	RW	Unknown	*4.5.3: MPU Region Number Register on page 101*.
0xE000ED9C	MPU_RBAR	RW	Unknown	*4.5.4: MPU Region Base Address Register on page 102*.
0xE000EDA0	MPU_RASR	RW	Unknown	*4.5.5: MPU Region Attribute and Size Register on page 103*.

1. Software can read the MPU Type Register to test for the precence of a Memory Protection Unit (MPU). See *MPU Type Register*

4.5.1 MPU Type Register

The MPU_TYPE register indicates whether the MPU is present, and if so, how many regions it supports. See the register summary in *Table 34 on page 99* for its attributes. The bit assignments are:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved								IREGION[7:0]							
								r	r	r	r	r	r	r	r

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DREGION[7:0]								Reserved							SEPARATE
r	r	r	r	r	r	r	r								r

Bits 31:24 **Reserved.**

Bits 23:16 **IREGION[7:0]**: Indicates the number of supported MPU instruction regions.
Always contains `0x00`. The MPU memory map is unified and is described by the DREGION field.

Bits 15:8 **DREGION[7:0]**: Indicates the number of supported MPU data regions:
`0x00` = Zero regions if your device does not include the MPU.
`0x08` = Eight regions if your device includes the MPU.

Bits 7:1 **Reserved.**

Bit 0 **SEPARATE**: Indicates support for unified or separate instruction and date memory maps:
0 = Unified.

4.5.2 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 HardFault or *Non-Maskable Interrupt* (NMI) handler.

See the register summary in *Table 34 on page 99* for the MPU_CTRL attributes. The bit assignments are:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved													PRIVDEFENA	HFNMIENA	ENABLE
													rw	rw	rw

Bits 31:3 **Reserved, forced by hardware to 0.**

Bit 2 **PRIVDEFENA**: Enable privileged software access to default memory map.

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.

1: If the MPU is enabled, enables use of the default memory map as a background region for privileged software accesses.

Note: 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.

If the MPU is disabled, the processor ignores this bit.

Bit 1 **HFNMIENA**: Enables the operation of MPU during HardFault and NMI handlers.

When the MPU is enabled:

0 = MPU is disabled during HardFault and NMI handlers, regardless of the value of the ENABLE bit.

1 = the MPU is enabled during HardFault and NMI handlers.

When the MPU is disabled, if this bit is set to 1 the behavior is Unpredictable.

Bit 0 **ENABLE**: Enables the MPU

0: MPU disabled

1: MPU enabled

When ENABLE and PRIVDEFENA are both set to 1:

- For privileged accesses, the *default memory map* is as described in *2.2: Memory model on page 20*. 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 10 on page 22*. 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 HFNMIENA 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 HardFault or NMI exception. Setting the HFNMIENA bit to 1 enables the MPU when operating with these two priorities.

4.5.3 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 34 on page 99* for its attributes. The bit assignments are:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Reserved								REGION							

Bits31:8 Reserved, must be kept cleared.

Bits 7:0 **REGION** Indicates the MPU region referenced by the MPU_RBAR and MPU_RASR registers. The MPU supports 8 memory regions, so the permitted values of this field are 0-7.

Normally, you write the required region number to this register before accessing the MPU_RBAR or MPU_RASR. However you can change the region number by writing to the MPU_RBAR with the VALID bit set to 1, see *MPU Region Base Address Register on page 102*. This write updates the value of the REGION field.

4.5.4 MPU Region Base Address Register

The MPU_RBAR defines the base address of the MPU region selected by the MPU_RNR, and writes to this register can update the value of the MPU_RNR. See the register summary in *Table 34 on page 99* for its attributes.

Write MPU_RBAR with the VALID bit set to 1 to change the current region number and update the MPU_RNR. The bit assignments are:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
ADDR[31:N]...															
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
....ADDR[31:N]											VALID	REGION[3:0]			
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Bits 31:N **ADDR[31:N]**: Region base address field
The value of N depends on the region size.
For more information, see *The ADDR field*

Bits N-1:5 **Reserved, forced by hardware to 0.**

Bit 4 **VALID**: MPU region number valid

Write:

0: MPU_RNR register 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.

Read:

Always read as zero.

Bits 3:0 **REGION[3:0]**: 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 MPU_RNR register.

If the region size is 32B, the ADDR field is bits [31:5] and there is no Reserved field.

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:

$N = Log_2$(Region size in bytes),

If the region size is configured to 4GB, 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 must be 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`.

4.5.5 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 33 on page 99* for its attributes.

The bit assignments are:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Reserved			XN	Reserved	AP[2:0]			Reserved					S	C	B
			rw		rw	rw	rw			rw	rw	rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SRD[7:0]								Reserved		SIZE					ENABLE
rw	rw	rw	rw	rw	rw	rw	rw			rw	rw	rw	rw	rw	rw

Bits 31:29 **Reserved**

Bit 28 **XN**: Instruction access disable bit:

0 = Instruction fetches enabled.

1 = Instruction fetches disabled.

Bit 27 **Reserved, forced by hardware to 0.**

Bits 26:24 **AP[2:0]**: Access permission field, see *Table 37: AP encoding*

Bits 23:19 **Reserved, forced by hardware to 0.**

Bit 18 **S: Shareable bit** see *Table 36 on page 105*

Bit 17 **C: Cacheable** bit see *Table 37 on page 105*

Bit 16 **B: Bufferable** bit, see *Table 36 on page 105*

Bits 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 106* for more information.

Bits 7:6 **Reserved, forced by hardware to 0.**

Bits 5:1 **SIZE**: Size of the MPU protection region.
Specifies the size of the MPU region. The minimum permitted value is 7 (b00111). See *SIZE field values on page 104* for more information

Bit 0 **ENABLE**: Region enable bit(1).

1. The region enable bit of all regions is reset to 0. This enables you to only program regions you want enabled.

For information about access permission, see *MPU access permission attributes on page 104*.

SIZE field values

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

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

The smallest permitted region size is 256B, corresponding to a SIZE value of 7. *Table 35* gives example SIZE values, with the corresponding region size and value of N in the MPU_RBAR

Table 35. Example SIZE field values

SIZE value	Region size	Value of N(1)	Note
b00111 (7)	256B	8	Minimum permitted size.
b01001 (9)	1KB	10	-
b10011 (19)	1MB	20	-
b11101 (29)	1GB	30	-
b11111 (31)	4GB	32	Maximum possible size.

1. In the MPU_RBAR, see *MPU Region Base Address Register on page 102*.

4.5.6 MPU access permission attributes

This section describes the MPU access permission attributes. The access permission bits, C, B, S, AP, and XN, of the MPU_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 36 shows the encodings for the C, B, and S access permission bits

Table 36. C, B, and S encoding

C	B	S	Memory type	Shareability	Other attributes
0	0	-(1)	Strongly-ordered	Shareable	-
	1	-(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	

1. The MPU ignores the value of this bit.

Table 37 shows the AP encodings that define the access permissions for privileged and unprivileged software

Table 37. 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.

4.5.7 MPU mismatch

When an access violates the MPU permissions, the processor generates a HardFault.

4.5.8 Updating an MPU region

To update the attributes for an MPU region, update the MPU_RNR, MPU_RBAR and MPU_RASR registers.

Updating an MPU region

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
```

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.

However, an instruction synchronization barrier instruction is not required if the MPU setup process starts by entering an exception handler, or is followed by an exception return, because the exception entry and exception return mechanism cause memory barrier behavior.

For example, if you want 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 using a return from exception, or by taking an exception, then you do not require an ISB.

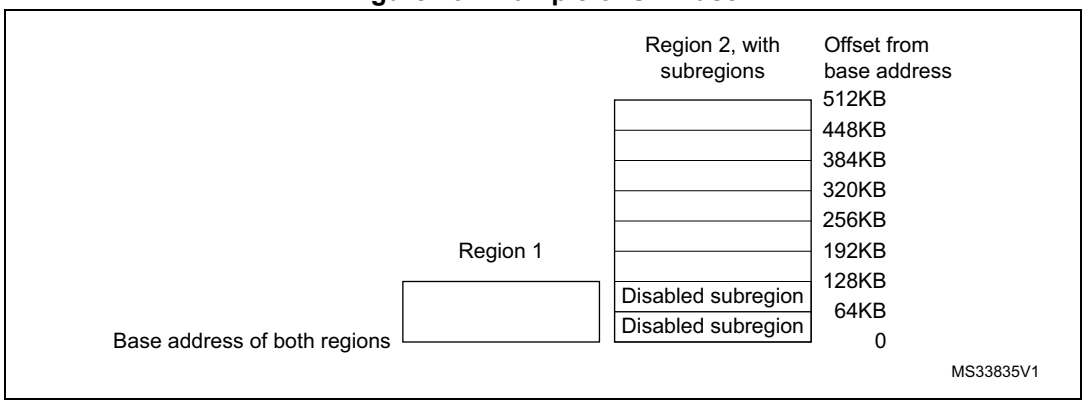
Subregions

Regions 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 103*. 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 the MPU issues a fault.

Example of SRD use

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

Figure 13. Example of SRD use



4.5.9 MPU design hints and tips

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

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

MPU configuration for a microcontroller

Usually, a microcontroller system has only a single processor and no caches. In such a system, program the MPU as follows:

Table 38. Memory region attributes for a microcontroller

Memory region	C	B	S	Memory type and attributes
Flash memory	1	0	0	Normal memory, Non-shareable, write-through.
Internal SRAM	1	0	1	Normal memory, Shareable, write-through.
External SRAM	1	1	1	Normal memory, Shareable, write-back, write-allocate.
Peripherals	0	1	1	Device memory, Shareable.

In most microcontroller implementations, the shareability and cache policy attributes do not affect the system behavior. However, using these settings for the MPU regions can make the application code more portable. The values given are for typical situations. In special systems, such as multiprocessor designs or designs with a separate DMA engine, the shareability attribute might be important. In these cases refer to the recommendations of the memory device manufacturer.

4.6 I/O Port

Cortex-M0+ implements a dedicated I/O port for high-speed, low-latency access to peripherals. The I/O port is memory mapped and supports all the load and store instructions given in *Memory access instructions on page 45*. The I/O port does not support code execution.

The general-purpose I/Os are accessed through the I/O port.

The I/O port can be protected by the MPU.

5 Revision history

Table 39. Document revision history

Date	Revision	Changes
15-Apr-2014	1	Initial release.
16-Jun-2017	2	Updated *Section 2.3.4: Vector table*
19-Jan-2018	3	Updated *Section 3.5.1: ADC, ADD, RSB, SBC, and SUB*
25-Oct-2018	4	Added STM32G0 Series.
10-Oct-2019	5	Added STM32WL and STM32WB Series.